The Climate-Energy Nexus

November 11-13, 2009

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CHINA • US

Joint
Research Center
for Ecosystem and
Environmental Change

The China-US Joint Research Center for Ecosystem and Environmental Change was launched in July 2006 by scientists from the University of Tennessee (UT) and Oak Ridge National Laboratory (ORNL) and researchers from the Chinese Academy of Sciences (CAS). The center, which occupies research facilities at UT/ORNL and CAS, addresses the combined effects of climate change and human activities on regional and global ecosystems and explores technologies for restoration of degraded environments. The center organizes annual workshops, held reciprocally in China and the United States. The 2009 workshop on the Climate-Energy Nexus was held November 11-13 in Oak Ridge and was hosted by Oak Ridge National Laboratory. This publication presents the proceedings of the 2009 workshop, at which researchers shared their findings in a mutually supportive environment and laid the foundation for future international research undertakings.

Partners of the China-US Joint Center for Ecosystem and Environmental Change

Joint Institute for Biological Sciences,
The University of Tennessee/Oak Ridge National Laboratory

Institute for a Secure and Sustainable Environment,
The University of Tennessee

Institute of Geographic Science and Natural Resources Research, Chinese Academy of Sciences

Research Center for Eco-Environmental Sciences,
Chinese Academy of Sciences

Center for the Environment,
Purdue University

University of Science and Technology of China

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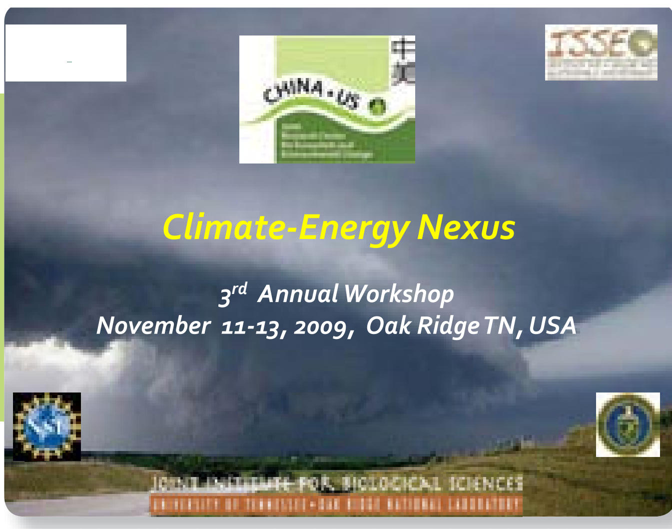
NOVEMBER 11-13, 2009
OAK RIDGE NATIONAL LABORATORY AND THE UNVERSITY OF TENNESSEE



Progress of a Partnership: Bridging a World of Environmental Change

When the framework of the China-US Joint Research Center for Ecosystem and Environmental Change (JRCEEC) was established in Beijing in 2006, the goal was to increase communication, collaboration, data exchange, and personnel exchange that would lead not only to a better understanding of climate, bioenergy, environmental change, and restoration issues that both countries face, but also to lay the groundwork for launching joint research programs together. These environmental changes result, in large part, from our continued reliance on fossil fuels. Some 80 percent of the world's energy comes from fossil fuels, which remain relatively inexpensive, relatively abundant, and easily transported. The dilemma is to reduce our use of coal, oil, and natural gas, which provide energy that is so valuable to us but which also create serious environmental problems.

The opening workshop in Tennessee in 2007 drew about 50 researchers from Oak Ridge National Laboratory (ORNL) and the University of Tennessee (UT), our collaborators from China, and a few outside participants. At our very successful second workshop, held in Beijing in 2008, we inducted two new members into the center, Purdue University in West Lafayette, Indiana, and the University of Science and Technology of China, both of which are now active participants in the center. Attendance at the 3rd Annual Workshop was more than double that of the opening workshop. Nearly 40 participants from China and 70 from the United States convened at ORNL in Oak Ridge, Tennessee, November 11-13, 2009, with more than 40 invited speakers. As our partnership progresses, we are working together to bridge a very complex and challenging world of environmental change.

In the past four years, our American delegations have had numerous opportunities to visit various regions of China and see first hand some of the difficult environmental challenges that exist there, and our Chinese partners have likewise gotten a close-up look at US efforts to tackle its own challenges. In addition, participants have had ample opportunities to forge international friendships through field trips, not just to various research institutions, but also on informal outings to important cultural and environmental tourist destinations, from the Great Wall of China to Great Smoky Mountains National Park.

The focus of the 3rd Annual China-US Workshop was the Climate-Energy Nexus. The objectives of the workshop were 1) to present an overview of advances in climate, bioenergy, ecosystems, and energy technology; 2) explore the strategies for reducing the impacts of climate change; 3) identify major opportunities for China-US joint programs; and 4) create opportunities for international student education.

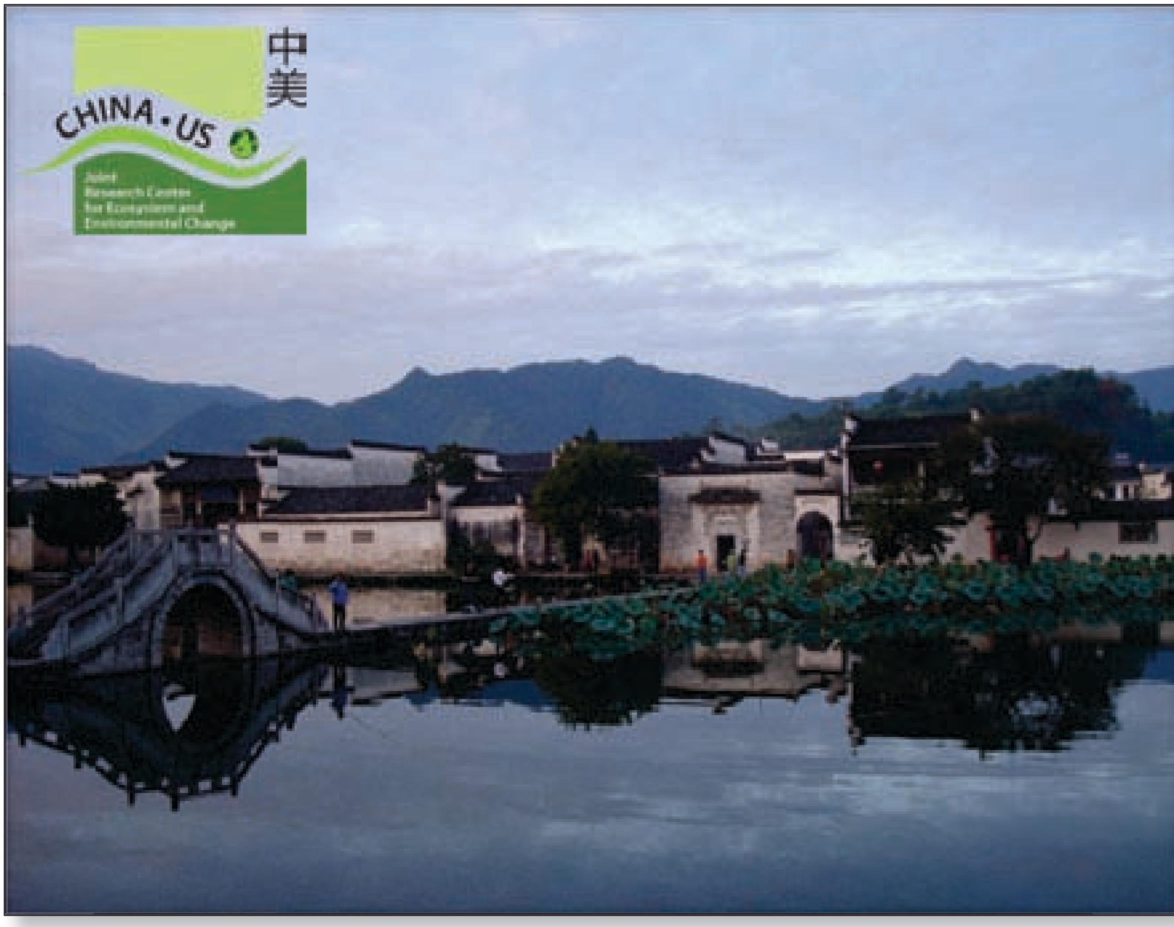
More broadly, however, a key objective of this workshop was to initiate ideas for joint collaborative research projects and begin to move forward in a harmonious fashion to address environmental change, climate, energy, and bioenergy issues, which are of major concern to both of our countries. The steady growth in the workshops demonstrates the importance of the challenge, the commitment of the partners, and the collaborative efforts to address it.

MUTUAL CHALLENGES

The United States and China are the two largest emitters of carbon dioxide. We therefore have the largest stake in finding the right solutions, both for our energy needs and also for the constraints on our energy choices. We are gaining a deeper understanding of the environmental impacts of those choices. People in both countries are demanding energy in ever increasing amounts, so we have simultaneous and sometimes conflicting demands for energy and an increasing understanding of patterns of energy generation, use, and distribution patterns. Our work to build international partnerships in research and education is of vital importance.

We will need breakthroughs in science and innovative technology to tackle the challenge of climate change and develop sustainable energy systems. By fostering these programs and engaging early career researchers, we are providing new pathways for finding the right solutions to these challenges. In 2008, UT invited three Chinese students and scientists for one year of study at the university. We hope to create additional opportunities for international student education at UT and also for young US scientists to study abroad in Chinese institutions.

During the course of the workshop, we had the opportunity to advance our programmatic objectives and to develop a focused research plan. Through our joint efforts and



VISITING SCHOLARS FROM THE EAST

Among its key goals, the China-US Joint Research Center for Ecosystem and Environmental Change seeks to promote academic and scientific exchange among senior researchers as well as graduate students and post-doctoral scientists.

In the fall, the University of Tennessee's Institute for a Secure and Sustainable Environment (ISSE) welcomed three scholars from the Chinese Academy of Sciences (CAS) who will spend a year at ISSE.

Yuling Fu, a CAS associate professor, is collaborating with researchers from the Environmental Sciences Division of Oak Ridge National Laboratory. Mi Zhang, a CAS fourth-year PhD candidate, and Chao Fu, a CAS third-year PhD candidate, are advancing their research on ecosystem response to climate change.

Wenjuan Shi, an associate professor of soil physics with the Institute of Water Resources and Hydro-electric Engineering at Xi'An University of Technology, began a residency at UT's Center for Environmental Biotechnology and ISSE in April. During her stay, Shi will collaborate with UT soil scientists and study techniques for measuring the distribution and transport of mercury and cadmium in soils.

Xiuli Dang, a lecturer in agricultural environmental engineering at Shenyang Agricultural University, began a year-long residency at ISSE in June. During her stay, Dang will study carbon sequestration in soil amended with biochar and will collaborate with scientists at the soil biochemistry laboratory of the UT Department of Biosystems Engineering and Soil Science (BESS). BESS professor Mark Radosevich and ISSE Research Director Jie (Joe) Zhuang are hosting Dang during her visit.

concurrent sessions over the course of the workshop, we hoped to generate new ideas that we can commit to paper and begin to crystallize key ideas for advancing the research frontiers that we all share in this endeavor.

CHINA'S COMMITMENT

The issues of climate change and energy pose many challenges to sustainable development across the world, requiring cooperative and vigorous actions from the international community. The Chinese government takes seriously the issue of climate change and energy. In 2007, China launched an aggressive national climate change program. China has taken energy conservation and emissions reductions as a starting point and is undertaking a series of measures such as energy conservation, improving the energy mix, raising energy efficiency, and promoting forestation. The Chinese government has earmarked substantial funding to improve energy efficiency, develop renewable energy, adjust the industrial structure, and protect the environment. Clear targets have been set for reducing energy intensity, cutting emissions of major pollutants, and expanding forest coverage.

China is a developing country with a per capita gross domestic product of just over $2,000 US. The country faces the multiple challenges of simultaneously alleviating poverty, improving people's livelihood, and tackling climate change. To that end, it will be necessary to develop a low carbon economy using advanced technology for greater economic returns, lower resource consumption, and less pollution. Innovations in scientific and technological progress are effective measures to mitigate greenhouse gas emissions and enhance adaptation capabilities.

Technological innovation plays a fundamental role both in China and the United States, and there are extensive areas for collaboration on energy and climate change. China already has outstanding collaborations with the United States in strategic and economic dialogue, including the U.S.-China Joint Commission on Science and Technology Cooperation agreement, the China/US Energy Efficiency and Renewable Energy Project, and the Fossil Energy Project. In 2008, the two countries signed a 10-year energy and environmental collaboration framework, taking our collaboration another step forward.

We are living under the same sky and on the same planet. The Earth is our common home, the only home we have. The future of our children and our children's children is in our hands today. The Chinese government attaches great importance to energy and climate change and is pleased to know that President Barack Obama also places great importance on issues relating to energy and climate change. China and the United States have the capacity to engage in win/win collaborations on climate change. As long as we both work in the same direction, we will be able to turn energy and climate change into another highlight in China-US relations. China stands ready to work closely with the United States to play an active, constructive, and responsible role in promoting international collaboration on energy and climate change.

JOINT PRESENTERS

Gary S. Sayler, Director
Center for Environmental Biotechnology and UT-ORNL Joint Institute for Biological Sciences

Randall Gentry, Director
Institute for a Secure and Sustainable Environment, UT

Thom Mason, Laboratory Director
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Jianing Cai, Counselor for Science and Technology
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Jie (Joe) Zhuang, Research Director
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WORKSHOP GOALS AND OBJECTIVES

- Review and assess advances in critical research and development in the areas of global climate change, bioenergy sustainability, ecosystem management, and technologies for mitigating carbon dioxide emissions.
- Explore effective, comprehensive strategies for reducing the impacts of global climate change.
- Identify major opportunities for China-US joint programs on climate, ecosystem, bioenergy, and technology development.
- Establish a mechanism to regularly bring students and junior researchers into cross-cultural international research on global climate change and renewable energy.

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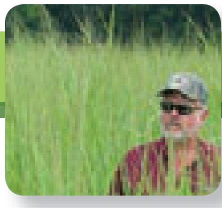
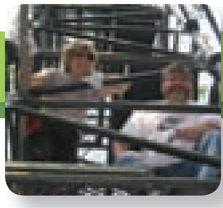


KEYNOTE SPEAKERS

CLIMATE CHANGE



ECOSYSTEM MANAGEMENT

BIOENERGY IMPACTS

ENERGY TECHNOLOGY

ECOLOGICAL OBSERVATION AND MODELING: FROM DATA TO KNOWLEDGE

CLIMATE CHANGE MITIGATION:
STRATEGY AND TECHNOLOGY

KEYNOTE SPEAKERS

MICHAEL MACCRACKEN
ZHIYUN OUYANG
XI-LIANG ZHANG
CARL O. BAUER

Achieving International Agreement and Climate Protection by Coordinated Mitigation of Short- and Long-Lived Greenhouse Gases

by
Michael MacCracken

Dr. MacCracken is Chief Scientist for Climate Change Programs of the Climate Institute, Washington, D.C.

About 40 years ago, when the first manned mission orbited the moon, Apollo 8 crewmember Bill Anders took a photograph, "Earthrise," which shows the Earth as a blue marble. The image inspired Archibald MacLeish, the US poet laureate at the time, to pen a phrase that appeared in the New York Times: "To see the earth as it truly is, small and blue and beautiful in that eternal silence where it floats, is to see ourselves as riders on the earth together, brothers on that bright loveliness in the eternal cold—brothers who know now they are truly brothers." This is a beautiful statement, but it is dated, because it suggests that we are just riders on the Earth together. We are no longer simply riders, we are now drivers of the Earth, changing it in very important ways .

These changes result, in large part, from our continued reliance on fossil fuels. Some 80 percent of the world's energy comes from fossil fuels, which remain relatively inexpensive, relatively abundant, and easily transported. The dilemma is to reduce our use of coal, oil, and natural gas, which provide energy that is so valuable to us but which also create serious environmental problems.

Current carbon-dioxide (CO_2) emissions are tracking above the fastest-growing fossil fuel emission scenario developed by the Intergovernmental Panel on Climate Change in its 2000 *Special Report on Emissions Scenarios*. Scientists don't like to be wrong, so they created this broad range of scenarios, thinking that emissions could not possibly increase at a faster rate, so where we are is quite disturbing.

With increasing greenhouse gas emissions, global warming is increasing at a rate of about 0.2°C per decade, and projections suggest that the rate of warming could increase further if emissions controls are not implemented. Leaders of the largest nations have called for the global average

Earthrise

Credit: Apollo 8 crew member Bill Anders, NASA

surface temperature to increase by no more than 2°C above its pre-industrial value to avoid the most catastrophic consequences of climate change. That will require sharply reducing global greenhouse gas emissions by 2050 and reducing net emissions to near zero by 2100. China and the United States lead the world in CO_2 emissions, with China's total emissions increasing rapidly, although per capita emissions remain about a quarter of those in the United States. Emissions are also increasing in nearly all countries, with the notable exceptions of the United Kingdom and Denmark.

To stabilize atmospheric composition, we have to get everyone near zero. Rather than consider total emissions per country, the developing nations suggest that the most equitable way to look at the emissions is on a per capita basis.

Accounting for the collective effect of all their greenhouse gas emissions, only Australia—which has significant methane emissions from its agriculture sector—exceeds the United States in per capita emissions, even though Australia's overall contribution to global CO_2 emissions is a mere 14 percent of that of the United States, owing to its much smaller population.

With respect to the climatic effects of past emissions, through 2008, 24 of the 25 warmest years since global record keeping began in 1850 have occurred since 1980. The 25th warmest year was 1944, though that measurement was apparently biased upward because of changes in observing procedures during World War II. In addition, 2007 set a new record for the minimum summer extent of Arctic sea ice.

It is clear that climate change is not strictly a CO_2 issue. As we reduce CO_2 emissions, we will also reduce the atmospheric loading of sulfate aerosols, which exert a cooling effect on the Earth system. If we were to achieve zero CO_2 emissions—particularly zero CO_2 emissions from coal—we would also achieve zero sulfate emissions. If we remove the sulfate aerosols, instead of having a current CO_2 equivalent concentration of about 375 parts per million (ppm), the CO_2 equivalent concentration reaches 450 ppm, which estimates suggest would lead to a global warming of about 2 to 2.5°C over pre-industrial levels. This means we're already over the threshold that international negotiations are, based on scientific findings, aiming at. The Kyoto Protocol, even if fully implemented, would have only a modest effect on climate change. Kyoto has been a very limited first step. The next steps will have to be significantly greater to stabilize and then bring the CO_2 concentrations back down to a level that will not lead to significant climatic impacts.

CO_2 and nitrous oxide have longer lifetimes (centuries) in the atmosphere than sulfates (days to weeks) and methane (about a decade). As the world begins to limit CO_2 emissions, the other greenhouse gases—methane, nitrous oxide, tropospheric ozone, and black soot—begin to play more important roles. Indeed, for emissions during the 21st century, only about half of the warming influence will come from CO_2 emissions—the rest will come from the non-CO_2 emissions.

Further, even if emissions of all greenhouse gases from non-OECD (developing) nations went to zero tomorrow, the projected emissions from the OECD (developed) nations would cause the temperature to increase by more than 2°C later this century. Likewise, if the emissions from developed nations went to zero tomorrow, the projected emissions from developing nations would cause global temperature to increase by more than 2°C by the end of the century.

An approach requiring comparable efforts by all nations has the potential to substantially limit warming, but there is no room for compromise either by developed or developing nations. The view in Washington seems to be that the problem is the developing nations because their emissions are rising rapidly, but that's only part of the problem. Even if developing nation emissions went to zero, the developed nations have to get off of fossil fuels to limit long-term warming, and they have to do it quickly.

A fair and balanced agreement would involve OECD and non-OECD nations taking on different responsibilities, but comparable challenges. Developed countries must aggressively reduce CO_2 and methane emissions and demonstrate that a modern nation can prosper on low greenhouse gas emissions.

To do their part in stopping global warming, developed nations must reduce their emissions of both CO_2 and non-CO_2 greenhouse gases. Meanwhile, developing nations must, in the near-term, improve their carbon efficiency and halt deforestation while sharply limiting their non-CO_2 greenhouse gas emissions. In the longer term, as the income levels of these nations grow and begin to approach those of developed nations, they should also join the developed nations in sharply reducing their CO_2 emissions.

Ecosystem Degradation and Restoration Studies in China

by Zhiyun Ouyang

Dr. Ouyang is Deputy Director and Professor of System Ecology at the Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences.

China faces a significant challenge in restoring its damaged ecosystems without compromising the financial well-being of the farmers who rely on those ecosystems.

The challenge is compounded by the diversity of China's ecosystems, which comprise alpine zones, deserts, grasslands, wetlands, and tropical rainforests. China's population of 1.4 billion exerts enormous pressures on the nation's ecosystems. Wood harvest consumes 248 million cubic meters annually; annual water demand exceeds 600 billion cubic meters, and annual sewage and industrial waste water discharge total 55.6 billion cubic meters per year.

Past decades have witnessed a significant decline in forest ecosystem services, including soil and water conservation and wildlife habitat. Erosion, which carries off 5 billion tons of soil per year in China, has hit the Loess Plateau, in the north-central highlands, particularly hard. Rocky desertification has compromised nearly 84 percent of the impoverished karst region of southwestern China. Some 90 percent of China's vast grasslands, mainly in western China and on the Tibetan Plateau, are also degraded.

The Wenchuan Earthquake of 2008, which struck in northern Sichuan Province, caused significant damage to 122,188 hectares (301,804 acres) of forest, grassland, and wetland ecosystems.

The Chinese government has mounted a response to these challenges that includes restricting future development in more sensitive ecosystems and banning it entirely in nature preserves and other protected areas, conserving areas that provide important ecosystem services, protecting productive cropland, and creating ecosystem management zones.

Rocky desertification in Guizhou karst area

Meanwhile, numerous scientific organizations, including the Ministry of Science and Technology, the National Natural Science Foundation, and the Chinese Academy of Sciences, have stepped up research on methods and technologies for restoring China's degraded ecosystems at study sites across the nation.

Technologies and Policies for the Transition to a Sustainable Energy System in China

by
Xi-Liang Zhang

Dr. Zhang is Professor of Energy Systems Analysis and Executive Director of the Institute of Energy, Environment, and Economy, Tsinghua University .

China, like the United States, possesses rich reserves of coal, which provide 70 percent of China's energy supply. Half of the expended coal goes to power generation, 21 percent to industry, and 19 percent to coking plants for the production of steel. Also, like the United States, China is a net importer of crude oil and oil products, with about half of the supply fueling the nation's transportation sector.

Since 2000, China's energy production, energy consumption, and GDP have increased on parallel tracks. At the same time, China's energy intensity, which measures the energy efficiency of the nation's economy (in terms of the cost of converting energy into GDP), has declined dramatically.

The number of vehicles on China's roads has more than doubled since 2000, reflecting an increasing trend toward urbanization of the nation's population. Consider, for instance, that from 2005 to 2050, China's urban population is expected to increase from 43 to 79 percent. Between 1990 and 2005, energy consumption in China's transportation sector more than doubled, with road transportation accounting for the majority of the increase.

The output of China's auto industry grew by more than 300 percent between 2000 and 2007, reaching nearly 9 million vehicles in 2007. The number of vehicles on China's roads increased from 1.6 million in 2000 to 4.2 million in 2007, with the bulk of the increase in passenger cars—a trend that is expected to continue.

Passenger cars are playing an increasingly important role in China. Chinese people want to have an apartment in the city and, like Americans, a private car to drive—China's younger generation is very much following the American dream.

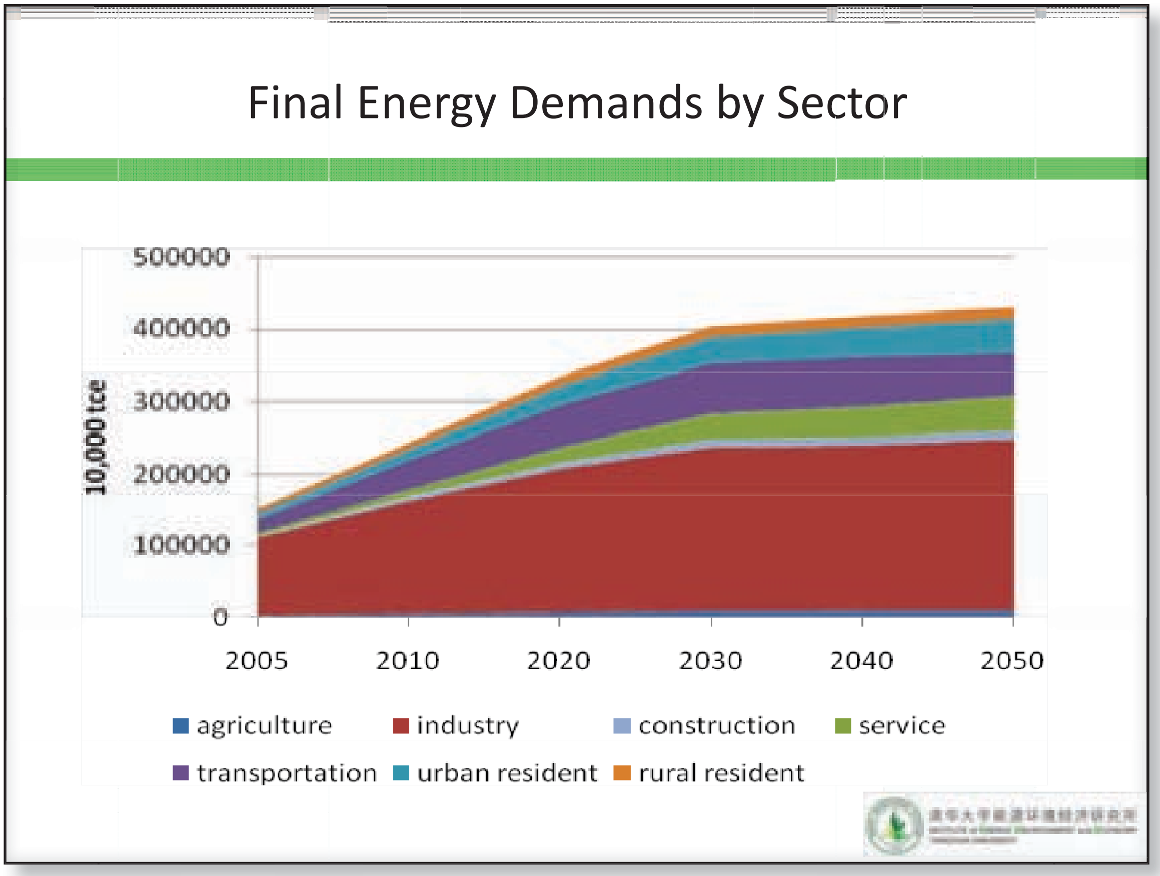
If we compare energy consumption patterns in the United States and China, we see that 80 percent of US GDP comes from the service sector, compared to only 40 percent in China. China's energy demand for industry is also much larger, 70 percent of the total compared to 25 percent in the United States. China is still an industrializing country, with most of CO_2 emissions coming from industry and power generation.

Between 2000 and 2005, fossil fuels contributed nearly 90 percent of China's SO_2 emissions. In 2007, China's CO_2 emissions surpassed those of the United States, though, in terms of cumulative emissions from 1800-2007, China's emissions total less than one-third of those of the United States. In 2005, China's per capita CO_2 emissions were less than one-quarter of those of the United States.

Several scenarios have been generated for China's future CO_2 emissions. All of them could negatively affect China's economy. Reduced reliance on coal and a shift to a low-carbon energy system could have serious implications for China's GDP.

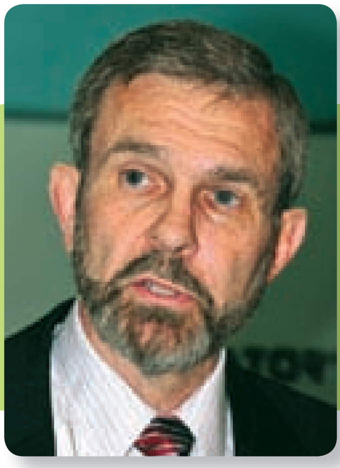
Achieving the 450 parts per billion (ppb) target, considered a "safe" level for avoiding the most serious effect of global climate change, by 2050 would require a 28-percent reduction in China's GDP. Clearly, the cost to China's economy would be significant. To reach the 450 ppb target, energy supply costs would increase by 70 percent. Based on current scientific and technical knowledge, it will be difficult for China to achieve a cost-effective sustainable energy system.

In 2008, renewable energy sources, mostly hydropower, accounted for 9 percent of China's overall energy consumption. Meanwhile, carbon capture and storage are not currently cost effective.



To achieve its environmental goals, China must develop new technologies, promote widespread adoption of cost-effective existing technologies, and shape new policies, including those that increase production of biofuels and bolster reliance on new-generation nuclear technologies and low- or zero-emission vehicles.

Energy Challenge and Technology R&D for Mitigation of CO_2 Emissions



by
Carl O. Bauer

Dr. Bauer is former Director of the National Energy Technology Laboratory, US Department of Energy.

China and the United States have worked hard over the last several years to find ways to cooperate in the area of clean energy, including the creation in 2009 of the US-China Clean Energy Research Center. The two nations have also pledged $15 million to explore technologies in support of increased energy efficiency, clean coal technologies, and clean vehicles. A memorandum of understanding between the two nations was signed in 2009 to enhance cooperation on climate change, energy, and the environment.

Together, we're trying to find a way to use the supply of energy in a way that meets our needs but that also addresses environmental impacts and issues of cost.

All energy sources face challenges, and they share challenges in the area of water use, particularly in thermal power generation, in terms of both cooling and production. Without water, you have substantial reductions in efficiency. The more expensive energy becomes, the more expensive water becomes.

Water and cost, at least in the near term, are as important as greenhouse gases. That might sound like heresy to some, but in the next decade, water may be more important than greenhouse gas because of the immediacy of its impact.

Challenges abound for all energy systems. For fossil-fuel-based power systems, the challenges include emissions, costs associated with carbon capture and storage, and raw water usage.

Challenges to the nuclear sector involve issues with fuel supply, construction costs, spent-fuel management, and operation and safety of next-generation nuclear plants. In the United States, we have about a 20-year supply of fuel, unless we substantially increase our uranium production.

The challenges to renewable energy can be framed as the question: how can I make enough of it, economically, how much surface area do I have to cover to make enough of it, and how far is the source from the actual end user?

The solar and wind hot spots in both China and the United States are relatively small. How do you move power from these small areas thousands of miles, taking into account the line loss that occurs in the transmission of electricity? Variability of supply is also an issue. It's tough to generate solar power at night.

As demand for transportation fuels increases, pressure on the global production capacity also increases. Unless we do something to reduce demand for transportation fuels, production of alternative fuels will do little more than help us keep up with demand. It won't help displace petroleum for the next several decades.

Continued reliance on fossil fuels means continuing production of large amounts of CO_2, which raises another question: How do we take the enormous amount of CO_2 produced and do something with it? The United States has seven regional carbon sequestration partnerships exploring the science and technology behind injecting large amounts of CO_2 underground. A further, and equally important, question is how to convince the public that the process will be conducted safely? There is currently a new spin on the NIMBY (not-in-my-backyard) syndrome, calling it NUMBY (not under my back yard), that might arise if the public fails to embrace carbon storage and sequestration strategies.

There is adequate underground carbon storage capacity in both China and the United States for several hundred years, in saline formations, unmineable coal seams, and oil and gas fields.

The largest capture area in United States is in North Dakota, where 4,000 tons of carbon are captured per day and transported to Canada's Weyburn Oil Field, where they are pumped into the ground to enhance oil recovery. To put that amount of carbon into perspective, consider that one 500-megawatt coal-fired power plant operating at about 33-percent efficiency generates 17,000 tons per day. If you're just going to stick it in the ground, you're not going to have a valuable commodity; when you use it for enhanced oil recovery, it's worth at least $20/ton, so you can afford capture technology that's fairly expensive. Absent a commercial use for the carbon, sequestration must become more cost effective to be practical.

Carbon can be separated and captured at various stages in the energy production process. Post-production capture removes CO_2 from flue gases after the combustion of fossil fuels, in the case of coal-fired power plants. Pre-combustion separates carbon from hydrogen through gasification—the carbon is captured, and the hydrogen is burned as fuel. Oxy-fuel combustion burns the fuel in oxygen rather than air, and the water vapor is condensed from the flue gas, leaving concentrated CO_2.

A number of new technologies for capturing carbon from energy production are on the horizon, but the challenge is to develop them and commercialize them quickly.

The increasing levels of carbon in the atmosphere might actually benefit the agricultural sector. Are increases in agricultural production strictly a result of being smart in picking or breeding the right plants and identifying the right fertilizer combination,or is it also because those plants have a richer CO_2 atmosphere to grow in?

Algae represent a particularly good biomass product. About half of the planet's oxygen produced each year comes from algae. Algal solids and oils could be used in production of pharmaceuticals, food products for humans and livestock, ethanol, and green chemicals.

Water and energy are inextricably linked. Energy is required to treat water and pump it from source to end users. Water plays a role in mining operations and is used to cool power plants. Geothermal, solar-thermal, and nuclear power systems, which may play a more prominent role in our future energy portfolio, actually require much larger amounts of water than coal-fired systems.

New research is exploring the use of CO_2, instead of water, as a "working fluid" in geothermal heat recovery, which is a two-for-one. Through this novel process, CO_2 is contained, or sequestered, but would be used to carry heat. With traditional geothermal systems, there is a loss of water as you bring the steam back up from underground. Situating a geothermal plant next to a fossil-fuel plant could solve the sequestration issue while providing for sustainable energy production.

REDUCING UNCERTAINTIES IN CLIMATE SCENARIOS

In its Climate Change 2007 report, scientists with the Intergovernmental Panel on Climate Change (IPCC) reached a general consensus that the climate is warming and that this trend is very likely the result of greenhouse gas emissions from human activities. Uncertainty remains, however, as to the trajectory of global climate change, specific regional and local effects, and the ability of humans to adapt to changing conditions.

As powerful as our computing and modeling abilities were at the time the report was issued, new and more powerful computers are coming on line. Nevertheless, says David Bader at Oak Ridge National Laboratory (ORNL), we could use a 10^{12} increase in realizable computing power if we are to answer some of the questions that will allow us to plan and implement mitigation and adaptation strategies.

Yao Huang with the Chinese Academy of Sciences cites China's efforts to reduce emissions of greenhouse gases and encourage land use planning that will increase the carbon sink of the country. Current estimates of the terrestrial carbon sink are subject to large uncertainties arising from an insufficient understanding of land use and land cover change.

Dan Bilello with the National Renewable Energy Laboratory says that renewable energy must be a part of the overall equation in addressing solutions to climate change. Current tools do not effectively model renewable energy production. A better understanding of the potential impacts of climate change on both traditional and renewable energy technologies will help the United States gain a more holistic picture of the social, policy, and economic benefits of our energy options.

John Drake with ORNL's Computational Earth Sciences Group is part of a national team working on better models for future IPCC assessment reports. Since the Fourth Assessment Report, the modeling community has been trying to extend the models and develop an Earth system model that will include processes and components not yet incorporated into previous models such as ice sheets and land ice sheet dynamics and the indirect effects of aerosols, which have a fairly large negative effect on climate forcing.

The "Omics Revolution" includes proteomics—the study of expressed proteins—and metabolomics—the study of small molecular weight chemicals. Paul Brown at Purdue University says that in terms of global change, these omics have the potential to further our understanding of the effects of pollutants, thermal changes, carbon dioxide, and energy production on the environment.

William Fulkerson with the University of Tennessee's Institute for a Secure and Sustainable Environment warns that we are headed toward a potential planetary emergency. We can avoid the risk of catastrophe by actively managing climate change with intelligent use of three strategies: mitigation, adaptation, and bioengineering, perhaps the most controversial of the three. All three strategies can be very expensive. The cost of doing nothing, however, is even higher.

Global Climate Modeling and Prediction

by David Bader

Dr. Bader *is Deputy Director of the Climate Institute, Oak Ridge National Laboratory.*

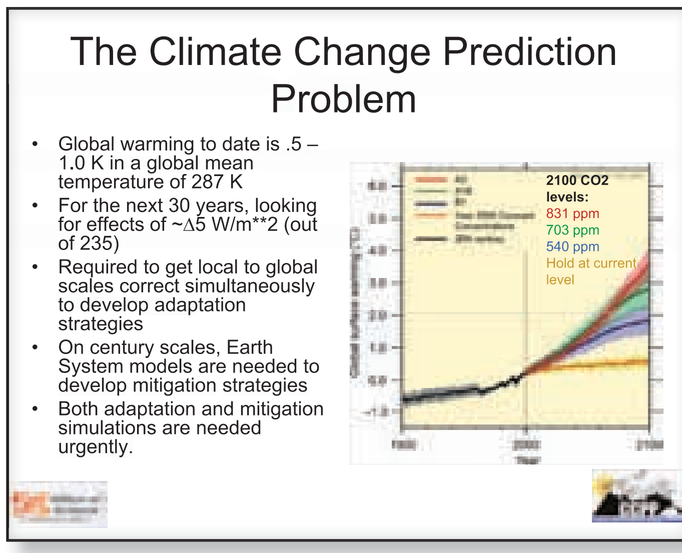
The work of climate modelers is never done, and many people wonder why we can't improve our predictive capabilities. For many reasons, predicting climate change gets more difficult all the time. For one, we are trying to find a very small warming signal, 0.5 to 1.0 °K, out of a very large base global mean surface temperature of 287 °K. That requires a very high level of precision and accuracy. In addition, over the next 30 years we expect an increase in the Earth's net radiative forcing on the order of about 5 watts per square meter (W/m^2) out of a base state of about 235 W/m^2 net incoming radiant energy. These are very small fractions.

If we were modeling any other planet but Earth we would have declared success a long time ago. The information we need, and the small changes that are important to activities on a human scale, are insignificant relative to geological scales. In addition, because warming affects human decisions, human activity, and ultimately our quality of life, we must predict decadal climate change impacts that are simultaneously correct, from the local to the global scale, in a consistent way. On a longer, century, time scale, Earth system models are urgently needed to develop mitigation and adaptation strategies.

The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) presented four warming scenarios based on future emission levels of CO_2 ranging from the current level up to 831 parts per million (ppm) by 2100. No matter which ultimate stabilization level of CO_2 we aim for or manage to achieve, we will need models in order to mitigate the effects of warming, and at the same time adapt to climate change. No matter what mitigation strategies we decide on today, we will still have the problem of adaptation to change. Over these long time scales, we do have choices about which trajectory to choose, but the choice must be made now. Modeling has become an important decision tool, but the level of accuracy in the models is not sufficient to meet these needs.

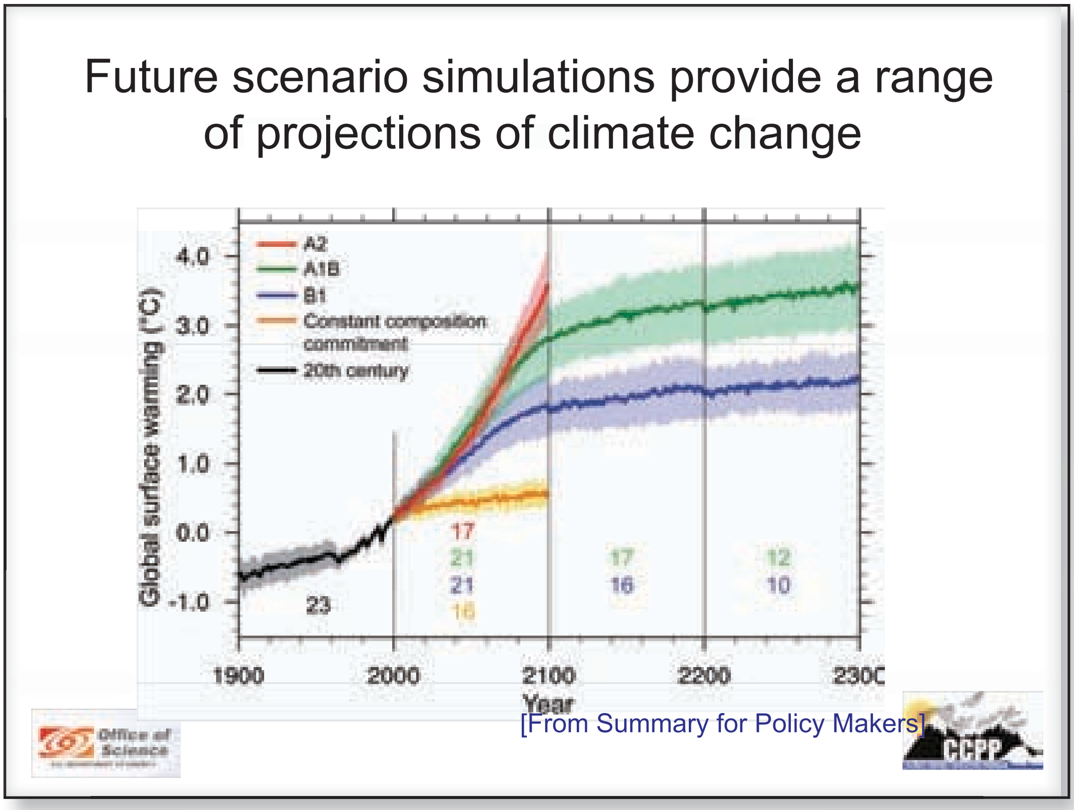
IMPROVED MODELS

For the IPCC AR4 report, *Climate Change 2007*, the working group on scientific assessment used Coupled Model Intercomparison Project 3 (CMIP3) experiments. CMIP3 was an unprecedented coordinated experiment by all of the major international modeling centers. The modeling groups did not simply analyze their own results; they also distributed the results in a common format to the community. CMIP3, with its rich database of model output, redefined the climate



modeling agenda by this coordinated set of experiments and their distribution. With thousands of users, CMIP3 heralded a transformational change in the analysis of results.

The next modeling project for the 2013 AR5 report, CMIP5, is designed to predict the climate of the next several decades. This requires multiple, very high-resolution, time-dependent climate model runs. Predicting the consequences of energy scenarios also requires many thousands of Earth system time-dependent runs. This is a two time-scale problem. One set of experiments will look at prediction using primarily the types of climate models we are now using, coupled atmosphere-ocean-sea ice-land-surface models without an interactive carbon cycle



component. Longer time scale simulations with fully interactive system models will include biogeochemistry—mitigation scenarios to counteract carbon emissions—and various changes in the carbon cycle to look at the effects of different mitigation strategies and possible solutions.

How useful are the CMIP3 models for climate prediction? There are some questions about their utility. What is the uncertainty of the model projections of the future? How does the skill in simulating the observed behavior of the climate system, both past and present, relate to the credibility of projections? What is the relative predictive skill of individual climate models?

Future scenarios provide a range of projections of climate change that are dependent on the level of carbon dioxide and other greenhouse gas (GHG) emissions to the atmosphere. For each of the four scenarios, several models were combined to arrive at a mean projected surface temperature change. Each of these models ran multiple realizations, which resulted in about 100 simulations of temperature for each emissions scenario. The shaded region in the figure above provided a range of results that is within one standard deviation of the mean. This range, in crude terms, represents the uncertainty within the models.

The predictive capabilities of global climate models over the next 30 to 50 years are generally, but not universally, in agreement. We find, for example, strong agreement on temperature change, but less agreement on precipitation patterns. In addition, the regional implications of global changes are less clear so, in effect, at the regional level we have very little predictive skill. The major challenge now is coupling global models to the regional scale. This has implications for adaptation planning. The models are in agreement about the rate of climate change. There is less agreement about precipitation effects except at continental scales. The impacts on the water cycle and hydrology are among the most pressing questions involved in climate change, and that is where we have the least confidence in the results. Uncertainties about regional precipitation effects, one of the effects people most care about, make it difficult to implement changes to water infrastructure. There is currently insufficient information upon which to base many of the planning decisions which must be made now.

DOWNSCALING

How do we downscale the global results of modeling to the resolutions needed for applications important for planning and decision making, such as hydrological modeling? Two approaches to downscaling are dynamical and statistical. In dynamical downscaling a coarse resolution global model drives a regional meteorological model with higher spatial resolution. Statistical downscaling results from developing empirical relationships between the large scale global climate modeling results and local scale climate.

With statistical downscaling, we take the global model results from the simulation of present-day climate, relate them to surface observations, develop statistical relationships among those simulations and the observations, and then apply those statistical relationships to simulations of future climate. There are many assumptions that go into that. First, the biases in the model are assumed to remain stationary as a function of climate change. In addition, it is assumed that those statistical relationships are constant in a changing climate. The advantage of statistical down scaling is that the assumptions can be stated explicitly, and then a formal uncertainty analysis can be formed around the results knowing those assumptions.

With dynamical downscaling, the course spatial resolution of the global model fields is used to drive a high resolution regional meteorological model similar to the type used for local weather predictions and research studies. This gives a view of the climate over a small area as simulated by that regional model.

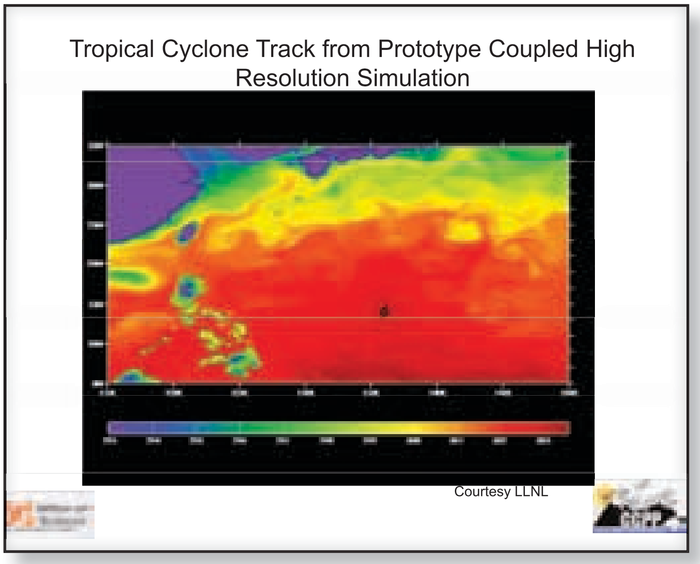
Lawrence Livermore National Laboratory in California ran such a model using a course resolution, global coupled model. Ocean temperatures from that run were used to drive a higher resolution atmospheric model, and a smaller piece of that run was used to drive a regional model over the area of interest, in this case the state of California. The result looked much better than the global model with its course grid, but when we did a quantitative analysis of these results and compared them against data, we found that these models are no better in the climatological average than the course resolution models we began with, so this downscaling gives a false sense of security; though it is precise, it is not necessarily more accurate.

NEXT GENERATION

A large and robust basic research enterprise is producing a steady stream of new knowledge about climate processes, climate dynamics, atmospheric dynamics, ocean dynamics, biogeochemical processes, and numerical methods to use with new computer architectures for climate modeling. The quantity, quality, and diversity of observational data to support climate research are increasing. New observational platforms, both *in situ* and remote, are spurring an exponential increase in the amount of information we have about the processes that make up a climate system.

The demand for model applications is also increasing in both magnitude and sophistication. Computing capacity is increasing dramatically, but it is very expensive and hard to use. It is becoming increasingly difficult to map the kinds of models we have onto these new computing architectures. More realistic models are much more complex, which makes it harder to quantify the uncertainties and feedbacks in them that lead to the uncertainties. The models must keep pace with scientific progress, and development and application must proceed simultaneously. We will need new models five, 10, and 15 years from now that are better than the ones we have now to answer the more difficult questions that will arise in the future. This leads to many conflicting priorities for human and computing resource allocations.

Traditionally, there have been two major directions of climate modeling: increases in spatial resolution and the inclusion of additional processes to make the system more realistic. In 2000,



the T42 model was capable of a horizontal resolution of about 500 kilometers (km). Today, a T170 model has about four times higher resolution than the T42 model. This improvement in resolution allows us now to begin to resolve large meso-scale storm systems, which was impossible to do before. Increases of resolution give us an increase in understanding effects that are driven by topography, such as coastlines and mountains. In addition, these improvements allow explicit simulation of the small scale processes that manifest themselves in large scale behaviors such as tropical storms.

In summer 2009, a multi-lab group of investigators completed a prototype simulation of a coupled high resolution model on computers at Lawrence Livermore National Laboratory. This model spontaneously generated and realistically simulated a category 4 tropical cyclone. In the wake of a tropical cyclone, cold water rises up to the surface and generates a wake behind it. Kerry Immanuel, a professor of Earth, Atmospheric, and Planetary Sciences at the Massachusetts Institute of Technology, has postulated that a change in tropical storm climatology could affect global climate as a result of this mixing of warm water downward. This was, to our knowledge, the first time anybody has simulated this phenomenon with a global model. The bad news, however, is that although we can realistically simulate the dynamics of the tropical storm system, we cannot get the storm climatology right with this model because of the large-scale biases that persist in the system.

High resolution still does not solve all the problems, for example cloud feedback in climate simulations of boundary-layer clouds. A study led by Bjorn Stevens, who is now director of the Max Planck Institute, evaluated large-eddy simulations of boundary-layer clouds using nocturnal observations of the marine stratocumulus. Two artificially produced visual images of what a satellite would see from these simulations with the same boundary conditions show two different cloud fields resulting in two different radiation effects on the climate. The processes that control boundary-layer clouds are even smaller than the highest grid resolution we are using for weather prediction, which is much smaller than we use with global climate models. Our current models are missing important, under-represented processes.

Another persistent issue in the climate change community is how to realistically include atmospheric aerosols in the climate system. Most models, for example, do not incorporate the aerosol effect of sand blowing off Africa into the Atlantic.

INTEGRATION OF INFORMATION

Future progress in our modeling systems will depend on integrating next-generation observational platforms with computing power. The climate change community is heading in this direction of integrating observations, measurement, and models in a more tightly coupled way. The numerical weather prediction community already does this.

One of the instruments that will revolutionize the field is the millimeter cloud radar. Cloud radars work like the more common precipitation radars, but are able to measure smaller cloud particles by sending an energy pulse into the atmosphere. This energy bounces off objects in the atmosphere and returns signals back to the instrument. This all happens in microseconds. In this manner the instrument is able to detect the cloud top and bottom, the density of the cloud, and the vertical velocities within the cloud. Millimeter wavelength energy can penetrate clouds that other types of radar cannot. This research instrument provides key information on cloud properties for the study of climate simulation and weather prediction.

We get very detailed information about the clouds at the same time we are taking measurements in the environment around them. Multiple observational data streams collected simultaneously is what we need to improve representations. CloudSat and Calipso are two satellite observation systems that were launched in 2006 and are part of a larger suite of satellites orbiting in space dubbed the A-Train. The A-Train concept is based on performing multiple measurements of multiple fields in as near real time as possible. We now have downward looking instruments that measure aerosols, clouds, and meteorological information all at the same time to help us improve the representation of these processes in models and, we hope, improve their accuracy.

A large question for mitigation efforts yet remains: can we accurately simulate the carbon cycle? There is a huge uncertainty about whether the carbon cycle will change over time. About half of the current human impact is mitigated by either absorption into the ocean or the take up of CO_2 by the terrestrial component of the carbon cycle. Whether that will change in a changing climate is a big issue. We want not just to put in trajectories, a time series of concentrations, we really want to drive these models with emissions, which we cannot do right now. That is why we are developing Earth system models. Some dated results show a very gross level of uncertainty. Two different simulations, by The Hadley Centre in the United Kingdom and the Institut Pierre Simon Laplace in France, using the same emissions trajectories, showed two very different responses. In the Hadley Centre simulation, the atmospheric concentrations are much higher than they are in the French simulations because in the former, a big carbon sink, the Amazon rainforest, dies off and stops taking up carbon from the atmosphere. One of the big carbon sinks essentially disappears and actually becomes a source of CO_2 to the atmosphere.

These are the kinds of gross uncertainties we have to correct if we are going to use these models for predictive simulation. We cannot do models without computing; computing is necessary but not sufficient. Based on our current understanding of processes and our capabilities with the models, we could use a 10^{12} increase in realizable computing power. If we were able to achieve that computing power, we would be better equipped to answer some of the questions that will allow us to plan and implement mitigation and adaptation strategies.

Greenhouse Gas Emissions and Terrestrial Carbon Sequestration in China

by Yao Huang

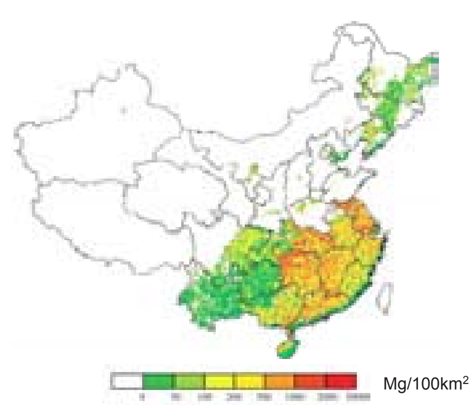
Dr. Huang *is a Professor of Environmental Science at the Institute of Atmospheric Physics, Chinese Academy of Sciences. He is also an Affiliate Professor at Auburn University, USA.*

One of China's responses to the challenge of dealing with climate change is to reduce its greenhouse gas (GHG) emissions through more efficient use of energy and to promote terrestrial carbon sequestration through wise land management. That seems a simple goal, but in fact, there are many uncertainties involved, both in estimating emissions and in quantifying the ability of vegetation and soils to serve as carbon sinks, not just in China, but also on the global scale.

In China, about 73 percent of greenhouse gas comes from carbon dioxide (CO_2), 20 percent from methane (CH_4), and 7 percent from nitrous oxide (N_2O). The global increases in atmospheric CO_2 concentration are due primarily to fossil fuel use and land-use change, while those of CH_4 and N_2O are primarily due to agriculture. Globally, about 41 percent of fossil fuel CO_2 emissions come from coal, 39 percent from oil, and 20 percent from gas. In the United States, about 37 percent of CO_2 emissions are from coal and 42 percent from oil. In Japan, about 50 percent of CO_2 emissions are from oil combustion. In Europe, the distribution of emissions for Organization for Economic Co-Operation and Development (OECD) countries is similar to that of the world. In China, however, more than 80 percent of CO_2 emissions are from coal and 10 percent from oil combustion.

The energy structure in China is different from that of the rest of the world and other large countries. Energy use efficiency as measured in CO_2 emissions per kilowatt hour (kWh) from electricity and heat generation is lower than the world mean. Worldwide, emissions are about 500 grams of CO_2 per kWh, in the United States 560 grams, and in European OECD countries less than 400 grams, whereas in China CO_2 emissions are 780 grams per kWh. According to recent estimates, energy use efficiency in China is about 33 percent, but for the developed countries it is closer to 40 to 45 percent. Methane emissions from agriculture represent about 50 percent, including rice cultivation and animal husbandry. Agriculture also accounts for more than 90 percent of N_2O emissions.

With a population that exceeds 1.3 billion people and is growing, China needs food, now and in the future. Grain yield in China has risen in the last 40 years, largely due to the increase in the use of synthetic fertilizer and also the introduction of new crop varieties. The increased use of synthetic N fertilizers would inevitably cause additional N_2O emissions. We have been conducting field experiments and establishing models to estimate CH_4 emissions and N_2O emissions from croplands. Model estimates indicated that emissions of CH_4 and N_2O from croplands in China have increased over the last 50 years. Most CH_4 emissions come from eastern, central, and southern China, where double, and even triple, cropping systems are standard practice. In southern China, for example, we typically use triple cropping systems, which means we have three harvests in a one-year cycle, mostly rice and other crops like rapeseed. In central and southern China, where intensive agriculture occurs and where most croplands are distributed, N_2O emissions are much higher than the national average .



Spatial distribution of CH_4 emission from rice paddies
(Wang *et al.*, 2009)

TERRESTRIAL CARBON BUDGET

In April 2009, Piao and colleagues published a paper in *Nature* magazine reporting on the terrestrial carbon budget in China. They estimated that, over the 1980s and 1990s, the biosphere in China sequestered an average of 190–260 teragrams (Tg) of carbon per year, which is much smaller than that in the conterminous United States but comparable to that in geographic Europe. Terrestrial carbon sequestration in China roughly corresponds to 28–37 percent of the accumulated CO_2 emissions from fossil fuels during that time, though uncertainties exist in these estimates.

Terrestrial carbon sequestration is likely attributed to an increase in summer precipitation and reforestation/afforestation across China particularly in the southern regions, reduction in fuel-wood collection that has led to an accelerated recovery of shrubland, and the expansion of crop production, combined with higher levels of crop residues returned to the soil that have produced increases in agricultural soil carbon.

