# Bioenergy Consequences

## for Global Environmental Change

October 15-17, 2008

中美

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 2008 workshop on Bioenergy Consequences for Global Environmental Change was held October 15-17 in Beijing and was hosted by the Chinese Academy of Sciences. This publication represents the proceedings of the 2008 workshop, which futher cemented the ongoing collaboration between Chinese and American colleagues.

## *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 Geographical 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

*Chinese and American Colleagues at the workshop in Beijing and on a field trip to the Qianyan=hou Research station*

*Front row left to right: Hong-Qing Wang, Yu-Ling Fu, Xue-Fa Wen, Virginia Dale, Jie Zhuang, Jiu-Xiang Huang, Yi-Dong Wang, Zhe-Qing Ma. Back row left to right: Yuan-Fen Huang, Keith Kline, Qing-Kang Li, Randall Gentry, Paul Hanson, Sheng-Gong Li, Hui-Ming Wang*

# TABLE OF CONTENTS

***Bioenergy Consequences for Global Environmental Change Opening Remarks/Workshop Objective***
by Cao, Zhuang, and Sayler, . . . . . 7

***Sustainable Production of Biofuels***
by Alan Hecht . . . . . 13

***Land Resources for Bioenergy Development in China from the Standpoint of Food Security***
by Gao-Di Xie . . . . . 19

***Recent Progress in Biomass Energy Studies at USTC***
by Qing-Xiang Guo and Ying Zhang . . . . . 22

***China's Renewable Energy Potential and Policy Options***
by Lei Shen and Li-Tao Liu . . . . . 25

***Environmental Grand Challenge of Biodiversity Loss: Potential Impact from Biofuels***
by John Bickham, Geoff Laban, and Mark A. Thomas . . . . . 29

***Woody Bioenergy Development and Its Possible Effects on the Ecological Environment in Jiangxi Province***
by Shi-Huang Zhang . . . . . 33

***Using Hydrologic Tracers and Geochemistry to Assess Surface Water and Ground Water Interactions for Ecosystem Sustainability***
by Randall Gentry . . . . . 36

***Crop Production Defined by Climate and Water in the North China Plain***
by Qiang Yu . . . . . 39

***Socioeconomic Considerations with Biofuel Production***
by Mary English . . . . . 42

***Emergy Response of a Crop System to Water Assignments in Taihang Mountain Piedmont***
by Xing-Guo Mo . . . . . 45

***Advances in Research on Germplasm Resources and Molecular Biology of the Energy Plant Sweet Sorghum***
by Gong-She Liu and Wei-Bin Gu . . . . . 47

***Selecting Metrics for Sustainable Bioenergy Feedstocks***
by Virginia Dale, Keith Kline, Pat Mulholland, Mark Downing, Robin Graham, and Lynn Wright. . . . . . 49

# TABLE OF CONTENTS


***Quantifying Soil Carbon Cycle Mechanisms and Flux: Implications for the Accumulation of Carbon in Soil***
by Paul J. Hanson . . . . . . . . . . . . . . . . . . . . . . . . . . . . 54

***Carbon Budget Patterns of Forest Ecosystems in Poyang Lake Basin from 1901 to 2001***
by Shao-Qiang Wang . . . . . . . . . . . . . . . . . . . . . . . . . . . 60

***Carbon Sequestration by Terrestrial Ecosystems and Its Contribution to Reduction of Greenhouse Gas Emissions in China***
by Sheng-Gong Li . . . . . . . . . . . . . . . . . . . . . . . . . . . . 62

***Ecosystem-Atmosphere Carbon and Water Exchange Derived from ChinaFLUX Network Observation***
by Yu-Ling Fu and Gui-Rui Yu . . . . . . . . . . . . . . . . . . . . . . 65

***Biotechnology Tools for Switchgrass Improvement***
by C. Neal Stewart, Jr . . . . . . . . . . . . . . . . . . . . . . . . . . 67

***Life Cycle Assessment: Principles and Its Application to Biofuels Technologies***
by Fu Zhao . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 70

***Production of Bio-Methane and Beyond***
by Jason C. H. Shih . . . . . . . . . . . . . . . . . . . . . . . . . . . 74

***Linking Biomass-based Liquid Fuel Production Capacity to Transportation Demand and Sustainability Goals***
by Loring F. Nies . . . . . . . . . . . . . . . . . . . . . . . . . . . . 78

***An Industrial Demonstration of Corn Stover-based Ethanol Processing in China***
by Jie Bao . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 81

***Anaerobic Granule-based Reactors: Biohydrogen Production from Organic Wastes***
by Han-Qing Yu . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 83

***An MEC and MFC-coupled Biocatalyzed System for Hydrogen Production***
by Guo-Ping Sheng . . . . . . . . . . . . . . . . . . . . . . . . . . . 86

***China-US Cooperation on Bioenergy R&D***
by Keith Kline, Jorge Sanchez, and William Wallace . . . . . . . . . . . . 88

# Bioenergy Consequences

## for Global Environmental Change

中美 CHINA • US Joint Research Center for Ecosystem and Environmental Change

**OCTOBER 15-17, 2008**
**INSTITUTE OF GEOGRAPHIC SCIENCES AND NATURAL RESOURCES RESEARCH, CHINESE ACADEMY OF SCIENCES**

## China-US Joint Center: A Greener Future

by Jinghua Cao

*Dr. Jinghua Cao is deputy director general, Bureau of International Cooperation, Chinese Academy of Sciences.*

It was in July 2006, here at the Institute for Geographical Sciences and Natural Resources Research (IGSNRR) in Beijing, that the framework of collaboration for the establishment of a China-US Joint Research Center for Ecosystem and Environmental Change was signed by the University of Tennessee-Oak Ridge National Laboratory's (UT-ORNL) Joint Institute for Biological Sciences (JIBS), UT's Institute for a Secure and Sustainable Environment (ISSE), representatives from IGSNRR , and the Research Center for Eco-Environmental Sciences (RCEES), the Chinese Academy of Sciences (CAS).

This year, two new players have joined the China-US Joint Research Center for Ecosystem and Environmental Change: the University of Science and Technology of China, and Purdue University. These new partners along with the original ones will further ensure that the China-US Joint Center will have a bright future.

The Center has multiple goals: to implement collaborative research programs; to exchange scientific information and the newest developments in the field; to provide international education and training to graduate students and young scientists from both countries; and to serve as a platform for bilateral and international investigation of the complex issues, challenges, and interactions of ecosystem processes associated with environmental change and human activities.

Since its inception, the Center has taken the environmental sustainability of bioenergy industry as one of its primary research targets. Energy is at the center of human survival and advancement. Every major step forward in human civilization has been marked by improvements and upgrades to the energy industry. Both China and the United States now rank at the very top in the consumption of fossil fuels and emissions of greenhouse gasses that contribute significantly to global warming. Our two countries' economies, as well as those of many countries in the world, are strategically linked to the sustainable development of alternative and renewable energy.

With the global warming scenario, price increases, and normal fluctuations of oil, and the gradual and eventual depletion of fossil fuels, it is important for China and the United States to take the lead worldwide to establish a sustainable energy system that can produce enough electricity and energy with the lowest possible greenhouse gas emissions for global environmental protection and human development. Our two countries must also realize that mass production and a sustainable supply of renewable energies to substitute for the depletion of fossil fuels is not just a grand challenge for the scientific community, but for all of society as well.

In seeking alternatives, bioenergy is considered part of our future energy mix. I am a technical believer. I believe that technology breakthroughs will solve some of the energy problems we face. Yet, we must not forget to pay attention to the environmental aspects of bioenergy production.

Bioenergy is one of the development priorities in China's energy strategy. About five years ago, China started to produce bioethanol using raw materials such as corn. In 2007, China's bioethanol production reached 1.6 million tons, of which 80 percent was produced from corn. Though its progress has been rapid in the past few years, the rising price of corn and the global shortage of grains have restricted the development of grain-based ethanol. In light of the global situation, the Chinese government has decided to stop expansion of this line of production. In early 2008, a decision was made to shut down these ethanol production facilities and encourage only non-grain based ethanol production.

In China, bioenergy development has been written into the long term National Economic and Social Development strategy. We believe that breakthroughs in basic science, such as genetically improved plants and microbes and enzymes, will improve the conversion efficiency of biomass to energy. We are entering the era of genomic-based biological tools, and humankind may significantly reduce the cost of producing biofuels by improving the efficiency of bioenergy production, and truly make bioenergy part of the future energy mix.

Yet there are complicated environmental issues attached to the bioenergy alternative, and those need to be seriously investigated. That is the point of this meeting. In the future, even though new genetic technologies will allow us to develop energy plants, freeing us from dependence on food plants, there will still be many environmental issues and unexpected environmental consequences.

The Chinese Academy of Sciences (CAS) attaches great significance to the development of renewable energy as well as other sustainable development issues. At the moment there are more than 20 research institutes within CAS involved in energy-related R&D, and there are several institutes whose research activities are directly related to bioenergy. As early as 1978, CAS founded the Institute of Energy Conversion to conduct bioenergy related research. In response to the national call for energy security and alternative energy development, CAS established a new institute in 2006, the Institute of Bioenergy and Bioprocess Technology focusing on bioenergy R&D and related biological processes. In addition, a number of other institutes are also involved in bioenergy related work, particularly the study of environmental impacts.

At present China emphasizes green development, lower emissions of greenhouse gases, and the search for renewable energy alternatives. Through scientific advancements, technical training, technology transfer, and international collaboration, we will be on a better road to build a healthy and sustainable bioenergy industry and a whole system of sustainable energy.

By addressing these issues, friendship and mutual understanding are significantly enhanced. After all, the most important outcome of this meeting is friendship and trust, through which concrete collaboration activities can be identified and various fruitful investigations carried forward.

# Towards a Coherent Bioenergy Strategy

by
Gary Sayler

*Dr. Gary S. Sayler is the director of the University of Tennessee-Oak Ridge National Laboratory Joint Institute of Biological Science and Beaman Distinguished Professor of Microbiology in the Department of Ecology and Evolutionary Biology at the University of Tennessee.*

Environmental change issues strongly influence bioenergy strategies. With increasing carbon dioxide ($CO_2$) concentrations and projections for temperature change over time, we may be looking at extreme temperature departures in terms of global warming over the next decades. These changes will have major consequences for biomass production, microbial soil respiration, nutrient cycles, and hydrologic cycles.

Many sources of $CO_2$ contribute to global greenhouse gas (GHG) emissions. The United States and China are big players in the production of those greenhouse gas sources. In the United States, we have an astonishing, disproportionately high, level of $CO_2$ emissions from our transportation fuel technology compared to emissions from fossil fuel combustion for power plants. China actually leads the United States in $CO_2$ emissions from power plants. Those differences help contribute to the complex problem of bioenergy, both in terms of its contributions to the problem and its solution.

It is currently estimated that about 30 percent of $CO_2$ emissions globally come from developing countries that burn biomass such as trees, shrubs, charcoal, and dung for cooking and heating. It is not just major contributing countries like China and the United States; it is the world's problem, one that affects all of us and knows no national boundaries. There will be major changes to address in the future with respect to land use and the overriding issue of sustainability. Can we indeed provide to our future generations, as a human species, the same resources and natural opportunities that we had for our generations? We are looking at bioenergy technologies as a way to break the fossil energy system and move towards a direct strategy of recycling $CO_2$ directly from the atmosphere for production of biofuels. The further we can move from the fossil energy loop, the better we will be able to ameliorate some of the problems associated with environmental change. Bioenergy and biofuels alone cannot solve all our problems, but they may give us more time to solve some other problems with new technologies to capture and store carbon, or perhaps to usher in more safe and secure nuclear energy sources or other renewable energy sources so that we can move forward in the future.

The United States has a goal, the 30/30 goal, to produce about 30 percent of our transportation fuels from renewable energy sources by 2030. That is quite a challenge. President Bush, in his 2007 State of the Union Address, talked about a 20 percent reduction or replacement of petroleum by renewable and bioenergy in 10 years, a 20/10 goal. That too is a tremendous challenge. How can we move new technologies forward to meet these particular objectives?

Ethanol plants in the United States are widely dispersed, and they now produce about as much ethanol as they ever will from corn and other grains. These plants are not actually making replacement gasoline; they are primarily meeting the U.S. requirements for fuel oxygenates that go into gasoline. Most observers assume that corn production for ethanol will be stable, but corn will never provide the levels of ethanol we need in the coming years to meet objectives such as the 30/30 or 20/10 goals. For that we need new sources of bioenergy biomass, particularly cellulose. If we are ever going to make a major accomplishment in transportation fuel replacements, cellulose will give us the fossil energy/carbon ratio that is attractive, while corn and other grain-based technologies simply cannot because of their energy intensive development and the fertilizer, nutrients, and water needed for production.

Over the past two years, the U.S. Department of Energy (DOE) has been aggressively funding a bioenergy strategy with three major large research centers that have been established. One of those centers, the Bioenergy Science Center, was established at Oak Ridge National Laboratory (ORNL) in collaboration with about eight other institutions. Its goal is to overcome the challenge of developing cellulosic biomass for renewable fuels. This is a $125 million program for the first five years, and it represents a major effort to overcome some of the associated technical hurdles. Questions have arisen, however, about whether there is enough biomass to support this technology. A few years ago, the U.S. Department of Agriculture (USDA) and DOE funded the "Billion Ton" study, which reported that we indeed can come up with enough biomass. Much of that biomass will come from cellulosic agricultural residues and forest products and from a new effort to generate perennial crops such as switchgrass to provide the cellulosic biomass we need in the future. Land use issues will play a huge role with respect to how biomass production affects environmental change issues.

The Bioenergy Science Center, led by its director Dr. Martin Keller, has made some initial progress in its short, one-year lifetime. Its major focus is not so much production of ethanol but rather overcoming the rate limitation and the process limitations of converting cellulose to sugars. Cellulose is an insoluble substrate. It is very resistant to breakdown. The major challenge is to effectively produce the sugars needed to make the ethanolic fuels.

One of the leaders who brought this center into being, Dr. Reinhold Mann, the associate laboratory director at ORNL, has recently announced he is stepping down from this post to join a new initiative in Kuala Lumpur to spend the next three years working on a $500 million dollar renewable energy research center for Malaysia. We are already taking some of our learning and moving that across to the Pacific region to bring it to bear on a more global scale.

With ORNL as the lead institution, the center's partners include the Georgia Institute of Technology, the University of Georgia, the University of Tennessee (UT), and Dartmouth College, among others. The institute is home-based in the UT-ORNL Joint Institute for Biological Sciences. It has a large analytical "-omics" capability established for the complete spectrum of plant and microbial genomics, metabolomics, and proteomics, and we have access to amazing analytical resources of ORNL and its partners.

We are trying to overcome one of the big economic issues in cellulosic ethanol production: making it even more cost competitive then corn based-ethanol. The challenge is to move away from the current technology, which is a multi-path pretreatment, hydrolysis, fermentation technology to one consolidated single process technology. If we can carry out that technology, the estimated cost savings for consolidated bioprocessing of cellulosic ethanol can be enormously beneficial, perhaps bringing the cost of ethanol down to less then $1 a gallon under optimal conditions. We will never be able to replace all liquid transportation fuels, but we certainly can make a major contribution in the range of 20 to 40 percent of our liquid transportation fuels. The research center focuses on three major topics: aspects of cell wall-biomass formation and the actual laying down of cellulosic and lignin, biomass pretreatment and selection of plant variants with improved sugar yields, and high throughput characterization and enzyme and microbe selection for cellulose deconstruction.

The two major target plant species in this work are poplar and switchgrass. We have other ongoing work in models such as *Arabidopsis* and alfalfa, but the focus overall is on the complex issues of how cellulose is made and laid down by plant cells. In order to modify that and to make the cellulose more digestible and easier to extract, we need to select natural variants or grow genetically modified plants that are better subjects for bioenergy production. Some early work is being accomplished using an alfalfa model that shows you can lower the content of lignin in alfalfa and dramatically increase the release of soluble sugars for fermentation. We would like to move that kind of technology into poplar and switchgrass.

We are also looking at different phenotypes of trees from different parts of the United States. We should also be looking at trees from China. We are looking at high throughput screening technologies to screen this mass of genetically modified and selected biomass. This is an area of major accomplishment in our center, where we can literally process dozens of samples through high throughput screening and mass spectrometry techniques literally in minutes.

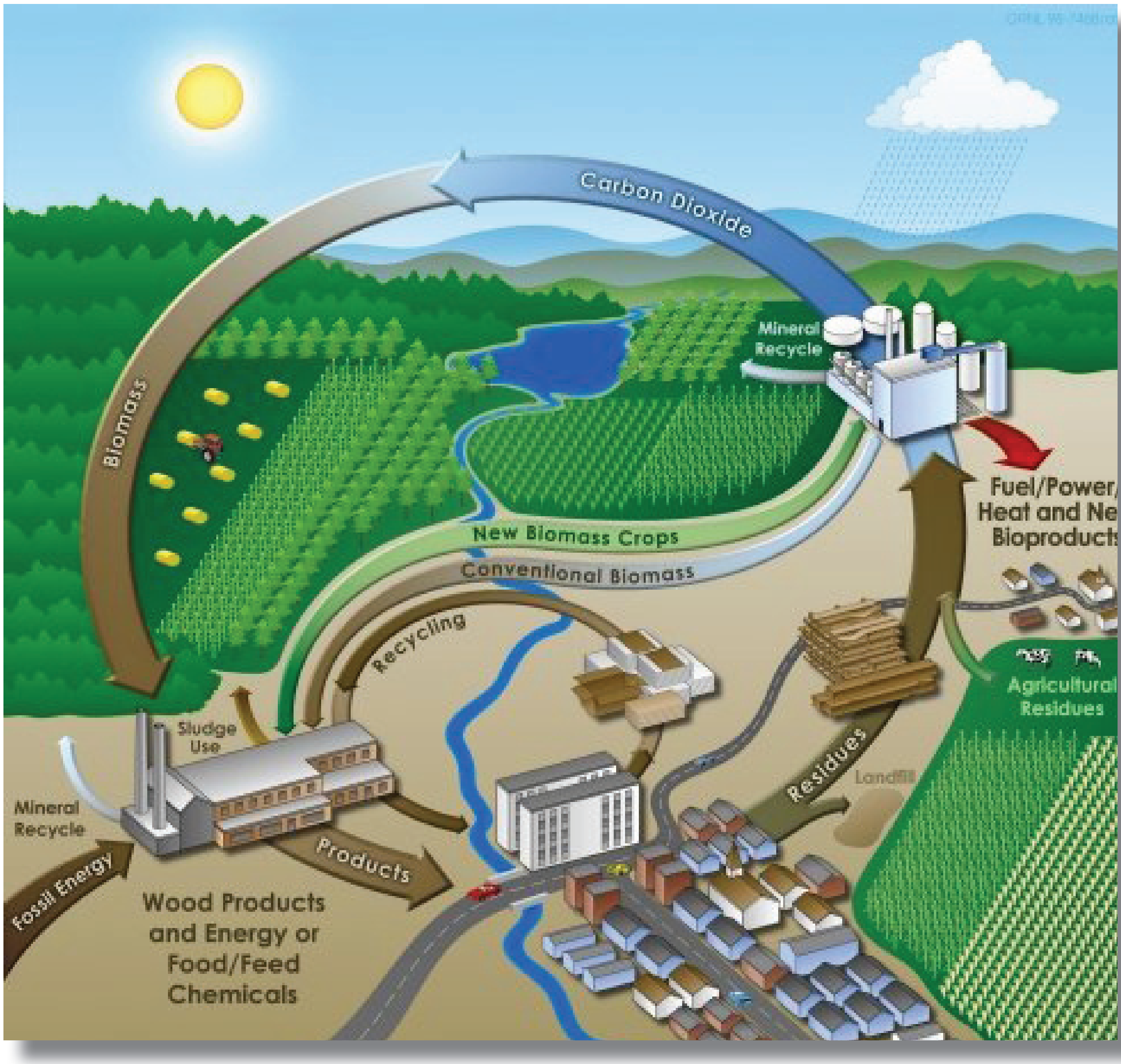
Now we are moving into the area of biomass deconstruction and conversion using the cellulose ecosystem both in terms of fungal free enzymes and bacterial systems that use cellulosomes from high temperature thermophylic microorganisms that will have more rapid processing capabilities then conventional microbes. We are finding that there are organisms that have high affinity for the cellulosic fibril structures and can perhaps improve rates of degradation of cellulose many-fold times over current technology. We are also looking at genetic engineering strategies of the cellulosome itself. These are the molecular machines that microbes use to degrade cellulose.

Tennessee has a complete vision for rural biofuels and bioenergy technology, a vision for rural economic development that couples agricultural production of energy biomass crops to regionally and locally located processing facilities to overcome logistic constraints. As this workshop was taking place, UT along with Dupont Danisco Cellulosic Ethanol LLC, a Danish company, were breaking ground on a new 250,000 gallon (1 million liter) per year pilot plant production facility for switchgrass and corncob cellulosic ethanol fermentation.

This new facility is collocated with an existing bioplant that Dupont-Tate and Lyle has in place for making fiber substrate monomers from corn syrup feedstock. We are looking at a bioprocessing agricultural economy that will grow sub-regionally in Tennessee, hoping to draw from the science that comes from the Bioenergy Science Center located just a few dozen miles away. We are looking at new directions not only for liquid transportation fuels but new kinds of fuels and feedstock starting materials. Through interactions with our Chinese colleagues, we have recently visited the Loess Plateau site where switchgrass is grown in experimental plots. This is exciting news. There has been selection for enhanced drought tolerant species already, and we hope our switchgrass researchers at the Bioenergy Science Center can develop immediate collaboration with our Chinese counterparts.

As we move forward, we are ultimately striving for a carbon neutral economy that embraces sustainability and future land use and economic development issues. This is the kind of model we all need to share, because the problems are not local, they are global. We are very pleased that the China-US Joint Research Center for Ecosystem and Environmental Change is now able to expand its expertise and area of influence by bringing new partners onboard: the University of Science and Technology of China and Purdue University. Together, all our partners are setting an example for international collaboration to solve some of the world's most pressing energy issues, and to do so based on a firm foundation of sound science and in a spirit of cooperation and friendship.

(http://bioenergy.ornl.gov/papers/misc/bioenergy_cycle.html)




*Credit: Oak Ridge National Laboratory*

# Workshop Objectives

by
Jie (Joe) Zhuang

*Dr. Jie (Joe) Zhuang is research director of the Institute for a Secure and Sustainable Environment; research associate professor of the Department of Biosystems Engineering and Soil Science, University of Tennessee, Knoxville; and the coordinator of the China-U.S. Joint Research Center for Ecosystem and Environmental Change.*

The first workshop of the China-US Joint Research Center for Ecosystem and Environmental Change Workshop was held September 11-14, 2007, at the University of Tennessee, Knoxville. The second China-US Workshop was held October 15-17, 2008, in Beijing and was hosted by the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (CAS), and sponsored by the U.S. National Science Foundation, the Bureau of International Cooperation, the National Natural Science Foundation of China, and the Institute of Geographic Sciences and Natural Resources Research, CAS.

The second workshop, Bioenergy Consequences for Global Environmental Change, was attended by 80 participants, including 26 scientists and program leaders from the United States, and featured six keynote and 20 contributing speakers, 14 poster presentations, and three field trips to the northwest, southeast, and east of China, respectively.

Each year, the workshop topics change, but they are all in the areas of environmental science and technology, climate change, and renewable energy. This year the workshop had five objectives.

First, through these presentations and discussions, we set out to evaluate the potential for carbon sequestration through bioenergy production. The carbon cycle, of course, is a critical process for understanding and managing global climate change.

The second objective was to address the role of biomass management in protecting eco-environmental systems. We hope bioenergy development will be an economically and environmentally sustainable approach to improve our degrading eco-environmental systems in many areas of the United States and China.

Third, we explored bioenergy strategies for incorporating social and economic issues into natural resources management. The ecosystem restoration project on the Loess Plateau in northwestern China, which has an arid climate, is an example of how bioenergy production can potentially address social and economic issues through the growth of switchgrass or other bioenergy plants.

The fourth objective was to develop a framework for large-scale China-US joint research on the sustainability and security of bioenergy production. This is very critical; every joint research project should have an underlying framework so we can forge concrete collaborations in an effective manner. Two new members, Purdue University and the University of Science and Technology of China, joined the China-US Joint Research Center for Ecosystem and Environmental Change.

Finally, we established a mechanism to engage students and young scientists in bioenergy-based eco-environmental and engineering research. This next generation of scientists is crucial to the long-term success of China-US research collaboration on renewable energy and climate. Creating opportunities for these young researchers also fulfills a requirement for support by the U.S. National Science Foundation.

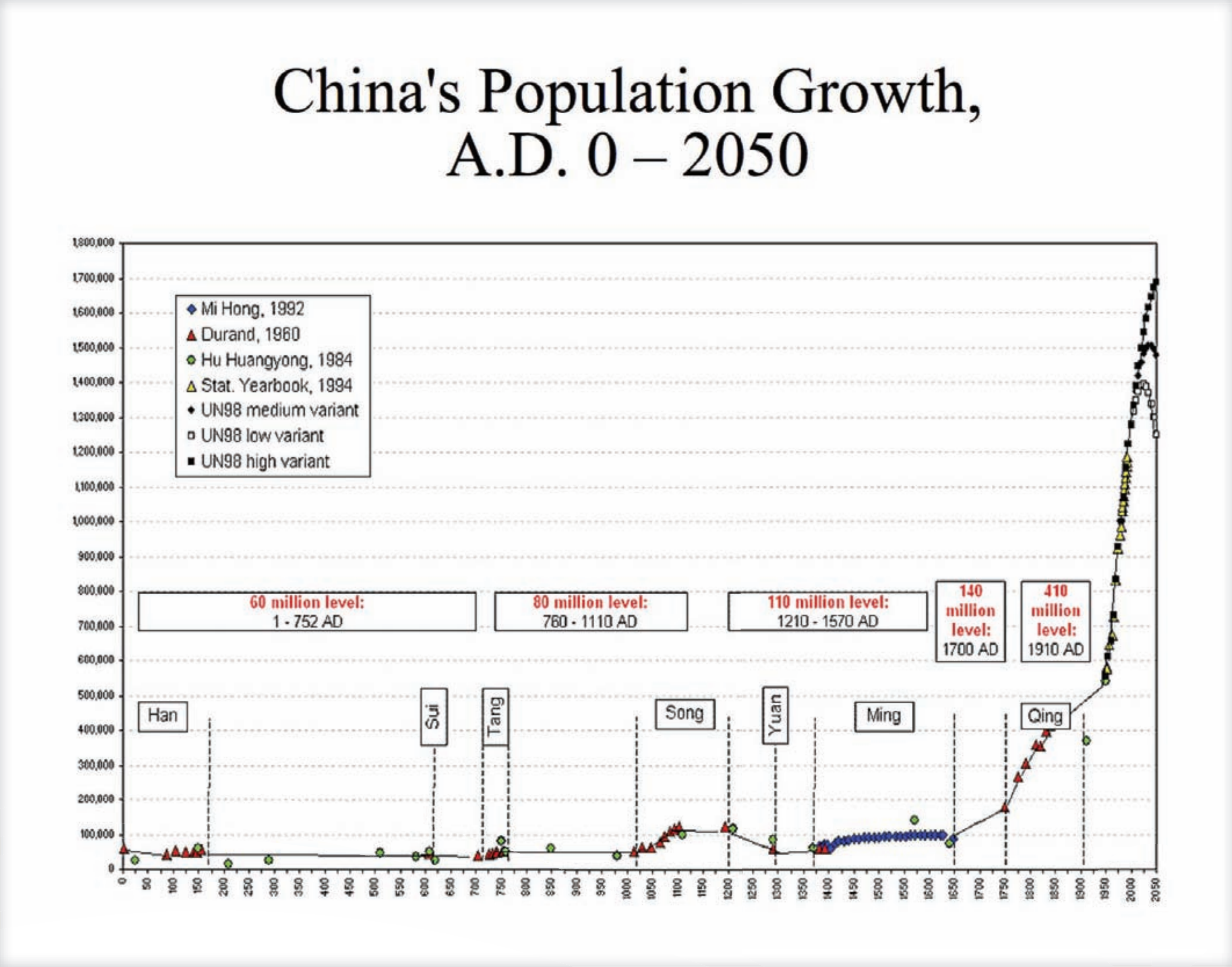
# Sustainable Production of Biofuels

**by Alan D. Hecht**

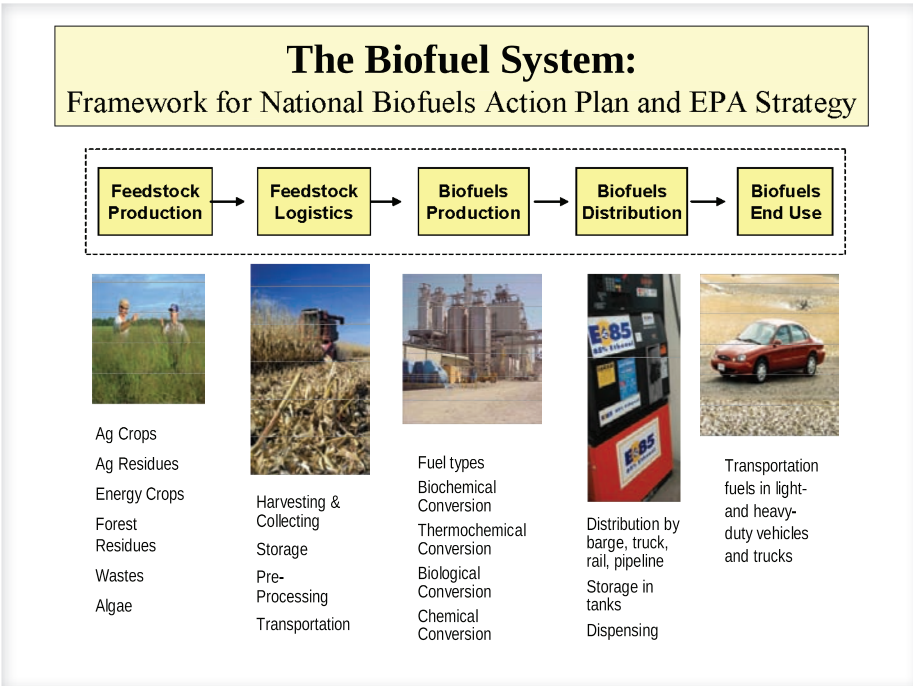
**Dr. Alan D. Hecht** *is the director for sustainable development at the U.S. Environmental Protection Agency.* **Alice Chen** *is an American Association for the Advancement of Science, Science and Technology Fellow with the U.S. Environmental Policy Agency's Office of Research and Development.*

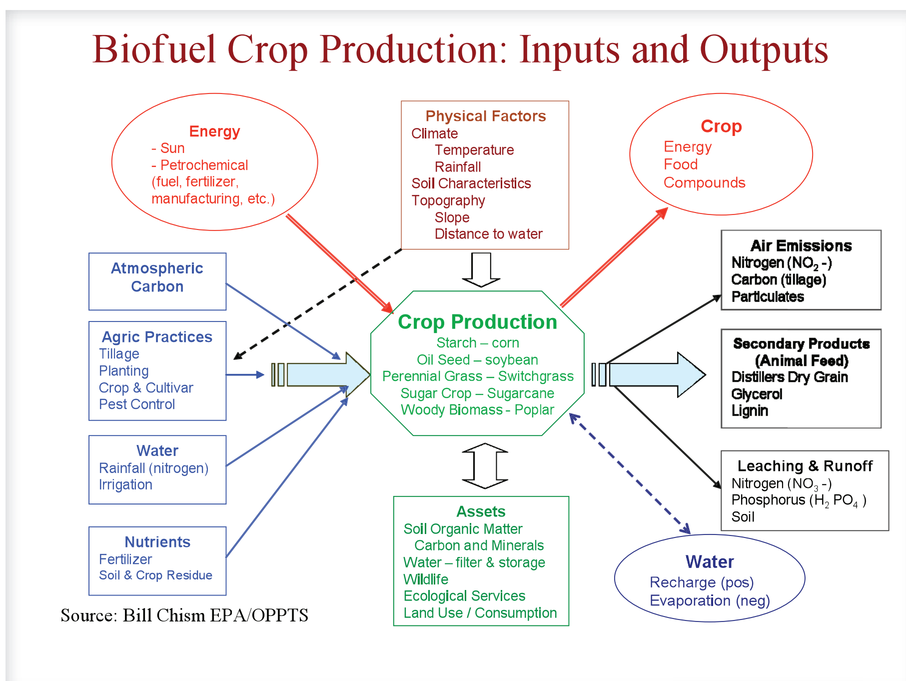
Three main forces are driving the development of alternate energy sources: population and economic growth, emissions of air pollutants including greenhouse gases, and energy security. The sustainable production and use of biofuels and other alternate sources of renewable energy have the potential to protect ecosystems, reduce air pollution, reduce greenhouse emissions, and enhance energy security.

In China, as in many developing countries, population growth is a strong social driver behind the search for alternative energy sources. From the beginning of the Han Dynasty in 206 BCE



to the end of the Ming Dynasty in 1644, the population of China doubled from about 60 million to 110 million. By the end of the Qing Dynasty in 1912, population had risen to 410 million. Since the turn of the 20th century, population has surged to more than 1.3 billion. Rapid growth in recent decades has increased the urgency for stronger environmental controls and energy security. In China as in the United States, much of our energy comes from coal, natural gas, or petroleum, all of which contribute carbon and other air pollutants emissions to the atmosphere. Continued population and economic growth in China and India, and consumption patterns in the United States, have caused these countries to become the three largest contributors of $CO_2$ to the atmosphere. The development of a second generation of biofuels—moving away from corn based biofuels—will take us to a new era, one in which we hope to reduce the levels of greenhouse gasses and other air pollutants.



Source: Bill Chism EPA/OPPTS

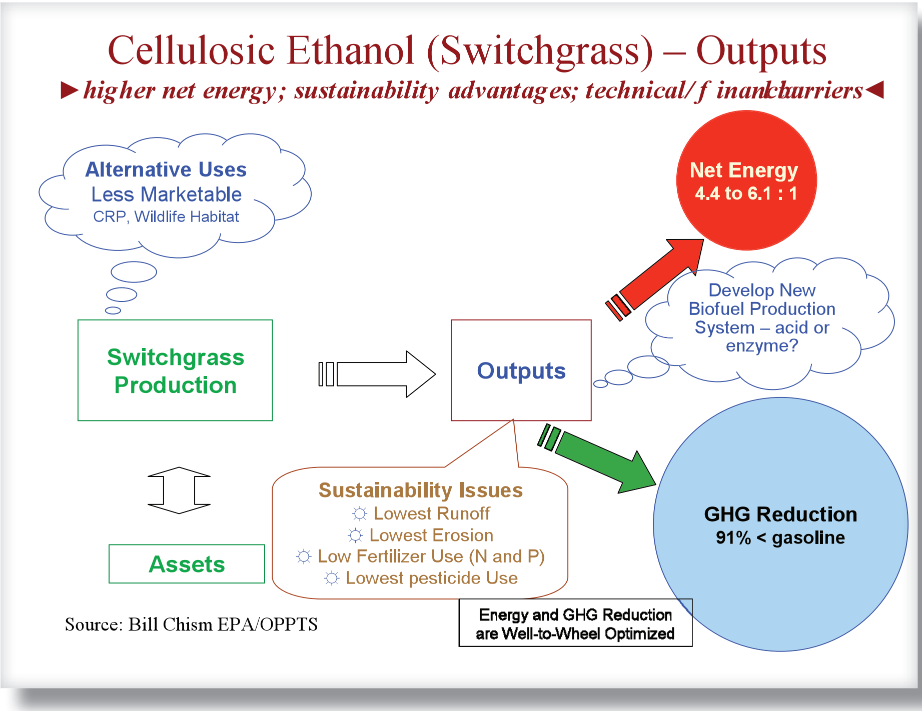
## Second Generation Fuels

What role can biofuels play in enhancing energy security? The International Energy Agency (IEA) in Paris has produced a number of scenarios for energy needs in the next decades. In their 2008 energy report, IEA predicts a worldwide increase of 26 percent in the use of biofuels in transportation fuels and an increase in land devoted to feedstock to produce ethanol and biodiesel from 5 to about 150 million hectares (12 to 400 million acres) by 2050. In addition to biofuel use in transportation fuels, IEA also foresees increasing use of biofuels in areas beyond the transportation sector such as electrical power generation, industry, and buildings. This expansion of usage will require biofuels to become part of an overriding energy policy that considers alternate fuels, carbon sequestration, energy efficiency, and many other elements.

## Systems Analysis of Biofuel Production and Use

The U.S. Environmental Agency (EPA) is evaluating the environmental impacts of biofuel production across all elements of the biofuel supply chain.

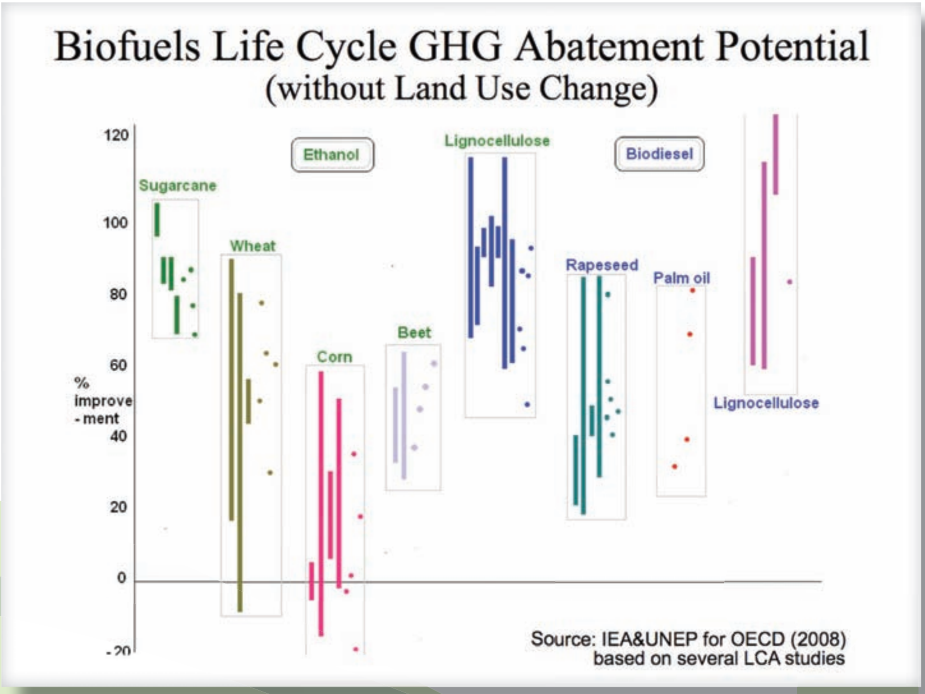
Many factors influence the environmental sustainability of biofuels. First, the production of feedstock has its own environmental costs depending on the choice of crops, as different feedstocks have different agricultural inputs, cultivation techniques, and harvesting practices. Energy output is also dependent on the distance from the field to the conversion plant, distance from the conversion plant to the end user, and type of transportation required to distribute the fuel. Conversion technologies likewise have environmental impacts depending on the source of power and chemicals used to convert feedstock to fuel and feedstock pretreatment requirements.



Source: Bill Chism EPA/OPPTS

From an environmental point of view, there are various ways to look at biofuels production, ranging from inputs, assets, and outputs. The inputs include physical factors of crop production such as water availability, climate, and soil conditions, all of which potentially could change over the next decades because of climate change. The assets include production of additional nutrients such as carbon, filtering and storage of water, and other ecological services such as protection of wildlife. All of these are important elements in ensuring the sustainability of the whole system. The overall environmental impact will depend on the feedstock utilized, such as corn, soybean, switchgrass, sugarcane, algae, or woody biomass, as different feedstocks require different inputs, such as water, soil, pesticides, and fertilizers. Feedstocks will also have to be diverse in order to accommodate regional soil, water availability, climate, landowner preferences, and infrastructure differences within the United States and other countries. For example in marginal lands with temperatures greater than 10°C (50° F), grasses could be an attractive feedstock as they require little agricultural input and exhibit fast and dense growth. However for areas that reach below 10°C (50° F), trees are the most promising alternative. The outputs not only include energy, food, or secondary products such as animal feed, but also include air emissions, potential leaching, and runoff of nitrogen, phosphorous, and pesticides. Good practices can lead to sustainable water resource management that ensure aquifers and streams are not being depleted, whereas poor practices can lead to rapid evaporation of water from sources such as soil and open algae ponds.

The reduction of carbon emissions is one of the central questions in the biofuels debate. The second generation of bioenergy production, such as cellulosic ethanol from dedicated energy crops such as switchgrass and biodiesel from algae, has potential to improve overall sustainability by reducing $CO_2$ emissions and net energy gain, reducing direct competition with the food supply, and by protecting the environment in new ways. Cellulosic ethanol production results in lower nutrient and pesticide runoff, lower soil degradation, lower fertilizer use, and complete lifecycle analyses of production systems are urgently needed if we are to understand all the impacts from an ecosystem perspective.



IEA lifecycle analysis of data for different feedstocks suggests a number of second generation biofuels could achieve greenhouse gas emission reductions.

### Advanced Biofuels

The full potential of biofuels will come from the next generation feedstock of cellulosic bifouel, also referred to as lignocellulose, which is composed of cellulose, hemicellulose, and lignin. Cellulose biomass is an attractive source for sugars as it is Earth's most abundant carbohydrate, found in every type of plant tissue, and therefore can be extracted from materials such as agricultural waste. However, cellulose biomass has evolved for millions of years to be structurally sound and resist destruction, which makes conversion of cellulose to sugars technically challenging and expensive. Currently lignocellulose needs to undergo severe pretreatment with hot acid or ammonia fiber explosion (AFEX) and then be degraded with enzymes extracted from microorganisms. When the cellulose is broken into individual sugars, the sugars are then fed to fermenting yeast to create ethanol. However, most fermenting species cannot tolerate an ethanol concentration of greater than 25 percent (v/v), which means that the ethanol must be distilled through an energy-intensive and expensive process. Many of these conversion challenges are still being addressed through the selective breeding or genetic transformation of plants and fermenting microbes as well as other technological advances such as thermochemical conversion processes.

Although bioethanol receives greater attention and funding in the United States, biodiesel extracted from sources such as *Jatropha*, algae, and soybean, may be a better option for different regions and different modes of transportation, such as air travel. Oils extracted from algae may be the most sustainable candidate as they can be grown on marginal lands, use brackish water, and have higher yields of oil. The main hurdles in algae biodiesel development are economic, and although open algae ponds are the most cost effective, they also lead to high levels of water evaporation as the ponds are shallow to maximize sunlight exposure. Several pilot closed algae systems have been built; however, they are expensive, and the lipid extraction process from algae is inefficient.

### 2007 Energy Independence and Security Act (EISA)

New legislation passed in December 2007, the Energy Independence Security Act (EISA), established a roadmap to increase the volume of renewable fuels to 136 billion liters (36 billion gallons) per year by 2022. These fuels include corn-based ethanol, cellulosic ethanol, and other advanced biofuels (derived from materials other than corn starch, such as biomass-based biodiesel). Table 1 shows the expected time scale and the volumes of fuels in the various categories needed to reach the goal of 135 billion liters (36 billion gallons) per year in 2022. Advanced biofuels are projected to make up 80 billion liters (21 billion gallons) per year, and of this amount over 80 percent would be derived from cellulosic materials.

In 2008, production targets for corn ethanol were set at about 22- 26 billion liters (6-7 billion gallons) a year with the expectation of a rise to 34 billion liters (9 billion gallons) by 2010, but production is capped at 57 billion liters (15 billion gallons) by 2016. In 2010, production targets for cellulosic fuels are expected to rise and continue to do so for the next 20-25 years.

**Table 1. EISA-Mandated Renewable Fuel Requirements for 2022**

| Fuel Category | Billion Gallons Per Year (BGY) | Timeframe |
|---|---|---|
| Total Renewable Fuels | 36.0 | 2006-2022 |
| Advanced Biofuels (Including biomass-based diesel) | 21.0 | 2009-2022 |
| Cellulosic Fuels | 16.0 | 2010-2022 |

Anticipating these issues, EISA states that corn can provide only 57 billion liters (15 billion gallons) of the total 135 billion liters (36 billion gallons), therefore 80 billion liters (21 billion gallons) must come from advanced biofuels such as cellulosic ethanol. Currently all bioethanol produced in the United States comes from corn grain, and the ability to achieve these volumes of advanced biofuels will depend on our ability to overcome process inefficiencies for largescale commercialization.

EISA requires EPA to assess greenhouse gas and other air emissions over the full biofuel lifecycle of different feedstock and establishes three lifecycle standards for renewable fuels in reducing greenhouse gas emissions, ranging from 20 to 60 percent less than conventional fossil fuels (table 2).

**Table 2. Greenhouse Gas Reduction Requirements by Fuel Category**

| Fuel Category | Minimum GHG Reduction Requirements* |
|---|---|
| Renewable fuels** | 20% |
| Biomass-based diesel | 50% |
| Advanced biofuels, including imported biofuels and biodiesel | 50% |
| Cellulosic fuels, including cellulosic ethanol, biobutanol, green diesel, and green gasoline | 60% |

To reach EISA's cap on corn ethanol production of 57 billion liters (15 billion gallons) per year, cellulosic and other advanced biofuels will have to play a growing role in renewable fuels, which in turn will require a diversity of new feedstocks and advances in conversion technologies. Congress recognized that relying on a corn grain base generates controversy and competition between food and fuel. Food-based fuel will affect the price of food not only in China and the United States, but throughout the rest of the world. If public concern over food prices increases, then the public's confidence in the biofuels industry will be undermined, which leads to an additional hurdle for biofuels to overcome. Therefore, development of accurate lifecycle analysis tools will be essential to measure the sustainability of biofuel production. Lifecycle analysis as defined in EISA includes:

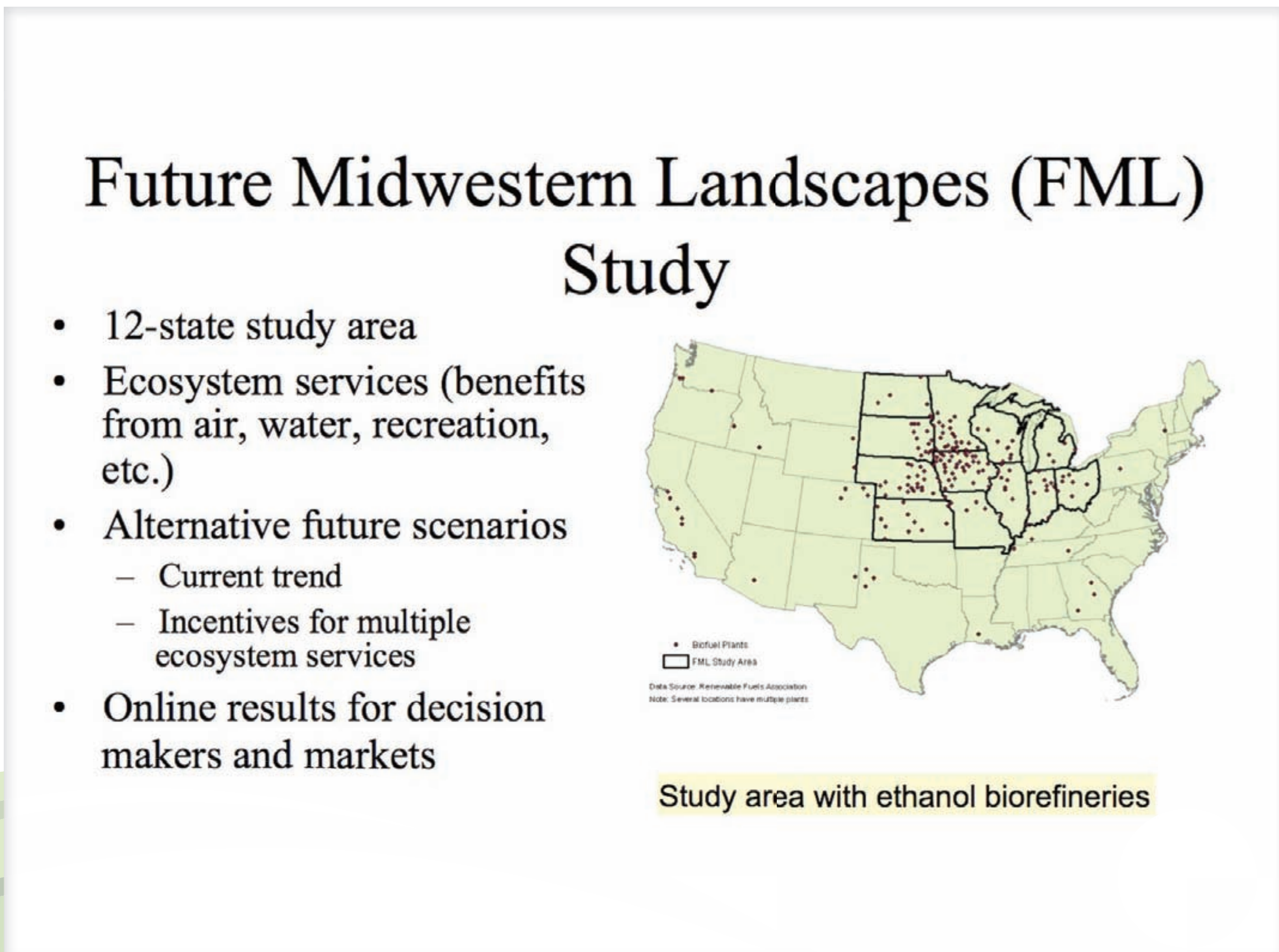
> the aggregate quantity of greenhouse gas emissions (including direct emissions and significant indirect emissions such as significant emissions from land use changes) ... related to the full fuel life cycle, including all stages of fuel and feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel to the ultimate consumer, where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential.

EISA requires that the lifecycle analysis take into account indirect land use changes around the world to determine the effects on greenhouse gas emissions. This is a very complicated issue if one considers the following scenario in which the United States diverts its corn for ethanol production and this leads to less corn imported to Europe or elsewhere. Europe then relies on Brazil, Argentina, or any other country to make up the corn deficit. When these other countries grow more corn, where do they grow the corn? Is it on existing agricultural land or new agricultural land created through deforestation? If it is new agricultural land, what is the carbon loss associated with the conversion?

### EISA Required Report to Congress

Another important EISA provision requires EPA to prepare a tri-annual report to congress to assess environmental impacts of biofuel production. Section 205 stipulates that no later than three years after enactment of the 2007 legislation, and every three years thereafter, EPA shall report to Congress on three issues, 1) the environmental impact of biofuels production, 2) resource conservation issues, and 3) the effects of genetically modified or invasive or noxious plants on the environment and agriculture. An important component of this section is the requirement to "assess and report to Congress on the impacts to date and likely future impacts" for the next decade or longer.

EPA is already engaged in a number of activities to assess the long-term environmental effects and ecosystem services of alternative fuel production systems. One of our studies—the Future Midwestern Landscapes Study—focuses on a 12-state



study area, where the majority of ethanol biorefineries are located, to study the changes in landscapes and ecosystem services. In effect we are looking at numerous models that project the environmental impacts as these systems evolve over the next decade.

### National Biofuel Action Plan

In October 2008, federal agencies working together issued the National Biofuels Action Plan (http://www1.eere.energy.gov/biomass/pdfs/nbap.pdf). This strategy involves a number of task groups and activities. As a specific action item laid out in this plan, my colleagues and I at EPA and the U.S. Departments of Agriculture and Energy (USDA and DOE) have been charged with developing a set of science based criterion indicators for measuring the sustainable production of biofuels. One additional approach to ensuring sustainable biofuels has been the development of technical criteria and indicators (C/I) for use by domestic agencies to assess trends and develop best management practices for biofuel production and use.

Criteria are categories of factors, capacities, or processes that are used to evaluate the environmental, economic, or social elements of a sustainable biofuel system. Indicators are measurable outcomes of a criterion, a means for measuring or describing various aspects of the criterion.

The purpose and function of developing C/I is to evaluate the overall impact of enhanced production of biofuels on existing environmental, social, and economic trends and to guide best management practices. The C/I are not designed for use in standards, certification, and labeling schemes. Rather they are intended to answer the question of how the enhanced production of biofuels might be affecting existing environmental, social and economic trends and to guide best management practices. This work is intended to provide relevant, practical, science-based, voluntary sustainability criteria and indicators to guide domestic activities. At present the proposed U.S. criteria and indicators are being reviewed by the new administration. Several other governments and non-government organizations have also proposed sets of critieria and indicators.

### The Sustainability Challenge

The R&D challenges we face in meeting the mandates to increase production of cellulosic material in a sustainable way are numerous. Can we produce enough feedstocks to meet demand, enhance productivity without disrupting markets and, increase competition for land use change? Can we produce feedstocks sustainably, providing ecological integrity and enhancing environmental values? Can we make biofuels competitive, optimizing agronomic and silviculture systems and introduce innovative conversion and delivery technologies? Can we encourage a rural renaissance as we shift to a bioeconomy and provide economic opportunities and assistance to the agricultural community? And finally, can we do all this without creating a crisis?

The challenge to all of us is making biofuels sustainable, so that we can provide the alternate energy we need without damaging the environment at the same time. To regulate, promote, and assess our progress, it is crucial that we rely on sound science. International cooperation between major energy users such as China and the United States, and sharing information on agricultural practices and efforts to make the system sustainable, will help guide energy policy and ensure energy security for both of our countries. The United States and China and our respective agencies—Natural Science Foundation of China, Ministry of Science and Technology of China, Department of Agriculture of China, and, in the United States, the National Science Foundation, EPA, USDA, and DOE—will all need to cooperate on advancing us to the next stage of sustainable production of biofuels.

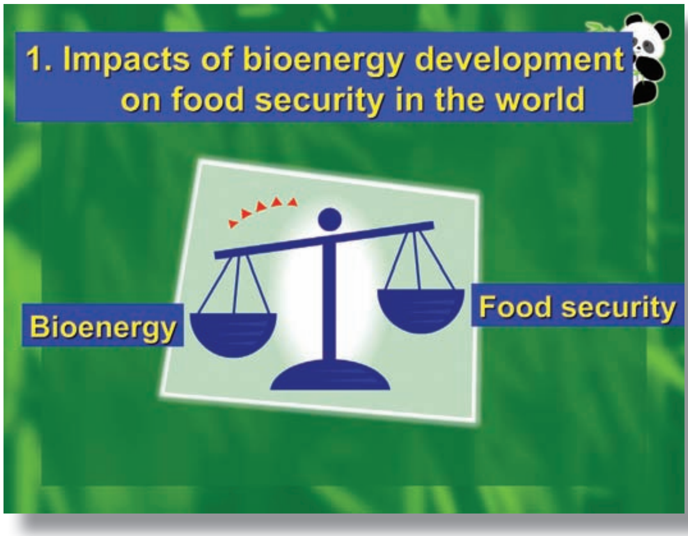
# Land Resources for Bioenergy Development in China from the Standpoint of Food Security

by Gao-Di Xie

**Dr. Gao-Di Xie** *is a professor and vice-director of the Research Center for Resource Sciences and the Research Center for Ecological Economics at the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences.*

The recent push to increase the amount of energy derived from biofuels is already having profound effects on food security in the world and in China. With its large population, booming economy, and limited availability of agricultural land, China must carefully weigh the costs and benefits of biofuel development.

Bioenergy provides 10 percent of the world's total primary energy supply and accounts for more than half of all renewable energy produced in the world. Despite serious doubts about the tradeoffs between production of fuel versus production of food, bioenergy already plays a certain role in the energy industry. Development of bioenergy will require balancing many factors such as climate change, biodiversity, community, and food.




According to the United Nation's (UN) working group UN-Energy, food security will be affected largely by agrofuels in the transportation sector. We have to make a choice, food first or energy first. Bioenergy competes with the human demand for grain and for arable land on which to grow the grain. Increased production of biofuels will result in food supply shortages, increases in food prices, and eventually will result in food crises in developing countries dependent on imported food.

### The Food Crisis

Despite several record-breaking harvests, world cereals production has fallen short of consumption since 2000. Grain stocks are at the lowest levels in 25 years, and global food prices have been rising steadily, up nearly 50 percent in 2007, according to the UN's Food and Agriculture Organization (FAO). Increased demand for grain-based biofuels is the main driver of high food prices. High petroleum prices, increasing demand from developing countries for food, and failed crops have also contributed to rising food prices.

The United Kingdom-based volunteer organization Biofuelwatch attributed 75 percent of the soaring rise in food prices to biofuel development. America's thirst for biofuels may also have contributed to the food crisis. In December 2007, the U.S. Energy Independence and Security Act required that 36 billion gallons of crop-based fuel be produced in the United States by 2022.

High prices are a grave threat to food security, and low-income countries that import much of their food have been hardest hit. Worldwide, 37 countries are in a food security crisis, and 21 of those are in Africa. High food prices have pushed 100 million people in low-income countries deeper into poverty in the last three years, according to FAO. So the question arises again, with limited grain resources, are we going to feed mouths or


Source: Plenty Magazine, 2008.

oil tanks? These startling facts elicit different responses from people in different areas of the world. In Europe, protestors in the street claim that agrofuels are a scam, that biofuels are causing higher food prices and deforestation of the rainforests.

The European Union (EU) is rethinking the great leap in biofuels. In 2007, in an effort to decrease petroleum imports and achieve emissions reductions, the EU biofuel program (E10) called for a mix of 10 percent bio-ethanol in transportation fuels by 2020. According to a report from the British government, producing biofuels with grains such as corn and soybeans requires large amounts of land to be converted to biomass production and leads to serious deforestation as forests are converted to crop production. Italy, Germany, and Great Britain suggested recently that the EU should lower the goal of E10.

## Fragile Food Security

With its huge population and limited land and grain production, food security in China is very fragile. Since 2006, Chinese authorities have tried to curb the negative impact of bioenergy on food security. Competition for arable land between bioenergy development and grain planting is nevertheless still acute.

China, with its 300 million ton coal equivalent (TCE), is the largest user of biomass energy in the world. It is the world's third largest producer of fuel ethanol after the United States and Brazil. In 2005, bioethanol production in China was 1 million tons, more than 80 percent of it from maize and some from wheat. Biodiesel production was 50,000 tons. In 2007, food prices rose 23.3 percent. Clearly, using corn to produce bioethanol contributed to an increase in the price of corn. Because of this trend, at the end of 2006, China began to limit grain-based biofuels.


There are several reasons for the increase in food prices: 1) grain prices worldwide are soaring, 2) the Consumer Price Index in the domestic market is growing, 3) the amount of arable land is decreasing, and 4) corn and wheat are being used to produce biofuel.

## Land: A Critical Threshold

China has very limited land resources for food production, only 130 million hectares (321 million acres) of available land, of which 74 hectares (180 million acres) consist of dry land, 22 million hectares (54 million acres) of irrigated fields, and 33 million hectares (80 million acres) of paddy fields.

The amount of arable land in China, with its high population density, is at a critical threshold, though per capita arable land varies by province, with more in the north than in the south, more in the west than in the east, more inland than in coastal areas. For example, in Inner Mongolia and Heilongjiang Province, the figure is more than 0.3 hectares (0.75 acres) per capita. In the southeast of China, which is a robust area for economic development, consumption of grain outpaces grain production.

Per capita arable land in six Chinese provinces is already less than the threshold for arable land security, 0.056 hectares (0.1384 acres), and less than the threshold of grain security, with per capita grain production less than 200 kilograms (440 pounds).

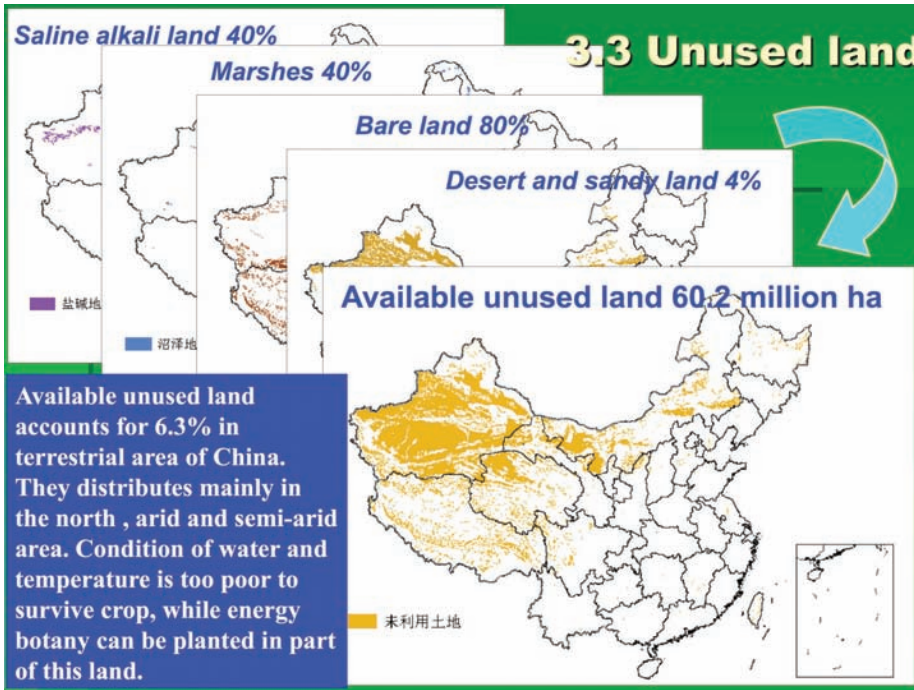
To avoid diverting more farmland crops from food to fuels, China is exploring the potential of non-grain feedstock to produce biofuels. The capacity for producing low-grade feedstock for biofuels has recently reached about 900 million TCE. Among the sources of these feedstocks, residues of agriculture and forests account for about 53 percent; energy forest 35 percent, and energy crops 12 percent. Available quantity of bioenergy in China is about 460 million TCE; crop residues account for only 38 percent of the total, fire wood 36 percent, and dung 22 percent.

In 2005, China's National Development and Reform Commission (NDRC) issued a report classifying the types, resource potentials, and exploitation scale of various forms of biomass. The report estimated 500 million TCE for total biomass resource potentials, with forest residues and crop stalks topping the list at 200 million TCE and 150 million TCE respectively. Industrial wastewater and manure could contribute 57 million TCE; grain, waste oil, and oil plants 50 million TCE; and solid waste 15 million TCE.

In terms of noncommercial energy consumption, NDRC estimated rural uses of energy at 1 million TCE, stalks at 160 million, wood fuel at 103 million, and biogas at 4 million.

## Competition for Arable Land

In determining the land resource potential for bioenergy development in China, we need to choose a strategy first for food production, second for animal feed production, finally for feedstock production. Bioenergy development for fuel uses in China should not compete with food for humans. Available land that can be used to plant feedstock for bioenergy includes degraded agricultural land first, timber forest second, and unused land and marginal available land last.




China has about 4.75 million hectares (11.75 million acres) of degraded agricultural land, or 4 percent of total arable land. By restoring these lands, most of this land can be reused to plant energy feedstock.

China also has nearly 283 million hectares (700 million acres) of forest land, and 57 million acres (140 million acres) of that is timblerless: forest that has been burned or deforested. The total area of burned areas and bare land after deforestation reaches 2.6 million hectares (6.4 million acres) on which energy forests can be planted.

Available unused land accounts for 6 percent (60 million hectares or 140 million acres) of the terrestrial area of China. It is distributed mainly in the northern arid and semi-arid area and consists of saline alkali lands, marshland, bare land, and desert and sandy land. Here, the conditions of water resources and the temperature are too poor for food crops to survive, but bioenergy crops can be planted on part of this land. Furthermore, in 2002 there were about 7 million hectares (17 million acres) of available land suitable for growing bioethanol crops.

Grain-based bioenergy has been subject to worldwide criticism for its negative consequences on greenhouse gas emissions and the recent spike in food prices. To guarantee food security, if China decides not to convert land from food production to fuel production, it still has available marginal arable land, degraded agricultural land, timberless forest land, and land unsuitable for food crop production. The question remains whether China will or will not develop grain-based bioenergy crops. If China can provide sufficient feedstocks, the next step is to address the technical challenges of efficiently converting biomass to usable forms of energy

# Recent Progress in Biomass Energy Studies at the University of Science and Technology of China

**by Qing-Xiang Guo and Ying Zhang**

**Dr. Qing-Xiang Guo** *is director of the Anhui Key Laboratory for Biomass Clean Energy and professor of chemistry at the University of Science and Technology of China.* **Dr. Ying Zhang** *is an associate professor at the Anhui Key Laboratory for Biomass Clean Energy.*

**Dr. Ying Zhang**

The mission of the University of Science and Technology of China (USTC), located in Hefei, the capital of Anhui Province, is to foster high-level personnel in science and technology necessary for the development of the national economy, national defense construction, and education in science and technology. In recent years, we have focused on combining science with technology, teaching with research, and theory with practice. Our studies in biomass energy concentrate on the conversion of biomass to bio-oil, production of hydrogen from bio-oil, production of hydrocarbons from biomass-based syngas, and production of chemicals and fuel additives from biomass. Our work in this area complements research studies in biomass energy at other universities and laboratories.

## National Efforts

Researchers across China are aggressively pursuing large- and small-scale technologies for producing energy from biomass. The first circulating fluid bed boiler in the world to use 100 percent rice straw, an underutilized resource, was developed at Zhejiang University and built in Jiangsu Province. Scientists at Zhejiang University have also launched a biomass gasification demonstration project that may be used to provide energy to 120 households.

The Guangzhou Institute of Energy Conversion of the Chinese Academy of Sciences is analyzing the reliability and economic feasibility of biomass gas and power generation (BGPG) using rice husks. Three joint-stock companies have been set up to promote application of BGPG, one in Guangzhou, the capital of the southern province of Guangdong, one in Jiangsu Province on the eastern coast, and another in Thailand.

Researchers at Tsinghua University in Beijing are demonstrating that advanced solid state fermentation can improve ethanol production from sugar cane and sugar beet by eliminating the squeezing process in order to save energy and labor and to fully utilize the sugar in cane or beet to increase the yield of ethanol. Researchers at Tsinghua University are exploring new technologies such as a rotary drum fermenter and a continuous solid state distiller.

Research on fuel ethanol resources and conversion technologies has been conducted since the 8th Five-Year Plan (1991-1995), and the government has set up R&D programs on production technologies utilizing different kinds of plant cellulose, including starch, Saccharum, and other biomass resources such as cellulose rich agricultural waste.

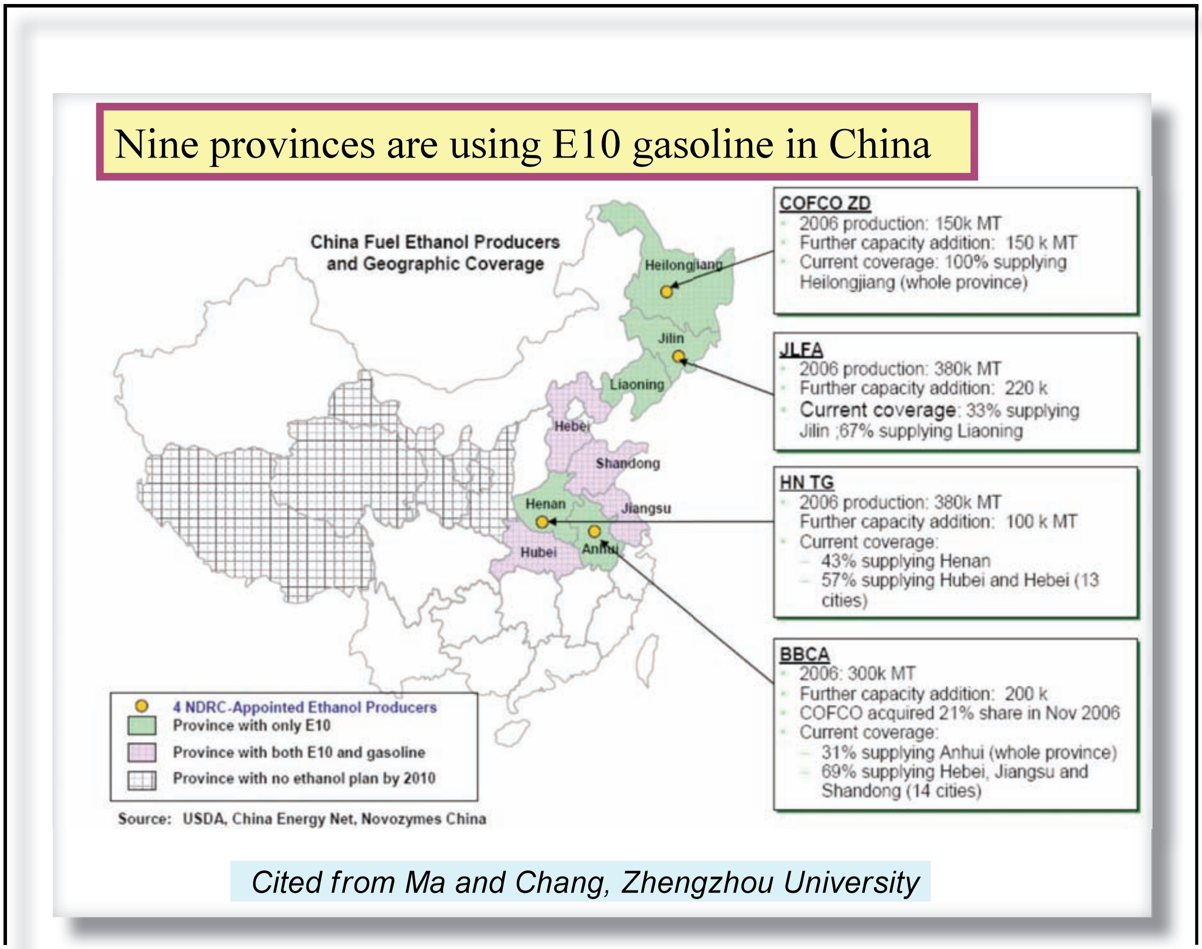
Nine Chinese provinces are currently using E10 gasoline—gasohol—from ethanol producers located primarily in northeastern China, and those suppliers are increasing production capacity. In 2005, yield of fuel ethanol was just over 1 million tons. The potential for ethanol production by 2020 is estimated at 8 million tons.

## Biomass Energy Studies at USTC

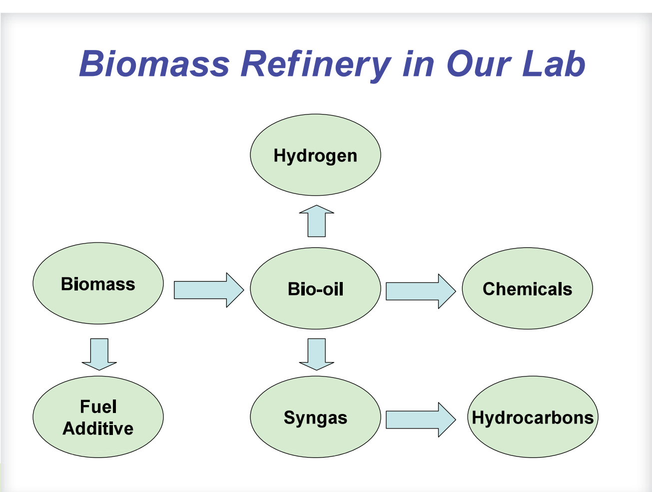
China produces more than 700 million tons of agricultural residues each year. Rice and wheat straw residues are often burned after harvest, creating air pollutants. These wastes can instead be used as starting materials from which to sustainably produce chemicals and energy. Our research shows that it is possible to use primary building blocks from renewable resources to produce commodity chemicals, which are currently produced from fossil resources such as coal, natural gas, and oil.

In our laboratory, we are working to convert biomass into clean energy such as bio-oil through a liquefaction method, fast pyrolysis, which uses heat to decompose the cell wall in biomass such as rice and wheat straw, which have similar structures.

Pyrolytic equipment designed and installed in our laboratory has been used to convert biomass from forest products, agricul-




tural wastes, and residues into bio-oil, a crude liquid fuel. We are also producing hydrogen from bio-oil, and hydrocarbon and fuel additives from biomass-based fuels.



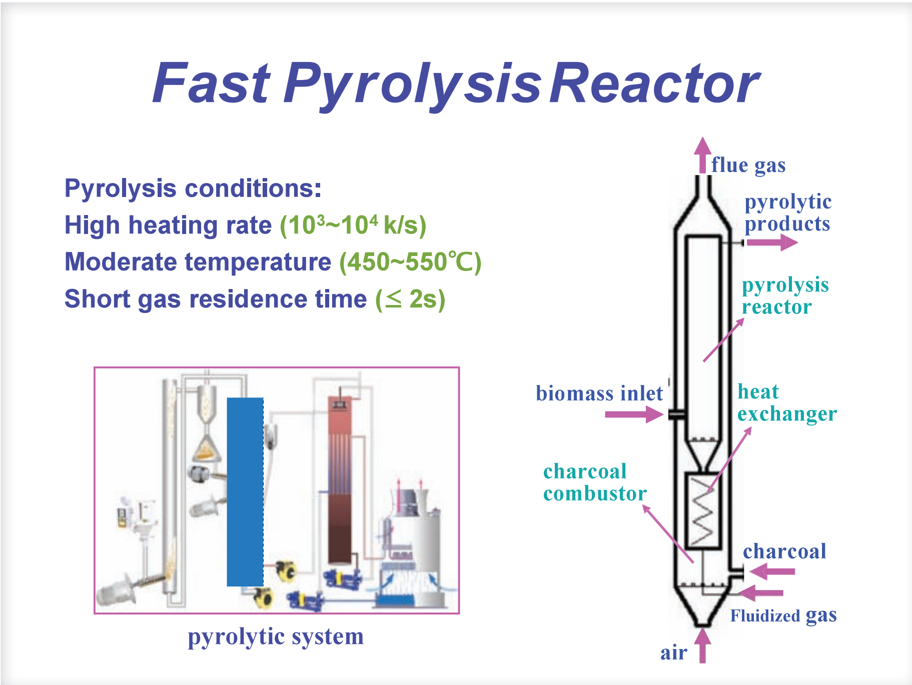

Lignocellulosic biomass can be used to produce fuels through different pathways. A major focus of our work at USTC is converting biomass to bio-oil. From bio-oil we can produce hydrogen, chemicals, and syngas, and from syngas we can also synthesize hydrocarbons.

Byproducts of the pyrolytic process include carbon in the form of charcoal and gas, which can be used to supply energy to fuel the pyrolysis reactor.

In fast pyrolysis, biomass is injected into the reactor and subjected to heat ranging from 450 to 550°C to perform the conversion to liquid bio-oil and charcoal. In the condensation unit, a spray of water cools liquid gas down to about 55° to 60° C, and the heat is carried off by water in the cooling tower. In the case of rice husks, as temperature rises from 420° to 540°, gas production increases, and charcoal production decreases. A demonstration plant in Hefei, the capital of Anhui Province, uses 1,000 kilograms (2,200 pounds) of biomass from agricultural waste to yield more than 50 percent liquid bio-oil.

At USTC we are also working to produce hydrogen from bio-oil. In this process, bio-oil can be converted to syngas through steam reforming. The syngas is then subjected to a water-gas shift reaction to produce hydrogen. This process has a high rate of carbon conversion, more than 90 percent, and a yield of hydrogen of more than 90 percent at a temperature below 500°. Another process to produce hydrogen is electrochemical catalytic reforming of bio-oil, which results in very high levels of hydrogen production.

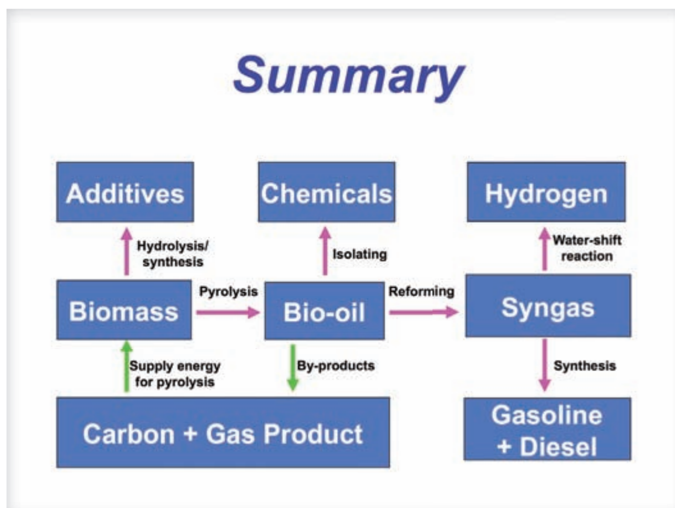
Chemicals and fuel additives are also produced from biomass. Biomass is converted by fast pyrolysis to intermediate products,




which are converted by catalysis to the final product. Even at same temperature we can get different products from cellulose, hemicellulose, and lignin. By altering the temperature or pressure on the synthesis process, we can achieve different products from pyrolysis.

It is also possible to add specific catalysts to achieve better biomass conversion and better product selectivity. Our work on different catalysts used in the pyrolysis of sawdust allowed us to produce benzene, toluene, and acetic acid from one catalyst and phenol derivatives from another catalyst. A third catalyst yielded furan derivatives and carbonyl compounds.

We are also developing a screening process to produce the fuel or fuel additive Gamma-valerolactone (GVL) from cellulose or other carbohydrates and to do so in a "greener" fashion, using less energy than the traditional method of GVL synthesis.




At USTC, we are using biomass through fast pyrolysis to produce bio-oil. Byproducts of pyrolysis such as carbon and gas products can be used to supply the energy for pyrolysis, decreasing dependence on outside energy sources. From bio-oil we can isolate chemicals and produce syngas. From syngas, we can either use a water-shift reaction to produce hydrogen, or a synthetic process to produce gasoline and diesel. This research will eventually help China reduce its dependence on finite fossil resources such as coal, natural gas, and oil as we learn new methods of using primary renewable building blocks from renewable resources that contain carbohydrates, lipids, and oils.

Acknowledgement: This research was supported by the MOST "973" Project, CAS and Anhui Province. The author is very grateful to Professors Xifeng Zhu, Quanxin Li, Lifeng Yan and Yao Fu for their collaboration.

# China's Renewable Energy Potential and Policy Options

**by Lei Shen and Litao Liu**

**Dr. Lei Shen** *is a professor at the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences.* **Litao Liu** *is a doctoral candidate at the Graduate University of the Chinese Academy of Sciences.*

**Dr. Lei Shen**

Biomass is an important source of renewable energy, one that plays and will continue to play a major role in the future energy structure around the world. The Chinese government has consistently promoted the development of biomass since the 1980s. In the past 10 years, renewable energy in general has developed rapidly in China. In 2005, renewable energy provided 8 percent of total energy consumption, excluding the traditional use of biomass energy, and renewable power provided nearly 16 percent of China's total electricity output. Since China's Renewable Energy Law took effect on January 1, 2006, renewable energy industries have received a great deal of attention. The hope is that, while meeting China's increasing demand for energy, the development of renewable energy in China will also make a great contribution to alleviating global climate change.

Biomass is at a rapid development stage in China, and some technologies are commercialized or nearly commercialized. These technologies have great development potential from resources, technology, and industry perspectives. Biomass has begun to play a role in the energy structure and has the potential for large scale development. It is expected that biomass will be an important substitute energy especially in remote rural areas.

At the Institute of Geographic Sciences and Natural Resources Research, we are analyzing resources availability and spatial distribution of biomass in China. We have also examined the three most prominent policy options in the United States and Europe to stimulate the commercialization of renewable energy projects. We are assessing conditions for applying these incentives and guidelines to China's biomass development. China, like the rest of the world, will need to explore options in legislation, strategic planning, and economic incentives to fully realize the potential of biomass as an important source of renewable energy.

### Meeting Energy Demand

China is the second largest consumer of energy in the world and the second largest importer of oil, with more than 40 percent of the total consumed coming from imported oil, according to estimates as of 2004. Growth in demand, however, is well above expectations, resulting in a shortage in generation capacity and transportation bottlenecks. The Chinese government has announced a massive expansion program to meet the demand for energy by 2020, which is expected to be double that of today.

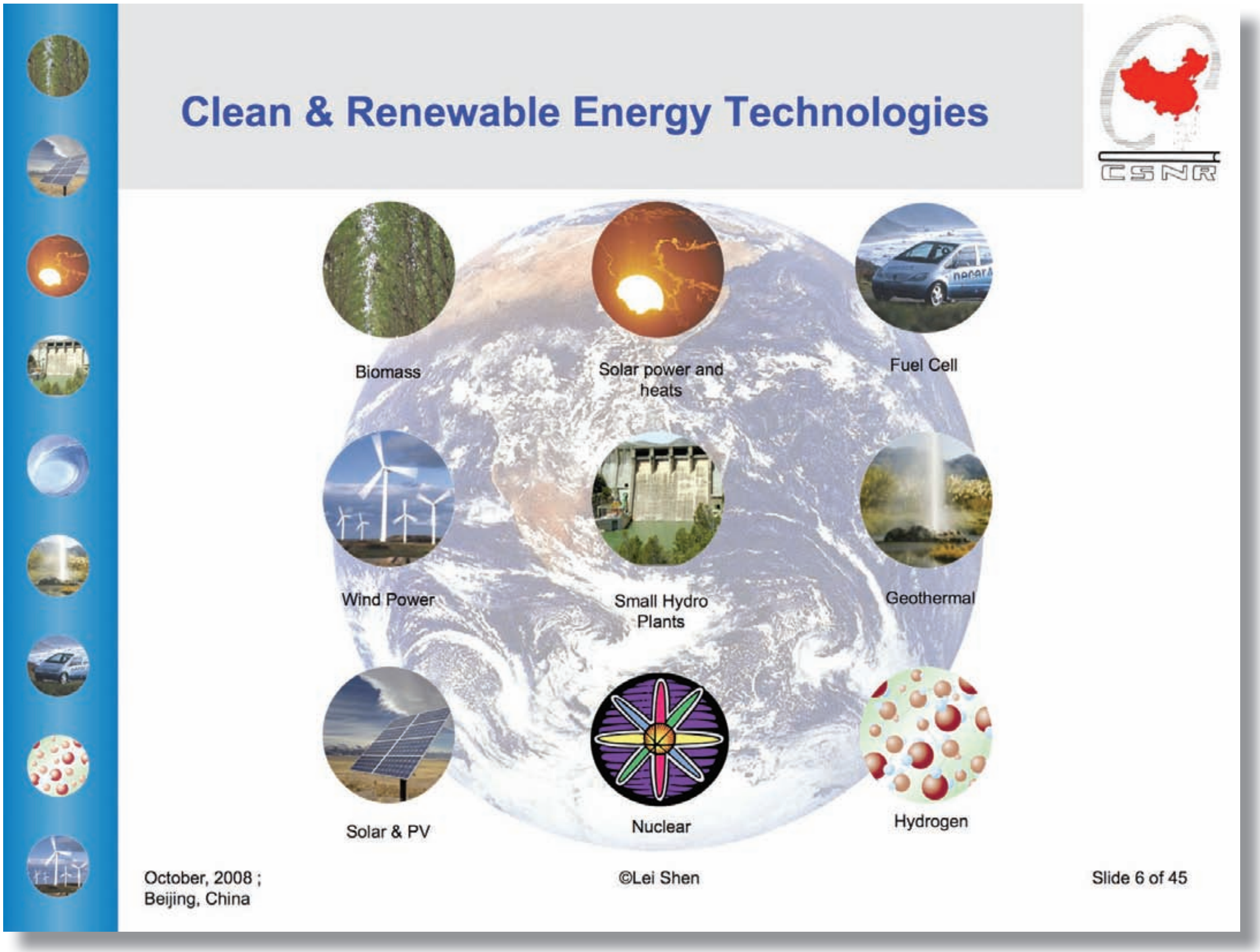
Increasing ownership of automobiles has caused the transportation market to explode. Energy intensity per unit of gross domestic product (GDP) is very high, and while energy efficiency has been improving, it is not improving fast enough.

The China Society of Natural Resources (CSNR) has declared that nine out of 10 of the most polluted cities in the world are in China, which is also the second largest emitter of greenhouse gases (GHGs). The director of the United Nation's Environmental Program has called China's economic goals environmentally unachievable due to resource constraints. In view of China's international commitment to reduce GHGs, reversing the trend toward environmental degradation is becoming a national priority.

China is still highly dependent on coal, which makes up more than 70 percent of its energy mix. Oil and gas resources are very limited, and the government is looking to a diverse energy supply for economic, environmental, and security reasons. While the option for this diversification includes purchasing liquid natural gas from overseas, we must also look to renewable energy as part of our energy portfolio.

China has a huge need for new energy resources to feed economic growth and economic security. Local and global resource constraints, which affect energy security, are driving the search for diversifying from traditional fossil fuels. Increasing awareness of global climate change has heightened environmental awareness. China's central government has resolved to eradicate poverty and achieve food security and the overall well-being of its citizens. Increasingly, China is demonstrating its world-class technological capabilities in renewable energy, especially wind and photovoltaic (PV).

The CSNR has identified a diverse array of clean and renewable energy technologies based on biomass, wind power, fuel cells, small hydro plants, geothermal, hydrogen, and nuclear. According to our studies, by 2020 the world will increasingly




rely on renewable energy, with a large percentage coming from solar thermal and wind, and relatively smaller portions from biofuel, biomass, geothermal, and solar PV. In the shorter term, the forecast is for a strong surge in the global market for wind and solar PV by 2013.