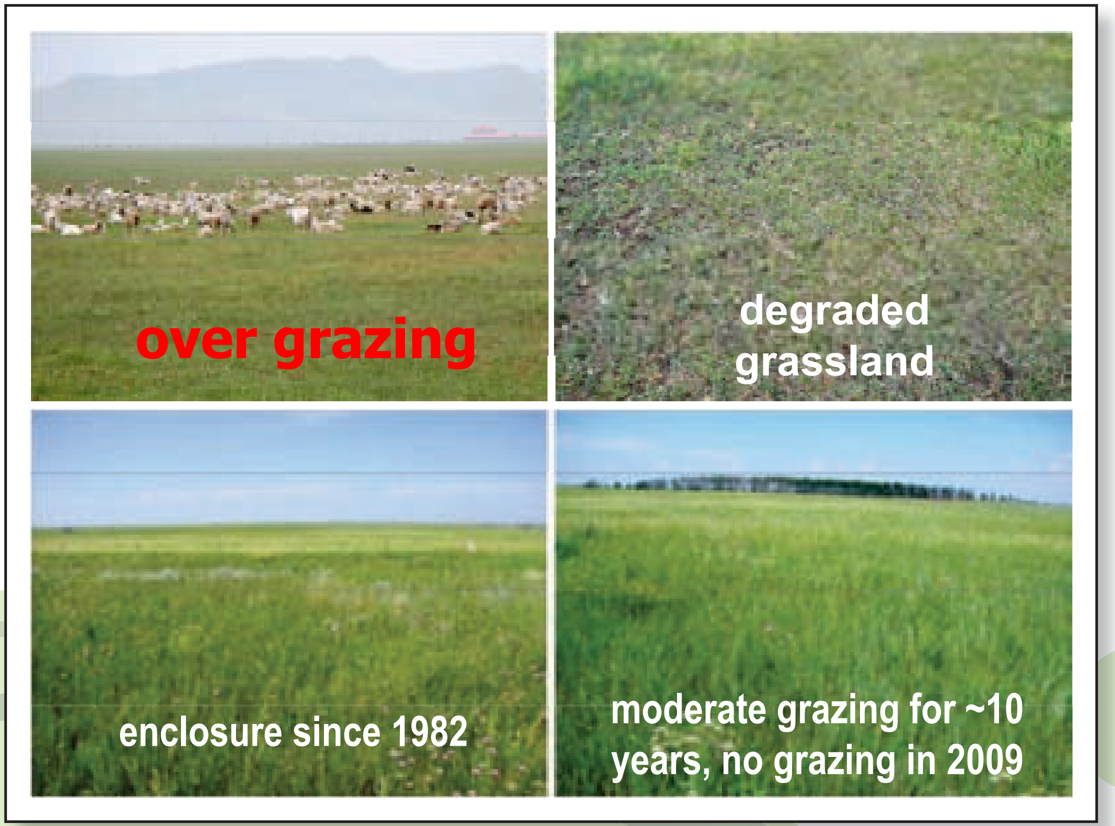
UNCERTAINTIES IN CARBON BUDGET

A combined estimate of the carbon budget on the national scale indicates that the mean value of the vegetation carbon sink is about 100 Tg per year, and the coefficient of variation about 51 percent. For soils, the mean carbon sink is about 70 Tg per year with a coefficient of variation about 64 percent. It seems from these data that the uncertainties in the estimated soil carbon budget are greater than for the vegetation carbon budget.

If we separate soil organic carbon (SOC) changes in different ecosystems—forest, grassland, and cropland soils—we see some changes in SOC density calculated from the models. Forest SOC was lost at a rate of some 360 kilograms (kg) per hectare per year, but the statistical models show an increase in SOC of about 120 kg per hectare per year; that is totally opposite. For grasslands, according to a paper that appeared in *Global Chinese Biology* in 2007, SOC in grasslands in China decreased at a rate of about 640 kg C per hectare per year. Yet the statistical model and some process level models showed that SOC in grasslands increased. That is a very large variation. In contrast, estimates by different researchers of SOC sequestration in croplands are generally comparable.

Forest soil. Inventory data on estimated changes in forest area indicate that total forest area increased by some 11 million hectares between 1990 and 2000. Remote sensing data using Landsat Thematic Mapper (TM) images, however, show that forest area decreased by about 1 million hectares over the same period. These conflicting findings suggest that we cannot accurately estimate carbon change if the land-use change is not accurately quantified.

More uncertainties exist in assessing the contribution of reforestation and afforestation to SOC accumulation. Two examples illustrate this point. First, researchers estimated SOC from afforestation in a southwestern province (Sichuan Province) where *Cryptomeria formne*, a conifer in the cypress



family, was planted. SOC density increased with stand age in an exponential fashion over some 25 years. However, field experiments from planting a different conifer, *Larix olgensis*, a species of larch, in a northeastern province (Jilin Province), showed a decrease in SOC in the first 10 years after planting followed by an increase over a period of 35 years. Changes in SOC related to reforestation and afforestation, therefore, depend on the climate. That is the climate rule. Changes in SOC also depend on different plant species, soil pH values, and soil clay content.

Grassland soil. Grassland degradation in China accelerated between the 1970s and early 2000s, and the Chinese government has been making efforts to protect the grassland. Overgrazing—stocking too many animals in the grassland—is a primary factor in grassland degradation .

Protective measures could change the production of grass vegetation, resulting in changes in SOC. Light, moderate, and severe degradation of grassland leads to corresponding depletion of SOC. In severely degraded grassland, SOC is much lower than in even slightly degraded grassland. Intensity of degradation is dependent on grazing density: light, medium, or heavy.

The Chinese government is now paying more attention to grassland protection, recommending that farmers use light grazing, enclosures, selective grazing locations, restoration of vegetation, and forbidding winter grazing. In 2006, the total area of protected grasslands amounted to about 139 million hectares. When the grasslands are protected and vegetation is restored, SOC increases.

Deep soil layer. There is general consensus that old growth forests can accumulate organic carbon in the topsoil, which is usually the top 20 to 30 centimeters (cm) of soil, but what about the deep soil layer? We have some evidence from literature datasets that reforestation and afforestation, agricultural practices, and grassland managements could contribute to SOC accumulations up to 100 cm deep. However, less attention has been paid to evaluating carbon changes in deep soil layers.

Model estimation. Model estimation of the terrestrial carbon budget is becoming increasingly important on regional and global scales. Uncertainties in the model estimates, however, may come from insufficient knowledge or inappropriate simplification during model development; imperfect inputs based on estimates of land use and land cover; and improper upscaling of model parameters such as climate, soils, and human activities. Insufficient model validation provides low confidence in the estimates of the carbon budget, particularly in SOC.

CONCLUSION

Greenhouse gas emissions in China have increased in the last decades. Adjustment of energy structures and improvement of energy-use efficiencies are expected to cut CO_2 emissions. From 1980 to 2000, the terrestrial carbon sink offset some 28 to 37 percent of greenhouse gas emissions.

Current estimates of the terrestrial carbon sink are subject to large uncertainties, particularly in SOC. These uncertainties come from the insufficient understanding of land use and land cover change, the contribution of reforestation and afforestation, the impact of grassland degradation and management to SOC accumulation, and carbon changes in the deep soil layer. Model calibration and validation using spatiotemporal datasets across a wider domain are essential to obtain higher confidence in the estimates of the carbon budget.

Impact of Climate Change on Renewable Energy

by Dan Bilello

Mr. Bilello *is Partnerships Manager with the Strategic Energy Analysis Center, National Renewable Energy Laboratory.*

In discussions on the uncertainties surrounding climate adaptation, response strategies, and climate variability under future scenarios, the production and use of renewable energy have not traditionally received a great deal of attention. The First US National Assessment of Possible Consequences of Climate Variability of Change, 1997-2000, for example, considered five sectors: agricultural production, coastal areas and resources, forests, human health, and water, but did not consider energy. The relationships between energy options, including renewable energy, and anticipated climate change, however, have important implications for our energy future and our respective countries' energy security.

In the energy sector, climate change discussions and research have tended to focus on greenhouse gas mitigation, not on impacts and adaptation. This is especially true in my field, renewable energy. In the last several months, however, there has been increasing attention paid to the question of energy security and system reliability and the uncertainties we face under different climate change scenarios.

A number of colleagues from the US National Laboratory network and I have contributed to a synthesis and assessment report, published by the U.S. Climate Change Science Program (CCSP) 2008: *Effects of Climate Change on Energy Production and Use in the United States*, which outlines key questions concerning the state of knowledge and science on the impacts of climate change on energy consumption and production in the United States. These questions include:

- How might climate change affect energy consumption in the United States?
- How might climate change affect energy production and supply in the United States?
- What other effects might climate change have that indirectly shape energy production and consumption in the United States?

IMPACT ASSESSMENT

In our energy sector impact assessment, CCSP Synthesis and Assessment Product 4.5 (SAP), we found several key outcomes of potential global warming. Air conditioning is a major electricity load in much of the United States, particularly in the American Southwest where increased demand from cooling technologies may affect our energy system as average temperatures rise. It is estimated that the demand for cooling will rise 5 to 20 percent per 1 C ° increase in warming, while the demand for heating will decrease 3 to 15 percent per 1 C ° of warming in other regions. Changes will vary by region and by season, but they will affect household and business energy costs and demands on energy suppliers. In general, the changes imply increased demands for electricity, which is likely to affect planning by the electric utility industry. Other effects on energy consumption are less clear.

We also looked at the infrastructure of delivered energy and the potential impacts of climate change on grid reliability in general and also during severe weather events. Grid reliability is essential in actually moving energy through the system, both liquid fuels and electricity. In addition, we assessed the state of knowledge on the effects of natural changes we anticipate with climate change on our energy infrastructure and the implications for energy decision-making, particularly in the realm of renewable energy. These impacts, which we are already experiencing, include potential sea level rise; intensity, location, and possibly increased frequency of severe weather; changes in the hydrological cycle and precipitation patterns; and agricultural productivity.

Some of these natural impacts will manifest as demographic change. Rises in sea level or temperatures may result in relocations of populations, which in turn will lead to geographical changes in electric loads in the coming decades. Will these changes alter the shape and duration of electricity consumption and demand curves? If we design an electric system or grid system to meet a certain anticipated load, will that change significantly in the coming years? How do we anticipate those changes under climate change and respond to them effectively?

Natural impacts will also affect system efficiency and economics. In most cases, renewable energy, excluding wind technologies, is on the cost margin of being competitive with traditional technologies. As the efficiencies of renewable technologies, which are directly tied to factors such as water availability or production of biomass feedstocks, are reduced, that can have a direct impact on the ability to make renewable energy projects economic and competitive in the electricity sector. Location and availability of renewable resources may change under different climate impact scenarios, and natural impacts such as severe weather events will also affect grid reliability.

CRITICAL OPPORTUNITY

Climate modelers and policy makers often see renewable energy technologies as a critical opportunity to meet growing energy demands in a low carbon way, so renewable energy must be a part of the overall equation in addressing solutions to climate change. The renewable energy community is most concerned about issues such as maintaining and improving system efficiencies and economics, which are tied to location and available resources that may undergo significant change. In addition, temporal and spatial change influences our ability to model and forecast. Decisions on where to site renewable energy projects relate to where that resource is located. If these localized resource allocations change significantly over time under climate change, that uncertainty makes it very hard to plan and implement projects that might have capital lifetimes of 20, 30, or 50 years.

Like thermal technologies, many of the renewable technologies also rely on water for cooling. Concentrating Solar Power (CSP) is one example. We have good solar resources in the Southwest, but most CSP technologies have significant water demands. Availability of water is dependent on the hydrological cycle. Changes in that cycle will have an impact on the cost and efficiencies of those technologies. Again, there is a direct tie back to our natural systems. Potential changes in wind patterns, levels of humidity, productivity in agricultural sectors, water availability, and solar insolation all have direct impacts on the ability of those technologies to produce power cost effectively.

EFFICIENT POWER PRODUCTION

Several renewable sources of power are available, but to be viable in the market place, they need to be cost effective in the long term. Using hydropower as an example, water supplies, which may be reduced or increasingly variable, have a direct impact on the ability of utilities to plan, develop, and dispatch power from hydro sources. Biomass likewise is dependent on water availability. Crop productivity will potentially be subject to increased competition for land under future climate change scenarios, affecting the availability and cost of biomass feedstocks for either biofuels or biomass power. Geothermal sources are also directly linked to water availability for production and cooling of those technologies.

Efficiency and Power Production

Hydropower: water availability for production

Biomass: water availability, crop productivity, competition for land

Geothermal: water availability for production and cooling

Less directly dependent on, but still related to, climate change are renewable sources such as solar, wind, photovoltaic cells, and storage of energy to meet changing demand patterns and requirements.

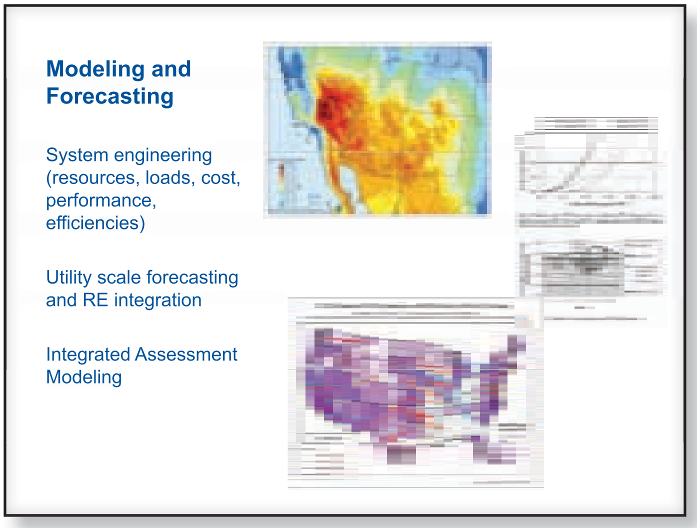
Solar: Solar power is a technology that is growing both in the United States and globally. In the American Southwest, where a good resource can be matched with a local load, water is still a key factor. In most cases these technologies rely on water cooled systems to maintain high efficiencies.

Wind: The ability to forecast the production of power from wind depends on the ability to forecast that wind resource and plan for the impact of extreme events on large, utility-scale wind sites.

Photovoltaic: For utilities to convert to large-scale wind farms or solar farms, they need data at hourly or minute-by-minute intervals on the resource available to them. Under a climate change scenario, increased variability in those resources will make them harder to forecast and model. From the perspective of the utilities, these uncertainties raise the costs and concerns over whether or not they want to opt for one of these technologies.

Storage: A key question about renewable energy is the ability to store power and electricity from a variable resource. As loads change, for example if you get many more cooling days in the American Southwest, the storage requirements that were anticipated for a certain technology may significantly change, and that in turn will change the economics of that project.

For utilities to make decisions on renewable energy technologies, forecast modeling is critical. From project-specific planning, to the utility scale, to integrative assessment modeling, key assumptions about the availability and cost of renewable energy resources must be factored into the process. If the quantity, cost, or availability of those resources changes significantly under climate change, the impacts will be felt on all the system engineering and tools and models that



forecast resources, loads, cost, performance, and efficiencies. Currently none of the modeling tools does a very good job at incorporating risks and uncertainties, nor can they effectively model renewable energy production. In terms of research and development, utility-scale forecasting is a major need. In addition, we need to work on integrated assessment modeling.

MANAGING RISK

Our focus at the National Renewable Energy Laboratory has traditionally been on research and development. Market and policy factors are also critical in making both renewable and traditional energy projects economic and to accelerate the deployment and application of new technologies on the ground. We must consider the potential implications on future scenarios in climate change and the economic viability of projects. Less reliable forecasting is a direct cost to a utility trying to grapple with how to incorporate a variable resource like renewable energy onto the grid. The greater the unreliability, risk, or uncertainty, the higher the cost of forecasting. In addition, changes in anticipated load or storage requirement may result in stranded investments. Planning for a concentrated solar power project established outside of Phoenix, for example, must incorporate certain assumptions about the availability of water. If that changes over time, the project could potentially become uneconomic. We have in some cases seen this with geothermal where projects are terminated because they cannot be made economic over time as the resource becomes depleted.

Cooling requirements also have a direct impact on system efficiency and on the cost competitiveness of those technologies. Scarcity of resources may affect the efficiency and potential competition for that resource. With a biomass power project, if the feedstock price rises significantly, the viability of the project may be jeopardized. In addition, a significant change in a power plant's output fluctuations due to climate change compared to what was forecast may create investor uncertainty and make it harder for the next project to find an investor comfortable enough with the economics of a given project to support it.

RESEARCH NEEDS

This workshop is a great opportunity for thinking together globally about the future research needs of the United States and China. A major focus of our dialogue is to better identify and measure the potential impacts and uncertainties surrounding climate change. We need to understand these issues at a geographically fine enough resolution to understand the implications in certain regions of the country, particularly where we anticipate significant development of renewable energy projects.

We must also develop a policy investment analysis and modeling and R&D responses and decide how, together, we can understand the impacts of our decisions and what steps can we take now in terms of R&D, portfolio, analytic requirements, and modeling requirements to effectively deal with risk and uncertainty for all the technologies in our nation's energy portfolio. Through a better understanding of the potential impacts of climate change on both traditional and renewable energy technologies, as well as the relative strengths and weaknesses of available technologies in the context of energy prices, energy security, and environmental emissions, our nation will be able to gain a more holistic picture of the social, policy, or economic benefits of our energy options.

A Scalable and Extensible Earth System Model for Climate Change

by John Drake

Dr. Drake *is a Group Leader in the Computational Earth Sciences Group, Computer Sciences and Mathematics Division, Oak Ridge National Laboratory.*

Climate modeling is important to the science and engineering community because models lead to discoveries of feedbacks between ecosystems and climate, improve the fundamental science of the effect of aerosols in the atmosphere, and encourage advances in modeling and simulation science for climate projection. Modeling is also important to the public because it shapes US energy policy and contributes to international assessments of climate change and its causes.

In developing global climate models and global Earth system models, two key words are scalability and extensibility. *Scalable* is a parallel computing term. Parallel computing requires the use of very high performance parallel computing equipment with thousands of processors. *Extensible* indicates that these models are expanding beyond just the physical climate system and are now growing into Earth system models that must be able to accommodate new components of the climate system.

The primary objective of the US Department of Energy's (DOE) Scientific Discovery through Advanced Computing (SciDAC) project is to develop, test, and exploit first generation Earth system models, based upon the Community Climate System Model (CCSM), which will run efficiently on thousands of processors and include significant model enhancements. Improvements to the representation of carbon and chemical processes for treatment of greenhouse gas emissions (GHGs) and aerosol feedbacks are being made in collaboration with DOE's Atmospheric Science, Atmospheric Radiation Measurement, and Terrestrial Carbon programs. This project will enable climate change simulations required for scheduled national and international climate change assessments to which the CCSM is committed as part of the US Climate Change Science Program (CCSP).

SciDAC is a consortium of all DOE national laboratories and the National Science Foundation (NSF), and in particular the National Center for Atmospheric Research (NCAR) is the NSF laboratory that is primarily involved.

THE GRAND CHALLENGE

The challenge that faces climate modelers is to predict future climate based on scenarios of anthropogenic emissions and changes resulting from options in energy policy. The Earth climate system is basically a heat transfer fluid flow system, but it gets more complicated quickly. Our goal is to be able to predict future climate based on anthropogenic emissions. This goal is different from what has been done for the Third and Fourth Assessment Reports (AR3 and AR4) of the International Panel on Climate Change (IPCC), and from what is proposed for AR5. The next generation climate models will be targeting AR6.

Much of our work for the last few years did not make it into the CCSM4 model that is to be released in June 2010 for NSF and DOE. Instead of having to prescribe the CO_2 concentration, we would actually like to compute it. We would like to simulate everything that is involved in the carbon cycle and make the model work so that as anthropogenic emissions are put into the model, it would predict the CO_2 concentration, giving an accurate prediction of regional and global effects. We modelers don't think we understand the interactions of the carbon cycle with climate until we can model it. That is perhaps a radical statement, but given the decisions that are being based on these models, I think it is an honest one. We need to acknowledge that often, we cannot get the right answer, that our predictions don't match the actual outcomes, and we need to know why that is. If we cannot model it, we essentially say we don't understand it yet.

Models are used in a very fundamental way to guide policy directions. In fact, even deciding that there is global warming, and that it is an issue for the future, is primarily a modeling result, so simulation is very important. For example, Warren Washington and colleagues with the Climate Change Working Group (CCWG) at NCAR used the CCSM to study low emission scenarios for the Synthesis Assessment Product (SAP) 2.1 report that came out shortly after IPCC's AR4.

The IPCC has suggested several scenarios for future climate change. We will look at three. The first, A1F1, assumes continued economic growth and reliance on fossil fuels and is considered the high end scenario. Under the B1 scenario, we move away from fossil fuels and toward alternative and renewable energy, a very optimistic scenario. In the middle is the A2 scenario, which projects slower economic growth and some adoption of renewable and alternative sources of energy over the century.

The CCWG asked whether we can we do better. What is the most optimistic scenario we could model. This, I believe, will be the AR5 450 parts per million (ppm) scenario, which the NCAR group is suggesting as the best carbon emissions scenario that we can hope to achieve. Is 450 ppm enough, and what level of good does it do according to the models?

In this scenario, the average global annual temperature rises and levels off, showing a warming in the Northern Hemisphere of somewhat less than 2 °C. In the high emission scenario, the Arctic ice disappears in the summer. But with the lesser scenarios, the ice stabilizes. If we can act quickly on a very stringent emissions scenario, we will reach a new climate equilibrium in fairly short order. This is the AR5 equivalent of the best outcome, the most optimistic scenario we have.

The A1FI scenario was part of the AR4 report, but very few people actually ran it. As it happens, emissions for the last decade fell somewhat above that scenario. Many of us thought we should focus on A1FI because that is actually the track we are on.

For the United States, the A1F1 model showed four predicted scenarios for temperature and precipitation for the 2050 decadal average, the decade between 2045 and 2055, and compared each of those ensembles with the 2000 to 2009 ensembles as well as the ensemble average. One of these scenarios shows much warmer temperatures than the others, but even so, by 2050 the numbers are 4 to 5 °C higher than present.

We cannot predict which of these will actually occur. Any of them could occur by mid century under the A1FI scenario. Regional rainfall totals for July show more spatial variability across ensembles than do the temperature monthly averages. That is, the models agree fairly well on temperature change, but not as well on precipitation. Within any single model, variability of precipitation is fairly high.

EARTH SYSTEM MODEL DEVELOPMENT

Since AR4, we have been trying to extend the models and develop an Earth system model, including additional processes and components not yet incorporated into previous models. The melting of ice sheets and sea level rise, for example, cannot be properly accounted for until we have realistic modeling of ice sheets and land ice sheet dynamics, and we don't have that yet. In addition, the indirect effects of aerosols, a fairly large negative effect on climate forcing, have not been incorporated into the models. In AR4, these were simply absent. Truth and honesty require us to try to incorporate full aerosol indirect effects in the models, and we are still working on that. We will probably have to wait until AR6 for correct inclusion of these processes.

We have done a lot of work on biogeochemical coupling, as well as carbon and terrestrial carbon models in the context of a fully coupled system. We also need to include dimethyl sulfide (DMS) fluxes from ocean ecosystems and how those interact in the atmosphere and consequently with climate. In addition, we need new dynamical formulations for algorithms. Finally, we need to consider the results of scaling towards the petascale.

Oak Ridge National Laboratory (ORNL) and China have some of the most powerful computers in the world. ORNL has super-computers capable of computational powers at the petascale, computing a quadrillion FLoating Point Operations Per Second (FLOPS). We believe these computers can help solve these problems. We are trying to make the models run as well as we can on these computers to take advantage of this new computing power to extend the models.

One area of immediate concern related to computing power is the resolution of the models. To model impacts and adaptation strategies in the future, we are currently missing the necessary tool to model extreme events such as hurricanes, but these tools are beginning to appear.

At ORNL, we have recently begun to use a new fluid dynamic solver that runs on a 1/8th degree grid, somewhat less than a 15-kilometer global resolution. We are now running it through its paces to be certified, validated, and verified. It is already generating very realistic hurricanes with interesting frequencies. We can now start thinking about using global models to perform impact analysis and adaptation planning. To run with that level of detail, we need the largest computers available. The current machines here at ORNL are on the order of 200,000 processors. Some of the improvements we have made have essentially doubled performance by using better algorithms.

As we put these models together, we are finding different levels of complexity. At the lowest level of complexity, we can model full three-dimensional atmospheric chemistry interactively running with the climate model. With the full climate model, the increased complexity makes the system run much slower, but by using a lot of processors, we can speed things up a bit. That is essentially what I mean by scalability; we are pushing the scalability of the models on these computers.

The second term I use, extensibility, means extending the models to include other climate components. The carbon cycle is probably the first and most important factor to include in these global models. In AR4, the carbon cycle was not closed in any of the models. For AR5, in fact, CCSM, will have the option of closing the carbon cycle. This is a big step forward.

If we confront the models with various types of satellite and ground based observations such as AmeriFlux, and compare these on a seasonal basis and with their equilibrium states, we arrive at a good enough carbon model to include in the

AR5. Nevertheless, everyone involved with this project gives all the carbon models about a C+/C rating. This indicates that our understanding of the carbon cycle is still incomplete. We have not represented all the processes necessary to model this correctly. This is ongoing science that needs to be done. Work on the nitrogen cycle, which interacts with the carbon cycle, for example, is still in its early stages.

SETTING PRIORITIES

The rate of 21st century ice sheet melting and sea level rise is extremely uncertain and is now recognized as a high priority for climate models. In 2008, William Lipscomb at Los Alamos National Laboratory, for example, was the only scientist in the DOE complex working on computer models of ice sheet dynamics in a coupled climate model. We will soon begin coupled climate experiments with a dynamic Greenland ice sheet model, which will be tuned as needed to produce a realistic control simulation, then applied to standard IPCC forcing scenarios. We will devote substantial resources to improving the ice sheet model during the next several years.

The development of the fourth CCSM model to be released in 2010 is one of the biggest improvements in the simulation of the El Niño-Southern Oscillation (ENSO). CCSM4 will be used to produce short-term climate forecasts to 2030. The new model's higher atmosphere resolution produces better rainfall predictions in the southeastern United States than previous versions, reducing the uncertainty of the predictive models. Ocean temperatures and ENSO cycles in the model are much more highly localized and correct, and there is also a better treatment of ozone. Improvements are seen especially in coastal upwelling regions.

In the next step, after the carbon cycle, we will begin to bring in some of the other components, the ocean ecosystem in particular, and try to include the sulfur cycle in the model.

In recent discussions with Dr. Hong Liao and colleagues at the Climate Research Center, Chinese Academy of Sciences, we have also begun to set goals for international cooperation in modeling advances.

REGIONAL AND GLOBAL EARTH SYSTEM MODELS

We recognize the need to develop high resolution global climate models, to develop and evaluate a dynamic vegetation module, to improve simulation of the carbon cycle, to gain a better understanding of cloud microphysics and aerosol-cloud interactions, and to improve our ability to simulate secondary organic aerosols.

Air quality-climate interactions. We aim through international cooperation to estimate impacts of climate change on air quality in China and the United States, to understand the major physical and chemical processes that influence air quality in China, to find better ways to assess the meteorological mechanisms of long-range transport of air pollutants and dust, and to understand the role of air pollutants in regional and global climate change.

Climate simulation and projection. Our simulations will be incorporated into the IPCC AR5, including projections of regional climate change in China and the United States, extreme events based on measurements and model results, and policy-relevant science for abatement and mitigation plans.

The results of our modeling research will be distributed for all international modeling groups through the Earth System Grid (ESG). ORNL is a major node on the ESG; in fact, because of our computing capacity we are a major part of the holding. Earth system simulations will occupy our focus once the computational and scientific performance of the CCSM4 is well established.

In the future, we hope to see many of the uncertainties inherent in the currently available models corrected and to incorporate a number of processes never before possible with earlier generation supercomputers. These advances will make predicting the future climate a more precise science, and allow us make decisions on the national and international level to respond to climate change.

Omics: Potential New Tools for Understanding Global Climate Change Impacts

by Paul Brown

Dr. Brown *is a Professor in the Department of Forestry and Natural Resources at Purdue University.*

The new "omics" disciplines that derive from the genomics revolution have the potential to further our understanding of many different types of biological systems. Potential is the key word. The scope of these omics is enormous in terms of the sheer amount of data generated by these new and emerging disciplines. The secondary scope relates to their applicability across the board in the real world.

Today, omics faces profound analytical challenges. We find ourselves as yet with few practical applications of these disciplines, and our efforts at this point are more exploratory than applied. Chemists are still actively working to establish methodologies and working definitions of the terms. A few examples of current research will illustrate the scope of the data, the types of data analysis we are involved in, and the challenges we face. It may not be too early, however, to suggest a few potential applications of the omics in understanding global climate change.

QUESTION OF SCALE

When people criticize science in the 21st century as being reductionist in nature, they are talking about the gradual shrinkage of focus. When I was a student at the University of Tennessee, I took a course in cell biology. I am not certain that cell biology courses are even offered anymore. We have gone from there to molecular biology and now into the omics. Indeed, molecular biology is almost becoming a passé term.

Replication of DNA has been driving fundamental biological discovery for a long time now, a good 40 to 50 years. Each major step in that replication is now considered a separate scientific discipline, if that is the right term. I call them disciplines simply because we are seeing journals entirely devoted to specific topics. We are seeing a continual evolution from genomics to transcriptomics, proteomics, and metabolomics. We can add several more to this list: lipomics, with a focus on lipid soluble compounds; in plant sciences, ionomoics, focused on ions. We can both blame and thank the chemists of the world for providing us with the analytical tools and techniques to advance into these omics and look at things on a much broader scale.

For people who work on global models, global scale means one thing. When I say a global scale I mean the global content of a cell.

Proteomics is simply the large-scale study of expressed proteins. The term *global* when applied to proteomics may be a misnomer; in proteomics the term means all the proteins in a sample. It is also referred to as shotgun proteomics, because we do not know what we are going to get. *Metabolomics* is the large-scale study of small molecular weight chemicals, typically in a range of 10 to 1,000 atomic mass units. Those are the big steroids and phospholipids. Again, we use the terms large-scale and global, yet we are talking about very small sample sizes.

The fundamental approaches in proteomics have largely involved gel-based electrophoresis to separate chemical compounds based on their mobility in gel phases. We are now moving into liquid chromatography (LC) based separation techniques and identification methods. These offer tremendous potential, but both approaches will have different applicability depending on specific questions and specific experimental designs. These approaches allow identification of peptide fragments; we cleave the proteins into small fragments and identify those using a mass spectrometer. Our mass spectrometry colleagues in chemistry are leading the way in creating these methods.

Currently we have multiple ionization methods. An ionization method is a component of mass spectrometry that allows us to identify the peptide fragment. There is very little overlap in proteins identified with the two primary ionization methods that we currently use.

FROM THE LAB TO THE FOOD CHAIN

To understand the protein component of a biological sample and identify certain suites of proteins and pathways, no one can really tell you which ionization method to use. It is too early in proteomics development to identify specifically the correct approach unless it has been done before.

Consider the example of two-dimensional gel electrophoresis. We conducted a gel based study with three different treatments on rainbow trout that were fed, not fed at all, or fed a little bit.

We separated 269 proteins by gel electrophoresis, and each one expressed a twofold difference in expression. Of those 269 proteins that were expressed at twofold difference, which biologically is a very large difference, only 97, less than half, could be identified. Most of those, 24, were related to glycolytic energy cycles in muscles. With slightly fed and unfed fish, you would assume some impairment in energy producing pathways. We also identified, however, a number of other, unexpected, protein complexes: apolipoproteins, iron metabolism, and energy metabolism in serum and liver. I am a nutritionist, and I still don't understand that one very well.

We also had a large suite of structural proteins in serum, liver, muscle, and the gastrointestinal tract. As animals are fed, the structural integrity of cells starts to change in a significant way. If you don't feed a fish, the fish will be stressed. Stress related proteins occur particularly in the pyloric cecae, an anatomical structure in the gastrointestinal tract. There is no real analogy in the human world, but the pyloric cecae in fish is a separate anatomical structure. The GI tract expressed a number of different stress related proteins.

Building on those efforts, we are now comparing two common ionization approaches. One is the Matrix Assisted Laser Desorption Ionization/Time-of-Flight (MALDI/TOF) ionization method. The other is Electrospray Ionization (ESI). These are two of the more common ionization approaches within the mass spectrometry world and are strictly LC-based approaches. At Purdue University, we have very good collaborations and a wide range of biological samples with which to compare these two platforms. For example, we have vertebrate embryos, in this case zebrafish. We also have some partially purified proteins from primordial germ cells, also from the zebrafish line. In addition, we have a mixed assemblage of algae and zooplankton. We are heading towards a concept of meta-proteomics. In the real world these may answer questions about the impact of human activities on the lower portion of the food chain. We also have breast cancer cells and tissues, in short a wide range of biological samples that we are sending through in this first study simply to find out which proteins we can identify by MALDI/TOF versus ESI approach. It is a very simple question but one that has not been addressed yet.

THE YOUNG (YNG) AND THE WILD

We have collected data using LC/ESI on two zebrafish lines, a wild line and a recessive mutant young (YNG) line with Brahma related gene 1 deficient (brg 1). This mutation causes the gene to lack a crucial enzyme, ATPase chromatin remodeling complex, which is directly involved in eye development. We identified 800 to 1100 proteins, which sounds like a lot, but we actually used only 588 in the analyses, about 50 percent. We started off specifically with a very small sample size.

The recommended sample weight for proteomics analysis is in the range of 250 milligrams (mg). In this case we had 10 embryos at 36 and 52 hours old, and our sample weight was in the range of 20 mg. Conventional wisdom would tell us that we are not going to get any proteins at all, but we went forward with this, because it is useful for our colleagues and collaborators. We are in the very early stages of proteomic development, and we wanted to test the minimum sample weights.

The embryos were 36 and 52 hours post *in vitro* fertilization. Zebrafish are a nice model vertebrate species because we are able to use controlled fertilization with them so that we know exactly when fertilization occurred. The zebrafish genome turns on at about 24 hours post fertilization, so the genome had been replicated for about 12 hours with the fish 36 hours post fertilization. We found a number of proteins that were expressed in the wild type and not expressed in the YNG line, and vice versa.

The data at this point in time tend to be qualitative in nature, indicating just the presence or absence of protein. To take it to quantitative levels requires a great deal more work and expense. There are several ways to make these data quantitative, but we first wanted to do a simple qualitative comparison. We found a number of novel proteins and proteins that we had hypothesized or predicted would be present. Even though the zebrafish genome has been fully described and we have an extensive zebrafish database, we are operating currently in the field of proteomics in a situation where we do not know what a lot of these proteins do. We have essentially never seen them before, though they have been predicted based on the DNA description. We think they should be there, that there should be a particular amino acid sequence, and we can indeed measure it with certain approaches, but no one has ever studied these proteins.

The various proteins themselves are beneficial to the YNG line. Let me cite just one example. If we look at the same types of data from older fishes, at 52 hours, and consider again that the genome kicked on at 24 hours, we start to see a lot of protein muscle development on the wild side that we do not see in the YNG line, and proteins related to eye development in embryos. This is a result we expected and anticipated. With MALDI/TOF, we have identified only a very few proteins, 10 in the wild side and 8 in the YNG line. Some were expressed in the wild type and not in the YNG, others were expressed in the YNG and not in the wild line.

We also found some major software differences between ESI and MALDI/TOF. Results are still being summarized, but it appears that there is a less than 10 percent overlap in identified proteins. With MALDI/TOF, we see far fewer proteins. MALDI/TOF communicates with a certain protein identification software program, while ESI communicates with a separate one. The very large number of proteins identified with ESI compared to the fewer number with MALDI/TOF may be related simply to the communication with the software programs. We expect to resolve that problem soon.

In the realm of metabolomics, nuclear magnetic resonance (NMR) has been one of the more common approaches over the years. We have access at Purdue University to gas chromatography (GC) and LC based platforms. Many chemistry researchers around the world still utilize NMR and utilize it very well, but it generally requires larger sample sizes, and most of the work we do is limited to small sample sizes. Some people would also argue that NMR is not as precise, though I have not seen data that actually compare the two. The GC approach we use is a tandem gas chromatograph (TGC), which involves chemical tagging and is destructive in nature. But TGC uses a database from the National Institutes of Standards and Technology (NIST), a U.S. government maintained database that is considered of very high quality for identification of metabolites based on molecular weights.

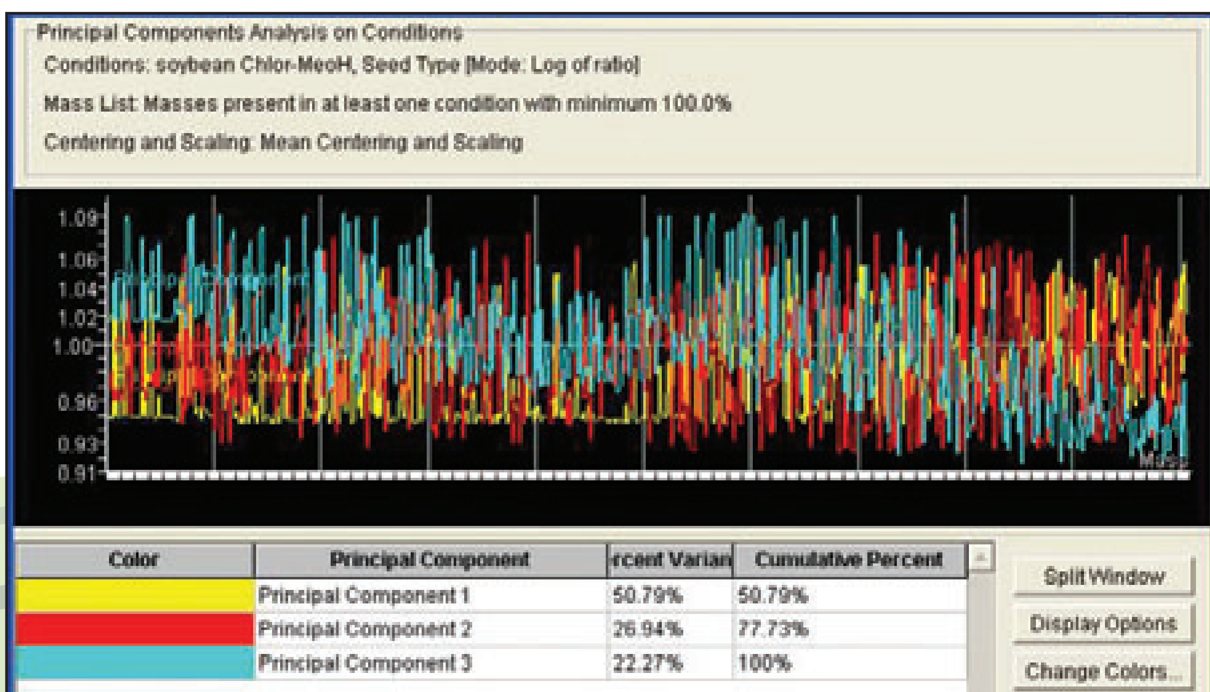
With the LC platform, there is no chemical tagging involved, so it is potentially nondestructive. Unfortunately, many of the newer databases, though they are currently free and are being maintained and developed by some very good groups, are not of NIST caliber and have smaller datasets than those of the NIST. In addition, from personal experience, I find the LC software platform more user friendly than other platforms.

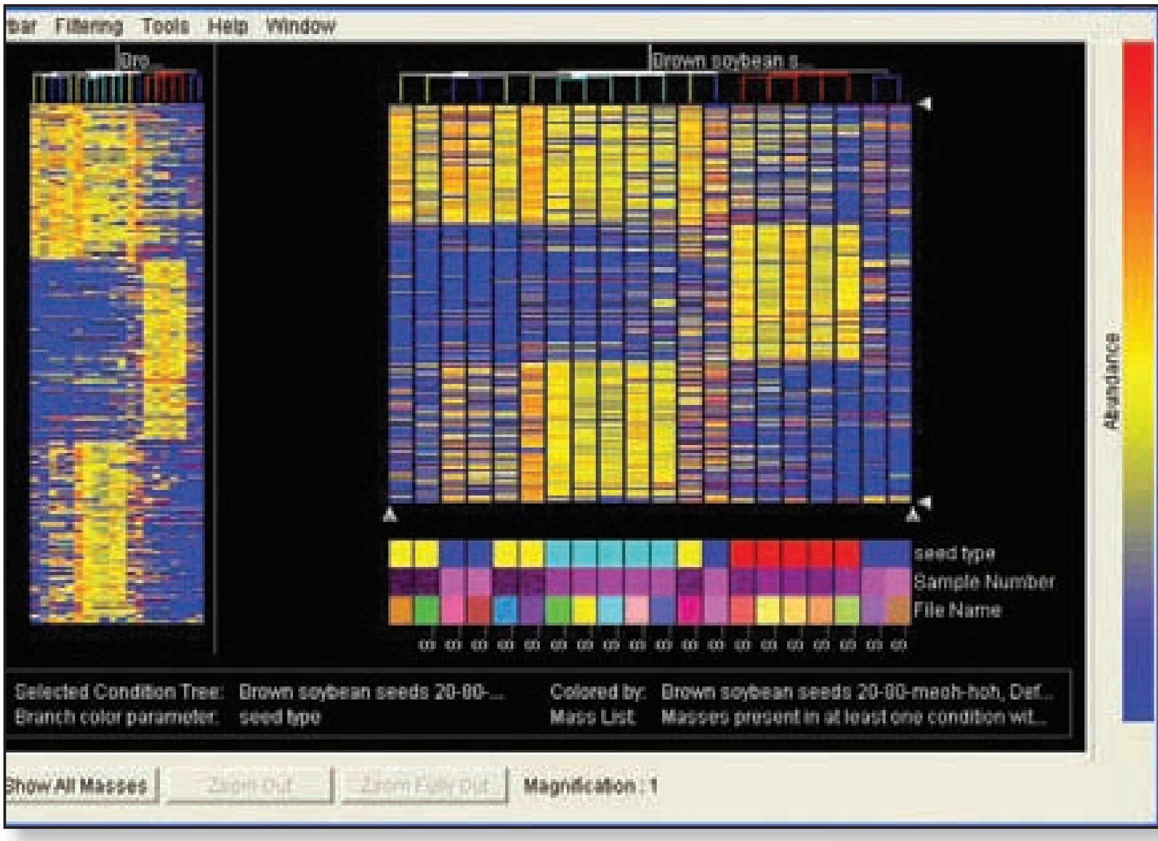
We also used a GC platform to analyze differences in serum, liver, and muscle of trout that were fed, underfed, or fasted. We found significant differences in a number of metabolites using this platform. There were well over 2,000 metabolites in each of the three tissue samples. Significant differences were apparent: 32 mostly related to fat metabolism in fed versus half-fed, 53 related to amino acids and lipids in fed versus fasted, and 55 related to amino acids and lipids in half-fed versus fasted. Again the scope is large, but by the time we filter down, analyze, and compare the data based simply on the presence or absence of metabolites, we wind up with relatively few numbers.

Other current projects likewise use an analytically based approach. We have conducted a formal comparison of LC and GC platforms and extraction protocols. Current metabolomics approaches require extraction of the chemical prior to injection into the chromatographs, GC or LC. Our extraction mediums consist of solutions of 2:1 chloroform methanol, 80:20 methanol water, and 20:80 methanol water. The initial samples are soybean seeds, algae, zooplankton, and mixed assemblages of algae and zooplankton.

We used soybean seeds because we wanted to include a botanical example, and because some soybean farmers in Indiana have expressed an interest in cooperating with us on some of our projects. We were fortunate to acquire a tropical soybean germplasm, a Brazilian soybean line. This research has implications in terms of country of origin labeling, branding by continent, and identification of agricultural crops shipped around the world. Indeed, we found that the tropical germplasm from Brazil has distinctly different metabolites than North American germplasm.

By using principal component analysis, we are able to explain a lot of variability pretty quickly. The three North American varieties we used are each distinct from each other and also distinct from the Brazilian types, as indicated by the simple presence or absence of metabolites.





RESEARCH CHALLENGES

Despite the number of biomarkers that identify a tropical soybean germplasm, analytical challenges remain. With proteomics those include sample size, protein loading on LC, identification of low abundance proteins, and protein identification programs. With metabolomics, problems related to sample size and continued development of metabolite databases remain. In the future, we will be moving from qualitative to quantitative analyses, but the first step is to work on the identification level and then move on to quantitative analysis.

The potential range of applications of omics research is quite wide. I have been interested in nutrient flows through food webs for a long time. In the aquatic food web, water-soluble vitamin C is of interest because it is such a labile nutrient and required by virtually all aquatic animals. Fat-soluble vitamins in polar food webs may also be of critical importance to the health of wildlife. Disruption of critical nutrient flows through food webs may lead to nutrient deficiencies.

In terms of global change, proteomics and metabolomics have the potential to further our understanding of the effects of pollutants, thermal changes, carbon dioxide, and energy production on the environment. Understanding and applying these approaches to inputs and outputs from biofuels or renewable energy stocks is an area of future research that is quite promising. We have seen wide variations in the germplasm of soybean seeds, for example, so I suspect renewable fuels inputs also have a good deal of variability associated with them.

Proteomics and metabolomics are intriguing new tools that appear to have large-scale applicability. Though the omics research of today may appear to be reductionist science, in fact, these are the first steps toward a meaningful contribution to answering community, landscape, and global questions.

A Framework for Managing Climate Change

by William Fulkerson

Dr. Fulkerson *is a Senior Fellow at the Institute for a Secure and Sustainable Environment, University of Tennessee.*

According to the International Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), greenhouse gases anthropogenically added to the atmosphere have been responsible for most of the global warming observed over the past 50 years. Speaking at the Pontifical Academy of Sciences in December 2007, Professor Myles Allan of Oxford University said that the warming observed since 1980 is predictable and predicted, and that no other explanation has survived scientific scrutiny.

What difference does it make that warming is occurring? Some brave people have tried to figure out the answer to this question. One result is the Stern Review, "The Economics of Climate Change" named after its compiler Sir Nicholas Stern (now Lord Stern), head of the UK Government Economics Services. Stern predicted the cost of climate change expressed as reduction in per capita Gross Domestic Product (GDP) over time under three scenarios. One of the scenarios includes both market and non-market effects and the risk of catastrophes. In that case, by 2100, the costs are of the order of 1 to 2 percent decrease in GDP per capita per year. By 2200, the costs are 6 to 14 percent. These cost estimates derive from the data about effects from AR4. Another study by Bill Nordhaus of Yale University gives similar numbers. The studies used very different discount rates leading to very different policy recommendations.

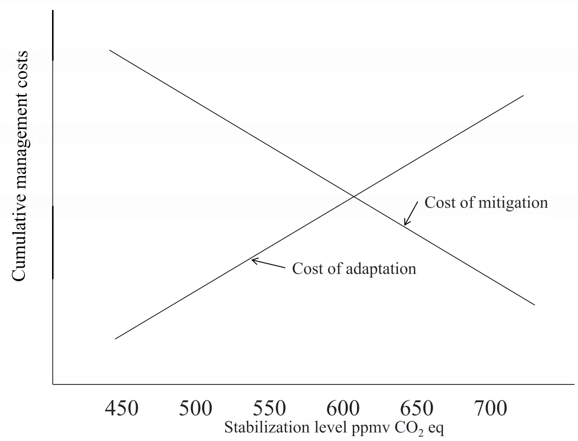
What are the catastrophes under this scenario? One would be tipping points such as the melting of the Greenland ice cap with an accompanying rise of sea level by half a dozen meters. Tipping points occur because warming has caused a more or less irreversible transition of parts of the planet from one state to another. For each tipping point, Tim Lenten from the University of North Umbria in England has indicated the range of global average temperatures at which such a tipping point might be triggered. For the Greenland ice sheet it is one to two degrees Kelvin.

So I am brought to this conclusion: Humans are changing the climate in ways and at such a rate that will soon constitute "dangerous anthropogenic interference with the climate system," a state to be avoided according to the United Nations Framework on Climate Change. Since we are messing with Mother Nature already we need a framework for managing change to the advantage of human and ecological well-being.

STRATEGIES

As far as I can tell only three strategies are available for this management framework. They are:

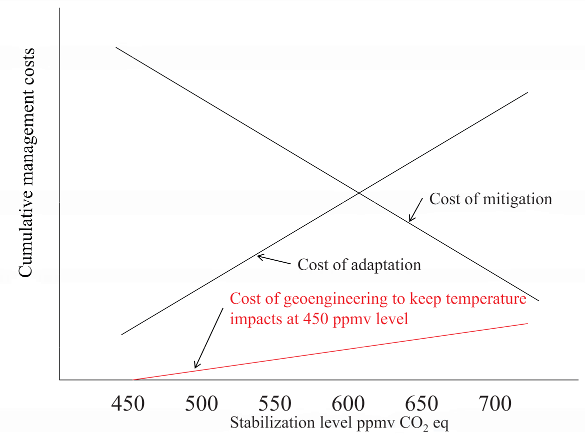
- Mitigation—Reduce greenhouse gas (GHG) emissions and/or enhance net removal of them from the atmosphere.
- Adaptation—Actions to reduce or eliminate the negative impacts of climate change that can't be avoided.
- Geo-engineering—Actions to reduce solar radiance to offset warming, a controversial strategy.



Schematic cartoon of climate change management costs

These three strategies can be pursued independently of each other. They are in that sense orthogonal; that is, one can take mitigating actions without doing geo-engineering or adaptation. But of course, how much mitigation one does influences how much adaptation is needed or whether geo-engineering is required to achieve a desired goal. Depending on circumstances, the overall framework for management may involve all three.

A simple straight-line cartoon illustrates our three strategies. The lines for each strategy depict total cost integrated over time for various levels of CO_2 equivalent at stabilization. To stabilize at 450 parts per million (ppm) is obviously more difficult than stabilizing at 750 ppm, so the slope of the mitigation curve is downward. Similarly the cost of adapting to 450 ppm is much

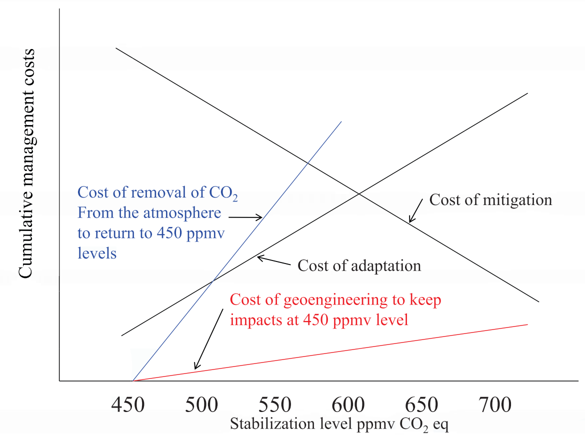


Schematic cartoon of climate change management costs

less than for adapting to stabilization at 750 so the adaptation line increases with stabilization level.

Now suppose that the best the world can do is to stabilize at 550 ppm. That would be very difficult to do, but suppose governments actually achieve this goal. Suppose also that stopping at 550 ppm will cause us to lose the Greenland ice sheet over the next century. To avoid that we would have to stabilize at 450 ppm, but we can't do it.

At this stage we choose to invoke geo-engineering in the form

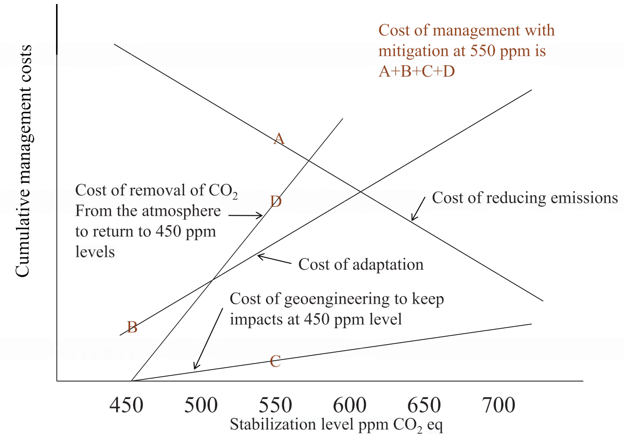


Schematic cartoon of climate change management costs

of injecting stratospheric or tropospheric particles to reduce solar radiation sufficiently to bring the temperature down to that equivalent to 450 ppm, and thereby we avoid losing the Greenland ice sheet. I have drawn the cost of solar radiation management as modest compared to adaptation or mitigation because that is what the literature argues is likely. Of course, we may have to continue geo-engineering by injecting particles every year or two perhaps for a century or more. In the meantime the ocean becomes more acidic and we may lose all sorts of ecological and food resources. We therefore need to bring the CO_2 levels back down quicker than will occur naturally.

So, we scavenge CO_2 from the atmosphere, and that will be expensive as shown by my fourth hypothetical curve . At least it will be more expensive than reducing emissions. By my definition the cost of mitigation is the sum of the cost of reducing emissions plus the cost of removing CO_2 from the atmosphere.

The total cost of management for the little problem I have postulated is the sum of A, the cost of emission reduction to



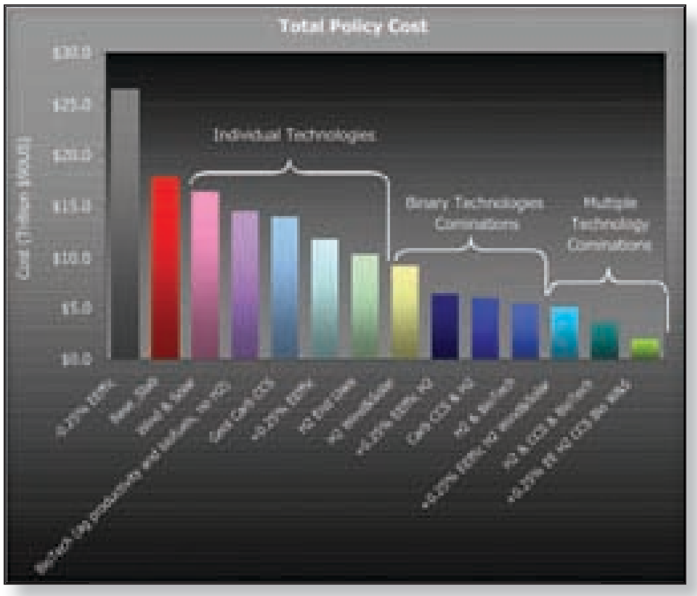
Schematic cartoon of climate change management costs

stabilize at 550 ppm, plus B, the cost to adapt to 450 ppm (not 550 ppm), plus C, the cost to geo-engineer the temperature down from the 550 level to the 450 ppm level, plus D, the cost of removing CO_2 from the atmosphere at 550 ppm to return it to 450 ppm level.

THE BIG THREE

That is how the strategies may be used to solve a problem. It's marvelous to pretend, however I am skeptical we will stabilize at anywhere near 550 ppm. Why? It's the economy, stupid. Let's look briefly at the situation for three important players, China, India, and the United States.

According to China's National Climate Change Programme of 2007, "…as a developing country, China will stick to its sustainable development strategy and take such measures as energy efficiency improvement, energy conservation, development of renewable energy, ecological preservation and construction, as well as large-scale tree planting and afforestation,



to control its greenhouse gas emissions and make further contribution to the protection of global climate system." In other words development comes first. China has also had the courage to deal with population growth, a possible corollary to mitigation.

In 2007, India issued its National Action Plan on Climate Change which states that "maintaining a high growth rate is essential for increasing the living standards of the vast majority of our people and reducing their vulnerability to the impacts of climate change." Poverty trumps climate change mitigation, and its eradication is a principal adaptation mechanism.

The United States has no official climate change plan. However, a bill has passed in the House, and similar legislation is pending in the Senate, which, if made law, would give the United States a plan. The President gives this legislation high priority. If no bill is passed the US Environmental Protection Agency has the power to regulate emissions of GHGs. For this reason, I think the United States will have a policy plan soon.

Why is there no plan yet? It would cost too much is the simple answer. The hope is that developing and deploying better energy and other advanced technologies will bring the cost down.

Can we do that? Yes, we can, at least partially.

Jae Edmonds and Steve Smith with the Pacific Northwest National Laboratory show that advances in many different energy technologies can bring down the cost of mitigation dramatically. The base case with today's technology leads to an integrated and discounted cost of about $18 trillion needed to keep the temperature rise less than 2 degrees in 100 years, a target favored by many in Europe. This cost is in the ballpark of what is estimated as the cost of doing nothing in the Stern Review. If one is successful at developing and adopting advanced energy technologies the cost could be reduced to about $3 trillion, these authors estimate.

Clearly what is needed is sustained and significant energy R&D. But what is actually happening? Investments by Organisation for Economic Co-operation and Development governments have been steadily declining over the past 20 years, though they may be rising now due to recent attention particularly in the United States.

Hence, I would say all three major players in climate change have adopted similar points of view expressed differently. None of the three wants to commit aggressively to mitigation. It costs too much. They may be willing to invest to create a technology fix. China, for example, seems willing to make significant investments and is interested in every advanced energy technology.