## Renewable Energy in China

The Bureau of Energy, created under China's National Development and Reform Commission, includes renewable energy in the nation's overall energy strategy. The development goal of renewable energy by 2020 amounts to 100 gigawatts (GW), or 10 percent of the total energy capacity. Goals for wind are 20 GW, for small hydro 50 GW, for solar PV 1-2 GW, for biomass 15 GW, and for all others 14 GW

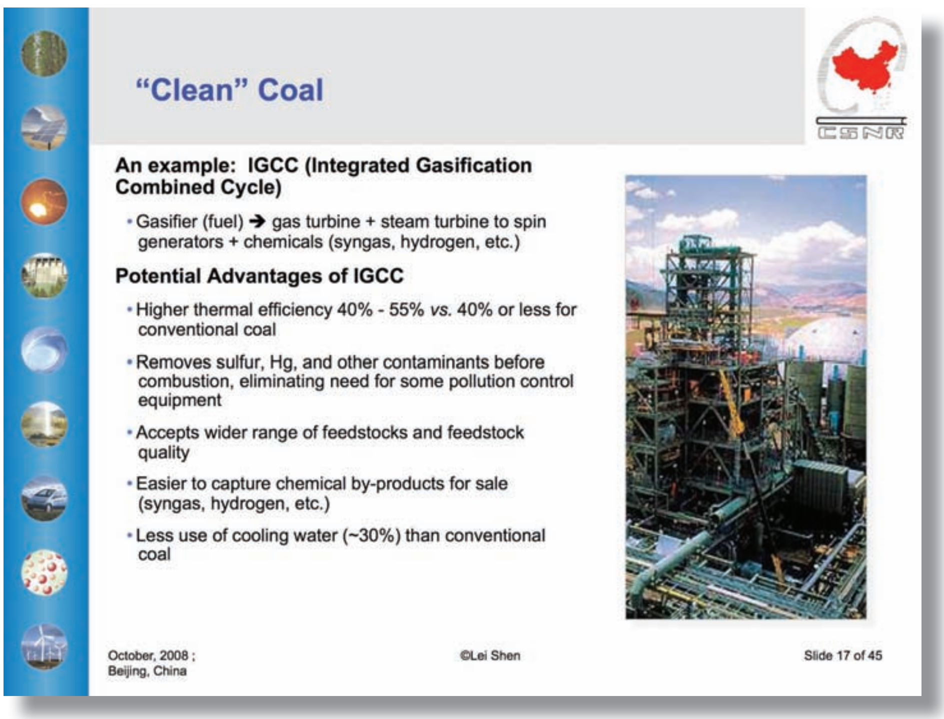
**Wind** Internationally, wind power is the fastest growing, grid-connected resource for generating electricity. By the end of 2003, the total global installed capacity was 40 GW. Wind power is expected to be an important contributor to the North American and European electricity supply. The share of wind energy for now is quite low in China, 5 to 20 percent. By 2003 China had installed just 557 megawatts (MW) of wind power capacity. Total potential for on-shore wind energy resources is greater than 253,000 MW. Upcoming policy support, however, may set off an investment rush similar to what Germany, Spain, and some other countries have experienced in recent years. Wind energy will also create an estimated 50,000 jobs by 2020.

**Solar Photovoltaic** Worldwide, solar PV has grown at a rate of about 30 percent for the last 10 years. Shell and BP, global leaders in solar PV, view this technology as an important and profitable technology in the 21st century. The industry focus now is on driving costs down via mass production and improved technologies.

In China, most solar PV is currently installed in rural locations with no grid-supplied power. Local manufacturing is struggling to produce PV cells at internationally competitive prices, as many of the raw materials are imported at a relatively high cost. Shell and BP are already important providers for high profile projects in China, but so far the market is very small, with about 5 to 6 MW of sales in 2003 with cell production capacity of 74 MW. By 2020, combined revenues from wind and PV are expected to double, and a minimum of 60,000 jobs will be created, according to European Union estimates.

**Hydrogen** The idea of hydrogen energy has attracted significant international attention, similar to the dot.com companies in the early to mid-1990s. Hydrogen is not an energy source, it is an energy carrier. It can be used in fuel cells and in combustion engines and turbines. Hydrogen can be generated from fossil fuels or from renewable energy processes. Major companies are supporting the development of hydrogen technologies as a potential replacement for oil and natural gas.

In China, there is considerable interest in hydrogen technology, but most activity has been in developing research papers and laboratory tests. China needs involvement from leading international experts and companies to quickly develop local capabilities. We have a huge opportunity to take the lead in hydrogen energy. China's demands for new energy supply make it the most efficient location in the world for introducing the new infrastructure required to support hydrogen and fuel cells, which are closely related due to their mutual dependency.




Clean Coal Integrated Gasification Combined Cycle (IGCC) technology has the potential for generating power using "clean" coal. IGCC has a higher thermal efficiency than conventional coal. The process removes sulfur, mercury, and other contaminants before combustion, eliminating the need for some pollution control equipment. It accepts a wider range of feedstocks and feedstock quality, it's easier to capture chemical byproducts such as syngas and hydrogen for sale, and it uses 30 percent less water than conventional coal fired power plants.

### China's Share of Biomass

The total exploitable annual capacity of biomass energy in China is 500 million ton of coal equivalents (TCE). The 11th Five Year Plan for Renewable Energy Development (2006-2010) calls for increasing biomass sources. Of the more than 600 million tons of biomass from corn stalks alone, half can be used to generate energy, representing a coal savings of 150 million TCE. Livestock and poultry manure theoretically could yield enough biogas to generate the equivalent of 57 million TCE. Firewood and wood biomass energy could create 200 million TCE, and municipal solid waste and wastewater could generate nearly 93 TCE.

Many types of crops are suitable for energy production in China. Rapeseed is one of the most important oil plants, accounting for more than 30 percent of the national total, and China ranks first in the world in rapeseed production. Other edible oil plants are also available as biomass, including some that grow in the wild such as sumac, Chinese goldthread, and sweet broomcorn.

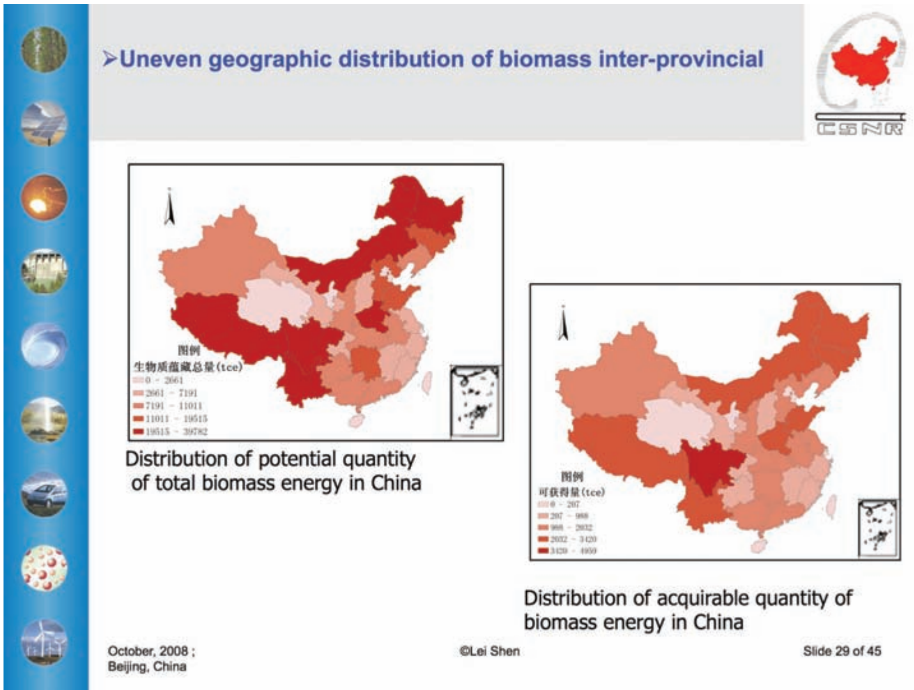
Nearly 40 percent of crop residues come from corn, followed by rice, wheat, oil crops, and beans, but there are regional differences in the distribution of biomass resource reserves in the provinces and autonomous regions of China. Livestock and poultry feces are mainly located in the more developed farming and animal husbandry regions. Forest and wood biomass resources are mainly distributed in China's major forested areas. Municipal solid waste and wastewater resources are greater in areas of economic development and high urban populations.

At present, biomass energy resources in China are utilized mainly in conventional combustion technologies, but newer technologies such as gasification, liquefaction, and power generation are being developed gradually. Currently the main technologies are ethanol fuel technology and bio-oil technology.

### Policy Options

Three renewable energy support policies have achieved some success, though none of these is an ideal policy.

Feed-in-tariffs (FIT) are governmental incentives to encourage adoption of renewable energy by setting a purchase price for renewable sources such as wind, solar, or biomass. The higher costs are offset by spreading the increased expense across a broad consumer base. Renewable Portfolio Standards (RPS) are government mandates that require utilities to generate a certain



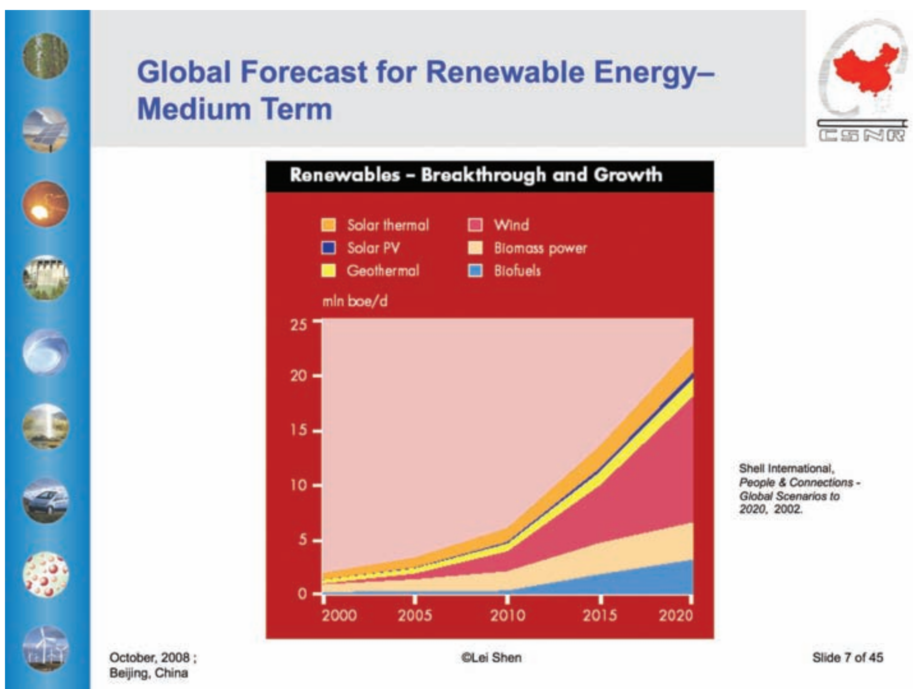

percentage of the total amount of electricity from renewables. Tendering Policies call for competitive bidding on certain projects to guarantee that the lowest bidder will have a sure market for its output. This gives some assurance that investment in R&D will result in a certain return. These incentives and combinations of them have been implemented with some success in Europe, Australia, and the United States.

China's renewable energy is evolving toward international best practices. The goal is to have10 percent of total electricity produced from renewables by 2020.China has a long history of central government support for renewable energy, especially since the 9th Five Year Plan (1997 to 2002). In 2004, the government released the first renewable energy law draft for discussion. The draft law says that the grid must buy approved electricity generated by renewables, and that the price will be decided by different categories.

There are, however, some barriers to adoption of renewable energy technologies in China, including higher upfront costs and subsidization of traditional energy, incomplete assessment of renewable resources, lack of domestic suppliers, and poor linkages from R&D to commercialization.

Three options are available to encourage biomass development in China: legislation, strategic planning, and economic incentives. The legislative approach, as embodied in the Renewable Energy Promotion Law, has sparked widespread attention to the development of renewable energy. The market is expanding rapidly, investment is increasing markedly, and renewable energy manufacturing has received a much-needed jump start. Strategic planning sets specific targets for increases in biomass development in incremental steps. Economic incentives include subsidies to the biomass energy industry and income tax concessions to promote renewable energy development. Other incentives aim to reform China's customs duties systems to promote foreign investment in China's growing renewable energy market.

China's energy challenges are not simply national challenges, just as global climate change is not a local issue but a global one. While China is rapidly exploring new technologies using renewable resources, we are also looking to the international market for ideas and investment, and customizing policies that work in other countries to our own needs.



# Environmental Grand Challenge of Biodiversity Loss: Potential Impact from Biofuels

**by John W. Bickham, Geoff Laban, and Mark A. Thomas**

**Dr. John W. Bickham** *is the director of the Center for the Environment (C4E) and a professor of Forestry and Natural Resources at Purdue University.* **Geoff Laban** *is a doctoral student in the Department of Forestry and Natural Resources at Purdue University.* **Mark A. Thomas** *is a doctoral student in the Department of Agricultural and Biological Engineering at Purdue University.*

**John W. Bickham**

The recent high gasoline prices prompted researchers and U.S. government agencies to aggressively explore alternative sources to safeguard U.S. energy independence. However, there is a need to address the environmental grand challenges associated with alternative energy sources and among these, energy, climate change, biodiversity loss, deforestation, clean water, and clean air loom large. This paper focuses on one aspect of the grand challenge of energy: biofuels, which will certainly play an important role as one of the new alternative energy sources.

The Midwestern corn producing states, such as Indiana, are among the world's most productive agricultural areas, which is the reason there is so much focus on corn-based ethanol in the region. In the short term, corn grain as an ethanol feedstock represents the low hanging fruit in the biofuels sector because of the tremendous quantity of corn produced, at least some of which can be converted to biofuels. The expected benefits of biofuels in Indiana and the United States as a whole include reduced dependency on foreign oil, positive environmental effects such as the reduction of greenhouse gases, and economic benefits to rural America.

Globally, biofuels represent an economic benefit to developing countries. Whereas many developing countries struggle to deal with the cost of energy imports, biofuels are a potentially home-grown source of liquid fuels that can be produced from a variety of sources including agricultural feedstocks such as corn stover.

In Indiana, we presently have seven ethanol refineries which produce 1.95 billion liters (440 million gallons) of ethanol from 6.7 million cubic meters (190 million bushels) of corn. There are five new refineries being constructed which are projected to produce 2.29 billion liters (605 million gallons) of ethanol a year from 7.9 million cubic meters (223 million bushels) of corn. Another 16 or so refineries are currently in the planning phase. The 12 plants already existing and under construction will produce approximately 3.78 billion liters (one billion gallons) of ethanol a year and use 40 percent of Indiana's corn crop. There has already been stimulating discussion about the implications of corn-based ethanol on agriculture and food production.

Many of the anticipated environmental benefits will be partially offset by certain adverse effects, including air pollution from the fossil fuels that might be used in ethanol refineries or to harvest the corn; increased use of fertilizers, herbicides, and insecticides; the impact of genetically modified crops; loss of valuable wildlife habitat; and increased water usage and lower water quality. All of these might affect the overall environmental equation as to the advantage of developing the biofuels economy.

### Causes for Concern

It is widely recognized that corn is not the optimal feedstock for biofuels, but it is the most suitable one to use in transition in the United States until the problems facing the cellulosic ethanol industry are worked out. Non-cellulosic feedstocks including sugarcane, soybeans, palm oils, and other plants used around the world to produce ethanol or biodiesel, but none of these are a viable replacement for corn in the near term. Thus, it is inevitable that some agricultural production will move from food to energy.

As a consequence of using corn for bioethanol, a resulting rise in the price of food is a major cause for concern, although this is not as worrisome as has been portrayed in the press. Based on current feedstock conversion technologies, if 100 percent of U.S. corn and soybean production went to biofuels, we could produce only 12 percent of needed gasoline and 6 percent of diesel fuels. The United States has a stated goal of producing 136.3 billion liters (36 billion gallons) of ethanol by 2022 of which 56.8 billion liters (15 billion gallons) or so will come from corn.

It is clear that other sources besides corn are more suitable as biofuels feedstocks, but these must be made available in sufficient quantities; nonetheless, in the future, the amount of corn likely to be used could take an enormous portion of the U.S. annual production.

However, there are some positive sides to bioethanol that are often overlooked. For example, the investment company Merrill Lynch estimates that ethanol held down gas prices by 15 percent in 2007. This illustrates the potential influence of bioenergy in reducing or maintaining gasoline price levels. Moreover, the President's Council of Economic Advisors has stated that ethanol accounts for only 3 percent of the global food price increase, which is much lower than the numbers often seen in the press.

Ethanol accounts for a 33 percent increase in the price of corn in the United States, but corn is only 30 percent of all grain, and grain accounts for just 20 percent of all food. So the overall impact of ethanol on food prices in the United States is probably not as great as it has been portrayed in the popular media. Moreover, technical advances may ease the current concerns associated with the food versus fuel debate. One Indiana ethanol plant reports a 6.4 percent increase in ethanol per bushel of corn, with 22 percent less energy and 26 percent less water used after five years of operating; in other words, efficiency increased dramatically after five years. The use of enzymes rather than heat to ferment ethanol decreases energy and water needs by 15 percent, and increased grain yields from hybrid cultivars might allow ethanol demands to be met without planting more acres. So as we develop better conversion technologies and genetically defined corn designed for producing biofuels, we might achieve even more efficient ethanol production.

## Midwestern Agricultural Systems

In Indiana and other parts of the Midwest agricultural region, the landscape is a patchwork of crop lands and natural habitat. These natural areas can be woodlots, waterways, riparian habitats and other sorts of natural systems that provide important ecological services, such as supporting a diversity of plants and wildlife. We have started to consider our agricultural lands as ecosystems in themselves and as part of a complex ecosystem.


These habitats support a diversity of plants and animals; Indiana's forests are particularly rich in biodiversity especially in hardwood trees. Protection of these woodland habitats is extremely important for wildlife and for maintaining biodiversity.

These habitats support a diversity of plants and wildlife, which could be threatened with an expansion of agricultural acreage to meet biofuel demands associated with corn grain as a feedstock. In addition, decades of government incentive programs designed to minimize agro-chemical usage, including excess fertilizer, herbicides, and fungicides, on those intensely managed landscapes could be negated if continued efforts are not made to address/ protect wildlife habitats.


## Global Diversity Loss

Of all the environmental grand challenges—energy, climate change, deforestation, clean water, and clean air—the loss of biodiversity and how it relates to biofuels is one of the most important, and the one on which considerable research at Purdue's Center for the Environment has been focused. Of course, these grand challenges are all connected; one cannot be solved without attention to the others. To use a basketball analogy, we need a full court press in our approach to solving the energy crisis. That is, we need multiple energy sources and we must simultaneously be concerned with the myriad potential economic, national security, environmental, and other implications of these varied energy sources.

Biodiversity and biodiversity loss are terms widely heard in the press. Currently we are in the midst of the worst crisis in terms of extinction rates that the world has seen in the last 65 million years. Many of the species likely to be lost during the course of the next century will never be known to science. There are about 1.6 million species of organisms formally described in the scientific literature, out of an estimated total of 15 to 20 million species. Since the beginning of our modern system of taxonomy, which began with Linnaeus in 1758, we have described only about 10 percent of the estimated biodiversity on the planet! With current rates of extinction, one to two thirds of the species of all plant, animal, and other organisms will disappear during the second half of the next century. The current extinction rate is nearly 1,000 times that of background rate and may reach 10,000 times over the next century. With extinction rates this high, at the historic rates of discovery we can describe but a small fraction of the existing biodiversity before it is lost forever. The finality of extinction is what makes this particular challenge such an important one to stakeholders.

### From Natural Lands to Managed Systems

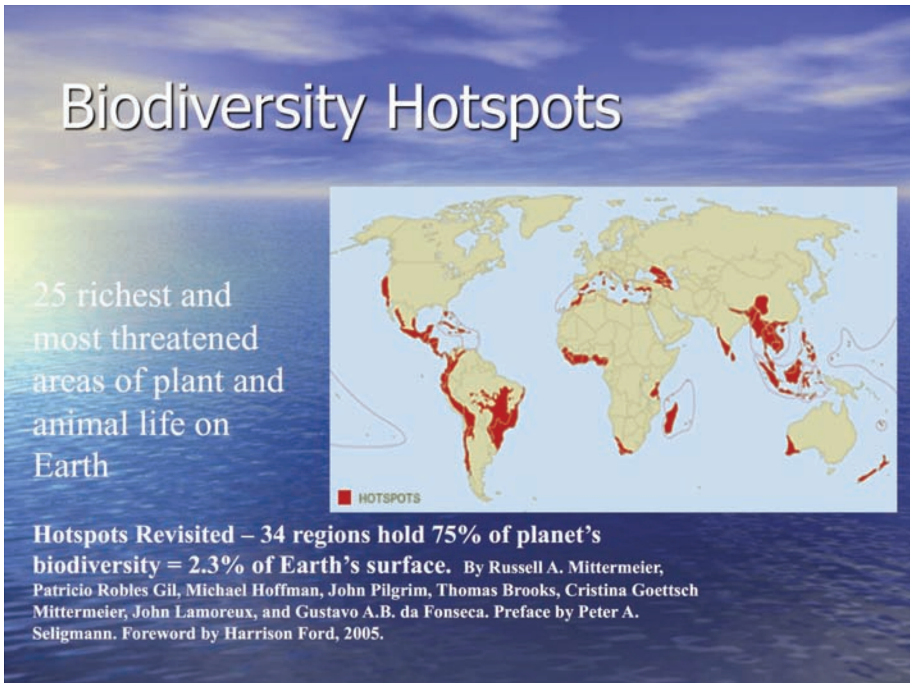
Anything we do that affects agriculture, including biofuels production, will play a role in biodiversity loss. In the United States, two important land conservation programs are the United State Department of Agriculture's (USDA) Conservation Reserve Enhancement Program (CREP), a voluntary land retirement program that addresses high priority conservation issues of local and national significance, and its offshoot the Conservation Reserve Program (CRP), which is a cost-share and rental program. Each of these programs helps agricultural producers protect environmentally sensitive land, decrease erosion, restore wildlife habitat, and safeguard ground and surface water. In other words, it is a way for the government to provide incentives to voluntary producers to put lands into wildlife habitat or establish approved conservation practices, not to produce crops during the contract periods.

USDA conservation programs are of great benefit to wildlife because they create new habitat for woodland, prairie, and wetland species. In the United States, there are 14 million hectares (35 million acres) of land in CREP, and this sequesters about 48 million metric tons of $CO_2$. The Indiana CREP targets the enrollment of 2,800 hectares (7,000) acres in three watersheds—the Highland/Pigeon, Tippecanoe, and Upper White River watersheds—where sediment, nutrients, pesticides, and herbicides run off from agricultural land. Landowners can enroll eligible cropland and marginal pastureland in these watersheds. However, 11 million hectares (26 million acres) of CRP land are coming up for renewal by the end of 2010.

Unfortunately, what happens to the price of corn as a result of biofuels production will play a role in farmers' decisions as to whether they participate in this program or not. Producers might no longer volunteer to participate because of the economic lure of high grain prices caused by increased demands for biofuels production. If so, thousands and perhaps millions of acres of low producing/highly erodible fields will move from the conservation program to regular annual crop production. That alone will have a profound impact on existing wildlife habitat.

To take a broader view, the Food and Agriculture Organization (FAO) of the United Nation's Global Forest Resources Assessment 2005 estimates that global deforestation is occurring at the rate of 13 million hectares (32 million acres) per year. FAO attributes much of the change to conversion for agricultural uses, including crops and livestock

It is clear that worldwide, agriculture has an impact on deforestation, and deforestation is one of the major drivers of biodiversity loss. The distribution of biodiversity in the world is highly unequal. High biodiversity hot spots are distributed mainly in the tropical areas of the world, and some of these areas correspond to the areas that are being deforested. This includes areas such as the parts of the Amazonian rain forest and tropical forests in West Africa and Indonesia.




A search of the published literature containing the word phylogeny, which is the evolutionary history and relatedness of organisms, reveals that since the 1990s, the number of publications in systematic biology describing species and studying the relationships of species has gone up dramatically, from fewer than 1,000 a year in 1990 to more than 8,000 in 2005. Today, we are in an unprecedented era of discovery in systematic biology. Just 20 years ago, a systematist could read all the papers in his or her field that occurred in a year; today that is not possible.

### Research at C4E

At Purdue's Center for the Environment (C4E), we conduct studies on the systematics and genetics of a variety of species and at multiple levels of biological organization. An example is a study of the Little Yellow Bat (*Rhogeessa tumida* complex) found in the tropics of Mexico, Central America, and South America. When this work began many years ago, it was thought this bat was a single species. After decades of research on chromosome structure and molecular genetics, the picture has changed remarkably.

Recently we sequenced mitochondrial and nuclear genes that produced a phylogenetic tree showing at least 12 distinct branches each of which represent different biological species. Most of the species have very limited distributional ranges; some are known only from a single locality. Studies such as these have led systematic mammalogists to conclude that species diversity of mammals is possibly underestimated by 25 percent. Many of these species are cryptic, like the forms of *Rhogeessa* that remained unknown until genetic studies were applied. The significance of these findings relates to our ability to conserve the world's biodiversity. For example, a plan to conserve the biodiversity of *Rhogeessa* based on our knowledge of genetic diversity in the group would look very different from a conservation plan based upon the old systematic concept of a single species of *Rhogeessa*.

But not all biodiversity is represented by species level distinctions. Within-species genetic diversity is another aspect of biodiversity that must be considered in conservation programs, because as genetic diversity declines, extinction probability increases. An example of new findings in biodiversity involves a study of Steller sea lions that is being conducted at C4E. The rookeries where this species gathers to breed and bear their young are distributed along the North Pacific rim from the Sea of Okhotsk in Russia across the North Pacific to central California. This is a single species, but a long-term study of genetics has shown there are multiple groups that we can define based upon the distributions, frequencies, and relatedness of mitochondrial DNA haplotypes. For example, the group in the Pacific Northwest of North America is genetically quite different from the group in Alaska that ranges from Prince William Sound to the Commander Islands in Russia, and that group is quite different from the group that occupies the Kamchatka Peninsula, Kuril Islands, and Sea of Okhotsk in Russia. Evolutionary analysis shows that these groups diverged as a result of isolation during the Pleistocene when the repeated glacial cycles caused multiple separations of these populations. The deep genetic subdivisions within their distributional range have led us to recognize two subspecies of Steller sea lions and multiple stocks within subspecies. These genetic studies have had a profound impact on efforts to conserve and protect the species, and presently one subspecies is considered endangered and the other threatened under the U.S. Endangered Species Act.

Yet another biodiversity study being conducted in the C4E is that of the bowhead whale. This study illustrates the use of genetics to investigate biodiversity and population management of a harvested species. The Scientific Committee of the International Whaling Commission conducts population genetics studies on all species of great whales. Plans to manage harvests must also include plans to conserve biodiversity. The take home message is that biodiversity studies must not only include lists of species, but they must also consider the genetic variation within species since that represents the ability of these organisms to respond to environmental stressors and other pressures.

### Understanding Biodiversity Loss

This paper highlights some general and potential concerns associated with utilizing corn-grain as a biofuel feedstock with emphasis on wildlife or biodiversity loss. While there are multiple reasons to pursue alternative sources of energy, it is important to note that a primary driver is environmental concern, especially the potential impacts on climate change. Nonetheless, subtle and even unexpected environmental consequences of biofuels and other alternatives can only be uncovered through comprehensive life-cycle analyses which must be based upon strong environmental databases.

The key message in this paper is that one of the most important environmental grand challenges, biodiversity loss, is not yet well recognized. The key database needed to evaluate the impact of the biofuels economy on biodiversity loss is minimally an understanding of the species of organisms with which we share the planet. That database is estimated to be only about 10 percent complete after 250 years of work by biological systematists. Without a serious effort to catalogue the diversity of life on earth we will never be able to assess this important impact.

### Acknowledgement

The Center for the Environment (C4E) at Purdue University is one of 11 core centers at Purdue's Discovery Park. Like the other core centers our main purpose is to facilitate large interdisciplinary research proposals and projects. While some of Discovery Park's centers operate large research facilities, like the Birck Nanotechnology Center and the Bindley Bioscience Center, C4E is a virtual center, with no large investment in infrastructure. Nonetheless, we have approximately 150 faculty participants from 30 different departments and seven colleges. This is indicative of the large number of faculty and researchers at Purdue who are interested in environmental issues, including the issue of biofuels and the intersection among energy, environment, and climate change.

# Woody Bioenergy Development and Its Possible Effects on the Ecological Environment in Jiangxi Province

**by Shi-Huang Zhang**

**Dr. Shi-Huang Zhang** *is an associate professor at the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences.*

If we take a glance backward, we realize that we passed the peak of world oil production in 2007, and that one day we are going to run out of fossil fuels. Since 1960, the price of crude oil has risen sharply and is expected to continue to rise. World energy consumption of all types, including oil, natural gas, coal, renewables, and nuclear energy, is also following an accelerating upward trend with no end in sight.

It is clear that we must counteract our dependence on fossil fuels, especially if we are to achieve energy supply security. This will require efficiency measures now, with an emphasis on renewable energy forms.

This can be achieved by assuring a diversified supply of vegetable oils from a broad variety of oilseed crops grown all over the world; by including nonfood oilseed plants such as *Jatropha*, *Populus*, and algae; and by growing crops on marginal soils and in the semi-arid climatic zone. Fossil fuel is finite and not sustainable. Liquid biofuels are a proven and sustainable alternative.

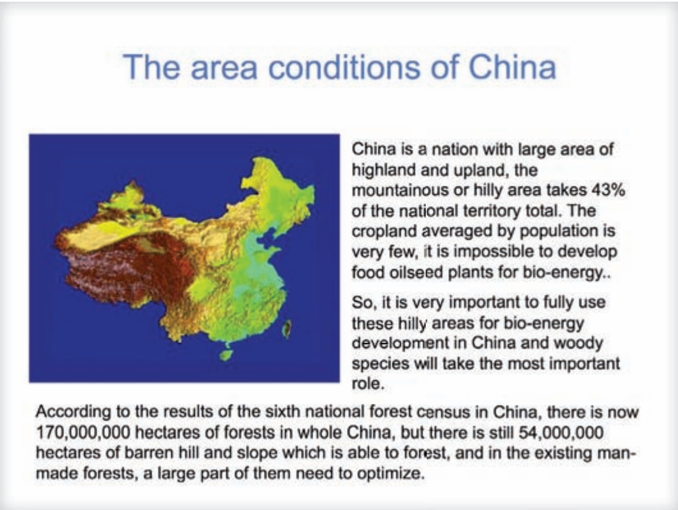
We must also counteract climate change by developing bioenergy trees to reduce consumption of fossil resources. The potential in non-food oilseed plants is huge. They can be produced efficiently, processed inexpensively, and they are highly sustainable. Liquid biofuels are climate friendly.

Political support for biodiesel is world wide. It is seen as a viable alternative to reduce the energy supply risks of fossil fuels, to support efforts to reduce climate change, and to create national jobs and income. It can be used in most of the world's vehicles.

Biofuel also has reasonable production costs. Feedstock cost can be reduced, especially with the use of non-food oilseed crops. Highly efficient processing technologies are available. In addition, high quality biodiesel can be produced from a broad variety of oilseeds.

Another advantage of biodiesel production is international trade. Production plants can be located close to feedstock sources, the logistical costs at deep sea harbor sites are low, and there is a low vulnerability in supply, as oilseed and oils are traded and transported world-wide. Biodiesel is already traded all over the world in large volumes.

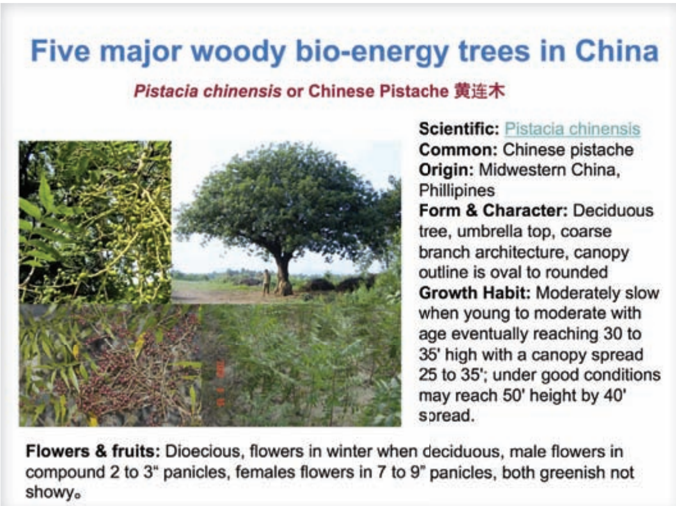
China is a nation with a large area of highland and upland. The mountainous and hilly areas occupy 43 percent of the national land total. In contrast, per capita food cropland area is quite low. It is impossible to switch food oilseed plants to produce biofuel, so it is very important to fully utilize these hilly areas for bioenergy development. Woody species will play the most important role. According to the results of the 6th national forest census, there are currently 170 million hectares (420 million acres) of forest in all of China, but there are 54 million hectares (133 million acres) of barren hills and slopes that could be developed as forests.




## Woody Bioenergy Trees

Five major woody trees in China are potential sources of bioenergy. *Jatropha curcas* L. is a large, coarse annual shrub or small, short-lived tree that can grow 3.5 to 4.5 meters (8 to 15 feet) tall. It has thin, often greenish bark which exudes copious amounts of watery sap when cut. It is native to tropical America but is now cultivated widely in tropical countries throughout the world.

*Pistacia chinensis*, Chinese Pistache, is a deciduous tree with an umbrella-shaped crown and a coarse branchy architecture. The canopy outline is oval to rounded. It grows moderately slowly when young but with age it eventually reaches 9 meters to 11 meters (30 to 35 feet) high with a canopy spread of 7 to 11 meters (25 to 35 feet). Under good conditions, it may reach 15 meters (50 feet) in height and 12 meters (40 feet) wide.




*Xanthoceras sorbifolia*, Yellowhorn, is an important oil tree species in northern, northeastern, and northwestern China. It has been introduced and cultivated in 14 provinces over a total area of about 50,000 hectares (123,000 acres). The annual output is about 3,750 tons.Yellowhorn is very high in linoleic acid, an essential fatty acid. Yellowhorn also yields an important material used in the manufacturing of liquid crystals for color televisions and calculators.

*Cornus wilsoniana*, the dogwood, is a deciduous woody tree native to the central part of China. It is distributed broadly to the south of Yellow River, but is concentrated in the reach of the Yangtze River, especially in Jiangxi, Hunan, and Hubei Provinces. It can be planted below 1,000 meters (3,200 feet) above sea level and can be used to produce the raw materials for biodiesel fuel, lipidic chemical products, paint, or edible oil.

*Camellia olefiera*, or tea-oil camellia, is an evergreen shrub that typically grows 9 to 6 meters (10 to 30 feet) tall and features elliptic to obovate, serrate, glossy dark green leaves. It is native to China, specifically for the seeds, from which is extracted commercial tea oil, known as oriental olive oil, an edible oil that is highly prized by consumers domestically and abroad.

## Woody Development to 2020

During the 11th Five-Year Plan (2006-2010), the State Forestry Administration of China developed the "national bio-energy directed forest construction program" and the "woody feedstock plantation plan for biodiesel." The plan designates


400,000 hectares (990,000 acres) of *Jatropha curcas* to be planted in Yunnan, Sichuan, Guizhou, and Chongqing Provinces; 250,000 hectares (620,000 acres) of *Pistacia Chinensis* in Hebei, Shanxi, Shaanxi, Anhui, and Henan Provinces; 50,000 hectares (123,000 acres) of *Cornus wilsoniana* in Hunan, Hubei, and Jiangxi Provinces; and 133,000 hectares (320,000 acres) of *Xanthoceras sorbifolia* in inner Mongolia, Liaoning, and Xinjiang Provinces.

Jiangxi Province, located in the southern part of China, is very suitable for development of woody bioenergy because the highlands and uplands occupy as much as 78 percent of the provincial territory. The total area of barren hills and slopes represents about 200,000 hectares (500,000 acres) in Jiangxi, and the area of *Cornus wilsoniana* plantation will exceed 66,700 hectares (165,000 acres) by 2010. At the same time, a total of about 333,000 hectares (823,000 acres) of high yielding *Camellia oleifera* forest will be planted.

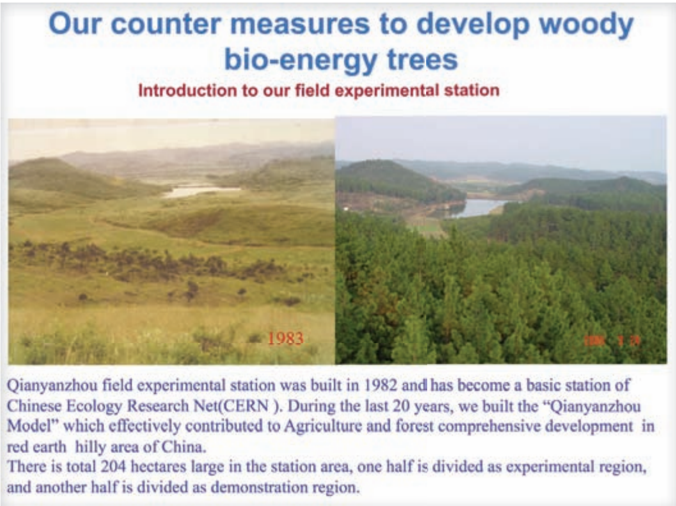
The existing plantation area of *Cornus wilsoniana* is about 600,000 hectares (1,500,000 acres), but yield is very low due to the need for extensive management and low quality of the trees. About 5,400 hectares (13,300 acres) of *Cornus wilsoniana* trees have been planted in Jiangxi and Hunan, especially in the southern part of Jiangxi.

## Experimental Field Station

In 1982, the Chinese Academy of Sciences established an experimental field station in Taihe County in the central part of Jiangxi Province, which has a subtropical monsoon climate typical of Asia. The Qianyanzhou Field Experimental Station is located in the northern part of the North Subtropic zone characterized by red earth hills. The original vegetation was evergreen broad-leaf forest, but due to degradation, the original forest has been replaced with plantation forests, grasslands, shrubs, and some secondary vegetation.

The Qianyanzhou Station has become a basic station of the

Chinese Ecosystem Research Network (CERN). Over the last 20 years, we have built the "Qianyanzhou Model" which effectively contributed to the development of a comprehensive agricultural and forest system in the red earth hilly area. Of the total 200 hectares (500 acres), one half is designated an experimental region and the other half as a demonstration region.




We have built a base covering 2 hectares (5 acres) for artificial breeding and selection for high quality varieties of *Camellia oleifera*, and we have been inoculating for high quality to improve the existing varieties of oil trees.

There are about 4 hectares (10 acres) of existing *Camellia oleifera* trees in the station area, but they have a very low yield of tea-oil. We plan to increase yield through inoculation and ecological management. We are also mixing plantings of *Camellia oleifera* in with plantings of the pure conifer *Pinus elliottii*. Mixed plantings improve the structure and ecoservice functions of artificial.

First we choose high quality biofuel trees through selection and breeding, and we inoculate the existing low quality biofuels trees. Ecological management also improves yield of biodiesel, and the increased yield raises income levels of the local population. In the future, we plan to develop a large demonstration area that will serve as a model for bioenergy development.

By identifying the most favorable woody bioenergy trees in China, assessing area conditions and current plantations of bioenergy trees in Jiangxi Province, and improving yield and forest health through genetics and ecosystem management, our research is poised to usher in a new era of biofuels development.

# Using Hydrologic Tracers and Geochemistry to Assess Surface and Ground Water Interactions

**by Randall Gentry**

**Dr. Randall W. Gentry** *is the director of the Institute for a Secure and Sustainable Environment and an associate professor of Civil and Environmental Engineering at the University of Tennessee in Knoxville.*

Much of the research on biofuels has focused on $CO_2$ as a driver of climate change and an obstacle to finding sustainable ways to meet our energy needs. As a hydrologist by training, I tend to look at sustainability science from the perspective of water supply, specifically at the broader scale, examining groundwater interactions at the drainage basin scale, a common unit in hydrology. Hydrologists try to shed light on the fluxes between surface water and ground water.

In 2004, the National Academy of Science's (NAS) Committee on Hydrologic Science began asking important questions about ground water and potential ground water/surface water interactions. Specifically, they asked, what is the relative importance of diffuse versus focused recharge in any specific hydrogeologic setting, and what are the effects of human activities on spatial and temporal groundwater recharge and discharge patterns? At that time, the issue was not presented as a sustainability perspective, though it obviously is just that.

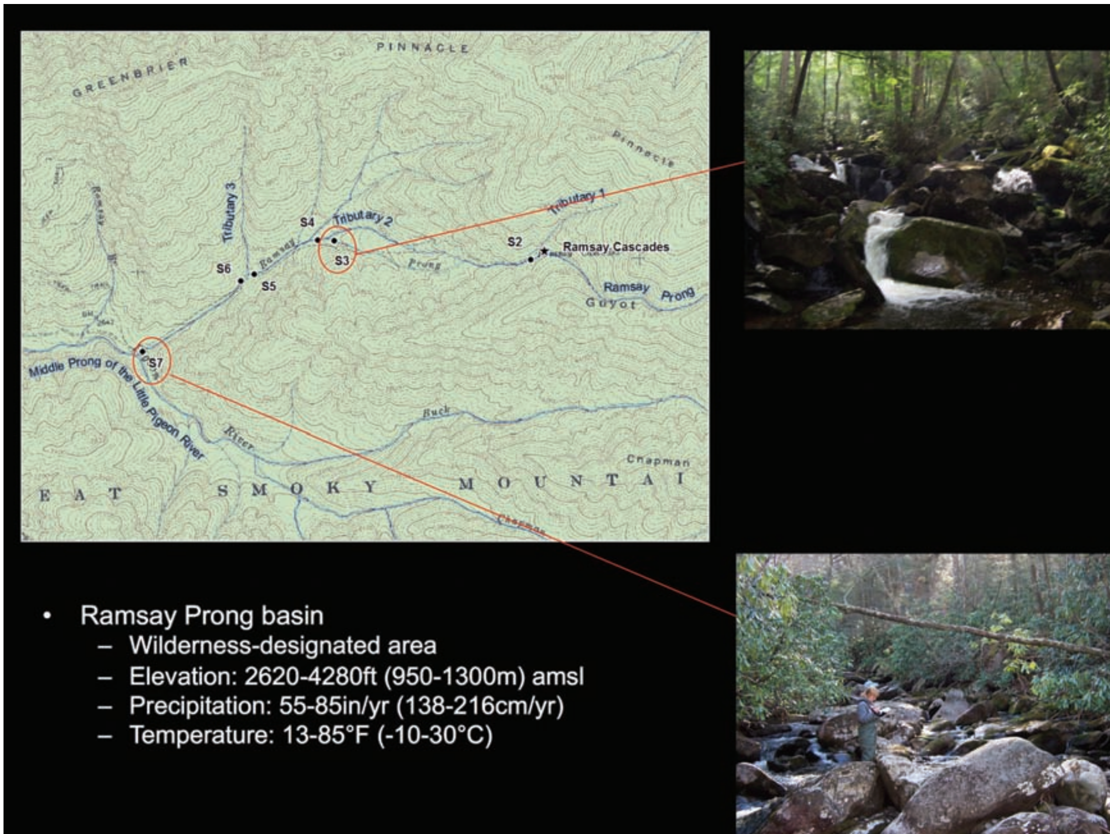
A more recent report from NAS addresses the water implications of biofuels production in the United States. The report asks whether there will be enough water to grow crops for the projected demand for biofuels. We can hypothesize about water use in the future, but we know that water resources are used based upon availability. If we grow switchgrass or any other crop, irrigation improves the yield. So we must come to some understanding about what will be a reasonable water resource use and sustainable use at the basin scale. If we look at a crop on the basin scale; the affected water resource is not just surface water, it is also ground water. In addition, as we begin to change the vegetative patterns in a particular basin, we also affect natural recharge and replenishment to the surface water tables and also the deeper aquifers. According to this report, "since groundwater accounts for almost all of the long term storage of water" and this is true at the continental scale, "extracting groundwater for irrigation that is subsequently discharged to streams may decrease the water available for future users of the aquifer." Whether we consider the issue of extracting groundwater from a shallow groundwater perspective or a deeper groundwater perspective, the long-term sustainability issue is to ensure the availability of drinking water resources. This does not mean that we should not irrigate at all, but we do have to make sure that irrigation is used in a sustainable fashion, which means not just water quantity, but also water quality.