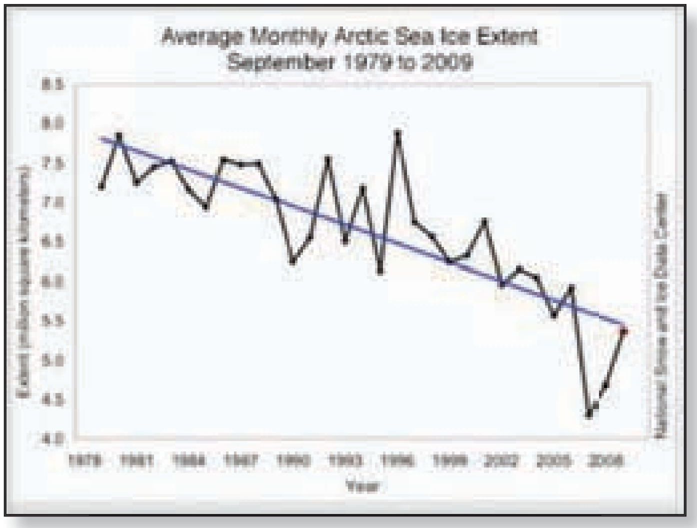
We should emphasize also the strategy of adaptation that is a major part of the plans of China and India.

- Mitigation requires global action but adaptation is mostly local.
- Cumulative investments in adaptation may buy time for mitigation, but mitigation can slow climate change and make adaptation easier. Remember my cartoon.
- Adaptation has been ignored, and R&D is likely inadequate.
- Pursuit of both can promote sustainable development.
- Building adaptive capacity and taking mitigative actions should be parts of overall optimum climate change response
- India and China seem to be developing such a response.
- The United States can learn from these examples. The House Climate bill does include adaptation measures.

LOSS OF ARCTIC SUMMER SEA ICE

Arctic summer sea ice has declined about 30 percent since 1980 and is dropping faster than models predict. If you linearly extrapolate data from the National Snow and Ice Data Center tracking declines since 1978, you would predict the summer sea ice going to zero in about 2080. This is a big change.

How important is the loss of summer sea ice? I don't know, but the prospects are troubling. There are positive feedbacks such as albedo decreases in the Arctic Ocean and increased disintegration of methane and CO_2 clathrates in permafrost. There are also ecological losses such as iconic species and disruption of weather patterns at lower latitudes. Warming of



the Arctic in general threatens the Greenland ice cap, a tipping point.

Geo-engineering via solar radiation management is the only remedy in our toolbox that can be applied in time to save the summer sea ice. Should we use our geo-engineering tool? It will involve injecting reflective particles into the troposphere or stratosphere at very high latitudes. Maybe we should use that tool, but we should certainly be doing the R&D to determine if the tool can be restricted to the Arctic, discover any negative consequences, determine reversibility, estimate costs, and determine governance including legalities. As far as I know no nation, except perhaps Russia, is spending any significant R&D dollars to develop geo-engineering as an option.

We may also be able to adapt to some negative impacts on the ecology. The Interior Department has proposed designating more than 200,000 square miles of land, sea, and ice along the northern shore of Alaska as a critical habitat for the shrinking polar bear population. Ken Caldeira and Lowell Wood have modeled the injection of sulfates into the stratosphere at high latitudes to cool the Arctic. The models indicate that the idea has merit. It suggests we can cool the Arctic preferentially, more or less.

I think this should be the first focus of geo-engineering R&D. The loss of Arctic summer sea ice may be an urgent problem. Only solar radiation management can be done in time. The other two strategies—mitigation and adaptation—are too slow. Geo-engineering can be geographically limited and limited in time. It only needs to be applied in the summer. It is reversible in the sense that the particles settle out in about a year.

In conclusion, we are changing the climate and are headed toward a potential planetary emergency. The cost of doing nothing may be very high but delayed. We can avoid the risk by actively managing climate change by intelligent use of three strategies: 1) mitigation of emissions of GHGs and enhanced net removal from the atmosphere, 2) adaptation to harmful impacts that can't be avoided by mitigation or offset by geo-engineering, and 3) application of geo-engineering as a last resort safety valve (e.g. for saving the Arctic summer sea ice). The cost of management can be reduced by research and development, demonstration, and deployment (RD3), but the investment must be sustained over time.

STEWARDSHIP OF THE LAND

Worldwide, grasslands play a critical role in the global carbon balance by offsetting emissions of greenhouse gases. Sheng-Gong Li with the Chinese Academy of Sciences says that China is committed to restoration of grasslands that have been degraded through overuse. To determine whether specific grassland ecosystems represent a carbon sink or a carbon source, the country has deployed a nationwide monitoring network, ChinaFLUX, to perform direct measurements at the ecosystem scale. ChinaFLUX is also involved in a network of collaboration among Eastern Asian countries to determine the role different ecosystems can play regionally in offsetting global warming.

The climate-energy nexus is essentially a feedback loop system that connects climate and energy through ecosystems as a mediator or component of the system. Whether we start with the effect of climate on ecosystems, or ecosystems on climate, there is a feedback of influence on local energy demands. Anthony King with Oak Ridge National Laboratory (ORNL) argues that ecosystems can no longer be considered in the traditional sense, in which the human elements of the system are not explicitly included. Instead, we need to include social ecosystems in our models.

With the rapid urbanization of China, the urban ecological ecosystem urgently needs radical transformation. Ru-Song Wang with the Chinese Academy of Sciences says that cities could be the solution for the human future if we shift from thinking of urban centers as Ego-cities to building livable Eco-cities. Otherwise, the modern city will become a time bomb, destroying our civilization.

ORNL's Virginia Dale takes a landscape-scale approach to the climate-energy nexus. Policy makers and managers can tailor landscape designs to determine energy choices that are more likely to be robust and resilient in the face of uncertainties such as climate change. In many situations, positive benefits of choices involving climate change, energy, and land use can be achieved with landscape design.

Loss of biodiversity is a calamity of global proportions, says Purdue University's John Bickham. Human activities unrelated to climate are compounding the effects of global warming, making many species more vulnerable to the inevitable effects of climate change. If we do not reverse climate change soon, the results will be devastating for the natural world and potentially for humans as well.

The French national agency for scientific research (CNRS), in collaboration with Chinese scientists, has been collecting regional details of carbon fluxes and their distribution in space and time in China. Philippe Ciais says that at our present level of understanding, there are still a number of processes unaccounted for. China is, in a sense, a world of its own, but at the same time it is the theater of all human and climate change processes that will determine the future of our planet.

Spatio-Temporal Variability of Carbon Cycles of China's Grasslands

by Sheng-Gong Li

Dr. Li *is Vice-Director and Professor with the Terrestrial Carbon Cycle Synthesis Center, Chinese Ecosystem Research Network, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences.*

Grassland ecosystems comprise one of the largest biomes in the world, covering almost one third of the global land surface. Global grassland biomes include the prairies of North America, the pampas of South America, the savannas and velds of Africa, the savannas of Australia, and the steppes of Eurasia.

These ecosystems play critical roles in the global carbon balance by offsetting the emission of greenhouse gases (GHG) from human activities. Whether they act as a sink or a source of atmospheric carbon dioxide (CO_2) depends upon several environmental and biotic factors. Especially in arid and semi-arid environments, where grassland ecosystems are widely distributed, productivity of grassland ecosystems is closely associated with seasonal and inter-annual variability of water availability.

China has a vast area of grasslands, covering more than 40 percent of its land surface, about 400 million hectares, mostly distributed on the Inner Mongolia Plateau, a temperate steppe, and the Qinghai-Tibet Plateau, a grassland meadow. Grasslands in China occupy more than 3.2 times the land area of croplands and 2.5 times more than forested areas.

Grasslands play very important roles in sustainable development for China's socioeconomic and environmental conservation. However, due to extensive and intensive anthropogenic activities such as over-exploitation and the conversion from grassland to farmland, China's grasslands are subject to large-scale degradation, and thus their potential to function as carbon sinks is likely weakened.

Degenerated grasslands account for almost one third of the total grassland area. Because most of these grassland ecosystems are located in arid and semi-arid areas in China, drought or erratic precipitation become the dominant factors affecting plant growth and carbon balance of the grasslands.

Based on an overview of carbon flux of grasslands in China using site measurements and network-based estimations, we aim to answer the following questions:

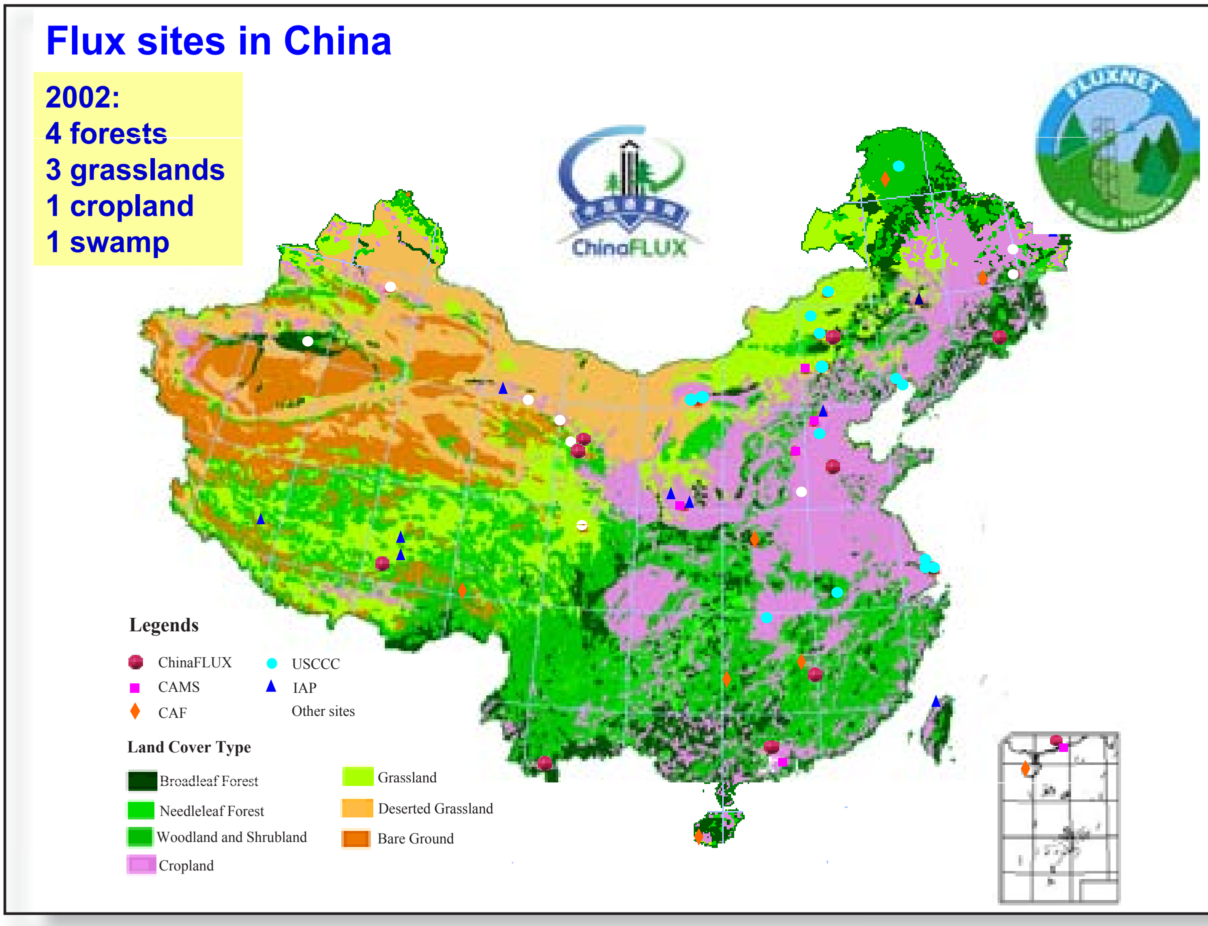
- Do China's grasslands act as a carbon sink or a source, with a focus on spatio-temporal variability or uncertainty in terms of net ecosystem carbon dioxide (CO_2) exchange?
- What environmental and biotic factors drive this variability or uncertainty?
- What is the likely trajectory of the carbon cycle of grasslands under conditions of climate change and intensive anthropogenic activities?
- What carbon sequestration potential is likely to be achieved for offsetting gradually increased emissions of GHGs?

ADVANTAGES OF EDDY COVARIANCE

We have many methods for studying ecosystem carbon fluxes, for example atmospheric inversion models, satellite monitoring from space, remote sensing from aircraft, biomass inventory or biometric methods, tower-based micrometeorological techniques such as eddy covariance (EC), and ecological models.

EC can be used to perform direct measurements of mass, energy, and momentum flux at the ecosystem scale. Compared with traditional biometric methods, EC has a large footprint extending from a few hundred meters to several kilometers. EC can also be used to collect data at a high resolution time scale, with continuous measurements over multiple hours, days, months, and years. Another advantage is that EC can be used for many different ecosystems, terrestrial and even marine.

The Chinese Terrestrial Ecosystem Flux Research Network (ChinaFLUX) was established in 2002. At first, the network included sites in just a few ecosystems: forest, grassland, cropland, and swamp. Over the past six years, the network developed rapidly, and we now have more than 70 sites across China.



Measurements through the ChinaFLUX network reveal large spatial and temporal variations across the grasslands in terms of whether the ecosystem is a carbon sink or source. The grasslands in Mongolia in the past 30 years, for example, have become a carbon source for CO_2 while in Tibet, the grasslands are a carbon sink or are carbon neutral. We have established a linear relationship between biotic factors and net ecosystem exchange (NEE) of carbon on the Stipa steppe in Inner Mongolia: as vegetation increases, the ecosystem becomes a sink and vice versa.

In Tibet and Inner Mongolia, we also observed that environmental controls, which affect soil water content, affect the maximum photosynthesis possible and thus tend to increase the uptake of carbon in the soil. On the Stipa steppe, NEE responds negatively to photosynthetically active radiation (PAR). The stress of drought also causes declines in NEE; when the stress is removed through precipitation, NEE increases.

MULTIPLE FACTORS

For China's grasslands, a drought or water shortage will change the relationship between the carbon cycle and environmental factors. When water is in short supply, the net ecosystem exchange (NEE) of carbon becomes very weak, and the system can change from a carbon sink to a carbon source. This result was observed during research conducted in Outer Mongolia in collaboration with Japanese scientists between 2003 and 2006.

Temperature also contributes to shifts from a carbon sink to a carbon source. There appears to be a temperature sensitivity at which the shift becomes dramatic. For example, in 2004, the threshold temperature for such a sink occurred at 3 ˚C in an alpine shrubby meadow at Haibei in Tibet, at 6 ˚C in an alpine meadow at Dangxiong in Inner Mongolia, and at 8 ˚C in a Leymus grassland in Inner Mongolia. Therefore, if temperatures vary during water shortage conditions, the NEE response will likewise change in these grassland ecosystems.

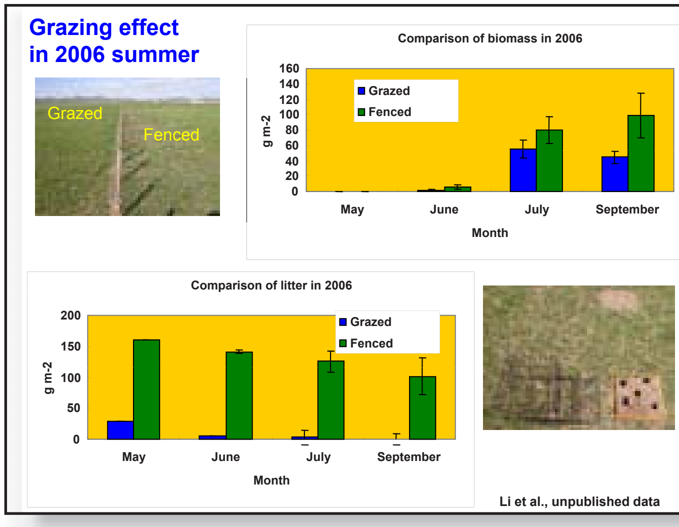
We have also measured the sensitivity of grasslands to temperature fluctuations during the four seasons and found that the shift from a carbon sink to a carbon source varies in different ecosystems. Under future global warming conditions, this sensitivity will have a strong effect on the carbon balance. We predict that for the Tibetan grassland, the shift from a carbon source to a carbon sink will occur with a 3 ˚C rise in temperature. For the Mongolian grassland, the shift will occur above 8 ˚C.

Grazing patterns also have strong effects on grasslands. If the land is not over grazed, the carbon budget can be a sink or neutral, but if the grassland is over-utilized for a couple of years, it becomes a source for CO_2. We used two methods to determine the NEE, EC and the biometric method. A comparison of the biomass and litter in 2006 between grazed and ungrazed land showed significant increases in the carbon sink in the fenced grassland where livetock were excluded.

A complicating factor in estimating the carbon cycle in grassland systems is the amount of carbon stored not just in above-ground biomass, but also below ground in the soil. There are many uncertainties in estimating the carbon stock of grasslands in China, and there is much work to be done in the future.

The big challenge for the Chinese government and Chinese scientists is that we are the largest emitter of GHGs, and these emissions continue to rise. The Chinese government wants to know whether its terrestrial ecosystem can play some role in affecting carbon GHGs emissions in the future. We can take many measures to reduce CO_2 emissions. One method is to restore the vegetation over degraded ecosystems, and that is the focus of one of our large research projects. More than 70 percent of grassland in China is degraded due to over grazing and other human activities. We want to restore this vegetation as one step in reducing GHG emissions.

Restoration of desertified sandy grasslands is also a high priority. One method we are exploring is to use a straw checkerboard to stabilize sand dunes, which will allow vegetation to recover. We also have begun a project plan to convert some current cropland to forest and grassland, and to protect grassland from over grazing. Over the past six or seven years, this effort has resulted in an increase in restored areas from 7.2 million to 39 million hectares.

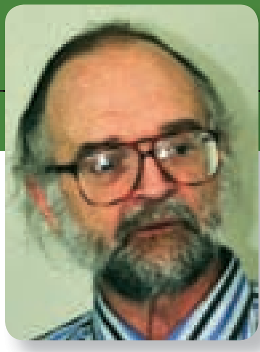


ChinaFLUX is also involved in a network of collaboration among different countries, especially Japan, China, and Korea. We want to know what role different ecosystems in East Asia can play in offsetting global warming. This project, involving JapanFlux, KoFlux, and CarboAsia, began in 2007 and runs through 2011. We hope to extend the collaboration another two to three years.

In short, we want to understand the current state and future conditions of carbon sequestration throughout the terrestrial ecosystem in East Asia. If this project is successful, we then want to extend our research to the carbon cycle in all of Asia and determine how we can mitigate climate change by taking specific measures to reverse the greenhouse effect.

Ecosystem Modeling in the Context of Climate and Energy

By Anthony King



Dr. King *is a Research Staff Member with the Ecosystem Science Group, Environmental Sciences Division, Oak Ridge National Laboratory.*

The breadth and diversity of models in the context of the energy and climate nexus is so large that it is impossible to give due consideration in one short presentation to the various models. Instead of sampling those models, I present a conceptual structure we can use to think about where ecosystem models exist in this context, and more importantly perhaps to identify gaps where models do not yet exist. In doing so, I will indulge my hyper-integration holistic tendencies.

There is an overlap in the domain between energy and climate. That is the point of this workshop, which addresses the nexus between energy and climate. Though there are many other connections, ecosystems and ecosystem science represent one of the nexi in that overlap.

CLIMATE AND ECOSYSTEM

As an ecologist, it is easiest for me to consider how climate affects ecosystems. We know that the climate distribution influences the distribution of ecosystems geographically in terms of biomes. Species composition within a biome varies with climatic differences. At the level of long-lived species, their reproduction, productivity, and growth respond to the climate, while shorter-lived individuals respond only to the weather component, one of the realizations of climate. There are, of course, models associated with each of those areas. In fact that particular loop is heavily populated; virtually any ecosystem model I am aware of, from population models up to those at the biome-level, has some weather/climate component to them.

Less populated in the realm of ecosystem science, but nonetheless important and becoming more so, are models that reflect the influence ecosystems have on climate. There are biophysical influences in terms of how the land surface, vegetation, and ecosystems influence the exchange of energy and water with the atmosphere and consequently the climate. Any state-of-the art, full complexity climate model incorporates ecosystem modeling in the form of a land surface model that incorporates biophysics. In addition, there are biogeochemical influences from the ecosystems onto the climate, primarily in the form of greenhouse gases (GHGs). The exchange of carbon dioxide (CO_2), nitrous oxide, and methane all influence the climate. The addition of biogeochemistry to the land surface models and climate models is a more recent phenomenon.

The Fourth Assessment Report of the International Panel on Climate Change (AR4), presents about a dozen climate models with an ecosystem land-surface component that adds biogeochemistry in addition to biophysics, primarily just carbon and CO_2 at the moment. Part of the loop is increasingly populated by models at a much larger spatial scale, including meso-climate scales. There are also ecosystem models representing the boundary condition between the land surface and the atmosphere outside of the influence on climate.

ECOSYSTEMS AND ENERGY

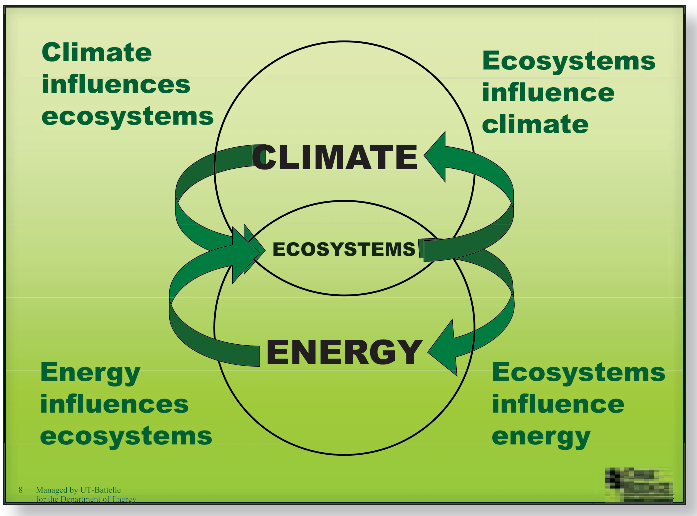
Ecosystems also influence energy. Long before we discovered rocks that would burn, in the form of coal, we used woody biomass, derived from forest and grassland ecosystems among others, as a fuel. Today, as we try to use biofuels in a modern context, the connection between ecosystems and energy is even more important.

In addition, ecosystems, including human systems, provide insulation from climate. Humans and other organisms build insulation from the climate using ecosystem products. This includes shading. In human systems, very local shading, from trees around houses for example, influences energy consumption. On the more mesoscale, forests tend to cool a somewhat larger local area and consequently influence energy consumption and demand in those regions.

Ecosystems also present environmental constraints on energy production. As we produce more and more energy, we have an impact on those ecosystems and ecosystem properties. These effects constrain how we produce energy and affect regulations on energy production. Ecosystems influence energy in a number of ways.

Conversely, energy influences the ecosystems. We have a long tradition of ecological impacts from energy production in the form of acid rain and other effects on ecosystems from energy production. More recently, we are realizing ways in which energy production and CO_2 influence ecosystem production through CO_2 fertilization. The demand for land to produce energy has been a constant throughout history. The production of energy requires using land in ways that affect ecosystems locally. As we begin to use biofuels and bioenergy, the demand for land and the impact on the ecosystems increase.

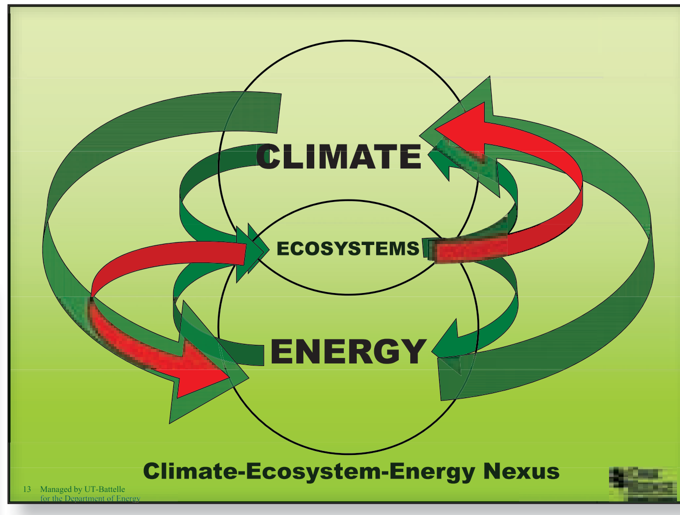
Essentially, we have a feedback loop system that connects climate and energy through ecosystems as a mediator or component of the system. Whether we start with the effect of climate on ecosystems, or of ecosystems on climate, there is a feedback of influence on local energy demands. Wherever we start, we end up looping through that system and looking at different components of the ecosystem nexus.



Some connections, do however, by and large, bypass the ecosystem nexus, the canonical version of that being energy production using fossil fuels that throws GHGs into the atmosphere and influences the climate. But that of course then loops around to influence ecosystems. If we think about mitigation of the fossil fuel influence on climate, either through the use of biofuels or through the use of bio-sequestration, there is a loop in which the ecosystem nexus is engaged beyond climate impacts.

Similarly, the climate bypasses ecosystems to influence energy. The concept of degree days is the easiest example. As regional temperature changes, the amount of energy demand changes based on whether there are lots of cooling days or lots of warming days. This effect bypasses ecosystems directly, but as a mitigation phenomenon we can also involve ecosystems, such as urban forests for neighborhood cooling, green roofs, and other manipulations to actually change the heating or cooling demand of buildings and neighborhoods using ecosystem properties and ecosystem services.

The diagram of this climate-energy nexus mediated through ecosystems and ecosystem modeling is rather loopy looking. In my experience, the loops that go from ecosystems to energy and energy to ecosystems are less well populated with models than other loops. We might consider what new models might be fed into these loops.



THOSE WERE THE DAYS

In thinking about ecosystem management or any resource model that uses ecosystem modeling, the days are quickly falling behind us when we can ignore how a changing climate might influence ecosystem management or resource models. In the past, some models have assumed a constant non-changing climate, and that includes some of my own models. That assumption is no longer tenable for models of future ecosystem behavior. Similarly, on the frontier of ecosystem modeling, we can no longer accept the notion of being able to do ecosystem modeling at large scales, global scales for example, without thinking about how those models actually influence climate. The days are gone of large global carbon models or large global biogeochemistry models that don't incorporate their influence on the climate, including the interaction between biophysics and biogeochemistry. Those models are dated if not quickly becoming obsolete.

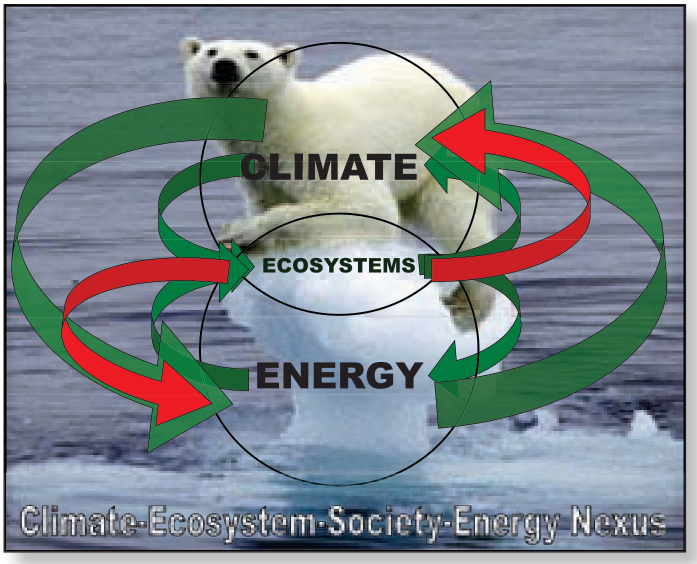
In biofuels modeling, for example, looking at either woody or herbaceous biofuels, we have to consider whether and how, if this is implemented, the production of biofuels will influence climate and similarly how climate might then feed back to affect ecosystem productivity. The production of woody biomass will also have some local effect on energy production, either through land use demands or through changing the local climate.

UBIQUITOUS ECOSYSTEM FEEDBACKS

Are there in fact any important processes through which climate change does not affect an ecosystem, which then feeds back to affect climate? Perhaps not. Even if we consider an ecosystem model that primarily looks at species population or productivity of an individual species or an endangered species recovery plan, we most likely want to think about that recovery in a scenario of potential change in climate. This is an example of a climate-to-ecosystem part of the loop with subsequent feedbacks throughout the system that affect the other components to various degrees.

Consider now the polar bear, which is quickly becoming the iconic endangered species from the perspective of climate change. This charismatic species could well replace the panda in the pantheon of iconic conservation of endangered species. If climate change occurs in the Arctic, as we see it happening and expect it to happen, and polar bears are negatively affected. I don't think they will go extinct. Basically, we will lose the ice flow population, and polar bears will adapt by becoming garbage feeders on the North Slope and other parts of Alaska. If you have ever seen pictures of polar bears in garbage dumps, they are not nearly as pretty as the ones out on the ice flow. That is not a picture we want to see even if they survive. But it's hard to see how this consequence would feedback to influence climate.

Upon further consideration, however, that picture, that perception, is not quite true. There is actually a loop between the climate impact on the polar bear and the impact on our energy production system. There is feedback through the polar bears. Think about the day your son or daughter comes home



from grade school and says, momma, daddy, why is our SUV killing the polar bears? I don't know what you will tell them, that we don't drive an SUV maybe. Nevertheless, the polar bear feedback system will have an influence on people's political concepts about pressures to do something about climate change. Pictures of dirty, not alone dead, polar bears could feedback to influence climate.

In actuality, this climate-ecosystem-energy nexus that I argue for is a climate-ecosystem-society-energy nexus. The ecosystem can no longer be considered in the traditional sense, where the human and societal parts of the system are not included explicitly. Instead, we need to start including social ecosystems in our models, and ecosystem science will have to evolve to treat this component of the nexus much more explicitly and with much greater understanding. Of course, that will involve creating an even loopier diagram.

Urban Ecological Restoration and Ecopolis Development in China

by Ru-Song Wang

Dr. Wang *is a Professor of Urban Ecology with the Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, and the former director and president of the Chinese Society of Ecology.*

The world is facing three large ecological challenges today: global climate change; regional degradation of ecoservices; and human, environmental-borne health problems.

In China, urbanization has occurred very rapidly. Between 1978 and 2009, our urbanization rate rose from 18 to about 45 percent. In 2003, the urban population of China stood at 520 million occupying an area of nearly 400,000 square kilometers. The eco-impacts of such rapid growth are myriad, including increased use of fossil energy, overcrowding of populations, air acidification, eutrophication of water, and biodeterioration.

In conceptual terms, we have broken the urban ecological effects down into five color categories: 1) red, heat island and global warming effects; 2) green, water eutrophication effects; 3) gray, fog and garbage effects; 4) yellow, sandy and drought effects; and 5) white, landscape spoiling and plastic effects.

There are many things wrong with our current situation. Industrialization transforms fossil energy into money, carbon, and heat. Urbanization transforms green land into brown land. Globalization makes the rich richer and the poor poorer. Modernization transforms Eco-culture into Ego-culture.

Cities could be the solution for the human future if we can rethink and change our production mode, lifestyle, and value systems; reform and integrate our institutions, governance, and maintenance; and renovate and disseminate our science, arts, and technology. Otherwise, the modern city will become a time bomb, destroying our entire civilization.

How do we reform and renovate our cities? We can think in terms of the three Rs to help in the transition to an ecopolis: *Rethink* our understanding of urban eco-complexity; *Reform,* using adaptive multi-ecological approaches to restoration; and *Renovate*, especially the five facets of ecopolis development in China.

RETHINK

To understand urban eco-complexity, it is helpful to think of a transition from a wild ecology to an urban ecology. What exactly does *eco* mean? *Eco* indicates a relationship between humans and our environment in the context of the *ecosystem*. *Ecology* indicates knowledge in dealing with the eco-context. *Ecological* indicates a harmonious approach to sustainability.

We can think about urban ecology in a human-dominated ecosystem in terms of red and green, merging the green vitality of nature—green land, blue sky, fertile soil, clean water—with the red network of human activities. We can also consider the basic eco-infrastructure of a city as the organs and metabolism of the human body: kidney, lung, artery, skin, and waste

system, which together nurture, detoxify, and cleanse the whole organism. However we think about the ecocity, we must radically alter our conceptions if we are to deal with the future of the urban metropolis.

An Ego-city is profit-oriented, a city in which individuals are concerned primarily with the economy. It is based on a reductionist approach to ecology, and its institutions tend to fragment society. An Eco-city, on the other hand, is characterized by a service-oriented, circular economy; a system ecology rooted in holism; and an adapted society focused on harmony.

How can we get from the Ego-city to the Eco-city, from thinking about the urban environment as a physical settlement to seeing it as an eco-settlement? There are some simple ways to do this. For example, in many cities, green land, the surface of the ground, is higher than the road. When it rains, the precipitation flows from green land to the road surface to the watershed, bringing with it pollutants. By simply lowering the green land surface below road level, the rain flows into vegetated land, which slows its movement, cleans it, and returns it to the ground. When the water reaches the watershed, it is already purified.

A city is a complex social, economic, and natural ecosystem. Five elements of the natural urban subsystem are water, wood, fire, soil, and metal. The elements of the economic urban subsystem are production, transportation, consumption, circulation, and services. The elements of the urban social subsystem are labor and intellect, demand and supply, governance and institutions, knowledge and technology, and culture and mind.

The central element is the human network, the city's technology institutions, and its culture. The key for our researchers and managers is to understand the relationship within each subsystem and among these three subsystems in time, space, quantity, pattern, and order. Eco-cybernetics encompasses exploitation, adaptation, feedback, and integration.

According to Chinese human ecological cybernetics, humans have to adapt to nature. We have more than 3,000 years of human ecological cybernetics in China embodied in our traditional systems: Yin and Yang, Wu-Xing, Zhong-Yong, Feng-Shui, and Wu-Wei. While we need all the technical knowledge available to attain ecological harmony, we must also fold our strong traditional concepts into our guiding principles to attain ecological balance between humans and nature.

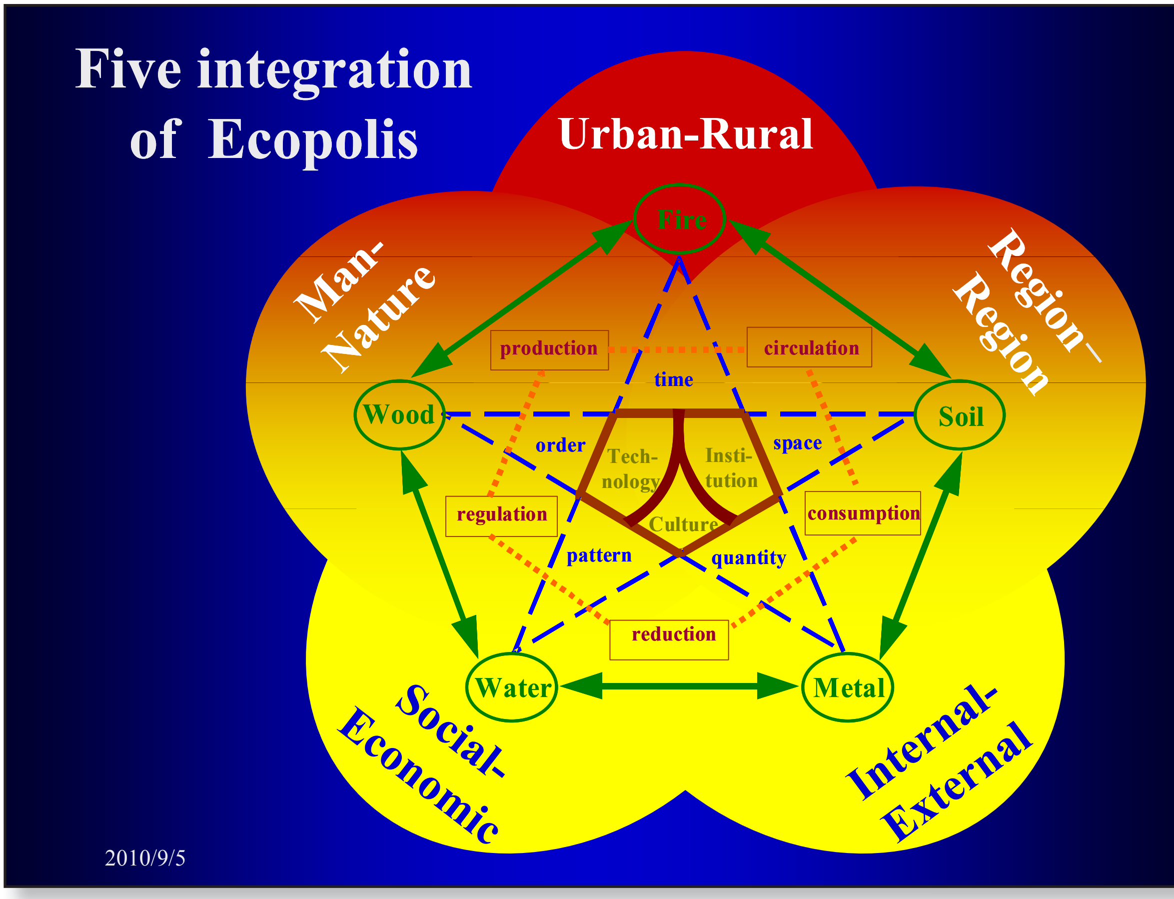
REFORM

Reform implies adaptive urban ecological restoration. In recent years, we have been restoring the urban ecosystem. Restoration enhances the ecological order of the socioeconomic and natural ecosystem. Revitalization of the industrial metabolism is accomplished through vertical, horizontal, regional, and social coupling. A renaissance of cultural creativity, amenities, and sustainability will improve the quality of citizens' lives and their social well-being.

Five natural elements are involved in restoration. *Water* restoration requires revitalizing urban rivers to deal with water pollution and the weakening of the service function of water. *Fire*, or energy, transition will entail moving from a fossil-energy dependent society to one driven by renewable energies. *Soil* revitalization addresses intensive urban land-use induced problems of soil contamination, soil sealing, landscape fragmentation, and loss of biodiversity. *Wood* is a living organism that can be grown in urban environments using fast restoration methods of high density planting, using local species, and encouraging urban agriculture and the greening of rooftops. *Metal* circulation involves encouraging waste exchange and regeneration, and industries that make full use of discarded materials.

In the context of social restoration there are four elements: economic transition and employment enhancement, institutional reform and integrative management, cultural renaissance and consciousness restoration, and habitat restoration and human ecosystem rehabilitation.

Several projects serve as examples of our restoration efforts.



Wangping, a town in west Beijing, has been approved by the Ministry of Science and Technology to serve as a state demonstration base for ecological restoration. Because of coal mining and pollution by chemicals and heavy metals, the ecosystem here was degraded. We used restoration technologies to stabilize the landscape and remove toxins from the soil. We have also restored areas where calcium and lime factories had laid the ground bare, and cleaned up many urban industrial sites and land contaminated by heavy metals and persistent organic pollutants.

The city of Yangzhou in Jiangsu Province in eastern China was a small town 30 years ago and now has a population of more than 10 million. The rehabilitation of an old part of the city involved a community-based approach, including watershed restoration and integrative water management; adaptive and innovative restoration of private and community gardening and public and regional greening; dissemination of eco-sanitation information on waste reduction, disinfection, regeneration, integration, and industrialization; and rehabilitation of old blocks through encouraging cultural conservation and eco-service enhancement. Eco-engineering projects helped restore 248 sites that were severely degraded.

The Shenzhen Bay, which separates Hong Kong from mainland China, was another focus of restoration efforts. We have worked to restore eco-service function of the Shenzhen River mouth wetlands; implemented aquatic eco-engineering to deal with sedimentation and water purification problems; applied comprehensive technology to achieve the recovery of aquatic ferns and rehabilitate mangrove habitat; and established a 160 hectare urban wetland park for citizens' recreation and education.

RENOVATION

An ecopolis is an administrative unit with an economically productive and ecologically efficient metabolism. The ecopolis has a systematically responsible and socially harmonious culture with a physically beautiful and functionally vivid landscape. There are differences between an ecocity and an ecopolis. An ecocity is usually confined to built up areas with regional ecosystem services, an administrative city government, and a peri-urban coupling. An ecopolis includes rural areas, suburban areas, and the watershed.

There are five points of integration in an ecopolis, the urban/rural connection, the human/nature connection, the social/economic connection, the internal/external connection, and the region/region connection. The system framework of an ecopolis includes environmental security, economic efficiency, social harmony, and system sustainability .

The primary goal of the ecocity is to provide citizens with a livable, workable, walkable, affordable, and sustainable human settlement. The basic requirements of an ecocity are to provide clean, tidy, quiet, and safe living spaces; to green the structure, function, and processes of the city; to vitalize the system with fresh water, fresh air, fertile soil, biodiversity, and resource regeneration; to provide for a robust, rich, resilient, and self-reliant population; and to beautify the environment through cultural identity, heritage, social texture, and aesthetics.

The Fifth International Conference on EcoCity Development resulted in the Shenzhen Declaration, adopted in 2002, which states that ecocity development requires:

- Ecological security: clean air and safe, reliable water supplies; food; healthy housing and workplaces; municipal services; and protection against disasters for all people
- Ecological sanitation: efficient, cost-effective eco-engineering for treating and recycling human excreta, gray water, and all other wastes
- Ecological industrial metabolism: resource conservation and environmental protection through industrial transition, emphasizing materials re-use, life-cycle production, renewable energy, efficient transportation, and meeting human needs
- Ecoscape (ecological-landscape) integrity: arrange built structures, open spaces such as parks and plazas, connectors such as streets and bridges, and natural features such as waterways and ridgelines, to maximize accessibility of the city for all citizens while conserving energy and resources and alleviating such problems as automobile accidents, air pollution, hydrological deterioration, heat island effects, and global warming
- Ecological awareness: help people understand their place in nature, cultural identity, responsibility for the environment, and help them change their consumption behavior and enhance their ability to contribute to maintaining high quality urban ecosystems.

Ecocity development encompasses the overarching concept of ecoculture, with its philosophical, physical, spiritual, institutional, and ethical components on the scale of the city. Ecopolis studies have broader scales, from the eco-province to the eco-prefecture, eco-city, and eco-county, on down to the smaller scale of eco-villages, eco-farms, and eco-factories. Each, the ecocity and the ecopolis, is adapted to specific scales, from the micro to the macro, and both encompass the strong philosophical traditions of China with the best available environmental technologies of the 21st century.

Using a Broad-scale Perspective to Address Changes in Land, Climate, and Energy

by Virginia Dale, Rebecca Efroymson, and Keith Kline

Dale, Efroymson, and Kline *are scientists in the Environmental Sciences Division, Oak Ridge National Laboratory.*

Virginia Dale

A broad-scale perspective on the nexus between climate change, land use, and energy requires consideration of interactions that were often omitted from climate change studies. While prior analyses have considered how climate change affects land use and vice versa (Dale 1997), there is growing awareness of the need to include energy within the analytical framework. A broad-scale perspective entails examining patterns and processes at diverse spatial and temporal resolutions.

An example of landscape pattern effects arises from considering how siting a city changes the nearby rural landscapes and energy supplies and vice versa. An example of process effects is how fertilizer production and use that may be associated with the production of biofuels may alter nutrient cycling, aquatic system productivity, and sanitation at various scales. Past land-use patterns and practices affect current land-use opportunities. While this broad-scale perspective is critical for effective decision making, it is relatively new to environmental science and largely builds upon the data, geographic information systems, and models that are only recently becoming available. Some aspects of this interaction are presented here, but a more detailed discussion is provided in Dale et al. (in review).

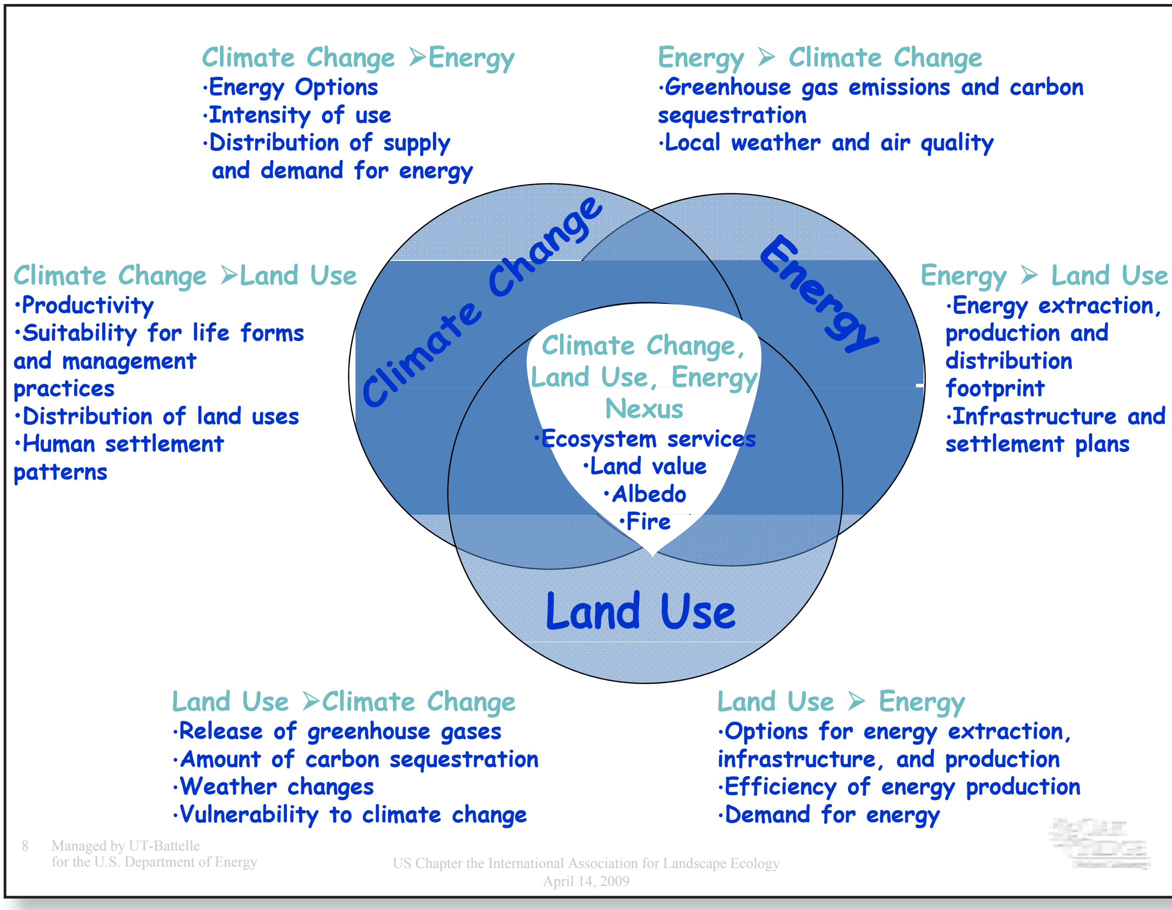
CLIMATE CHANGE and ENERGY

Interactions between climate change and energy are complex. Climate change affects energy via energy options, intensity of use, and distribution of supply and demand for energy. A direct influence of climate change on energy occurs via prevailing effects on energy demand, particularly in regard to climate control systems (i.e., heating and cooling) in most buildings and vehicles in the developed world. As climate changes over time in a certain area, so may energy demand. In the southeastern United States, for example, the use of air conditioning is likely to increase if the climate warms, and all climate change models project warmer temperatures for all months and all future years (IPCC 2007). The intensity of energy use may also change. As the climate gets physically warmer, air conditioning systems not only operate more frequently, but work harder to compensate for the larger temperature differentials between desired indoor temperature and outdoor temperatures. Operation of these systems pushes increasing amounts of waste heat into the local atmosphere, adding to urban heat sinks and to a cycle of increasing demand for air conditioning. Since current technologies for electricity production and cooling systems in the Southeast depend primarily on fossil fuels, the added requirements for fossil fuel combustion to support the increasing loads further exacerbates both heat emissions to the atmosphere from fossil fuel plants and the production of heat trapping greenhouse gases.

Energy use affects climate change through greenhouse gas (GHG) emissions and carbon sequestration, as well as local weather and air quality. An increasing concentration of GHGs in the atmosphere is attributed to human activities and is largely responsible for recent changes in the rate of climate change (IPCC 2007). Different energy options affect the atmospheric concentration of GHGs in different ways. The US National Research Council has noted that CO_2 is by far the largest single contributor to global climate change and is thus the focus of many mitigation efforts (NAS 2010). Nuclear and wind energy production have relatively little effect on CO_2 emissions; whereas fossil fuel combustion is responsible for the majority of global CO_2 emissions (80 - 92 percent) (Canadell et al. 2007, van de Werf et al. 2009, Le Quéré et al. 2009). There are many examples of how energy use can affect local land use, weather, and air quality, such as large hydroelectric projects that require an abundant water supply and can affect local groundwater tables and climate conditions.

LAND USE and CLIMATE CHANGE

Land use affects climate change via release of GHGs, impacts on albedo (reflectivity of Earth's surface), latent heat (flux of energy from Earth's surface to atmosphere associated with transpiration and evaporation), rates and amounts of carbon sequestration, and local weather changes. Land-use options are in turn influenced by changes in climate. While the land-use changes involved in conquering new frontiers (including resource extraction and deforestation) were historically a large contributing factor to GHG emissions and thus climate change, more recent models and bookkeeping calculations have



found that contributions to atmospheric CO_2 that derive from land-use changes—e.g. those associated with forest clearing (fires) and intensive agriculture—represented about 1.2 Pg C yr-1 or 12 percent of total anthropogenic CO_2 emissions in 2008 (Le Quéré et al. 2009). Furthermore, terrestrial systems including forests and croplands absorbed an estimated 4.7 Pg C yr-1 in 2008, or nearly four times more than the estimated land-use emissions (Le Quéré et al. 2009). The relative contributions to anthropogenic CO_2 emissions associated with deforestation have slowed considerably in the past two decades as fossil fuel use has risen and access to forests to exploit and clear has decreased due to several factors including improved policies and enforcement, and the diminishing area of natural forests. The major contributors to GHG emissions are fossil fuels, and their relative importance is likely to predominate until those resources also begin to run dry. Given the tremendous opportunity for land management to contribute to enhanced GHG sequestration, efforts to conserve remaining forest ecosystems, reforest, and improve management of other land areas merit priority attention when considering energy, land-use, and climate in an integrated manner.

Climate affects land use by means of its influence on productivity, suitability for particular life forms and management practices, frequency and intensity of major disturbances (floods, fires, droughts), and distribution of land uses and human settlement patterns. The climate of a particular area, combined with its soils, has great influence on how productive an area might be. That influence is often expressed through suitability of an area for certain life forms and for specific kinds of management practices. These considerations affect the distribution of land use as well as human settlement patterns. Human settlement is concentrated in the more habitable portions of the Earth, but areas suitable for human habitation are likely to change as climate changes.

ENERGY and LAND USE

Energy affects land use via the footprints and processes involved in energy exploration, extraction, production, and distribution as related to settlement patterns and infrastructure. Above and below-ground mining, for example, have very different effects on potential land uses in a region. Flooding for hydroelectric dams is another energy extraction process that greatly affects the land. In addition, infrastructure and settlement plans have historically been associated with energy developments ranging from suitable river sites for hydropower, to major mining towns in areas that would otherwise be unlikely candidates for habitation. The transportation infrastructure built to support oil and gas exploration and exploitation, for example, has often been the primary conduit for human colonization and occupation of areas that previously had been inaccessible forests and wild lands. Even today, in much of the developing world, a single road built through public lands and jungle to access a preferred site for hydro-electric or fossil fuel projects, or to establish transmission or pipelines for movement of energy products, creates a new opportunity for impoverished groups and others seeking land. A new road allows other products (timber and non-timber forest products, wildlife, etc.) to be extracted and sold and new settlers quickly clear and deforest areas to stake their claims. Over time, clearing and settlement patterns increasingly expand into the interior forests following the access provided by new road (and port) infrastructure.

As energy affects land use, land use also has impacts upon energy, specifically on our options for energy extraction, infrastructure, and production; realized efficiency; and demand for energy. In most countries, decisions about where urban lands are sited are based largely on historical settlement patterns initiated by transportation routes, trade routes, energy resources, and so forth, but not upon any strategic management plans based on available natural resources. The unplanned colonization and clearing that has followed road infrastructure into forests around new hydro-electric projects has often undermined the utility and useful life of the projects by accelerating erosion and sedimentation and affecting stream flows. The way land is used also affects the demand for energy; for example urban and industrial areas require more energy than rural areas. As another example, the delivery of energy in rural settings often involves long-distance travel to small populations.

THE NEXUS

The nexus of climate change, land use, and energy is what occurs at the center of these overlapping issues. There are four critical factors: ecosystem services, land values, albedo, and fire. Ecosystem services that occur at the center of the nexus include water quality and quantity, biodiversity, and air quality. Albedo, or surface reflectivity, is another integrating factor, for reflectance is changed by land-use practices and has an effect upon the energy as well as the climate of the Earth. Fire is also very much an integrating factor. Much of the land in the developing world is regularly burned for energy, heat, or, in some instances, as a way to have some control over the land, to establish ownership, for example. Another classic example of the energy, climate, land-use nexus is related to the use of biomass for domestic cooking fuel in poor urban centers. The need for this fuel contributes to the clearing of land near these centers, leading to increased demand for other sources of energy or charcoal (which is cheaper to transport longer distances), leading to further forest clearing and lower efficiencies.

BROAD-SCALE CHALLENGE

By focusing on the land-energy-climate change nexus, it is clearly not possible to make informed choices about where and how the environment is used without considering these three factors. However, in many situations, positive benefits of choices involving climate change, energy, and land use can be achieved with landscape design.

A key challenge we currently face is to identify the extent and location of underutilized, "available suitable" agricultural land, and the key policies and socio-economic conditions which influence management (or mis-management) of these lands. Definitions of which lands are "marginal" are inconsistent, in part because global data on land cover are incomplete and inconsistently measured and classified and in part because definitions vary depending on circumstances.

Another challenge is understanding indirect effects that may occur within the nexus. For example, global equilibrium economic models developed to understand trade among commodities have been used to estimate the indirect effects of bioenergy choices, but these models do not consider the many potential drivers of land-use change and cannot address how local politics, local lifestyles, road access, and local agricultural practices affect choices. Hence it is clear that there is a need for a variety of perspectives on the nexus, both global and local. A final challenge is documenting sustainability benefits and metrics for different energy and land-use options under specific climate conditions.

There are many contributions that a broad-scale or landscape perspective can make to the energy-climate change-land use nexus. In particular, policy makers and managers can tailor landscape designs to determine energy choices that are more likely to be robust and resilient in the face of uncertainties such as climate changes. The areas and types of land affected by any project should be characterized in terms of the potential effects upon ecosystem services.

Global changes in land use, climate, and energy that are induced by humans, when viewed from the perspective of process and pattern, can offer insight into climate change and dynamic approaches to meet energy needs in light of changes in land-use activities. There are complications and benefits of examining all three forces at once. Decision makers should use an integrated approach to consider the changes that can occur in climate, land use, and energy use, including their implications for the environment.

ACKNOWLEDGEMENTS

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Implications of Climate Change and Energy on the Conservation of Biodiversity

by John W. Bickham

Dr. Bickham *is the Director of the Center for the Environment and a Professor in the Department of Forestry and Natural Resources, Purdue University.*

Today, we are experiencing a biodiversity crisis, with current extinction rates nearly 1,000 times the background, and this rate may reach 10,000 times that over the next century (Honeycutt et al., 2010). Some people characterize this extinction event as comparable to that of 65 million years ago when an asteroid or comet hit the planet and caused the extinction of vast numbers of species, including all the dinosaurs, and many other groups of animals. While the current extinction is not due to a sudden event, in fact it will play out over a number of human generations, nonetheless in evolutionary terms, it is virtually instantaneous.

There are only about 1.6 million species of organisms officially known or described, and most organisms going extinct are unknown and have never even been given scientific names. Conservative estimates of the number of species on the planet are around 15 to 20 million, so we have documented only about one-tenth of the biodiversity on the planet, and most of that is at the microbial level. With current rates of extinction, as many as one-third to two-thirds of the species of plants and animals on the planet will disappear during the second half of the next century. This is a calamity of truly global proportions because our species has evolved in a world with rich biodiversity. It is not at all clear to me whether our society can survive in a biodiversity impoverished world. Unlike other grand challenges to the environment, this one is truly irreversible. If we allow the disappearance of such a vast diversity of organisms, we are dooming future generations, for all time to come, to live in a world without the natural resources to meet their foreseeable and unknown future needs, be they industrial processes, pharmaceuticals, or food.

Biodiversity encompasses the diversity of all living things, of all the habitats in which they live and the genetic diversity of individuals within a species.

— London Natural History Museum

CAUSES OF BIODIVERSITY LOSS

The causes of biodiversity loss are multifactorial and include, but are not limited to, deforestation, other forms of habitat loss, over fishing and other abuses of ocean life, illegal harvest of forest products and wildlife, environmental contamination, and climate change.