The objective of sustainability science with respect to the study of hydrology is to conduct use-inspired fundamental research aimed at understanding the nature of watershed-scale behavior and sustainable resource use. Even before the term sustainability gained widespread recognition, researchers in the United States were already talking about deployable hydrological observatories, much like those of Chinese Center for Ecosystem Research Network (CERN), using focused science and technologically deployable instrumentation to capture as much information as possible. In the United States, two examples of this are CUAHSI (the Consortium Of Universities For The Advancement Of Hydrological Sciences Inc.), and NEON (National Ecological Observation Network). Both of these groups have been struggling in recent years due to funding shortfalls but are still moving forward. In fact, although it has not yet been announced, one of the new NEON observatory nodes may be in the Walker Branch Watershed of Oak Ridge National Laboratory (ORNL), which could present a great opportunity for collaborative explorations with the University of Tennessee.

## Watershed Dynamics: Ramsey Prong

At the watershed or basin level, it is important to understand that the change in moisture at any given time within a watershed is proportional to the distribution of moisture spatially throughout the watershed. We have somewhat random discontinuous signals, whether driven by evaporation or precipitation, and we have internal storage budgets that are very important. The question as we produce bioenergy crops is what the net impacts to these systems will be.

A simple case study of our work will help us understand the hydrologic behavior at a fundamental scale, in this case the Ramsey Prong basin in Great Smoky Mountains National Park. This is a nationally designated wildland area with an elevation of 950 to 1,300 meters (2,620 to 4,280 feet) and annual precipitation of 138 to 216 centimeters (55 to 85 inches). Its hill slope hydrology makes it sensitive to extreme change such as drought, heavy rainfall, and changes in vegetation.




Historically, researchers have focused on the problem of increased acid deposition in the park, the disappearance of native trout, and long-term biodiversity. The primary hypothesis to explain this disappearance is acid deposition in the system. There is also a lot of aluminum in the system, and at the low pH typical of acid deposition, the aluminum tends to be toxic. Another factor may be that the trout simply moved out of an area for refuge and could not get back, due to elevation changes, morphology in the stream, or continued high toxicity levels.

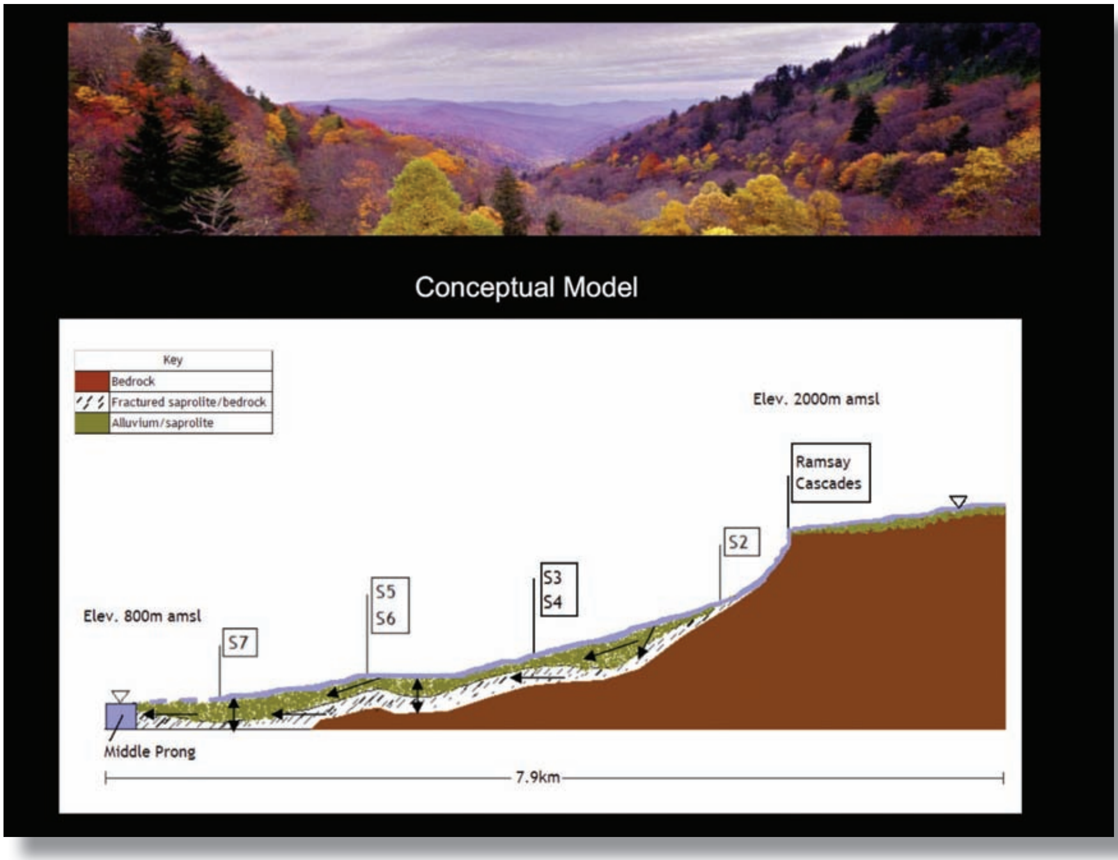
We conducted a synoptic stream evaluation of the geochemistry, measuring deuterium ($^{2}H$), and oxygen 18 ($^{18}0$) during base flow events, at least 48 hours after any precipitation event. We are fairly convinced that we captured a base flow perspective with no storm influences, truly reflecting the groundwater drainage from most of the system up to a certain point.

We started at a waterfall near the top of the headwaters of the stream and collected samples for some standard geochemistry parameters: stable isotopes, flow, temperature, and conductivity. At two different sites, we find a fairly high energy system in which large boulders and cobbles get moved over time down to the lower part of the basin, an interesting geomorphology.

From the geochemistry perspective, we looked at cations and anions throughout the system, not just measuring the concentration but looking at the mass flux perspective, that is the concentration times the flow. Silica is a constituent that is representative of groundwater influences. It is picked up from bedrock in systems with long residence times and varying sources of base flow throughout the system. On three different sampling dates, we measured actual flux, mass flux, as measured in milligrams per second of silica through the system.

The system typically behaves like any hill slope hydrology; it has a fill and spill perspective. A system gets wetted up and then the moisture is concentrated towards the bottom of the basin eventually even at base flow, causing large increases in flow but also mass fluxes of these anions and cations. We find a lot of acid deposition at high elevations in the forest. By the time the water reaches the bottom of the basin, the acid neutralizing capacity in the stream itself provides some ecological refuge.

We also looked at fractionation of deuterium and the oxygen isotopes oxygen-18 and oxygen-16 ($^{16}O$) using the Vienna Standard Mean Ocean Water Standard. We looked at all the samplings across multiple sampling events. The slope of the data indicated probably something that would be equivalent to the local meteoric water line. Oxygen-18 and oxygen-16 enrichment occurs due to atmospheric changes. Oxygen-16 is preferentially evaporated leaving an enrichment of oxygen-18 in the atmosphere. The same can happen across different vapor phase changes and different reactions where there is a thermodynamic condition that will enrich or deplete oxygen-18, particularly in the case of silica hydration. In this case the surface water signature is due to evaporation, and we see deuterium




enrichment and oxygen-18 enrichment. A groundwater signature typical of rock water interactions may result in deuterium enrichment and oxygen-18 depletion occurring primarily from hydration reactions with silica or other constituents.

This work has allowed us to develop a conceptual model of the system to better understand surface water exchange from Ramsey Prong. We basically find two prominent flow systems that work in this drainage basin, a shallow fractured saprolitic/bedrock system and a deeper bedrock system. In essence, at the lower part of the basin the fractured bedrock system becomes more important between the basement bedrock and the stream, perhaps providing more acid neutralization capacity and possibly an ecological refuge for some of the trout that still exist in this system.

Synoptic studies within watersheds, however, are still rare due to costs. We chose the Ramsey Prong in part because there are automated samplers located at two different places in the basin that have been used in ongoing trout studies, but it is actually very rare to find multiple sampling points within a basin, particularly a small basin. We could use different tracers, some of which may be a little bit more time dependent. Using isotopic tracers in a synoptic manner to better define hydrologic storage interactions will be important for evaluating natural system shifts, just as with any resource.

Not only is this work important for understanding the overall ecology of the system; it also better helps better understand sustainability at a catchment scale. This is just one example of how hydrologic tracers and geochemistry can be used to assess surface water and ground water interactions to better understand ecosystem sustainability

# Crop Production Defined by Climate and Water in the North China Plain

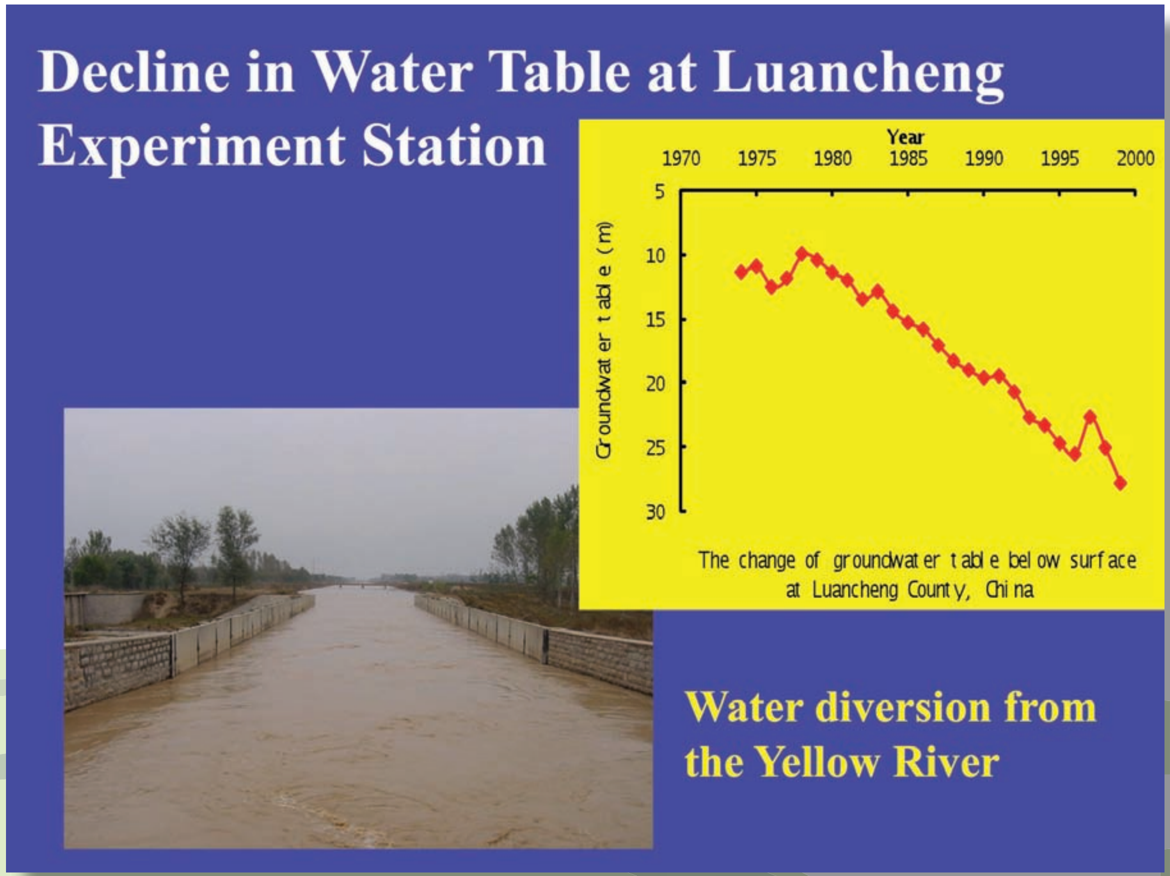
**by Qiang Yu**

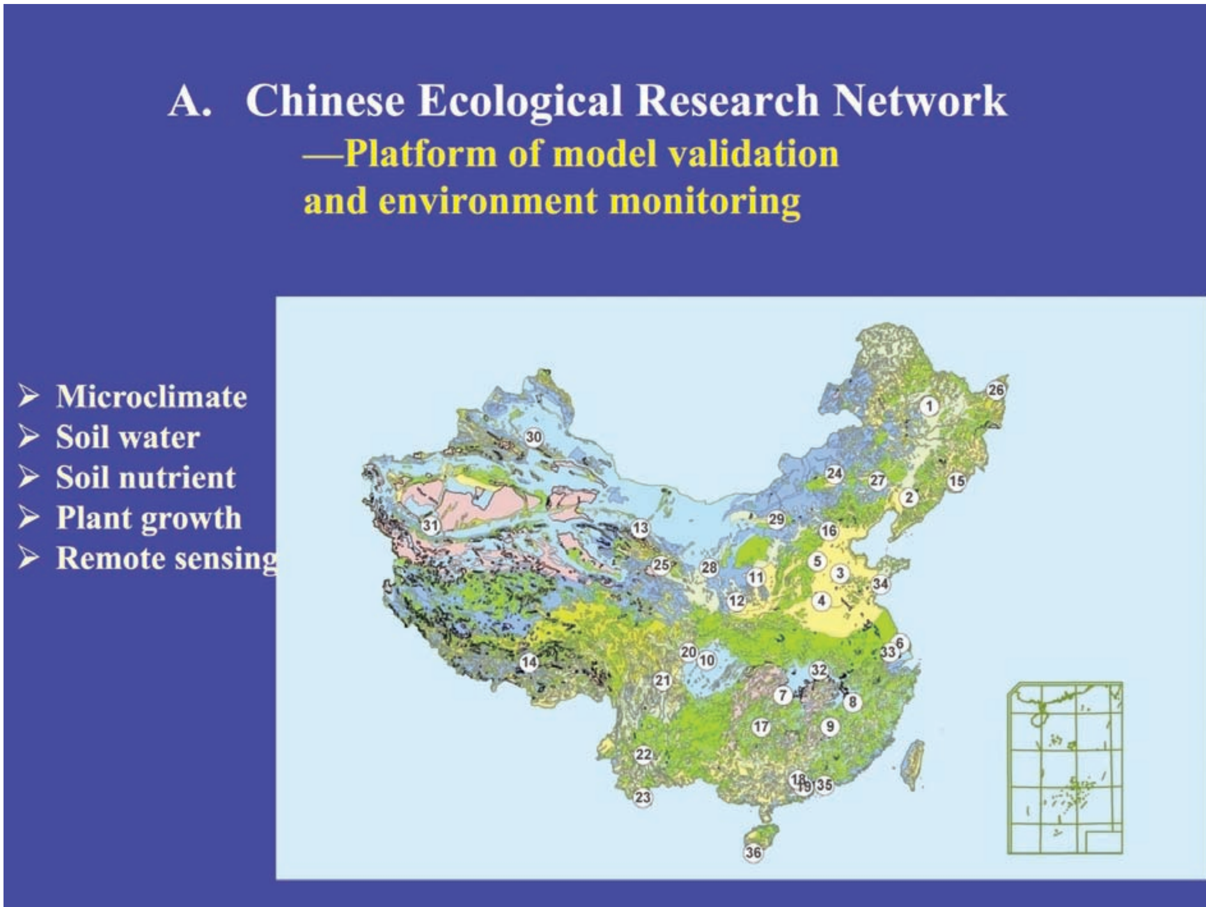
**Dr. Qiang Yu** *is a professor and vice-director of the CAS Key Laboratory of Ecosystem Network Observation and Modeling with the Institute of Geographic Sciences and Natural Resources Research at the Chinese Academy of Sciences.*

For the past 50 years, the North China Plain has undergone great changes that threaten the sustainability of farming systems. Factors contributing to the decreasing proportion of water available for agriculture include the low level of water resources per capita, the diversion of water from the Yellow River, highly variable rainfall in the monsoon climate, and population increase and economic growth that compete with agricultural uses. Moreover, the area has been intensively farmed to sustain a high yield of production.

Between World War II and 2000, the population of Shandong Province, situated on the eastern rim of the plain, doubled, increasing the demand for food while the total area of farm land was shrinking. Food production in Shandong has risen sharply in the same time period, increasing demand for water. Since the 1960s, larger amounts of fertilizer have also been applied to boost crop yields, resulting in nitrogen leaching into rivers and streams and the water table. The relative proportion of water used for agriculture has decreased as the demand for water for industrial uses has risen.

To maintain or increase agricultural production, farmers need to learn how to use water resources sustainably. In the past 20 or 30 years, pumping of ground water has led to a decline in the water table. At the Luancheng Experiment Station in






Luancheng, a mostly rural county in Hebei Province, in 1970, the water table was about 10 meters (33 feet) below ground surface, but by 2000 was drained down to 30 meters (98 feet). Water has also been diverted from the Yellow River, which, in 2002, completely dried up for about 226 days.

There also wide geographic variations in precipitation. In the southern part of the North China Plain, annual precipitation is about 800 millimeters (31 inches) while in northern part it is about 400-500 millimeters (16-20 inches), with wide temporal variations as well.

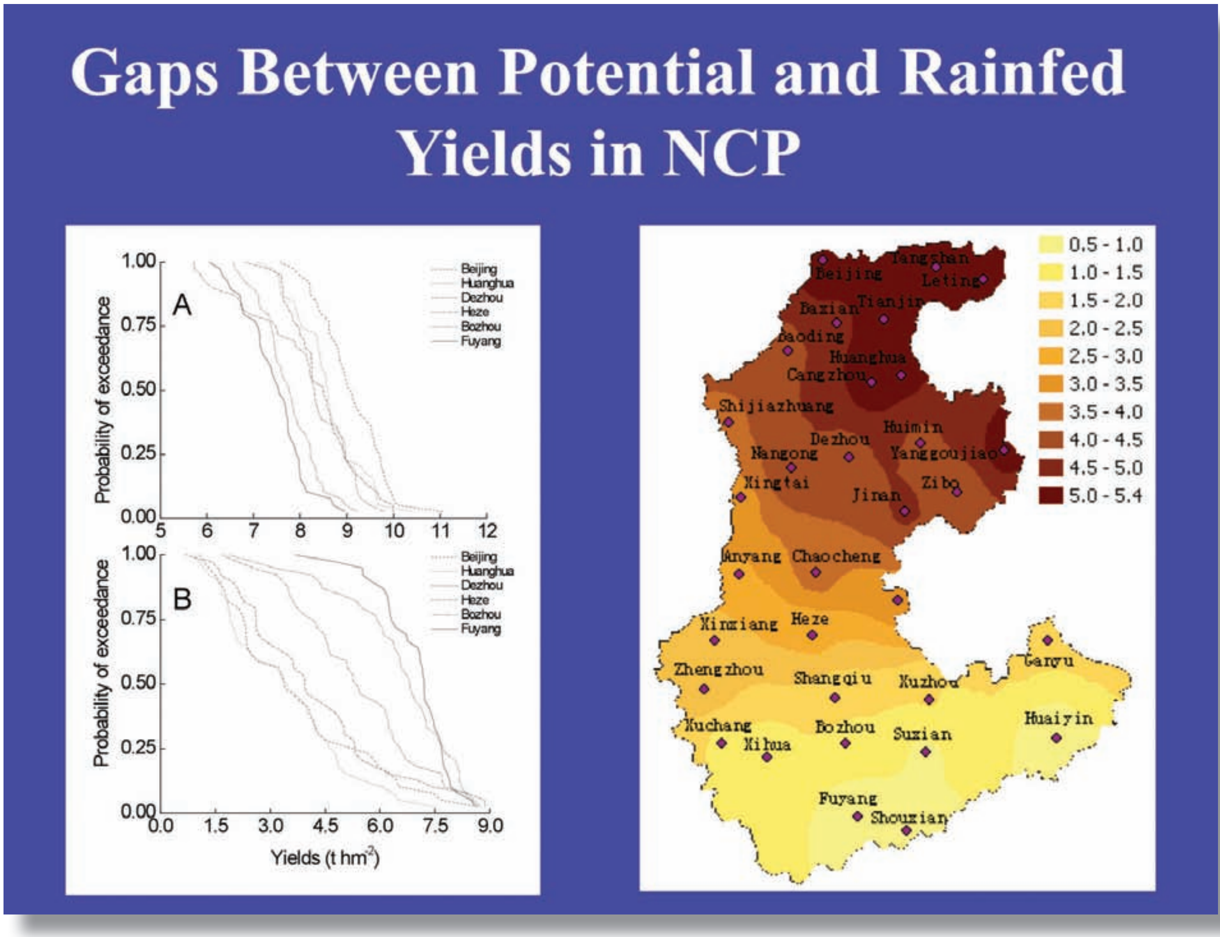
### Systems Research

To achieve sustainable agricultural production, we need to understand the impacts of decreases in rainfall, and we must respond by changing the farming system to adapt to less precipitation. Research conducted at the Institute of Geographic Sciences and Natural Resources Research (IGSNRR) includes experiments in monitoring and modeling. IGSNRR has three stations in the Chinese Ecological Research Network (CERN).

These stations perform measurements of the microclimate, soil water, soil nutrients, and plant growth, and have remote sensing capabilities. These sites measure water and energy transfer, water evaporation, the crop-nutrient relationship, greenhouse gases, and water, heat, and $CO_2$ flux.

In addition to monitoring, we use agricultural system models in water management. Our water quality models are based on systems developed in the United States, the Netherlands, and Australia; and we also designed our own model systems that allow us to calculate the potential yield of rain-fed crops in farming systems based on water availability. We can feed information on two variables, climate and soil conditions, and find the gap between the two yield potentials. This helps establish the best investment of resources to achieve a sustainable agricultural output. Other information we can feed into our models includes solar radiation, temperature, and precipitation; soil water content; and evapotranspiration in a wheat-maize crop rotation system to determine potential and actual yields at different sites in the North China Plain. In general, we find our models do a good job of simulation and are quite close to actual measured variables.

Solar radiation and temperature contribute to the fluctuation of the potential yield. At all stations where meteorological data are available, we find the potential yield is quite high, but with low rainfall, actual crop yields are very low. In addition, annual fluctuation in precipitation is very high. Rainfall and yield are




much higher in the northern part of the North China Plain than in the southern part.

In future research efforts at IGSNRR, we plan to explore the effects of climate variability on the instability of crop production, water resources security and an unsustainable water balance, the design of new farming systems and land use patterns, and modeling and integration of information for long term sustainability in the agricultural sector. With increased demand on water resources, both surface water and ground water, for agricultural, industrial, and domestic uses, this line of research will be critical in ensuring sustainable agriculture in the North China Plain

# Socioeconomic Considerations with Biofuels Production

**By Mary English**

**Dr. Mary R. English** *is a research leader with the Institute for a Secure and Sustainable Environment and an associate of the Center for Applied and Professional Ethics at the University of Tennessee in Knoxville.*

Switchgrass, a perennial grass native to North America, is thought to be a promising candidate for producing ethanol, especially when compared with feedstocks such as corn. Farmers face many new challenges, however, when deciding whether to grow switchgrass for ethanol. In the case of some biofuels, the producer simply diverts a conventional crop – soybeans perhaps – to a new market. Switchgrass, in contrast, usually involves a new and unfamiliar enterprise. Converting arable land from hay or other crops to switchgrass can have large paybacks, but the paybacks are delayed and the initial effort and outlay are significant.

The requirements for high-productivity switchgrass stands are many. Adequate acreage with good drainage and medium soil fertility is necessary, as is good-quality seed. Switchgrass seeds have a high rate of dormancy, so breaking seed dormancy adds another preparatory step. Weed control is required, especially in the first year, as is an adequate water supply, especially in spring and mid-summer. The crop then must be properly harvested and stored before being transported to the processing plant.

These are not minor requirements. Not all farmers will be able to "switch to switchgrass," and many may not want to.

### Making the Switch to Switchgrass

A 2007 study at Iowa State University notes the importance of economic considerations in a farmer's decision to make the transition to switchgrass. The study cites several economic factors. Crop yields were most important, but other factors – land charges, fertilizer prices, storage costs, and distances to processing plants – also entered into the equation. All of these affect farmers' evaluations about whether it will be profitable to get into switchgrass production.

There are also important psychological and social considerations. Today, a widely accepted premise among social scientists is that a prospective switchgrass grower – indeed, any human being – is not a wholly rational, self-interested economic actor with perfect information. In order to predict the decisions of farmers with reasonable accuracy, we must take economics into consideration, but we also must look further into individual and shared human traits.

### Potentially Relevant Values and Beliefs

Values classically are defined as internal conceptions of that which is desirable or undesirable. Beliefs, in contrast, are internal conceptions of what was, is, or will be. The first has normative content; the second, factual content. But both are internal, and both are subject to change, though some values and beliefs may be held more tenaciously than others. The values addressed in this talk concern personal risk, personal change, cooperative activities, and altruism. The beliefs addressed here concern credible sources of information and interpersonal or system trustworthiness.

### Personal Risk and Personal Change

In a formal sense, risk is defined as a combination of probability and consequence. For example, some risks (e.g., a tornado) may have a low probability of occurring but a high consequence if they do, while other risks (e.g., a two-week dry spell) may have a high probability of occurring but a low consequence if they do. In addition to this formal construction of risk, however, each of us brings values to our personal assessments of risk. For example, all other things being equal, some of us may be risk takers while others may be risk averse.

Personal change is somewhat different from personal risk. Values concerning personal change have to do with whether we welcome new experiences or whether we prefer continuity and familiarity. A side note: In Tennessee, the average age of the full-time farmer is more than 55 years old. This may reveal something about what a farmer's proclivity for change will be.

Two factors relevant to the risks of switchgrass production are the uncertainties of seed germination and the unpredictability of rainfall. Other risks include the possibility of crop damage in storage, which could significantly affect the financial bottom line, and the long lag time to realize economic payoffs. In addition, the farmer must take into consideration the estimated opportunity costs of investing land and capital in switchgrass as opposed to another crop.

### Cooperative Activities and Altruism

Another potentially relevant set of values concerns attitudes toward cooperative activities. Some people are loners who prefer to act on their own, while other people prefer group activities. These differences can be deeply rooted in individual personalities, and – all other things being equal – they will affect a farmer's inclination to share planting, harvesting, and transportation equipment. The typical switchgrass plot is harvested twice, or perhaps more optimally once, a year. If a farmer invests in specialized equipment, it may be financially beneficial to loan that equipment to others, but people have different attitudes about the desirability of loaning expensive possessions. In addition, unlike some other forage crops, switchgrass is best stored under cover, so another consideration might be the farmer's attitude toward sharing storage facilities.

Altruistic values also may be relevant. How does the farmer perceive the national goal of energy independence and the global goal of climate change mitigation? What are his or her values concerning the importance of food availability? If all else is equal, a farmer might decide to grow food rather than switchgrass for ethanol, if the farmer thinks food production is the better thing to do for society. Altruistic values also may

*Left: Switchgrass stands have been under evaluation for more than 20 years at the University of Tennessee's AgResearch and Education Center at Milan, Tenn.*

*Above: Switchgrass is being studied as a dual use crop for grazing and for energy production in the state of Tennessee.*

*Photos courtesy of the University of Tennessee's Institute of Agriculture, Bioenergy Program.*

arise if a producer takes into account environmental sustainability. In summary, if we think of farmers simply as self-interested economic actors, we tend not to think of altruism as an important factor in their decisions, but that may not always the case.

### Credible Sources of Information

Our beliefs are formed partly by our sources of information. Sometimes we seek out information; sometimes we reject information that comes to us. Regarding switchgrass production and the prospects of switchgrass-based ethanol, relevant information could be, for example, whether land set aside in conservation reserves is likely to be opened up to switchgrass production. If producers believe that this is likely in the near future, they may be more inclined to venture into switchgrass production. .

In the United States, technical information on optimum production techniques often is provided by agricultural extension agents, who typically appear to be trusted, well-regarded, and deemed as credible sources. Technical information coming from corporations, on the other hand, might be regarded as suspect. In addition, because farmers are business people, they will need legal information on how best to negotiate contractual arrangements for feedstock production, which can be rather different from contracts for food production. Where will they turn for this information?

### Interpersonal or System Trustworthiness

Assessments of interpersonal or system trustworthiness also can affect beliefs. Trusting another person (e,g, an extension agent) is different from trusting a system (e.g. the U.S. Department of Agriculture). Systems can change unpredictably as some people leave and others are hired. A belief that a particular individual within a system is trustworthy does not necessarily translate into a belief in the trustworthiness of the system as a whole. Corporate and government policies will affect the process of taking switchgrass from the field to the fuel pump. A farmer's assessment of the trustworthiness of the systems spawning these policies may play an important role in the decisions s/he makes.

### Decision-Making Contexts

Just as there is an environmental context to growing switchgrass, there also is a decision-making context. Macro and micro economics are important, of course, but so too are psychological and social factors affecting how individuals make decisions. Four types of factors come to mind: 1) decision-making heuristics, 2) social norms, 3) social learning, and 4) adaptive group processes:

1) Decision-making heuristics have been called "fast and frugal" by some cognitive psychologists: Fast, because information is processed quickly; frugal, because people don't look for perfect information. Instead, people act on information they can summon up quickly to reach reasonably good decisions that don't require complex analysis. Most of us use decision making heuristics all the time.

2) Culturally transmitted values can become social norms. These norms are another means to make judgments rapidly: We can reach a decision more readily if we are within the comfort zone of conformity with others who are like us.

3) Social learning is another useful decision-making crutch. It has been said that the fool learns from experience while the wise man learns from the experience of others. Through social learning, farmers—particularly those who proceed cautiously—can learn from the experience of others.

4) Adaptive group processes often emerge as an enterprise goes forward. It may become evident to those involved in the enterprise that collective changes are needed in the ways business is conducted. This is a dynamic system: In the case of switchgrass for ethanol, for example, changes might flow throughout the process but come back down to the swtichgrass producers.

When we think about whether farmers will embrace producing switchgrass or other energy crops, an understanding of economics is important, but it is not sufficient. Social and psychological factors must be taken into account as well.

# Emergy Response of a Crop System to Water Assignments in Taihang Mountain Piedmont

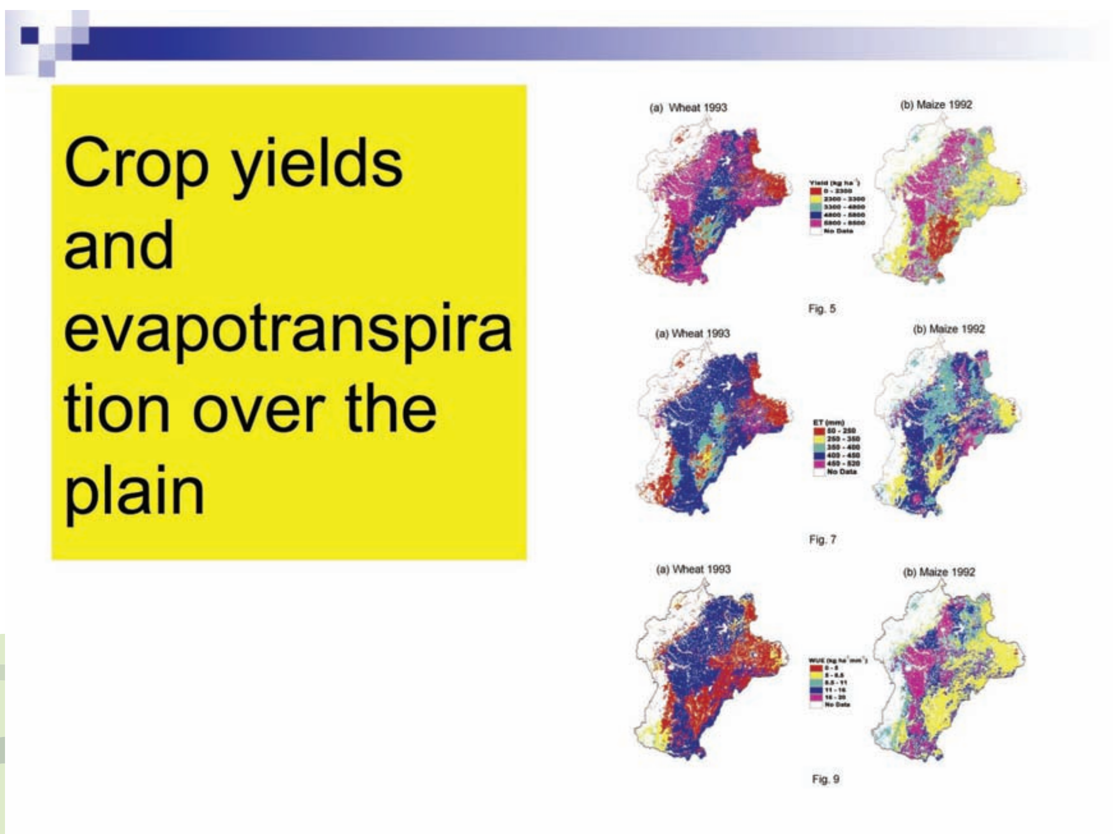
**by Xing-Guo Mo**

**Dr. Xing-Guo Mo** *is a professor at the Institute of Geographic Sciences and Natural Resources Research at the Chinese Academy of Sciences.*

The Taihang Mountain piedmont is located in the northern part of the North China Plain in Hebei Province. Average annual rainfall in the piedmont is about 500 millimeters (mm) (20 inches), while evapotranspiration is twice that, 1,000 mm (40 inches). A double cropping system, typically winter wheat followed by summer maize, therefore, requires irrigation to be sustainable. There is not enough surface water to irrigate the crops, however, so farmers have turned to pumping groundwater for irrigation. In addition, to obtain a high yield, fertilizer from fossil fuels must be applied.

Pumping of groundwater has resulted in serious environmental problems as the water table has dropped rapidly in the past 30 years due to intensive agriculture. The water table in the city of Baoding is now as low as 20 meters (65 feet), 30 meters (100 feet) in the provincial capital Shijiazhuang, and 55 meters (180 feet) in the city of Xingtai, getting lower from east to west. The wheat crop is planted in October and harvested in June. Maize is then planted and harvested at the end of September.

Excessive groundwater mining and fertilizing in the plain has resulted in heavy nutrient loading, adding to the overall environment burden. In order to maximize utilization of natural resources, we need to minimize environmental loading and assess the energy of the crop system.

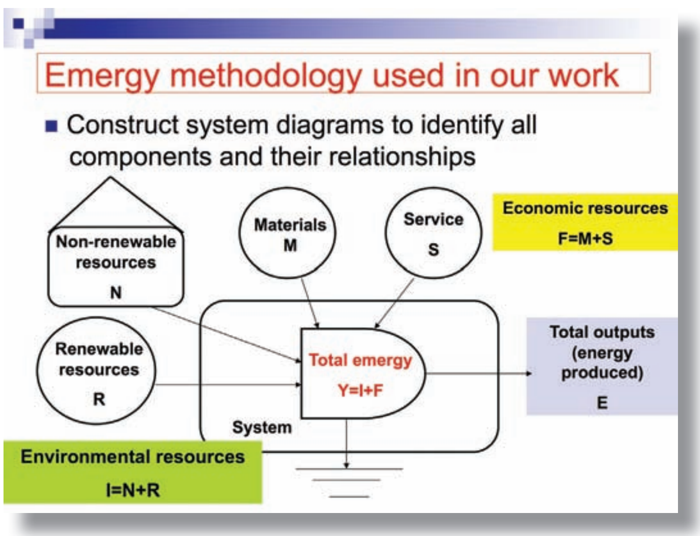


## Emergy Methodology

*Emergy* is the amount of available energy of one type, usually solar, that is directly or indirectly required to provide a given flow or storage of energy or matter. In evaluating the emergy used to make a product, total emergy inputs are summed up, including both fossil fuel energy and environmental energies. When processes are evaluated, all inputs are expressed on a common basis, solar emergy.

At the Institute of Geographic Sciences and Natural Resources Research (IGSNRR), we construct system diagrams to identify all components of the emergy system and their relationships. The total emergy of the system consists of environmental resources and economic resources. Environmental resources include nonrenewables such as soil, groundwater, and surface water; renewables such as rain, precipitation, irrigation, and solar energy; materials, including renewable materials and energy such as organic manure and seed, and nonrenewable materials such as fertilizer, pesticides, electric power; and services such as labor. Output is measured as the net production of energy.

By subjecting the inputs expressed as solar emergy to a series of calculations, we are able to derive a number of emergy indicators: solar transformity, energy yield ratio, and energy investment ratio. From these indicators we can derive an environmental loading ratio—the ratio of non-renewable energy to renewable inputs—and an environmental sustainability index.




We used our model to calculate yield under different water assignments and photosynthesis capacity. The emergy methodology was used to analyze energy flow in different treatments.

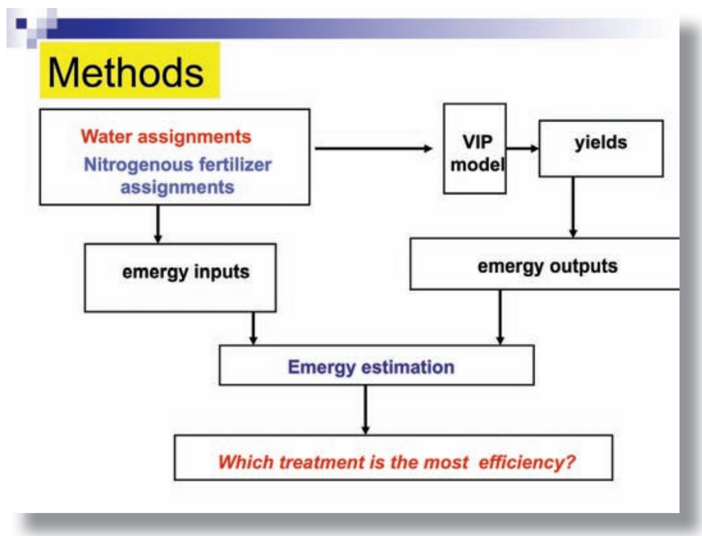
## Tweaking the Variables

In a series of experiments, we were able to predict the response of wheat and maize to varying inputs of water and nitrogenous fertilizer and determine the most efficient application of each.

In one experiment, we found that with wheat, the more water used in irrigation, the higher the yield. From 90-180 mm (3.5-7 inches) the yield increases quickly, but when the levels rise to 180-360 mm (7-14 inches), the yield continued to rise, but at a slower rate. We also found inputs of nitrogenous fertilizer to wheat in the range of 120 kilograms per hectare (100 pounds per acre) yielded the highest output of wheat. With maize however, irrigation did little to improve yield, while the addition of nitrogenous fertilizer resulted in a higher yield.

In another experiment we analyzed emergy efficiency by calculating the emergy yield ratio, the emergy investment ratio, the environmental loading ratio, the environmental sustainability index, and by conducting a planting structure analysis. This experiment also confirmed that the more irrigated water is applied, the higher the yield of wheat. With maize, however, all treatments have a similar yield.

Overall, our research showed that the wheat system has high solar transformity, a high emergy investment ratio, and a high environmental loading ratio, which means it has a high utilization ratio in inputs and a high loading in the environment. The maize system has a low utilization ratio in inputs. We should, therefore, treat these two systems differently.




## Optimum Use of Resources

If we irrigate with 60 mm (2.5 inches) of water before winter, in the plant's elongation stage in the case of wheat, and in the plant's earing time in the case of maize, we find that a little bit of water goes a long way. When we irrigate with more water in the wheat system and less in the maize system, the whole planting system performs better. Irrigating with 120-150 mm (5-6 inches) of water, the wheat system has the highest utilization of natural resources.

We still need to refine our emergy indicator system to further improve our ability to choose the best treatment. There are many other water and fertilizer assignments in wheat and maize, and we will continue to investigate what is the best treatment for the whole planting system.

# Advances in Research on Germplasm Resources and Molecular Biology of the Energy Plant Sweet Sorghum

by Gong-She Liu and Dr. Wei-bin Gu

**Dr. Gong-She Liu** *is a professor at the Institute of Botany and an assistant director of the Research and Development Center for Energy Plants.* **Wei-bin Gu** *is a professor at the Institute of Botany, Chinese Academy of Sciences.*

**Gong-She Liu**

Today, all the sciences are developing very fast, especially the life sciences, including plant sciences like genomics, transcriptomics, proteomics, all these -omics that have become powerful tools to analyze the network of the plant cell. These studies are characterized by a strong level of disciplinary crossover and integration. In addition, biotechnology based pathways are directing the development of newly designed crops including energy plants.

There are four drivers of bioenergy research today: 1) increasing consumption and the rising price of fossil fuels, 2) security of supply concerns, 3) environmental benefits, and 4) agricultural/rural development.

The environmental benefits of biofuels compared to fossil fuels are many. First, they are renewable resources. In addition, they could lower greenhouse gases by 55 percent, carbon by 40 percent, particulate emissions by 20 to 40 percent, sulfur emissions by 80 percent, and volatile organic compounds by 55 percent.

In China, with 21 percent of the world's population but only 7 percent of the world's fresh water and cropland, 3 percent of its forests, and 2 percent of its oil and with its large expanses of arid

land, food and feed security are paramount. There are, however, bottlenecks in the production of bioenergy. We need a durable supply of raw material, but 60 to 90 percent of production cost is in feedstock costs. An increase in plant productivity will have a significant economic impact on cost.

Energy plant production in China depends on the suitability of each region. Generally we propose that the northwest is suitable for shrubs and sorghum, the southwest for Jatropha and cassava, the southeast for sweet sorghum, and the northeast for forest and sorghum.


### The R & D Center for Energy Plants

In 2007, the Chinese Academy of Sciences established an independent sector within the Institute of Botany, the R & D Center for Energy Plants. The mission of this group of researchers is to strengthen the development and system integration of energy plants. This independent center's main task is to develop a plant molecular-biology breeding technology for high-yield plants that are tolerant of stresses such as drought, salt, and arid land. We also aim to develop theories related to using sweet sorghum as a model research material of energy plants.

Our research focuses on a number of topics. First, we are evaluating the germplasm of energy plants and analyzing important genes for carbohydrate metabolism and for stress tolerance to determine the suitability of plant species and their potential. We are also studying the molecular design of energy plants and continuing our study of the photosynthetic mechanism to determine highly efficient means of energy transfer and energy storage. In addition, we are looking for efficient, large-scale cultivation techniques for the production of sweet sorghum. Finally, we are building a database of germplasm resources.

We have four groups now and will build two to three new core groups and a number of other satellite groups, one of which is in Singapore.

### The Sweet Sorghum Model

Sweet sorghum grain has traditionally been grown to produce China's national liquor, maotai, and about 1 million hectares (2.5 million acres) of land are already in production today. Sweet sorghum grows to a height of 3 to 5 meters (10 to 16 feet). It has a high yield with very good sugar content in the straw, it is a very efficient photosynthesizer, it is salt resistant, and it is distributed all over China. It also highly resistant to heat and drought, and it absorbs a large amount of $CO_2$. Sweet sorghum is also a multi-functional crop which can be used to produce distiller's grain and sugar juice for ethanol production. The residue bagasse can produce heat and electricity, and its byproducts can be used as animal feed. Compared to sugarcane, it has a life span three times shorter, uses one third the water, costs half to cultivate, and is comparable to if not better than sugarcane as a source of ethanol.

### Genetic Resources

For more than 30 years, the Institute of Botany (IB-CAS) has collected germplasm of sweet sorghum (*Sorghum bicolor* [L.] Moench) from more than 300 sources worldwide, and we have crossed these genotypes to produce more than 10,000 offspring every year. For our energy plant studies, we are evaluating and screening for new varieties suitable to different environments all across China: the autonomous regions of Xinjiang and Inner Mongolia, the provinces of Gansu, Hebei, and Qinghai, Beijing, and the southernmost, tropical island/province of Hainan.

We are now beginning to select sweet sorghum types that are drought and salt resistant in the seedling stage. Another recent goal of our breeding program is to create new varieties of sugar sorghum, a "super energy" plant that will produce more biomass.

Other initiatives include performing an analysis and expression of DREB (Dehydration Responsive Element Binding Protein) resistance to abiotic stress; developing a tool for genetic transformation, developing a database based on genome sequencing of the U.S. Department of Energy, and re-sequencing by the Institute of Biology and the Tamasek Life Sciences Laboratory (IOB-TLL).

We also have strong international collaborations. Our core research group is the IOB-TLL Joint Reseraarch and Laboratory. We have been cooperating with the Program for Sustainable Development of the Food and Agriculture Organization of the United Nations, and the first international sweet sorghum conference was held in our institute in 2007. The Center for Energy Plants is a fairly new research effort.

Energy plants will be increasingly important in China's efforts to meet energy demand without compromising food security. We hope our research will allow to meet this goal while reducing costs and adverse effects on the environment.

# Selecting Metrics for Sustainable Bioenergy Feedstocks

**by Virginia Dale**

**Dr. Virginia Dale, Keith Kline, Pat Mulholland, Dr. Mark Downing, Dr. Robin Graham,** and **Lynn Wright** *are scientists in the Environmental Sciences Division, Oak Ridge National Laboratory.*

**Virginia Dale**

When we thik about sustainable bioenergy feedstocks in the United States, we ask ourselves what we will grow, where we will grow it, and how much we will grow. We also must consider the local as well as the broad-scale implications. From the perspective of landscape ecology, we tend to look at the broader scales. This is one of the big challenges of bioenergy, not just looking at what happens to the local farmer but thinking about broader implications. From a global perspective, we also need to ask the same questions, how much, what type, and where?

We also need to understand what drives land-use change to determine how we can address causes of land-use change equitably in order to foster social benefits as well as economic and environmental benefits across the board. A number of reports on the topic of sustainable bioenergy are currently being published, which reflects the increasing number of groups that are working on this issue of land-use change and equity. This topic is an international issue and presents an opportunity for international cooperation.

## From Field to Fuel

The sustainability implications of biofuels choices are large and complex. It is, therefore, crucial to identify what is known, what is not known, and where the uncertainties lie with hopes that over time some of those uncertainties can be reduced. Opportunities will arise to make biofuels choices that can optimize the socioeconomic and ecological benefits. Unlike historic conventional agriculture, with bioenergy there is an opportunity to design systems and put in place a landscape context so that benefit can be achieved from all these aspects. To that end, it is useful to consider a suite of sustainability metrics.

Getting feedstock from production to the downstream markets is a complex process involving growing and harvesting, transportation, conversion, fermentation production of ethanol and other chemicals, separation of these products, and finally delivery to the marketplace. It is critical to consider this whole system and how each part of the system is spatially positioned relative to the other parts. Biofuels feedstocks are heavy materials, and the transport issue will be very large. Though our focus is primarily on feedstock production, we recognize that the big picture needs to be considered.

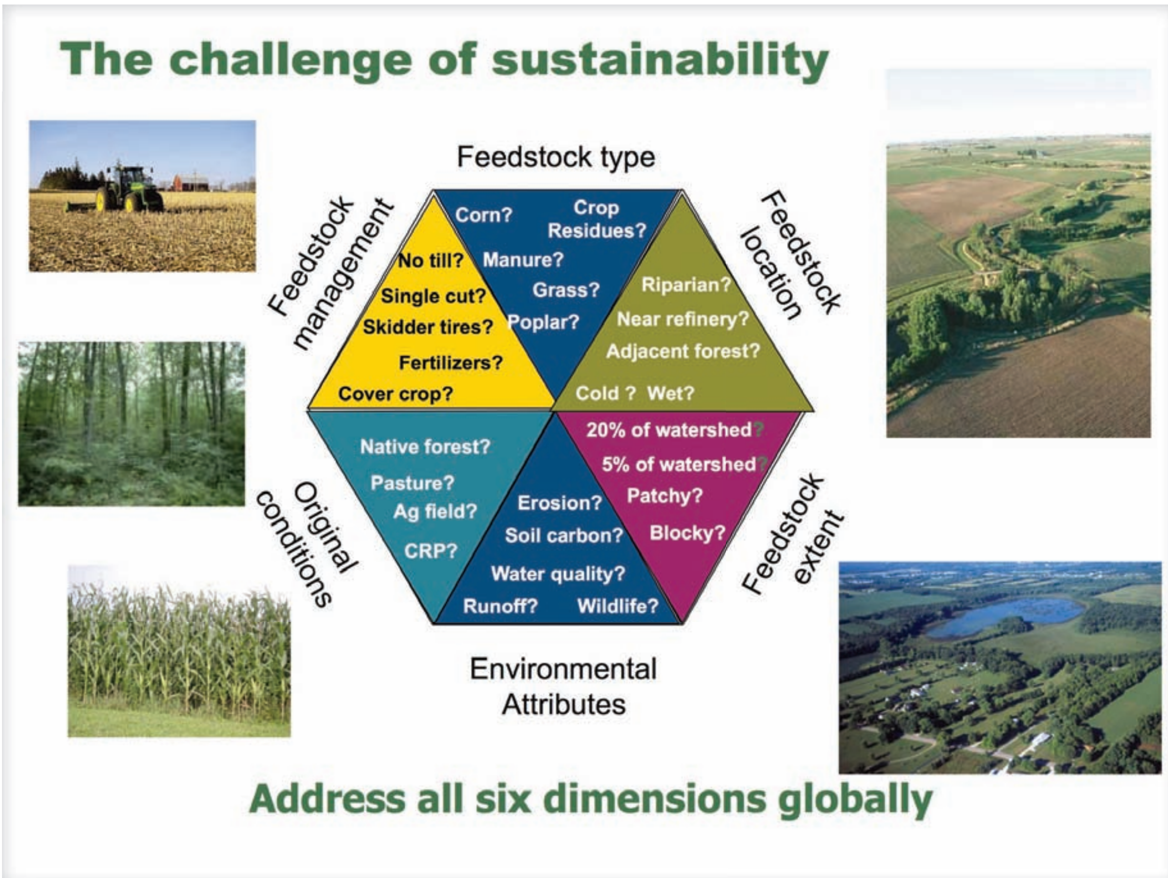
## Sustainability Challenge

The challenge of sustainability is broadening our perspective to take into account the influences and implications on the key components of the system. In addition, future feedstocks may come from a variety of sources, and thus the components of the system may differ. In the United States, the focus now is on corn crop residues or stover. There is also much investigation into the production potential of perennial grasses such as switchgrass. Oak Ridge National Laboratory (ORNL) has treated switchgrass as a model crop, though not necessarily the only one. Researchers are also investigating the potential for other plants to serve as feedstocks, such as short rotation tree crops, like poplar. Dense, fire-susceptible trees common to forests in the western United States can also figure into the mix. Many stands are too dense because of past management practices under which fires were controlled in stands where fire would naturally have served as a thinning and rejuvenation agent. Reducing the densities of these forests by using them as bioenergy feedstocks can at the same time potentially reduce wildfire hazard.  Another source of feedstocks is industrial waste.

Each decision about bioenergy that is made presents a sustainability challenge, not just in deciding what feedstock type we will choose, but also in determining the location. Of the diverse environmental attributes, the original conditions of the land are important, whether it is agricultural land, pasture, forest, or key habitat for rare species. Management activities, likewise, affect the environmental attributes. The amount of fertilizer, the type of fertilizer, and the timing of the harvesting can affect environmental quality in a number of different ways.

biodiversity and habitat, greenhouse gas emissions, air quality, land-use impacts, and water quality and quantity as well. We need to look at all of these components of the environment as one integrated system.

The rising cost of food has recently become an issue of international concern. As of summer 2008, global food prices had increased by as much as 43 percent, mainly due to energy factors.



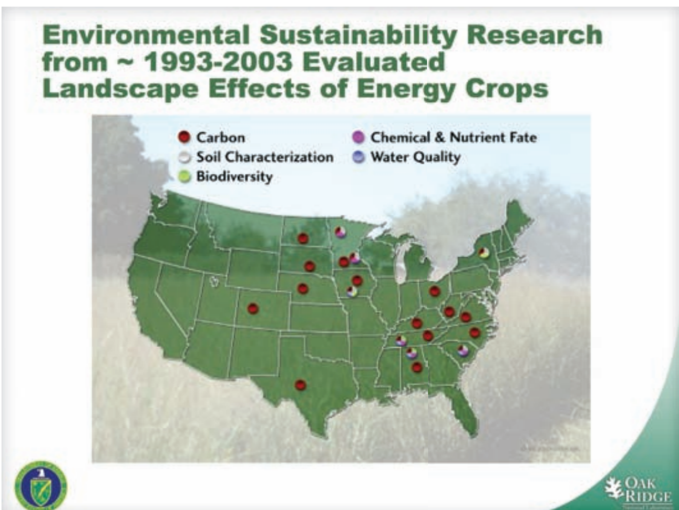

## Society, Economy, Environment

Social, economic, and environmental components of sustainability also factor into our suite of metrics. Social issues such as food security, energy security, jobs, public perception, and land rights and displacement can complicate the decision-making process. Public perception can be especially problematic, and this issue has not always been well managed in the United States and Europe. Land rights and displacement are challenging social issues because the right to own land and use it in ways that can support the owner is an important social opportunity and/or cost. Economic aspects of rising food costs include prices, market conditions, trade, and costs, which are also part of bioenergy sustainability. The environmental components are also complex. Environmental issues include soil conditions, erosion and degradation, genetically modified organisms,

The use of fertilizer at that time comprised about 45 percent of the cost increase, and the use of fuel about 37 percent. Other contributing factors included drought in food-exporting countries such as Australia, increased demand for food in emerging economies, cutoffs in grain exports by major suppliers, market-distorting subsidies, a tumbling U.S. dollar, and speculation in commodity prices. Yet the popular media have singled out corn ethanol as the primary culprit for higher food prices, even though only about 1.5 percent of global food costs have increased due to corn prices. This presents a real opportunity for science, which is often absent from public discussion, to contribute to the public debate. Research is often years ahead of actual agricultural practices that are implemented on the farm, but now is the time for relevant research products on appropriate landscape deigns for bioenergy crops.

## Environmental Sustainability

In order to measure sustainability, it is necessary to define some indicators of what is meant by sustainability. To ease implementation of collection of these indicators, the metrics need to be useful to all parts of the integrated production systems and able to be collected in a cost-effective fashion. Metrics of environmental sustainability are affected by the underlying conditions, and the metrics vary across scales, large and small. Measurable landscape conditions range from land cover to air quality. Aquatic conditions and soil conditions are included in the metrics. These conditions can also change along a geologic scale that sets the initial soil conditions, along a gradient of land-use practices, and under varied economic and social conditions. We need to consider the different axes along which each of these metrics can change and view them in that broader context.




Between 1993 and 2003, ORNL performed a number of field experiments in a variety of environmental conditions and different bioenergy crop options across the United States. This research examined measures of environmental conditions such as carbon, soil characterization, biodiversity, chemical and nutrient fate, and water. The landscape design experiments considered the geographic distribution of potential biomass crops selected from more than 140 trial species.

We concluded that the environmental benefits of perennial energy crops are most positive when we replace annual crops or pastures, not forests; when we use minimal tillage and cover-crop management activities; when nutrient and chemical applications for those perennial crops are less than for annual crops; when native or noninvasive species are used; when harvesting considers things like the timing of bird nesting and other characteristics of organisms that may naturally exist in the system; and when perennials are used as buffers between annual crops and water.

Cellulosic biofuel crops could be a win/win scenario for hydrology and water quality, but that would depend on which lands are converted. Using stream hydrology metrics, we have documented the negative effects of using corn for bioenergy. Streams draining agricultural watersheds can have large agricultural response factors such as sediment runoff. After a rain event, there is a greater runoff from agricultural lands as a fraction of the precipitation and total stream flow than occurs in other systems such as forests. If corn acreage is expanded to marginal or conservation lands, this change could increase the stream hydrological response to those storms, with higher storm water flow and lower base flows.

The irrigation demands of corn might actually reduce the aquifer water levels and stream base flows in some regions. If you compare the flashy stream hydrology, nitrogen export, erosion and sediment export, and pesticide export of corn compared to analogous effects of woody vegetation or intensive forestry bioenergy, woody vegetation is associated with fewer adverse effects on stream hydrology or the nitrogen export erosion. There is, however, a potential for herbicide export.

## A Model Perennial

When a perennial grass like switchgrass is planted on land that once was in agriculture, there are fewer adverse effects compared to unmanaged lands including forests and pastures, and there are several environmental benefits. Switchgrass was selected as a model perennial crop for study, and much information is now available about it. A native, warm-season perennial, switchgrass can be grown on marginal lands or rotated with other crops. It provides excellent nesting habitat for vertebrates and is also important habitat for invertebrates. Its root mass can reach quite deeply, which provides a carbon sink. This deep rooting system also provides system benefits in terms of retention of nutrients in the system. Switchgrass also has lower fertilizer applications than annual crops such as corn, and it allows greater infiltration and less erosion from surface flow. It is a large plant, which helps protect soil from wind erosion due to decreased wind flow and evapotranspiration.

Unfertilized switchgrass is commonly used as vegetative filter strips and riparian buffers in agricultural watersheds. Results from a number of watershed studies of switchgrass find sediment export reductions of 50 to 95 percent, nitrogen export reductions ranging from 25 to 90 percent, phosphorus export reductions from 20 to 85 percent. The percentage of retention is positively related to the width of the buffer along riparian corridors.

Bioenergy represents a great global opportunity, but it requires some scrutiny. Eventually some kind of certification schemes to ensure sustainable use of the land will be required. Overall, however, we see switchgrass and other native perennials grasses and trees as a win-win situation for emissions, energy security, food security, and development.

## Land Use Change

Current models of land-use change and lifecycle assessments, are inadequate to address some of the issues of sustainable production of biofuels. Most models are highly sensitive to land cover and use assumptions. The initial land cover on the site can greatly influence what lifecycle analyses estimate. Economists often build from baseline projections based on remote sensing imagery. Yet it is very hard to know what crop is actually grown on the ground from these remote sensors or to measure how land use has changed. When land–cover observations are recorded from space, what is measured is the reflectance from these different land-cover types such as grassy vegetation or forest vegetation, but it cannot be determined how the land is used, what the fertilizer applications are, or even what specific crops are planted. Furthermore, to understand changes that occur on the land over time requires ground-truthing, actual field sampling of vegetative type or soil type.

In addition, changes that occur in land-use practices over time are not always documented in the satellite imagery. There may be a several year interval between those satellite images, and land practices are quite dynamic in some of the developing world. There is a great need for land-use change data better suited for global projections.

Land-use change and its interactions with carbon emissions are also complex. Land-use decisions are driven by integration among several forces, including cultural decisions, technological decisions—whether you have a shovel or a tractor—biophysical conditions like the original soils, political decisions, economic decisions, and demographic decisions. In any one area, you may find a complexity of factors that determines what is going to happen. An economic decision based on the price of a particular crop, for example, is just one factor and is often not the driving factor. It is essential to consider each site on a case by case basis to gain a broader perspective.

Consider the effect of changing land use on carbon emissions and associated carbon storage. Hundreds of studies of land-use practices in developing countries around the world have found that access for the extraction of a natural product is the first step in land clearing. Whether the resources are the trees themselves or oil or any other resource, the key to gaining access is putting in a road or going up a river.

Once the land is accessible, people move in along that access route and subsequently may try to carve out a living. In developing countries, this often means slash-and-burn agriculture, which obviously contributes to carbon emissions. Of the 100 to 160 million hectares (250 to 400 million acres) of land burned each year around the world, the majority occurs on agricultural frontiers, mostly in relatively poor areas. From 80 to 95 percent of all fires around the world may be intentionally caused by humans, and concerns are rising about the growing frequency and intensity of such burning in developing nations.  Reduction of slash-and-burn agriculture can reduce carbon emissions. In many developing countries, however, people don't have title to the land they use. By burning the land, they produce what they call pasture, but the land does not support high numbers of livestock, and often the animals are in poor condition.  Nevertheless, people burn the land to lay claim to it.


## Available Suitable Land

To fulfill the future demand for biofuel, only 10.8 million hectares (27 million acres) may be needed globally. Biofuels offer employment opportunities and can help establish economic stability.  In addition, establishing a perennial biofuel crop on these lands could reduce the recurring use of fire on previously cleared land and minimize pressure to clear more land.  This may be an option in some places.

Land to be used for biofuels can focus on underutilized, "available suitable", agricultural land. A 2008 study by Searchinger et al. showed that agricultural land use due to biofuels is projected to increase by 108,000 square kilometers (42,700 square miles). A study by the United Nations' Food and Agriculture Organization, however, showed that there were 30 to 40 million square kilometers (12 million to 15 million square miles) of underutilized, frequently burned, non-forest "available suitable" land that would not need to be irrigated in order to grow some of these perennial crops, so there is a lot of available land worldwide compared to what is needed for bioenergy crops. The challenge is to find the land in the right place.  Much land is available for agricultural expansion without clearing new forests, yet forest clearing continues throughout the world with its associated numerous environmental impacts.

The bottom line is that these land-use changes are complex, dynamic processes largely independent of the crop markets and more a function of the local forces.

One factor that has not been adequately considered is the influence of soil carbon sequestration. Much of the developing world has been cleared for pasture, but this land is often fairly low in productivity. A recent study in South America estimated that if you plant a deep-rooted, perennial biofuel crop on cleared lands, you could increase soil carbon storage by 0.5 to 1 metric ton per hectare per year, so there is also a real opportunity for carbon storage as well as reduction in carbon emissions.

Many strategies are being proposed to address biodiversity loss and tropical deforestation, including bioenergy strategies. Solutions involve support for sustainable production that can improve rural livelihood while reducing fire hazard, land-use and management plans to replace haphazard development, land tenure issues, increased capacity of governments and communities in terms of decision making and enforcement, and better inventories and identification of key areas that need protection.

We think these alternative land-change conclusions are possible where biofuels can reduce the recurring use of fire and greenhouse gas emissions, reduce pressure to clear more land, and improve soil carbon. But this must be done sustainably. Certification schemes may work. Those certification schemes that have worked around the country offer three lessons. First, they have to be simple. If they are too complex, they will not be implemented. Second, they have to be low cost. Some countries simply do not have sufficient resources. Third, they have to be reliable.

Overall, different places and different goals have unique solutions. The scheme that we have laid out is a global one in which we maximize opportunities for biofuels to meet our sustainability goals with an approach tailored for different regions. Some areas will grow trees, some will support grasses, and some will not grow bioenergy crops at all but rather food. We must learn from past experiences, develop partnerships, and develop and use a suite of sustainability metrics to characterize the effects of land management practices.

Acknowledgment

The review of this manuscript by Rebecca Efroymson is greatly appreciated. Research on sustainability issues related to bioenergy was supported by the U.S. Department of Energy (DOE) under the Office of the Biomass Program. Oak Ridge National Laboratory is managed by the UT-Battelle, LLC, for DOE under contract DE-AC05-00OR22725.

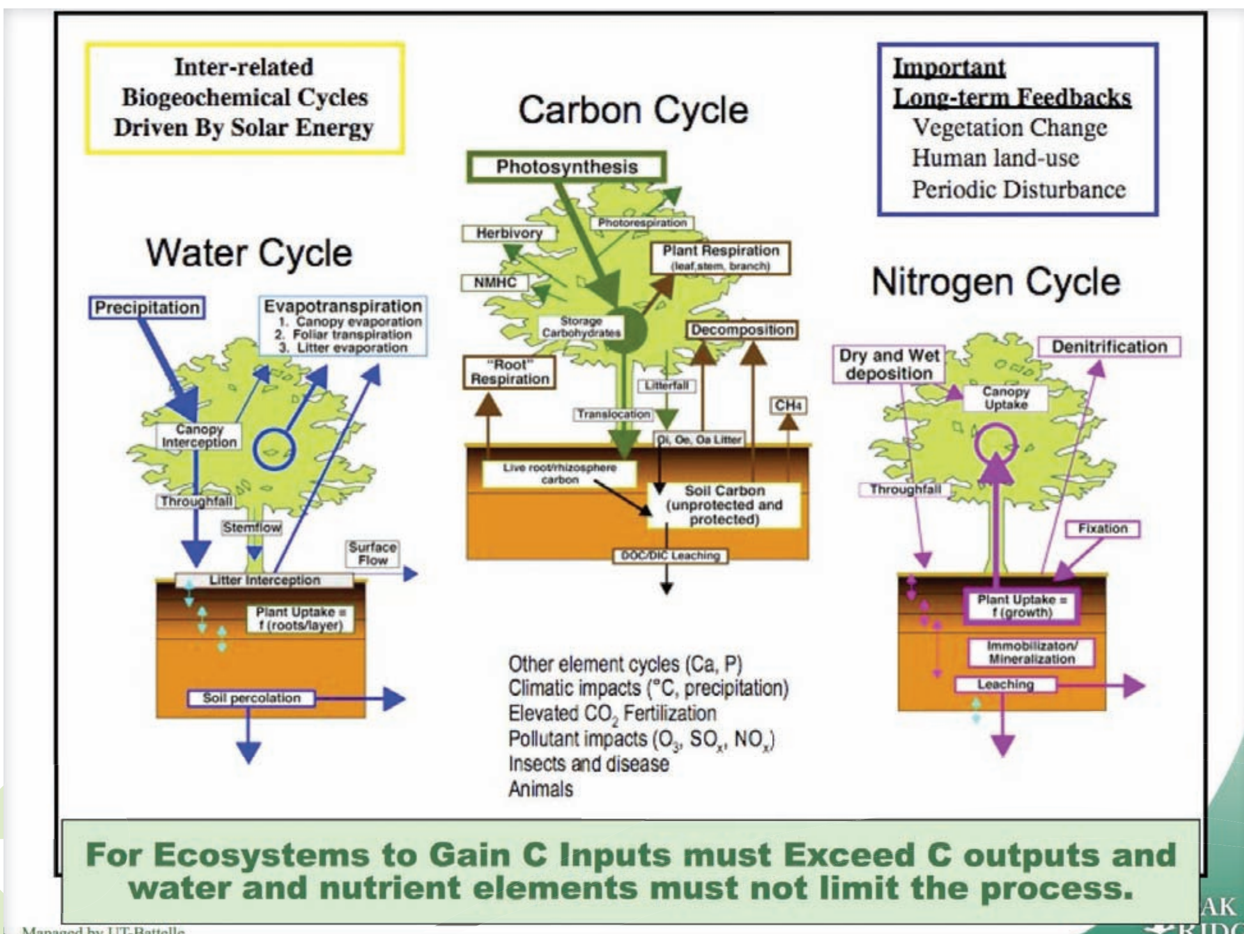
# Quantifying Soil Carbon Cycle Mechanisms and Flux: Implications for the Accumulation of Carbon in Soil

**by Paul J. Hanson**

**Dr. Paul J. Hanson** *is a distinguished scientist with the Ecosystem Science Group, Environmental Sciences Division at Oak Ridge National Laboratory. He is recognized as an international expert in carbon cycle research and has also worked with the International Panel on Climate Change in an advisory role along with another team at ORNL.*

Carbon cycle science and climate change are intimately related. The science has clearly moved beyond the discussion of what causes climate change, and a dominant role for greenhouse gas accumulations in the atmosphere has been established, primarily from fossil fuels but also via release from terrestrial systems that are disturbed through land use changes. We need to understand natural and managed ecosystems and their effects on the carbon cycle as key components for characterizing what future atmospheric greenhouse gas concentrations might be.

It is the imbalance between anthropogenic emission carbon inputs and the natural cycling of carbon through ecosystems combined that lead us down the path of climate change. Scientists at Oak Ridge National Laboratory (ORNL), like our colleagues in China, are measuring terrestrial ecosystem carbon cycles using the Eddy Flux Technique. Such measurements combine landscape scale fluxes of carbon, water vapor, and energy with ground level fluxes of soil respiration to detect an annual cycle of carbon flow.



Continuous observations of flux components allow for the elucidation of control mechanisms, such as season of the year or drought effects on net carbon exchange. The net carbon flux, however, does not reveal the final fate of long-lived carbon or where it resides in the ecosystem. In many ecosystems net carbon uptake by forests or grasslands ends up in biomass, but in some cases it may end up in soil carbon pools. It is important to understand where carbon is accumulating in ecosystems through time. Is it in the biomass, where it can be utilized and harvested? Or is it in the soil system where it remains sequestered?

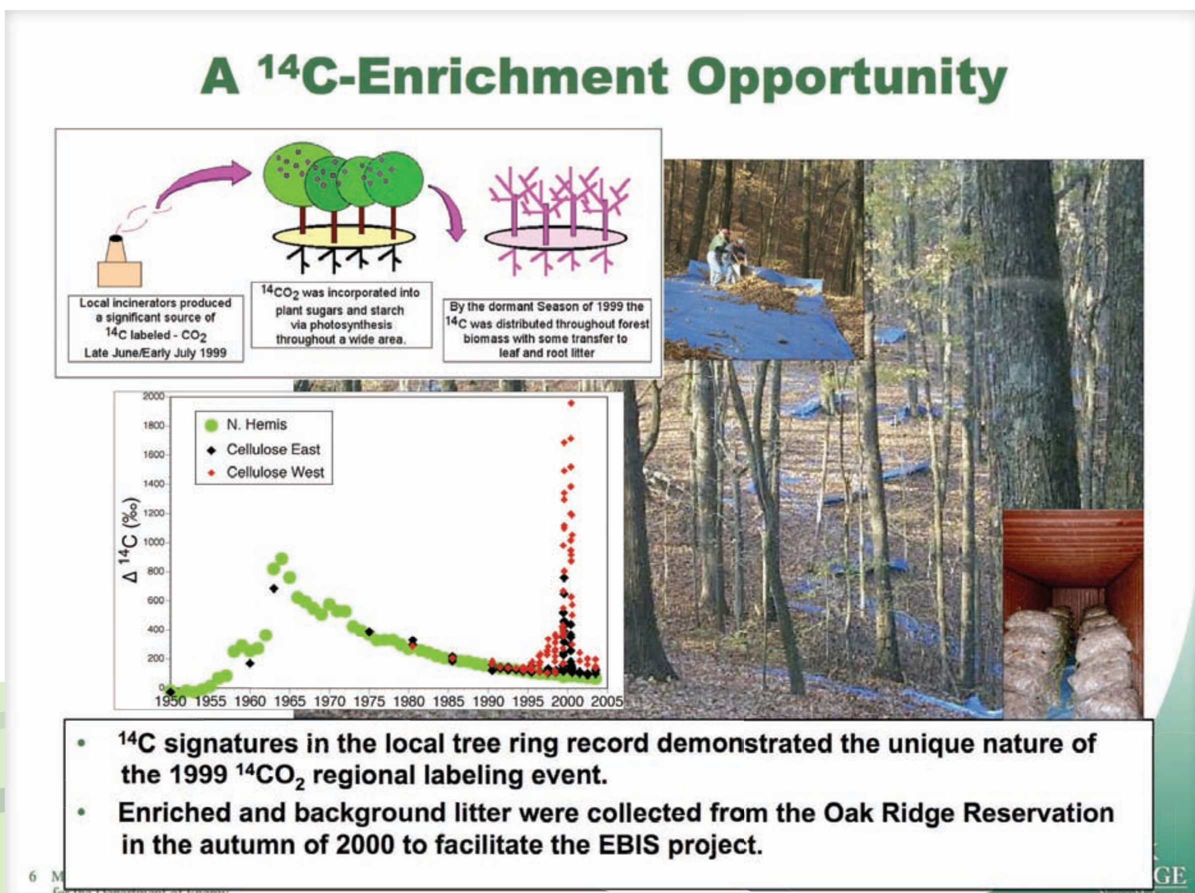
To understand the net fate of this cycle, we must know whether the water cycle, the carbon cycle, or the nitrogen or other nutrient element cycles represent key limitations to net carbon gain. If we continue to explore the use of bioenergy, we need to look for the utilizable components of carbon versus the carbon that might be sequestered. For ecosystems to gain carbon, inputs must exceed outputs, and water and nutrient elements must not limit the process. That's pretty simple in theory but relatively complex in practice.

## Soil Carbon

Soil carbon resides in a more stable environment with moderate temperature variation, making it somewhat resistant to environmental variations. At depth, lower oxygen levels inhibit decomposition. Typically the forms of carbon that are sequestered within mineral associations are recalcitrant, not being decomposed as fast. In addition, carbon stored in the soil is less susceptible to fire. A very hot fire might consume some surface-soil carbon.

What are the options for evaluating long-term changes in soil carbon pools? The traditional approach is to simply measure total soil carbon stocks over time using analytical combustion-based approaches. It may take decades, however, for this approach to yield a highly resolved measurement of change. Alternatively, one can use isotopic labeling to track changes in soil carbon pools. Tracking of the carbon-14 ($^{14}C$) near background signature of soils can allow us to resolve soil carbon pool changes in just a few years that would normally take perhaps five to 15 years to resolve with traditional methods.

Research activities on or near the Oak Ridge Reservation are diverse and range from fundamental science investigations to the clean up and processing of legacy wastes. An unanticipated scientific benefit of ongoing waste processing, for instance, was the enrichment of local background $^{14}CO_2$ atmospheres. During the summer of 1999, local incinerators processed $^{14}C$-labeled compounds, perhaps amino acids but we don't know the exact substance, and produced a significant amount of $^{14}C$



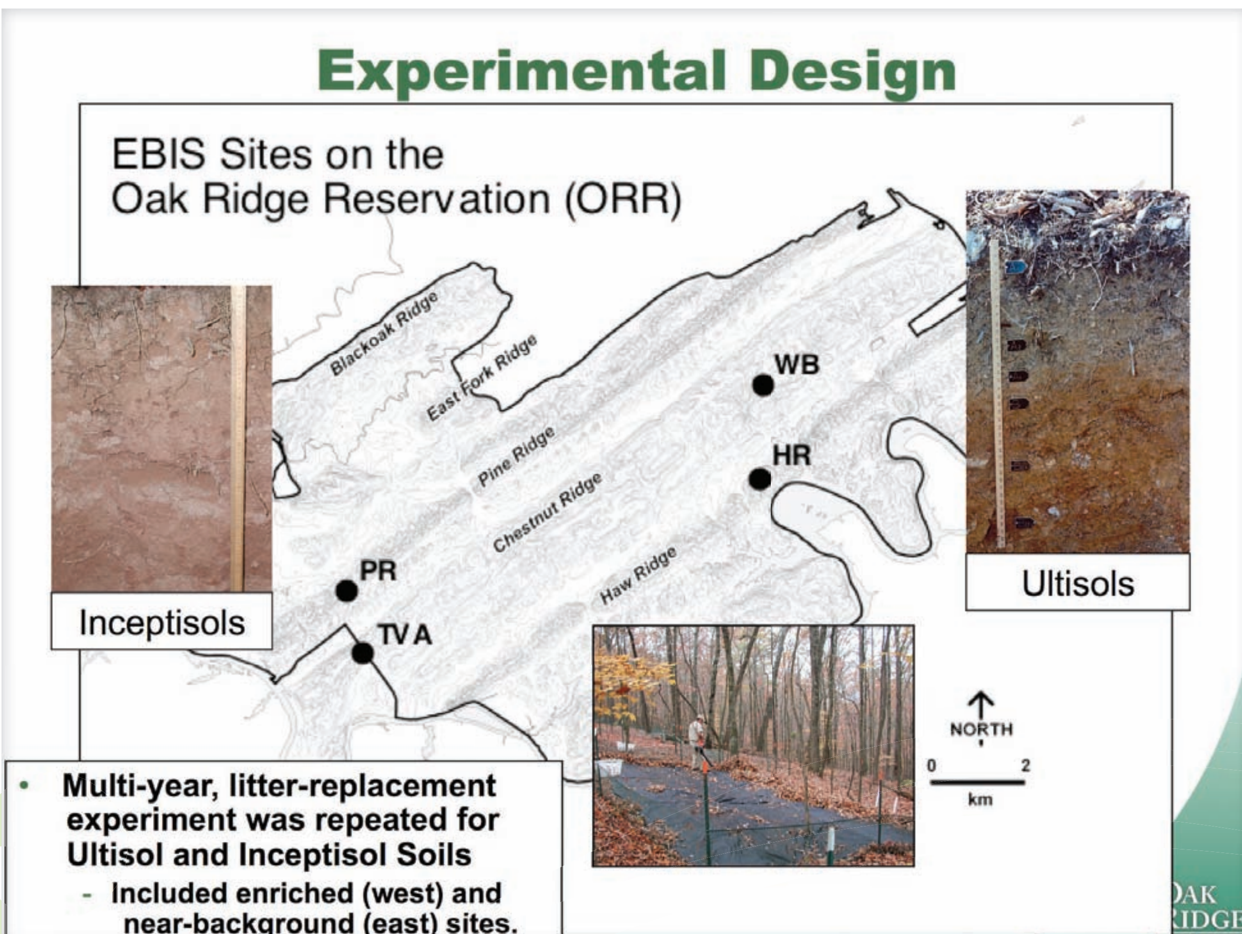
–labeled carbon dioxide ($CO_2$) into the atmosphere. These levels did not represent a health or safety concern, but provided a unique ecological opportunity. The $^{14}C$-labeled $CO_2$ was incorporated into an upland oak and maple ecosystem producing a stable carbon pulse that was evident in plant carbohydrates stored in vegetation during the 1999-2000 dormant season. The $^{14}CO_2$ was incorporated into plant sugars and starch via photosynthesis throughout a wide area with some transfer to leaf and root litter. We were able to evaluate the carbon injection into the forest biomass by quantifying the $^{14}C$ signatures in the local tree ring record. The measurements revealed the unique nature of the 1999 $^{14}CO_2$ regional labeling event in the context of decadal changes in northern hemisphere $^{14}CO_2$ levels.

### The EBIS Study

To facilitate our Enriched Background Isotope Study (EBIS), in the autumn of 2000, enriched and background litter were collected from the Oak Ridge Reservation for the purpose of tracking soil carbon cycles through time. The EBIS project seeks to improve our understanding of, and ability to model, the fate and accumulation of carbon within organic and mineral soils of deciduous oak-dominated forests comprising 46 to 60 million hectares (114 to 150 million acres) of North America. The mechanistic understanding of soil carbon cycling derived from the EBIS project will be valuable for assessing the impact of changing climate on long term soil carbon stocks and element cycling processes.

The $^{14}C$ pulse gave us truckloads of leaf litter which we added to the surface of replicated plots in order to see how it migrates through the soil from the recognizable leaf litter layer that falls on the forest floor, to the humus layer—the amorphous, unrecognizable, decomposed organic layer above the mineral soil—and at various depth increments of the mineral soil. The EBIS study contrasted $^{14}C$-enriched material from near the incinerator with near-background material gathered at a distance. A key objective was to determine how fast carbon is transported from the surface to the mineral soil and the rate at which it is incorporated into pools of soil carbon. Some carbon pools are short-term labile forms that don't last very long, maybe less than a year; others are long-lived forms representing stable carbon uptake and sequestration.

The incinerators were located on the western end of the Oak Ridge Reservation. We established four experimental plots, two located near the incinerator source with high $^{14}C$ levels throughout the vegetation—in the roots and in the trees—and two on the eastern end, with near ambient background levels



of $^{14}C$. Enriched litter additions were made to replicate plots at each of these sites.

The Oak Ridge Reservation includes recurrent patterns of ridges and valleys. Half of the ridges are topped with "younger" Inceptisol soils with poorly developed soil horizons, and the other half are based on the "older" well developed and highly weathered Ultisols. We installed replicated EBIS studies on both soil types to determine if carbon movement, migration, and uptake were controlled by edaphic conditions. On the west end, where the $^{14}C$ source was high, we saw enriched leaves and roots. In 2000, $^{14}C$ -labeled litter was applied to the sites, and treatments were repeated in 2001 and 2002. We then let the sites return to ambient litter fall. Annual additions of enriched litter to the surface were followed by sampling and characterization of the carbon, nitrogen, and $^{14}C$ levels of the litter, humus, and mineral soils to a depth of at least 60 cm (24 inches). At sites, ambient litterfall was excluded and replaced with $^{14}C$-enriched tracer material. We measured environmental factors such as soil water and soil temperature at all sites to facilitate interpretation and extrapolation of the results.

Three years of enriched leaf-litter additions altered the organic layer $^{14}C$ in the recognizable litter layer (Oi) and the humus layer below it (Oa), but we saw minimal effects at various depth increments in the mineral soil. This pattern was the same for both soil types. Enriched levels stayed high until the addition of new ambient litterfall in 2003 diluted the materials and brought the mean signature back down. The $^{14}C$-enriched materials were originally expected to accumulate in surface minerals soils, but this was not observed. After three years enriched litter cohorts did migrate into the humus layer. No statistically significant net increase in mineral soil C was observed after three years of enriched cohort additions and two subsequent years of tracking. The surface addition of $^{14}C$-labeled carbon, whether it is coarse woody material or leaf litter material, has no net effect on mineral soil carbon storage in this ecosystem.

Surface mineral soils do support substantial root turnover, root growth on an annual basis leading to the addition of carbon to soils from root litter production. Root carbon inputs to mineral soils might have masked the $^{14}C$-enriched carbon moving down to mineral soils through particulate or dissolved organic carbon (DOC) transport. Root growth derived from older $^{14}C$-labeled material would have contributed to such masking

The litter, organic layer, mineral soil complex in eastern Tennessee forest soils can be modeled as a layered sequence of stocks of carbon, nitrogen, and $^{14}C$. Leaf litter cohorts may survive into a second or even third year as recognizable litter, but then decompose into humus. In order to model this temporal transition and to understand it, we developed a model that captures annual layering and the temporal dynamics of decomposition. In such a model decomposition processes also need to be expressed as a function of temperature, water potential, or water content of the litter. The mass and quality (decomposability) of the litter is also important to quantify. The soluble carbon in each of these layers leaches out every time it rains and migrates downward with mass flow of the aqueous soil solution and is transferred into the mineral soil horizon. Dynamics of annual litter additions, and intra-annual hourly, daily, and seasonal dynamics of decomposition and stand hydrologic flow all need to be modeled to evaluate carbon movement and $^{14}C$ movement in and through the soil system. Leaf litter respiration is a function of temperature and leaf water potential. The respiration of leaf litter drops with drying and increases with temperature. When litter is wet and warm, decomposition proceeds quickly. Litter cohort modeling for the EBIS sites showed that each annual cohort of litter input provided a unique $^{14}C$ signature, driving complex mixtures of cohort contributions within the two litter horizons (Oi and Oa). Decomposition models can also capture observed inter-annual differences in mass loss with time driven by year-specific weather patterns.

Interpretation of EBIS data through our model suggested that vertical movement of carbon from leaf litter to mineral soils must occur. However, net movement of carbon into the Oa and A, or humus, horizons was surprisingly slow for two reasons. First, acidic upland oak soils support few earthworms or large macrobiotic organisms that would normally lead to bioturbation of the surface soils. With few if any earthworms present, minimal bioturbation occurred and little surface litter carbon incorporation took place. Second, although carbon does indeed move down through the soil as DOC every time it rains, that carbon is of a labile nature and is rapidly consumed by microbes through time. The differential loss of $^{14}C$-signature via decomposition and dissolved organic carbon leaching needs to be verified for intra-annual time steps. These lessons learned are being translated as appropriate to general soil carbon cycling models.

### Mesocosm Study

Conclusions drawn from EBIS litter cohort modeling combined with the field studies on carbon movement showed that we can track isotopes on an annual basis. However, we need to improve the level of detail in our models and use more frequent measurements to adequately capture the mechanisms responsible for carbon movement within an annual cycle. We developed a parallel study with mesocosms to supplement the EBIS annual field observations. In the mesocosm study we added enriched litter to defined homogeneous humus and mineral soils layers, exposed them to ambient weather in the field, and harvested them at sub-annual time steps. The mesocosm study allowed us to determine if enriched litter would, in a more controlled system, be found in a transient state within the mineral A horizon layer. The results suggest that the $^{14}C$ added to the mesocosms moves down into the mineral soil, but is re-evolved through decomposition within an annual cycle. The transported $^{14}C$-compounds are consumed by microbial organisms and lost from the mesocosms as gaseous $CO_2$. Annual sampling resolution of the EBIS field study couldn't resolve this mechanism for carbon transfer and loss. The mesocosms also demonstrated a gradual net accumulation of $^{14}C$ in mineral soils.

Combining results from the EBIS field and mesocosm studies allowed researchers to hypothesize that carbon accumulation in the mineral soil was largely derived from root turnover and root carbon sources. While leaf-litter derived carbon does migrate to soil depths in the form of DOC, little of that carbon remains after an annual cycle to contribute to net carbon storage. Such amounts are very small, however, only 2 to 4 grams of carbon per square meter (10 square feet) per year. Surface carbon additions are therefore not a viable mechanism for accumulating soil carbon in unmanaged soils without viable bioturbating fauna.

A key unknown deserves further attention. While canopy leaf litter inputs can be accurately quantified and we can measure carbon losses from the soil, we have a limited capacity to measure root litter production and turnover within soils. Until we have a better means to characterize root-litter carbon inputs to soils, we will not be prepared to understand the true capacity of soils to sequester carbon via natural carbon cycling processes (i.e., those that don't require additional energy expenditures).