What is the relationship of energy to this process of extinction of biodiversity? The impact of the extraction and transportation of fossil fuels is an obvious factor. These include mountaintop removal mining and other forms of strip mining that contribute to extinction and environmental contamination, and habitat loss related to fossil fuels and the biofuels industries. In addition, the use of fossil fuel contributes to increased greenhouse gas concentrations in the atmosphere, which leads to climate change.

Climate change is anticipated to be the major driver of biodiversity loss by the middle of this century. Entire ecosystems will disappear, particularly in montane regions where, as global warming progresses, lower elevation ecosystems move higher into the mountains, eventually causing the disappearance of alpine tundra and other higher elevation ecosystems. In places such as southern South America, large tracts of alpine habitats with unique communities, including many endemic species, will disappear.

Extinctions will also result from massive distributional changes as plants and animals strive to adapt to climatic shifts. Already, our roads and agricultural ecosystems are subdividing the landscape, making this natural dispersal difficult because of the patchiness of suitable habitat. We need to consider the impacts on biodiversity as we plan our efforts to mitigate climate change through the development of biofuels. These will include both positive and negative impacts.

As an example of agricultural impacts on species, consider the US midwestern agricultural landscape, a patchwork of corn and soy bean fields and natural habitat such as forests. In West Lafayette, Indiana, along the Wabash River, close to where Purdue University is located, small patches of riparian forests and cropland create a patchwork quilt effect. If we switch to a biofuels economy, the landscape could change, and that would alter the ways in which animals perceive their surroundings, and would modify the function of these small patches of forest. John B. Dunning, Jr., a professor of Forestry and Natural Resources at Purdue University, recently co-authored an article on the value to migratory birds of these small patches of forest and agricultural lands in northwestern Indiana (Packet and Dunning, 2009). This area is located on the central flyway for migratory birds, including Neotropical migrants, one of the most vulnerable groups of birds.

Dunning analyzed data from more than 3,500 observations from 76 species of birds. He reported in a 2009 issue of *The Auk*, the journal of the American Ornithologists' Union, "small, isolated woodlots composed largely of forest edge with high fruit and insect abundance may…be important conservation targets in highly fragmented landscapes where forest cover is limited." Even though they are small, these areas represent important stopover habitat as birds migrate from their summer nesting ground in the north to their wintering grounds in the tropics or the southern United States. If land owners decide that a particular woodlot is more valuable as cropland for biofuels than as land set aside in a conservation reserve program, they may plow it and plant it. The loss of habitats such as small woodlots could be an unintended consequence of the development of the biofuels economy. This is one small example of the impact of energy on one particular group of organisms, migratory birds, but the example is one that extends around the world to other groups of organisms that could disappear as we convert land to produce bioenergy crops.

In short, climate change soon will be a major driver of biodiversity loss. The development of a biofuels economy is one strategy to reduce climate change and thus reduce biodiversity loss, which is good. But we must take care to ensure that the unintended consequences of conversion to biofuels do not exacerbate the biodiversity crisis.

ABUNDANCE DWINDLING

Biodiversity loss and population abundance are of course related. Human activities are having broad-scale impacts on the abundance of natural populations. *Abundance* is the number of organisms within a species or within a certain population. Reductions in abundance, or the effective population size as measured by geneticists, cause increased inbreeding and the loss of genetic diversity. When genetic diversity within a species is diminished, it is also a loss of biodiversity and reduces the ability of organisms to adapt to change. Worldwide, we are already seeing a significant decline in population abundance of many plants and animals, including vertebrates. Since 1970, the numbers of most species of terrestrial, marine, and freshwater vertebrate species have steadily eroded (Honeycutt et al., 2010). As a result, species are potentially losing genetic variability, and thus their ability to adapt to changing environments.

William M. Muir, a professor of animal sciences at Purdue University, co-authored an article in the *Proceedings of the National Academy of Sciences.* The paper (Muir et al. 2008) examined the problem of biodiversity in poultry. Since the chicken genome has been sequenced, it is possible to carry out very fine genetic-scale analyses. Muir was interested in the relationship of inbreeding, a result of small population size, to biodiversity loss.

Domestic poultry originally came from a wild bird, the Red Junglefowl, which is native to Southeast Asia and was domesticated as early as 1,000 BC. By the 19th and early 20th centuries, there were about 100 standard breeds in the world, which were bred for eggs or meat, or both, or simply as "fancy" chickens that people kept for their beauty or as gaming fowl. However, with the commercial consolidation of these breeds, by the mid 1900s the number of standard breeds used in agriculture declined to fewer than 10. That represents most of the genetic diversity of commercial populations of chickens.

What does this mean in terms of biodiversity loss for chickens? By and large we think of biodiversity loss within a species as lost allelic diversity. Alleles are different forms of a gene which determine certain traits such as blue eyes or brown eyes. Loss of allelic diversity is correlated to a loss of heterozygosity, which is directly correlated with fitness. Muir characterized biodiversity loss as the proportion of alleles lost in the poultry population relative to the ancestral population. As he looked at the lines of birds in captivity, he found that at a minimum, 55 percent of allele diversity has been lost in broiler lines compared to wild populations. He based this estimation upon both simulations and data from the genetics of chickens.

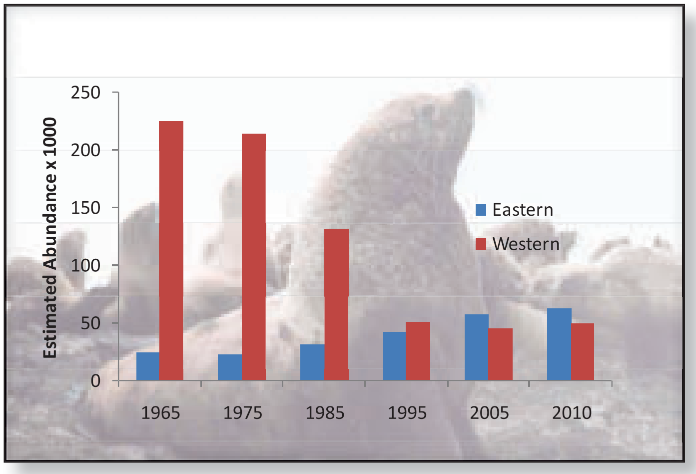
Is it possible, since we have multiple lines, to cross them and perhaps recover the diversity of native populations? If we do that and calculate what can be recovered from these lines, that still leaves us with about 10 percent inbreeding, which translates to about 50 percent allelic diversity loss. This means a significant portion of genetic diversity was lost during the development of these commercial breeds. Muir's data from the genetics of chickens correlate precisely with the simulation results: 10 percent inbreeding corresponds to 50 percent loss of allelic diversity.

The initial inbreeding of the Red Junglefowl to create a domestic species caused about a 50 percent biodiversity loss, which occurred prior to the development of the modern commercial poultry industry. We can, of course, go back and get new chickens out of the wild. Natural populations represent a resource for biodiversity that we can use to replenish what we have, as long as wild populations remain. The continued availability of natural populations is extremely important for all domesticated crops and animals as potential sources of new genetic information that might be useful.

Unfortunately, we cannot do that for wild organisms. If we lose 50 percent of the genetic diversity of a population or species, is 10 percent inbreeding something we are likely to see in natural populations? The answer to that is, yes. Worldwide, wildlife populations are declining, which is likely to be associated with reduced fitness as a result of increased inbreeding.

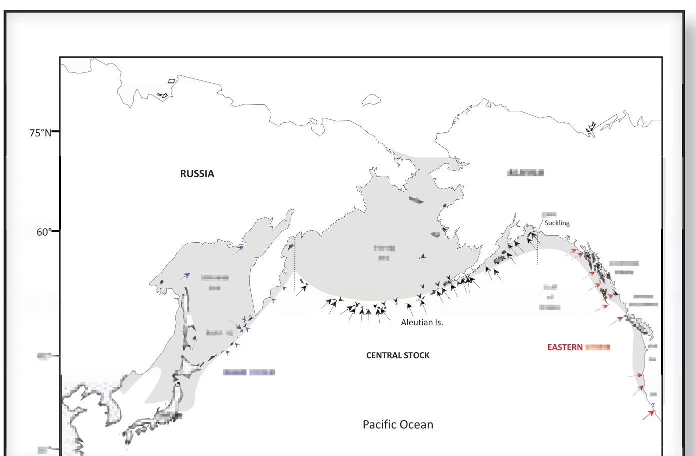
A STELLER EXAMPLE

There are two ways to determine the effect of climate change on biodiversity of species. We can look forward and predict what will happen, perhaps using computer simulations, and we can also look back in time and see how climate change



Credit: National Marine Mammal Lab/ Alaska Fisheries Science Center

has affected populations in the past. For the last 18 years, my colleagues and I have studied the genetics of Steller sea lions, named for the 18th century German explorer and naturalist Georg Wilhelm Steller, who identified and described the species during his travels in the Bering Sea. Based on our work, the species has been divided into three stocks: eastern, western, and Asian. Population decline for the federally endangered western and Asian stocks closely parallels the worldwide decline of the major terrestrial, freshwater, and



Credit: National Marine Mammal Lab/ Alaska Fisheries Science Center

marine vertebrate species. In the 1960's the western and Asian stocks included an estimated 180,000 adult sea lions. Today, the population is below 20,000. This represents a decline of 90 percent over the vast range of these stocks, from Prince William Sound in Alaska to the Sea of Okhotsk in Russia. For this reason a great deal of research has been done on the ecology and evolution of this species.

Steller sea lions breed at rookeries, which are isolated small islands free from terrestrial predators. We have studied samples from nearly every rookery and examined the mitochondrial DNA sequences from more than 2,500 Steller sea lions from throughout their range across the North Pacific Ocean from the Sea of Okhotsk and Kuril Islands in Russia, across the Aleutian Island chain to the Gulf of Alaska and south to California. By examining each unique sequence—haplotype or allele—of the mitochondrial DNA (mtDNA), an image emerges of a network, resembling a bush, with the tips of the branches being the sequence or haplotype. The farther we go along the branch towards the stem, the further back in time we go. Each step along a branch represents a genetic mutation each of which has taken an estimated time to occur and become established in the population.

Credit: John Bickham

Phylogenetic analysis (the process by which we study the described bush and infer evolutionary history) and the geographic distributions of the haplotypes give us a picture over the last 360,000 years of history of Steller sea lions. We have developed a method to accurately calculate mutation rates for the mtDNA and correlate that with past climate to show the history of Steller sea lions associated with climate change from the glacial and interglacial cycles throughout the Pleistocene (Phillips et al., 2009). From this information we can infer when a mutation evolves and what demographic effect caused that mutation to be associated with the past unique geographic distribution. We find that as we go back in time, the earliest changes are mainly associated with population fragmentation and restriction of gene flow, whereas more recently these changes are associated with range expansions (Phillips, 2008).

This leads us to ask why we find a shift in demographic effects during these early glaciation periods versus more recent ones. Our genetic studies confirm what we always suspected based upon theory. The evolutionary history of Steller sea lions shows three distinct periods of climate impacts. When population sizes were high, as in recent times, there were no significant impacts from glaciation. That is, there were no correlations of mutations with geographic distribution. When population sizes were intermediate, between 50,000 to 100,000 years before the present (ybp), demographic inferences were primarily range expansions. However, when population sizes were smallest, prior to 100,000 ybp, demographic inferences involved population fragmentation. Thus, we infer that during these glacial periods sea lions were isolated in small populations for extended periods of time with no apparent gene flow or dispersal among regions. This signature of demographic effects is written in the DNA sequence of the mtDNA chromosome.

Credit: John Bickham

When species are composed of small populations, climate change or any other challenge has higher impacts. As human populations affect the abundance of wildlife, animal and plant species become more vulnerable to climate change impacts. Human impacts unrelated to climate are thus compounding the effects of global warming .

It is clear from the studies reviewed in this paper that we cannot afford to continue this assault on wildlife; the impacts of a broad diversity of human activities ranging from agriculture to energy production will make species more vulnerable to the inevitable effects of climate change. I am not very hopeful that we can reverse climate change anytime soon. It will be devastating for the natural world and potentially for us too. Frankly, I don't know how well our society will survive 100, 200, or 500 years from now with the current and projected loss of biodiversity.

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Modeling Climate Change Impacts on the Terrestrial Carbon Cycle in East Asia during the Last Century

by Philippe Ciais

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Regional carbon budget estimates are important for a number of reasons. They can help link the sum of regional fluxes to the global increase of the greenhouse gas (GHG) effect, which is driven mainly by carbon dioxide (CO_2). Moreover, as we collect regional details of carbon fluxes and their distribution in space and time, we are better able to disentangle the original processes that drive these fluxes such as land use, climate, and other contributions to the carbon cycle. Better knowledge today allows us to better predict, with smaller uncertainties, the future impacts of humans and climate on the carbon cycle. This information will help us define mitigation policies.

A controversial study published by S. Fan et al. in *Science* magazine in 1997 sparked a great deal of interest in the climate change community. For the first time, Fan and colleagues used atmospheric data to show, from the surface gradients of atmospheric CO_2 , across a network of atmospheric measurement stations, that North America was a huge sink for fossil fuel emissions. This study motivated continental-scale field experiments and the synthesis of different ecosystem fluxes. People realized that the uncertainties were so large that the system had to be measured using 10 to 100 times more data than before. The article likely spurred the development of major programs to closely observe the carbon cycle such as the North American Carbon Program (NACP), CarboEurope, and ChinaFLUX.

ATMOSPHERIC VIEW

The net carbon balance of a piece of land, at the regional or continental scale, is made up of fossil fuel emissions and, importantly, the sum of the carbon balance of different ecosystems, and landscape components. The atmospheric approach used by Fan et al., while useful, has not allowed us to make much progress because the number of monitoring stations has remained quite small in the past 20 years except over some specific regions. The atmospheric approach also has uncertainty because the physical signals, the gradients of CO_2 in the atmosphere that are interpreted using inverse transport models, are truly very small. A small error in the observation propagates into larger error on the fluxes.

The tools we use to perform this backward propagation of error are atmospheric transport models which are subject to large uncertainties. From an ensemble of these models, the International Panel on Climate Change (IPCC), in its Fourth Assessment Report (AR4), (Chapter 7), confirmed that the gradient of CO_2 between the Northern and Southern Hemispheres cannot be fitted by models without placing a land sink north of the equator.

The magnitude of the Northern Hemisphere land sink is uncertain. In the AR4, the IPCC estimated the sink at 0.5 to 4 petagrams of carbon (PgC) per year (1 Pg C = 1015 g C). However, using new data collected by examining the vertical structure of CO_2 in the Northern Hemisphere from aircraft, Britt Stephens from the National Center for Atmospheric Research and his colleagues were able to exclude from the ensemble about half of the transport models that did not match vertical CO_2 profiles used as cross validation data. In an article published in *Science* magazine in 2007, Stephens estimated the Northern Hemisphere terrestrial sink at 1.1 to 2.1 PgC. This discrepancy is disturbing; the so-called best modeling group was rather over confident in their models. We were also over confident that the ensemble of models we were using revealed the truth, when in fact, the whole ensemble was biased.

A number of researchers have assessed the carbon balance of the United States, Europe, and Russia, including Siberia. When the numbers for the land sink are combined, the uncertainties remain large, ranging from 0.4 to 1.8 PgC per year. For fossil fuel emissions, the sum of all the regions is 4.8 PgC per year. In other words, for the Northern Hemisphere, there is a significant, but uncertain, carbon sink. In this context, the carbon balance of China remains to be further quantified.

COMPILING DATA

We still have no comprehensive assessment of the carbon balance of China, but we do have a great deal of data from which to infer the carbon balance. As part of a cooperation led by the University of Beijing, with participation of the Laboratory for Climate Sciences and the Environment led by Dr. Shi-long Piao, who has been working in both institutions, we have compiled available information from eight different data sets: 1) forest inventories and field biomass data from about 200,000 permanent and temporary sample plots measured between 1997 and 2004; 2) grassland biomass inventory data measured using remote sensing; 3) statistics for crop yield, area planted, and other crop information; 4) national soil inventory data collected in the 1980s on a data set of nearly 2,500 typical soil profiles; 5) changes in soil carbon storage for cropland over time from more than 130 publications representing 23 soil groups and more than 60,000 soil sample measurements; 6) satellite vegetation index datasets using the Normalized Difference Vegetation Index; 7) the results from five Dynamic Global Vegetation Models; and 8) two atmospheric inverse models ecosystem models.

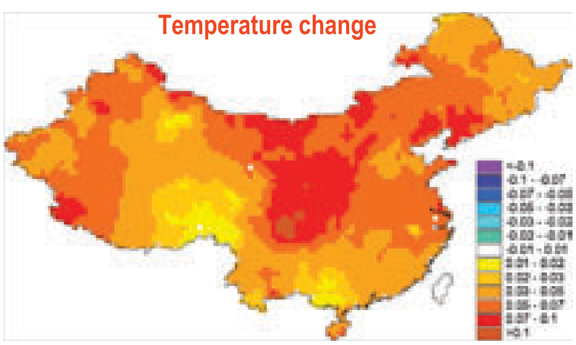
There are problems inherent in most of the available data sets. Ecosystem models such as dynamic vegetation models, for example, are a weak method to understand the carbon budget of China, because these models do not describe the effect of ecosystem management on their CO_2 balance. These models are only driven by CO_2 and climate. They are therefore inadequate to describe the carbon budget of a country like China. In our study, models were instead used as an auxiliary tool to estimate the fraction of the carbon balance that could perhaps be explainable by CO_2 and climate. These models cannot accurately explain the observed fraction of the observed sink; they can only give an order of magnitude of what could be explained by the models. Likewise with other data sets; each has its own limitations, whether from sampling bias or other confounding factors.

TRACKING CLIMATE TRENDS

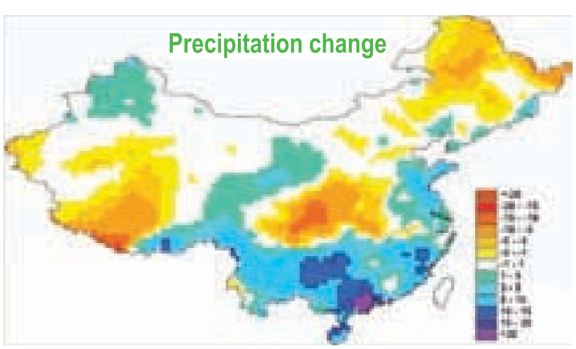
Over the past two decades, significant climate change has been observed in China, with a strong warming trend in central and northeastern China and changes in precipitation that vary spatially from region to region. Mean annual temperature over China increased by more than 0.6 °C per decade, a much faster rate than the mean global trend over land, estimated in 2007 by the IPCC at about 0.27 °C.

Changes in precipitation have varied from region to region, and changes in seasonal rainfall patterns have also have been observed. Decreased rainfall in the north of China has been associated with more pollution, and a pronounced acceleration of snow melt. Summer precipitation has increased significantly in some regions and less so in others. In southern China, the total amount of rain decreased marginally or did not increase, but the frequency of light rain events has decreased quite a bit. The same amount of rain is falling, but more often in the form of thunderstorms and less as light rain events. This has a large impact on the ecosystem and also on the carbon balance.

Since the 1980s, China has been launching major national



- During the past two decades, mean annual temperature over China increased by more than 0.6 ºC/decade, a much faster rate than the mean temperature trend over land (~0.27°C/decade; IPCC, 2007).

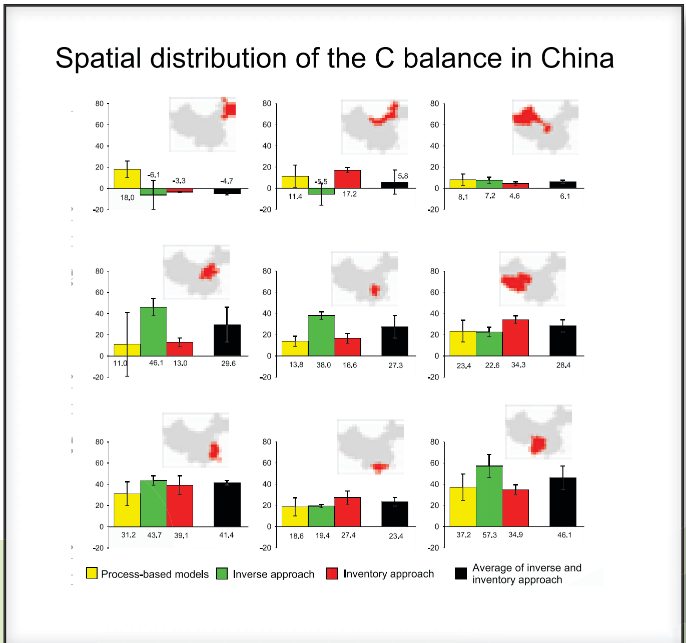


- Change in precipitation varies across space. Different season also show different change. Summer precipitation is significantly increased.

CRU climate data (Mitchell et al., 2003) afforestation and reforestation projects. These were not initiated primarily for carbon sequestration purposes, but for soil and water conservation. China now has approximately 20 percent of the total forested plantation area of the world. These forests are relatively young and not very dense. They have a large potential to continue to store carbon in the next decades, if there is no adverse climatic change affecting the growth of these plantation forests.

Rapid urbanization in China is now, and will continue to be, one of the most important drivers of climate change due to the loss of carbon from urban settlements and an increased environmental footprint on the landscape as usage shifts from croplands to cities and transportation routes.

Atmospheric measurements of the carbon balance of China, using transport models in so-called atmospheric inversions, are not an accurate estimate of change in carbon storage in China. Some of the CO_2 taken up by photosynthesis is not returned to the atmosphere in the form of CO_2 but rather in the form of carbon monoxide. Inventory-based terrestrial biosphere carbon balance combined together with atmospheric inverse modeling estimation, can be used to present a broader account of carbon emissions and carbon uptake, accounting for multiple effects such as non-CO_2 carbon fluxes, carbon monoxide, methane, volatile organic compounds, and wood and food products imported to urban areas. In this land-based accounting, we also made estimates of changes in soil carbon and biomass due to the mass of everything that contains carbon, factors that are not considered by simply measuring the role of forest. Erosion of cropland soils must also be factored into our estimates, as carbon removed from topsoil and re-deposited in deeper horizons and floodplains can produce a carbon sink.



COMBINING DATA

In our studies, we have combined estimates of the carbon balance for different ecosystems in China, including the different types of vegetation and soils, together with process-based models, inverse and inventory approaches, and the average of inverse and inventory approaches. In the final analysis, we arrived at estimates indicating a 0.2 PgC per year sink over the past 20 years, but the uncertainties in these estimates are quite large.

The largest component of the carbon sink of China lies in its forests, and here, the uncertainties are probably relatively small because there is a very good forest inventory system. The uncertainties are higher for forest soils. Shrubland in China is a significant component of the carbon sink, but it also has 100 percent uncertainty, and no one has made a comprehensive study of shrub or woody encroachment in China. There is also uncertainty about the role of croplands as a carbon sink. Surprisingly, in our literature survey, we found that soil carbon in Chinese cropland was increasing, but again, large uncertainties remain.

We have divided China into broad regions, not provinces but groups of provinces, and compared the results of bottom up accounting with one atmospheric inversion model. We used very simple, and probably imperfect, tools. The atmospheric gradient method is interesting in principle, but there are so few stations over China that the errors are extremely large. The inventory approach is probably reliable except for shrublands and other systems that are weakly measured. By averaging results from inventory analyses and atmospheric modeling, a broad pattern emerges. Over the productive areas of southern and central China, with their high productivity and a wetting trend in the climate, the carbon sink is much higher than over drier parts of northeastern and northern China.

If we compare the total carbon balance of China with that of Europe, the United States, and Russia, using PgC, and adjust for the different ecosystem areas, we arrive at an estimate of the intensity (per unit area) of the carbon sink for each region. Carbon sink intensity in China and Europe is comparable, and is slightly lower than in the United States. The intensity of the carbon sink for Russia appears very large, but the uncertainties there are also huge as the information relies on just one study. If you look at the biome that is supposedly driving this apparently enormous sink, the southern Russian forests, it is hard to believe that such a low-productivity system is such a big carbon sink. We may need to divide that estimate by at least half.

In this study we showed that Chinese ecosystems behaved as a mean carbon sink of about 0.2 PgC per year between 1980 and 2005, offsetting a significant fraction, about 30 percent, of emissions. Emissions are increasing so fast, however, that this represents a smaller fraction of the carbon balance as of today, about 10 percent. Of that sink, about 50 percent is likely taken up by forest plantations and up to 20 percent by shrublands.

We are still a bit blind with respect to the processes involved. We found an important contribution of a wetter climate and rising CO_2 in southern China, and adverse effects of soil warming in northern China. The forest sink is expected to be saturated in 30 to 40 years. One big driver of the carbon sink in the future will be urban development pathways.

BUDGET UNCERTAINTY

Despite a multi-faceted approach to estimating the carbon budget, very large uncertainties remain. The soil carbon balance is inferred, not actually measured by repeated inventories. For cropland soil we had to rely on the published literature because there is no repeated long term survey of carbon change in croplands. We have very few data on shrublands. There was no repeated inventory for croplands. There is little data density on atmospheric inversion, but Chinese research groups are already constructing a very dense network of atmospheric measurement over China that will probably reduce the errors in this area. The largest single source of error is in fossil fuel emission inventories.

We are also left with unaccounted-for processes and ecosystems in our models, including a lack of information about ozone or nitrogen deposition on plants, the effects of erosion, the quantity and quality of radiation from aerosols and pollution, feedback from effects of snow melt, changes in carbon in the permafrost of mountainous regions, and the eventual effects of bioenergy production, which are not counted in forest inventories.

Given the fundamental uncertainties in the systems we are looking at and the very small number of actual observations, the uncertainty is probably much larger than we have estimated. We are, however, fairly confident that using the different methods, including the atmospheric method, modeling, and land accounting systems, there appears to be some compatibility among them.

If we really want to reduce the uncertainties pertaining to the carbon balance across China, the first priority is to refine the oil and fossil fuel emission inventories. If want to estimate the ecosystem carbon balance, we should focus on getting better data on the shrublands. At our present level of understanding, using the best models available and the equations we currently employ, there are still a number of processes unaccounted for.

China is, in a sense, a world of its own, but at the same time it is the theater of all human and climate change processes that will determine the future of our planet. It is an extremely fascinating and very complicated system to study. We have a long way to go towards refining our understanding of multiple, converging factors. We have not yet factored in the effect of increased ozone pollution on plants, the effect of nitrogen deposition in the soil and water, the effect of soil erosion, the changes in radiation quantity and quality and its impact on photosynthesis, changes in shrublands and forest plantations, the feedback from snow melt, changes in permafrost carbon particularly on the Tibetan Plateau, and the effects of burning of biomass to cook or heat. None of these elements that contribute to climate change and alter the carbon sink has yet to be incorporated into our models or inventories. Many uncertainties have yet to be analyzed, and many more studies are needed to better understand the carbon balance of China, and of Europe and North America as well.

FUELING THE FUTURE

The forest products industry is a significant sector of the US economy, especially in the southeastern United States, generating various sources of biomass, including waste from harvest operations and manufacturing processes. Tim Rials with the University of Tennessee's (UT) Institute of Agriculture says that the biofuels industry presents new prospects for efficiently utilizing process residues and low-quality raw material. A developing technology to achieve this conversion of forest biomass to fuel is the integrated biorefinery, which subjects residues to thermo-chemical processes to produce fuels and chemical co-products.

Brian Davison with Oak Ridge National Laboratory's BioEnergy Science Center (BESC) cites two overriding reasons for the interest in biofuels: energy security and global climate change. Biomass is our only renewable source of carbon-based fuels and chemicals. BESC has a vision of a carbon neutral cycle for producing fuels and valuable co-products and creating sustainable technologies to address the need for energy security and mitigation of climate change.

Corn is the well-known first-generation bioenergy crop currently used to produce ethanol. Researchers in the Agronomy Department at Purdue University have been working to identify and characterize existing or candidate species of crops with known or potential value as second-generation bioenergy crops. In the past, say Sylvie Brouder and Jeff Volenec, crop yield of agricultural systems was the major driver of decisions, but there are other benefits that various agro-ecosystems can provide, such as greenhouse gas mitigation and improvements in water quality.

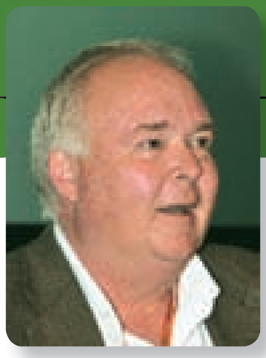
In considering the water quality impacts of bio-feedstock production, the overriding question is what the unintended consequences may be to water quality. Indrajeet Chaubey and colleagues at Purdue University have begun to model best management practices specific to land use and land cover conditions. They conclude that agricultural management decisions are more important than shifts in cropping systems.

Daniel De La Torre Ugarte with UT's Agricultural Policy Center maintains that agricultural products are not like other commodities. To reduce the environmental costs of agriculture, he proposes investing in technologies that are less intensive in fossil inputs and more in tune with local soil and food habits. If we continue with the prevailing mentality, we will have missed an opportunity for poverty reduction, increased agricultural productivity and food security, and mitigation of climate change.

In the United States at least, we tend to take the abundance of clean water for granted, but Reuben Goforth with Purdue University warns that conversion of land once set aside in conservation reserve programs may put irreversible pressure on stream quality. Streams have an amazing ability to remediate themselves when chronic stressors are removed, but the gains of the past may well come undone in response to increased biofuels production.

The Integrated Biorefinery: New Perspectives for Existing Biomass Industries

by Timothy G. Rials



Dr. Rials *is the Director of the Center for Renewable Carbon at the University of Tennessee's Institute of Agriculture.*

A key focus area for the Office of Bioenergy Programs at the University of Tennessee (UT) is the development of alternative fuels from cellulosic feedstocks, especially lignocellulosic feedstocks. One of the concepts that is routinely discussed in our group, and advanced by the U.S. wood products industry, is that of the integrated biorefinery. The term integration is somewhat open ended. Generally it refers to the development of a suite of biochemical and refining processes of biomass similar to those of petroleum refineries.

Integration, however, can take on many different shapes and perspectives. For example, it also opens up new ways of thinking for some of our existing industries and can provide new perspectives on the relationship between the forest industry and the emerging bioenergy industry.

The production of ethanol from corn often raises debate about using crops to produce fuel versus food. In the wood products industry, there is debate over using this valuable raw material to produce fuel versus fiber products. The forest products industry is a significant industry sector, especially in the Southeast. The South has been known as the "fiber basket" for some decades now and is a major producer and exporter of a wide range of forest and wood products, from pulp and paper to lumber, composite materials, and whiskey barrels. In the Southeast, the volume of the forest products industry is quite high. A recent report by the US Departments of Energy and Agriculture, popularly known as the Billion Ton Report, estimates the potential contribution of residue, in the form of woody biomass, to the biofuels and bioenergy economy at roughly 370 million tons. Woody biomass can play a vital role in providing biomass for the developing biofuels sector without diverting material away from production of fiber products.

The forest products industry generates various sources of biomass, including waste from harvest operations and manufacturing processes. This industry and the bioenergy industry are very much entwined. That is, without pulp, paper, and lumber operations, there would be no forest residue from harvests for bioenergy. By the same token, the biofuels industry presents new prospects for efficiently utilizing process residues and off-specification raw material.

THE INTEGRATED BIOREFINERY

The fully integrated agricultural and forest residual biorefinery model may be comprised of both biochemical and thermochemical approaches. The pulp and paper mills of today are effectively biorefineries at a very early stage; that is, they are producing a primary product, paper or pulp, and at the same time are likely burning their black liquor to produce energy, heat, and steam to operate their equipment. As the level of integration of the two processes accelerates, there will be increased opportunities to draw from technologies that have been developed in the biofuels and bioenergy arena such as biomass gasification and enzymatic technologies for conversion of sugars to fuel and other co-products. These new technologies have the potential to further the interaction between the two industry sectors.

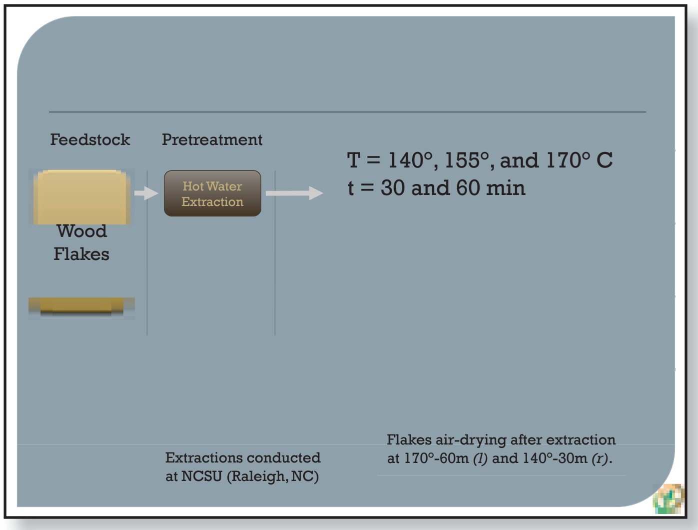
One promising new technology in the pulp and paper industry is known as "value prior to pulping," which essentially introduces a new step in the process where the hemicellulose or carbohydrate phase of the wood is extracted from wood chips prior to the pulping operation that produces fiber. These hemicelluloses, or five-carbon sugars, can then be redirected for production of ethanol or other types of liquid chemicals. This creates higher value products without adversely affecting the quality of the primary product—paper. It also introduces a new process stream and a new product line for the industry. A typical kraft mill consuming about 1,500 tons per day of wood chips could at the same time produce about 15 million gallons a year of ethanol. At a larger scale, if a certain percentage of the pulp and paper mills across North America were to adopt this technology, we might see a total market potential of about 2 billion gallons per year of ethanol, a significant contribution in meeting the nation's goal of reduced petroleum dependence.

If the potential for ethanol production can be so beneficial for the pulp and paper industry, we might wonder if there are opportunities as well for the wood composites industry, which produces oriented strand board—waferboard—particle board, medium density fiber board, and other types of wood composite materials. This is a substantial industry sector in China as well as in the United States. There are certainly opportunities for extracting hemicellulose to create new product streams and diversification for this industry. This could be vital to a very competitive industry. Process residues can be used to generate heat and power, as well as alternative fuels; however, the idea of extracting value prior to processing is currently at the proof-of-concept stage.

SYSTEMS INTEGRATION

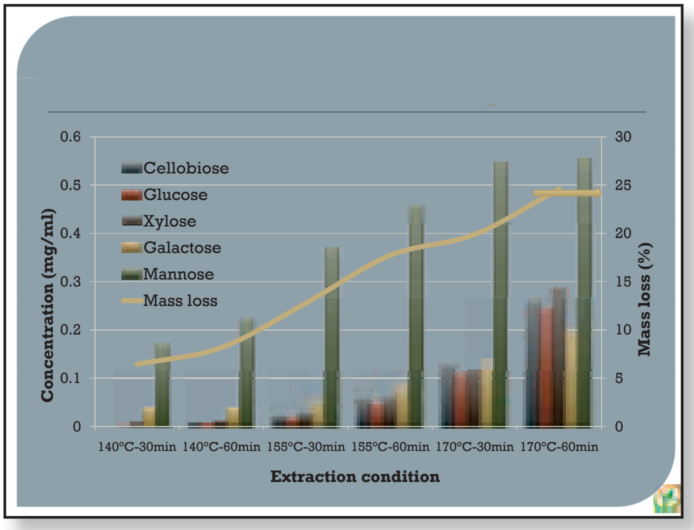
There are many opportunities for process residues to be treated with thermo-chemical processes for the production of fuels and other types of chemicals. In the analagous value-prior-to-processing approach, which extracts sugars before processing, the Center for Renewable Carbon has been looking at simple hot water extraction of wood flakes at limited levels. When wood flakes are processed with hot water extraction, part of the material is converted into composite materials, and the extract is separated for production of ethanol, animal feeds, chemicals, and polymers. Process residues can be pretreated, subjected to hydrolysis, and converted thermo-chemically into heat and power, fuels, and chemicals.

We have recently conducted experiments to test this concept. We made wood flakes from fresh raw materials (southern pine logs harvested from the East Tennessee Research and Education Center in Oak Ridge, Tennessee). The logs were de-barked at a local lumber company in Coalfield, Tennessee, and sent to the Louisiana Pacific Research Center in Franklin, Tennessee, where they were further processed to produce wood strands. We then took the flakes to North Carolina State University for larger scale extraction procedures. The flakes were



subjected to a hot water extraction process at relatively mild temperatures, 140,155, and 170˚C, in two batches processed for 30 and 60 minutes. The flakes were then air dried for further manufacturing in the UT Forest Products Center's laboratories.

We found substantial differences as indicated by dramatic changes in color of the flakes which indicated changes in the chemical composition of the flakes. We paid particular attention to the effluent itself using a simplified process developed by the National Renewable Energy Laboratory (Golden, CO) for characterization of sugars, byproducts, and degradation products in the liquid fraction samples. The maximum weight loss in this relatively mild extraction



procedure did not exceed 25 percent under the most severe condition, with temperatures of 170˚C and processing time of 60 minutes. At the mildest conditions, the process produced primarily cellobiose, but we found galactose to be a prominent five-carbon sugar that is present regardless of severity of the extraction process. While we are beginning to focus on these milder extraction conditions, we do note that increased treatment severity increases the range of sugar degradation products. We will need to find some balance in the process to minimize degradation products. Complexity in composition adds to the expense of separations and cleanup, and reduces the value of this new product stream. This presents a real implementation challenge in industry because of very significant barriers in cleanup for a final product or final process stream.

PERFORMANCE TESTING

To determine how pretreatment might affect the properties of the wood strands or the wood cell wall we also conducted nanoindentation experiments, a mechanical test of the hardness of the extracted flakes, on a very small scale. These tests were inconclusive, but in theory this is a valuable test method for looking at small scale mechanical properties. In terms of hardness, we were able to determine there was little impact on the mechanical properties of the cell wall until it was subjected to the very severe treatment range. In terms of the stiffness of the material (i.e., the elastic modulus) we found a fairly gradual decline as the severity of treatment and weight loss of the material increased, so we can assume the cell wall of the wood flakes will retain reasonable performance post treatment. We were very surprised at the results of our test for the modulus of rupture, which is the overall toughness of the oriented strandboard composites. We found a dramatic increase in the toughness of the panels as we extracted sugars, until we reached the most severe of treatment conditions. This increase in the modulus of rupture is a substantial enhancement in properties for a composite material.

In addition to significant improvements in the mechanical properties of the composite material as we extracted hemicelluloses or the carbohydrate phase, we also noted significant decreases in water absorption and thickness swell—the material's tendency to interact with moisture. This has a huge impact on the durability of the panel depending on how it is used. For example, in exterior applications, where it might be exposed to moisture this property is very important. In terms of its suitability in interior applications, we also found that by removing some of the food source for micro-organisms, the composite material's susceptibility to mold and mildew became essentially nonexistent. These are very real advantages in the performance characteristics of the core panel product. To improve the product, and at the same time generate a new product stream for fuel or chemicals, represents a significant accrual of benefits.

ACCRUAL OF BENEFITS

The advantages to the wood products industry of this manufacturing technology are many. For example, raw materials that are of low quality may be redirected, improving the efficiency of composite manufacturing. The term "suboptimal strand geometries" is commonly used in the industry to refer to strands that are too small and provide no structural benefit to the composite panel. These materials can be rerouted, further improving panel properties and providing an outlet for sub-optimal materials. Other benefits include significant reductions in natural gas demand for scrubbing emissions of volatile organic compounds (VOC), since we achieved dramatic reductions of VOCs during pressing and drying. As we extract the hemicelluloses, we also see large reductions in the energy required to dry the flakes, improvements in the thermal stability, and increases in moisture resistance, making the panel product more durable in its overall lifecycle. Extended product lifetime also effectively enhances carbon sequestration.

We are enthusiastic about the prospects of the integrated biorefinery. The bioenergy industry and forest products industry can derive great benefits from each other. With an established supply chain, the forest products industry is positioned as an important supplier of feedstock. Extraction of non-structural carbohydrates improves many performance properties of wood panels. Control over chemical removal can be achieved through controlling the severity of treatment. Questions about the overall economics of the process, however, remain, and we will need to explore further treatment options in the future.

Bioenergy: Challenges for Deployment

by Brian Davison

Dr. Davison *is Chief Scientist for Systems Biology and Biotechnology and Deputy Director of the BioEnergy Science Center, Oak Ridge National Laboratory.*

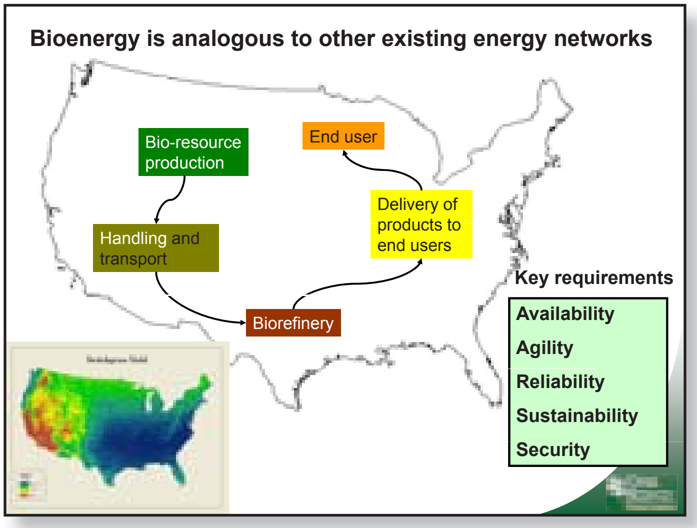
There are two overriding reasons we are interested in biofuels: energy security, given the uncertain future availability of oil and gas, and global climate change. In the transportation sector, technology options on the supply side include locating and extracting oil and gas from underutilized or new sources, increasing the amount of biofuels, and moving toward hydrogen powered vehicles. On the demand side, we can improve vehicle efficiency and increase the number of hybrid vehicles.

As we move toward deployment of bioenergy and bio-feedstocks, we need to understand that not all of our energy and mass flows are infinitely interchangeable. Scientists at Lawrence Livermore National Laboratory have tracked energy flows between different commodities and markets in the United States. Petroleum is by far the greatest energy source, accounting for nearly 40 percent of the total. Most of the petroleum serves the transportation sector and to a lesser extent the industrial sector. Coal, natural gas, nuclear, and to a much lesser extent alternative, renewable sources of energy produce electricity for residential, commercial, and industrial uses. Biomass is a small piece of the energy pie, less than 3 percent.

The 2007 Energy Independence and Security Act (EISA 2007) set targets of about 35 billion gallons of renewable, biofuels-based energy that would be used within the United States by 2030. In the next few years, conventional renewable fuels produced by our current corn starch industry are expected to peak at around 15 billion gallons per year. A key challenge then is to achieve a major increase in the amount of non-starch based biofuels, in particular cellulosic based fuels, in order to boost the production up to the goal.

DEPLOYMENT CHALLENGES

While the growing need for sustainable electric power can be met by other renewables, biomass is our only renewable source of carbon-based fuels and chemicals. From the broader perspective of deployment, bioenergy is analogous to other existing energy networks, from production of the bio-resource, through handling and transportation of the feedstock, to



conversion at a bio-refinery, to delivery of the product to distribution points and ultimately to its end use in the tank of a vehicle. The first three of these steps present several challenges in deployment of bioenergy, and one of the greatest is in the conversion phase. Other challenges include sustainability and perceived risks of biofeedstocks.

Biomass utilization is a multifactorial, or multiple choice, problem. First, we must choose among the types of land we will use, current cropland, fallow land, marginal land, rangeland, or forestland. The next choice is the type of feedstock, whether grain crops, switchgrass, animal wastes, oil crops, or other. Then we have to decide what process technologies will be used, fermentation, pulping, gasification, thermo-chemical conversion, anaerobic digestion, or something else. Finally, we need to identify what outputs we produce, whether chemicals, ethanol, butanol, diesel, methane, syngas, fertilizer, or other.

In the United States, more than 98 percent of current renewable biomass utilization essentially follows one route, from cornstarch and some other starches produced on current cropland to conversion technologies to deployment of the end product. The potential use of cropland and food and feed sources for ethanol production sometimes causes confusion in the debate, in the United States and in China as well, over current policy options and other technology options for second and third generation types of improvements where non-food biofeedstocks can be used.

Market forces also play a role in the deployment of bioenergy. In the United States, in the last four years, there has been a good deal of instability in gasoline and spot ethanol prices. At times, ethanol was competitive with petroleum even without subsidies. At other times, in the United States and elsewhere, ethanol was completely uneconomical, and anyone producing cornstarch-based ethanol in the United States was bound to lose money. The mood of investors and producers concerning investment in bioenergy infrastructure since enactment of the Energy Policy Act of 2005 Energy (EPAct 2005) has been characterized as going from guarded optimism, to exuberance, to caution, to stalling or cancellation of new projects, to panic and pullback. In the early days, just after the act was signed into law in July 2005, ethanol producers realized a consistent return on investment (ROI) in corn ethanol, about 15 to 25 percent, which seemed a profitable market. After Hurricane Katrina in late August 2005, oil prices spiked, and producers were making 100 to 200 percent ROI from cornstarch-based ethanol, sparking a frenzy of investment in ethanol plants and leading to a market glut. As producers built capacity, ROI started falling again. Then, just before the financial collapse when oil prices fell again in the summer of 2008, ROI declined to negative 50 percent. Today, we are almost at zero plus or minus ROI. Because of market forces that caused people to greatly build up cornstarch-based ethanol capacity, we now have a large amount of potential, idle capacity. Construction of new plants as the credit crisis unfolded is stalled, and current and future project development frozen. We are, nevertheless, already approaching the 10 to 15 billion gallons of ethanol production capacity in the United States that EISA 2007 set as its goal for 2022.

NEXT GENERATION PLANTS

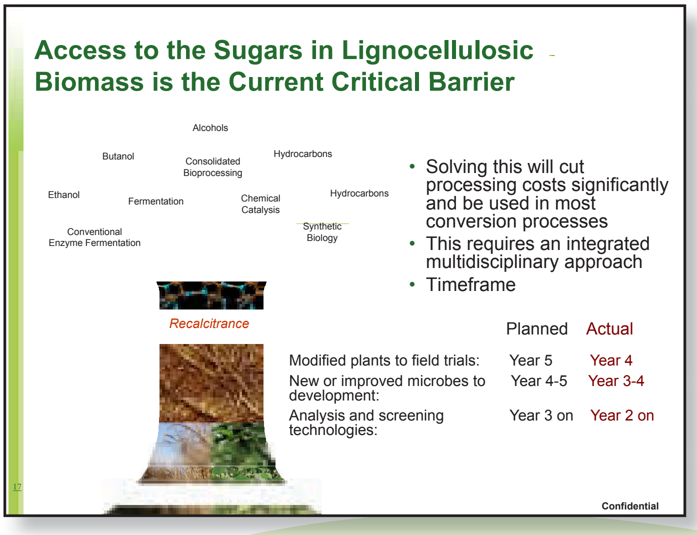
The US Department of Energy (DOE) is working hard to develop first generation cellulosic plants. If we consider cornstarch-based ethanol as generation zero, DOE is now encouraging development of first and second generation biomass-based conversion technologies at multiple sites, including eight small-scale pilot bio-refinery projects, four commercial-scale bio-refinery projects, four improved enzyme projects, five projects for fermentation organisms, and five thermo-chemical/syngas projects.

In February 2007, DOE announced winners of funding for six full-scale cellulosic ethanol demonstration bio-refineries capable of producing 100 million gallons or more each, sited in a wide variety of locations using a number of process technologies and feedstock sources, from corn stover to agricultural residues and yard waste. We do not know which technology is going to be the winner within these technologies and categories of feedstocks. It is quite a challenge to transform a technology into reality, and all these projects have proceeded slowly in terms of locking in their financing and feedstock contracts. Two of them have already broken ground, and others are moving forward, but the process has been slower than expected. Two of the companies that bid on the funding are no longer part of the program. One of them moved to build their demonstration plant in Canada, based on better incentives, and the other had financing and other issues and simply decided it could not go forward, which is not unexpected considering the challenges of testing new technologies.

THE CONVERSION CHALLENGE

In broad terms, there are two technological strategies being considered to improve the conversion of cellulosic feedstocks into fuel. The biological route has a lower theoretical yield but results in higher achieved yield and potential high-value co-products. The thermo-chemical route has a higher theoretical yield but much lower achieved yield and less desirable co-products, including methane.

The BioEnergy Science Center (BESC) is working on ways to overcome biomass recalcitrance and improve access to the sugars in lignocellulosic biomass, which is the current critical barrier to converting biomass to fuel. There are multiple routes of conversion in the current first generation processes using conventional enzyme fermentation or some of the more advanced concepts such as production of butanol, chemical catalysis of sugars into hydrocarbons, or synthetic biology involving completely novel fermentation routes to produce



hydrocarbons. Overcoming these recalcitrance barriers will cut processing costs significantly. This will require adopting an integrated multidisciplinary approach and establishing a timeframe for implementation. The five-year time frame BESC has adopted includes moving modified plants that more easily convert energy from the lab to field trials, developing new or improved microbes to break down lignocellulose, and analyzing and screening the technologies available for conversion.

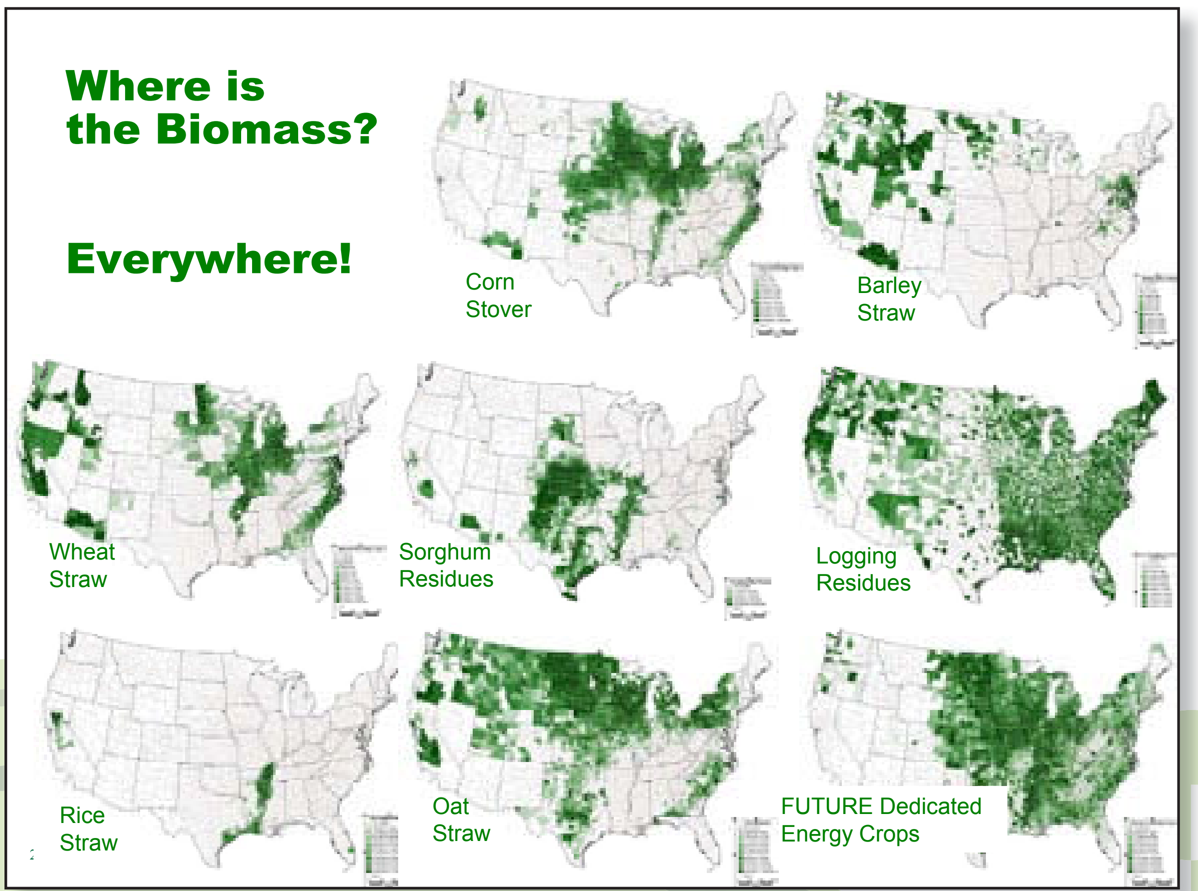
We are confident that the BESC team can revolutionize how biomass is processed within five years and develop a much simplified process with greater overall yields. In general, we will achieve this by modifying plant cell walls to decrease recalcitrance, thereby reducing the severity of pretreatment and perhaps eliminating it altogether, and by developing advanced conversion systems featuring consolidated bio-processing. Our work in both of these areas will be made possible by state of the art analytical tools to understand the scientific basis of recalcitrance.

EYE TO THE FUTURE

The Renewable Fuel Standard created under EPAct 2005 defined advanced biofuel as "renewable fuel, other than ethanol derived from corn starch, that has lifecycle greenhouse gas emissions…that are at least 50 percent less than baseline lifecycle greenhouse gas emissions." Advanced, fungible, biofuels are interchangeable, and generally compatible, with currently available fuels; their energy content is similar or equal to that of hydrocarbon fuels; and they are usable in today's refineries, pipelines, and distribution networks.

DOE has outlined future needs in the United States for biofuels and bioenergy. Beyond the deployment of current, first generation technologies, according to its Office of Biomass Program, second and third generation technologies will require newer and higher energy feedstocks, will be capable of producing advanced biofuels and value-added products and co-products, will assist in carbon mitigation, and will stimulate and leverage the scientific process. New feedstock sources include energy crops, waste, and algae. Advanced biofuels include algal-based fuels, fuels with higher alcohol content, green gasoline made from cellulose, renewable diesel, and renewable jet fuel formulations. Value-added co-products from the integrated bio-refinery process may provide a larger economic value. Carbon mitigation may play a potential role in future carbon legislation.

The challenges to deployment of conversion technologies are real. Risk and volatility in the marketplace, for example, is no theoretical construct; the data on the last two years of market volatility has made that glaringly apparent. Consider a recent, clear, business example: Pacific Ethanol, at one point the largest bioethanol producer in the United States, went bankrupt about a year ago because it missed the bet on the corn futures markets. The market changed, and within a



month the company had to declare bankruptcy. Major business catastrophic events like this make capital and investment very challenging.

In addition, the United States is starting to approach the "blend wall" of 10 percent in most gasoline formulations. Furthermore, if we are to meet our goals of developing and building full-scale bio-refineries in the next 20 years, we will need to see from 100 to 300 bio-refineries become operational. The first generation of technologies is now ready to be deployed, and new generations of improvements are in the pipeline. Do we invest in currently available technologies, or wait for better ones a year or two down the road? One of the challenges for technology developers is to design bio-refineries that can be rapidly upgraded in biocatalyst capability or increased fuel product as technology improves.

In terms of feedstocks, the Billion Ton Study, conducted by Oak Ridge National Laboratory for the US Departments of Energy and Agriculture and published in 2005, showed a great deal of potential for significant biomass resources, up to 30 percent of our transportation fuels by 2030 given certain assumptions. A follow-up study that is still under review has determined multiple locations where biomass could be produced, much of it in the Midwest and increasingly in the Southeast. The sustainability of biomass production is unclear, however. We also need to consider multiple aspects, including the original condition of the land and the management, type, location, extent, and environmental attributes of various feedstocks.

FOOD VERSUS FUEL

There is common agreement that the use of food crops for fuel has raised the price of grains and seeds, but the amounts have been hotly debated as many other factors have changed as well, and the amount of that increase has not been as significant as popularly believed. Soaring energy prices, which increase the cost of food production, were probably the largest part of this particular dynamic. Other factors include drought in food-exporting countries, increased demand for food in emerging economies, cutoffs in grain exports by major suppliers, a tumbling US dollar, and speculation in commodities markets. Yet the popular media point to corn ethanol as the primary culprit. In fact, only 1.2 percent of global food costs have increased due to corn prices.

To meet the challenges in feedstock deployment, we need to move beyond starches and even beyond agricultural residues into dedicated cellulosic bio-feedstocks. We need to develop improved tested varieties, and we have no strong strategy for that. We need a lot more field data to identify proper management practices and conduct assessments of life cycle, land use, carbon balance, and the larger issues of indirect land uses.

We also need to plan ahead and start planting two to three years before each biorefinery opens and consider the acreage needed to provide feedstock to that biorefinery. For example, when the University of Tennessee (UT) partnered with Genera Energy to begin feedstock planting of switchgrass, we hit a window where we had bought up nearly all the U.S. switchgrass seed supply. UT is now increasing its own seed supply, and seed companies, seeing a perceived demand, have increased their production. We have to think ahead toward these potential dislocations of markets, especially in new areas.

Finally, we need to optimize the scale and siting of feedstock production. Conversion, like most technologies, has economies of scale: the larger the field where a feedstock is grown and the shorter the distance from field to refinery, the more economic the conversion process will be.

PERCEPTION OF RISK

The perception of risk by the market and the public centers on the actual carbon balance for bioenergy, that is, the real sustainability and environmental impact on water, land, diversity, and society. Food and fuel debates, local and global, will not go away, and we will continue to deal with those concerns. Questions about genetically modified organisms of feedstocks and their deployment will likewise persist. Societal questions from interest groups, and the NIMBY (Not in My Back Yard) phenomenon, as with any other technology, will remain with bio-refineries. Many people like the idea of a bio-refinery, at least in theory. As Genera Energy considered where to locate the plant, the first question the company heard from the public was: Is it going to smell? Not whether the refinery might compete with food sources or whether the technology is good for the total soil carbon balance, but whether there would be an odor downwind from the plant. Questions like that will not simply disappear.

Despite these ongoing questions and concerns, BESC has a vision of a carbon neutral cycle for fuels and valuable co-products, incorporating a fully integrated agro-biofuel-biomaterial-biopowercycle for sustainable technologies that will help address the crucial need for energy security and mitigation of climate change.

Ecosystem Services of Existing and Candidate Bioenergy Cropping Systems: Critical Research Questions

by Sylvie Brouder and Jeff Volenec

Drs. Sylvie Brouder and Jeffrey Volenec *are Professors in the Department of Agronomy, Purdue University.*

Sylvie Brouder

Corn grain used for ethanol is the most familiar first-generation bioenergy crop in widespread production throughout the United States. Nevertheless, even with well-studied cropping systems such as corn, a number of questions pertaining to production remain unanswered. Complete lifecycle analysis (LCA) is needed for all systems, and to perform an LCA, quantitative data are needed for the analysis. Researchers in the Agronomy Department at Purdue University, in West Lafayette, Indiana, have been working to identify and characterize existing or candidate species of crops with known or potential value as second-generation bioenergy crops, including corn stover, switchgrass, *Miscanthus*, sorghum, and native prairie grasses.

Though data on some bioenergy crops such as corn and switchgrass are available, for crops that are less well known, like *Miscanthus*, a novel crop for the United States, we don't have enough sound data for the agro-ecozones where it may be grown. *Miscanthus*, a perennial grass native to the tropics and subtropics, is already being grown on an experimental basis as a bioenergy crop in Europe and Asia and is a candidate crop in the United States.

Miscanthus is a putative high yield crop that is thought to use nitrogen (N) fertilizer more efficiently than corn and other bioenergy crops, but quantitative analysis of its N use efficiency (NUE) is required to verify this hypothesis. In general, for all of our candidate species and systems, we do not have a good handle on basic environmental questions such as nutrient cycling, system water use efficiency (WUE), and system NUE. In addition, we know little about other ecological services such as wildlife habitat, biodiversity, and overall valuation of ecosystem services.

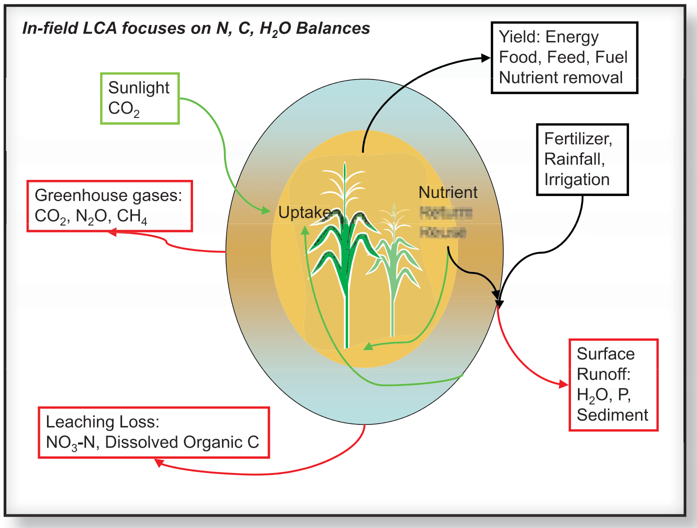
Agro-ecosystems are not pristine; we have modified them in many ways from the pre-agricultural, natural species distribution. However, much like natural ecosystems, all farming systems provide services. Agricultural systems provide crop yield, which in the past has been the major driver of decisions, but there are other benefits that various agro-ecosystems can provide, such as greenhouse gas (GHG) mitigation and improvements in water quality. But unlike yield, these are poorly understood and their economic and societal values are often not known. We have to identify and prioritize services we want to encourage, because there is no such thing as a win-win situation.

BROADENING FOCUS OF LCA

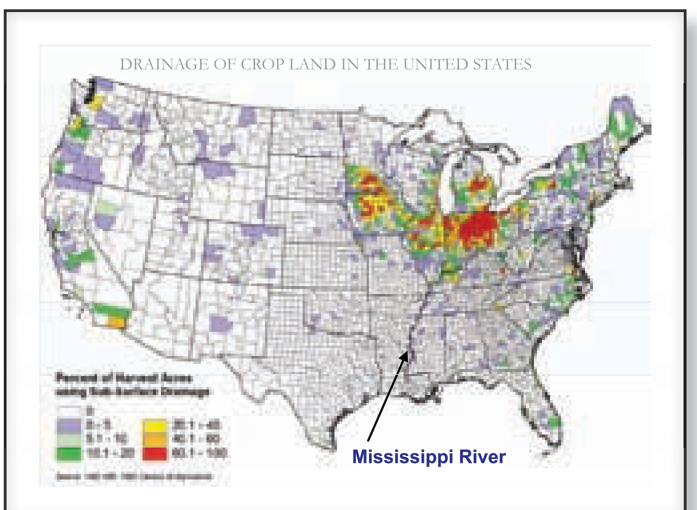
The nitrogen-carbon (N/C) cycle is at the core of the climate-ecosystem-energy nexus. So far, LCA of agro-ecosystems has focused on the carbon footprint of bioenergy crops. Feedstock yield is a positive driver. The ideal is to use the fewest inputs to achieve the greatest yield from an agricultural system. Yield of energy, however, is highly dependent on the conversion technology or multiple technologies that transform a crop into bioenergy.

On the other hand, system N loss is a negative driver. We know that nitrous oxide (N_20) emissions are a serious component of a crop's global warming potential, but of all the GHGs, it is the least understood. Nitrate (NO_3-N) losses from leaching impair surface and groundwater, but these losses, and their effects on the balance of GHG emissions, are not yet explicitly accounted for in LCA studies. Our focus, as we decide what crops to grow and which have environmental benefits, has been on a simultaneous understanding of both GHG emissions and water quality risks from candidate bioenergy systems. We may well need to revisit the boundaries of LCA studies to include other, critical environmental systems, especially water systems. Moreover, N/C cycling, including carbon sequestration, is not sufficiently understood across candidate systems to perform a complete LCA that can guide our policy decisions.

The in-field component of LCA analysis focuses on N, C, and water balances. Nitrogen, C, and water cycle through the plant. If the system is perturbed to improve one factor, there are often unanticipated and perhaps undesirable effects on the other factors. Midwestern research facilities have a long history of studying water quality, N, pesticides and other problems related to water quality because, among other things, there is no scarcity of rainfall in the region. At times, precipitation is scarce late in the growing season, but in spring there is too



much water. To dispose of excess water, artificial drainage has been installed and these tile lines serve as direct conduits to move rainfall into surface and ground waters. The distribution of tile drainage acreage in the United States is most intense in the upper Midwestern area. The drainage is carried to the Ohio River, to the Mississippi River, and eventually to the Gulf of Mexico, which now has a huge hypoxic zone from the nutrients carried off from agricultural soils. According to US Geological Survey figures, the source of most of the N in the Gulf of Mexico hypoxic zone is primarily due to row-crop agriculture in the Midwest while much of the phosphorous in the Gulf can be traced to pasture and range in the region.



A BALANCING ACT

There are many grand challenges in balancing crop production with ecosystem health. Among the most important are ensuring secure and sustainable food and fuel production; maintaining clean, safe available water supplies; and mitigating the effects of GHG emissions. Long-term, multi-factorial studies have outlined the many tradeoffs among ecosystem services provided by different cropping systems. These factors include the biomass yield, NUE, and WUE; cell wall composition of a particular species; species suitability and environmental interactions; and potential sequestration of C and N in the soil,and their losses to the atmosphere and to surface waters. These considerations translate into myriad on-the-ground management decisions that must be made.

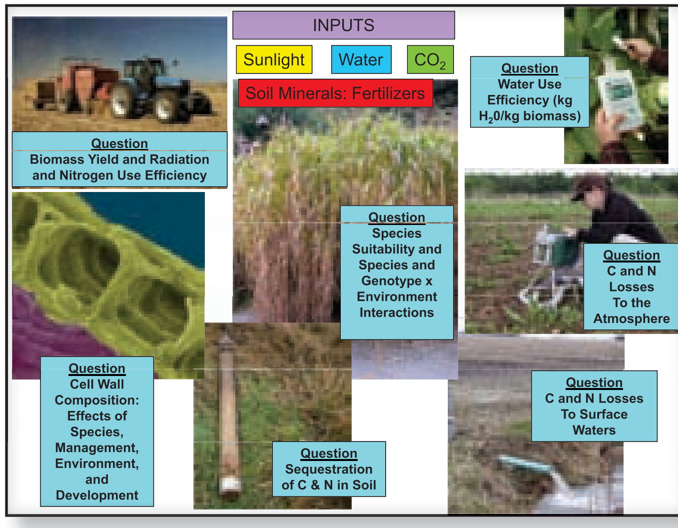
For example, fall-applied manure to corn can result in large amounts of N loss to surface waters. The alternative is to spring-apply the manure, which reduces N losses to water but increases N lost to the atmosphere as N_2O and global warming. These trade-offs highlight the challenge of finding win-win solutions to Grand Challenge problems in agriculture.

Another difficult tradeoff has been documented for the native prairie grass, big bluestem. An older study determined that big bluestem is very efficient in terms of producing biomass per unit of N. The overall production of biomass, however, is very low, so low, in fact, that it is probably uneconomical for use as biomass. To boost productivity, N inputs must be increased but this leads to potential problems with regard to GHG emissions and reduced water quality. This clearly demonstrates the trade-offs that complicate decisions facing agriculture as tensions between productivity and environmental quality are vetted.

Few studies can provide all the necessary information to make the best decisions. If we compare earlier studies on big bluestem and Indian grass with data available today on switchgrass, the current favorite as a bioenergy crop, we find all three candidate species are responsive to N fertilizer applications, but each also varies in terms of NUE. The ideal candidate bioenergy crop would possess both high yield and greater NUE, but as stated above this win-win is not often realized. Part of the problem is how we manage N for perennials plants. Newer species may be more efficient than older ones in terms of NUE, but because N is surface-applied, losses can occur via volatilization. This is especially true of urea-based products. In addition, no matter how the N is applied there will always be the potential for leaching losses. All these factors must be considered in an LCA.

NO MAGIC PLANT

We have some agronomic information on the native perennial plants being considered for bioenergy production, but with novel crops such as *Miscanthus*, there is little data for a valid LCA. Some of the data do seem promising. For example, NUE of *Miscanthus* estimated using tissue N levels measured in February initially seemed higher than corn, sorghum, wheat and other species. However, re-analysis of NUE estimated using N uptake in mid-summer reveals that this species is similar to corn and other species. Another approach to NUE issues in *Miscanthus* confirmed the initial conclusions. The N requirements for *Miscanthus* compared to other candidate species scale the N uptake; the amount of N found in the plant is a linear function of biomass largely irrespective of species and management input. One outlier emerged from this preliminary analysis. Sorghum is one species where NUE trends upward and may hold promise for producing high yield with lower fertilizer N inputs. Additional study of sorghum, including germplasms with high tissue sugar levels and high yield, may reveal promising candidate biomass species where annual plants are preferred and corn is not well-suited because of soil or water limitations.



CROP-TRAIT IMPROVEMENT

We know some about NUE in maize, but that knowledge is incomplete. The genes and pathways that are thought to govern the efficiency of N uptake have been identified, but we still are not able to take full advantage of the process. NUE reflects both plant and soil processes, and these processes interact between themselves and with the prevailing environment. Nitrogen is mobile in the soil. The uptake process at the root surface often does not limit plant N acquisition; rather it is N availability in the root zone that constrains plant N uptake. A number of studies show that the suite of traits responsible for efficient uptake are probably already optimized in most corn germplasms because intense selection for high yield by plant breeders would likely result in simultaneous co-selection of high NUE.

We know less about physiological efficiency (PE) of N use in maize. The key to improving primary N assimilation may lie in a key gene or pathway involved in N assimilation. However, studies aimed at improving corn yield by selecting for high nitrate reductase activity (NRA, a key step in N assimilation in corn) have been disappointing. Eight cycles of selection of corn for contrasting (high versus low) NRA did not improve yield or grain N in plants selected for high NRA, but was effective at reducing grain N and yield in plants selected for low NRA. This suggests that NRA was high enough in the unselected, original population to meet the N assimilation needs of these plants. This study underscores the fact that the mechanisms affecting yield and N assimilation are complex. Improvements in NUE that will improve the final yield depend on numerous genes. It is also important to realize that NUE is driven by overall crop performance, which depends on the actions and interactions of multiple genes with the environment and with varying agricultural practices. This is important to consider before we spend valuable resources manipulating individual genes to see what happens.

NO SIMPLE ANSWERS

To expand the LCA concept to include ecosystem services, we need to look at the many different alternative cropping systems and candidate bioenergy crops, understanding that for each there will be tradeoffs. Should we use a perennial crop such as switchgrass or an annual such as corn? How do we value a crop's ability to store carbon in the soil? What is the NUE and total N need of each candidate species? What is a species' WUE and total water use, and how do these relate to the fuel produced from the biomass? Does the biomass require storage or can it remain in the field prior to use? Is this species pest and disease resistant? What is the crop's contribution overall to GHG emissions or nutrient loss from leaching? In addition, we must consider essential ecosystem services such as biodiversity, habitat, and water filtration.

Our choices will not be a simple yes/no; instead they will be quantitative numbers that need to be used for a comparative analysis of the trade-offs. However, once these data are in hand, knowledge for the choice can be created, and science-based policies developed that benefit society and humanity. There are many unknowns as we look to the future of agriculture, biofuels, and the modern eco-farm, questions that it is appropriate for two major agricultural nations such as China and the United States, with our rich and complementary research capabilities, to address together.

Impact of Biofuel Production on Hydrology and Water Quality in the Midwestern United States

by Indrajeet Chaubey

Dr. Chaubey *is an Associate Professor in the Department of Earth and Atmospheric Sciences, Purdue University.*

The Energy Independence and Security Act (EISA) mandates that agencies such as the US Environmental Protection Agency, the US Department of Agriculture (USDA), and the Department of Energy report to Congress the current and future environmental and resource conservation impacts of biofuels production in the United States. EISA also requires these agencies to integrate water quality into fuel assessment analyses. Whether these hydrologic and water quality impacts are positive or negative will depend on a number of factors including crop selection, watershed characteristics such as slope and soil conditions, climate conditions, and landscape-scale management practices.

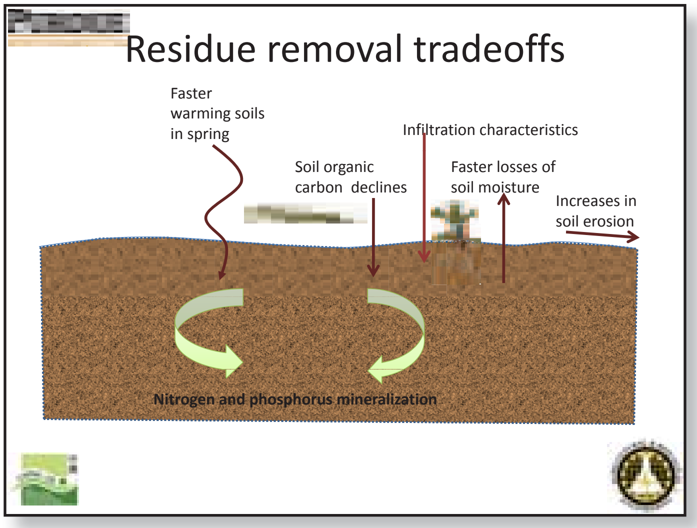
In the future, the focus on bio-feedstock production will likely vary depending on the timeframe, long- or short-term. The current focus is mainly on corn-based ethanol production. In the near future the focus will probably shift to a mixture of corn silage and corn stover removal from the landscape in addition to grain-based ethanol production. Beyond 2015, we will likely focus more on switchgrass, *Miscanthus*, fast growing trees such as poplar, and other second generation biofuel feedstock.

In considering the water quality impacts of bio-feedstock production, the overriding question is what the unintended consequences may be to water quality due to large-scale biomass demand. The sequence of processes that takes place in biofuels production begins with feedstock production and continues through the logistics of storage and transportation, and then to the production, distribution, and end use of biofuel.

PRODUCTION IMPACTS

Production of bio-feedstock is very relevant to the Midwest in general and Indiana in particular. The Mississippi River Basin, which flows to the Gulf of Mexico, currently drains about 31 states. Of these, nine states contribute 75 percent of the total nitrogen and phosphorus that reaches the Gulf of Mexico. However, these nine states account for only one third of the total area of the Mississippi-Atchafalaya River Basin (MARB), so one third of the area is contributing three fourths of total nutrients into the Gulf of Mexico.

Until very recently, nitrogen has been the limiting nutrient in promoting hypoxia, and 86 percent of that comes from corn/soybean areas located mostly in the Midwest. What happens to the biofuel scenario in the Midwest is therefore extremely relevant to water quality in the Gulf of Mexico.



Two approaches to assessment of bio-feedstock production impacts are monitoring and modeling. We need an integrated monitoring/modeling approach because either of the two approaches alone may not give us the entire picture. From the monitoring standpoint, we must collect data at different watershed scales and different time frames to understand different processes. Collecting data at the watershed scale, however, is very time consuming and expensive and sometimes not even possible to do. We can supplement monitoring with a modeling approach to help us answer different "what if" questions. What if we change the crop rotation? What if we take the land that is in the conservation reserve program and plant certain bio-feedstocks? Models can help us answer those kinds of questions. However the current generation of watershed models cannot handle some of the new scenarios related to biofuel production. Existing models require modifications to fully evaluate with greater confidence second generation bio-feedback production impacts on water quality.

One likely scenario between now and 2015 is increased removal of corn stover from the landscape. Corn stover as residue plays a very important hydrologic and water quality role in the landscape. When corn stover sits on top of the soil profile, it does a great job of reducing the amount of erosion that can occur. If that cover is removed, soil moisture may be lost. At the same time, in spring the soil temperature might warm up much faster. The combination of moisture loss and temperature shift will certainly affect nitrogen and phosphorus mineralization rates and may also change infiltration characteristics in the spring. In addition, soil organic carbon will decline because the residue that used to be incorporated in the soil will be removed. This is one of the key questions about the unintended environmental consequences of increased corn production to meet biofuels demand; we are already seeing removal of corn stover from the landscape.

In the future, we will also need to assess the environmental impacts of various second generation bio-feedstock production systems to meet cellulosic ethanol demands. Will the management of cropping symptoms involving corn silage be adequate to meet cellulosic ethanol demand with minimal environmental impacts? Moving further beyond 2015, what are the broad-scale water quality implications of energy crops such as switchgrass grown for bioenergy production on highly erodible soil? What modifications are needed in the current generation of watershed models to adequately represent current and future bio-feedstock scenarios, including various levels of biomass removal, new crops and new varieties of crops, and potential crop failures?

Establishment of some of the second generation biofuels crops is reported to fail about 10 to 15 percent of the time. Finally, how can we incorporate all this information into decision support tools to help different agencies and stakeholders make watershed management decisions that will meet our production goals and at the same time minimize negative impacts and promote positive impacts?

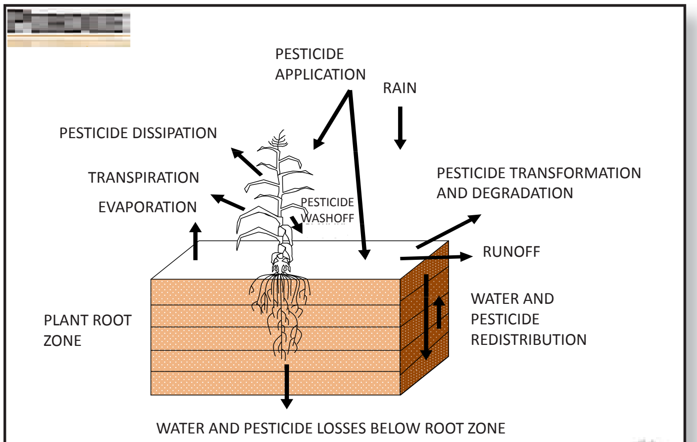
DUAL APPROACH

In Indiana, we are combining modeling and monitoring using data collected in a number of different watersheds to build and refine our models, focusing on agriculture watersheds typical of the Midwest, where we expect to see land management changes arising from biofuel production.

The two models we use are Groundwater Loading Effects of Agricultural Management Systems (GLEAMS), a field-scale model, and Soil and Water Assessment Tool (SWAT), a watershed-scale model. The model simulations have been adapted to several regional soils and watersheds across the state.

GLEAMS can model the physical system and processes of various soils using different variables such as sediments, nutrients, and pesticides. Using a soil profile of a biofuel crop such as corn, we can show for example how a pesticide that is applied may be intercepted by the plant or, depending on rainfall characteristics, wash off from the foliage and the ground and become runoff. Another portion of the pesticide may infiltrate through the soil and leach into the groundwater table. The physical processes of transpiration and evaporation also affect the fate and transport of pesticides.

SWAT is a watershed scale model to simulate the impact of watershed management and climate forcing on hydrology, water quality, and crop growth in mixed land-use watersheds. It models upland processes from agricultural, riparian, and forested areas to determine how much sediment, nutrients, pesticides, and bacteria get into the water. SWAT uses a very detailed stream process to determine the fate, transport, and timing of the delivery of these outputs. SWAT delineates the watershed into sub-basins, which are further divided into the smallest unit of calculation, Hydrological Response Units (HRUs), based on land use and soil distributions. Model calculations allow tracking of the transport of flow sediment, nutrients, pesticides, or any output of concern, all the way from the HRU of any of the sub-watershed to the watershed outlet.



The physical system and processes represented in **GLEAMS** (modified from Leonard *et al.,* 1987)

To ensure a high degree of confidence in the models, we compare actual flow from US Geological Survey data with simulated flow from our model and calibrate the model to make sure that it captures the response of the watershed. Once we have calibrated the model we validate it to make sure that we have represented watershed processes adequately. We expect the validation dataset to be similar to the calibration dataset. In two separate studies, we found the simulated and measured data were very close to each other, which gives us the confidence we need to start posing different "what if" questions to the model.

We found in running the model on pesticide data some differences between simulated and observed information. One challenge with water quality data on the watershed scale can be a lack of continuous data collection, as measurements may be made every two weeks, or every two months, so we are working with only about six to 14 data points in any given year. To build confidence that the model is capturing the general trend, we conduct different study-scale comparisons.

UNINTENDED CONSEQUENCES OF CORN PRODUCTION

The production of corn-grain based ethanol to meet biofuel demands has numerous hydrologic and water quality consequences that our modeling studies can track. These impacts include surface runoff and percolation, erosion, nitrates, total phosphorus, atrazine, and an entirely new foliar fungicide, pyraclostrobin. We have used these models specifically to compare different cropping systems. Currently, most producers follow a two year rotation, i.e. corn followed by soybean. With increasing demand for corn, producers may grow corn two years in a row followed by one year of soybeans, or they may even grow corn continuously. These are some of the scenarios that are already happening the Midwest.

We have begun to model best management practices (BMPs) specific to land use and land cover conditions. These best practices include grassed waterways, terraces, no till production, biomass removal, and nutrient management. We examined scenarios of the hydrologic impacts of different crop rotations, corn/soybean, corn/corn/soybean, and continuous corn. Three different soil types are commonly found in Indiana—Blount silt loam, Hoytville clay, and Oshtemo—and each type of soil has different characteristics that affect the rate of surface runoff. We determined that all three cropping systems within any given soil will have very little effect on runoff. There are, however, significant differences in percolation, the ability of soil to absorb water, with rotational systems compared to continuous corn. The fraction of rainfall and precipitation that will infiltrate and move through the soil profile with continuous corn would be significantly less than with the corn/soybean or corn/corn/soybean scenarios.

In terms of water quality impacts we see a pronounced difference. The amount of sediment lost from erosion with continuous corn cropping would be significantly greater than with corn/soybean or corn/corn/soybean. High demand for corn to produce ethanol might influence some producers to return highly erodible conservation lands into corn production and significantly increase sediment losses.

We see similar trends with nitrate. Continuous corn requires higher fertilizer rates and thus significantly higher annual nitrate losses compared to the other two cropping rotation scenarios among all three soil types. Total phosphorus impacts were even more pronounced with continuous corn; the relative increase in erosion and sediment loss was much greater for all three soils. Both nitrate and total phosphorous contribute to hypoxia in the Gulf of Mexico.

We also ran simulations to show the statewide impacts of the herbicide atrazine. Within the three crop rotations there may not be a statistically significant difference; there will be regional differences in those areas where higher concentrations of atrazine are found. We need to be vigilant about those impacts. In one region of the state, communities are already experiencing atrazine concentrations in their surface water systems higher than three parts per billion (ppb), which is the drinking water standard set by the US Environmental Protection Agency.

An emerging issue of great concern is pyraclostrobin, a foliar fungicide that is used to increase corn yields. *The Journal of Environmental Engineering* is publishing the results of our work on this fungicide, information not in the literature and a benchmark for US studies. Agricultural fields in Indiana are shrinking, and fungicides and other pesticides are now being applied as a preventative rather than a curative agent to increase corn yield on less land. We were able to model pyraclostrobin based on chemical properties, and results are consistent with the expected behavior in the environment.

We found that runoff concentrations of pyraclostrobin do not vary among cropping systems, which is good. Among different soils, however, the responses would be different. Pyraclostrobin has a high affinity to bind with the sediment so the amount of this fungicide moving with the sediment will be significantly greater with continuous corn. Long-term statewide simulations of runoff of the fungicide showed regional differences, though there was not just one "hot spot" like what we found with atrazine. Concentrations in our study ranged from a low of 0.0 to 1.3 ppb in some areas to as high as 1.8 to 2.5 ppb in others. A study conducted in Indiana by researchers from Purdue University examined the toxicity effects of pyraclostrobin on the crustacean *Daphnia magna*, which is considered an aquatic indicator species, and found that the fungicide has toxic effects in the range of 0.014 to 0.12 ppb. The use of pyraclostrobin is becoming more and more popular in corn crops, so increasing the amount of corn production, which leads to higher erosion rates, will also pose increased risks to surface water.

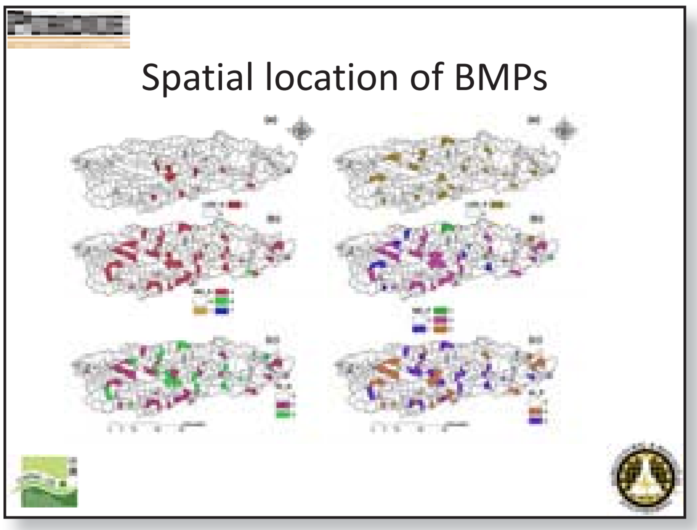
We have also simulated how the removal of corn stover at four different levels will affect erosion losses.

As we remove the stover from the landscape, erosion losses can be expected to increase. In addition, when we remove the stover from the landscape, pyraclostrobin losses will also likely increase.

BEST MANAGEMENT PRACTICES

Considering the probable adverse impacts of increased corn production, we need to determine different best management practice (BMP) strategies to minimize these unintended consequences. There are three approaches to implementing BMPs. We can randomly assign BMPs on a first come/first served basis for farmers willing to adopt them. We can target the hot spots where we foresee the most negative impacts on water quality. Or we can optimize the BMPs to get the best mitigation effects for the smallest investment.

We have compared these three strategies using our models, with a special emphasis on optimization. Using the SWAT model to quantify pollutant loads, we determined the best site selection and placement for BMPs using a genetic algorithm. We start with a population of solutions, evaluate the effect of modifications, and discard the inferior solutions until we reach an optimal solution. This process is a multi-objective optimization where we minimize the pollutant load after BMP placement and also minimize the net cost.



Using this process to analyze nitrate and total phosphorous, we can determine how much it will cost to reduce yield for a certain cost in any watershed and choose where in the watershed those BMPs should be placed under an optimization scenario.

WORK AHEAD

In our studies, we have concluded that agricultural management decisions are more important than cropping system shifts. To encourage best management decisions on a wider regional basis, Purdue University, Oak Ridge National Laboratory, and the University of Arkansas are now moving forward on a cooperative, national facilitation project. Funded by the USDA Cooperative State Research, Education, and Extension Service, this project will extend our work beyond Indiana to evaluate bio-feedstock impacts in the Midwest and Southeast.

We will continue to improve watershed models to adequately represent second generation biofuels feedstocks, evaluate the regional differences, and conduct workshops and outreach to disseminate those models and results. We will also design a Web-based decision support system through which queries and data from specific sites can be fed into the GLEAMS and SWAT models. Existing data will be continuously updated, and the models can be run for different scenarios. The output can be downloaded at the field scale and watershed scale in an easily understood format using figures and tables, allowing the user to evaluate different options and determine the best management decisions to help us meet our bio-feedstocks goals and at the same time minimize negative water quality consequences.

Can Biofuels Be Sustainable in an Unsustainable Agriculture?

by Daniel De La Torre Ugarte

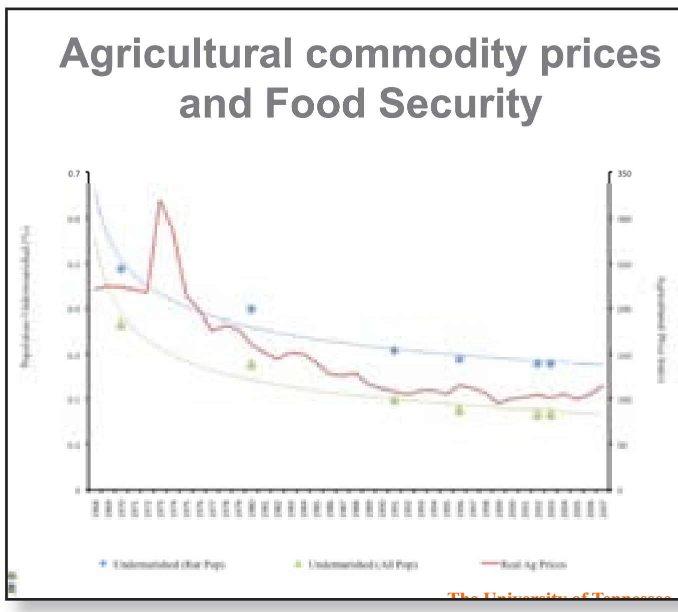
Dr. De La Torre Ugarte *is a Professor and Associate Director with the Agricultural Policy Center, University of Tennessee.*

As the biofuels sector grows in response to increasing energy demand and efforts to generate renewable sources of energy, a great deal of attention has been paid to the unintended consequences of producing biofuels. We need to ask whether these consequences are truly unintended or simply an inevitable and foreseeable result of the agricultural systems and technology upon which the industry is based. It may be more accurate to talk not about unintended, but rather ignored, consequences.

On a global scale, not just in Indiana or Tennessee, in the United States or China, agriculture is a major economic force that is not confined within national boundaries. Today, whatever happens in a particular agricultural market will transfer to other parts of the world.

It is important to look first at the big picture. The livelihood of about 5.5 billion people, more than half of the Earth's population, depends directly or indirectly on agriculture. Of those 5.5 billion people, 2.5 billion live in households directly involved in agricultural activity, and 1.5 billion of those households are small holders. Between 800 and 900 million people suffer from food insecurity every day. They cannot meet the nutritional requirements to perform the normal duties of their life. Worldwide, 80 percent of those people live in rural areas where the main source of livelihood is agriculture. In many developing countries, more than half of employment depends on the agricultural sector, and about a fourth or more of the gross domestic product (GDP) is based on the agricultural sector. Agriculture in most of the developing world is a very important sector in terms of providing employment and generating income. In the 2009 World Development Report, the World Bank indicated that agriculture is twice as efficient in reducing poverty as any other sector of the economy.

Price is a very important component in determining the performance of the agricultural sector, the other element is technology. Looking at the long-term trend in agricultural commodity prices from the early 1960s until today, both the nominal prices and the real prices have lost half of their value, which means that 5.5 billion people who make a living from agriculture have lost half of their income. Only in the last two to three years have prices turned around and shown a positive increase. As agricultural prices declined, food security followed a downward trend in terms of total populations and in the rural areas. However, even in the presence of falling prices, progress in improving food security has stagnated.



As the expansion in the production and use of biofuels took off—especially in Brazil, the United States, and Europe—between 2000 and 2005, world inventories of commodities such as corn, wheat, and rice in most agricultural markets were already declining. This decline in stocks was partially in response to the elimination of government reserve programs in the United States, the European Union, and many developing countries. The belief that the private sector will find the optimal level of carryover was oversold in many countries. So in addition to declining inventories in the agricultural market, demand was increasing and, not surprisingly, prices were higher than expected.

In terms of technology, public investment in agriculture has stagnated or declined in agricultural-based, transition-based, and urban-based countries alike, but the decline has been more pronounced in agricultural-based countries. Countries that are characterized by a transformation of the economy away from an agricultural economy—such as India, China, South Africa—and urbanized countries as well have maintained, but not increased, their level of investment, while the level of investment in agricultural-based countries has stagnated. In short, investments in agriculture may be increasing, but in the wrong places.

ENVIRONMENTAL PERFORMANCE

Data from the Fourth Assessment Report of the International Panel on Climate Change confirms the impression that between 1970 and 2004, after fossil fuels, the second largest source of global anthropogenic greenhouse gas emissions (GHG), roughly one third, comes from agriculture and deforestation. A 2008 study led by Princeton University researcher Timothy Searchinger shocked the biofuels community. Searchinger's message indicated that the environmental performance of biofuels is not as good as people were claiming. Conversion of cropland for biofuels production generates additional emissions of GHGs. However, in the aftermath of those observations, the fact is that for more than 20 years we have been ignoring and living in peace with the fact that 31 percent of greenhouse emissions comes directly from agriculture; even to the point that one of the activities that generates the most GHG received a pass in the Kyoto protocol. The bottom line is that the current agricultural system, with its land use implications, does not perform to the level at which priority environmental targets and objectives should be.

THE RAZOR'S EDGE

This new demand for agricultural resources to produce biofuels has contributed to driving commodity prices higher, and prices have gone from being depressed to walking on a "razor's edge." It is harder to predict if next year's prices for corn are going to be closer to two or five dollars per bushel. Biofuels are becoming the straw that would break the camel's back. While the productivity success experienced in agriculture in the last 100 years cannot be ignored, the types of agricultural systems and technological progress that have resulted heavily depend on the availability of a very cheap source of energy, i.e. fossil fuels.

The current industrial agricultural system is not sustainable, as is it based on a non-renewable source of energy, which contributes to climate change and negatively affects agricultural activities. Biofuels sustainability largely depends on the way feedstocks are produced. The system is reaching its limits; biofuels just accelerated the trend. Today's agricultural, economic, environmental, and social problems are not caused, but rather exacerbated, by biofuels. The question is not how much biofuel we can produce. Instead we must ask under what conditions biofuels can be an opportunity for reducing poverty, mitigating climate change, reaping environmental benefits, solving the energy crisis, and achieving energy independence, not just one, but all of these goals.

Increased agricultural prices, while undesirable for some, may contribute to driving new investment into agriculture. If a sector generates higher profits, that is where the investment will go. If a sector consistently loses money and faces depressed prices, are we going to invest there? No. For the first time in about 35 years we have the opportunity to help the agricultural sector, an opportunity that may be attractive for innovative public and private investment.

At the same time we have to be mindful of the close relationship between agricultural prices and food security. A huge percentage of the population of the world lives directly from agriculture, so if prices increase, food security may also increase. If prices continue to rise, however, everybody, including the rural poor and those living in urban areas, will have to pay too much for food. If that happens, food security may decrease. The challenge is to generate new investment that will increase production and at the same time change the structure of agricultural relationships and of the economic dynamics. Investments directed to improve the share of high prices captured by farmers would improve food security. The right type of investments in the agricultural sector can expand the productivity, production, and quality of life worldwide.

INVESTMENT STRATEGY

What kind of investments will allow us to achieve a higher level of food security with the same level of prices?

A key issue is to increase the farmer's ability to capture a larger share of higher prices. Consider the role of biotechnology in agriculture, which is in the hands of a very few players. Genetically modified seeds are being marketed to farmers at a price that negates any additional profit expected from the increase in efficiency or in yield. If genetically modified cotton seed saves the farmer $20 to $25 an acre, but the cost of that seed is about $20 to $25 more per acre than the previous seed, the one extracting most of the benefit is not the farmer, but the one providing the seed.

To counter that trend, we must invest in farmers' access to markets, improve marketing and distribution systems, and improve the quality of the product. We must also improve access to land, water, and productive resources worldwide. This is the state of mind we need to approach economic growth, biofuels, and food security on the global scale. So far, the only element dominating agricultural development worldwide has been free trade, and free trade is not a guarantee for any of these objectives. We need to invest in research and extension to improve the profitability of local markets and take advantage of the local resources. At the same time, because we know we are facing higher prices, we should implement programs to ensure access to food for vulnerable populations.

There is a tradeoff between agricultural prices and environmental costs. Under current agricultural practices and food consumption patterns, an increase in agricultural prices could accelerate environmental costs. When prices of agricultural commodities increase, more land is converted to agricultural uses. As the price of soybeans rises, there is pressure to expand soybeans acreage in Brazil that could result in increasing the rate of deforestation. If the price of bio-oil increases, tropical forests in South East Asia could be converted to oil producing tree plantations. If the price of corn increases, we may just forget the biological complement between corn and soybean rotations and plant as much continuous corn as possible, no matter if we pay later through loss of soil carbon and crop productivity.

TIME FOR A CHANGE

To reduce the environmental costs of agriculture, we must invest in technologies that are less intensive in fossil inputs and more in tune with local soil and food habits. We cannot continue in the current path, using crop systems and technologies that contribute to generating one third of all GHG emissions to the atmosphere. Instead, we need to rethink how we invest in the agricultural sector. We need a major change in the production structure and technological base of agriculture.

Some of the solutions may seem obvious, but others are seldom put on the table. We could reduce the environmental costs of food production by:

- drastically changing the composition of our diet to more efficient sources of protein and food of local origin,
- investing in research and extension aimed at reducing the use of fossil-based inputs, improving management practices that increase the environmental performance of production agriculture, and ensuring the best use of soils and the landscape,
- balancing crop and livestock activities to grow more food on less land, and
- integrating GHG emissions and other environmental impacts into the farmers' balance sheet.

The main reason we have high yields the United States, Europe, and Brazil is that we have been extremely efficient in taking advantage of very cheap resources: oil and natural gas. Sometime soon those resources may not be so cheap. We cannot base the next evolution in agriculture-based economies on an input that will be increasingly expensive and scarce.

Institutional investment in the agricultural sector should be directed at efforts to 1) strengthen land property rights and enforcing mechanisms to protect small holders; 2) support a transformation of agriculture into local, domestic enterprises; 3) encourage development of an international food system; and 4) foster global coordination of biofuels development.

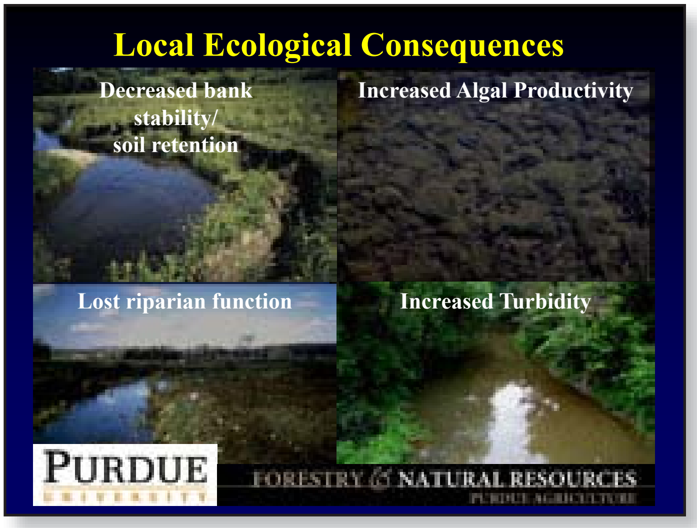
We must begin to understand that agricultural products are not like other commodities. When we want to move textiles or cars, we can simply move a factory from Detroit to Mexico City. We have not learned yet to move the soil from Indiana to the African Sahara. If we continue with the prevailing mentality, we will have missed an opportunity for poverty reduction, increased agricultural productivity and food security, and mitigation of climate change.

Aquatic Ecosystem Responses to Land Use Changes Associated with Biofuel Crop Production

by Reuben R. Goforth

Dr. Goforth *is an Assistant Professor in the Department of Forestry and Natural Resources, Purdue University.*

W*ater, water everywhere* ... There is a lot of water on Earth, and even some pristine or semi-pristine aquatic ecosystems remain. However, there are serious challenges to be met to guarantee continued availability of water suitable for use by a large and growing global human population. In the United States, we tend to take for granted that fresh water is nearly universally available—just turn on the nearest tap and you have potable water. This is not true in much of the world. Even in the United States, however, we need to take a closer look at a resource we cannot live without.



In the present era we now call the Anthropocene, human activities have resulted in highly fragmented landscapes. We generally do not consider the kinds of impacts we are having on these extremely modified landscapes. We just jump in and develop, making drastic changes in our land use without considering the consequences down the line, until suddenly, we think, "This is not right, we have lost something here."

What have we lost, and what are the historical abuses that we see, particularly in our agricultural systems? Stream changes related to agricultural land uses include increased sediment and nutrient inputs. In addition, the hydrology, light regime, and water temperatures change. These effects combined, which are not visually pronounced at first, lead to more obvious consequences such as decreased bank stability and lowered soil retention, increased algal productivity, loss of riparian function, and increased turbidity. In addition, loss of the canopy leads to more radiant energy, and stream water temperatures rise.

These changes cause significant shifts in local biological communities. While these ecosystems are generally resilient and can take a fair amount of modification before things spiral out of control, changes are generally predictable given chronic environmental changes, as fish and other organisms that are fluvial specialists or flowing water specialists are displaced by those more tolerant of degraded environmental conditions.

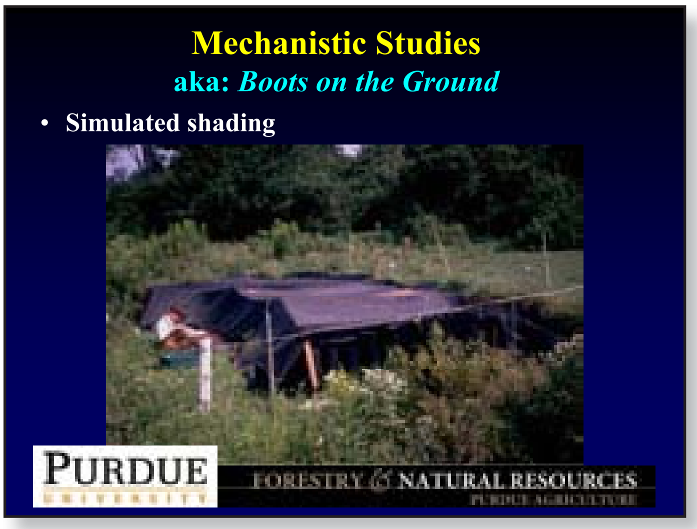
STREAM OF DREAMS

Changes in ecological properties can be stark, but there is still a good bit of resilience under moderate levels of disturbance. This resilience gives us some hope for making these aquatic systems functional again. It is the concept that, "if we build it they will come." That is, if we make certain changes to allow these systems to recover, a community representative of what we would expect in a natural landscape will return. For example, if we exclude cattle from watering in a stream, within one year we can expect to see some recovery along the bank because that chronic stressor has been removed.

There is obviously some value to such improvements, but these actions do not completely address the problem of what is going on in the stream. The apparent recovery of a stream, taken out of context or over a very small area, does not reflect the bigger picture. If you do nothing upstream, the stream will remain highly impaired regardless of the recovery along the riparian area. We have to think about these things at the right scale, not just at the level of small, isolated "islands in the stream," recovered areas that may still be subject to stresses at the landscape scale.

It helps to consider aquatic ecosystems and their parent landscapes from a mechanistic standpoint, and such considerations have been greatly facilitated by modeling efforts.

As a "boots on the ground" kind of person myself, I support and fully recognize the importance of modeling to address environmental problems. However, it is also important to step back once in a while, or actually step in and get one's feet wet, as a reality check to make sure that what the models suggest is a realistic representation. I have, for example, created artificial shading in streams to see if I can elicit responses to simulated stream canopy restoration in pasture streams. I have also used a "natural" field experimental design based on existing conditions in the watershed to evaluate how biological communities vary in streams flowing through varied land use intensities. The results suggest that it is possible to realize some level of response by aquatic biological communities to environmental improvements, and modeling can help to project such responses over large areas to enhance planning and management activities to improve water resilience.



There are streams that were once provided with some level of recovery through the National Conservation Reserve Program (NCRP). Land use history can track what happens to streams that were managed for crop land or pasture and then left alone for quite some time. Streams have an amazing ability to remediate themselves when chronic stressors are removed. Such removal of chronic stressors alone may be sufficient to effect improvements in stream ecosystem resilience. Now, however, the gains of the past are coming undone in response to increased biofuels production due to reuse of once protected NCRP lands for crop production.

Mitigation efforts can moderate effects and make streams more resilient, but restoration and recovery efforts must be carefully coordinated and holistic to be truly effective in agricultural landscapes. Because of the unidirectional flow, from upstream to downstream, and because of flow dynamics during floods, streams are fairly efficient at ridding themselves of excess nutrients and sediments. Keep in mind, however, that biofuel cropping may reverse previous gains. If NCRP lands wind up being turned back over to production, we will see an increased use of so-called marginal lands. If we do not plan for these contingencies, such as providing a buffer between the activities on those lands and the streams themselves, we will run into more problems. In addition, we can expect more intense effects from alteration of crop rotations and loss of crop residues.

FOCUS ON FISH

To avoid falling into the same sort of traps we have in the past, we must seize every opportunity to develop biofuel crops in a sustainable manner. Climate and societal factors also must be considered along with ecosystem factors.

The direction my colleagues and I at Purdue University and Michigan State University are now taking is evolving. We are developing a conceptual model we hope will be helpful in planning so that we make smart decisions and help other people make smart decisions. We have devised a model of aquatic ecosystem resilience for sustainable biofuels development, but the model still needs to be grounded in reality.

Part of my work is focused on whether, for certain stream fish species, there are critical thresholds we can avoid reaching as the land is developed. Consider the case of a little fish called the mottled sculpin (*Cottus bairdii*). This fish is typically found in clear running water, and it tends to disappear if the water gets too cloudy, with too much fine sediment. I have started exposing these fish to different levels of suspended sediment in customized respirometers, using oxygen consumption as a proxy for stress, to determine whether there are thresholds that we can recognize, in this case the amount of suspended sediment that is introduced to the system that may affect the fish. There is, in fact, a threshold, between 1 and 1.75 grams per liter of sediment added to the respirometer, at which these fish appear to become detectably affected by the sediment. Interestingly, the fishes' oxygen consumption rates tend to decrease at even higher sediment levels, perhaps because they begin to decrease their metabolism to avoid the ill effects of sediment on their gills. While this would be an advantageous strategy over the short term, chronic exposure to high sediment levels would likely cause the fish to suffer long-term effects. In the future, I would like to collaborate with other researchers to apply these kinds of data in larger-scale models and try to recognize where the trouble spots in landscapes might be so we can come up with the ideal development plans for those landscapes. In short, I would use mechanistic experiments, whether it is a microcosm or perhaps an *in situ* mesocosm approach to look at different aspects of these systems and integrate those results into larger scale models.

Another approach is applied monitoring, where we take existing conditions in the landscape and look at certain responses, such as finding out how long it takes for systems to respond and what strategy is best for eliciting a response in these systems. The US Environmental Protection Agency is very interested in knowing how to determine whether or not certain actions actually have an effect. This information can then be incorporated into the modeling system. If we use this approach in sustainable biofuels crop development, at least from an aquatic standpoint, we can make some improvements.

Public buy-in and participation are crucial components in this approach. People have to get excited about it. People need to see fish. People are often shocked and amazed at the diversity of freshwater fish found even in agricultural ditches. A fair number of fish still hang on in these systems, and I am constantly surprised at how excited people get when I pull one of these fish out, young people especially. Often these fish rival in coloration or morphology those that are available in pet stores for tropical aquariums.

Young people represent a great starting point in terms of getting folks excited about making changes that will allow us to effectively address the grand challenge of maintaining adequate freshwater availability to meet current and future human needs. At the risk of being overly pessimistic, I worry that the only way we are going to effect change is to have a crisis that will make people think and act differently. I would like to be proven wrong on that point, but I fear that it will take a significant water crisis to change peoples' attitudes to the extent needed for meeting the grand challenge of sustainable fresh water.

As I was preparing for this workshop and tailoring my talk based on what I have learned from attending the sessions, I was listening to music. There was a certain synchronicity of events as the song "Listen to the Water" by Doug Cox, a roots singer and songwriter, played while I was writing. I heard a refrain that spoke to me and, in many ways, explains my passion for research and efforts to wake people up to the importance of change: "One of these days, it won't be long, you look to the water and the water be gone."

FROM BIOMASS TO THE GAS TANK

Thanks to efforts by the US Department of Energy (DOE) to encourage daring research, C3Bio is laying the foundation for third generation biofuels, converting biomass to hydrocarbons, says Mahdi Abu-Omar with Purdue University. C3Bio (the Center for direct Catalytic Conversion of Biomass to Biofuels) is part of a network of centers promoting high-risk, high-reward research to meet the nation's energy challenge.

Research at the Key Laboratory for Biomass Clean Energy of Anhui Province is focused on fast pyrolysis to convert biomass into crude bio-oil. Yao Fu says that upgrading bio-oil, and converting non-edible biomass to energy, will improve the efficiency of energy production and lessen the environmental impact of our increasing demand for clean energy.

Certain species of algae are considered among the more promising sources of biomass, with very high yield compared to other agro-products. Chang-Wei Hu with Sichuan University, says we need to further explore the not-so-humble algae's power to harness the energy of the sun and satisfy our demand for a truly renewable source of energy.

Converting cellulosic biomass to sugars is the dominant obstacle to cost-effective production of biofuels. Martin Keller, director of the BioEnergy Science Center (BESC) at Oak Ridge National Laboratory (ORNL), says that BESC is engaged in an unprecedented interdisciplinary effort focused on overcoming the recalcitrance of biomass. With the power of the neutron science and supercomputing facilities at ORNL, BESC and its partners are exploring new technologies to make the conversion of biomass into biofuels economically feasible and environmentally sustainable.

Due to the large number of polluted lakes in China, a large area has been planted with tons of aquatic plants, triggering a crisis in terms of disposal. Researchers at the University of Science and Technology of China (USTC) are finding ways to turn this crisis into an opportunity. In fact, these plants are a renewable resource that can be harvested as biomass. The research team has developed a microbial fuel cell using rumen microorganisms from the goat's digestive system to produce electricity from the plants' lignocellulosic material.

In some cities in China, people know when the harvest season has arrived because smoke from burning straw adds to the urban air pollution. USTC's Ying Zhang says that by utilizing such sources of biomass, we can help the environment while increasing income for farmers. By using selective pyrolysis targeting high quality compounds and screening for new catalysts, it is possible to produce high quality fuel and chemicals.

Fu Zhao with Purdue University says that successful biomass conversion technologies will ultimately be those that are sufficiently adaptable to a myriad of environmental, geographic, and economic conditions. Thermo-chemical conversion that utilizes a wide range of biomass residues can bring flexibility to the feedstock and production sides of a plant.

Center for Catalytic Conversion of Biomass to Biofuels

by Mahdi Abu-Omar

Dr. Abu-Omar *is a Professor in the Department of Chemistry and Associate Director of the Center for direct Catalytic Conversion of Biomass to Biofuels at Purdue University.*

The Center for direct Catalytic Conversion of Biomass to Biofuels (C3Bio) comprises a partnership between Purdue University, the National Renewable Energy Laboratory (NREL), UT, and Argonne National Laboratory (ANL). C3Bio is part of a network of research centers, the Energy Frontier Research Centers (EFRC), supported by the US Department of Energy (DOE). In creating this network, DOE decided to do something different from business as usual: fund high-risk, high-reward research at the fundamental level to meet the nation's energy challenge. The mission of EFRC is to enhance US energy security and protect the global environment in the century ahead, harnessing the most basic and advanced discovery research, and to establish the scientific foundation for a new US energy economy. A better understanding of the fundamental science will allow breakthroughs that can be channeled into practical applications. For now, our research is targeted at making fundamental discoveries in the energy field and understanding their economic impact.

Biofuels are considered one of the "Holy Grails" in engineering. In the United States, however, renewable energy is a very small part of the overall energy portfolio, and liquid biofuels for the transportation sector an even smaller piece. *Biofuel* is perhaps a misnomer, because most people equate the term with ethanol. EFRC (C3Bio) is laying the foundation for third generation biofuels, converting biomass to hydrocarbons rather than converting cellulose to ethanol. Just as we have seen happening with breakthroughs in genetics and computing, third generation biofuel technology is going to change the playing field. To that end, we are encouraged to be bold and imaginative and to have an impact. This can only be achieved through basic science. As a chemist, I consider gasifying biomass and using lignin for heat generation a waste when nature has put so much effort into creating carbon-carbon bonds. Lignin is rich in carbon-carbon bonds, and to burn it for heat is a blasphemy.

ENERGY FRONTIER

The grand scientific challenge in creating a new energy frontier is to create a culture of creativity within which to conceive of advanced biofuels with maximized carbon and energy efficiencies. I am extending the definition of biofuels here with the caveat that our goal is fundamental science for third generation fuels, making hydrocarbons rather than ethanol or derivatives of alcohol. To that end, EFRC is dedicated to educating new bioenergy scientists, fostering interdisciplinary team work, creating synergistic links to DOE bioenergy research centers, and taking advantage of the unique resources of DOE's National Laboratories.

We need to increase dramatically the carbon energy efficiencies of biofuels production and the carbon atom economy. Researchers at C3Bio have estimated the agronomic footprint of biofuel feedstocks in the United States, the amount of land required to displace 30 percent of gasoline by 2030 with ethanol made from corn. It would take about 1.25 million square miles of agricultural land to meet that goal. Switching from corn-based ethanol to cellulosic biomass is a huge improvement, but it would still require 187,000 square miles of land. It is a very significant accomplishment to change from using the starch in the corn kernel to using cellulosic biomass. However, if we were to replace 30 percent of gasoline with hydrocarbon fuel made from biomass, we could reduce the agricultural footprint to only 62,500 square miles.

One main thrust at C3Bio is the catalytic conversion process. We are building the knowledge base of biomass-catalyst interactions for optimized catalytic pathways and biomass tailored for its end use. The catalytic conversion process does not use enzymes but chemical catalysts instead. To do that successfully is a very difficult problem that requires team work. We rely for our analysis on researchers in biology to perform nanoscale imaging of biomass-catalyst interactions. In addition, we are working on understanding the remarkable properties of the cell wall and ways to control these properties. Most importantly, we want to integrate research across the fields of chemistry, catalysis science, chemical engineering, and plant biology to arrive at novel ways to engineer plants to be amenable to the catalytic processes we are developing.

The agronomic footprint of biofuel feedstocks to displace 30% gasoline by 2030 with ethanol

The primary cell wall at the nanometer scale is composed of intertwining cellulose polymer, which accounts for 60-70 percent of the biomass. The secondary cell wall, however, contains a thicker additional layer of lignified cellulose that increases wall rigidity. The overall lignin content of biomass is approximately 20-25 percent. The cellulosic material is composed of sugars, the carbon building blocks from which liquid fuels can be made. The challenge is how to get to the cellulose and thus the sugars.