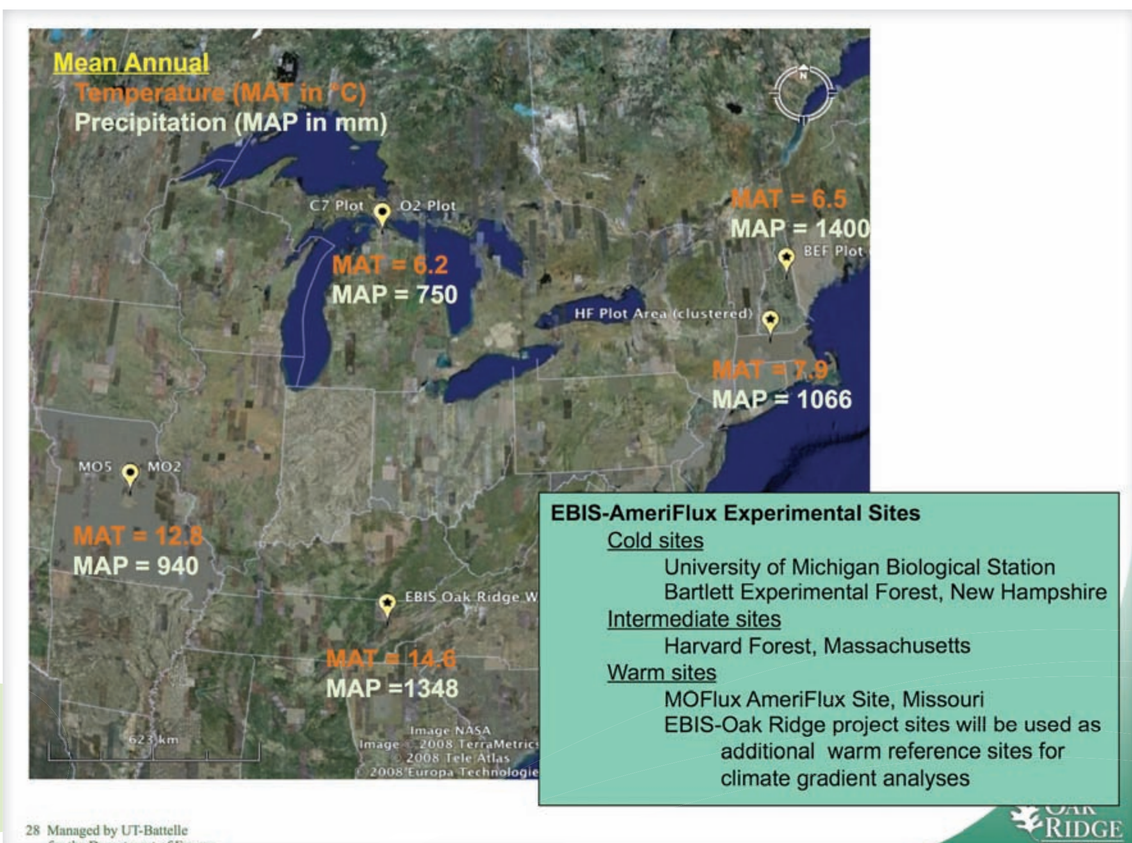
The EBIS studies demonstrated within a short time span (~ 5 years) that $^{14}C$-tracer studies can provided a robust means to quantify rates of soil carbon inputs, turnover, and accumulation applicable for short (annual) and long term (decades to a century) extrapolations. EBIS results also showed that soil carbon cycle model complexity must be improved to capture the fate of canopy versus root litter associated with soil carbon accumulation. In the future, semi-independent organic and mineral soil carbon cycles are needed for the evaluation of sub-decade soil carbon cycling processes in upland-oak forests.

## General Applications

The results from Oak Ridge reservation in eastern Tennessee may not be applicable to all forest ecosystems. Regional vegetation differences, variable soil parent materials, and the presence or absence of macrobiotic bioturbators (e.g., earthworms) could play a large role in determining whether surface leaf litter carbon would be held behind and sequestered in other surface mineral soils.

A new multi-site study titled EBIS-AmeriFlux has been initiated to further evaluate these general concepts at a number of sites off the Oak Ridge Reservation. Sites include upland hardwood forests in Missouri (a warm but drier site), the lower peninsula of Michigan (a comparatively cold site), and two sites in New England with intermediate climate regimes. We are attempting to understand whether the lessons learned from the Oak Ridge EBIS study have the same meaning across a broad regional gradient of temperature and moisture.

The Daycent Model represents a common model used to project soil carbon cycles for globe land areas. The model as it



exists today, and various other global land models, incorporate dead plant material (litter inputs) into a single pool and then add it into unlayered homogeneous boxes to model soil carbon dynamics. The EBIS Oak Ridge results suggests that such an approach does not provide sufficient detail to capture important soil carbon cycling mechanisms needed to project the influence of future soil carbon manipulations. New versions of Daycent are being proposed to answer this need.

Management of below ground carbon stocks in forest systems, if they all perform like the Oak Ridge site, should consider root production as the logical means of proactively addressing soil carbon accumulation. Adding carbon on top of the soil won't do the job in such a system, and it may or may not be a logical thing to do in many systems. On the other hand, engineering crops to place carbon into root growth and eventually feed belowground carbon stocks is a great idea, but it might work counter to efforts to engineer plants for the optimized production of aboveground plant parts to be harvested for bioenergy applications. Both options might be considered in the future in alternate ecosystems; in fact, ongoing projects at ORNL are currently looking at such alternatives.

New applications of stable $^{13}C$ or near background $^{14}C$ isotopic tracers should be considered for application at various locations globally, perhaps in China. Using isotopic tracer approaches represents the means by which we can understand the fundamental mechanisms of soil carbon cycle within a short time period. Providing mechanistic models of the belowground portion of ecosystem carbon cycles is a key component for resolving carbon cycles in important ecosystems throughout the Earth. Improved belowground carbon cycle models will also be needed to fully characterize ecosystem carbon cycling under warming and precipitation change associated with projected climate change. Fundamental information on the carbon cycles of natural and managed ecosystems is needed to determine the fraction of the Earth's carbon cycle that might be sequestered within global ecosystems for the management of anthropogenic emissions.

Related References

Cisneros-Dozal LM, Trumbore S, Hanson PJ (2007) Effect of moisture on leaf litter decomposition and its contribution to soil respiration in a temperate forest. Journal of Geophysical Research 112: G01013, doi:10.1029/2006JG000197.

Fröberg M, Hanson PJ, Trumbore SE, Swanston CW, Todd DE (2009) Flux of carbon from $^{14}C$-enriched leaf litter throughout a forest soil mesocosm. Geoderma 149:181-188.

Hanson PJ, O'Neill EG, Chambers MLS, Riggs JS, Joslin JD, Wolfe MH (2003) Soil respiration and litter decomposition. In: Hanson PJ, Wullschleger SD, Eds, North American Temperate Deciduous Forest Responses to Changing Precipitation Regimes. Springer, New York, pp. 163-189.

Hanson PJ, Swanston CW, Garten CT Jr., Todd DE, Trumbore SE (2005) Reconciling Change in Oi-Horizon Carbon-14 With Mass Loss for an Oak Forest. Soil Science Society of America Journal 69:1492-1502.

Swanston CW, Torn MS, Hanson PJ, Southon JR, Garten CT, Hanlon EM, Ganio L (2005) Initial characterization of processes of soil carbon stabilization using forest stand-level radiocarbon enrichment. Geoderma 128:52-62.

Trumbore S, Gaudinski JB, Hanson PJ, Southon JR (2002) A whole-ecosystem carbon-14 label in a temperate forest. EOS 83:265,267-268.

# Carbon Budget Patterns of Forest Ecosystems in Poyang Lake Basin from 1901 to 2001

**by Shao-Qiang Wang**

**Dr. Shao-Qiang Wang** *is the director of the Office of Research and an associate professor with the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences.*

Poyang Lake Basin is located in Jiangxi, a southern Chinese province with a population of about 43 million as of 2000. Poyang Lake is the largest freshwater lake in China, and the area of Poyang Lake Basin is about 97 percent of the total land of the Province. This basin provides a perfect experimental area for studying the carbon cycle in China. Since the 1980s, integrated management of Poyang Lake watershed has caused great changes in the landscape and ecosystem. These ecological restoration projects had a large effect on the carbon cycle and carbon transport in Poyang Lake Basin. In 1985, forest covered about 30 percent of Jiangxi Province, but by 2005, forest coverage had expanded and occupied 60 percent of the area.


*Before and after: Poyang Lake Basin in 1985 and 2005*

Our carbon cycle observation research platform was established in 2002, when we began a long-term observation of carbon flux and storage and controlled field experiments of the carbon cycle process. We were trying to use ecosystem carbon data and environmental data to measure the spatio-temporal patterns and biogeography-driving mechanism of carbon sources or sinks in Poyang Lake Basin.

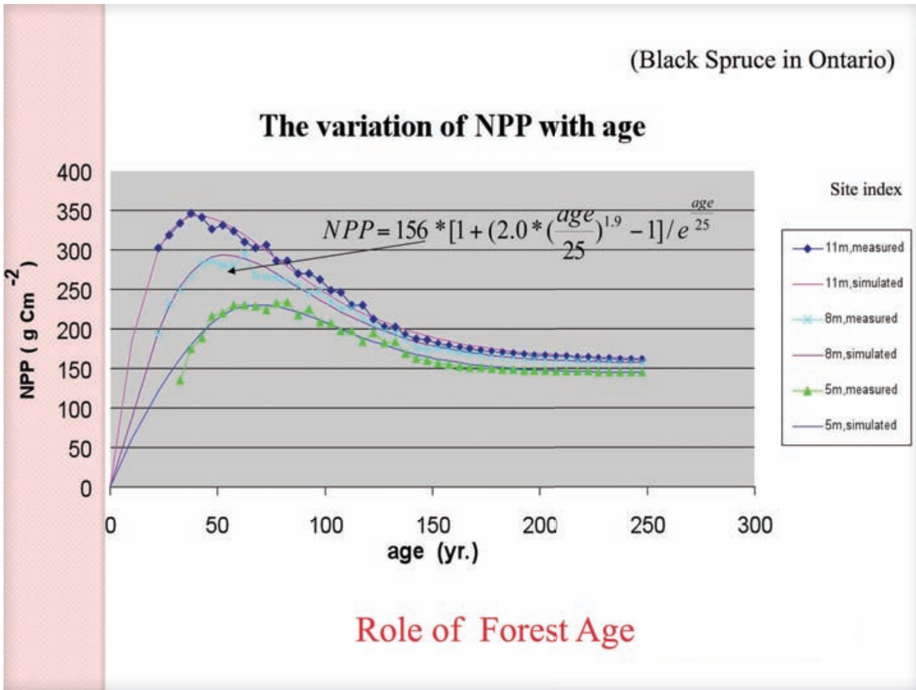
### A Biogeochemical Model

The InTEC model (Integrated Terrestrial Ecosystem C-budget model) is a process-based biogeochemical model designed to simulate annual carbon (C) and nitrogen (N) fluxes and pool sizes in forested ecosystems. This model is driven by spatial datasets, including climate, soil texture, vegetation parameters (leaf area index [LAI] and land cover type), forest stand age, and N deposition datasets. It progressively simulates historical annual net primary productivity (NPP) for each pixel in terms of the initial value of NPP in the starting year of the simulations. It also simulates age-dependent productivity of the forest and the combined effects on NPP of climate, carbon dioxide ($CO_2$) concentration, and N deposition.

The inter-annual variability of NPP is separated into contributions from changes in $CO_2$ concentration, growing season temperature, N content of foliage, growing season length, and LAI. The model assumes that all disturbances cause complete stand mortality, and that the disturbed forest regenerates without cover type change in the second year after a disturbance. Like other terrestrial biogeochemical models, InTEC uses a fixed land cover map in the whole simulation period. The incorporation of land use change and vegetation dynamics are areas for further model improvement.

For the application of this model to China's forests, its soil carbon module was calibrated using measured soil organic content (SOC) density and the decomposition rates of different soil C pools measured at several forested sites in China. The InTEC model was established based on different models, including Farquhar's leaf photosynthesis model, the Century C cycle model, the N mineralization model, and the Forest Age-NPP relationship. The model takes into account non-disturbance factors such as temperature, precipitation, $CO_2$ concentration, and N deposition. Disturbance factors include forest fire, insect induced mortality, and timber harvest. The historical variation in NPP is central for estimating the amounts of dead organic matter.

Using these functions to simulate variation of NPP with forest age in China, we found that about 30 percent of the forests in 1992 were under 30 years old. That means that the forests in Jiangxi Province are very young and productivity very high.




From 1901 to 2001, the total C storage of Poyang Lake Basin forests ecosystems decreased. From 1901 to the1950s we found that the forests were a small C sink, but from 1955 to 1988 the forested ecosystem in Poyang Lake Basin was a source. We found the carbon pool of forest ecosystems in Jiangxi Province decreased during the 1970s.

We also simulated C densities of forest C pools from 1901 through 2001 for the Poyang Lake Basin forest. The density of biomass and SOC of this simulated result was just a little higher than observed data. We found that NPP decreased from 1970 to 1988. From 1901-1960s changes in C pools of the basin were very small, but from the 1960s to the 1980s, the vegetative C pool decreased very quickly. We find two reasons for this decrease. One is the Great Leap Forward and, in the 1970s, the Cultural Revolution of the 1970s, when people cut a lot of trees in Jiangxi Province for production.

We also simulated changes in the C sink and source. Between 1901 and 1955 the forest ecosystem in Poyang Lake Basin was a small C sink, but from 1956 to 1988, the forest ecosystem was a C source. Then from 1989 to 2001, the forest was a C sink due to large-scale plantation in Jiangxi Province. Overall, from 1901-2001 total forest C storage in Poyang Lake Basin decreased.

It is hard to verify the InTEC model because some important C cycle observation data and key parameters are not available. Furthermore, the temporal interval of the model is too coarse. We need to further improve the temporal resolution. There are also large differences between the inventory method and the simulation approach. We therefore need to further analyze the C sink or sources pattern of the forested ecosystem in greater detail.

# Carbon Sequestration by Terrestrial Ecosystems

**by Sheng-Gong Li**

**Dr. Sheng-Gong Li** *is a professor and vice-director with the Synthesis Research Center of Chinese Ecosystem Research Network, Institute of Geographical Science and Natural Resources Research, Chinese Academy of Sciences.*

The Fourth Assessment Report of the International Panel on Climate Change (2007) declared that "most of the observed increase in global average temperatures since the mid-20th century is very likely (>90% probable) due to the observed increase in anthropogenic greenhouse gas concentrations." In other words, global warming is driven by human activity, and carbon dioxide ($CO_2$) is the most important human produced greenhouse gas (GHG) contributing to global warming.

As a consequence of rapid economic growth beginning in 1978, China will soon surpass the United States as the largest producer of GHG emissions. China is now in a position to find efficient ways to achieve the goal of reducing its GHG emissions goals in a sustainable energy mode that is environmentally friendly. To achieve this purpose, the terrestrial ecosystem in China may play a critical role.

## Sequestration Options

In China, we have several options for carbon sequestration, including ocean sequestration, geological disposal, terrestrial ecosystems sequestration in soil or plants, and chemical techniques, a new technology.

China has a very complicated mix of climate zones. For example, in southern China we have a tropical and south subtropical climate. As we move north, we reach the humid, subtropical zone, then the warm temperate zone, and in the far north a cold temperate zone. As we move from east to west, we go from a humid zone to a humid and semi-humid zone, an semi-arid and arid zone on the Qinghai-Tibet Plateau, and further north and west a warm temperate zone, and arid and semi-arid zones.

To achieve our goal of carbon sequestration, we need to understand a number of factors. First, we must estimate the current status of carbon sequestration by terrestrial ecosystems in these complicated natural conditions. Second, we need to analyze the main biophysical factors that control spatio-temporal patterns of sequestration. Third, we want to know the future trajectory of carbon sequestration in the global warming scenario. Finally, and perhaps most importantly, we must confront new challenges to find an efficient way to increase the potential for carbon sequestration in China.

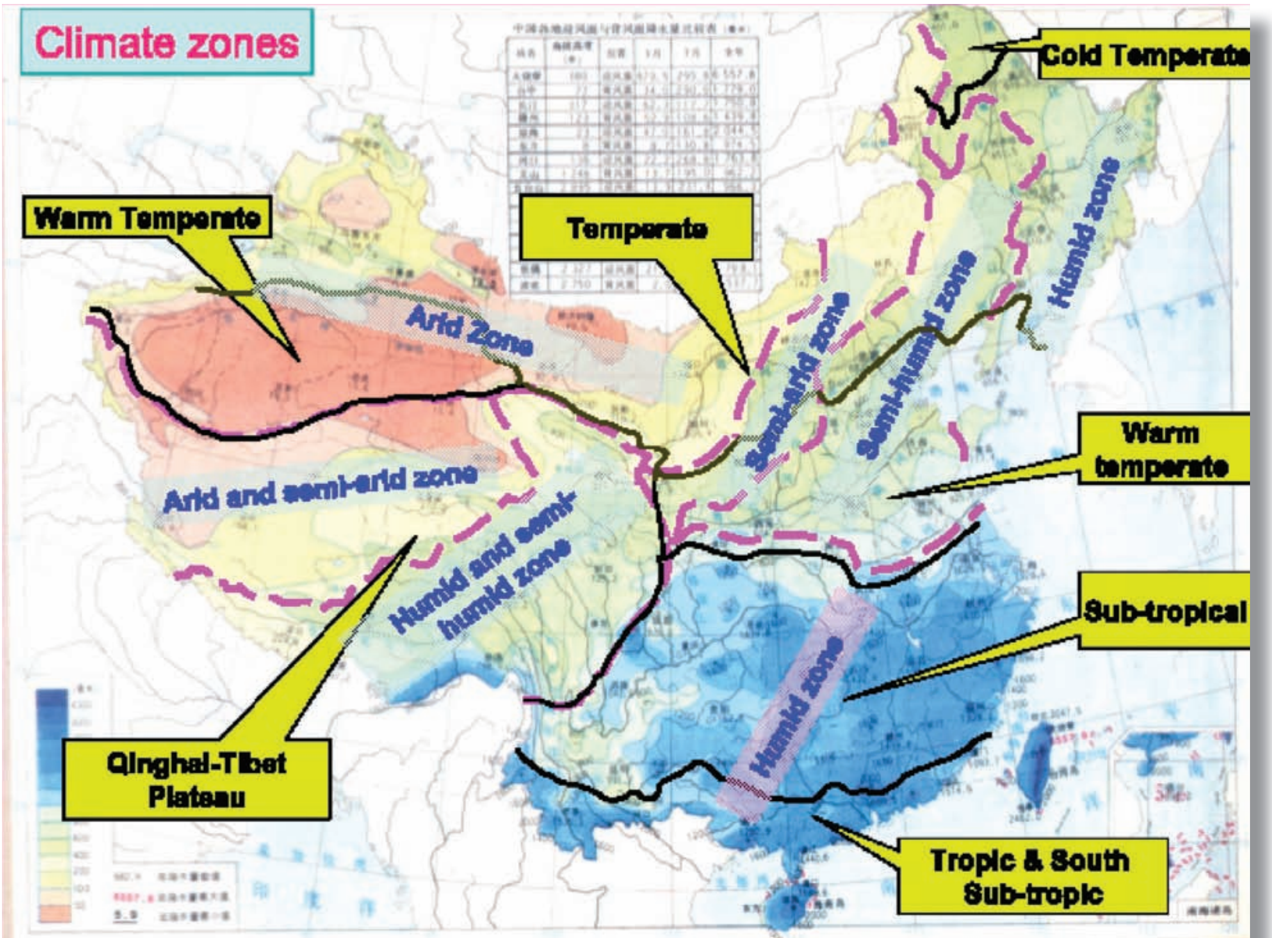
## Carbon Storage Capacity

There are many ways to understand ecosystem carbon sequestering capacity. Researchers in China generally use three measures. One is an estimation based on inventory data, the second is based on measurements from the ChinaFLUX network (Chinese Terrestrial Ecosystem Flux Research Network), and the third is the ecosystem process model. Projects to support this research include the Chinese Academy of Sciences Knowledge Innovation Program, which studies the carbon budget in terrestrial and coastal ecosystems of China. The largest project is the National Key Basic R&D Program which examines the carbon cycle and its driving mechanisms in terrestrial ecosystems. The third project is the Natural Science Foundation of China (NSFC) R&D Program. NSFC also supports many small projects.

When we review the literature on estimating the total carbon storage of terrestrial ecosystem in China, we find conflicting data from many sources. There are wide variations in estimates of total carbon storage of terrestrial ecosystems in China, whether stored as organic carbon in vegetation or as organic or inorganic carbon in soils. In addition, there is a great deal of spatial and temporal variability of carbon sequestration.

Many studies suggest that the Chinese ecosystem has a higher carbon storage and sequestration capacity than many other areas. There are four possible reasons.

- Afforestation and reforestation. The United Nations Food and Agriculture Organization (FAO) reports that China has the most planted forests in the world, 24 percent. The area of planted forests is still increasing with implementation of large national forest plantation programs.
- Restoration and recovery of degraded ecosystems, wetlands, grasslands, and sandy lands.




- Improved agricultural management such as fertilization, little or no tillage, residual return, and better crop selection.
- Climate change from $CO_2$, fertilization, nitrogen deposition, and precipitation. Precipitation in China could increase during the next 50 years, with a projected nationwide increase of 2 to 3 percent by 2020 and 5 to 7 percent by 2050, according to the National Climate Change Report 2007. Elevated nitrogen deposition is likely to enhance vegetative carbon sink in north China.

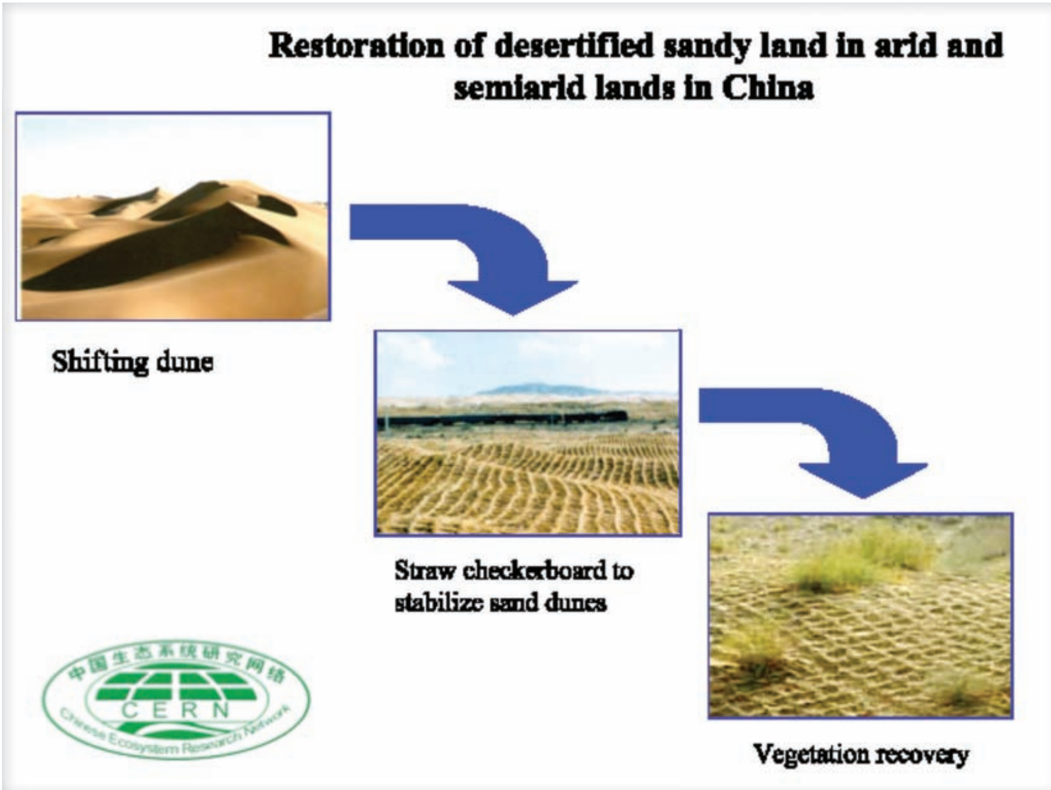
Our ChinaFLUX measurements suggest that the carbon sequestration capacity is driven mainly by the co-variation in temperature and precipitation. In addition, conversion from crop lands to forests, implementation of grassland projects, and protection of grassland against grazing are increasing year by year. Recent studies suggest that old growth forests can accumulate carbon in soils. Our flux measurements suggest that forests in northern China act as a carbon sink. Biomass inventory statistics and modeling work show that even 150 year old forests in northeastern China have a high capacity for $CO_2$ uptake.

### Challenges Ahead

We are facing many challenges in carbon sequestration to offset GHG emissions. These include:

- Future responses of carbon sequestration to climate change and human induced influences and their respective contributions
- Techniques to improve carbon storage and sequestration
- Management practices to increase carbon sequestration potential on grasslands, wetlands, agricultural farmland, forest lands, and even desert ecosystems
- Vegetation restoration impacts on carbon sequestration such as afforestation and reforestation
- Emissions reductions to stabilize atmospheric GHG in the soil.

The 2006 Stern Review on the Economics of Climate Change says that we must stabilize $CO_2$ levels in the atmosphere at 450 to 550 parts per million (ppm). The annual decrease of $CO_2$ emissions should be 6 to 10 percent by 2010 and by 2020 another 1 to 2.5 percent. The future is now, and the earlier we act the lower the cost and greater the economic benefits.




Net carbon uptake by global terrestrial ecosystems is likely to peak before mid-century and then weaken or even reverse. What's true at the global scale is also true in China. Some models suggest a decline of carbon sequestration in China's terrestrial ecosystems over the next 50 years. Without management, this decline will be more pronounced. With good management, carbon sequestration will increase.

We have several choices to increase Chinese ecosystem carbon sequestration capacity. But first, we must take measures to restore Chinese ecosystems from their currently degraded state to their previous healthy condition. Eco-restoration of water-eroded soil on the Loess Plateau and restoration of desertified sandy land in arid and semi-arid lands are two priority systems where efforts have been made to restore vegetation. By restoring degraded systems such as grasslands, to cite one example, we can increase our national level of carbon sequestration capacity.

# Ecosystem-Atmosphere Carbon and Water Exchange Derived from ChinaFLUX Network Observation

**by Yu-Ling Fu and Gui-Rui Yu**

**Dr. Yu-Ling Fu** *is an assistant professor and* **Dr. Gui-Rui Yu** *is director of the Synthesis Research Center of the Chinese Ecosystem Research Network and deputy director and a professor at the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences.*

**Yu-Ling Fu**

The Chinese Terrestrial Ecosystem Flux Research Network (ChinaFLUX) is a long-term national network of micrometeorological flux measurement sites that measure the net exchange of carbon dioxide, water vapor, and energy between the biosphere and atmosphere. The ChinaFLUX network includes eight observation sites encompassing 10 ecosystem types and a large range of latitudes, altitudes, climates, and species. It relies on the existing Chinese Ecosystem Research Network (CERN), fills an important regional gap, and increases the number of ecosystem types in FLUXNET, the global network of more than 400 sites that use eddy covariance flux measurements to monitor exchanges of carbon dioxide, water vapor, and energy.

ChinaFLUX was established in 2002 with funding from the Chinese Academy of Sciences, the Ministry of Science and Technology, and to a degree from the Natural Science Foundation of China. This network will continue to run until 2010. Our main focus is on the carbon budget and the carbon cycle. We also study the nitrogen cycle and nitrogen fluxes and their coupling relationship with carbon and water cycles.

Eddy covariance flux measurements can provide abundant information for studying the characteristics of carbon and water exchange over specific ecosystems and their responses and adaptations to climate change. Groups of flux towers spread across a landscape or biomes have evaluated the effects of disturbance, complex terrain, biodiversity, stand age, land use, land management (e.g. irrigation, fertilization, thinning, grazing, cultivation, prescribed burning) and low-probability events (e.g. summer droughts/heat spells, wind-throw, freeze damage) on carbon and water fluxes.

ChinaFLUX has carried out continuous measurements of carbon, water vapor, and energy fluxes over typical forest, grassland, and cropland ecosystems since 2003. The ecosystems where eddy covariance flux measurements have been recorded include Alpine shrub meadow, Alpine swamp, Alpine meadow, tropical seasonal rainforest, evergreen broadleaf forest, subtropical planted forest, winter wheat-summer maize double cropland, and temperate deciduous mixed forest.

We measured the seasonal and inter-annual variation of ecosystem carbon flux and annual budgets of carbon and water fluxes of these typical terrestrial ecosystems from 2003 to 2007 and investigated their response to environmental (radiation, temperature, water, and soil nutrients) and biotic (photosynthesis, canopy structure, ecosystem function type, and growing season) factors. We observed significant seasonal and inter-annual variations of the natural ecosystem carbon exchange, especially at some sites that suffered from drought stress in some years, such as the temperate steppe at the Mongolian site in 2005 and 2006.

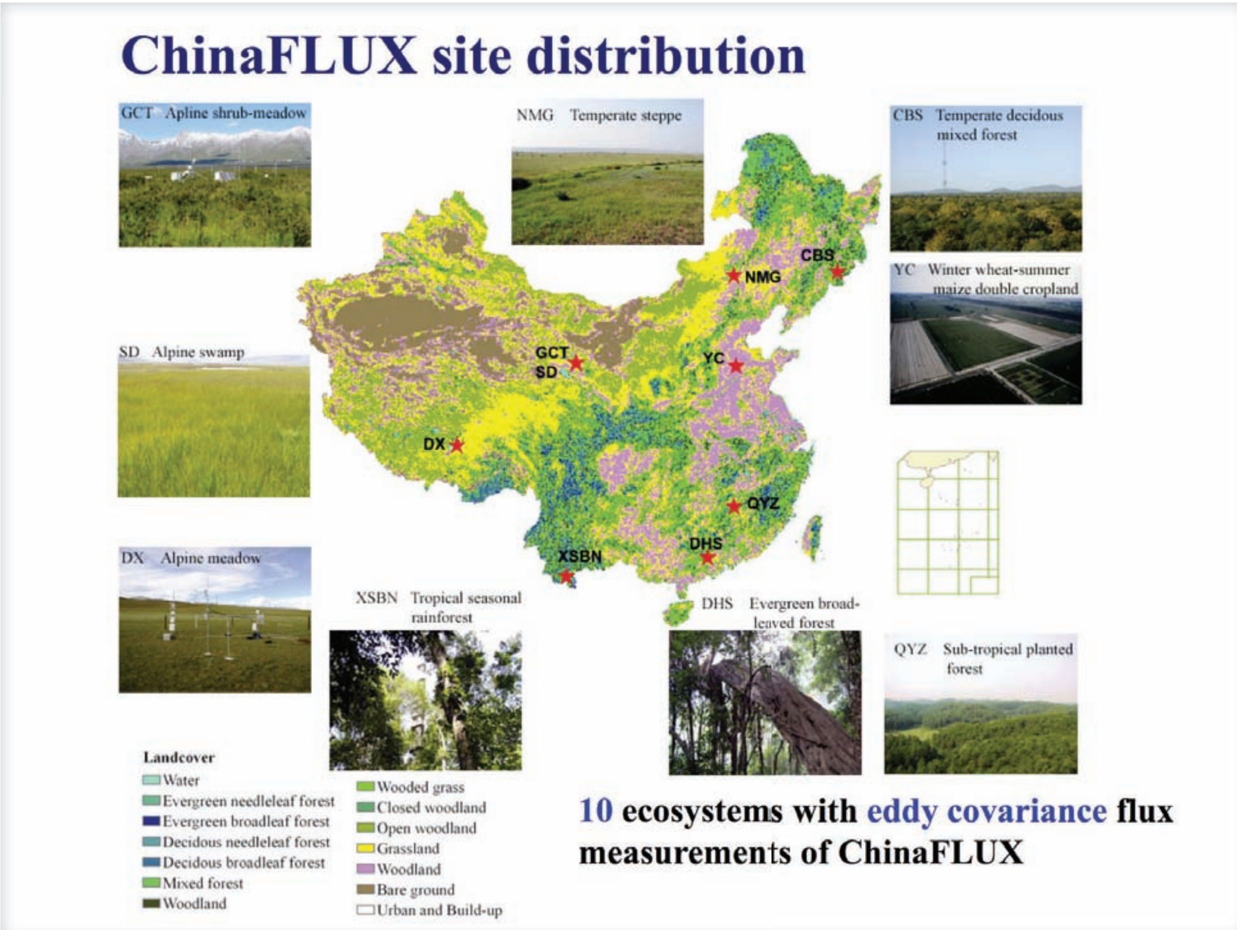
Both the temperate forest and the subtropical evergreen forest in eastern China were carbon sinks over the observation years, even though there was considerable variability in their annual ecosystem-atmosphere exchange (NEE) due to climate fluctuations. There is large spatial and temporal variation in the carbon budget over different grassland ecosystems in China. We found that temperature and precipitation are the two key factors controlling the spatial pattern of the ecosystem carbon budget in China.

We also estimated water-use efficiency (WUE) at the stand level of different forest and grassland ecosystems using flux observations. The average annual WUE was high in old temperate mixed forests and young subtropical plantations, and low at old subtropical evergreen forests. We also found that temperate and subtropical forest ecosystems had different relationships between gross primary productivity (GPP) and evapotranspiration (ET). The asynchronous response of GPP and ET to climatic variables determined the coupling and decoupling between carbon and water cycles for the two forest types.

Mean annual temperature and annual precipitation were also the main factors controlling the spatial pattern of WUE for forest ecosystems in eastern China, especially in the vegetative season. In grassland ecosystems, WUE correlated closely with GPP in seasonality, suggesting that photosynthetic processes were the dominant regulator of the seasonal variations in WUE. Analysis indicated that leaf area index is responsible for the seasonal and inter-annual variations, as well as the inter-site differences in WUE of grasslands.

Overall, we found that

- All the forest and grassland ecosystems showed distinct seasonal and inter-annual variation in carbon and water fluxes due to the fluctuation in climatic conditions;




- Both the temperate forest and the subtropical evergreen forest in eastern China are carbon sinks, while there is much variability and uncertainty in annual NEE of grasslands due to their sensitivity to variation in precipitation;
- Ecosystem respiration is a function of temperature, while its temperature sensitivity is considerably affected by variations in soil moisture and substrate availability;
- Temperature is the primary factor that controls daily carbon uptake in temperate forests, while radiation is dominant at two subtropical forest sites;
- Soil water availability plays a key role in regulating the carbon budget in semiarid grassland ecosystems.

Data and site information are available online at the ChinaFLUX Web site (http://www.chinaflux.org/). Expanding the scope of the FLUXNET database, ChinaFLUX offers new opportunities to quantify and compare the magnitudes and dynamics of annual ecosystem carbon and water balance and to explore the biotic and abiotic effects on ecosystem processes of carbon dioxide and water vapor exchange that are unique to ecosystems in China. In addition, ChinaFLUX provides more insights to help define the current status and enable future prediction of the global biogeochemical cycles of carbon, water, and trace gases.

# Biotechnology Tools for Switchgrass Improvement

by C. Neal Stewart, Jr.

**Dr. C. Neal Stewart, Jr.** *is a professor and Racheff Chair of Excellence in Plant Molecular Genetics in the Institute of Agriculture's Department of Plant Sciences at the University of Tennessee.*

Switchgrass is a very powerful and versatile plant that can be grown to produce biofuels feedstock or to remediate degraded land. In the U.S. Department of Energy's BioEnergy Science Center (BESC), managed by the University of Tennessee (UT) and Oak Ridge National Laboratory, efforts are underway to make the plant even more powerful through genetic improvements. In addition to agronomic improvements, such as making its cell walls less recalcitrant to processing, another goal of our research is ensuring the biosafety of switchgrass. How can we produce a transgenic switchgrass plant that governmental regulators will be assured is safe? What features will it have?

In the plant sciences, biotechnology is defined as finding novel means to improve or alter plants. Creating transgenic plants is also a powerful tool for basic science studies. At BESC, for example, investigators are cloning cell wall biosynthesis genes and sending them to one of four different transformation labs to alter the cell wall structures of switchgrass. This involves over-expressing genes, or knocking them down, which is at the basic science level. Researchers are also altering cell wall biosynthesis and modifying the lignin in the plant to break down cell walls into simple sugars from which to make fuels and bioproducts.

Another high risk project that may one day be useful as an applied technology is to try to express cellulosomes, different enzymes tethered together, in plant cell walls. We are also looking into dwarfism and domestication of switchgrass, altering its carbon sequestration traits, and ways to make sure the bioengineered plant does not crossbreed with wild and non-transgenic switchgrass.

As we know from years of plant improvement, dwarf crops produce a higher yield than their wild cousins. At this point, switchgrass is a very wild plant and not domesticated. Work can be done to decrease the internodes and stems and make leaves more erect so that they are more effective in capturing sunlight. Genes have already been identified to allow that to happen. The genomics and other -omics revolution is also taking over switchgrass, and we are now having its genome sequenced. We will probably be able to alter the plant's ability to sequester carbon, for example by producing roots that can store more carbon underground. Many genes have been identified to enable carbon sequestration.

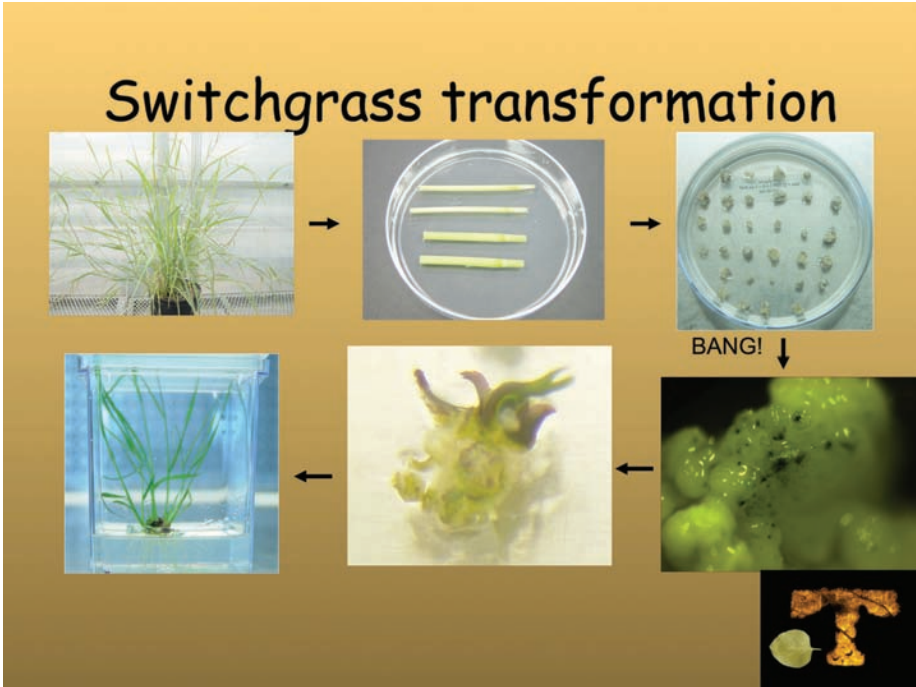
### Switchgrass Transformation

Switchgrass is a North American grass native to the United States, Canada, and Mexico. Regulators in the United States and elsewhere are concerned about the transgenes from transgenic plants escaping into native populations. There are biotechnology tools that could be used for biocontainment of switchgrass by transgenes, which would disallow gene escape from transgenic populations.

Genetic engineering mobilizes a cloned DNA into plants, in this case one carried by *Agrobacterium tumefaciens*, a common soil pathogen that can be used as a gene delivery system. We also use the Biolistic Particle Delivery System, or gene gun, to integrate transgenes stably into the plant chromosome. Researchers at UT pioneered the switchgrass transformation method, which involves cutting stems containing immature flowers, or inflorescences, excising the top hollow stems, or culm nodes, to make embryogenic callus, which can then be shot with a gene gun or subjected to *Agrobacterium* tumefaciens-mediated transformation, selected using an antibiotic—hygromycin is the best one. Transgenic plants are then regenerated. This takes about six months, and we have worked on this system now for a couple of years to make the process more efficient.

We will undoubtedly be able to make transgenic plants that are much better than wild type plants. We can currently obtain a dry yield of switchgrass from 8 to 10 tons per acre per year. We can feasibly double that yield with transgenic switchgrass, which would double the price the farmer can get, by simply altering the morphology of the plant. More importantly, we will be able to alter the plant so that the cells walls are more easily digested. Several companies are also pursuing these technologies in the laboratory, but if regulators won't let them grow the plants outside, their investment is not worth very much. It is therefore urgent to address the problem of biocontainment from the beginning.

When I started working in transgene flow in the early 1990s, I thought for sure that the more we learned about transgene flow the less important it would become as a regulatory and consumer concern, but the opposite has occurred. The issue has grown in importance, and regulators in China, the United States, and everywhere are very concerned about it.




## Biocontainment

Several tools are available to mitigate transgene flow. One is to put the transgenes on chloroplasts, since, in most plants, the chloroplasts are not transmitted via pollen, but it is hard enough to make transgenic plants, much less transplastomic plants, so this is probably not a viable option for switchgrass. Transgenic mitigation is a better tool if you are worried that transgenes will jump from a crop to a weed. With transgenic mitigation, two genes are tied together, one that is good for the crop and maybe good for a weed it might hybridize with. But you want to engineer it so that the gene that is good for the weed is tied to the gene that is good for the crop, but bad for the weed, such as dwarfing. Weeds do not survive dwarfing very well.

Another possible tool to achieve biocontainment is using site-specific recombination systems or zinc finger nucleases, which are designer enzymes that can be tailored to virtually any DNA sequence; these could be used to remove transgenes from pollen. This has worked in model species, and we now are seeing if this will be effective in switchgrass. Tissue specific apoptosis, leading to male sterility, is another possible tool. We have recently applied to the U.S. Department of Agriculture's Animal and Plant Health Inspection Service (APHIS) for the first transgenic field test of switchgrass in the United State, but it is uncertain whether APHIS will allow us to move forward without a number of stipulations. The application is pending.

For site-specific recombinase-mediated transgene excision, we are looking at a combination of various systems. We use a pollen specific promoter to drive the transgene, and the transgene simply gets cut out, leaving a recognition-site footprint. A pollen-specific promoter drives the recombination, and when the marker gene is expressed it will self-excise, leaving no transgenes in the pollen genome, just a trace of what used to be there. This has worked fairly well in tobacco, and we are now using this technique in canola (*Brassica napus*). If you compare a control plasmid that has beta-glucuronidase (GUS) positive pollen with a gene deletor system, you find there are no transgenes in the pollen in the progeny plants. Tests have been made for some 30,000 pollen grains in the tobacco system. We are going to take this to the field and replace GUS with the green fluorescent protein (GFP), which will allow us to look at millions of pollen grains of canola. Next we will apply this technology to switchgrass.