Why is it so hard to extract the cellulose? Because the lignin polymer is robust and very difficult to break up (lignin recalcitrance). On the bright side, nature uses light to convert carbon dioxide into biomass including lignin, which is composed of aromatic compounds. However, biomass contains too many oxygens, and lignin is very difficult to break up. That is really the key issue, nature has built a polymer full of rich, beautiful aromatics, but we have to unzip or break apart that polymeric structure and remove the oxygens to end up with a hydrocarbon liquid fuel that is competitive with what we have from fossil sources today.

NOTHING VENTURED, NOTHING GAINED

High-risk research does not always result in practical applications in the immediate future, but it does shed light on basic processes and expand the pathways of research that will result in revolutionary new concepts.

Five different monomers make up lignin. My biology colleagues have identified many of the biochemical pathways for making those monomers. A chemist would take the functional group in the lignin and attack it with a catalyst. A plant biologist would suggest making a lignin that is rich in one type of monomer, for example, sinapyl alcohol . Thus sinapyl-rich lignin contains aldehyde functional groups that can be exploited by the chemists for selective functionalization and catalysis. It is exciting to work on merging chemistry and plant biology to produce selective aromatics from biorenewable lignin.

Initial products we may expect from this line of research may be liquid fuels. Joseph Bozell and Alison Buchan from UT are working on dihydroxylation, which would allow us to break lignin down further to get rid of the aromatics and get directly at hydrocarbons. Of course, that may not be the most desirable option because aromatics are good fuels, but once we get to this point we can start to envision using catalysis to produce high octane gasoline from lignin directly.

Some of the ideas being generated by these partnerships are considered quite daring and risky. One such notion is to tailor biomass by introducing catalytic sites into plants as they grow by controlling the biochemical pathways, in essence incorporating catalysts as part of the lignin. When we put this idea into our grant proposal, one of the reviewers actually said the idea is so wacky we have to try it. These are the kinds of high-risk research projects that the C3Bio groups are engaging in thanks to DOE's efforts to encourage third generation fuels.

In evaluating current and future biotechnologies, we have compared various biofuel technologies according to carbon efficiency, process energy efficiency, and estimated liquid fuel yield. At the low end are biomass gasification and cellulosic ethanol, with carbon and process energy efficiencies between 35 to 40 percent and fuel yields from 75 to 120 ethanol gallon equivalent per ton of biomass (ege/ton). At the high end are two new technologies that are in the research pipeline: biomass fast-pyrolysis and H2Bioil, with estimated carbon efficiencies around 70 percent and process energy efficiencies between 77 and 82 percent, and much higher liquid fuel yields from 163 and 230 ege/ton.

Our main thrusts at C3Bio are to model the compounds, cell walls, and genetic variants of biomass; tailor biomass through catalytic transformations; and perfect advanced analytical and imaging technologies. With the ultimate goal of creating advanced biofuels with optimized carbon and energy efficiencies, and interfacing in a meaningful collaborative way with plant biologists, chemists, engineering, and analytical scientists, we are working at the fundamental level of research to promote new knowledge of catalysis science, genetics, and plant biology. We are not yet at the point of moving from basic science to end applications, but we are creating a knowledge base from which we hope the third generation of biofuels may emerge.

Catalytic Conversion of Bio-oil and Biomass to Fuels and Chemicals

by Yao Fu

Dr. Fu *is an Associate Professor of Biochemical Engineering at the University of Science and Technology of China.*

With diminishing fossil fuel reserves, great efforts are now being made worldwide to convert renewable biomass into fuels and value-added chemicals. The Key Laboratory for Biomass Clean Energy of Anhui Province focuses on fast-pyrolysis technology, converting biomass into crude bio-oil, and on identifying, separating, and refining other components of organic compounds.

Two important aspects of our work are catalytic upgrading of bio-oil and catalytic conversion of non-edible biomass. Catalytic upgrading involves bio-oil separation, esterification, and ketonic deoxygenation. Catalytic conversion of non-edible biomass requires converting cellulose to levulinic acid (LA) and valerolactone, and the synthesis of hydroxymethylfurfural ethers (HMF) from glycerol.

Catalytic upgrading. Until now, fast pyrolysis technology has been an effective and commercially available method for converting biomass to liquid fuel. The resulting product, pyrolysis oil, or bio-oil, has great potential as a substitute for fossil resources. The advantages of this technology are its high capacity, 1.0 tons per hour; it is auto-thermal, meaning it is energy independent; and it is environmentally friendly, producing less nitrogen and sulfur than fossil resources. The disadvantages are that it has a low pH value, a high oxygen content, and poor thermal stability.

Biomass conversion. We all know the basic pathway of biomass conversion. Through photosynthesis, solar energy converts carbon dioxide (CO_2) and water into biomass, both edible and inedible. Since we don't want to use food biomass for energy production, we prefer to use inedible raw materials such as agricultural and wood waste for fuels and chemical production. The components of these raw materials are cellulose, hemicellulose, and lignin from which, using fast pyrolysis, we can create bio-oil that can be burned in a boiler to produce heat or electricity.

We can also convert biomass into useful chemical forms using acid hydrolysis to create HMFs, LA and formic acids, valerolactone, and furfural. In addition, we can create useful compounds directly from bio-oil by separating it into lignin and distillate. Using pyrolysis, esterification, and ketonic condensation we can produce aromatics, esters, and ketones.

Another focus of our research is the distillation of bio-oil in the presence of glycerol to produce aromatic compounds. To separate bio-oil by distillation we used a byproduct of biodiesel as a solvent. We mix the glycerol and the bio-oil together and heat it to 225 °C, producing a liquid distillate containing mostly water and acid, with some aromatics and foreign compounds. A separate mixture of lignin and glycerol produces pyrolytic lignin, a black solid liquid from which we can produce more aromatic compounds. The glycerol can be recovered during this process at a high rate, 86 percent. This process shows promise in accomplishing the separation of bio-oil, so we built a lab-scale apparatus for bio-oil distillation. This equipment can produce about 200 kilograms of bio-oil per hour.

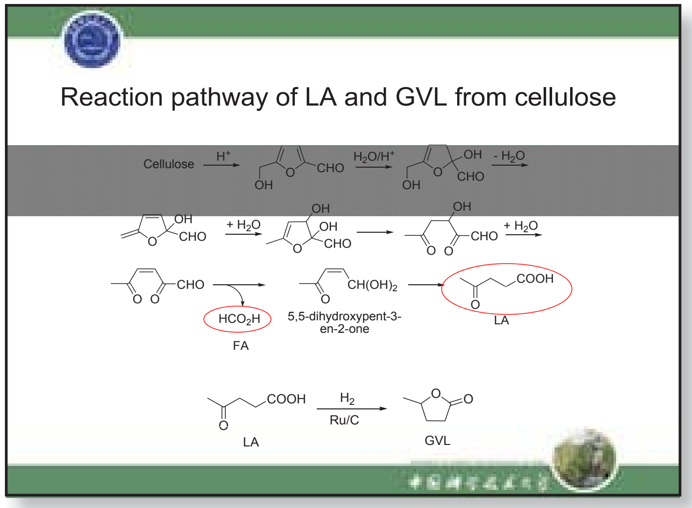
Further work on refining bio-oil involves esterification of organic acid using acidic ionic liquid catalysts. In this catalysis, bio-oil reacts with ethanol to produce ester mixtures at very high rates of conversion and conversion selectivity, about 95 percent. In addition, we are in the experimental stages of upgrading the acidic components of bio-oil through catalytic ketonic condensation, whereby a carboxylic acid-rich phase of bio-oil is converted to a ketone-rich product.

TRANSFORMATION OF CELLULOSE

In addition to our work on refining bio-oil and bio-catalytic conversion, we are working to transform cellulose to useful compounds. Recently, Horvath et al. demonstrated that the biomass-derived compound G-valerolactone (GVL) may be used as a liquid fuel, food additive, solvent, and organic intermediate in the synthesis of fine chemicals. Both LA and GVL are important and versatile chemical building blocks .

We are also exploring a new route to convert various biomass-derived oxygenates such as cellulose, starch, and sugars to GVL without using an external hydrogen supply. We found that LA can be selectively reduced to GVL without producing undesirable byproducts. Moreover, this hydrogenation process can be accomplished using only the formic acid produced from the original acidic dehydration step. This new conversion route not only improves the economy of the process, it also avoids the energy-costly step to separate LA from the aqueous solution mixture of LA and formic acid.

We also found interesting phenomena related to the effects of CO_2 on LA hydrogenation. We think the CO_2 has a solvent effect because, as we add CO_2, the yield increases steadily. Our concern is with the water content. If water content is raised to 75 percent, yield is significantly decreased. Lignin is not soluble in water, so perhaps CO_2 may be used as a solution factor in this reaction. We are trying to improve on this study by using catalyst immobilization to increase yield by creating heterogeneous catalysts. The results are promising, but we still cannot transfer the biomass directly and get a very good yield of GVL.



HMF: A VERSATILE INTERMEDIATE

Hydroxymethylfurfural ethers (HMFs) are a versatile intermediate between biomass-based carbohydrate chemistry and petroleum-based industrial organic chemistry. HMFs can be used to create many useful chemicals. HMF has been produced from fructose to produce soluble polymers and insoluble humins. Fructose, however, is refined from sucrose and is an edible form of biomass. HMFs can also be produced from glucose. The disadvantage to that is the high cost of ionic liquid used as a solvent in the process, and that glucose is also edible. Recently we have been working on synthesizing HMFs from cellulosic material, untreated corn stover. This could represent a breakthrough in the effort to synthesis HMF from non-edible biomass. HMF could be used to deal with byproducts of the production of biodiesel.

Though our work is unfinished, the Key Laboratory for Biomass Clean Energy has found a good, renewable solvent for bio-separation, and the method has the potential to be developed into a commercial process. We have synthesized dicationic ionic liquid that is used as the catalyst for bio-oil upgrading through the esterification reaction. After upgrading the acid-rich phase of bio-oil via ketonic condensation by weak based catalysts, most acetic acid can be transformed to acetone in model reactions.

In addition, we have set up a new route to convert various biomass-derived oxygenates—cellulose, starch, and sugars—into GVL without using any external hydrogen supply, and we have found a new platform compound, 4-HMF, which can be synthesized from bio-derived glycerol.

Some of our research efforts are already being adopted by industry, such as the apparatus for the distillation of bio-oil, which has been used as a supplemental power source in coal-fired power plants. Others remain in the experimental or exploratory stages. Upgrading bio-oil, and converting non-edible biomass, will improve the efficiency of energy production and lessen the environmental impact of using biomass to satisfy our increasing demand for clean energy.

The Catalytic Conversion and Upgrading of Algae-based Biomass Components

by Chang-Wei Hu

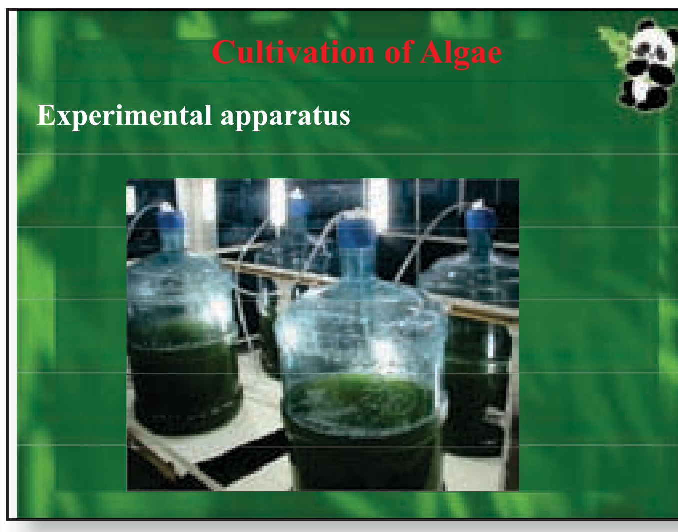
Dr. Hu *is Dean and Professor at the College of Chemistry and Director of the Key Laboratory of Green Chemistry and Technology, Sichuan University.*

The concentration of carbon dioxide (CO_2) in the atmosphere is rising due to our consumption of fossil fuel resources. The greatest challenge we face is how to stabilize the concentration of CO_2 in the atmosphere. One approach is to recycle CO_2 during the production of energy and chemical co-products. Biomass—including agricultural wastes, forest wastes, fast growing plants, and algae—is the only available resource that contains hydrocarbons and is also capable of recycling CO_2.

Certain species of algae are considered among the more promising sources of biomass. In the presence of sunlight, algae converts CO_2, water, and minerals into lipids, sugars, proteins, carbohydrates, and other substances. It is a kind of micro-bioreactor driven by light. All kinds of algae occur all over the world and in many different climates. It grows very fast and has a high output. There are more than 100,000 species of algae on the Earth, and more than 40 percent of total fixed carbon is attributed to algae.

Compared to other agro-products such as corn, soybeans, and Jatropha, the oil productivity of algae is very high. For example, the oil content of corn is 7 percent by weight, while that of micro-algae is 20 to 50 percent. Algae can also be cultivated on a very small amount of crop area compared to other sources of oil. Certain micro-algae have higher oil content than others and are therefore good candidate species as an energy resource. One of these is *Nannochloropsis oculata*.

The utilization of algae for the production of fuel is attracting a great deal of attention. The basic strategy is to extract lipids from the algae and convert the lipids to biodiesel using liquid or solid catalysts. Some of the extracted residues are considered waste, but others can be used as animal feed or converted through fermentation to ethanol.



In the Key Laboratory of Green Chemistry and Technology, we have taken this conversion process to another level. In addition to converting lipids to biofuel, we use catalytic decarboxylation to produce both fuel and high quality chemicals. We subject the extracted residue to catalytic pyrolysis to obtain bio-oil instead of ethanol. We are also exploring intensifying the process, combining extraction and esterification to obtain biodiesel from algae directly, in one step.

CULTIVATION OF ALGAE

In our lab, we are concentrating on the cultivation of one promising type of algae, *N. oculata*, which grows very fast, doubling its biomass in 24 hours. Its oil content is very high, about 30 to 50 percent of its weight, and it utilizes high levels of CO_2.

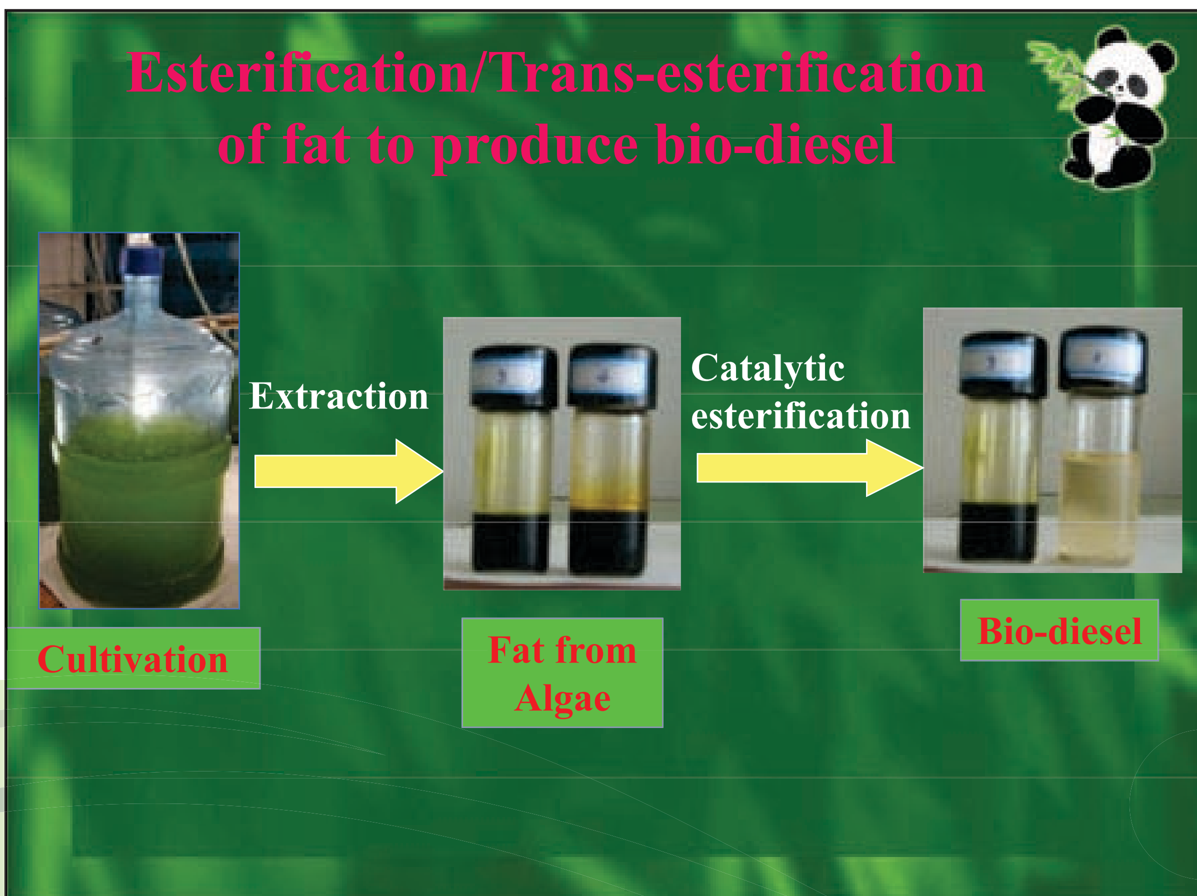
Algae need both air and CO_2 to grow. To optimize growing conditions, we tested the rate of airflow and the concentration of CO_2 that produce the fastest growth rates. The higher the airflow, the faster it grows. The growth rate is also much higher at a concentration of about 1 percent CO_2 than without CO_2. We rotate the exposure of the algae to light, turning the laboratory lights off at night and on during the day.

N. oculata is cultivated under the following conditions. The volume of the culture is 10 liters in each reactor. The airflow rate is controlled at 500 milliliters per minute, temperature at 22°C, and light intensity about 3500 lux (lx) by day and 14 to 10 lx at night. We found that algae grow fastest at a concentration of 0.5 to 1 percent CO_2. The main components of micro-algae powder include about 46 percent lipid, 21 percent carbohydrate, 4 percent moisture, 26 percent ash, and 12 percent other components. After subjecting the powder to centrifugal drying, vacuum drying, extraction, and purification, we achieved an oil yield of about 30 percent.

Fat is extracted from the cultivated algae and undergoes catalytic esterification and transesterification to produce biodiesel. Using a variety of solid acid catalysts and catalytic techniques, we were able to optimize the reaction and significantly increase the yield of biodiesel, or methyl esters. Esterification and transesterification to produce biodiesel oil is now common, but there are some disadvantages; for example, methanol, which is usually obtained from fossil fuels, is required in the process. In addition, the oil produced is not the highest quality.

ONE-STEP PRODUCTION

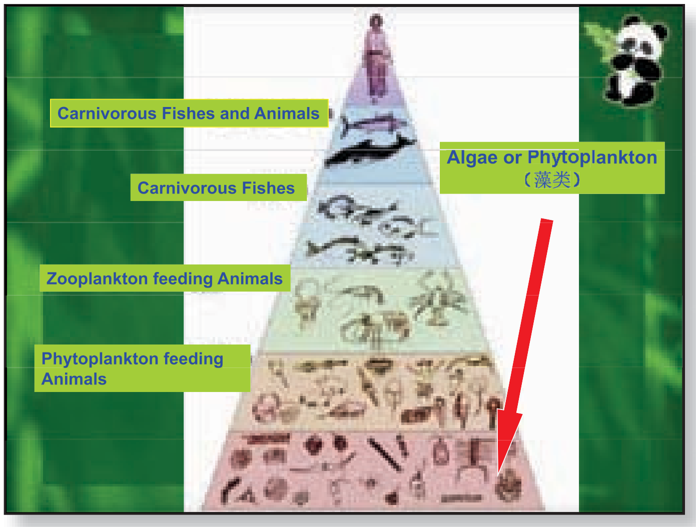
The traditional process for producing bio-diesel is a two-step method in which the micro-algae lipid is first extracted using methanol and dichloromethane. The excess solvent is then evaporated and the remaining lipid undergoes a catalytic reaction to produce biodiesel. A higher yield of methyl ester can be obtained from a one-step catalytic preparation directly from micro-algae powder using catalytic esterification.
The one-step process basically combines the extraction and



esterification or transesterification reaction together. In our experiments, we optimized the reaction conditions to find the maximum value, the highest yield of methyl ester under different reaction conditions depending on the composition of the catalyst. Not only do different catalysts result in different yields, the yield is also time sensitive.

We have also explored the direct pyrolysis of *Nannochloropsis* sp. The temperature required to achieve pyrolysis of algae is much lower than for the lignocellulose biomass, but the product obtained is limited to a few alkenes, hydrocarbons, and aromatic compounds. Nevertheless, with algae cultivated under optimized conditions and using catalytic pyrolysis of the residual, we could eventually obtain high quality oil or chemicals.

We have shown in our lab that algae can effectively fix CO_2 if we optimize the conditions of algae cultivation. The optimized catalyst is about 90 percent effective at converting algae to oil. Compared to lignocellulosic biomass, algae may potentially achieve a 30 percent, high-quality fat directly by simple extraction. The pyrolysis of extracted residue provides another 20 percent of high-quality bio-oil. In all, 50 percent of algae can be converted to oil, the composition of which is close to that of fossil-fuel derived oil. In addition, we have shown that the intensified one-step process is more efficient than the two-step process.



Algae are relatively simple organisms, the lowest on the food chain. They are, nevertheless, powerful bioreactors capable of photosynthesis. Considering the abundance of algae on the Earth, the relative ease with which it can be cultivated, and the need to stabilize CO_2 emissions while reducing the amount of land devoted to the production of biomass, we need to further explore the not-so-humble algae's power to harness the energy of the sun and satisfy our demand for a truly renewable source of energy.

The U.S. Department of Energy's BioEnergy Science Center

by Martin Keller

Dr. Keller *is Associate Laboratory Director for Biological and Environmental Sciences and Director of the BioEnergy Science Center, Oak Ridge National Laboratory.*

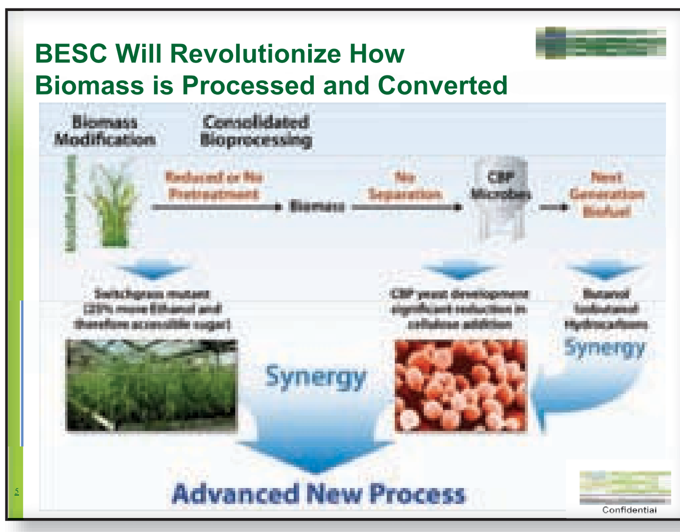
The challenge of converting cellulosic biomass to sugars is the dominant obstacle to cost-effective production of biofuels. The BioEnergy Science Center (BESC), funded by the US Department of Energy (DOE), is addressing this challenge with an unprecedented interdisciplinary effort focused on overcoming the recalcitrance of biomass. In addition to Oak Ridge National Laboratory (ORNL), the team consists of Dartmouth College, the University of Georgia, the Georgia Institute of Technology, the University of Tennessee, the National Renewable Energy Laboratory, the Samuel Roberts Noble Foundation, and four industrial partners, totaling more than 300 individual people from various institutes. By combining engineered plant cell walls to reduce recalcitrance with new biocatalysts to improve deconstruction, BESC is revolutionizing the processing of biomass.

CRITICAL BARRIER

One of the main barriers preventing us from having a sustainable bioenergy industry and an economically feasible source of biofuels is gaining access to the sugars in lignocellulosic biomass. We have many ways to meet that challenge, including fermentation to produce ethanol and butanol, consolidated bioprocessing (CBP) to produce alcohols, and chemical catalysis and synthetic biology to produce hydrocarbons.

BESC has three high-level goals: 1) modifying plants so they are more easily digested and testing them in field trials; 2) developing new or improved microbes for CBP, and 3) improving analysis and screening technologies to overcome recalcitrance. We are confident that the BESC team can revolutionize how biomass is processed within five years and deliver a much simplified process with greater overall yields. We will achieve this goal by modifying plant cell walls to decrease recalcitrance, thereby reducing the severity of pretreatment and perhaps eliminating it altogether. At the same time, we are developing advanced conversion systems featuring consolidated bio-processing. Our work in both of these areas is made possible by applying state-of-the-art analytical tools to understand the scientific basis of recalcitrance.

BESC takes a two-pronged approach to increase the accessibility of biomass sugars. First, we are working on modifying the cell wall of plants such as switchgrass and poplar to increase accessibility. Then we look at ways to improve combined microbial approaches that release sugars and ferment them into fuels. Both approaches utilize rapid screening for relevant traits followed by detailed analysis of selected samples. Our original goal was to accomplish these breakthroughs within five years, but we have been able to move even faster than we anticipated within the center.



Current methods of converting biomass into fuels require several steps. Biomass is pretreated, and the solids and liquids are separated through an enzymatic digestion process to produce cellulose and pentose sugars. The pentose sugars are then fermented to produce biofuel, and the cellulose is further converted through enzyme hydrolysis and hexose fermentation to produce biofuel. The first step, pretreatment, is a major cost factor. By genetically modifying the plants that provide the biomass, and combining the digestion and fermentation process into one step, we will eliminate major production costs.

SWITCHGRASS AND POPLAR

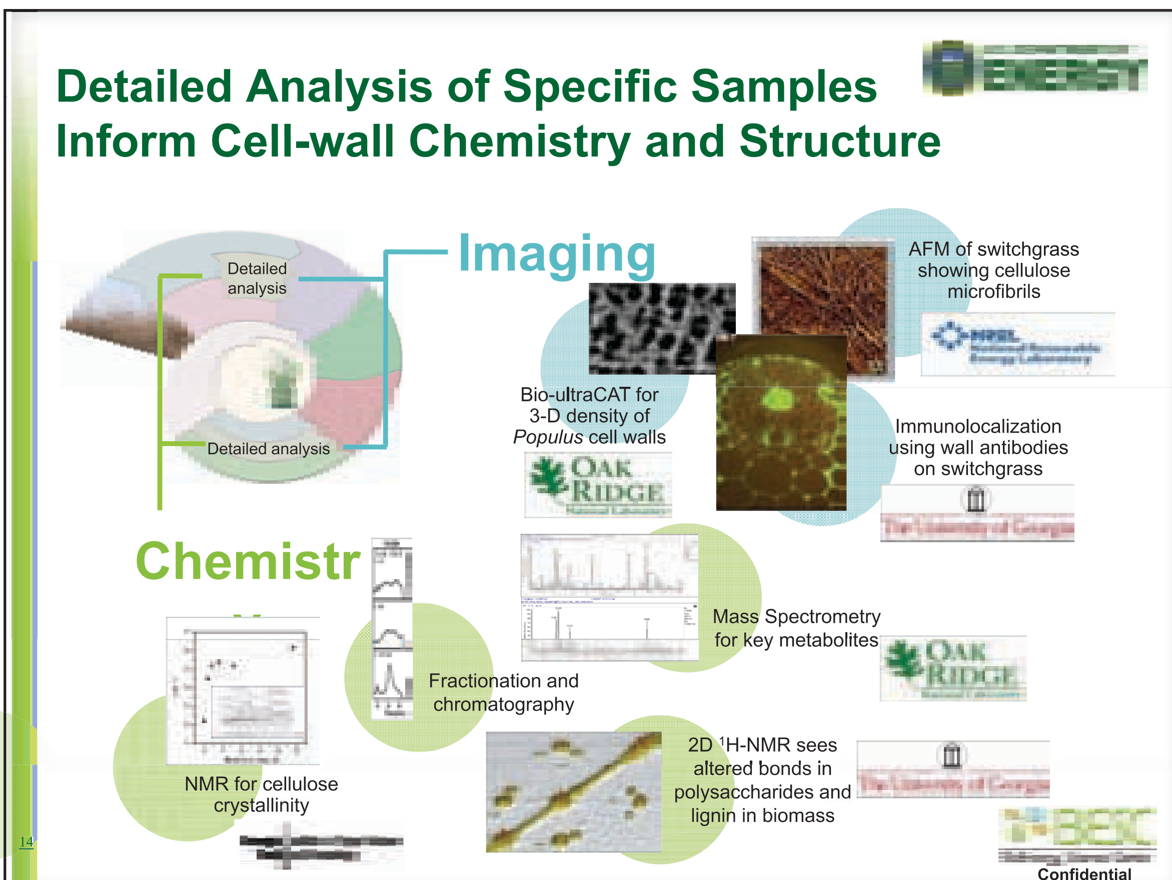
Switchgrass is a high-yield crop that grows well in many different parts of the United States. Another model plant species that grows very well in most of the United States is *Populus*. Compared to poplar, we lag a bit behind in the tools necessary to characterize and modify the plant cell wall and structure of switchgrass, but we are developing more genetic tools to catch up to poplar, including the mutation that increases the yield of ethanol.

Together with the Samuel Roberts Noble Foundation, we have produced a transgenic switchgrass that can increase the yield of ethanol compared to the wild type by 25 percent when subjected to traditional conversion technologies. One of our partners, Mascoma Corporation, has made tremendous progress in engineering new strains of yeast that produce their own enzymes and thus combine enzymatic treatment and fermentation, lowering the amount of added enzyme to convert lignocellulosic material to biofuels significantly. The next generation of combined biogenetics and engineering technologies will produce other fuel molecules such as butanol, isobutanol, and hydrocarbons and will revolutionize our current technology for producing biofuels.

We have completed genomic sequencing of poplar trees and have all the genomic tools to manipulate it. BESC has a major research effort underway in Northern California and Canada to better understand the natural variation of this native tree. We are looking for variants that are more easily digested than others. We have collected 1,300 samples from the study area, brought them into the laboratory, propagated them, and then planted them in common gardens in three locations in the United States where they will be grown under the same environmental conditions. The goal of this research is to determine whether the digestibility of certain strains is determined by genetics or the environment.

UNDERSTANDING RECALCITRANCE

A piece of wood or switchgrass, or any lignocellulosic material, has three major components, lignin, cellulose, and hemicellulose. The more lignin, the less sugar, and vice versa. BESC uses a three-step, high-throughput (HTP) characterization pipeline for determining the recalcitrance phenotype and obtaining detailed chemical and structural analyses of thousands of samples as they flow through the pipeline. We start with composition analytical pyrolysis to characterize specific samples to determine how much lignin, cellulose, and hemicellulose is present in each sample. Then we pretreat the biomass, softening up the structures through dilute acid and steam. For this second stage, we have developed



a brand new technology that is set up at the National Renewable Energy Laboratory with which we can analyze tens of thousands of samples within the screening pipeline. The third step is determining enzyme digestibility and the amount of sugar present in the samples. The more sugar at the end of the pipeline, the greater the digestibility. That information helps guide us towards solving the recalcitrance issue.

We screened 1,200 varieties of *Populus* using hot water only as a pre-treatment and found sugar release varies from 25 to more than 90 percent of the theoretical sugar release. This large spread was completely surprising and unexpected. Our preliminary observations revealed that the sugar yield correlates to the S/G ratio (S: syringyl-like lignin structures; G: guaiacyl-like lignin structures); or to put it more simply, it is not necessarily the amount of lignin but the ratio in the lignin of S to G that seems to influence digestibility.

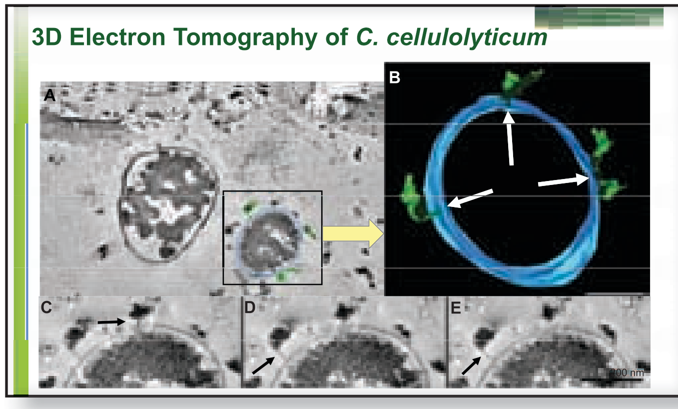
We still face the question of determining environmental versus genetic factors. We do know that there is significant diversity among healthy normal trees based on genetic mutations across the genome. However, at this stage it is not clear if this variation in sugar release is due to genetic variation or environmental influences. If this variation is based on genetics and we could keep this phenotype, we would have made a significant step toward solving the digestibility issue, or recalcitrance, of biomass, leading to an industry that is economically feasible.

The advanced technologies of ORNL and its partners are also allowing us to better understand wood chemistry of different species and obtain a detailed analysis of specific samples at the level of cell-wall chemistry and structure. Imaging techniques include atomic force microscopy of switchgrass showing cellulose microfibrils, immunolocalization using wall antibodies on switchgrass, and Bio-ultraCAT for 3-D density of *Populus* cell walls. Chemical analysis tools include mass spectrometry, fractionation and chromatography, and nuclear magnetic resonance.

COLLABORATIVE GAINS

The applied objective of CBP organism strategies is to produce industrial strains of microbes capable of producing the desired product at high yield without added enzymes. There are two strategies to increase yield, recombinant and native. The recombinant strategy uses heterologous enzyme expression to enable cell wall fermentation, for example cellulose utilization in yeast. The native strategy uses metabolic engineering to improve yield and tolerance; for example, the bacterium *C. thermocellum* is a microbe capable of high cellulase production and utilization of hydrolysis products. The fundamental underlying issue is to understand cellulose hydrolysis at a microbial rather than an enzymatic level.

Our BESC partner, Mascoma Corporation, has been able to increase the expression level of some of the cellulase in yeast



3D Electron Tomography of *C. cellulolyticum*

by about 3,000 fold over 20 months. This reduces commercial cellulose addition by more than half. The Mascoma Yeast can convert paper sludge to ethanol without any addition of other enzymes, a big step forwards towards CBP.

In other collaborative research, BESC has made great strides in a variety of technologies to break the recalcitrance barrier and speed research along towards application at the industrial level. These include:

- dissecting bacterium *C. thermocellum* growth on pretreated switchgrass and ethanol tolerance using systems biology tools,
- developing new strains of *C. thermocellum* and *A. thermophelium*,
- performing 3D Electron Tomography of *C. cellulolyticum*,
- characterizing the cellulosome of *C. thermocellum*,
- understanding the structure and function of the cellulosome, and
- performing computational microscope assays and analysis framework.

EDUCATION AND OUTREACH

A very important part of the mission of BESC is education and outreach. National Geographic, through its Jason Science project, recently filmed an educational module on energy, Operation: Infinite Potential, featuring students performing experiments with BESC researchers. In addition, in 2009, BESC co-sponsored a seminar series with the University of Tennessee on "The Future of Bioenergy." And in September 2009, we co-hosted the Georgia Glycoscience Symposium held at the University of Georgia.

We are also engaging a number of industrial partners such as ArborGen, LLC; Verenium Corporation; Mascoma Corporation; and Ceres, Incorporated to facilitate strategic commercialization.

From 2008 through September 2009, BESC has produced more than 100 scientific publications in cooperation with our partners; 25 workshops and seminars for BESC researchers and graduate students; 16 inventions disclosed that are under evaluation by the BESC Commercialization Council; more than 100 presentations to stakeholders; and more than 75 television, radio, and print interviews. In addition, an educational program with the Creative Discovery Museum in Chattanooga, Tennessee, has developed a Biofuels Outreach Lesson.

BREAKING THE COST BARRIER

BESC leverages high-performance computing and neutron capabilities. The neutron science and supercomputing facilities at ORNL provide state of the art tools with which to physically characterize lignocellulosic biomass and interactions with associated microbial enzymes. Understanding biomass recalcitrance to hydrolysis requires the development of self-consistent simulation tools on a number of length and timescales. This ranges from the examination of detailed interactions, to the examination of the physical properties of biomass components, to the simulation of full biomass systems before and after pretreatment—the latter requiring the full petaflops power of ORNL's Jaguar XT5 machine. Together with our partners, BESC is close to solving the recalcitrance problem and finding new processing technologies to make the conversion of biomass into biofuels economically feasible and environmentally sustainable.

Direct Electricity Recovery from *Canna Indica* by a Microbial Fuel Cell Inoculated with Rumen Microorganisms

by Guo-Long Zang , Han-Qing Yu, and Guo-Ping Sheng

Mr. Zang *is a Ph.D. candidate in Environmental Engineering,* **Dr. Yu** *a Professor of Environmental Engineering, and* **Dr. Sheng** *an Associate Professor of Microbial Fuel Cell, at the University of Science and Technology of China.*

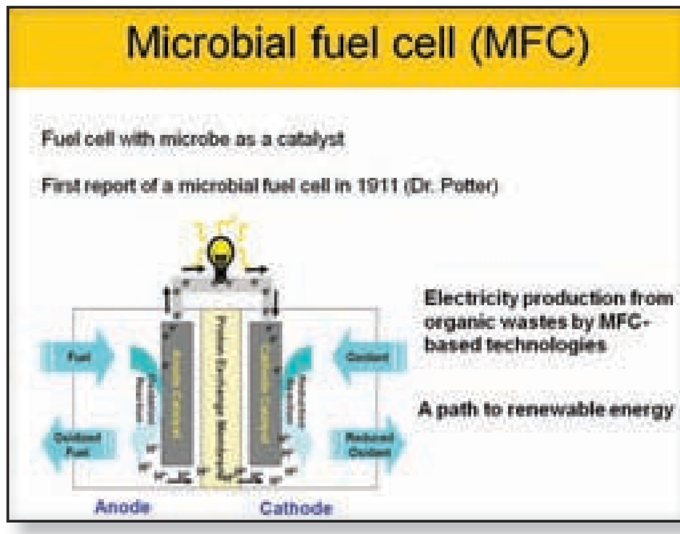
Guo-Ping Sheng

Water pollution and eutrophication have caused serious environmental and social problems in China, but in recent years, our government and scientists have paid more attention to finding solutions to these problems. One of the most efficient technologies to control water pollution is bioremediation. A number of aquatic plants have been found to be effective in the bioremediation of eutrophied waters. The cost of using aquatic plants and the consumption of energy are very low, and aquatic plants are compatible with nature. There is, however, one problem with using aquatic plants for bioremediation: if the plants are not disposed of properly, they will pollute the water again after they die.

Due to the large number of polluted lakes and other bodies of water, a large area has been planted with many tons of aquatic plants, triggering a crisis in terms of disposal. This emergency has given rise to a new point of view: regarding these plants not a waste product, but as a potential renewable resource to be harvested as biomass. Ethanol, hydrogen, and methane can be extracted through chemical and biological processes. The structure of the cells, however, presents a problem. There is a layer of wax lignin on the outer surface of the cell wall, and lignin, hemicellulose, and cellulose are found in the secondary cell wall, preventing degradation by microorganisms, so that costly pretreatment is needed. The aim of our study is to harvest electricity from aquatic plants without pretreatment using a microbial fuel cell.

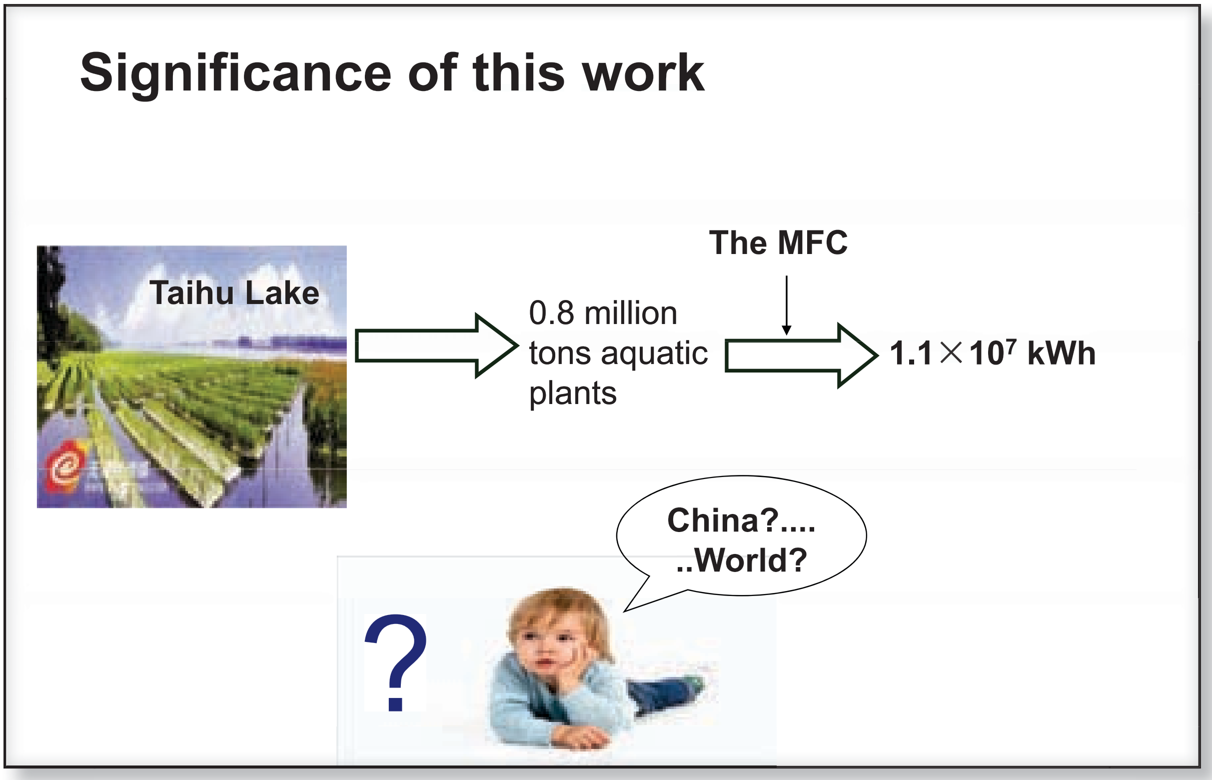
CANNA INDICA MFC

Microbial fuel cells (MFCs) use microbes as a catalyst. The technology was first reported in 1911, when a British botanist, M.C. Potter, created a device to generate electricity from *E. coli*. Since Dr. Potter's first report nearly a century ago, the technology has developed very slowly. In recent years, however, interest in MFCs has increased as it became apparent that the technology can be used to harvest energy from wastewater. Professor Bruce Logan at Penn State University, for example, pioneered a new way to turn domestic waste into electricity using MFCs.



At the University of Science and Technology of China, we have produced electricity directly from a lignocellulosic aquatic plant rich in cellulose, hemicelluose, and lignin—*Canna indica*—without pretreatment. In our study, rumen microorganisms were harvested from the stomach of goats. These are diverse, complex, and non-pathogenic organisms that are very efficient at degrading cellulosic material. In our air-cathode MFC, by inoculating *C. indica* samples with goat rumen microorganisms, we were able to produce a maximum power density of 360 milliwatts per square meter (mW/m2). The overall energy recovery of this MFC was calculated to be 68 Joules per gram (J/g).

Using cyclic voltammetry, an electro-analytical tool to study redox reactions, we examined the electron transfer from the bacteria to the electrode. The reaction in an electrode without rumen microorganisms produced no redox peaks, but after the rumen was introduced to the reactor, small redox peaks occurred. At first, the redox peaks were very high, indicating that redox activity is very high. At the end of the reaction the redox peaks disappeared. We conclude that the electron transfer in this microbial fuel cell was mainly through electron shuttle with self produced mediators. The redox peaks in the process likely originated from the mediators produced in the *Canna* hydrolysis process.



We also analyzed intermediate products such as volatile fatty acids (VFAs) and sugars during the degradation process over 300 hours. We found that at first the VFA content increased sharply and then dropped abruptly at about 200 hours. The sugar content at first was very low, and then increased sharply at about 200 hours before dropping almost to zero at 300 hours. Examining the amount of cellulose, hemicellulose, and lignin fractions in raw and residual *Canna* and their removal efficiencies in the MFC, we found approximately 46 percent of cellulose, 61 percent of hemicellulose, and 22 percent of lignin were degraded. This result further confirms that rumen microorganisms could be utilized for bioconversion of lignocellulosic wastes into electricity.

The mechanisms of degradation of *C.indica* in the MFC were elucidated using X-ray photoelectron spectroscopy (XPS) and X-ray diffraction (XRD). XPS probes revealed that the oxygen/carbon ratio in the raw *Canna* was lower than that in the residual samples, while the relative amount of *Canna* was higher than the theoretical values of lignin. The fraction of cellulose in the *Canna* sample increased rapidly, and this result is in agreement with results of the chemical composition analysis of the raw and residual samples.

XRD probes of cell structure showed that the intensity of the amorphous region of the residual *Canna* was lower than that of the raw *Canna*, and the intensity of the crystalline region was greater than that of the raw *Canna*. This indicated that the crystal structure of the *Canna* was disrupted, perhaps due to degradation of the cellulose and hemicellulose.

ONE LAKE, ONE WORLD

Taihu Lake in the Yangtze Delta Plain is one of the five largest lakes in China. This one lake produces about 0.8 million tons of aquatic plants per year. If we use these plants to harvest energy using our MFC technology, we could harvest about 11 million kilowatt hours. If we can harvest that much energy from one lake, think how much we could reap from all the lakes in China, not to mention the possibility of harvesting energy worldwide.

Our work is one attempt to directly produce electricity from a lignocellulose aquatic plant rich in cellulose, hemicellulose, and lignin without pretreatment and at very low harvesting costs. We have demonstrated that rumen microorganisms may be used in MFCs to produce electricity from complex lignocellulosic material, rather than from pure cellulose. The approach proposed in our work might have great potential as an effective method to generate electricity from lignocellulosic materials.

Selective Biomass Pyrolysis and Catalytic Bio-oil Upgrading

by Ying Zhang

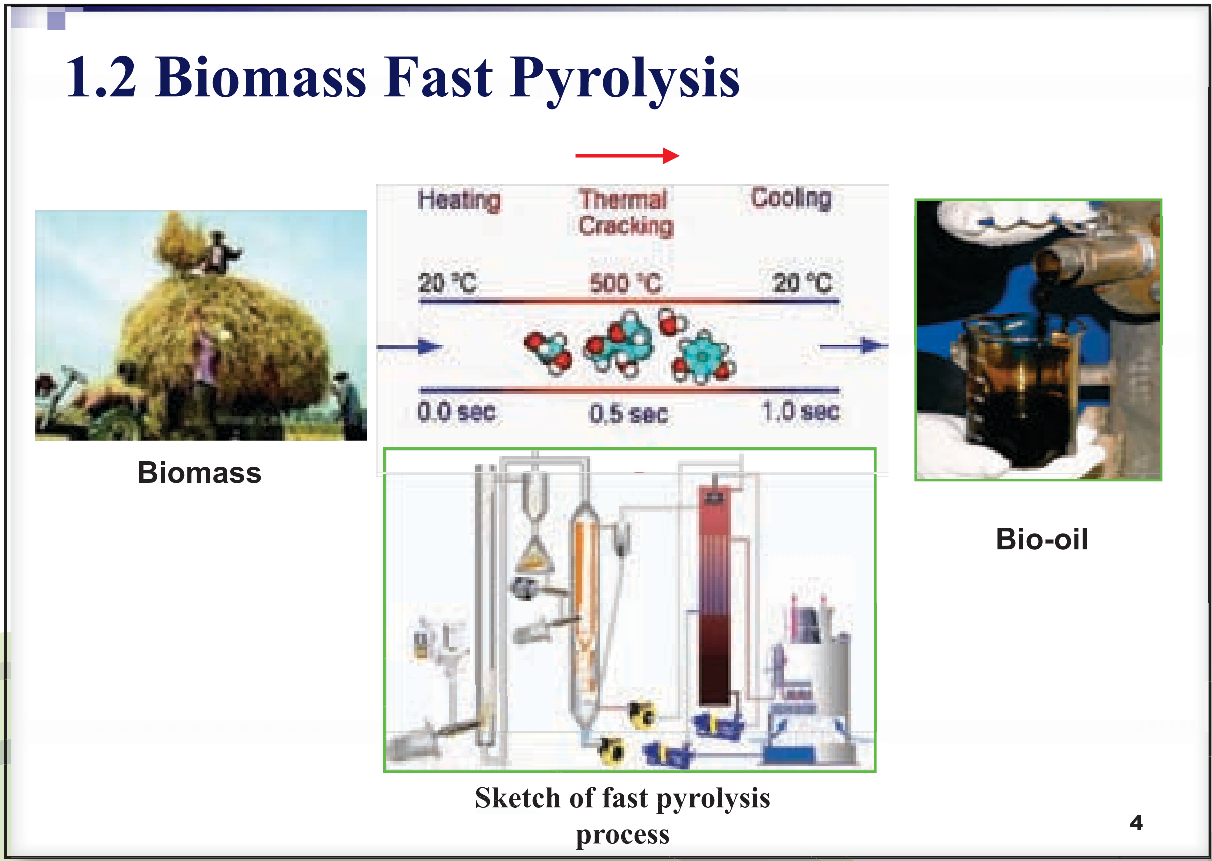
Dr. Zhang *is an Associate Professor of Biochemical Engineering at the Anhui Key Laboratory of Biomass Clean Energy, University of Science and Technology of China.*

China has many reasons to look to biomass as a renewable source of energy. China has available a large amount of low-cost, or even free, biomass resources in agricultural waste alone. For example, about 0.7 billion tons of straw are produced per year, equal to 0.2 billion tons of standard coal, and 60 percent of this waste straw can be used as an energy source. In some cities in China, which already suffer from air pollution and haze, people know when the harvest season has arrived because farmers who cannot deal with large amounts of straw simply burn it. By utilizing this biomass, we can turn scrap into treasure, improving the environment while increasing income for farmers.

In addition, fuels derived from biomass are greenhouse gas neutral, because any CO_2 produced during fuel combustion is consumed by further growth of biomass. And, unlike other renewable energy resources such as nuclear, wind, and solar from which we can produce electricity, biomass is the only renewable resource for producing liquid fuels and chemicals.

SELECTIVE FAST PYROLYSIS

Fast pyrolysis is a very quick and efficient way to convert biomass to liquid fuels. Basically, dried, crushed biomass is added to a reactor and heated up from room temperature to



500 ˚C. During this process, the biomass is thermally cracked and converted to vapors which are then cooled down in just a few seconds to produce bio-oil. Unfortunately, the quality of the bio-oil is low, and it cannot be used as transportation fuel.

Because fast pyrolysis happens in seconds and is terminated in seconds, the bio-oil produced has high instability and high viscosity. It also has high oxygen content and high polarity, which means it cannot be mixed with fossil fuels for use in the transportation sector. In addition, during this process a lot of acid is produced, so the corrosiveness of the bio-fuel is high, especially under elevated temperatures. To use bio-oil created by fast pyrolysis as a transportation fuel, it must be upgraded. Currently, the common processes used to upgrade bio-oil, such as hydro-treatment and catalytic cracking, result in a low yield of liquid fuel, high coke and tar formation, and deactivation of catalysts.

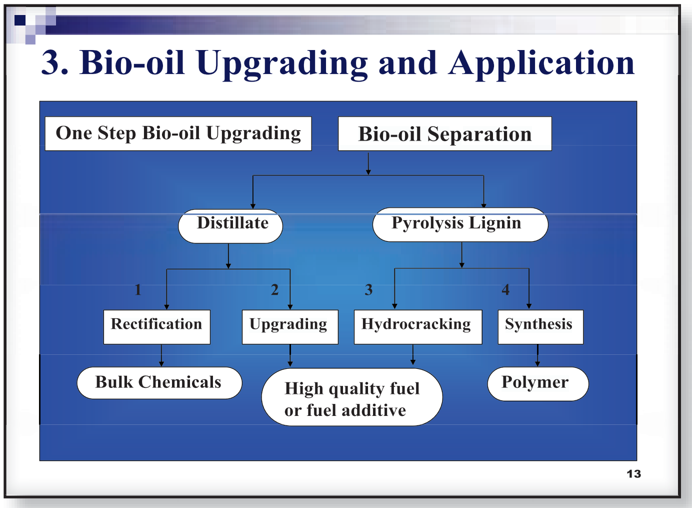
At the Anhui Key Laboratory of Biomass Clean Energy, we have been seeking to improve the quality of the content of bio-oil. One solution is to develop selective pyrolysis techniques. There are more than 300 kinds of compounds in bio-oils, and none of them except water represents 10 percent of the total. Selective pyrolysis targets certain high-quality compounds. Another way to improve the quality of the bio-oil is to upgrade the system and screen new catalysts. Finally, by separating and upgrading bio-oil we may produce high quality fuel or chemicals.

In our lab we have two systems for achieving selective biomass pyrolysis. The first, the analytic pyrolysis-GCMS system, is very efficient. Small amounts of biomass are heated up quickly, and the content of the vapors is analyzed by gas chromatography-mass spectrometry (GC-MS). This allows us to screen catalysts and explore the reaction conditions. The trouble with this system is that we cannot collect products for further analysis. Therefore, based on the mechanism of fast pyrolysis, we developed a very simple lab scale pyrolysis system to further analyze the products and ultimately improve the yield of the targeted compounds.

Selective biomass pyrolysis can be used in the production of furfural. According to Wikipedia, furfural is an industrial chemical compound derived from a variety of agricultural byproducts including corncobs, oat, wheat bran, and sawdust. Furfural is used as a solvent in petrochemical refining to extract dienes, which are used to make synthetic rubber, from other hydrocarbons. Furfural, as well as its derivitave furfuryl alcohol, can be used either by itself or together with phenol, acetone, or urea to make solid resins. Such resins are used in making fiberglass, some aircraft components, and automotive brakes. Furfural is also used as a chemical intermediate in the solvents furan and tetrahydrofuran. In short, furfural is a very useful compound.

Many kinds of biomass may be used to produce furfural. We used the fast pyrolysis system on untreated and treated poplar wood. When we put untreated poplar into our reaction system, heated it up to 400 C˚, and analyzed it using GC-MS, we did not produce the kinds of outputs we wanted. So we treated the poplar wood with certain catalysts, then heated it up to 300 ˚C, and got a very concentrated amount of furfural from the treated wood.

Fast pyrolysis can also be used in the selective production of levoglucosenone (LGO). LGO is relatively small (six carbon atoms) nonracemic chiral, rigid molecule with several important functional groups, including a ketone group—a double bond conjugated with ketone—and two protected hydroxyl groups. Although LGO has been known for more than 30 years, it has as yet found only limited applications in organic synthesis due to certain difficulties in the synthesis, purification, and handling of this compound. The results of our GC-MS analysis revealed a fairly low yield of LGO, using a starter material cellulose, about 10 percent.



A third example of the utility of selective biomass pyrolysis is the promotion of phenolic products. The oxygen content in phenolic products is low, but, if we can increase the amount of phenolic products in bio-oil, we can increase the heating value of the total bio-oil. We screened a few catalysts and found one that improves phenolic production.

Based on these three examples, we find that using certain catalysts, we can indeed select for certain targeted chemical compounds. As yet, however, bio-oil cannot be commercialized for two reasons. One, there is not a continuous supply of bio-oil, and two, upgrading bio-oil is not an easy task. For now, the price of bio-oil is too high for it to compete with fossil fuels. Fast pyrolysis, however, may allow us to produce more-valuable products that can compensate for its high price as a fuel.

BIO-OIL UPGRADING AND APPLICATION

In our efforts to improve the quality of bio-oil, we are working on one-step upgrading. Pyrolytic lignins (PLs) are the major components in fast pyrolysis bio-oils, and PLs have detrimental effects on bio-oil properties. The existence of PLs also makes bio-oil upgrading rather difficult due to their non-volatility and thermal instability. In one-step upgrading, we separate the bio-oil into pyrolysis lignin and a distillate. In the lab we can deal with the distillate in two ways, rectification and upgrading. With the right equipment, ideally we can separate the light part of the bio-oil and then collect the bulk chemicals. Or we can simply upgrade the light part of the bio-oil to get high quality fuel or fuel additives.

Because it takes a lot of heat to break down PL, we use the catalytic hydro-cracking process to produce high quality fuel or fuel additives. PL is also a very good substrate for the synthesis of polymers which are, ideally, biodegradable.

We have found that bio-oil can also be upgraded using a combination of hydro-treatment, esterification, and cracking. Our results indicate that the upgrading process is effective and that the properties of the upgraded bio-oil are significantly improved over crude bio-oil. The amount of aldehydes and ketones appeared to decrease; aldehydes in particular were almost completely removed. Most of the acids were converted into corresponding esters, and at same time new types of esters were produced.

During the catalytic upgrading process, at temperatures above 100 °C, PLs rapidly polymerize to form tar and coke on the catalyst surface and subsequently cause deactivation of the catalyst. On the other hand, PLs contribute a great deal to the heating values of bio-oils due to their low oxygen content, and PLs are also regarded as promising material for making adhesives (phenolic resins) or aromatic bulk chemicals. Therefore, it is not sufficient to treat PLs by simply removing them from bio-oils. Converting PLs to stable monomeric compounds should be the primary task for catalytic upgrading of bio-oils.

The new system for hydro-cracking PL represents a significant improvement over traditional systems. Using a catalyst, we were able to achieve very low coke production, less than 3.3 percent; high organic liquid production, more than 95 percent; and a heating value up to 34.9 megajoules per kilogram (MJ/kg). A method to further purify LGO remains elusive, as our gas chromatography analysis shows.

Perhaps in the future, collaboration with other researchers will allow us to optimize and scale up our system. The ultimate goal is to improve the quality of bio-fuel from agricultural waste, making it commercially viable as a fuel for the transportation sector, while at the same time extracting useful chemical compounds of high value.

Aspen Plus Process Simulation of Flexible Feedstock Thermo-chemical Ethanol Production

by Fu Zhao

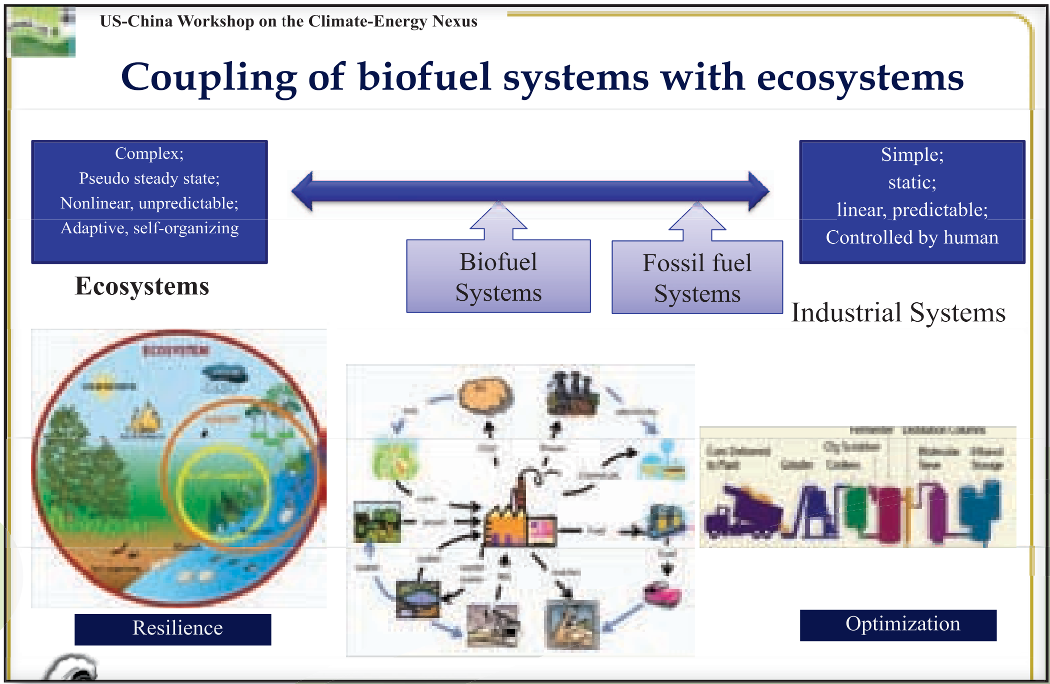
Dr. Zhao *is an Assistant Professor in the Department of Mechanical Engineering and the Division of Environmental and Ecological Engineering, Purdue University.*

The current US transportation sector mainly relies on liquid hydrocarbons derived from petroleum, and about 60 percent of the petroleum consumed comes from areas where supply may be disturbed by regional instability. This has led to serious concerns about energy security and global warming. Numerous alternative energy sources have been proposed to address these issues. Among them, second generation biofuel is one of the most promising technologies.

Industrial-based, fossil fuel systems are relatively simple, static, linear, and predictable, and are controlled by humans. Ecological systems, on the other hand, are complex, nonlinear, unpredictable, adaptive, and self organizing. Biofuel production, unlike traditional transportation fuel production, relies more closely on the ecosystem, specifically agriculture. This suggests that biofuel production may be more vulnerable to disturbances originating from the ecosystem it relies on.

Our conventional, industrial system based on fossil fuels attempts to optimize economic performance first, and then later to combine environmental and economic performance. For ecosystems, it cannot truly be argued that efficiency is always maximized—in fact, in general ecosystems are not optimized for efficiency—but the ecosystem can tolerate large and sometimes unpredictable disturbances. That is, they are more resilient. In the future, our biofuel production needs to be resilient also. Despite the uncertainties embedded in the ecosystem, a biofuel-based production system can better handle variances or disturbances and maintain a stable output, in other words, profit.

The biomass conversion technologies that will ultimately be most successful are those that are sufficiently adaptable to a myriad of environmental, geographic, and economic conditions; mutually symbiotic with a variety of industry sectors; environmentally efficient; consistent with decentralized deployment; and readily scalable.



US-China Workshop on the Climate-Energy Nexus

Flexible Feedstock

Proximate

Feedstock	Moisture	Fixed Carbon	Volatile	Ash
MSW	20	17.29	80.24	2.47
Corn Stover	15	19.25	75.17	5.58
Wood Chips	50	15.29	83.84	0.89

Ultimate

Feedstock	C	H	N	S	Ash	O
MSW	46.54	6.24	0.67	0.23	2.47	43.85
Corn Stover	43.65	5.56	0.61	0.01	6.86	43.31
Wood Chips	50.88	6.04	0.17	0.09	0.92	41.9

Fu Zhao, Sustainable Product Engineering Research & Education (SPERE) Laboratory
School of Mechanical Engineering & Division of Ecological and Environmental Engineering

THE IDEAL PLANT

Resilience is the capacity of an ecological system to maintain or recover basic functions relative to large or unforeseen changing conditions, damages, or perturbations. The ideal, resilient biofuel plant should be able to respond to the unpredictability of complex systems it is embedded in.

One promising technology for developing a resilient biofuel plant is thermo-chemical conversion, such as gasification. Gasification can utilize a wide range of biomass wastes and residues and bring flexibility to both feedstock and production sides of a plant. In our work, we investigated a flexible feedstock production process. Because no such facility is currently in commercial operation, we evaluated the feasibility of the technology through process simulation, updating an existing model developed by the US Department of Energy's National Renewable Energy Laboratory (NREL). The original model was used to explore the feasibility of using only woodchips in the production of ethanol.

The simulated plant is hypothetically located near a major city in Indiana with a population of more than 200,000 in a region where corn stover is harvested once a year. Proximity to a large city guarantees a source of municipal solid waste (MSW). It is also assumed that forest residues are available year round.

Using the Aspen Plus based model, we compared the single-feedstock scenario with multiple-feedstock scenarios in terms of economic performance, field-to-gate greenhouse gas (GHG) emissions, and survivability under extreme weather conditions. For the purposes of this study, we used flood and drought only as the extreme conditions since those two extremes have significant effects on the production of corn stover. Future simulations could include other weather perturbations.

We used three feedstock management strategies: corn stover alone, corn stover supplemented by MSW, and corn stover supplemented by MSW and woodchips. MSW is an almost free resource and represents a predictable supply of feedstock that can be calculated on a per capita basis. Corn stover, on the other hand, is subject to disruptions in supply, losses during storage, and significant cost fluctuations. Woody biomass from forest residue can be used as a backup if the supply of corn is disrupted. This guarantees continuity in supply and output and minimizes the economic risks to the plant operator.

Our model has shown that we can predict the yield of ethanol under varying conditions and availability of different feedstocks. By analyzing the effects of extreme weather such as flood and drought on the economic outcomes and the environmental performance, we found that multiple feedstock strategies increase the likelihood that the initial high cost of building a plant will be recouped, whereas single feedstock strategies put a plant at risk of bankruptcy during the pay-back period. In other words, the ability to switch from corn stover to wood chips during a disruption in supply of corn stover allows continuous production and output and protects against bankruptcy if corn stover is in short supply. Though the GHG emissions of wood chips are slightly more significant than from corn stover, the land use change due to tree farming could offset the increased emissions.

RESILIENCE

Our primary goal is to design a bio refinery that is resilient against outside disturbance, either from the supply side or the market demand side. To that end, we must quantify or measure resilience or the ability to absorb disruptions. We have borrowed principle concepts from system dynamics and control theory. Potentially this approach is applicable to other industrial systems besides biofuel production. By calculating the variance in input and output, we can determine how certain inputs will affect the output, such as biofuel yield and profit. According to control theory it is possible to have robust or adaptive control strategies implemented, but ideally we want a bio-refinery where we can change not just the operating condition, but also the structural configuration. Similar efforts have been attempted for manufacturing systems, i.e., reconfigurable manufacturing systems. Again, the modeling we are now performing can serve as a starting point for exploring these opportunities. Eventually it is expected that guidelines and methodology will be developed to design a reconfigurable bio-refinery system that can respond to ever-changing scenarios and remain profitable.

GARBAGE IN, GARBAGE OUT?

Purdue University, partnering with Rochester Institute of Technology, is in contact with a relatively small company in Lee County, New York, which is planning to build a pilot municipal solid waste-to-ethanol plant. The plant is expected to handle about one ton of municipal solid waste per day. As a waste management company, it already has the ability to separate metal and glass out of the municipal solid waste so what remains will be biomass, plastics, and wastepaper.

We know that waste to energy or fuel has potential, but how can we know it is not garbage in/garbage out, creating even more new pollution from the plant? In addition, for the plant to be economically viable, it cannot use very advanced treatment technology because the cost will be too high for a plant of this scale. We are considering a relatively low cost approach to treat the waste coming out. With thermo-chemical conversion, the pollutants from the gasification process would be excessive, so we built a lab-scale gasifier, characterized the waste stream, collected the pollutants from the process, and tested the feasibility of using modified biomass feedstock as filter and recycling waste filter medium in the gasifier.

We need to perform these process simulations because when we scale up, we need a model that will serve as a design guideline. In addition, from the environmental perspective we need to do a life cycle analysis (LCA) to better understand the material energy flow in and out of the bio-refinery. This kind of process simulation model can provide that information. For now, our Aspen Plus model does not include the total waste stream. We plan to expand that model to include how the waste is dealt with using the data we collect in our lab.

KEEPING AN EYE ON EARTH SYSTEMS

To estimate greenhouse gas emissions and devise mitigation strategies to reduce future impacts of climate change, decision makers need hard data and sound information. Researchers at the Laboratory of Ecosystem Network Observation and Modeling (ENOM), Chinese Academy of Sciences, are providing this information through network observation, field experiments, and modeling of carbon, nitrogen, and water cycle processes. ENOM researchers use every tool available to understand the basic mechanisms that drive climate change.

China and the United States rank fourth and fifth globally in the extent of forested lands, and both countries are engaged in efforts to increase the carbon sink of forests. Recent Chinese government figures show that total forest cover has increased in the last 50 years because of plantation efforts, but mature forests with good quality timber are declining. Despite uncertainty about precise amounts of carbon sequestered in forests, the general consensus is that since the 1980s, Chinese forests have become a carbon sink. Purdue University's Guofan Shao says that both countries, with their common issues and different histories, have much to learn from each other in exploring the role of forests in offsetting CO_2 emissions.

Climate scientists have already begun creating the next round of simulations and analysis that will be included in the Fifth Assessment Report of the International Panel on Climate Change. Peter Thornton with Oak Ridge National Laboratory says these new efforts will help improve predictions of future greenhouse gas concentrations and climate change. In addition, biogeochemical cycles are now being incorporated into global climate models. More-accurate modeling of complex interactions such as the tight coupling of the carbon and nitrogen cycles will help build a mechanistic foundation for Earth system modeling and add the human dimension to climate system models.

Earthworms play a complex role in ecosystems, which can be understood by analyzing the chemistry of their fecal matter. Timothy Filley with Purdue University has examined the biopolymer signatures of plant and microbial components in fecal matter to track how earthworms control the movement of carbon or nitrogen within soil and litter systems. Compound-specific isotope analysis is a powerful approach to soil/litter dynamics that allows us to track movement of carbon and nitrogen in a system tied to specific classes of organisms.

The Loess Plateau in China is named for its silty soils, which can be very fertile but which are also highly erodible. Land that once supported agriculture has, over time, been deforested and overgrazed. Today, 20 percent of the plateau is severely eroded. Jun Fan with the Chinese Academy of Sciences says that although China is making headway in reversing the effects of centuries of degradation of the landscape, there is an urgent need to pay more attention to regional assessments of sediment erosion and soil and water conservation.

Carbon Flux/Storage in Terrestrial Ecosystems in China and its Impact Mechanism Based on Network Observation

by Gui-Rui Yu and Yu-Ling Fu

Dr. Yu *is Deputy Director and Professor of Ecosystem Management at the Institute of Geographic Sciences and Natural Resources Research (IGSNRR), Chinese Academy of Sciences, and the Founder of China FluxNET.* **Dr. Fu** *is an Associate Professor of Terrestrial Ecology with the Key Laboratory of Ecosystem Network Observation and Modeling, IGSNRR, and a visiting scholar at Oak Ridge National Laboratory.*

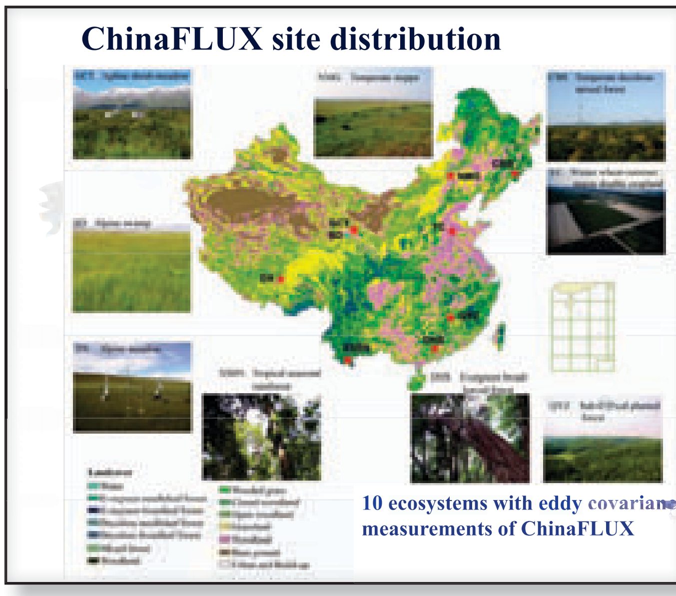
Gui-Rui Yu

The major objectives of the Key Laboratory of Ecosystem Network Observation and Modeling (ENOM) are to 1) build an observational and experimental network platform for carbon cycle research in China, 2) understand the process and underlying mechanisms of carbon cycles, 3) quantify the spatial-temporal variations of carbon storage and flux in the major terrestrial ecosystems, and 4) estimate potential carbon sinks and explore approaches to increase carbon sinks in terrestrial ecosystems.

In the last few years, the Chinese government has expended a great deal of effort to enhance research on the carbon cycle. In 2001, the Chinese Academy of Sciences (CAS) funded the first major Knowledge Innovation Key Project, and starting in 2002, the Ministry of Science and Technology began basic research and development projects. These two major projects launched the ChinaFLUX network.

In these early efforts, we focused on carbon and water flux observations in the different major terrestrial ecosystems in China and also began modeling work on carbon cycles. As these projects came to an end, the Key Laboratory of ENOM received funding from the National Science Foundation of China (NSFC) for two projects. One is the Key Project focused on a transect study of nitrogen and carbon fluxes in typical ecosystems. This project also included a transect inventory of soil and vegetation of the environment. Then we began to develop a data-model fusion system based on the data we observed and a land use change and process-based ecosystem modeling of carbon cycles to estimate the carbon exchange in all of China.

In 2008, the NSFC funded another key international collaborative project for estimating the terrestrial carbon budget across Asia, a joint study among ChinaFLUX, Japan's JapanFlux, and Korea's KoFlux. This joint project also extends cooperation to other countries in East Asia. These two projects will end in 2010. In 2009, we received funding from the Ministry of Science and Technology (MOST) to continue the carbon flux research and transect and modeling studies, and we added new research methods and content. One major new direction we are planning is to carry out controlled experiments in typical ecologic regions on warming, grazing, precipitation, and nitrogen deposition.



Most of our studies are based on two national networks of the CAS, the Chinese National Ecosystem Research Network (CNER), a nationwide network including 53 field stations, and the Chinese Ecosystem Research Network (CERN), with more than 40 field stations. Based on these two national networks we developed the ChinaFLUX network of 12 flux stations and have already achieved results about carbon sinks or sources in the different typical ecosystems in China.

Our first major research method is network observation, with which we carry out ecosystem flux, biomass, and meteorological observations of different sites. The second method uses experiments on warming, grazing control on grasslands, precipitation control, and nitrogen deposition. The third major method we use is modeling, using different ecosystem process models and remote science-based models to model carbon, nitrogen, and water cycle processes.

ChinaFLUX has since its inception made major progress, and our work has resulted in numerous publications and three books focusing on carbon storage, carbon flux methods, and results of carbon flux observations.

CHINAFLUX MILESTONES

The ChinaFLUX sites are distributed across various ecosystems typical of China. Altogether we have four forested sites ranging from subtropical planted forest, to tropical seasonal rain forest, evergreen broad-leaved forest, and temperate deciduous mixed forest. The grasslands include alpine shrub-meadow, alpine swamp, alpine meadow, and temperate steppe, and we have one cropland site of winter wheat-summer maize double cropping in Inner Mongolia.

Between 2003 and 2008, we tracked seasonal and inter-annual variations in carbon fluxes in all ChinaFLUX forest, grassland, and cropland sites and found very clear seasonal and inter-annual variations among the different types of ecosystems. Based on the average annual carbon budget of the different ecosystems over six years, we found that the forest ecosystem in eastern China was a major sink and that crop land was also a sink. For grasslands, the results were mixed; some represented a sink, but others, such as the steppe of Inner Mongolia, acted as a source. The alpine meadow steppe acted at times as a source or sink or, in some years, was carbon neutral.

We also analyzed environmental and climate factors of the ecosystem carbon budget, measuring the different temperature sensitivities of ecosystem respiration of forest lands. We found that the temperate forest ecosystem of Inner Mongolia has much higher sensitivity to variations in temperature. In the grassland sites, open meadows have much higher temperature sensitivities. This higher sensitivity means that as temperature increases with global warming, these two ecosystems will be more sensitive to climate change than others.

In addition, we analyzed spatial variation of the temperature coefficient (Q10), and the temperature sensitivity of ecosystem respiration. Our studies show that the Q10 values decrease as the mean annual soil temperature increases, that Q10 values increase with increases in soil organic carbon (SOC) throughout China, and that Q10 values increase with changes in latitude from south to north.

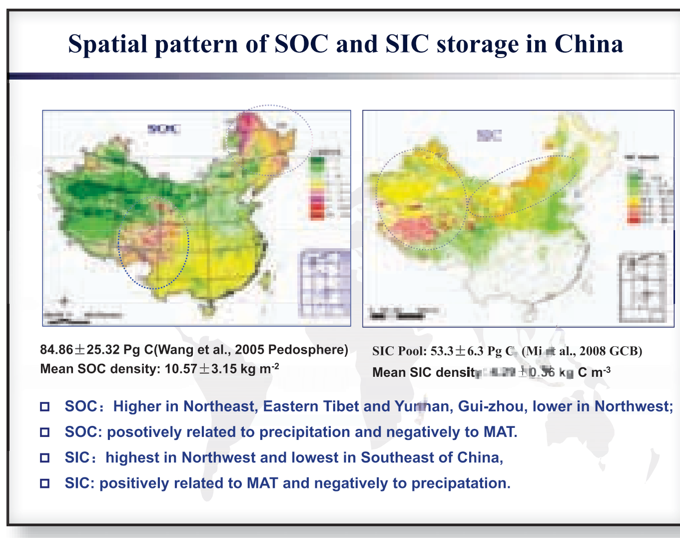
Analysis of environmental controls on the gross ecosystem production (GEP) of three forested sites showed that the GEP of the temperate forest is correlated with temperature variation, while for the tropical and subtropical forest sites, solar radiation and soil temperature have much more influence than air temperature on carbon fluxes.

Our analysis of spatial patterns of net ecosystem production (NEP) revealed that NEP decreases markedly with increasing latitude, indicating that subtropical forests have a larger potential for carbon sequestration than temperate forests. This latitudinal trend of NEP is consistent with that of European forests. Both ecosystem respiration and GEP determine the relationships between the latitude and NEP in eastern China.

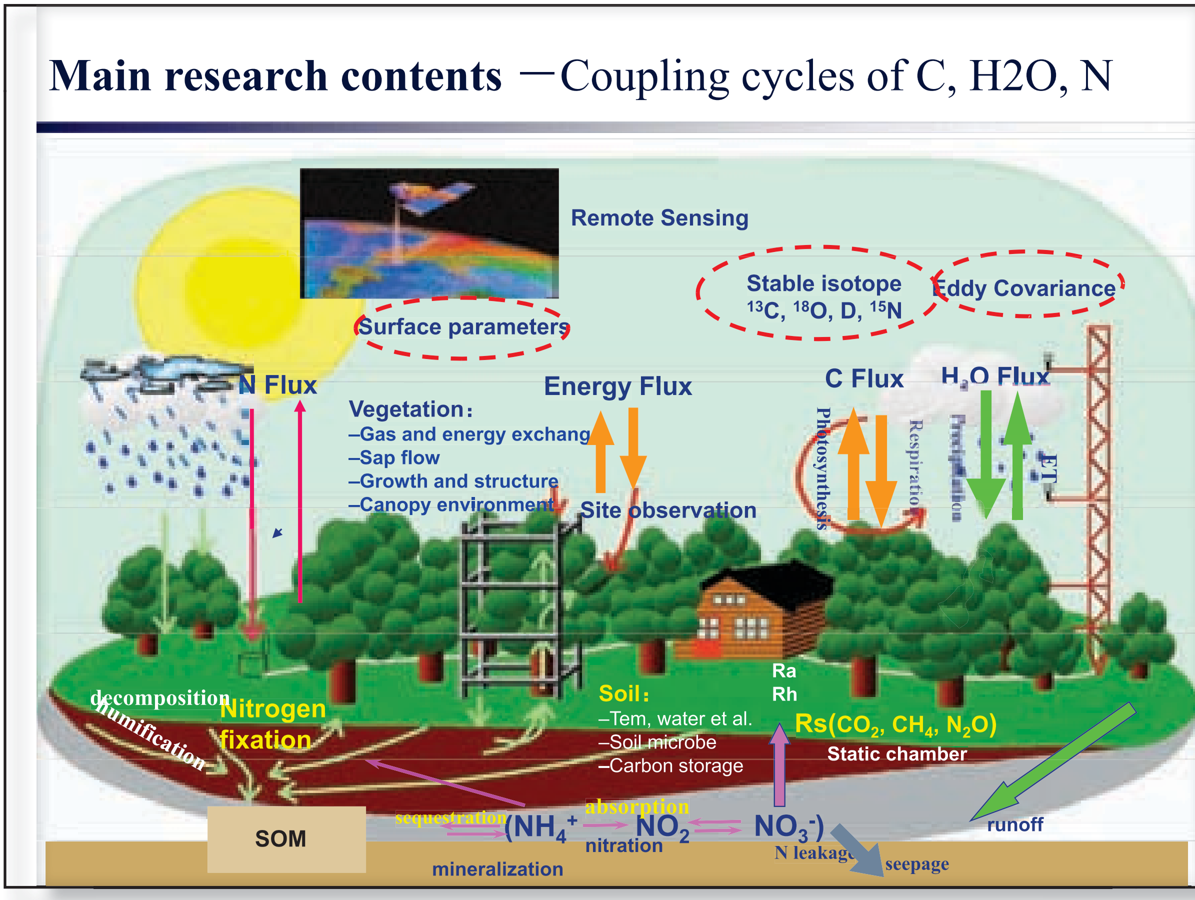
Based on several years of study of the grassland sites, we found that leaf area index (LAI) has a very strong effect on the inter-annual and inter-site variations of GEP and on nitrogen ecosystem exchange of carbon fluxes. LAI was mostly controlled by soil moisture and annual precipitation across the grassland sites. Using carbon flux water use efficiency (WUE) data, we estimated the average WUE of the different forest, grassland, and croplands sites and found that forest sites have higher WUE than grassland sites, and the tropical rainforest site has the highest WUE.

Climate variables also affected the coupling between the gross primary production (GPP) and evapotranspiration; responses of GPP and envirotransportation to meteorological factors were very different between the two zonal forest types. At the regional scale, WUE of the forest site was mostly determined by annual precipitation and mean annual temperatures.

In grassland sites, a spatial pattern emerged that grasslands with high productivity also had high WUE. LAI plays a very important role in regulation of the inter-site and inter-annual variation of WUE and has a key role in the variation of WUE through its regulation of annual transpiration and evapotranspiration.



Besides site scale observation of carbon and water cycles we conducted regional inventories of the SOC and soil inorganic (SIC) storage. The data shows that SOC is higher in northeastern China, in eastern Tibet, and in Yunnan and Gui-zhou provinces in southern China, and lower in the northwestern region. SOC is positively related to precipitation and negatively related to the mean annual temperature. SIC is highest in the northwestern area and lowest in the



southeastern region of China. SIC is also positively related to the mean annual temperature and negatively related to annual precipitation.

Field investigation and transect studies of the vegetation and soil carbon storage of grasslands sites have determined the vegetation carbon densities of the grasslands in China. Grassland vegetation carbon density averages about 1 kilogram per square meter and decreases with precipitation in northern temperate grassland and alpine meadows on the Tibetan Plateau. Temperate grasslands account for only about 18 percent, and alpine meadows in the Tibetan Plateau about 56 percent, of the total carbon storage in the grassland.

Using the InTEC model to estimate the NEP of the forest ecosystem in China, we found that from 1980s to 2002, the terrestrial ecosystem in China is a net carbon sink. Northeastern China is a net source of carbon due to over harvesting and degradation of forests. Southern China accounts for more than 65 percent of the carbon sink nationwide, which can be attributed to regional climate change, the creation of large-scale plantations since the 1980s, and the recovery of shrubs in the region.

NEXT STEPS

We have already done a lot of work, but much remains to be done. We will continue our framework of long-term observation of the carbon and water cycles, and next year we will begin a new National Basic Research Development Project 2010-2015 (NBRDP) to explore the coupling cycles of carbon-nitrogen-water in terrestrial ecosystems and responses to environmental changes. This project will use new methods, including controlled experiments on temperature increases and warming, carbon enrichment, nitrogen deposition, and alterations in precipitation patterns.

The goal of our future work is to answer two major questions. The first concerns the effects of precipitation changes on terrestrial carbon sequestration. The Fourth Assessment Report (2007) of the International Panel on Climate Change indicated that global climate change is already happening. A drought in northern and northeastern China between November 2008 and February 2009 was the most severe since 1951. On the other hand, most areas had much greater precipitation. In November 2009, for example, a severe snow storm blanketed more than 30 provinces. The timing of this snow storm was also the earliest in the last 50 years. We want to know what the effects of future variations in precipitation will be and what effect climate change will have on carbon flux and terrestrial ecosystems.

A second question concerns the effects of nitrogen deposition and fertilization on cropland in China, one of the largest nitrogen deposition regions in the world. Though we don't know yet, we have already done experiments estimating low, medium, and high nitrogen depositions in forest ecosystems. Our results showed that nitrogen deposition will reduce soil carbon emissions, but it will enhance soil nitrogen emissions. Increased nitrogen deposition will also depress methane emissions in nitrogen-rich forests.

The new NBRDP project continues to be based on ChinaFLUX and the CNER networks. We will continue observational studies at 12 flux sites and on eight controlled experimental sites in typical regional ecosystems. Using observational and experimental data, we will expand our understanding of the response and acclimations of the carbon, nitrogen, and water cycles to global changes.

This project will cover two transects, the northern transect of eastern China where most forested areas are located and the grasslands transect from the northeastern to the southwestern areas. We will use site specific observation of fluxes and stable isotope techniques on eight forest sites, five grassland sites, and three cropland sites. We will also conduct controlled experiments on four typical regions: temperate forests, subtropical forests, temperate grasslands, and alpine meadows. The experiments will examine the effects of warming, water control, nitrogen deposition, and grazing.

One of our research methods involves using modeling techniques, taking the observational data and the experimental data to parameterize these models. In addition, using climate vegetation information data and remote sensing data, we want to estimate the nationwide carbon, nitrogen, and water cycles and develop a new-generation process model of their coupling cycles. Finally, we will use these new-generation process models to estimate the patterns and changes of carbon sinks or sources of the terrestrial ecosystem.

The main thrust of our research is to use every tool available to study the coupling cycles and to estimate spatial and temporal variations and patterns of carbon, nitrogen, and water vapor fluxes in China, and to understand the basic mechanisms that drive them. Our results will provide data to support decision makers and provide information for estimating GHG emissions for China and devising mitigation strategies to reduce future impacts of climate change.

Roles of Forests in Offsetting CO_2 Emissions: China vs. US

by Guofan Shao

Dr. Guofan Shao *is a Professor of Geo-Eco-Informatics in the Department of Forestry and Natural Resources, Purdue University.*

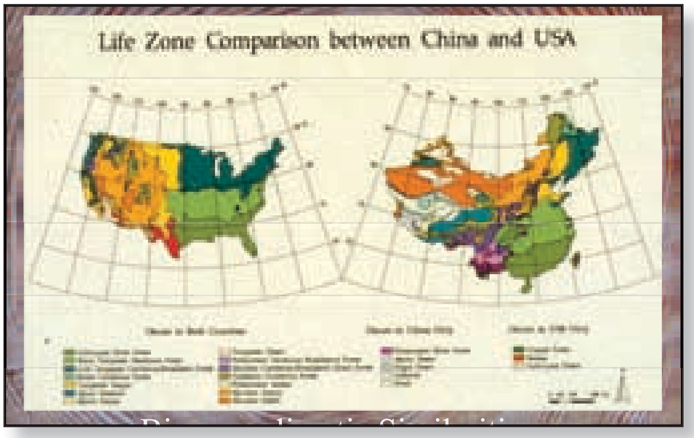
Research on forest carbon accounting has a history of about 20 years, beginning in the late 1980s to early 90s with the issue of missing carbon. As people began to study the global carbon cycle, they found 2 billion tons of carbon unaccounted for. Where did the carbon go? Many researchers believed that terrestrial forests must have partly contributed to the missing carbon.

Globally, land ecosystems are estimated to absorb approximately 2 billion tons of carbon a year, ocean systems 2 billion, and the atmosphere 3 billion tons. About 1.5 billion tons of carbon a year are produced by deforestation, and 6 billion by burning fossil fuels, though the numbers are always changing. Now some believe fossil fuels may produce 8 billion tons a year. The net increase in carbon in the atmosphere is about 3 billion tons a year. In fact, in studies of vegetation carbon sequestration processes, the complexity is too great, the approaches too varied, and the uncertainties too high to ensure completely accurate estimates. As a result, there is tremendous variation in the outcomes. This level of variation and uncertainty is not acceptable for engineers who plan land management designs, but for the study of carbon related issues, such variation is common.

At a global level, people believe that if we can prevent deforestation and reforest or afforest abandoned or degraded lands, we could increase carbon sequestration significantly. For example, if we make every effort to maximize the amount of carbon sequestered in forests, in the first 50 years of the 21st century we could achieve sequestration of 100 billion extra tons of carbon, at 2 billion tons per year, in addition to the 2 billion tons currently estimated to be taken up by forests. A doubling of sequestration by forests would represent a tremendous contribution.

CHINA VS. US

As of 2005, of the 10 countries with the largest forest areas, Russia, Brazil, and Canada rank in the top three, followed by the United States—872,000 square miles—and China—631,000 square miles. Thus, the two countries are very close in the amount of forested land. China and the United States share other interesting similarities. Of the more than 20 life zones, eco-regions that share similar plant and animal communities, 14 of them are found in both countries. An American traveling to eastern China will see many familiar trees, such as oak and maple trees.



The western regions are a different story. The Tibetan Plateau of China with its alpine meadows and treeless steppes, for example, bears no resemblance to the western coast of the United States with its redwood forests and giant sequoia trees, but otherwise the similarities between the two countries outweigh the differences, and so it makes sense to make a comparative study between the two countries.

US FORESTS

Looking at the history of the United States, we can divide forest carbon sequestration into three stages. Between 1600 and 1800, the forest was neither a sink nor a source. Between 1800 and 1900, large areas of forests were cut, and forests became a carbon source. Since the beginning of the last century, around 1900, there was a growing movement to protect forests, to leave them alone. With no activity, the forests naturally made a come-back and in general became a carbon sink. This has been the case for the last 100 years.

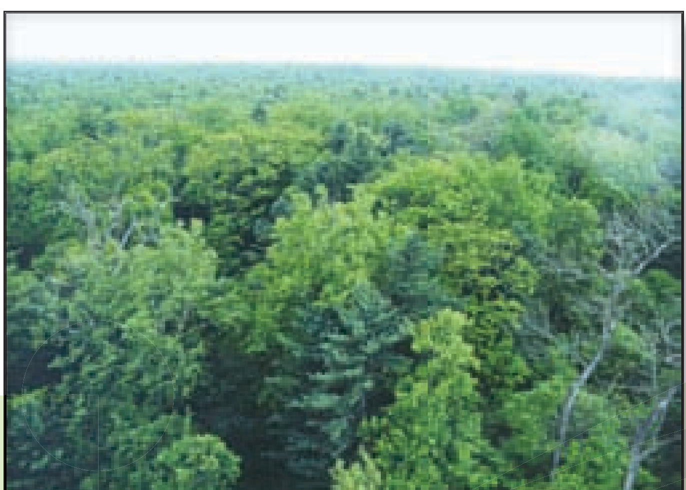
According to one of many studies of US forest carbon sequestration, the total sequestration is about 220 million tons of carbon per year, offsetting 10 percent of US CO_2 emissions. Another study predicts that for the next 50 to 100 years, the carbon sink could continue to expand. Yet another study calculates that another 100 to 200 million tons of carbon sequestration could be achieved, roughly doubling the sequestration of carbon, but that would require a major investment in forestry practices.

There is a problem with these estimates however. A couple of years ago, I looked at the role of forest fire on carbon emissions. Every summer in fire season, the western part of the country is plagued by numerous wildfires. The US National Fire Information Center estimates that the five-year average number of forest fires between 2003 and 2007 was more than 60,000 a year, consuming 2,300,000 hectares of forest. The 10-year average (1997 to 2006) was similar to the five-year average. These forest fires emitted about 220 million tons of carbon per year. The carbon emissions from forest fires, therefore, are greater than the net carbon sequestration of forests, and also greater than the target level for forest carbon sequestration. This is a major factor that contributes to our not reaching the maximum level of carbon sequestration in the United States.

CHINESE FORESTS

About 100 years ago, an American forestry ecologist, Norman Shaw, visited China and wrote a book about his travels, *Chinese Forest Trees and Timber Supply*. Shaw believed that the forest resources in China, particularly in northeastern and southwestern China, were so rich he could not imagine such rich resources could be exhausted, used up by human beings within 100 years. It turned out that was not the case.

The Chinese population has increased about 2.5 times in the last 50 years. In the forested area, human population has increased fivefold. Sprawl is occurring in forested areas, not just around cities and not just in populated areas, but in forested areas. Natural forests have been continuously cut for timber production or other purposes such as the cultivation of ginseng, a mainstay in Chinese medicine.



On the other hand, plantation-style forests in areas that were previously not forested have increased the total forest coverage. The health of the plantation forests, however, is not always good. For example, in the area where I grew up, trees planted 20 years ago now appear thin, weak, and unhealthy. Nevertheless, that kind of plantation is counted as forest even

though production is very low. Forests are planted in areas where the climate is unsuitable, while highly productive natural forests are harvested.

For the last 50 to 60 years, tree planting has been an important activity in China. School children have been involved in planting trees as part of their volunteer work. This is a very challenging task, and sometimes the effort has to be repeated, for example if trees die for lack of rain. They just keep trying until the trees make it. That kind of effort is amazing and is one of the reasons China can be successful in achieving forest recovery.

Recent government figures show that total forest cover has increased in the last 50 years because of the plantation effort, but mature forests with good quality timber are declining. Data on the timber trade indicate that China is increasingly importing timber from abroad to make furniture that is then exported, so the end customer is not necessarily Chinese even though the manufacturers consume a lot of timber.

Three studies on carbon sequestration came to widely differing conclusions about the question of whether China's forests are a carbon sink or a carbon source. One study published in

2001 in Science magazine showed that Chinese forests were a carbon source before the 1980s and became a carbon sink after the 1980s. Another study published in 2004 took a different approach using the very same data and found the earlier study had underestimated carbon sequestration. This is one example of the level of uncertainty in drawing conclusions about the role of forests in carbon sequestration. Different analytical methods and different models can arrive at very different results. The 2001 study estimated only some 30 million tons of carbon were sequestered, while in the 2004 study the amount was double, more than 60 million tons. More recently a study published in 2009 arrived at a figure of 90 million tons of carbon sequestered per year. These three studies with different methods and models show the high level of uncertainty and variation in estimating the role of forests as a carbon sink.

RESTORATION EFFORTS

Despite the uncertainty about precise amounts of carbon sequestered in the forests, the general consensus is that since the 1980s, the Chinese forests have become a carbon sink, primarily due to concerted efforts in forest restoration. The Three-North Forest Ecological Engineering project was launched in 1978 and will run through 2050. So far, about 25 million hectares of forest in 551 counties have been restored. Since 1988, the Natural Forest Conversation Program has protected more than 100 million hectares of natural forest. The Returning Farmlands to Forests Program (Grain-for-Green) has, since 2000, planted nearly 27 million hectares of forest in 1,887 counties.

The latest government figures estimate the total annual carbon sequestration in China's forests at about 135 million tons. Recent reports indicate that the goal is to increase stocking from 2008 to 2010 by 20 percent, in 2020 by 23 percent, and in 2050 by 26 percent. This is a tremendous effort that will be enhanced by voluntary tree planting, afforestation engineering, timber forest development, forest ecosystem management, logging administration, forestland use administration, and forest law enforcement, fire prevention, and pest control.

The challenges to reaching these goals are daunting. As in the United States, China has extreme weather conditions. Insect damage is another major factor. While forest plantations increase, so does the damage by insects and pests, perhaps because too many trees are planted too fast and also because the species selected were not appropriate. China could learn something from the US experience by selecting more suitable species or planting more diverse species rather than monoculture plantations to ensure the forest will be healthy in the future.

Despite the similarities between China and the United States, the differences are striking. Whereas China had 162 million hectares of forested area in 2005, the United States had 223 million hectares. The history of forest damage is also different, with most of the damage in China occurring in the 19th century while in the United States the damage occurred mostly in the 20th century. Only 5 percent of China is devoted to forest plantation, as opposed to 35 percent of the United States, mainly in the southern part of the country. In China, there has been too much human interference on forested areas, while in the United States there has been too little human interference, which has led to high accumulations of biomass and increased danger of wildfire.

China has new policies in place that will change the forest ownership system along the lines of its farmland policy, dividing the land into smaller pieces and placing each family owner in charge of managing the land as they see fit. Forest carbon sequestration in China is 100 million tons per year, about half that of the United States. In China, the top consideration is pest control, while in the United States the top priority is fire prevention. In addition, despite a recent increase in the number of studies on forestry and carbon sequestration in China, the United States has made more effort in research on these issues.

Both countries, with their common issues and different histories, have much to learn from each other in exploring the role of forests in offsetting CO_2 emissions. Future international efforts and collaboration can transfer combined knowledge and lessons learned about managing forests to increase carbon sequestration.

Coupled Climate Biogeochemistry Modeling: Carbon, Nutrients, and Land Cover Change

by Peter E. Thornton

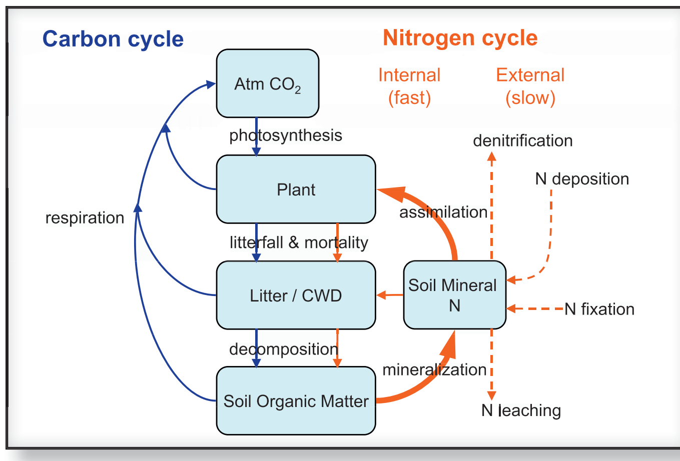
Dr. Thornton *is a Research Scientist with the Ecosystem Simulation Science Group, Environmental Sciences Division, Oak Ridge National Laboratory.*

Climate scientists have already begun creating the next round of simulations and associated analysis that will be included in the Fifth Assessment Report of the International Panel on Climate Change to be issued in 2014. We are motivated by several concerns. Of course, we want to improve predictions of future greenhouse gas (GHG) concentrations and climate change, and we are beginning to introduce biogeochemical cycles into global climate models.

More broadly, we also know that we must be prepared to frame questions directed toward the policy community more so than we have done in the past. These policy-directed science issues include allowable emissions to reach prescribed CO_2 and climate change targets; interactions of climate, biogeochemistry, energy policy, land cover change, and water resources; and a tighter integration between the climate modeling and integrated assessment communities. These trends are leading us toward building a mechanistic foundation for Earth system modeling and adding the human dimension to climate system models.

CLIMATE-CARBON CYCLE FEEDBACK

The components of the climate-carbon cycle feedback, and the interactions between the climate system and land carbon storage on atmospheric CO_2, are complicated. We know for sure that as atmospheric CO_2 increases, there should be an increased uptake of carbon on land due to the CO_2 fertilization effect, but the magnitude of that effect is still quite uncertain. We also suspect that as temperature increases and precipitation patterns change, there will be a change in land carbon storage. Previous work has suggested this would result in a net release of carbon from land ecosystems, but the magnitude of that release is uncertain. We know from an ecological perspective that carbon and nitrogen cycles are tightly coupled, and we suspect that coupling should have a strong impact on the response of CO_2 to temperature and precipitation changes. Earlier hypotheses suggested that CO_2 fertilization might be even smaller when the nutrient cycle is considered. Preliminary results also suggested we might actually change the influence of temperature and precipitation by including nutrient dynamics. We don't yet know what the overall feedback is because of uncertainty in the magnitude of the CO_2 fertilization effect, and uncertainty in the counteracting climate change effect .



The nitrogen cycle can be represented as a combination of relatively slow inputs from and losses to the external environment, and relatively fast internal cycling. The external cycle is a very slow cycling of nitrogen deposition and fixation as the input, with denitrification and other gaseous losses and leaching as the output. Internal cycling is a fast cycling in the soil, litter, and plant ecosystem. The key new feedback we are adding in this context is a very strong one. The influence of warming on soil organic matter is certain to increase respiration, resulting in a loss of CO_2, but at the same time causing a mineralization of nitrogen which is then made available to plants and microbes. There is, therefore, the potential for a fertilization effect that would lead to a significant change in the dynamics for the carbon cycle.

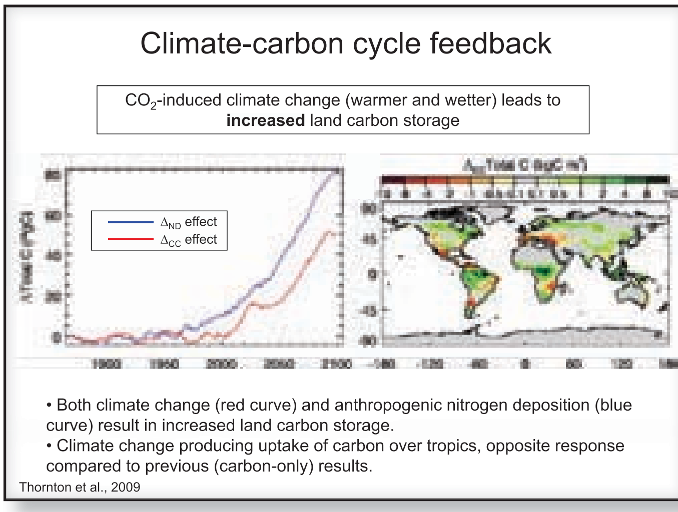
In sum, we have two hypotheses: first, that the smaller CO_2 fertilization effect compared to a carbon-only model implementation would be an important result of carbon-nitrogen (C-N) coupling; second, that we might have reduced strength or even change in what was previously assumed to be positive feedback from climate change, particularly warming. We can look at the CO_2 fertilization effect using a couple of different modeling studies, the National Center for Atmospheric Research's (NCAR) Community Land Model coupled to carbon/nitrogen cycling (CLM-CN) and a fully coupled Community Climate System Model (CCSM3.1). We used the two models to project land carbon cycle sensitivity to increasing atmospheric CO_2 from observed climate from 2000 to the present and predicted climate out to the year 2100. The carbon-only version of the model and the C-N version showed a significant difference, with a much smaller CO_2 fertilization effect when the nitrogen limitation effect is taken into consideration. With the fully coupled CCSM3.1 model, we found essentially the same sort of behavior. The effect of C-N coupling is to increase atmospheric CO_2 substantially compared to previous model results that relied on carbon only dynamics. From the simulation perspective,that part of the hypothesis seems to be quantitatively robust.

We also modeled the effects of increasing CO_2 on nitrogen availability from the 20th century through 2100. As CO_2 increases there is actually a decline in nitrogen availability. We see increased nitrogen availability due to anthropogenic nitrogen deposition, which is not surprising, but we also found an increase in nitrogen availability due to climate change. As the climate warms, the mineralization effect makes new nitrogen available.

Research on the Oak Ridge Reservation of Oak Ridge National Laboratory is providing support for this hypothesis with observations and experimentation. The Oak Ridge Experiment on CO_2 Enrichment of Sweetgum is a Free-Air CO_2 Enrichment (FACE) experiment. The sweetgum (*Liequidambar styraciflua*) plantation is a closed-canopy deciduous forest that was started in 1988. CO_2 exposure (545 parts per million) began in 1998. We have reported that net primary production (NPP) showed a consistent response to elevated CO_2 between 1998 and 2004. We found that NPP has been declining in both ambient and elevated CO_2, and the response of NPP to elevated CO_2 has also declined. There is evidence from foliar nitrogen concentration measurements that for both the elevated and ambient plots the sites had a declining nitrogen economy over that period and that the declining NPP response is probably related to the decline in the nitrogen economy. These findings suggest that there is real evidence for this mechanism, that this is not just a model fantasy land.

Another simulation we have run uses CCSM3.1, combining an atmospheric model, an ocean ecosystem model, plus the C-N model mentioned earlier. The simulations run in the stable control configuration for one thousand years so that we know the climate simulation itself is stable. We force the atmosphere with fossil fuel emissions and nitrogen deposition from the high forcing (A2) scenario of the IPCC's Special Report on Emissions Scenarios. This allows us to look at the effects of two different implementations in the model, one where the radiative effect of atmospheric CO_2 is coupled and another where that radiative effect is fixed; that is, simulation with and without radiatively forced climate change. We ran four simulations: a control experiment, a climate change experiment which switches between this radiative CO_2 forcing either fixed or prognostic, and an additional nitrogen deposition experiment.

Our hypothesis was that the difference in the carbon cycle would be related strongly to nitrogen availability. We also wanted to look explicitly at the influence of hitting the system with higher nitrogen deposition. As expected, from 1850 to 2100, as nitrogen deposition increases, the total carbon in the land ecosystem increases. In addition, with a warmer climate and changing precipitation patterns, we actually had an increase of carbon on land as opposed to a decrease, contrary to what previous modeling studies had found. Both climate change and anthropogenic nitrogen deposition result in increased land carbon storage. There were some important spatial variations that also differed from previous results. In the tropical zone we see a net uptake of carbon as opposed to net loss These results highlight the importance of tropical systems in terms of understanding this dynamic on the ground. Moreover, the temperate and high latitude systems appear to be an important part of the picture as well.



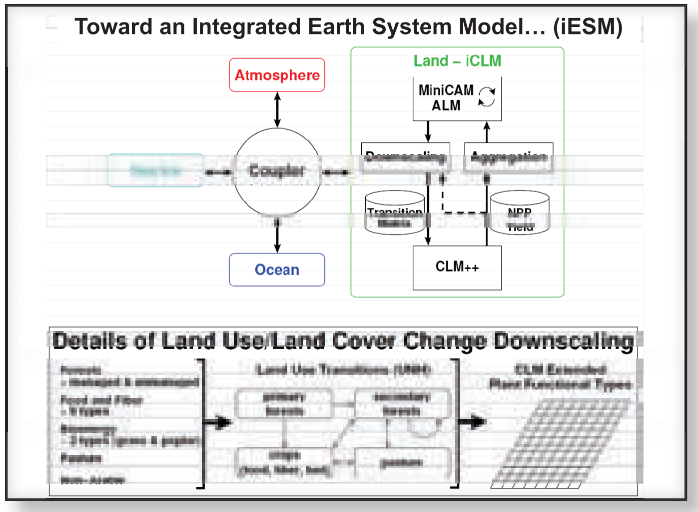
We have also been able to accurately pin down in the model the response of gross primary production (GPP). GPP is highly correlated with gross nitrogen mineralization. The same pattern appears for the climate change effect. We see a much bigger increase in GPP associated with a strong increase in gross nitrogen mineralization. Increased nitrogen deposition also causes an increase in soil organic matter and vegetation carbon stocks. With the climate change effect, we get a very strong increase in vegetation carbon that is related to decreased soil organic matter and litter. This is consistent with the idea that increasing temperatures are increasing the respiration rate, driving carbon out of the soil system but at the same time mineralizing nitrogen which fertilizes plant growth. That is a robust mechanism in the model.

In the end, when the CO_2 fertilization effect is combined with the climate change feedback, even though the climate change feedback tends to bring down atmospheric CO_2 compared to previous results, the combined effect, reducing CO_2 fertilization while at the same time making climate change feedback weaker, leads to a higher than predicted CO_2 concentration. In the AR5 version of simulation models, we therefore expect to see higher than previously predicted CO_2 concentration and predictions of climate change as well.

There is, of course, a range of uncertainty in these dynamics. We are not really sure how these will play out over time. Depending on the way those mechanisms operate in space and time, we could see an uncertainty of up to 400 parts per million in the CO_2 concentration by 2100, a very significant effect. These dynamics are also not yet adequately constrained by experimentation. This is an important message for the experimental community and the modeling community as well. We are at a juncture where we are just beginning to design and implement some of these experiments to evaluate these kinds of hypothesis.

GLOBAL DYNAMICS

Using a global, offline model not coupled to the CCSM based on observed weather data through the present day, we are looking at four different effects. The first is the influence of CO_2 on the net ecosystem exchange. At present, we estimate about a 1 petragram of carbon (PgC) per year global uptake due to CO_2 fertilization. The influence of increasing nitrogen deposition represents about a quarter of the PgC present day influence. In terms of land use cover change flux, we estimate quite a big uncertainty due to inter-annual variability. It is not really useful to separate the land use/land cover change component of this budget from the rest of the land response because there are interactions between CO_2 fertilization and the distribution of nitrogen availablity. When we consider all those effects, we find the land is just now in a neutral state and may be on its way to a net uptake as the CO_2 fertilization effect increases. Land use and land cover change effects eventually plateau.



Is it important to have these interactions happening within the same model? Could you just make a linear combination of these effects, or is it really important to have the interactions captured? As CO_2 concentration and nitrogen deposition increase, there is an interaction effect that leads to increased uptake because nitrogen deposition is alleviating some of the nitrogen limitation, so the CO_2 response can be stronger. Land use change effects on the other hand are strongly negative in terms of net source of CO_2 to the atmosphere. As land use change proceeds, more and more area is taken out of circulation as a potential carbon sink; the same is true for the nitrogen deposition-land use interaction effect. All these interactions together lead to a very significant interaction effect. This trend appears to grow exponentially over time. We expect that by 2100, this interaction effect will approach a first order effect on the climate system.

Based on these preliminary results, we have begun to implement a program to couple the dynamic land allocation component of several different integrated assessment models into the CCSM. The overall strategy, based on the Integrated Earth System Model (iESM) that we have in place and the historical land use information that comes into CCSM, is to predict climate change and updated carbon stocks and fluxes due to land use change. We can feed that information back to iESM and close the loop on these dynamics. That is something we have not been able to do before.

New experimentation is needed to address fundamental uncertainty in climate-carbon cycle feedbacks. We also need to increase the relevance of this modeling and experimentation to the policy making and decision-support community. Human modification of land use may represent a dominant control on carbon-nutrient-climate interactions over the coming century. We must use our modeling and experimentation capabilities to integrate these dynamics as quickly as possible.

Molecular-isotope Approaches to Track Soil Organic Matter Dynamics: The Impact of Earthworms in High Atmospheric CO_2 Forest Experiments

by Timothy R. Filley

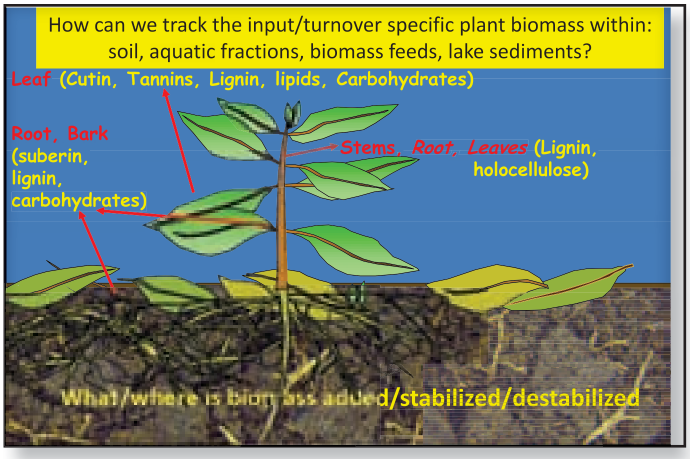
Dr. Filley *is an Associate Professor of Isotope Geochemistry in the Department of Earth and Atmospheric Sciences, Purdue University.*

Scientists in the 21st century are not the first to consider the importance of earthworms to soil health. In *The Formation of Vegetable Mould through the Action of Worms, with Observations on their Habits* (1881), Charles Darwin was impressed with the amount of organic matter brought up to the soil surface by deep burrowing earthworms in a pasture in Staffordshire, England. If Darwin had had a mass spectrometer, we might be much further along today in understanding the dynamics of soil organic matter

We can study the complex role that earthworms play in ecosystems by analyzing the chemistry of their fecal matter. In particular, we can look at the biopolymers signatures of plant and microbial components within fecal matter to track how earthworms control the movement of carbon or nitrogen within soil and litter systems. This tracking can also help us determine whether carbon is stabilized or destabilized by this action and what carbon pools are made available during times of stress or in the absence of stress. Also, when we couple structural analysis of biopolymers to stable carbon isotope analysis of those compounds we can determine how earthworms and forest systems have responded to new carbon input and determine the input and turnover rate of specific plant biomass within soil. We can do this where plant communities have large differences in natural stable isotopes or where ^{13}C-labeled plant material is added to the soil by fumigations with ^{13}C-labeled CO_2 or by adding isotopically labeled litter.

STABILIZATION OF SOIL ORGANIC MATTER

Different organs of plants can have distinct chemical components that can be used as markers for a particular kind of plant input to soils, sediments, and water. For example, an organ may have very distinct cutin, tannins, lignin, lipids, and carbohydrates that set it apart from roots of that same plant or distinguish it from other plants. There are also microbial-derived biopolymers that can be used to track their input of carbon and nitrogen to soils. In addition to the knowledge of the quantity and chemistry of what is added to soil, it is imperative to know the physical associations organic matter has in soil as that gives us a good indication of the level of stability of the soil carbon.



We have known for a long time that many factors control the stability of soil organic matter: the mineralogy and texture, the abundance and type of microbial populations, the type and rate of plant input, the chemistry of the input, soil moisture, and soil temperature. Additionally, we need to consider what physical structures the soil organic carbon resides within. For example, micro-aggregated soil organic carbon typically turns over at a much slower rate than carbon pools outside of micro-aggregates. So, if particulate organic matter is not micro-aggregated to more accessible microbes, water, and oxygen, it thus undergoes decomposition more readily than if it is micro-aggregated.