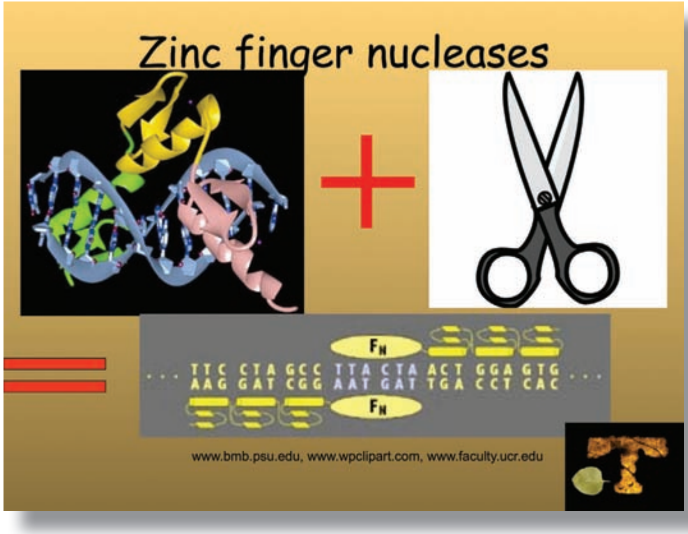
Other systems that we are evaluating in collaboration with researchers at other universities are other site specific recombination systems, zinc finger nucleases, and a male sterility system—which could be more efficient than site specific recombination systems—in which we are cloning genes that will essentially lead to programmed cell death, apoptosis, by combining a pollen-specific promoter and a toxin gene. The idea is to try several different approaches in hopes that at least one of them works.

One clever tool in plant biotechnology that has worked very well in tobacco is a gene screening tool that we are now applying to switchgrass. Agroinfiltration is a means of rapid assessment of gene expression in plants. With this technique, genes in *Agrobacterium tumefaciens*, the natural plant genetic engineer, are simply introduced via syringe into leaf tissue. If we use a green fluorescent reporter gene, the puncture hole for the *Agrobacterium* in the syringe and the genes are expressed about two days later. We are using this tool to look at different cellulases, for example, or any kind of gene that has a discernible phenotype on leaves.

We are also introducing toxin genes into the plant using the same technique, which induces tissue specific apoptosis, killing part of the leaf. We can use these as screening tools to take candidate genes that we can express in pollen. If we can kill pollen, we should be able to limit gene flow in switchgrass.

Switchgrass will benefit from these advances in biotechnology. If we can double the yield of switchgrass, or make the cell walls more easily digested in a biorefinery, we will have a much more straightforward and efficient means to produce cellulosic ethanol.

The main regulatory concerns are gene flow and preventing gene flow in plant species that have natural populations or wild relatives in the same vicinity. This may not be as big a concern in China, which does not have wild populations of non-geneti-





cally modified switchgrass. It could have important applications for the perennial grass *Miscanthus*, however, which might be a better feedstock than switchgrass in China. In the United States, transgenic switchgrass will require biocontainment for deregulation, and we are developing the tools to achieve that goal.

# Life Cycle Assessment: Principles and Its Application to Biofuels Technologiest

**by Fu Zhao**

**Dr. Fu Zhao** *is an assistant professor at the Sustainable Product Engineering Research and Education Laboratory (SPERE) in the School of Mechanical Engineering and Division of Ecological and Environmental Engineering at Purdue University.*

The U.S. Energy Bill of 2007 calls for the production of 36 billion gallons of biofuels per year. In order to be certified as advanced biofuels, and thus receive subsidies, a biofuel has to achieve more than 50 percent reduction on greenhouse gas (GHG) emissions on a life cycle basis when compared with petroleum gasoline. That is to say, if a company wants to claim its biofuel product as advanced biofuel, it has to back up the claim with a life cycle assessment (LCA).


A question that arises naturally is why the reduction on GHG emissions has to be on life cycle basis. The reason is that, similar to living organisms, engineered products have their life cycle as well, i.e. from raw materials extraction and acquisition, manufacturing, transportation and distribution, use and maintenance, reuse and recycling, all the way to disposal and waste management. A product interacts with the environment through energy and material flows at every stage of its life cycle. This complicates the development of "greener" products since traditional analyses focus only on one certain life cycle stage and may lead to shifting of environmental consequences from one life cycle stage to another, from one geographic area to another, and from one environmental medium to another.

A classic example that demonstrates the complexity of life cycle environmental impacts is the selection between plastic and paper shopping bags. This is not trivial since, in order to make the right decision, an environment-conscious customer has to compare the environmental impacts associated with paper bags and plastic bags through their entire life cycle. Paper bags are made of a renewable resource i.e. wood, instead of petroleum as for plastic bags. But by tracking the entire life cycle of paper bags from wood felling, pulp milling, all the way to waste paper recycling or landfill, one finds that the process consumes large amount of fossil fuels. Therefore, the paper bag is not carbon neutral, and detailed study even suggests that paper bags actually consume more fossil fuel than plastic bags. Even though this is a simple case, the result may be counter-intuitive, and one must perform detailed analyses in order to arrive at a scientifically sound answer. Biofuel production is much more complicated than the case of paper vs. plastic shopping bags. In order to identify and quantify the real environmental costs and benefits, a complete, rigorous LCA will have to be performed. In fact, the Organization for Economic Co-operation and Development declared in 1995 that, "In principle, all decisions that affect or are meant to improve the environmental performance of a product/service should be scrutinized in terms of their life cycle implications."

## LCA: A Brief History

The history of LCA is relatively short, some 45 years or so. At the 1963 World Energy Conference, Harold Smith presented the results of a study on the cumulative energy requirements for the production of chemical intermediates and products. In 1969, the Coca-Cola Company did the first multi-criteria study to determine from an environmental perspective which beverage container, glass or plastic, was better. The study considered the raw materials and fuels used, environmental releases, and end-of-life options—recycling or disposal—for the two types of containers. Contrary to expectations, plastic bottles were found to be better from the environmental perspective. The company never published the raw data, however, and many people questioned the validity of the conclusion.

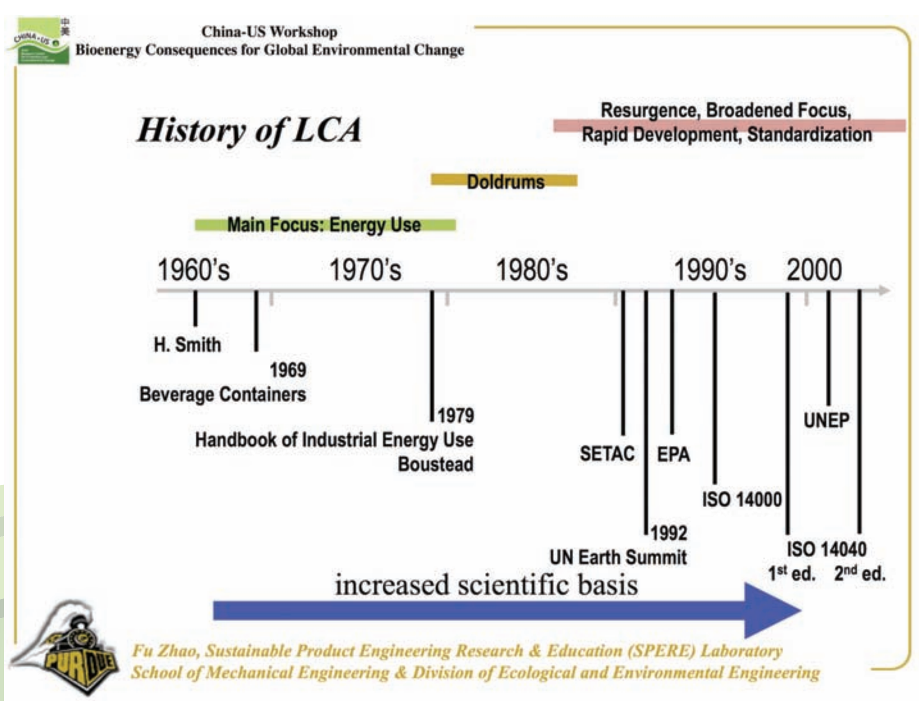
Between the 1960s and the late 1980s, progress in LCA was rather slow. The European Union's interest grew as its Environment Directorate was established, and the Liquid Food Container Directive was issued in 1985. By the early 1990s, the U.S. Environmental Protection Agency (EPA) and the Society for Environmental Toxicology and Chemistry (SETAC) developed a series of environmental impact analysis methods. In 2002, the United Nations Environmental Program and SETAC launched their Life Cycle Initiative. Collaboration between the United States and Europe by the mid-1990s eventually resulted in the first version of the International Organization for Standardization (ISO) 14000, which established principles and standards for life cycle assessment. A second edition of these global environmental management system standards, ISO 14040, was issued in 2006.

### LCA Challenges

According to the ISO standard, four steps are required to perform a formal LCA. The first step is goal definition and scope. If one focuses on just one product, for example, the approach will be quite different than if one performs a comparison of two different designs.

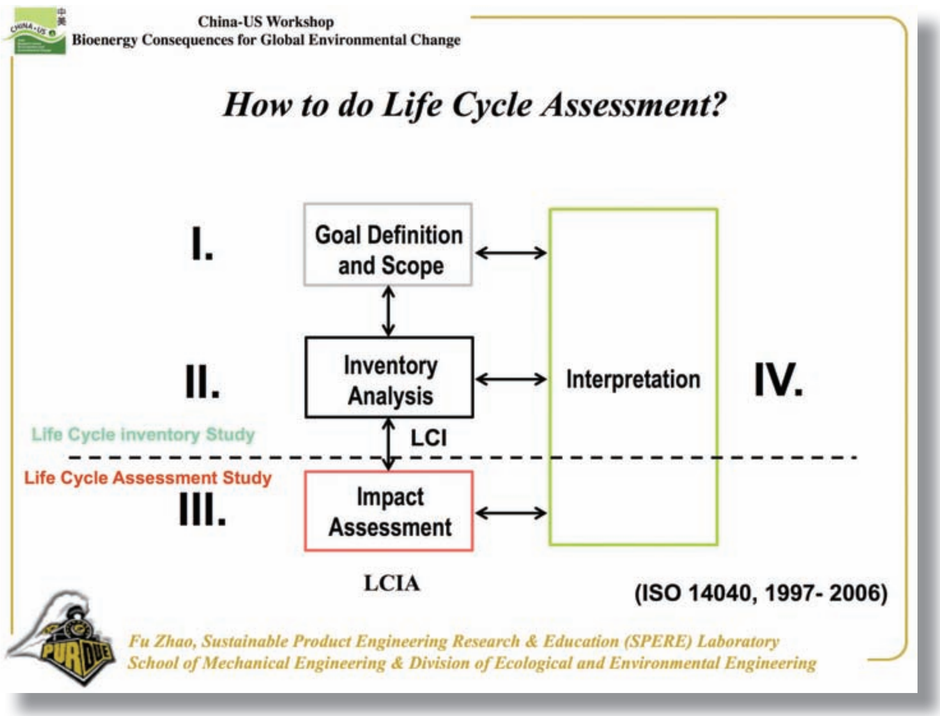
The second stage is inventory analysis, which is a very data intensive process. Data must be collected on energy flow and material flow for every single process involved in each life cycle stage. Once the inventory analysis is established, one has the choice to either move ahead to do a life cycle assessment or stop there and move to the fourth stage, interpretation.

Until now we have not had an internationally accepted measure or model to do an impact assessment. For example, it is known that many gases—such as $CO_2$ , methane, nitrous oxide, and ozone—could lead to global warming. But these gases are not created equal with regard to their capability of increasing Earth surface temperature. Models have been developed to convert other GHGs to $CO_2$ equivalent, and most researchers consider the models developed by the IPCC (Inter-government Panel on Climate Change) as the standard conversion methods, but the conversion is clearly not free of debate. If one wants to move forward and evaluate the real impacts of a certain amount of the $CO_2$ or $CO_2$ equivalent release, huge uncertainties arise. It is known that GHGs may have impacts on human health and the ecosystem, but the extent of the impacts is under intensive debate, and models that have been proposed will give significantly different predictions. Therefore, it can be seen that for inventory data that fall into a certain impact category such as global warming, one has the option to stop at the middle of the impact chain, for example converting all GHG emissions to $CO_2$ equivalent, or going all the way to real impacts on human health and ecosystem. Accordingly, most popular approaches for impact assessment can be classified as a midpoint method and an endpoint method. The Tool for the Reduction and Assessments of Chemical and Other Environmental Impacts (TRACI) developed by the U.S. Environmental Protection Agency is a representative of the former, while the Eco-indicator 1999, which was developed by Pre Consultants of Netherland, is a representative of the latter,. Due to the uncertainties, many LCA practitioners decide to skip the impact assessment stage and move directly to interpretation.




At the interpretation stage, the results from inventory analysis or impact assessment are analyzed in order to make suggestions for improvements. It should be noted that LCA is by no mean a one-way process. At some stage one may need to go all the way back to the beginning and redefine the goal and scope—for example, the scope may need to be narrowed if, for some impact categories, no data are available—and run the inventory analysis and impact assessment again.

Of all the steps involved in an LCA, the inventory analysis is




the foundation. The life cycle inventory can be established using two different approaches. One is unit process based, in which one can break down a certain industrial activity into several connected unit processes. According to the ISO standard, the unit process is defined as the smallest portion of a product system for which data are collected when performing a life cycle assessment. For every unit process there are inputs and outputs of materials and energy, including raw materials, energy needed to drive the process, the final manufactured product, and the associated emissions, waste, and effluents. Clearly, all activities in industrial systems can be broken down and represented by thousands or even tens of thousand of unit processes. Life cycle inventory for a product or a process can be established if we have a database that has information for all the unit processes.

In reality it can be very difficult to develop this kind of database. There is an alternative approach to life cycle inventory that is relatively simple, one based on economic input and output data. Instead of focusing on a specific industrial process, one may think in terms of different economic sectors. For the U.S. economy, one can break it down to roughly 500 different sectors. The U.S. Department of Commerce conducts an industry wide survey every five years and publishes monitory flow data between these sectors. EPA also collects data for environmental releases from major industrial facilities that belong to different sectors every year. By associating the environmental release with the economic flow, one finds a different way to calculate the life cycle inventory. This approach is usually referred to as Economic Input-Output LCA, and the Green Design Institute at Carnegie Mellon University has developed a web based model. Unfortunately the model used 1997 survey data and may not be suitable if industrial activities in rapid changing sectors such as computer and electronics manufacturing are involved.

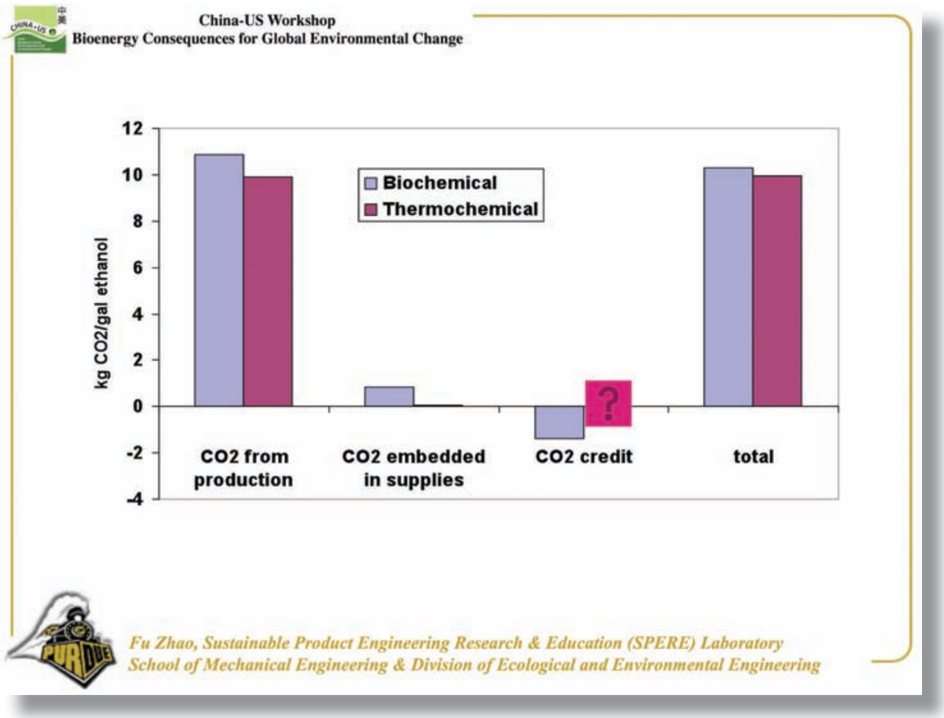
### The Transportation Sector

For transportation fuels, the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model is the one most commonly used. With the GREET model one can choose to perform an analysis over the fuel cycle only, either well-to-pump or well-to-wheel, or include the vehicle cycle, i.e. taking into consideration vehicle manufacturing and end of life recycling/disposal. From an LCA assessment standpoint, GREET is not a "full" analysis since only total energy consumption, fossil fuel consumption, and air emissions—including emissions of $CO_2$ equivalent GHGs and six criteria pollutants—are included. Information on water resource consumption and land use is not included. Also, the GREET model draws a very narrow boundary around the fuel/vehicle life cycle. It includes only environmental impacts from energy flow and ignores those associated with material flows. Since biofuel production has intensive material/energy exchanges with many industrial sectors as well as the ecosystem-locally, regionally, and globally—there are numerous challenges to applying LCA to evaluate environmental performance of different biofuel production technologies.

A simple example is to compare the life cycle GHG emissions of two cellulosic ethanol production technologies, i.e. biochemical and thermochemical conversion, using the GREET model. Since we assume the same feedstock will be used for both processes, and that the two processes produce ethanol of the same quality, we don't need to consider upstream—i.e. feedstock cultivation, collection, and transportation—or downstream—i.e. distribution of fuel and combustion in internal combustion engines—environmental impacts, which significantly simplifies the analysis. One can find that the thermochemical pathway, although it receives less attention when compared with biochemical conversion, has almost identical GHG emissions as compared to biochemical pathway. This suggests that more R&D efforts should be put into thermochemical conversion to diversify cellulosic technologies.

### Sustainability and Resilience

Though LCA is a good approach to evaluate environmental sustainability, we must remember that we cannot consider sustainability as a steady state; it is inherently dynamic. In a traditional engineering approach, engineers try to design a system that will be quite robust to small disturbances, but if we have unforeseen disturbances then the system may just collapse. For biofuel technology, it is preferable to have some resilience built in, so that if a plant using the technology runs into a shortage of supplies of the feedstock specified in design, it can accept a wide range of very different feedstocks and at the same time can be configured to generate multiple products. In this manner, we will ensure diversity, efficiency, adaptability, and cohesion, which will bring resilience to the plant and to the process. Apparently, the current biofuel plants are all lacking this resilience and are thus not really sustainable. Future development of sustainability assessment tool has to integrate resilience consideration into a life cycle assessment.



# Production of Bio-Methane and Beyond

by Jason C. H. Shih

**Dr. Jason C. H. Shih** *is a professor in the Department of Poultry Science at North Carolina State University*

Everybody enjoys fresh, nutritious eggs, especially at breakfast, but consumers typically ignore the ugly, smelly byproduct of egg production, chicken manure. An average sized egg farm keeps about a million laying hens, or layers. One million layers produce approximately 100 tons of fresh manure every day. Even small farms with 100,000 birds have to handle about 10 tons of manure every day. Waste management is a big challenge for animal farmers.

When I came to North Carolina State University (NCSU) in 1976, with background training in microbiology and biochemistry, I was asked to develop a process to manage and utilize this byproduct. The process that I chose to study is called anaerobic digestion. In the absence of oxygen, organic matter can be degraded by a host of bacteria that anaerobically break it down to organic acids and alcohols and then convert these into $CO_2$ and methane.

*Above and right, eggs and manure effluent*

Hundreds of kinds of these bacteria can be divided into three groups, 1) the hydrolytic group, 2) the acetogenic group, and, 3) the methanogens. The hydrolytic group converts complex polymers to simple monomers. The acetogenic group converts fatty acids into acetic acid, $CO_2$, and hydrogen. The methanogens convert acetates and $CO_2$ into methane. The gaseous product is derived from a biological process, hence the term biogas for the mixture of methane and $CO_2$. Because of its biological origin, it should more accurately be called bio-methane, distinct from natural methane, which comes from natural gas.

## Thermophilic Anaerobic Digestion

Thirty years ago, we set up laboratory digesters at NCSU. These digesters, more aptly called bioreactors, were used to find the proper conditions to maximize methane, or biogas, production. We had two sets of digesters, each of two sets had four 1-liter digesters, a total of eight, with which we could control temperature, concentration, and retention time to determine the optimum combination of these variables. These bioreactors were in operation around the clock for about four years.

When we set out on this research, it was the first time that a basic laboratory approach had been employed to see how much methane or biogas could be produced from animal waste, chicken waste in this case. Many studies had been conducted using municipal waste, cattle waste, dairy waste, and pig waste. Typically, working with one large biogas digester on a farm, it was difficult to evaluate multiple operational parameters effectively and to produce statistically significant results. By varying the retention time, concentration, and temperature with those eight digesters, we eventually found the best combination of parameters to maximize the production of methane from the chicken manure. This study illustrated how to determine the methane potential from any given type of waste.

We compared the temperature effect during anaerobic digestion, mesophilic (35° C or 95° F) vs. thermophilic (50° C or 122° F). Thermophilic digestion turned out to be most efficient in terms of the rate of gas production and pathogen control.

Some critics told us that if we ran the digestion at a higher temperature, our energy input would be higher and, therefore, net energy gain lower, but that turns out not to be the case. From the laboratory comparison, the net gain of energy is 10 percent lower for the thermophilic operation. But, because the bioreaction rate is higher, we can process 2 to 4 times higher amounts of waste at higher temperatures to generate 2 to 4 times more biogas. Alternatively, since the retention time is shorter, a digester can be smaller to process the same amount of waste, and the heat loss of the system can be drastically lower.

With this information, we then estimated the energy potential from the chicken manure. A 1 million layer farm produces 100 tons of manure per day, which can be digested into 8,000 $m^3$ (2,115,000 gallons) of biogas. A biogas engine generator with 25 percent conversion efficiency can convert the biogas into 12,000 kilowatt hours (kwh) per day and 4,400 megawatts (MW) per year, in addition to other benefits associated with the digester system. The results are encouraging. Some people thought that laying-hen waste was not the ideal substrate for methane production because the nitrogen content tends to be high. But, in fact, the bacteria in the digester are believed to be adapted to that high nitrogen content.

## From the Lab to the Farm

The next step was to move to the research farm and to see whether we could prove the concept by reproducing the results in the laboratory. We built a small plug-flow digester with a sausage-shaped plastic bag, insulated, in a trench. Four hundred kilograms (880 pounds) of fresh manure from a hen house with 4,000 laying hens were scraped daily into an auger system where the manure was delivered and flushed with hot water into the digester. The digester was maintained at a high temperature, 50 to 55° C (120 to 130° F), depending on the temperature of the hot water. We controlled the amount of hot water and thus the concentration of the manure in the digester as well. We tried to reproduce all the operational parameters that we learned in the laboratory. A gas meter in a small shed monitored how much gas was produced every day. It was a simple digester and a simple operation. We operated the system for about three years and reached about 80 percent of the volumetric biogas rate and 100 percent of the gas yield that we achieved in the laboratory. It was a successful field trial at a small scale, and proof that we can scale up the thermophilic digestion to large digesters.

*Farm trials*

## China: Grandfather of Biogas

In 1985, I helped organize the first international symposium on anaerobic digestion (biogas) in China and was able to visit a number of biogas units. China, the "grandfather" of biogas, has been using this method for more than 100 years. We visited one farm in a small village that has a pig house with 700 pigs. All the manure is flushed into an underground digester, and the gas is then piped out to provide cooking fuel and hot water for a big cafeteria where the whole village eats. A series of fish ponds next to the digester utilized the nutrients in the digester effluent to grow fish. A large part of the effluent was pumped to a hilltop and used to irrigate and fertilize the orange grove. This ingenious system is extremely efficient and is capable of supporting a whole village, providing income, food, and fuel.

To handle the waste from 700 pigs at ambient temperature, the underground digester was as big as a basketball court. I suggested that they try the thermophilic anaerobic digester. With the higher temperature operation, they could use a much smaller digester, about the size of a ping-pong table, to handle the same amount of waste.

Later, in 1992, supported by the United Nations Development Program (UNDP), I helped design and build a thermophilic digester in a village of Beijing, Liumingying. The basic design was similar to our prototype design in North Carolina. It is still in operation after 16 years. This is a concrete compact digester (100 $m^3$ or 26,400 gallons) to handle the manure of 50,000 laying hens that produce 5 tons of manure everyday. It produces biogas three to four times the volume of the digester each day, achieving results very similar to the laboratory results. The biogas is piped underground to 200 households in the village for cooking and heating. The effluent is piped to the rice paddy, where rice grew better than with chemical fertilizer.

These trials have demonstrated that our laboratory results can be applied from very small to very large farm operations. In fact, China has already installed 20 million small and large digesters in rural areas.

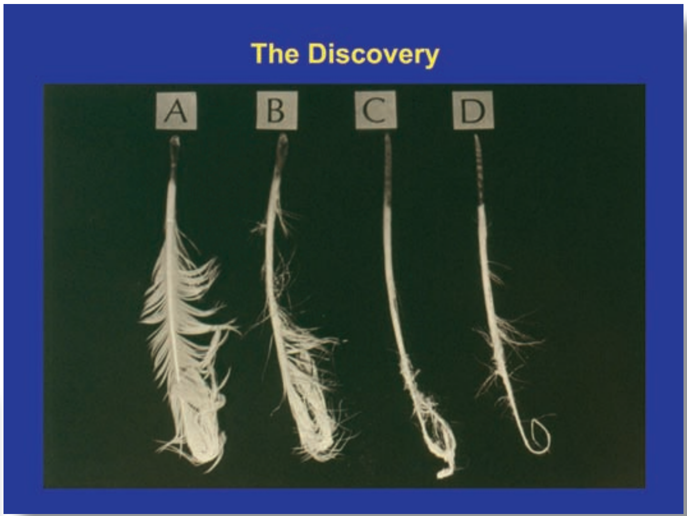
The technology of anaerobic digestion has multiple benefits. It reduces odor and conserves nitrogen, phosphorous, potassium (N-P-K) fertilizer value. It generates and utilizes methane as an energy source. It reduces the emission of green house gas, ammonia, and hydrogen sulfide. The thermophilic digester effectively destroys manure-born pathogens and thus protects environmental health and food safety. Beyond all these benefits, the digester itself is a novel biodiversity and bioresource.

## Biodegradation of Feathers

We discovered an interesting phenomenon when we operated the digester on the university farm. The chicken feathers shed into manure always disappeared in the digester. One day, a hen escaped from her cage and was inadvertently delivered into the digester. When we opened the digester, we could not find the chicken, not even a single chicken feather. It was speculated that something must be breaking down the feathers, which like human hair and fingernails are made up of a very tough protein called keratin.

We spent two years trying to solve this puzzle, and we finally found a feather-degrading bacterium from the digester. When we put a whole feather into the test tube of medium solution without inoculation of the bacteria, the feather stayed intact after 10 days. When the medium was inoculated with the bacteria, the feather was degraded by the growing bacteria in a few days.

This discovery opened up yet another area for study. The isolated bacterium was identified as *Bacillus licheniformis*. Since it was the first microorganism isolated from the poultry waste digester, it was given a strain name, PWD-1. We also purified the enzyme from the bacterial medium. It is a protease. Because of its novel capability in keratin degradation, it is called keratinase.




Where there is an enzyme, there must be an encoding gene. We finally teased out the gene, sequenced it, and found the basic gene structure. With the gene in hand, we began to perform genetic manipulations to improve the yield of keratinase. Two techniques were used. One was introducing a strong promoter for hyper-expression, and the other was inserting multiple gene copies into the chromosome. Both techniques worked. The genetically modified strains produced 4 to 5 times more of the enzyme.

For the application research, the keratinase must be produced in larger quantities. With funding from the North Carolina Biotechnology Center, we were able to install the fermentation facility. The complete facility consists of a 150-liter (40-gallon) pilot industrial fermentor, a 15-liter (4-gallon) bench-top fermentor, and other associated equipment. With this facility, the enzyme can be produced at a rate of 200-300 grams (7-10 ounces) per batch for application research and commercial development.

One of the applications was to add the enzyme into the process of cooking feathers into feather meal. It was found that keratinase could help improve the digestibility of the feather meal. Also the enzyme could facilitate the cooking process by reducing the cooking time and cooking temperature. The enzyme process can improve the nutritional quality of feather meal and upgrade the utilization of this by-product of the poultry industry. One million tons of feathers are produced and collectible in the United States each year. Ninety percent of feather material is keratin protein.

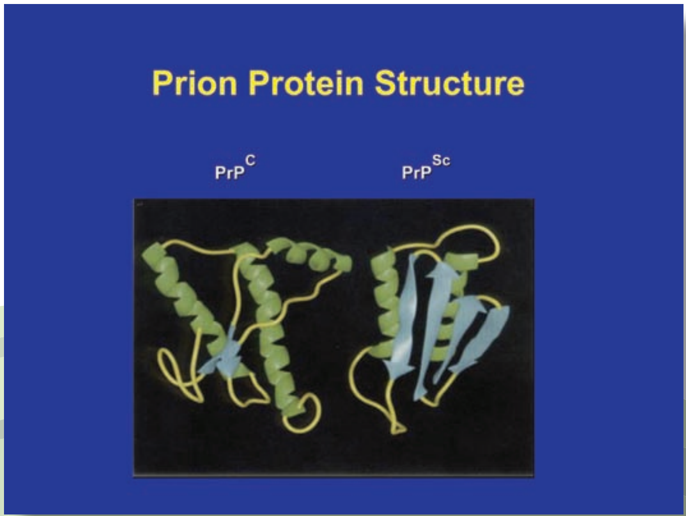
## Keratinase as a Feed Enzyme

In 2001, I suggested to a graduate student who was working with me on her Master's degree that she add the enzyme in a small amount to the feed to test its effect on the growth of broiler chickens, the meat-type chicken. Two types of feeds, one with low protein and the other with a standard protein level, were used. Interestingly, the birds on a low protein diet grew as big as the birds on the standard diet, as long as the keratinase was included in the feed. More follow-up experiments repeated the same effect of the enzyme additive. It was concluded that the enzyme as a dietary supplement can improve the body weight gain by approximately 100 grams (3.5 ounces) per chicken at the market age (42 weeks). Alternatively, it can help spare about 10 percent dietary protein from a normal diet without negative effect on growth.

The keratinase additive also improved the feed conversion ratio, a measurement of the feed efficiency or quality in supporting chicken growth. As we now know, keratinase is a potent protease and, therefore, improves the digestibility of protein in the gastrointestinal tract of the chicken, thus the bird gets better nutrition and grows bigger. Based on the FCR improvement, the monetary value of the feed enzyme additive can be estimated. When keratinase is added at a level of 0.05 percent, it can save $20 to 30 per ton of broiler feed, depending on the market price of soybean meal. The total cost saving worldwide for growing broiler chickens is multi billions of dollars. A biotechnology company, BioResource International, Inc., is producing this enzyme for the global market.

### Degradation of Prion Protein

Fifteen years ago, Europe experienced an outbreak of mad cow disease, bovine spongiform encephalopathy (BSE), caused by an unusual protein called prion protein. Prion protein has two iso-forms with the same primary structure but different secondary structure or mis-folding. The natural cellular isoform is harmless and rich in α-helical structure. The pathogenic iso-form is rich in-sheet structure and tends to aggregate into ß-amyloid plaque. The pathogenic prion protein (PrPSc) is believed to be infectious, self-perpetuating, and the causative agent of prion diseases including BSE, scrapie in sheep, and Creutzfeldt-Jakob in humans.




Due to the unique structure, PrPSc is a very stable protein, resistant to sterilizing methods such as alcohol, heating, and autoclaving, and resistant to common proteolytic enzymes. I noticed that its property is similar to that of feather keratin. In 2001, I carried the keratinase that we discovered in my laboratory to ID-Lelystad in the Netherlands to test its ability in degrading PrPSc. My colleague was skeptical in the beginning. After three days of work in his isolation laboratory, we made the first discovery of the complete digestion of PrPSc by the enzyme. More studies confirmed the first result and perfected the digestion process. This discovery opened up the possibility of enzymatic inactivation of prion protein and a potentially new method for the decontamination of prions to prevent the spread of prion diseases.

From the laboratory study, a thermophilic digester was systematically developed. A digester was constructed in a small village in China using biogas energy from animal waste and it has been in operation for 16 years. From a digester, a feather-degrading system that includes the bacterium, enzyme, and gene was unfolded. Industrial scale production of the keratinase made the commercial applications possible. The keratinase was found useful in processing feathers, feed additive, and prion disinfection. This series of studies is a good case demonstration of science-based modern agriculture.

References:

Shih, J. C. H. (1987) From anaerobic digestion to holistic farming. Chapter 1, pp. 1-16 in Bioenvironmental Systems, Vol. II, D. L. Wise (ed.), CRC Press, Boca Raton, Florida.

Shih, J.C.H. and Wang, J.J. (2008) From biogas energy to keratinase technology. Pp. 231-238 in Biocatalysis and Bioenergy, C.T. Hou and J.K. Shaw (eds.), John Wiley & Son, Inc., Hoboken, New Jersey.

For further information, contact Jason Shih, North Carolina State University, Raleigh, NC 27695-7608, USA jason_shih@ncsu.edu

# Linking Biomass-based Liquid Fuel Production Capacity to Transportation Demand and Sustainability Goals

**by Loring F. Nies**

**Dr. Loring F. Nies** *is an associate professor in the School of Civil Engineering, Division of Environmental and Ecological Engineering, at Purdue University.*

Human civilization uses lands for multiple purposes: to produce food, protect water resources, preserve biodiversity, and increasingly to harvest biomass as we convert our transportation system from one based on fossil fuels to one that uses biomass-based liquid fuels. We need to find the most efficient system for harvesting energy from land and applying it to the wheels of a vehicle, as land use becomes the next grand environmental impact.

A great deal of intellectual and financial capital has been brought to bear on producing biofuels, or attempting to. But we also need to think about where these fuels are going and how we can optimize the demand side of the transportation system. Today, we have a very simple energy system. We burn petroleum to provide transportation. Almost every kind of transportation system is based on the combustion of petroleum.

Though it is risky to predict the future, I think that as energy becomes more expensive, energy systems are going to become much more complicated. We can't, however, predict the energy vehicle technologies that will be adopted. Will the least efficient technology, the internal combustion engine, remain the standard? Will the fuel cell or electric motor prevail? In order to achieve sustainability as we move from petroleum products to agriculturally based products, we need to rethink the energy conversion equation of well to wheels to land to wheels. We must find the best system for harvesting energy from the land and the best system to apply that energy to the wheels of a vehicle.

### Comparing Footprints

To provide a reference case, consider our corn ethanol system based on traditional agriculture. We grow corn, mill it, prepare the mash, ferment and distill it, extract byproducts, then denature the alcohol to produce fuel ethanol. In the process, only 25 percent of the potential energy of the crop makes it to the wheels. Why are we putting so much effort into making ethanol and then putting this valuable commodity into a technology that has been around for 150 years? Of course corn ethanol is not a system that we will wind up using in the long run. We will be moving to cellulosic biofuels or something else, but the point is, there is a great deal of energy loss as we move the product into an internal combustion vehicle, and the internal combustion engine itself is incredibly inefficient. Not only do we need to think about the entire production chain of a technology, we also need to think about the kind of vehicle in which the fuel winds up, and we need to be aware of other global phenomena, such as rapid urbanization trends, that we are witnessing today.


A possible alternative is to use traditional agriculture, but in a more futuristic scenario, the fuel cell. In this system, about half the energy makes it to the wheel. This could double the energy transportation efficiency and energy conversion efficiency of the vehicle, but there are still challenges to overcome. Fuel cells are not yet commercially viable. They don't last long enough, and they are too expensive.

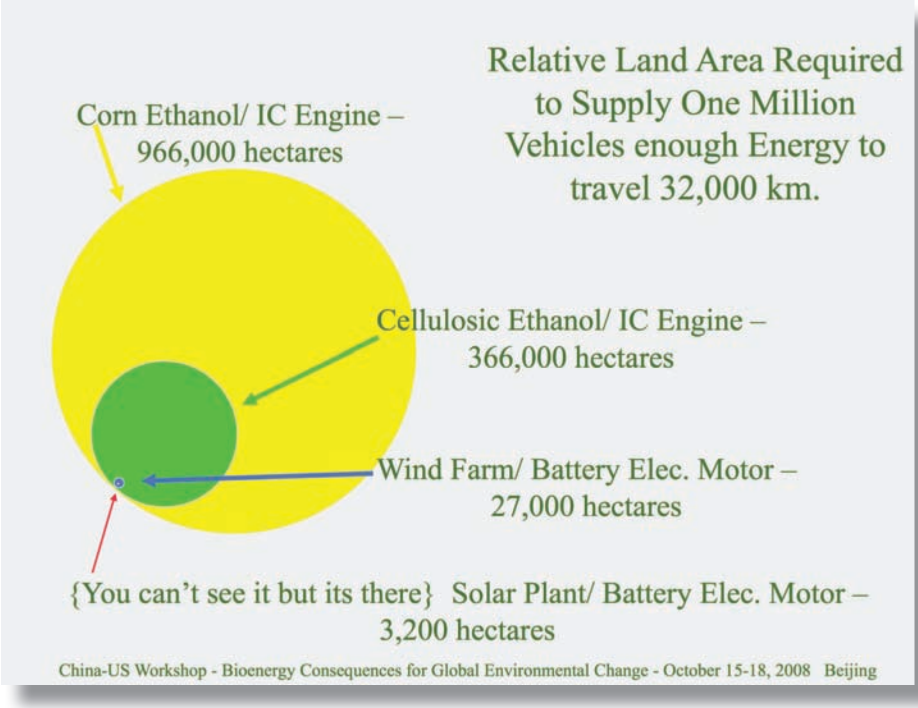
If we can modernize our agricultural system, however, we can dramatically increase the amount of energy we pull from a unit of land. Wind farms are a good example. Energy from wind farms can be used in a conventional energy conversion system, batteries, which are very efficient at storing energy and transferring it into power. Electric motors are extremely efficient and work well in cars, and it won't take too much effort to produce electric vehicles with a range and performance acceptable to consumers. Compared to cellulosic ethanol, the amount of energy per land area from wind turbines is tremendous. Using modern agricultural systems to produce cellulosic ethanol, only 56 percent makes it to the wheels. Nearly 75 percent of the energy produced on a wind farm makes it to the wheels, and agricultural crops can coexist with wind turbines, which will also affect the crop footprint very little.

If we use solar photovoltaic to provide energy for batteries that power electric motor type vehicles, we can produce energy even more efficiently. Of course, solar photovoltaic panels are very expensive, but we expect the cost to come down. The amount of energy per unit of land with solar energy is enormous. Even on a solar energy plant in Indiana, a terrible place to put up solar panels, we are able to transfer more than 5,000 gigajoules (GJ) per hectare (2,000 GJ per acre) to vehicle wheels from 7,000 GJ of solar energy harvested per hectare (3,000 GJ per acre). If we locate solar energy plants in the southwest or near the equator, we can substantially increase the efficiency of solar panels, which today are only 12 percent efficient. Oak Ridge National Laboratory has solar panels in the lab that are about 40 percent efficient. If we increase efficiency and lower costs of solar energy, we can minimize the amount of land required to produce energy for electric vehicles compared to that required to produce biomass for internal combustion engine vehicles. Again we need to think of the whole power transportation system, from the supply side to the demand side.

Alternatively, we could produce hydrogen from wind farms to power fuel cells instead of charging batteries. Batteries and hydrogen are both portable sources of stored energy. We need to decide what level of portability we want, what kind of performance we want, what kind of energy conversion technology we have. Our decisions depend on a suite of choices. As I said, the future will be complex. We will not have just the internal combustion engine and a fuel for it, or an electric car with a battery or fuel cell, or an electric car that recharges through the grid.

We have a wide variety of options. Do we want to put energy into the grid? Do we want to store it? How portable do we want it to be? Is the application an urban system, a rural system, or a remote system? Do we want to power aircraft? We are almost certainly not going to have electric battery powered airplanes. We will still need liquid fuels for aircraft and ships. With vehicles, we can plug them into the grid or run them on batteries.

As kind of a thought experiment, I have calculated the land area that would be required for powering 1 million passenger vehicles for 32,000 kilometers (20,000 miles). Corn ethanol for the internal combustion engine requires 966,000 hectares (2,400,000 acres), cellulosic ethanol for the internal combustion engine 366,000 hectares (90,000 acres), wind farm for the battery powered electric motor 27,000 hectares (67,000 acres), and a solar plant for the battery powered electric motor only 3,200 hectares (8,000 acres).




If we think about all the different options we have for vehicles, and ways we can take stress off of the land or find dual uses such as putting wind turbines on agricultural land, we can find ways to minimize ecosystem impacts, and we should.

## Funding Priorities

Several reports have been issued lately about the types of technologies that are receiving funding. A U.S. Department of

Energy roadmap for ethanol came out in 2006, "Breaking the Biological Barriers to Cellulosic Ethanol." Though the report mentions biodiesel in passing, the main focus is ethanol. In 2007, a group of chemical engineers held a workshop in Washington, D.C., drawing attention to pyrolysis and other thermochemical techniques, and they charted their own roadmap for making hydrocarbons instead of alcohols. The interagency Biomass Research and Development Board published an action plan in 2008 that pulls those two previous reports together and identifies all the funding agencies or organizing agencies that are supporting the development of biofuels. The plan calls for managing these in an integrated fashion. The chemical engineers' plan is to use different types of biomass to produce "green gasoline", which would work in our conventional distribution system and conventional internal combustion engines. This report appears to give short shrift to the biological conversion processes.

I personally don't think that any one technology is going to win out over the other; there is a role for both of these. The chemical engineering document outlines the potentially lower cost characteristics of green gasoline that gives them an advantage. Green gasoline's advantages include using the existing distribution infrastructure, local refining, and low water consumption. Perhaps they will be cheaper, but whether or not we make alcohols or alkanes will depend on the type of fuel cell technology that vehicle manufacturers choose. If it is solid oxide fuel cells that use the alkane hydrocarbons, then the chemical engineering technology is probably going to dominate, whereas if it is the direct alcohol fuel cells, it is more likely that we will continue to try to make ethanol. In any case, people are already talking about using alcohol fuel cells to power laptops and cell phones. It is likely that both technologies will be available.

### Change Is Coming

In 2005, the United States consumed almost 21 billion GJ of liquid transportation fuel. The goal for future cellulosic liquid fuel production is to produce about 9.8 billion GJ. Until the economy crashed and oil prices declined recently, this number was growing at a rate of 2.7 percent a year. We don't know what the future holds, but perhaps we can keep this number at around 20 billion GJ. It would take enormous policy changes and also changes in the way we conduct business in terms of transportation, but it is possible.

We have to take advantage of the global urbanization phenomena that are occurring and seize this as an opportunity, not as a challenge. We have to reinvent the way we behave in cities. Today, 60 percent of the petroleum used in the United States is consumed in what I call the last mile, people driving to work, school, shopping, and entertainment, usually just one person per giant SUV. The other 40 percent carries all the goods and commodities by aircraft, rail, shipping via heavy trucks, and the military.