PROXY BIO-MACROMOLECULES

Bio-macromolecules are major sources of carbon input to soil. Consider two bio-macromolecules, both of which are polyesters. One polyester is suberin, which is found in roots and is a main constituent of cork. Another is cutin, which is embedded within cuticular waxes of plants. Suberin has a large amount of aromatic monomers and is dominated by C18 type monomers. Cutin, on the other hand, which is part of the waxy coating of leaves, is dominated by C16 monomers, is hydrophobic, and does not have the aromatic backbone of suberin. This distinct chemistry is important because we can determine their relative input in soils through molecular chemolytic biomarker means.

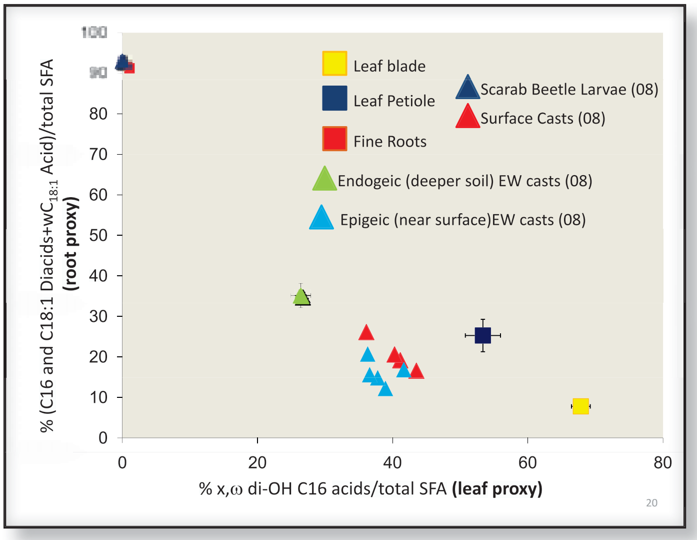
There are challenges to studying the composition and stable carbon isotope composition of lignin, cutin, and suberin as the biomarker approach requires analytical chemical or thermal decomposition to break down biopolymers into fragments that are chromatography amenable. The assumption then is that we can take those fragments and rebuild the macromolecule to some degree, but that is not always true. Some signature will be lost. Moreover, structures can be highly variable among plants. Lignin, for instance, has a huge amount of structural variability and also undergoes structural changes during decomposition and plant growth stages. Finally, these isolation tools are incomplete. Sometimes the material is highly degraded, and as a result the extraction efficiencies decrease.

SLEUTHING THE SOIL

We have analyzed soil samples from a sweet gum plantation at Oak Ridge National Laboratory, part of a Free Air CO_2 Enrichment (FACE) Experiment investigating the impacts to forests under a high CO_2 atmosphere. We wanted to know whether we can look at soil particles and determine whether leafy tissue or fine root tissue is selectively preserved in the soil. The distinct cutin and suberin chemistry of sweet gum leaves and roots gives us the capacity to track relative input and stabilization. Additionally, because the CO_2 used for fumigation is isotopically depleted in ^{13}C with respect to the atmosphere, the sweet gum produces organic matter highly depleted in ^{13}C with respect to natural plant matter. This permits the quantification of fraction of new and old pre-fumigation carbon in soil particles and biopolymer fragments extracted from the soil and soil physical fractions. We analyze the ^{13}C content of the biopolymer fragments using compound specific isotope analysis.

WORM'S EYE VIEW

We applied these diagnostic isotopic tools to study the fecal matter of invasive and native worms as well as June beetles found at FACE sites to determine what the worms are eating, whether mostly leaves or mostly fine root, or whether it was eating background soil formed prior to fumigation by the ^{13}C-depleted CO_2. Our preliminary data demonstrates how scarab



beetle larvae feed on fine root tissue and contain nearly no pre-FACE fumigation carbon. Also, the endogeic worms, the deeper soil dwelling and burrowing earthworms, had a good deal of recent-FACE CO_2-derived root suberin, but contained older background pre-FACE lignin. However, the epigeic, or litter and surface dwelling worms showed an abundance of cutinous material but little pre-FACE fumigation biopolymers. This means the endogeic worms are passing and mixing up old soil carbon.

Compound-specific isotope analysis is a powerful approach to soil/litter dynamics. It allows us to track movement of carbon and nitrogen in a system tied to specific classes of organisms. We must, of course, consider the limitations of any soil/molecular technique. To get the most benefit out of these techniques we must isolate from the soil functionally important particles that relate to stabilization chemistry. In addition, there is a great need to standardize soil analysis and archival methods, especially if we are going to set up joint projects that focus on how we view the soil in different ecosystems.

Landscape Changes and Vegetation Restoration on the Loess Plateau in China

by Jun Fan

Dr. Fan *is an Associate Professor of Soil Physics at the Institute of Soil and Water Conservation, Chinese Academy of Sciences.*

The Loess Plateau is located in the middle reaches of the Yellow River and encompasses 640,000 square kilometers (km^2). The plateau is named for its silty—loess—soils, which can be very fertile. Loess soils, however, are also highly erodible. Land that once supported agriculture has, over time, been deforested and overgrazed. Today, 20 percent of the plateau is severely eroded

The plateau is divided into three regions from south to north. The southern part, which we call South Tableland with Gullies, is used for farming. In recent years, part of this region was converted from typical local crops like winter wheat to orchards, which bring in more money to local farmers than other crops. It is very important to keep these lands in production for the benefit of local farmers, but the challenges of dealing with erosion are great.

The middle part of the region, which we call Central Hilly with Gullies, is a highly eroded landscape with a different soil texture than that of the South Tableland. The gullies are created by precipitation. Here too, most of the land is still used for food production. Every year as people farm this land, soil erosion increases, and more gullies are created. There is some tableland in this area, but people still use sloping land for agricultural production. More than 15 percent of cropland is located on steep lands with more than 25 degrees of slope. Forest land occupies less than 12 percent of the total, and only 6.5 percent of the forest land is effective at controlling soil erosion.

The northern region is called North Water and Wind Erosion. In the fall and winter, serious erosion occurs due to heavy winds, while in summer, erosion from precipitation is high. Grassland occupies about 30 percent of total land area, and nearly 70 percent of the grassland is degraded due to overgrazing.

In the Loess Plateau, the total amount of soil erosion is about 3,700 tons per km^2 per year. Sediment in the whole Yellow River Basin is 1.6 billion tons per year, and almost 90 percent of that is from the Loess Plateau. Almost half of the total Yellow River Basin suffers from soil erosion.

Sediment from soil erosion is deposited in rivers, lakes, and reservoirs, and we have committed substantial amounts of money toward construction projects to protect the Yellow River. Nevertheless, the riverbed of the Yellow River rises about 8 to 10 centimeters (cm) yearly. The riverbed near Kaifen City, located along the river, is 30 meters higher than the city, creating dangerous conditions for people who live there. The economic impacts for local farmers, who cannot make a profit from this eroded ecosystem, are severe.

Water erosion has also caused quite serious changes. Data collected for the past 20 years shows that water erosion has decreased from 1990 to 2000; wind erosion, however, has increased during the same period.

ACTIONS AND ACHIEVEMENTS

The Loess Plateau is considered one of the national key projects of soil and water conservation. The Chinese government has invested money to transform slope land to terraced land. Contour ditches on steep slopes retain enough water so that plants and shrubs can be planted. Water-retention basins known as fish-scale pits also retain water and improve soil moisture, allowing trees to be planted there. We have also constructed reservoir systems in the gullies. Water impounded behind the dams can be used for irrigation and may also

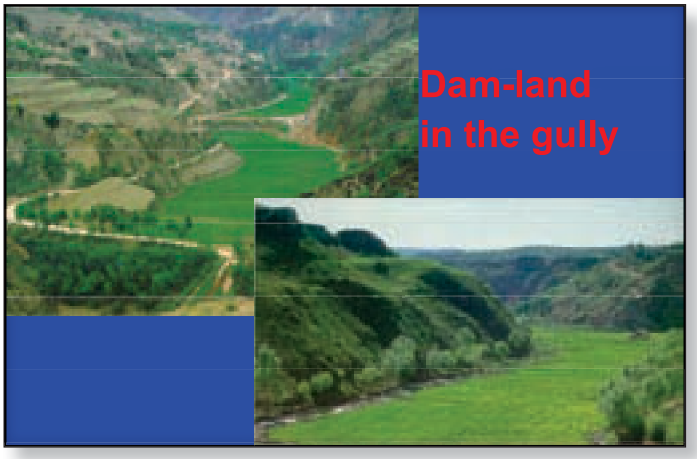
we have made headway in reversing the effects of centuries of degradation of the landscape. Recent trends in soil and water conservation provide some encouragement. Almost 15 percent of the total area has been controlled, sediment has been reduced by 374 million tons, 2 million hectares have been converted to terraced fields, 0.3 million hectares have been dammed, and the capacity of reservoirs has increased to 10 billion m^3.

In 1999, former Premier Zhu Rongji visited the Loess Plateau with the governors of Shaanxi Province, calling attention to the plight of the land and the people who live there and calling for a major commitment to controlling soil erosion. Much has been accomplished since then, but there remain numerous

recharge the groundwater table. After many years, the dams may retain enough sediment to create fertile land, with higher water content and soil nutrients.

The Chinese government has also established experimental and demonstration sites to provide different models for soil water conservation. We already have many field stations and a few models to show how to reduce the loss of soil. We also hope to expand experiments and demonstrations from the small watershed scale (10 km^2), to the catchment scale (700 km^2), to the regional scale (80,000 km^2). Comprehensive management of small watersheds can result in increased soil moisture content and allow planting trees, and perhaps some grassland, on top of mountains.

Though the silty soils of the Loess Plateau are highly erodible,



opportunities and challenges for Chinese researchers. The problems on the Loess Plateau need more attention from the public. The area still needs a larger amount of investment from the government for research and local land changes. We must also develop advanced technology to conserve the soil and water.

We urgently need to pay more attention to the regional impacts assessment of sediment erosion and soil and water conservation. There are five major areas of concern: water quality and quantity; soil quality and sedimentation; climate, whether drier or wetter in response to global change; biology, the structure and distribution in different regions of the plateau; and social and economic structure.

Our research in these areas will allow us to tell decision makers what the future holds, whether positive or negative. The overall objectives for the future are 1) by 2010, assure control of 60,000 km^2 of eroded area; 2) by 2030, control 1 million km^2 of eroded area, 3) in the mid 21st century, realize a sound eco-environment in the Loess Plateau and in China as a whole. The future is bright, but we have a long way to go.

MITIGATION STRATEGIES

Without major advances in energy efficiency, rising demand for energy will outpace any gains China makes in reducing emissions of carbon and other greenhouse gases. Yan-Jia Wang with Tsinghua University says gains in energy efficiency during the first years of the 21st century have been offset by economic growth. At some point, the economy may become more reliant for increased gross domestic product on less energy-intensive industries such as services and banking. As long as the country's economy is heavily invested in energy-intensive enterprises, it will be difficult to achieve the targeted goals the government has set.

Studies of the urban thermo, or heat island, effect, in China's cities confirm the impression that temperatures in urban areas are higher than in surrounding areas. Jin-Lou Huang with the Chinese Academy of Sciences says urbanization causes heat waves that intensify the effects of global warming. Cities should be encouraged to lower urban sources of carbon by using renewable energy sources and add green space and vegetation to counter urban climate change. Both actions contribute to the improvement of human well-being.

The Clean Development Mechanism (CDM) is one of three Flexibility Mechanisms defined in Article 12 of the Kyoto Protocol and entered into force in 2005. One aim of the CDM is to allow industrialized countries to receive some emission reduction credits at a lower cost by investing in low carbon emission projects in developing countries. Sheng Zhou with Tsinghua University says that in the future, we will need to improve or modify the rules with an aim to increase efficiency, improve the feasibility of implementation, bring costs down to an acceptable level, encourage low-carbon technology transfer, and enforce the rules as originally designed.

The sharp rise in energy consumption in China is fueled in large part by the growth in exports, which have risen dramatically in recent years. Tsinghua University's Alun Gu says that a key question is whether carbon emissions should be accounted for at the point where goods are produced and emissions generated or instead at the point where the products are consumed on the basis of their embodied energy, the total amount of carbon emitted in producing, delivering, consuming, and disposing of the goods. China needs to seriously consider export embodied energy/emissions and avoid becoming a pollution haven.

One of the biggest hurdles in making the use of cellulosic bioethanol feasible is cost. One promising option to achieve cost reductions is consolidated bioprocessing (CBP). Qiang He at the University of Tennessee says that improving the efficiency of CBP will depend on finding a biocatalyst that reduces the process to a single step. A candidate biocatalyst that can accomplish this is *Clostridium thermocellum*. Genomic sequencing of bacteria reveals one strain that outperforms the others as a catalyst.

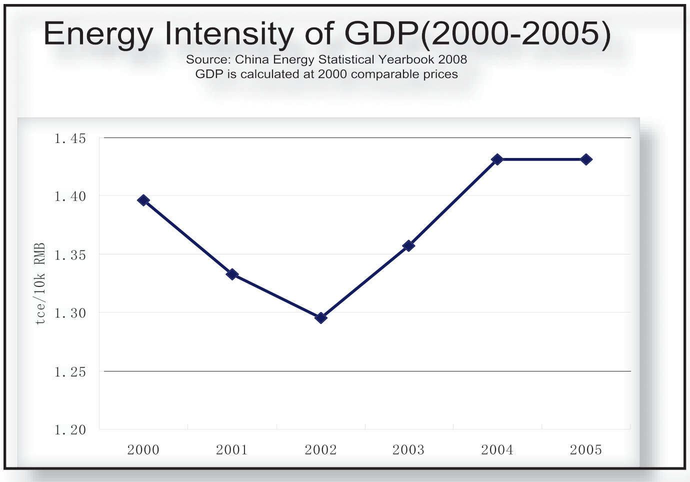
China's Efforts for Energy Efficiency in Industry

by Yan-Jia Wang

Dr. Wang *is an Associate Professor of Energy Analysis at the Institute of Energy, Environment and Economy at Tsinghua University.*

For all the efforts made to convert renewable resources to energy products, without major advances in energy efficiency, rising demand for energy will outpace any gains China makes in reducing emissions of carbon and other greenhouse gases (GHGs). It does not make sense to create a source of energy and then use it inefficiently.

Energy intensity is a measure of the amount of energy it takes to result in a rise in Gross Domestic Product (GDP) of a country. For decades China experienced a decrease of energy intensity even as its energy consumption and Gross Domestic Product (GDP) rose. After 2002, energy intensity began to rise. To understand why, it is helpful to look at some basic events that occurred between 2003 and 2005 .



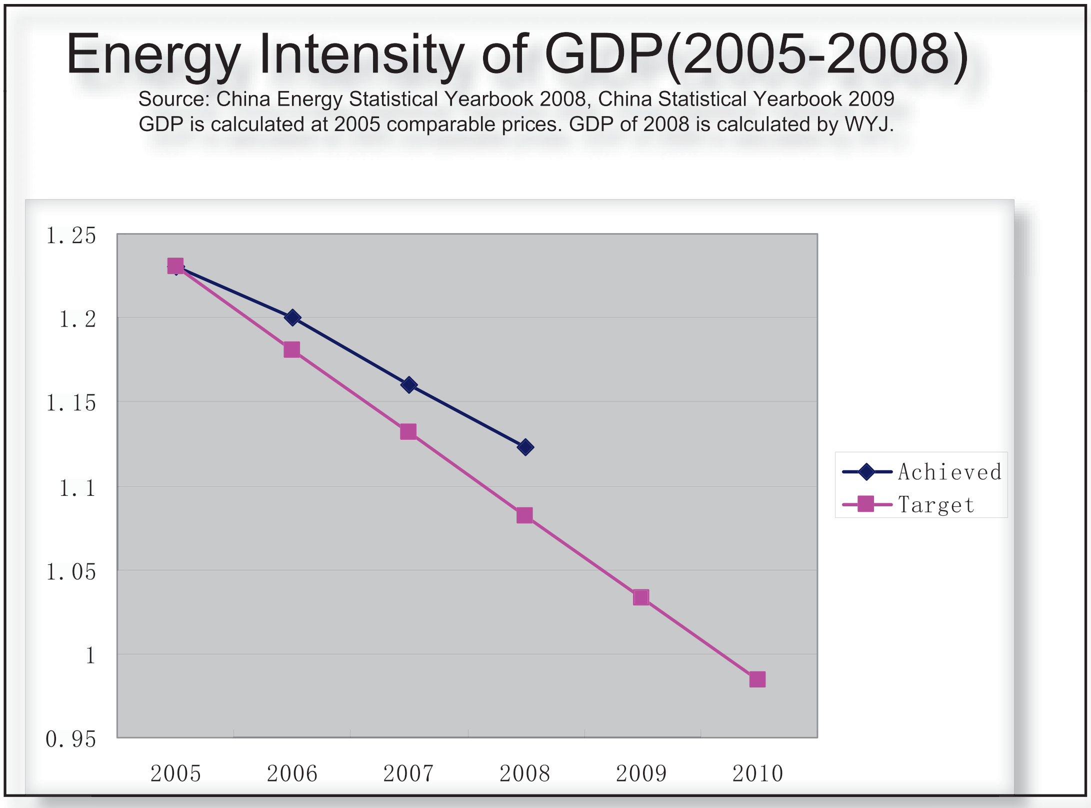
In 2003, China experienced energy shortages in three areas: electricity, oil, and even coal. There was a quick switch from surpluses to shortages spread across a broad regional range, in 24 out of 31 provinces. These shortages continued until 2005. At the same time, energy consumption rose. This situation raised worries about international oil prices, emissions from coal consumption, and energy security—internally, regionally, and worldwide. As a result, the Chinese government included energy efficiency goals in its 11th Five-Year Plan (2006-2010), which sets a target of decreasing energy intensity of GDP by 20 percent within five years. This is the first time the government has set a quantified target on energy efficiency in its Five-Year Plans. Responsibility for implementing the total target is divided among provincial governments, large industrial groups, cities, and large energy consumers. Industry, of course, is the most important sector because it consumes more energy than the others and emits more GHGs.

TARGETED GOALS

The 11th Five Year Plan establishes what is called the Top 1,000 Enterprises Action Plan. Nine energy intensive sectors were defined: steel, non-ferrous, coal production, electricity generation, petroleum, chemical, building materials, textiles, and paper. Each of the approximately 1,000 enterprises identified consumed at least 0.18 tons of coal equivalent (TCE) per year and accounted for 33 percent of the national total and 47 percent of the industrial total in 2004. These enterprises are required to report their energy consumption to the central government annually.

The plan also calls for rethinking the tariff subsidy policy. The government used to subsidize energy intensive industries to lower the price to large consumers by direct supply or sales agreement. That subsidy has been reduced a bit but the plan still kept some subsidies to large industry. The plan also includes shutting down small coal-fired power plants. By the end of June 2009, the government had closed more than 50 of these small plants, so the share of small-scale plants decreased from 30 percent in 2005 to 14 percent in 2009 in total capacity. The first to be shut down are small capacity plants, second are those that do not meet environmental standards. Large plants are given a certain time to adjust to the facility and meet the standards. If these larger plants still cannot meet the standards, they are also shut down.

In 2007, the government revealed that no province had reached its target for efficiency improvements at the end of the first year of the Five-Year Plan. Some provinces did not implement the changes ordered by the central government in part because of some confusion about the policies and the



targets, but also because many did not understand how serious the central government is about energy efficiency. The policies themselves also have some inherent problems.

The government then set several new policies to improve energy efficiency and began rethinking the tariff subsidy policy, including canceling or reducing discounts to aluminum, ferrous-alloy, and alkali enterprises. In 2007, the government also renewed its emphasis on shutting down smaller and older coal-fired power plants and other plants that failed to reach the new environmental standards. In addition, small co-generation plants were to be replaced by larger ones, and medium-scale power plants were encouraged to retrofit to co-generation capacity. Other initiatives included installing flue gas desulfurization (de-Sox) equipment to high capacity generators and prohibiting the transfer of public power plants to private enterprises.

MORE ACTION NEEDED

Despite all these efforts, more-specific and measurable actions are needed. In evaluating improvements in energy efficiency, we found that in 2006, no region had reached its target. It has also been difficult to determine the linkages between GDP and energy efficiency targets. In October 2007, the National Development and Reform Commission (NDRC), the Ministry of Finance, and the Power Supervision Commission together published a new policy that would 1) stop subsidies to the ferrous-alloy sector by the end of October unless an enterprise received an exemption from the NDRC, 2) stop special subsidies to aluminum producers by the end of 2007, 3) stop subsidies to the Chlor-Alkali industry by the end of 2008, and 4) stop all subsidies from local governments immediately. The penalty for non-compliance was suspension of new power plant projects or reduction in the number of new projects.

The new policy calls for very specific efficiency improvement targets and mandatory standards for energy-intensive products. Effective June 1, 2008, the norms for energy consumption per unit of product were published. These norms cover a variety of products, from crude steel to ferroalloys, cement, ceramics, and metals, and more new norms are under development.

To determine whether the standards are being met, the energy reporting system has also been restructured. Enterprises consuming more than 5,000 TCE per year are required to report their previous year's energy consumption by the end of April each year. The central government, provincial governments, and even some cities give financial awards if the business demonstrates significant improvements in energy efficiency.

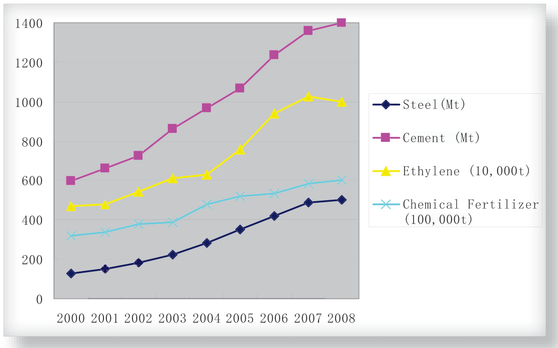
An example of improved energy efficiency is the implementation of low temperature waste recovery for power generation at cement plants. In addition, an automobile accessory company has introduced on site aluminum smelting to transfer liquid aluminum directly to the casting facility, eliminating the need to re-smelt the aluminum and saving 1 million cubic meters of natural gas per year.

Between 2005 and 2008, the energy intensity of GDP showed significant declines, though the achieved result still lags behind the targeted improvements. Of 31 regions, 11 have reached more than 60 percent of the targets. These 11 provinces produced 55 percent of GDP in 2008.

Achieving energy efficiency goals depends heavily on economic structural changes, and we have a long way to go. While improvements are being made through shutting down old power plants, retrofitting others, and canceling subsidies to energy-intensive enterprises, the actual number of energy-intensive industries has increased since 2000.

China is a major producer of steel, cement, ethylene, and chemical fertilizer. At some point, the economy may become more reliant for increased GDP on less energy-intensive industries such as services and banking. As long as the country's economy is heavily invested in energy-intensive enterprises, however, it would be difficult to achieve the targeted goals the government has set.

While Energy-intensive Industry Increased…



Source: China Statistical Yearbook 2001--2009

Urban Climate Change: A Comprehensive Ecological Analysis of the Thermo-effects of Major Chinese Cities

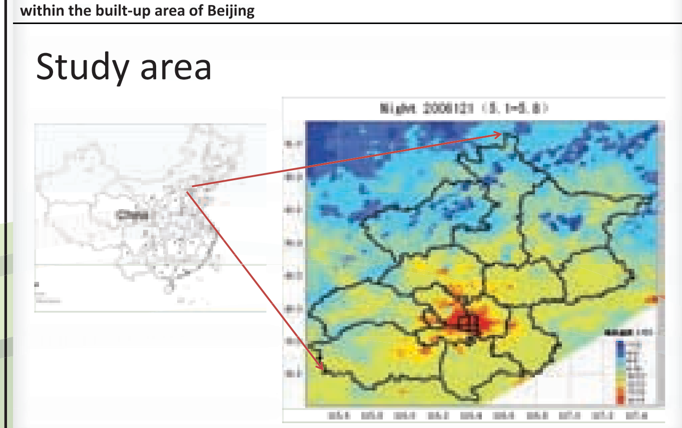
by Jin-Lou Huang

Dr. Huang *is an Assistant Professor of Urban Ecology at the Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences.*

More than 50 percent of the world's population live in urban areas, which are characterized by large areas of impervious surfaces and more intensive use of fossil energy than is the case in rural areas. Because of the urban thermo-effect, or heat island effect, the temperature in urban areas is higher than in surrounding areas. Urbanization increases greenhouse emissions (GHGs) and contributes to global climate change, causing heat waves that intensify the effects of global warming. Urban climate change also has adverse impacts on human well–being such as heat disease and high consumption of energy for air conditioning, which worsens air pollution.

At the Research Center for Eco-Environmental Sciences, we have conducted the first nationwide study of 89 major Chinese cities to 1) determine how the urban thermo-effect has changed during the past 50 years of rapid economic development in China, 2) identify the main factors that affect the urban thermo-effect, and 3) find ways to adjust controllable factors to mitigate increasing urban temperatures. In 2004, the total population of these large cities was more than 600 million people, over half of the population of the whole country, and the Gross Domestic Product (GDP) of these cities accounted for two thirds of the total GDP for the whole country.

Case 2: Simulation of thermo-effects due to different amounts of urban vegetation within the built-up area of Beijing



The temperature data we used included the highest average monthly temperatures from 1950 to 2007 recorded by national urban weather stations located in each city. The changes in average monthly temperatures through the decades are an indicator of the urban thermo-effect. We also compared the spatial distribution of the urban thermo-effect in the 1990s and 2000s with that of the 1950s.

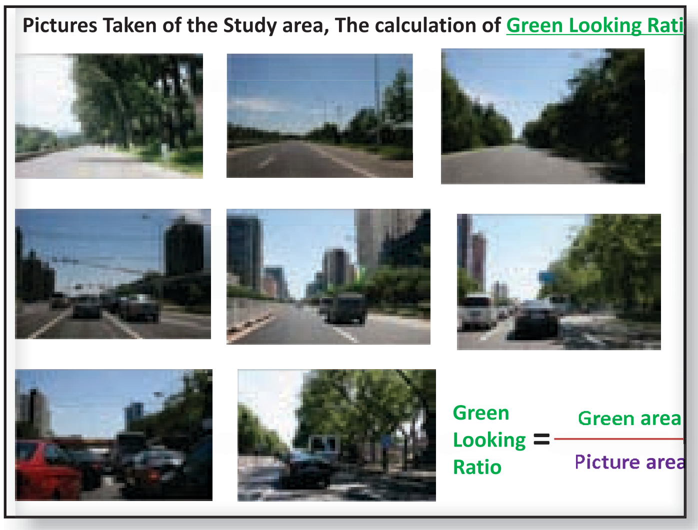
By understanding which indicators affect the urban thermo-effect, we may be able to mitigate the effects. Out of 22 types of indicators, we selected six that had a positive correlation with the urban thermo-effect: GDP of the built-up area, population of the built-up area, size of the built-up area, transportation as measured by gross of freight, annual electricity consumption, and green areas within built-up areas as measured in hectares. These comprise the main factors for a comprehensive ecological analysis of urban thermo-effects.

URBAN VEGETATION

Urban vegetation can have a mitigating effect on urban heat islands. We therefore performed a simulation of the thermo-effects of varying amounts of urban vegetation within the built-up area of Beijing. We tried to quantitatively explore how the temperature might change under various scenarios, from removing all vegetation to increasing the current amount of vegetation in the city. This gave us an idea of how much vegetation is required to cool the urban area to a temperature comfortable for humans.

We focused on the Forbidden City in the middle of Beijing. The total area is 900 km^2 and almost 7 million people live and work there every day. Currently, the urban green area, consisting of urban parks and other vegetation, is about 230 km^2. We used the Normalized Difference Vegetation Index from remote sensing as the indicator for the green area, applied a mono-window algorithm for retrieving land surface temperature from Landsat TM data, and then applied a linear relationship between the surface temperature and the near-surface temperature. Our analysis showed how important green vegetation is in the urban area.

We considered five scenarios: the city barren of vegetation, the city with deteriorated or unhealthy vegetation, a baseline of the city as it was in 2005, the city with somewhat more vegetation, and the city with a high amount of vegetation. Based on projected land surface temperature changes and near-surface temperature changes from these five scenarios, we determined that with sufficient vegetation, the urban heat island becomes less pronounced. Without any other strategy at all, the city can be cooled just by increasing the amount of urban vegetation. This information provides a reference tool to the Beijing government for urban land use and management decisions. In addition, our formula can be applied to any city to show how large the green area should be to reduce the urban heat island effect.



URBAN ROADS

Another case study focused on the thermal effect of the urban road ecosystem in Beijing on summer days. We specifically explored the relationship between the thermal effect of the urban road ecosystem and the "green looking ratio." This ratio is estimated from photographs taken from a camera mounted on a car deployed throughout the urban area. The thermal effect was obtained by recording the temperature in the center of Beijing and in surrounding rural areas . We found significant differences in temperature between the northern rural area, the southern rural area, and the Forbidden City of Beijing, which is clearly a heat island surrounded by cooler areas. I have since taken photographs and measured the green looking ratio of Knoxville and found the ratio is generally very good. The formulas we create with these tools can be very important in making landscape design decisions. By simply measuring the amount of green in a photograph, it is possible to predict the cooling effect of vegetation. Green vegetation in urban areas and along roadways is an important tool in mitigating the urban thermo-effect.

In addition to measures designed to cool the urban environment, cities should also be encouraged to lower urban sources of carbon by using renewable sources such as wind power, hydro power, biomass, and solar power. More green space and vegetation can counter urban climate change, while increased production and use of renewable energy counters global climate change. Both actions contribute to the improvement of human well-being.

Carbon Market and Clean Development Mechanism (CDM) in China

by Sheng Zhou

Dr. Zhou *is an Associate Professor of Carbon Market at the China Automotive Energy Research Center, Tsinghua University.*

The Clean Development Mechanism (CDM) is one of three Flexibility Mechanisms defined in Article 12 of the Kyoto Protocol and entered into force in 2005. According to the United Nations Framework Convention on Climate Change, the CDM "allows emission-reduction (or emission removal) projects in developing countries to earn certified emission reduction (CER) credits. The mechanism stimulates sustainable development and emission reductions, while giving industrialized countries some flexibility in how they meet their emission reduction limitation targets." One aim of the CDM is to allow for industrialized countries to receive some emission reduction credits at a lower cost by investing in low carbon emission projects in developing countries.

CURRENT STATUS

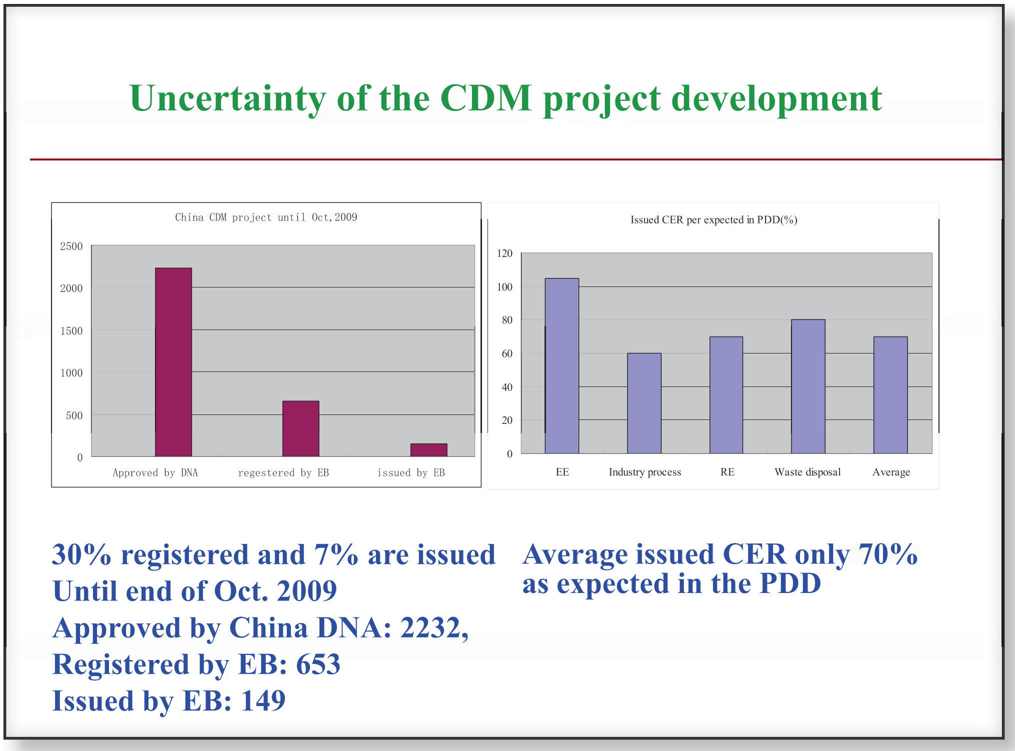
China is the largest CER carbon credit supplier in the world market, accounting for more than 50 percent of the total of all developing countries. Since 2005, the number of CDM projects has increased rapidly. By November 2009, the number of registered CDM projects is 653, which accounts for 35 percent of the world total, and from these registered projects, the expected average annual CERs is 190 million tons, which accounts for 59 percent of the world total; for the already issued CERs (to some extent actual revenue from CDM) the average is 159 million tons, which accounts for 46 percent of the world total.

Because of rapid economic development and low efficiency of energy utilization, there is huge potential for greenhouse emission reductions in China. Among several different approaches to calculate that potential, one is based on the Chinese Government National Plan and on expert estimation. The potential for emission reduction credits is about 520 million tons, including renewable energy, energy efficiency, coal mine methane, HFC23 and nitrous oxide, and others. Although the CDM increased dramatically, less than 50 percent of the potential are at the validation stage for seeking CDM revenue, which may become CDM projects.

Before 2005, research on the potential credits in China for carbon emissions reduction indicated about 80 million tons could be achieved mostly from electricity generation sector (50 percent) and energy efficiency areas (40 percent). The gap between expected carbon market credits and reported status of registered projects by the end of September 2009 was surprising. We found that the current total average annual emission reductions are two times greater than we expected before 2005, and that the share of contribution components is also much different than we expected, only about 31 percent from electricity generation, just 8 percent from energy efficiency projects, and about 60 percent from other sectors. In a word, the actual implementation of CDM is very different than originally expected. The question is, why?

UNCERTAINTIES

There are many possible reasons for the discrepancy. One is the uncertainty of CDM project development. A number of steps must be carried out in the CDM project cycle. The first is project document design (PDD) according to the approved methodology. If there is no such applicable methodology existing, a new methodology must be developed, which takes at least 12 months. Even the approved methodologies are updated frequently. The second step is the validation stage. After a project design document (PDD) is drawn up, it is submitted to a third party, a Designed Operational Entity (DOE), to determine whether or not the document meets CDM rules. After the first two steps, the report is submitted to the executive board of CDM to request registration; during this stage, the project may require an additional review process, which takes more than six months each time. In addition, even if the project is registered successfully, it is still a long way to get the real revenue from CDM, because monitoring must be very strict and fully consistent with the PDD. After registration, the project is monitored on a daily basis or more frequently, which is very costly and an additional burden for the project owner. Finally, the project owner must prepare a monitored report based on the project emission reduction activities to a DOE. After DOE verification, which is similar to the validation process, the project is then submitted to



the executive board for CER issuance. Each step means uncertainty, risk, and maybe failure, and it takes at least two years for revenue from CER to be realized. To illustrate the magnitude of uncertainty, consider that by the end of October 2009, the Chinese government had approved more than 2,000 projects, but only 30 were registered and about 7 percent had been issued. Please note that only if the emission reduction of the project is issued successfully, can the host project owner really get the CER revenue.

Another important factor in CDM project development is the transaction cost. In order to get the CER revenue, the additional cost should be paid up front, when the CDM project begins. The transaction costs include all expenditures made by buyers and sellers to complete the transfer of issued CERs: project research, PDD preparation, business negotiations, DOE validation, registration, monitoring, and verification and certification. Generally, the total transaction cost is from $60,000 to $300,000 before registration and about $50,000 per year during the monitoring stage. As a result, some small scale projects (emission reduction per year less than 150 kCER), including energy efficiency projects, were considered financially unfeasible and did not survive the lengthy and costly review process.

Considering the uncertainty during project development, different types of CDM projects have different probabilities of success, because for each step every project faces three possible outcomes: success, delay, or failure. If the project is delayed, the outcome is, once again, success or failure. Further, considering the transaction costs, the success of a wind farm (success meaning the final issuance of CER over the potential emission reduction as expected) is much higher than that of energy efficiency projects.

DISPUTATION ISSUES

Since CDM project implementation began about five years ago, we have also found a number of disputed issues concerning eligibility criteria. Originally, the rules or mechanisms were designed on a theoretical basis, but in actuality the issues are very complicated. Article 12 of the Kyoto Protocol states that CDM projects must result in "reductions in emissions that are additional to any that would occur in the absence of the project activity." This statement is very clear and simple, but how to demonstrate the "additionality" of a project is actually very difficult.

Some tools are available for demonstrating and assessing additionality. The first step is identification of alternatives to the project activity consistent with mandatory laws and regulations. The second step is an investment analysis including sensitivity analysis to conclude that the proposed CDM project activity is likely or unlikely to be financially attractive. The third step (optional) is barrier analysis to demonstrate that there is at least one barrier preventing the implementation of the proposed project activity without the CDM. The fourth step is a common practice analysis to demonstrate that no similar activities are observed, and if similar activities are observed, there are essential distinctions between the proposed CDM project activity and similar activities. If all conditions for the fourth step are met, the project is considered additional. If one of the conditions is not met, the project is not additional.

A second issue of dispute is implementation feasibility. CDM projects must consider whether the emissions reductions are measurable, reportable, and verifiable (MRV). To date, there are nearly 100 approved methodologies, but only about 10 are actually applied. There is very little consideration of how to implement the MRV requirements in an actual project activity, and monitoring of cost and work may not be acceptable or feasible. Taking the case of biomass generation projects, most of the share of emission reduction, more than 99 percent, is from biomass electricity generation displacing other fuel sources, and the monitoring work is only one electricity meter. But emissions from the biomass transportation is a very small share, less than 1 percent, and its monitoring work is too huge and costly, because we must monitor the 40,000 trucks traveling distances and consuming oil. Other similar projects such as household biogas and green lighting face similar challenges in calculating the real benefits and feasibility during actual implementation.

The third issue in dispute is technology transfer. Most CDM projects in China so far use domestic technology, which is not part of the original goals, one of which was to facilitate the transfer of advanced technologies from developed to developing countries. Very few low-carbon technologies have been transferred under the CDM, especially for energy efficiency technology, although the potential for emissions reduction is huge.

In the future, if the Clean Development Mechanism and the Kyoto Protocol continue to be viable after 2012, we will be facing questions on how to improve or modify the rules with an aim to increased efficiency with low uncertainty, improvements in the feasibility of implementation, bringing costs down to an acceptable level, encouraging low-carbon technology transfer, and enforcing the rules as originally designed.

Embodied Energy and CO_2 Emissions in China's International Trade

by Alun Gu

Dr. Gu *is an Assistant Professor of Energy Modeling at the Institute of Energy, Environment Economy, Tsinghua University.*

China has become the biggest emitter of CO_2 emissions in the world. As gross domestic product (GDP) rises, so do total energy consumption and the value of imports and exports. This sharp rise in energy consumption is fueled in large part by the growth in exports, which have risen dramatically in recent years. In terms of carbon emissions accounting, a key question is whether carbon emissions should be accounted for at the point where goods are produced and emissions generated or instead at the point where the products are consumed on the basis of their embodied energy, that is the life cycle processing, the total amount of carbon emitted in producing, delivering, consuming, and disposing of the goods.

Some countries have become pollution havens; that is, as the developed countries adopt and enforce strong environmental regulations or laws, some energy intensive industries have shifted to the developing countries which had weaker environmental regulations. In addition, we need to factor in the import-export ratio of energy intensive production and the characteristics of energy intensive and low-value added products. We know that in China there is high proportion of international processing trade, about 50 percent recently. That means if goods imported will be involved in domestic production as the intermediate input, the embodied energy should be deducted because such embodied energy is not consumed domestically.

IMPORT/EXPORT TABLES

The import and export goods classification is based on the import/export (I/O) table. The conversion coefficient from money value to physical quantity equals the ratio of energy section total production quantity and the energy sector total value based on the year 2002. Chinese data are based on the I/O tables for 2002 and 2005 and the China Statistical Yearbook. Japanese data are obtained from the Japanese mining industry and the Japan Statistical Yearbook. To avoid double calculation, only coal, oil and gas, hydro, wind, and nuclear power are considered. The proportion of the international processing trade of China is 50 percent. If the goods imported will be involved in domestic production as the intermediate input, the embodied energy should be deducted because such embodied energy is not consumed domestically.

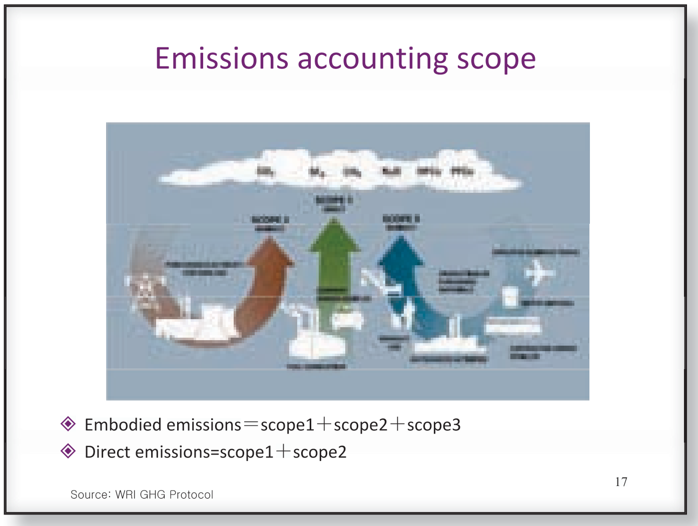
With the basic 2002 and 2005 I/O table, the assumptions of industry structure, technology status, and energy efficiency are supposed to stay at the 2002 and 2005 level for the next few years, thus the export embodied energy of the next years will be overestimated. The goods classification method has effects on the estimation of embodied energy. Assuming the same technology level of other countries and adoption of the Japan I/O table, the import embodied energy will be underestimated.

With rapid economic development, the export goods' embodied energy in 2002 reached 0.2 billion tons of coal equivalent (TCE), accounting for about 13 percent of total energy consumption in China; that means 13 percent of the energy consumed for export production. This share increased to 25 percent with total export growth until 2007.

We can use the Japan 2000 I/O and required coefficient to calculate the annual import embodied energy. The import products which come into intermediate production have to be deducted. We can correct the Japan energy efficiency by using the GDP energy efficiency of the top 13 trade partners to solve the underestimation.

As annual import products increased, embodied energy rose at the same time. In 2005, the net export embodied energy was about 0.28 billion TCE, accounting for 12 percent of total energy consumption. China is therefore a big net exporter of embodied energy. Comparing the carbon emission factors of Japan and China, we find that China's emission factor is 2.4 tCO_2/TCE while Japan's is 1.70 tCO_2/TCE.

Exports are one of three vehicles driving economic growth. After deduction of the value-added processing of products and intermediate inputs for domestic production in import products, the export value-added share resulting from domestic production accounts for 21.4 percent of GDP in 2005. This indicates that export does not increase the weight of energy consumption intensity in the industrial sectors, but export has increased the weight of the industrial sector, thereby increasing energy consumption intensity per GDP. The large number of Chinese manufacturing industry exports is the reason for an increasing proportion of our country's secondary industry.



From 2005 to 2007, annual energy cost of export products accounted for about 13 percent of total export value. If we deduct the import intermediate products factor and consider the domestic energy cost, the total energy cost share decreased to 9 to 10 percent. The electricity cost accounted for 60 percent of total energy cost, and electricity price changes have significant effects on the export energy sector cost.

BORDER CARBON ADJUSTMENT

Climate change is both an economic issue and an international competitiveness issue. Border Carbon Adjustment (BCA) is defined as import fees levied by carbon-taxing countries on goods manufactured in non-carbon-taxing countries. BCA is intended to address competitive concerns and carbon leakage from highly regulated to less regulated countries. One option is a border tax levied on imports into a country that has a carbon cap. There are others such as a mandatory allowance purchase by importers or carbon emissions standards.

There are three scenarios to make the assessments of BCA: one is based on the European Union Emission Trading Scheme (EU-ETS) average carbon price, another is the Norway average carbon price, and a third is the middle level carbon price. There are two methods to calculate the products' embodied emissions, one is based on the life cycle process, the other is based on the site emissions. In the former case, the export tariff rises from 4 to 8 percent; while in the latter case, the export tariff rises from 1.5 to 2.5 percent. In general, the total former tariff is about $16-28 billion US, four times the latter .

In 2005, China export products value is 1.2 times greater than import, and export embodied energy is 1.9 times greater than import. This status in the international trade and industry chain is determined by our technical level and development stage, and this imbalance will remain for the medium term. The top 20 embodied emissions sectors are for the most part not the most energy intensive; therefore the policy shouldn't be forced to observe gross limits, but industry should upgrade and improve export emission intensity. The service sector in China should be encouraged once BCA is implemented. In the United States, for example, in 2002, entertainment was the largest export. Some embodied emissions are low not because of low emission intensity; the small export value is the dominant cause.

Mitigation policies are applied not only in the carbon market or by the carbon tax; there are also some technology standards and regulatory actions that can be used, such as an explicit carbon price based on market instruments and an implicit carbon price based on administrative instruments. BCA could be an effective protection. Trade policy will play a large role in solving the carbon leakage only in the case that emissions per products of importers are lower than those of exporters. In some key sectors, Chinese energy consumption of products is lower than in other developed countries.

In sum, we need to seriously consider export embodied energy/emissions and avoid becoming a pollution haven. We also need to understand that embodied emissions calculations require very complex data depending on the industry chain value. We should encourage a large amount of upgrades in the industrial sector because its market power could offset the negative effects of energy consumption. Administrative mitigation policies should not be neglected in the future international climate change action architecture.

Developing Co-Cultures for Cellulosic Bioethanol

by Qiang He

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One of the biggest hurdles in making the use of cellulosic bioethanol feasible is cost. By some estimates, if all the material costs are factored in, the price at the pump of bioethanol from switchgrass could be $5 a gallon. Obviously, we have to reduce the cost.

A 2008 report in *Nature Biotechnology* showed various options to achieve cost reductions, including increasing fermentation yield, halving cellulose loading, and eliminating pretreatment. Of all the proposed options, the one that shows the most promise in cutting cost is consolidated bioprocessing (CBP). The current technology for CBP is to pretreat the lignocellulose, convert cellulose into sugars through hydrolysis, and then ferment sugars into ethanol, in two separate steps in two reactors.

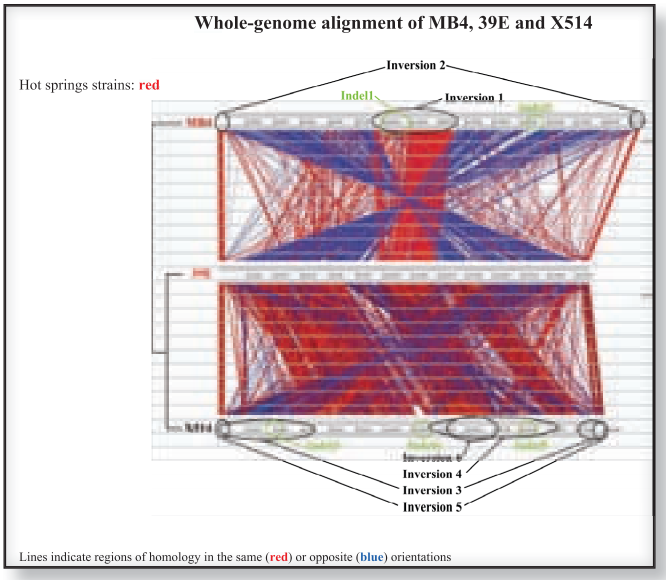
The first person to promote CBP was Lee Lynd at Dartmouth University. The basic premise is to convert cellulose into sugar, both pentose and hexose, and sugar into ethanol using one reactor in a single step to achieve bioconversion. This is a one reactor, one step conversion, but the biomass will still need to be pretreated to remove some of the inhibitors. An even more radical approach is to include pretreatment into the one-step process.

The problem is how to implement the process. If everything is folded into one step, you will need some sort of biocatalyst that can do it all. There is, in fact, a candidate biocatalyst that can accomplish this, *Clostridium thermocellum*.

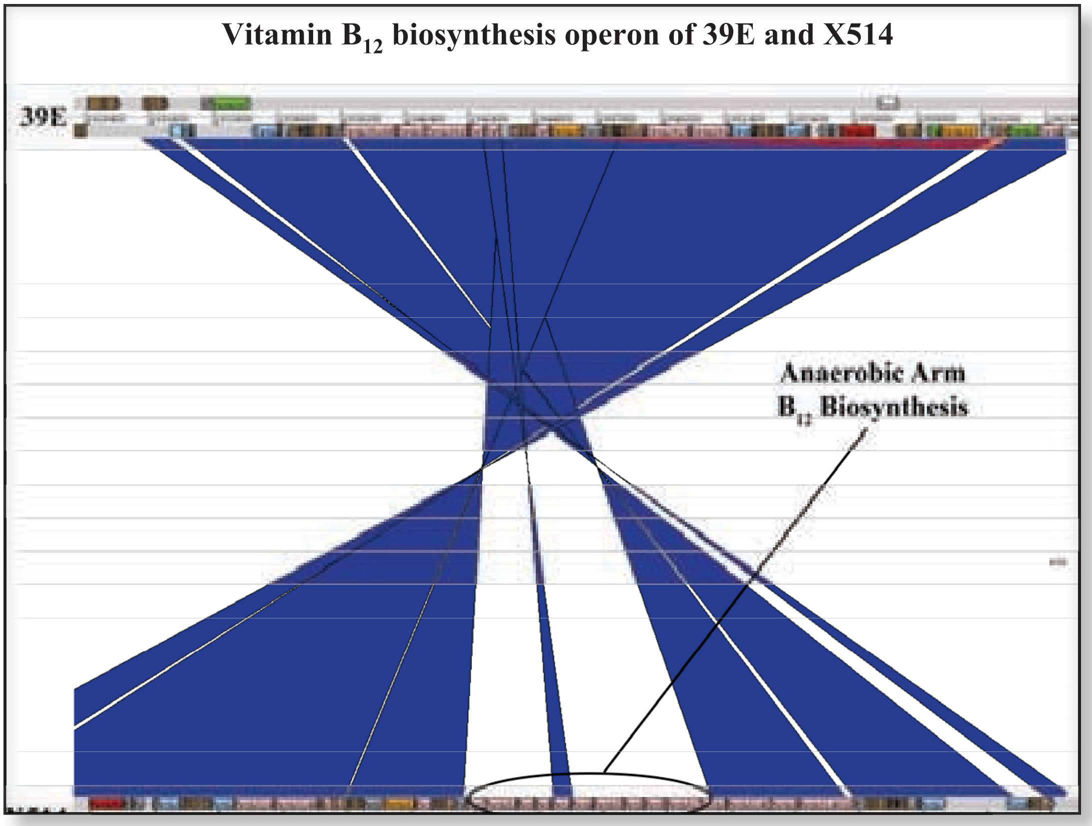
A MODEL BACTERIUM

C. thermocellum is the most important model for cellulosic ethanol production. First, it is thermophilic; that is, it can operate at temperatures as high as 65°C, hot enough that it is easier to distill the ethanol out of the water and minimize contamination. Second, *C. thermocellum* is a bacterium well known for the presence of cellulosomes, unique components that degrade cellulose. One drawback is that *C. thermocellum* utilizes hexose only, and not the pentose also present in biomass material. As a result, ethanol yield may be lower than optimal. So even though this model is almost the best cellulolytic bacterium that we have, it can only do so much.

To make *C. thermocellum* useful for the CBP concept, we need to develop thermophilic co-cultures that decompose cellulose and convert both hexose and pentose into ethanol. The idea is not new. There are references dating back to the oil crisis of 1973, when there was a boom in demand for ethanol production and a big incentive to produce ethanol from biomass. This resulted in a lot of very good work on ethanol fermentation. At the time, a group of researchers at Michigan State University had very good results testing one co-culture for enhancement of bioethanol production, but they tested only one co-culture. Today, genome sequencing is much easier than before.



My colleagues from the Department of Civil and Environmental Engineering at the University of Tennessee and from the University of Oklahoma and I wanted to know whether certain co-cultures of bacteria can better combine to make decomposition and conversion more efficient. Are there genetic differences between different kinds of partners? To find out, we first proposed sequencing the genomes of candidate bacteria in order to understand the system.



The bacteria we proposed to sequence were chosen according to several criteria. They must be thermophilic, operating at higher temperatures compatible with *C. thermocellum*, and they must be able to ferment both hexose and pentose, so they can degrade all the fermentation products from cellulose. So far, we have proposed to sequence about nine species of *Thermoanaerobacter* and *Thermoanaerobacterium* for genomic sequencing, and we are close to finishing sequencing of three more. There are many more that we have not begun to sequence.

When we took this project on, we found among this broad spectrum of bacteria three *Thermoanaerobacter* whose genomes were available at the time and that met the required standards of being thermophilic and able to ferment both hexose and pentose. We therefore wanted to look closer at these three to see if they are similar or different and whether they are appropriate for co-culture development.

We examined the physiological characteristics of three strains of *Thermoanaerobacter Caldanaerobacter*—39E, X514, and MB4. Strain 39E—which was isolated from an algal-cyanobacterial mat in Octopus Spring, Yellowstone National Park in Wyoming—is a well known model for sugar fermentation since the early studies at Michigan State University. Strain X514—originally found in deep subsurface rock in Piceance Basin in Colorado—was first isolated by scientists at Oak Ridge National Laboratory not because of its potential for ethanol production but rather its ability to reduce metals for bio-mediation purposes. Only later, after the boom in bioenergy research, did we take a closer look at this bacterium and find it to be very efficient in fermenting sugars into ethanol. Strain MB4—which was found in a hot-springs sediment/water mix in Yunnan Province, China—was sequenced by Chinese scientists

We found that all three strains are thermophilic, but none can degrade cellulose on its own. To encourage fermentation, these bacteria require a cellulose degrading partner. Only two, 39E and X514, can utilize the plant sugar xylose. When we measured the capability of these two strains to ferment cellulose or sugars and produce ethanol, we found that X514 degrades or ferments sugar faster than 39E.

We then wanted to know whether the faster one will be better at producing ethanol in the presence of a cellulose degrading partner than the slower one. To find out, we compared the growth rate, substrate consumption rate, and ethanol production rate of 39E and X514. We found that X515 grows better and yields higher levels of ethanol than 39E on both glucose and xylose, and it also yields higher levels of ethanol than 39E.

The next question is which enzymes are responsible for these differences in ethanol production. If X514 is faster than 39E, is it because it has more alcohol dehydrogenase (ADH) genes? Genome sequencing answers that question. X514 essentially has more ADH; in other words, X514 has the genetic capacity of producing ethanol. But what is the reason for the difference in speed of degradation and fermentation? It turns out X514, has an additional fermentation pathway and also has additional pentose metabolism genes; essentially X514 can synthesize B-12, a very important cofactor in bacterial growth. So in this respect X514 has a genetic advantage over 39E.

Other researchers have examined the relative flux distribution of carbon between X514 and 39E and its effect on the rate of glucose and xylose utilization and found that absolute flux in X514 is significantly greater than in 39E. It is possible that additional, unique genes in X514 could enhance carbon flux, but despite numerous genomic analyses, we still don't why X514 is faster in turning over carbon, in this case into ethanol. When we look in more detail at energy metabolism, we find very few differences we can dig into between X514 and 39E; the genetic components are very similar.

THE VITAMIN CONNECTION

One of the more interesting details in our studies of the three strains is related to the vitamin B-12 biosynthesis pathway of *Thermoanaerobacter* and *Caldanaerobacter*. Since MB4 cannot ferment xylose, we focused on X514 and 39E, comparing every single enzyme in each of the pathways. X514 has a complete vitamin B-12 synthesis pathway, while 39E has an incomplete synthesis pathway .

To determine the significance of vitamin B-12, we cultured X514 and 39E, adding different amounts of vitamin B-12. We found that B-12 has no influence on X514, but it does increase ethanol production in 39E by enhancing cellulose fermentation by *C. thermocellum*. Even very small amounts of B-12 are beneficial for the fermentation of sugar in 39E.

When we examined the effect of vitamin B-12 on ethanol fermentation in a co-culture, we found *C. Thermocellum*-X514 has the highest yield. We are pursuing further studies, but so far our results suggest an important link, putting X514 together with co-culture bacteria to produce constantly high ethanol production. The co-culture with 39E without B-12 is much lower, but with the addition of the vitamin, ethanol production increases. The B-12 biosynthesis pathway is the key.

We will be conducting more genome sequences on strains of bacteria related to 39E, X514, and M4B, but for now our detailed analysis of the B-12 biosynthesis pathway suggests that few are likely to be as promising as X514 in a co-culture and with addition of B-12. This is essential validation of our hypothesis that we need to feed these bacteria more B-12 in order to increase production of ethanol via consolidated bioprocessing.

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