We can take advantage of the fact that more people are moving into cities where there are transportation alternatives to driving a single passenger vehicle. We must redesign our cities to minimize fuel demand. We know how to do that through sustainable development, which mitigates land use impacts of transportation energy use and economic development. Sustainable urban development includes

- Clustering buildings with smart community design
- Mixing commercial and residential uses
- Planning development around public transit routes
- Providing bicycle and pedestrian commuting
- Creating cohesive neighborhoods
- Developing urban public transportation networks
- Using transportation technology that minimizes consumption and maximizes efficiency and air quality.

All we need to do is keep petroleum prices high, which will provide the incentive for change. If we take the pressure off of the biofuels production side by reducing demand and changing our behavior and lifestyles, we can minimize the impact on the environment and ecosystems from biofuels production.

# An Industrial Demonstration of Corn Stover-based Ethanol Processing in China

**by Jie Bao**

**Dr. Jie Bao** *is a professor of engineering and deputy director at the State Key Laboratory of Bioreactor Engineering, and director at the Center for Biomass Energy Research, East China University of Science and Technology.*

Roadmaps for the deployment of renewable energy in China and the United States are very similar, calling for steady increases in the production capacity of demonstration projects of starch-based ethanol production, then switching to ethanol demonstration plants, and leading eventually to high volume, commercial production of ethanol over the next 25 to 30 years.

China started with starched-based ethanol in 2005. Now we are working on an ethanol demonstration to produce 50,000 tons per year in the next five years. By 2030, we hope to catch up with the United States and have the capacity for high-volume commercial production of cellulosic ethanol.

Four large companies in China have been working to increase productivity of starch-based fuel ethanol. In 2005, capacity was about 1 million tons annually, and in 2007, capacity was 1.5 million tons. In 2006, government regulation banned further increases in production of any kind of starch-based ethanol, whether from wheat or corn, and production of corn-based ethanol was capped at 1.5 million tons per year. This regulation makes it even more important to move to corn stover-based ethanol production

## Industrial Demonstration

A demonstration project in northeastern Jilin Province, sponsored by PetroChina (the National Petroleum Corporation of China) and by the National Development and Reform Commission of China (NDRC), produces 3,000 tons per year of fuel ethanol from corn stover. This is one of several industrial demonstration plants for cellulosic ethanol, all of which use an enzymatic hydrolysis technology. Pretreatment choices include steam explosion, base treatment, and dilute acid. Primarily glucose is fermented, leaving xylose behind. Some of the processes use molecular sieve purification for fuel ethanol, which cuts energy usage significantly.

The demonstration project focuses on several issues. First and foremost is to achieve as high an ethanol concentration as possible. Currently, the minimum concentration is 7 percent, and the goal is to increase it to 8 to 10 percent. Ethanol yield based on corn stover is less than 6.6 tons of corn stover for 1 ton of ethanol. Ethanol hydrolysis conversion is 5 percent, and ethanol yield from glucose is 90 percent. This makes it possible to use fewer than 12 tons of fresh water to produce 1 ton of ethanol, and the cost of the enzyme should be less than 2,000 Chinese Yen, almost equivalent to $285.00 U.S. dollars.

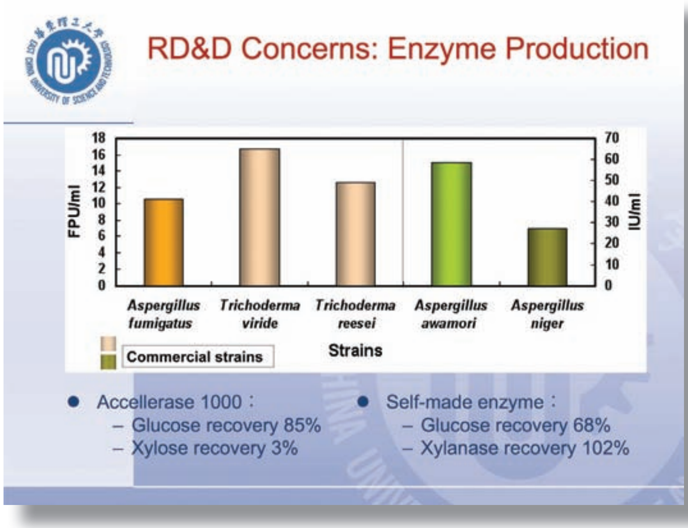
Technical choices are challenging in the pilot plant, and the process is quite slow, but PetroChina has a very clear strategy for deployment of the options. Beginning in 2007, the startup operation has chosen the most conservative technical options. The next step is to improve the technology and move it into optimal operation by 2010.

## R&D Concerns

For pretreatment in the startup operation, we first used a continuous steam explosion technology with equipment made by a Canadian company, Sunopta. In the second phase, we tried using dilute acid at ultra low concentrations and applied combined processes to reduce energy costs and minimize equipment erosion using equipment made in China in order to reduce dependence on imported equipment. Steam explosion is accomplished at temperatures of 230° to 250° C (450° to 480° F), so we wanted to decrease the temperature by at least 50° C (120° F) to cut energy costs. Other energy saving techniques include special grinding and additives. Finally we explored a biological method for lignin degradation. There is a lot of research on this method, but so far we have not found an effective means to degrade lignin. We did find that the treatment can stabilize the pH. With pH regulating materials, we can keep fermentation and hydrolysis at a very stable level.

For enzyme production at the startup stage, we purchased the newest cellulose enzyme, Genencor's Accellerase 1000™. We should be able to produce a hydrolysis yield higher than 80 percent at a cost of less than 2,000 Chinese Yen (U.S. $285) for 1 ton of ethanol production. Then we will produce the ethanol enzyme on site in this demonstration plant using Chinese technology collaborators' technologies, including strain development and fermentation. We will also add xylanase enzymes. This improved technology operation will produce more enzymes and allow us to cut enzyme costs to less than 1,000 Chinese Yen (U.S. $142) for 1 ton of ethanol.

Using Accellerase 1000™, we can obtain glucose recovery at 85 percent and xylose recovery at 3 percent. In our laboratory, we made new cellulose enzymes and found that while cellulose activity is a bit lower than with the commercial enzyme—68 percent glucose recovery with our self-made enzyme—xylanase enzyme recovery was much higher at 102 percent.




In the startup operation we use a thermo-tolerant *Sacchaomces cerevisiae* mutant yeast to achieve an ethanol yield from glucose greater than 85 percent at a temperature of 37˚ C (99˚ F) and an ethanol tolerance greater than 10 percent. As we improve the process we will increase the ethanol yield for glucose to greater than 90 percent. A very important step is to increase temperature tolerance to 45˚ C (113˚ F) to enhance the hydrolysis process. The second strain we are using is the bacterium *Zymomonas mobilis* to improve growth under a high stress environment. We reconstruct xylose utilizing the pathway in *Z. mobilis*. This work is still in the development stage, but so far it is going smoothly.

Simultaneous Saccharification and Fermentation (SSF) is a major concern. Our target is to save energy with minimal usage of water and to optimize cost savings of the operation by achieving a higher solid loading, higher ethanol concentration, and higher ethanol yield. To reach a higher ethanol concentration, you have to put as much as possible in raw materials, particularly corn stover, and concentrate everything in a very high solid loading. In the industrial fermentation strain, the basic organic source is added without expensive, complicated ingredients.

High loading is accomplished using extremely low amounts of water in the feedstocks. We will improve the mixing performance of the high viscous multiphase system by borrowing bioreactor designs from an industrial petrochemical reactor to make a specially designed stirrer. In the improved operation we will use Calculation Flow Dynamics to simulate the mixing performance by considering the dynamic solid loading change, dynamic viscosity change, and the dynamic carbon dioxide ($CO_2$) release. We can characterize the fermentation performance under these high viscous conditions and also develop a methodology for the SSF scale-up for the high viscous, high solid loading, and high ethanol concentration.

There are some concerns about the industrial scale demonstration. One problem for this system is that a complete biomass database is not available for the simulation. A second concern is direct distillation. We do not use any steam to strip the ethanol from the high viscous fermentation approach, because the addition of steam would dilute the ethanol concentration. A third concern is lignin gasification. Lignin now is burned in a boiler to get more heat, but in our process we ferment the residue, lignin, using well established gasification or co-gasification with coal to produce syngas, which will be used for the production of methanol.

In the future, China hopes to increase production of fuel using cellulosic ethanol to replace gasoline. The goal is to produce 50 million tons of cellulosic ethanol by 2006 and 60 million tons by 2010. To replace all the gasoline in China, we would need to produce 0.4 billion tons annually, assuming we can produce 1 ton of ethanol from 6.6 tons of stover. This would entail using 40 percent of the total agricultural residues in the country. The cellulosic ethanol industry network would consist of 600 plants with a productivity of 100,000 tons a year, or 1,000 plants with 60,000 tons production of ethanol. That's what the system of ethanol production will need to put in place in order to replace all the gasoline in China.

# Anaerobic Granule-based Reactors: Biohydrogen Production from Organic Wastes

by Han-Qing Yu

**Dr. Han-Qing Yu** *is a professor of environmental engineering at the University of Science and Technology of China.*

The crisis in energy sources and problems with pollution have led many to regard hydrogen ($H_2$) as an ideal new energy carrier in the future. $H_2$-based fuel cells have already been widely used in cars and motorcycles, and research is ongoing to find sustainable sources for hydrogen production. At the University of Science and Technology of China—which was founded by the Chinese Academy of Sciences in Beijing in 1958 and moved to Heifi, Anhui Province, in 1970—we have focused in our laboratory on $H_2$ production via direct fermentation. Compared with many other $H_2$-producing processes, direct fermentation has some advantages.

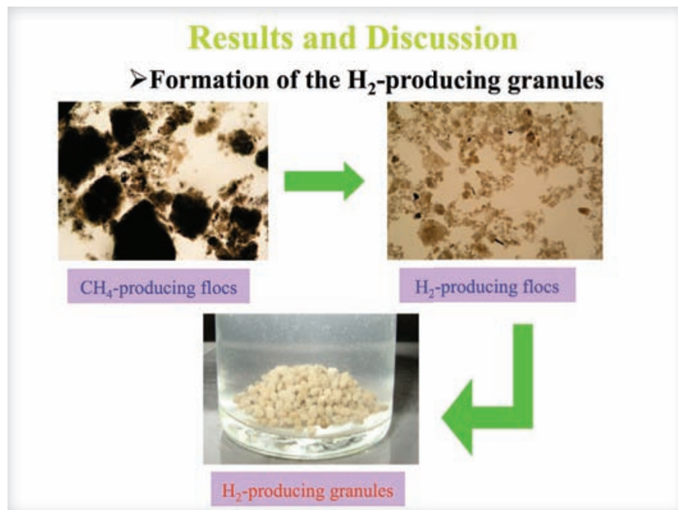
Various acidogenic microbes have a high ability to convert organic substrates into $H_2$ and volatile fatty acids (VFAs). Organic substrates include carbohydrates, protein, and even lipids. This process has many advantages. The dark fermentation process produces no demand for light, the working conditions are quite simple, the process has wide utility, and the costs are low. The process does, however, have some disadvantages that need to be overcome, such as low yield and low stability.

Our work has three objectives. The first is to investigate $H_2$ production at various substrate concentrations in an upflow anaerobic sludge bed (UASB) reactor with $H_2$-producing granules. The second is to explore the feasibility of employing a UASB reactor for efficient, continuous $H_2$ production. The third is to evaluate the characteristics of the $H_2$-producing granules.

## Energy from Sludge

In this investigation we used substrate collected from a full-scale methane-producing UASB for the treatment of waste water from the processing of starch. After we fed the reactor with seed sludge, the pH was kept very low, at 4.4, to enrich the $H_2$-producing bacteria and, at the same time, suppress the activity of methanogenic bacteria. The seeding sludge concentration is 6.3 grams of volatile suspended solids (VSS) per liter. The substrate is sucrose at a range of 5 to 30 grams of chemical oxygen demand (COD) per liter. The UASB reactor is a typical anaerobic reactor for treatment of waste water.

After seeding, most of the anaerobic sludge was in the form of flocs. Initially, after two months of operation, the flocs were methane-producing, but because of the very low pH venting in the reactor, methane production was suppressed, and finally there was no methane production from the reactor, only $H_2$. In this case we can call them $H_2$-producing flocs. After six months of operation, we finally obtained beautiful $H_2$-producing granules.




We also evaluated the effect of the substrate concentration on the substrate degradation efficiency and the $H_2$-producing yield rate. In the substrate tested range, sucrose degradation efficiency was very high, exceeding 96 percent. When we explored the effect of substrate concentration on substrate degradation and influent alkalinity, we saw influent alkalinity rise with increased substrate concentration. The $H_2$ partial pressure generally decreased from the initial 0.57 to 0.37 atm at COD concentrations near 30 COD gram/L. On the other hand, the $H_2$ production rate generally increased, but the $H_2$ yield decreased.

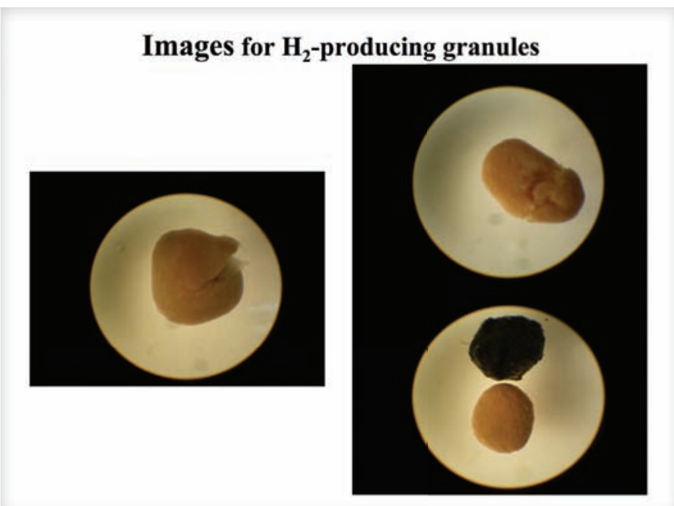
With the production of $H_2$, we also get some VFAs and ethanol in the effluent at various substrate concentrations. Total VFA and ethanol concentration increased from 1,791 at COD of 5.33 g/L to 7,219 mg/L at COD of 28.1 mg/L. Butyrate was the main acidogenic product. Other important products were acetate, valerate, caproate, and ethanol. Percentages of propionate and i-butyrate were less than 5 percent. A mixed type, butyrate-type fermentation was dominant.

Kinetic analysis on $H_2$ production in the granule-based UASB reactor gave kinetic parameters such as yield. We compared the yield of the $H_2$-producing granules with that of the flocs. In this study the granule sludge yield is around 0.334 g-VSS/g-COD, higher than that of flocs. At the present time we have little idea of the reason for this difference.

### Characteristics of $H_2$-producing Granules

The H2-producing granules were in the range of 1.0 to 3.5mm with around 1.06 g/mL. The settling velocity was high, around 32 to 75 m/h. The ash content was about 11 percent, and the granules were yellow in color. Some of the granules were broken into pieces. These are not typical of methane-producing granules, which are normally very black; the $H_2$-producing granules are yellow.

After the formation of the $H_2$-producing granules we tried to characterize the physical and chemical properties of the granules including settling ability, permeability, porosity, strength,




stability, extra-cellular polymeric substances (EPS) interactions, and modeling. In many ways, investigations into $H_2$ require multiple approaches: biological, physical, mathematical, chemical, and even imaging.

For a spherical and impermeable particle, its settling velocity can be described by Stokes' law. The actual settling velocity of a granule in a solution is U. If U is equal to Us we can say the granule is impermeable. But if U is great than $U_s$, this indicates that the granule is permeable. We performed a very simple experiment using Stokes' law, and the experimental results generally show that $H_2$-producing granulations had a settling velocity in the range of 32 to 75 m/h in water. Comparison between the measured and calculated settling velocity indicates the granules were permeable, but such a difference is not significant. In other words the settling velocity of the granules was only slightly greater than predicated with Stokes' law. This means there was little advective flow through the granules' interior.

We performed the settling experiments not only in water but also in sodium chloride solution and EDTA solution. We compared the settling velocities in the denser solution and the water. The ratios of the settling velocities in the denser solution and the water are larger than theoretical predictions about the rapid completion of mass transfer throughout the granules. This indicates a certain amount of water was enclosed and remained in the pores of the granules. This resulted in a slower settling velocity in the denser liquid than predicted. We also compared the ratios of settling velocity in water, sodium chloride, and EDTA solutions. We found that molecular diffusion plays an important role in the mass transfer through the $H_2$-producing granules.

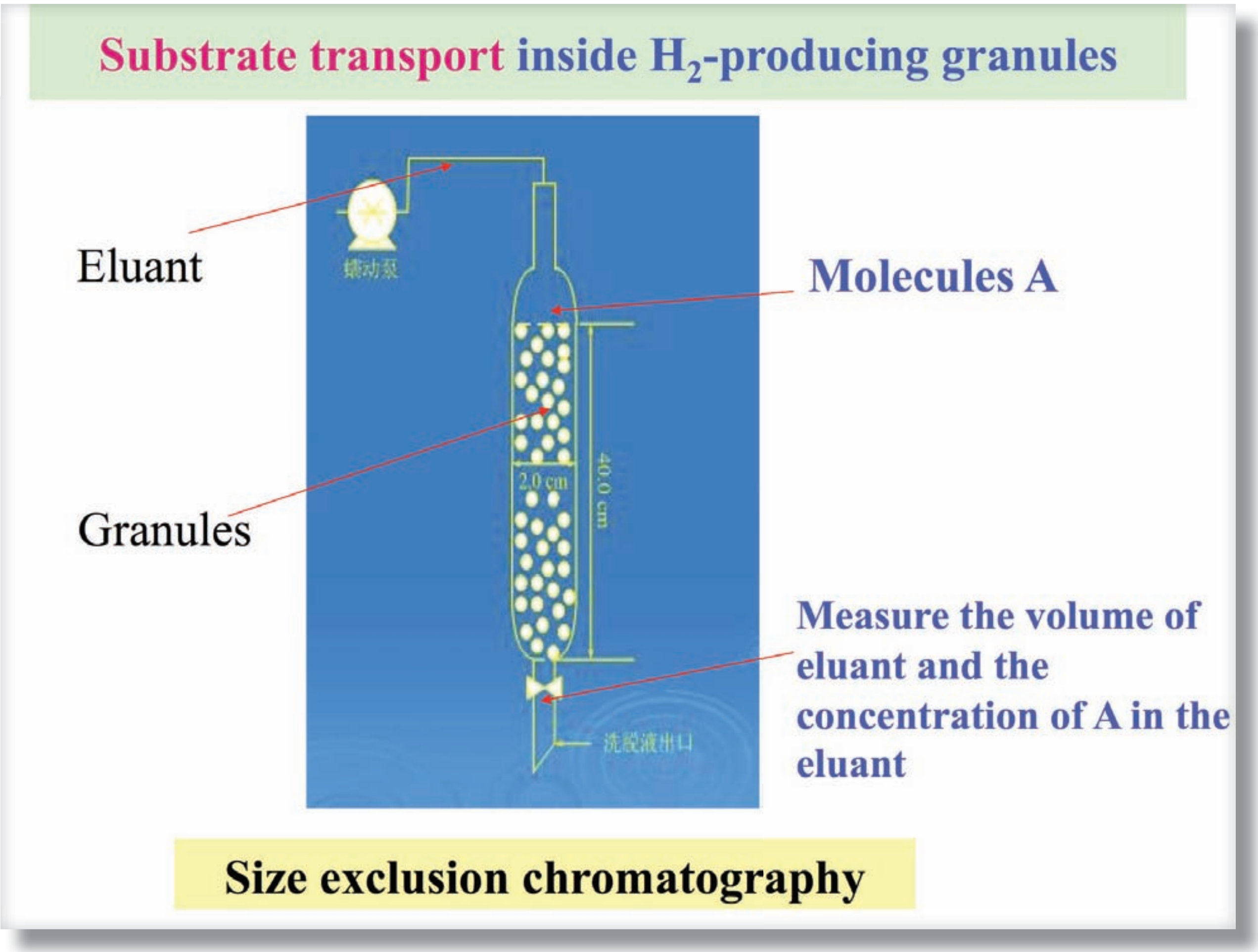
We also tried to estimate substrate transport inside $H_2$-producing granules. In a very simple experiment using size exclusion chromatography, we packed a column with $H_2$-producing granules and found its working principles were very similar to gel permeation chromatography (GPC). We introduced molecules A with a different molecule weight. The eluant was pumped into the column, and as it exited the column we measured the volume of eluant and the concentration of A.

We also calculated the partition coefficient (Kav). This index indicates the porosity of granules with different diameters. Finally we used the exclusion limit as molecular weight (Da), indicating the pore size of granules. The granule pore size was in a wide range and was less than 40,000 Da. We found the pore size of the hydrogen-producing granules generally decreased with increasing size and their porosity decreased with the increase in size.

With the porosity and permeability concept in mind, we also tried to estimate the drag coefficient of the granules. The settling velocity of the granules is greatly related to the drag coefficient. We established a new approach taking into account the porosity and permeability in order to evaluate the drag coefficient of granules. We found their drag coefficient was heavily dependent on their porosity and permeability.

When we talk about $H_2$-producing granules we have to mention the EPS, the higher molecular substances outside of cells. They could be excreted by the microorganisms themselves, or produced from cell lysis and hydrolysis, or adsorbed from waste water. They have three major components including proteins, polylsaccharides, and humic substances.

EPS have been found to be a very important factor in the function of microbial aggregates, including the formation of microbial granules. We calculated the surface dynamics and tried to establish a relationship between the EPS concentration and the cell surface characteristics. We also tried to characterize the EPS of granules using three dimensional excitation emission fluorescence spectroscopy and Zeta potential. Using these




techniques, we identified three peaks. Peaks one and two are attributed to the protein-like substances but the third peak was likely to be related to humic substances.

In our lab, we have also established a multiplayer model for biogranule structure. In the outer layer, dispersible particles were surrounded by some readily extracted EPSs. The particles were loosely bound and entirely dispersible under a high shear. In the inner layer, some non-dispersible particles were surrounded by not readily extracted EPSs. They were tightly bound and had no effect on granule stability. The contents of dispersible particles and readily extracted EPSs depend on the granule characteristics.

This work was supported by the National Natural Science Foundation, Chinese Academy of Sciences and the Ministry of Science and Technology.

# A MEC and MFC-coupled Biocatalyzed System for Hydrogen Production

**by Guo-Ping Sheng**

**Dr. Guo-Ping Sheng** *is an associate professor in the Department of Chemistry at the University of Science and Technology of China.*

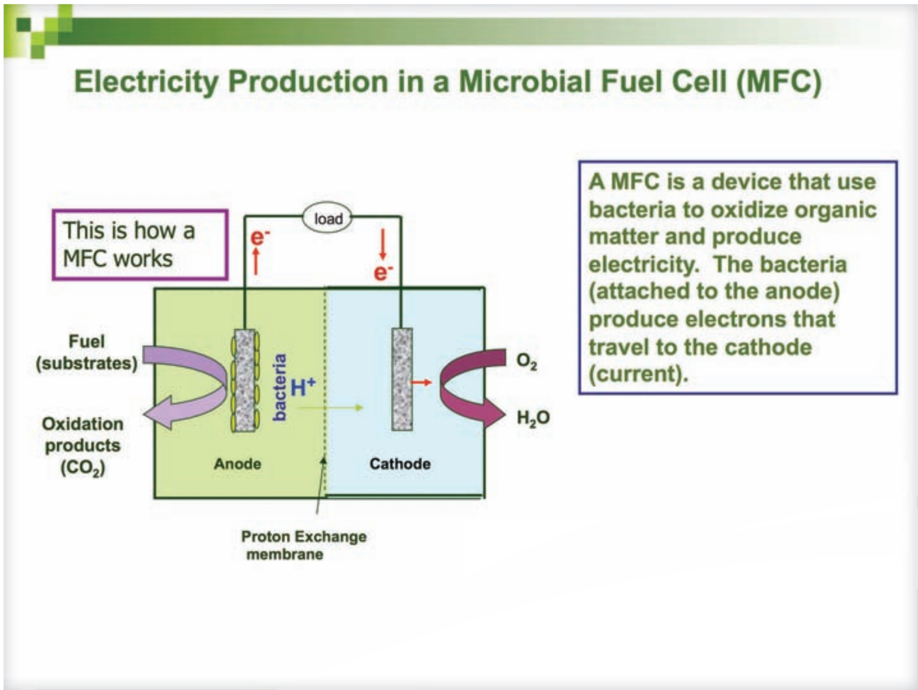
Microbial fuel cells (MFCs) are devices that use bacteria as the catalysts to oxidize organic and inorganic matter and generate current, whereas microbial electrolysis cells (MECs) are reactors for biohydrogen production using an extra power, about 0.6 volts.

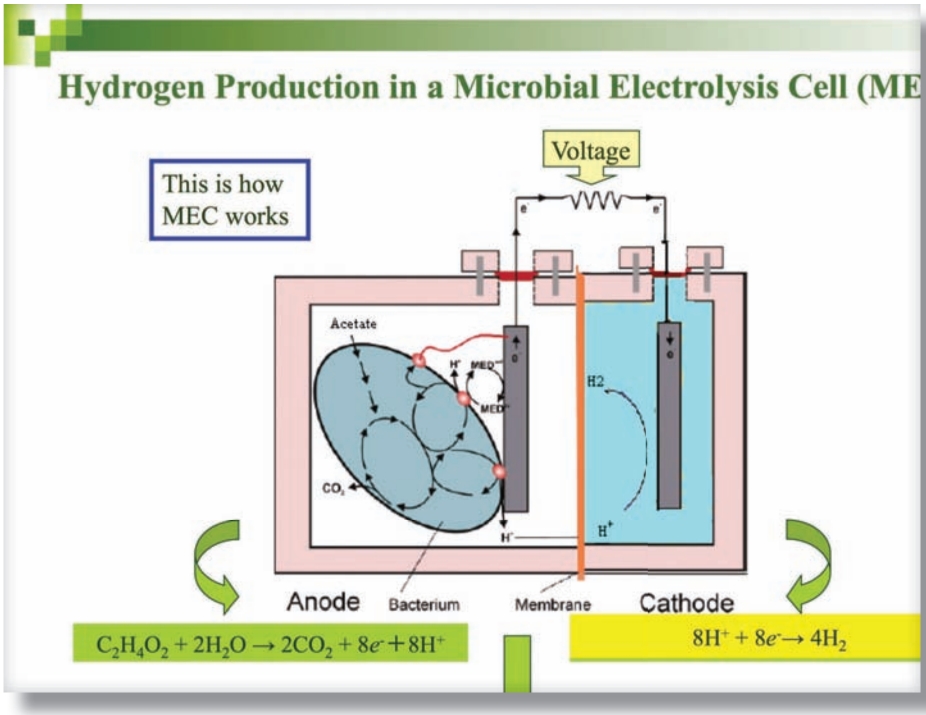
The MFC uses bacteria to oxidize organic matter and produce electricity. The battery, attached to the anode, produces electrons that travel to the cathode. The development of MEC by Professor Logan has expanded the application of MFCs. The exoelectrogens in the anode chamber catalyze the oxidation of organic substances to carbon dioxide via several metabolic reactions. Electrons from these reactions travel through an external circuit and combine with protons migrating through the proton exchange membrane to form hydrogen on the cathode

In an MEC, an external voltage must be applied to overcome the thermodynamic barrier. Hydrogen can be produced from various substrates, including glucose, cellulose, acetic acid, butyric acid, lactic acid, propionic acid, and valeric acid.

The objective of our research was to reduce the cost of the external power necessary to operate the MEC. The output voltage of an MFC could achieve 0.6 V and was deemed a good substitute as a power supply. The MEC-MFC-coupled biocatalyzed system was configured by combining the MEC and MFC, in which hydrogen was produced in a hydrogen-producing MEC and the extra power was supplied by an electricity-assisting MFC. The advantage of this system is the *in-situ* utilization of the electric energy of the related MEC/MFC as well as hydrogen production without an external power supply.

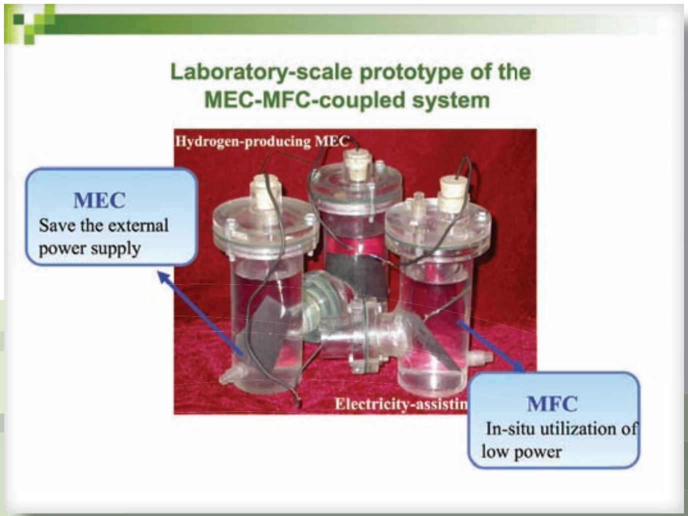
Hydrogen production was elevated by increasing the phosphate buffer concentration. At 10 mM of phosphate buffer, the cathodic hydrogen recovery ($R_{H2}$) and systemic coulombic efficiency (CE) were 88-96 percent and 28-33 percent respectively, and the overall systemic hydrogen yield ($Y_{H2}$) peaked at 1.21






mol-$H_2$ mol-acetate-1. Hydrogen production in the MEC-MFC-coupled system was manipulated by the power input on the MEC. $RH_2$, CE, and $Y_{H2}$ decreased with the increase in the loading resistance, and increased with the increase in the MFC output voltage. When the cathode electrode was coated with phosphate, the $H_2$ producing rate increased six times.

To further improve the power supply for hydrogen production, other MFCs were introduced into the coupled system in series or in parallel connections. When the MFCs were connected in series, hydrogen production was significantly enhanced. In comparison, the parallel connection slightly decreased the hydrogen production.




The MEC-MFC-coupled system has a potential for biohydrogen production from wastes, and provides an effective way for in-situ utilization of the power generated from MFCs. Connecting several MFCs in series can effectively increase power supply for hydrogen production, and has the potential to be used as an enhanced hydrogen production strategy in the MEC-MFC-coupled system.

Reference

M Sun, GP Sheng, et al. 2008. An MEC-MFC-Coupled System for Biohydrogen Production from Acetate. Environmental Science and Technology 42, 8095-8100.

## China-US Cooperation on Bioenergy R&D s

**by Keith Kline, Jorge Sanchez, and William Wallace**

**Keith Kline** *is a research staff member in the Environmental Sciences Division of Oak Ridge National Laboratory,* **Jorge Sanchez** *is a U.S. Department of Agriculture Foreign Agricultural Service Officer in Beijing, and* **Dr. William Wallace** *is a staff member at the National Renewable Energy Laboratory, U.S. Department of Energy.*

**Keith Kline**

The current US-China Agriculture, Science and Technology Protocol has evolved from a long history of close scientific collaboration between American and Chinese colleagues. The Protocol was renewed in 2007 by the U.S. Department of Agriculture (USDA) and China's Ministry of Science and Technology (MOST). Under this Protocol, a joint working group promotes exchanges related to agriculture, natural resources, and bio-products, including biofuels. Of the many cooperative ventures involved in this exchange, agricultural biotechnology, natural resources management, biofuels R&D, and water saving agricultural technology are relevant to biofuels production.

One way the agreement promotes collaborative research is through what is termed virtual laboratories, connecting researchers in both nations through the Internet to work together on common research topics and experiments such as ecosystem management issues, erosion, soil and water conservation, plant genetic resources, and bioenergy topics.

As an example of collaboration in the realm of bioenergy research, USDA and MOST recently agreed to work with Tsinghua University's Institute of New Energy Technology to create a Sino-U.S. Biofuels Research Center. The Center is developing joint research proposals including a project to study the potential for ethanol production from sweet sorghum stalks—"sorganol."

In December 2007, a China-U.S. Biofuels Cooperation Memorandum of Understanding (MOU) was signed between the U.S. Department of Energy (DOE), the USDA, and China's National Development and Reform Commission (NDRC) focusing on biofuels and sustainability. The MOU facilitates collaboration on scientific, technical, and policy aspects of biofuels development, production, and use. Sustainability, conversion technologies, bio-based products, and rural development strategies are high priorities. This MOU provides a framework under which we initially have identified about 40 or 50 potential project areas for collaborative research. The parties are in the process of prioritizing the most promising areas of research to select a few areas of initial focus.

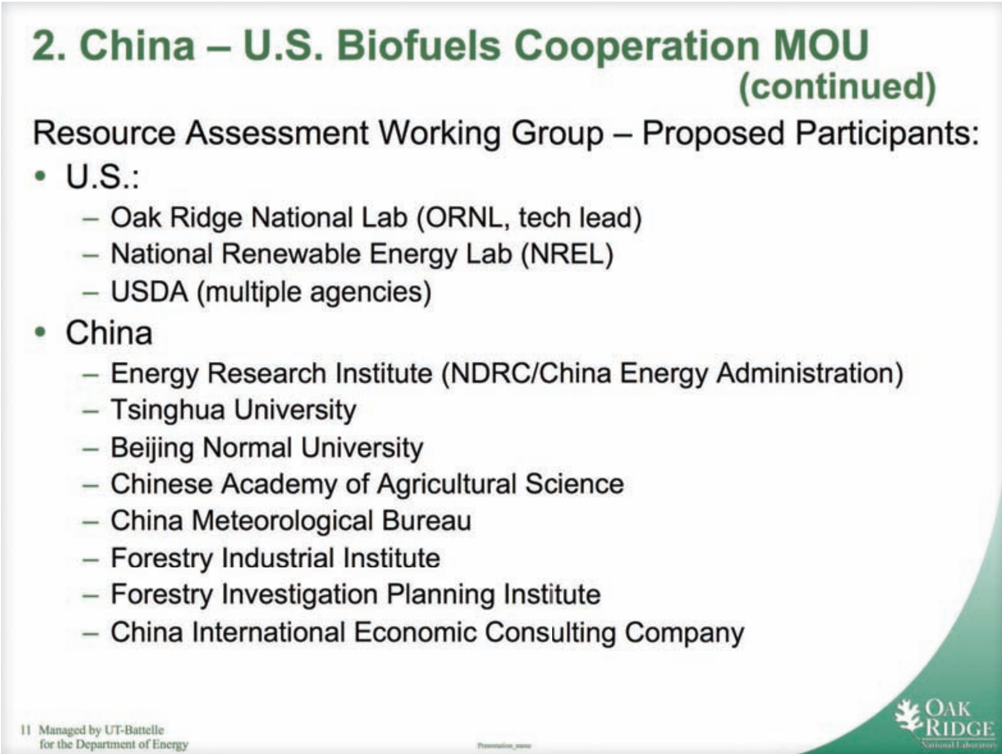
One of the first priorities that both sides agreed upon is a proposed collaboration to develop an improved biomass resource assessment methodology. Draft proposals, including objectives, results, and preliminary work plans, were exchanged and comments shared, leading to the first working group meeting and subsequent steps for the resource assessment collaboration. We hope this activity will help pave the way for similar collaborative activities on other bioenergy topics under the MOU. The biomass resource assessment methodology proposal integrates two topics from the China-U.S. priority matrix, one on analyzing resource potential and one on exchanging and applying software tools, GIS, and remote sensing technologies. It also incorporates sustainability issues that affect potential resource availability. Though this is in at an early planning stage, the productive discussions held thus far suggest that sustainability needs to be part of any resource assessment.

The defined resource assessment objectives are to "assist China to develop a biomass resource assessment methodology that meets local planning and rural development requirements; exchange experiences, knowledge and tools that support crop resource assessment and analytical projections of future supplies (including examples of remote sensing and economic modeling); and integrate sustainability as appropriate throughout the process."

The proposed U.S. participants in the Resource Assessment Working Group include Oak Ridge National Laboratory (ORNL), the DOE's National Renewable Energy Laboratory (NREL), and USDA. ORNL was named the lead for facilitating the biomass resource assessment. NREL is the lead lab for coordinating the overall agreement and communications for this MOU. USDA will be participating in most of the topic areas under this agreement.

The NDRC proposed several potential Chinese participants representing the forestry sector, the agricultural sector, the academic sector, and renewable energy expertise. This is important in order to pull in the data and resources necessary to perform a truly comprehensive biomass resource assessment.

Specific goals in the draft collaborative plan include 1) fostering exchanges to assess approaches, data availability, and methodologies; 2) providing assistance in establishing a framework to support national biomass production estimates and planning; 3) establishing a pilot area to test methodologies; 4) building




institutional capacity on models, tools, and approaches; and 5) preparing recommendations for a national biomass resource assessment methodology.

In addition to the resource assessment methodology, several other areas are contemplated under the MOU. One of the proposed research objectives in biochemical feedstock conversion is the characterization of advanced solid state fermentation processes for sweet sorghum conversion to ethanol, the characterization of promising fermentation organisms, and joint technology development for sweet sorghum and lignocellulosic conversion processes. A Biochemical Feedstock Conversion Working Group has been proposed to include U.S. representatives from NREL, the USDA National Center for Agricultural Utilization Research, and U.S. universities; and Chinese participants from Tsinghua University's Institute of New Energy Technology and the Joint US-Sino Center for Biofuel Research, and private companies such as the Tianguan Group and the Fengyuan Group, and other institutions.

Thermal chemical feedstock conversion is another area we are poised to move ahead on. The proposed working group is exploring pyrolysis of biomass and syngas conversion to mixed alcohols. This task area also considers environmental issues and cleanup, catalyst development and conversion optimization, and processes that are more efficient with less environmental impact. Other issues include fuel specifications and combustion studies—how the products from these processes are used and what the impact is in motors and engines. A proposed U.S. participant is the Pacific Northwest National Lab, one of ORNL's sister labs in DOE. Chinese participants may include the New Energy Engineering Center of Chinese National Offshore Oil Corporation, Sichuan University, and other companies and institutions.

Life cycle assessment (LCA) is also included in this MOU. The agreement seeks to promote synergy and opportunities to make more connections among people performing LCA in the United States and China. The scope is not yet final, but the Biofuels Sustainability and LCA Working Group could use LCA to help determine environmental, economic, and social impacts of biofuels development, and to evaluate the conversion process. Proposed U.S. participants are DOE's Argonne National Laboratory, ORNL, NREL, and USDA. Participants from China may include China International Economic Consulting Company of the NDRC, the National Petroleum Company and Sinopec, and Tsinghua University.

In addition to the mechanisms for collaboration involving USDA and DOE mentioned above, many other China-U.S. relationships are relevant to bioenergy. The U.S. Department of State and the Asia-Pacific Partnership for Clean Development and Climate are negotiating collaborative public/private partnerships involving research, development, and application for renewable energy, biomass resource assessment, sustainable quality assurance, and land reclamation. The working group of the U.S.-China Joint Commission on Commerce and Trade, with the U.S. Environmental Protection Agency as a co-chair, is working on a U.S.-China Environmental Industries Forum that will link U.S. and Chinese representatives for the deployment of environmental technologies, especially technologies that increase efficiency and help control contamination.

### Why Collaborate?

Having mentioned a number of mechanisms for collaboration, it is worth mentioning that perhaps the most relevant area of collaboration is exemplified by those attending this workshop, Bioenergy Consequences for Global Environmental Change. The dialogue taking place among participants offers living proof that the spirit of collaboration between our two countries is very strong indeed.

The United States and China have many similar policy goals and objectives in terms of increasing our energy security without compromising food security. We have an interest in seeing cellulosic or other nonfood resources provide some of the increase in liquid fuels. We also face similar constraints in terms of land, water, technology, and the environment. Collaboration makes sense when you have common goals and common constraints. Scale is also important. To make a real difference in the world, not just in our own back yards, but on the global scale, we need to begin with major contributors to greenhouse gases such as China and the United States.

Another incentive to collaborate is to develop common understandings of plans and impacts. Research process, reports, and data can be easily misinterpreted if there is not sufficient cooperation and understanding to provide a basis for comparison. The MOU for bioenergy includes the goal of sharing better information so that when numbers are compared, or you see a pie chart on the wall, you understand what they mean. Without a collaborative networking relationship, misunderstandings will be more likely to arise.

The results from an informal survey elicited many interesting comments from workshop participants in response to the question "Why collaborate?" Here are a few examples:

- Collaboration exposes the next generation to international issues.
- It builds common frameworks to understand problems and build consensus on solutions.
- We make friends and learn something new.
- It provides messages on scientific progress that can help resolve food/fuel conflicts.
- For a bright future
- To share advanced ideas on science and technology and learning opportunities

We have a mutual interest in facing common challenges such as climate change and environmental protection. As I drove around Beijing, I saw the billboards for "One World" (Beijing Olympics) everywhere. It is a great idea, a beautiful concept. Beijing is a beautiful city and China is beautiful country.

Energy security, water, climate change, food production, trade… in today's new economy these are all interrelated; they are interconnected. The United States and China are perhaps the players that have the biggest impact globally. This makes collaboration between these two nations all the more important because, in short, collaboration  builds relationships and trust, and these are foundations for all else that follows.

# What is the Benefit of China-U.S. Collaboration?

*An Informal Survey conducted during the workshop by Keith Kline*

China - US

## China-US collaboration is important because…

*The United States is the largest developed economy and China the largest developing economy, with global impacts and common interests.*

*It is most important for China, the United States and the rest of the world to develop sustainable supplies of renewable energy, and address environmental issues.*

*The workshop provided timely messages on scientific progress. This will help to resolve food-fuel conflicts.*

*It leverages capabilities for research programs.*

*Anything we can do to reduce emissions for the United States and China makes a tremendous contribution to global welfare, for all humankind.*

*The workshop is direct. Working through the government-government process is very slow and difficult. Given the problems in the world today, it is important to establish links through which we can quickly share new research and technologies.*

*It offers a "Bright Future." Even my father, a farmer, cares about this, because everyone wants a better day tomorrow.*

*It exposes the next generation to international issues. We need peace before we can join in research.*

*It allows participants to develop common frameworks for understanding problems and for building consensus on goals and approaches, and to develop productive solutions to mutual challenges such as climate change and sustainable development.*

*We shared advanced ideas on science and technology and learned of opportunities for students and researchers in both nations.*

*The workshop provided a better understanding of each other's culture, education, and research systems, and improves capacity on technical issues important for China.*

*China's economy and energy consumption are growing very fast, so U.S. technology and experience are very important to improve efficiency and reduce emissions. Resources for collaboration may be available since this topic is a priority for the government.*

*Problems of sustainability and climate change are global. The United States and China are essential actors when it comes to greenhouse gas emissions and how they can be reduced.*

*There is a symbiotic relationship offering great mutual benefits.*

*Expanding our understanding of values, beliefs, histories, policies, and technologies will promote development in both countries and benefit the world.*

**It builds friendship and trust, essential foundations for everything else.**

*Sponsored by*

*US National Science Foundation*
*Natural Science Foundation of China*
*Chinese Academy of Sciences*