Bioenergy Production and Sustainability:

Environmental Aspects

中美

CHINA • US

Joint
Research Center
for Ecosystem and
Environmental Change

Bioenergy Production and Sustainability:

Environmental Aspects

SEPTEMBER 9–12, 2007
THE UNIVERSITY OF TENNESSEE, KNOXVILLE

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

As the largest consumers of energy in the world, China and the United States are grappling with the thorny issues surrounding conversion from a finite energy resource based on fossil fuels to a more Earth-friendly paradigm. The production of bioenergy is a first step in gaining independence from coal and petroleum. Bioenergy is also one of the most high-profile and problematic environmental questions our generation will ever face. Our decisions today on global environmental health will have repercussions for many decades to come. We are, in fact, on the verge of a trajectory that may be irreversible, and one that has global environmental repercussions. Global problems require international solutions.

Informal conversations and unofficial collaborations with our colleagues in China have been ongoing for more than a decade and recently culminated in the formation of a joint research center between experts here and experts in Beijing: the China-U.S. Joint Research Center for Ecosystem and Environmental Change. In 2006, Chinese and American scientists signed a framework accord in Beijing to launch this initiative, and in September 2007 the first international workshop was held at the University of Tennessee's (UT) Conference Center in Knoxville.

We have gathered together in this publication the presentations from the workshop by researchers from the Chinese Academy of Sciences (CAS), Oak Ridge National Laboratory (ORNL) the University of Tennessee (UT), the National Science Foundation, and other research institutions.

The Chinese delegation also included members from the Ministry of Science and Technology of China and the Science and Technology Infrastructure Center. Their presence at the workshop was a guarantee of the sustainability of the China-U.S. Joint Research Center.

The three-day workshop, "The Environmental Aspects of Bioenergy Production and Sustainability," was hosted by UT's Institute for a Secure and Sustainable Environment (ISSE) and ORNL and attended by nearly 45 American participants and more than 15 Chinese delegates.

Existing partnerships between UT and ORNL have already born fruit in the recent establishment of two bioenergy and biofuels initiatives, one funded by the U.S. Department of Energy—the Bioenergy Science Center at ORNL—and the Tennessee Biofuels Initiative funded by the state of Tennessee. Our Chinese colleagues from research arms of the CAS, including the Research Center for Eco-Environmental Sciences and the Institute of Geographical Sciences and Natural Resources Research center, brought their expertise to this meeting.

The workshop was organized around three priority objectives. The first was to gain perspective on current advances in biotechnology and to address the sustainability aspects of bioenergy production, including the technical challenges of converting biomass to energy, advances in plant genomics that may make biomass production sustainable, and the potential of bioenergy production in China's terrestrial ecosystem. Second, we outlined the potential impact of bioenergy on our ecological and environmental systems, including unintended adverse consequences of biomass production. Third, we explored the avenues of developing China and U.S. joint research programs and addressed the importance of collaboration as our countries transition to new sources of energy. In 2008, we will conduct a second workshop in Beijing to further explore the possibilities of cooperation.

In this country we have very aggressive goals to displace fossil-based transportation fuels with bio-based transportation fuels. With the current, primarily corn-based production of ethanol as a first generation fuel, it is apparent that we are soon going to reach maximum capacity, in fact probably within a year or two.

We must, therefore, consider other sources of biomass, such as lignocellulosic feedstocks. This is the purpose of both the federal investment in the Bioenergy Science Center and of investment by the state of Tennessee in the biofuels initiative. A confluence of factors will position this area, particularly East Tennessee, as a major player in bioenergy research and development.

On the global scale, if lignocellulosic bioconversion advances to the point where it becomes an efficient technology for fuels and feedstock production, the implications with respect to land management could be enormous. In order to reach the capacity needed for liquid fuels in this country as well as the rest of the world, literally millions of acres of previously unusable farm land, marginal lands, or even agricultural lands will go into production for lignocellulosic biomass.

China is rapidly becoming the world's dominant economy, and utilization of energy there is mushrooming. The country is evolving from an agricultural society to an urban and industrialized society. Increased utilization of natural resources there could negate anything that is done in the United States or Western Europe with respect to carbon policies. Of course, bioenergy is not new to China. Farmers have traditionally used biomass to fertilize the land and as fuel for heating and cooking. In modern terms, however, bioenergy means the industrial production of biofuels. For China, this is a major transformation from the pre-industrial period when biomass was burned to produce energy, causing serious environmental problems because of a shortage of energy in the countryside.

The way we approach these research topics, not only in this group but in research groups worldwide, will perhaps become the benchmark for what biology, environmental science, and technology achieve over the next 100 years. Carbon neutral technologies may ensure the future of life on Earth and the maintenance of human existence.

As the United States advances, we need to develop research opportunities that help us advance in step with Chinese and other Asian societies. As we move forward in this partnership, we hope our Chinese colleagues will continue to share their understanding of the situation. This workshop was a first step in developing a cohesive international collaboration.

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

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

Jie (Joe) Zhuang, research director
Institute for a Secure and Sustainable Environment and Center for Environmental Biotechnology, UT

Researchers from the Chinese Academy of Sciences enjoy a pre-workshop hike to Abrams Falls in the Great Smoky Mountains National Park. ISSE Research Professor Jie (Joe) Zhuang (in foreground wearing glasses) helped organize the three-day workshop, which explored the environmental aspects of bioenergy production.

Table of Contents

Sustainable Bioenergy: Context, Challenges, and Opportunities
U.S. Energy Production and Consumption: The Role of Bioenergy
by Dr. Jerry Tuscan 6

Eco-environmental Impact of Bioenergy Production
by Dr. John Bickham 11

Conversion of Lignocellulose to Ethanol
by Dr. Brian Davison 17

Status of Bioenergy Development in China: An Overview
by Dr. Giu-Rui Yu. 20

China's Energy Demand and the Potential of Bioenergy Production in China's Terrestrial Ecosystem
by Dr. Ming Xu 23

The Tennessee Biofuels Initiative: A Model for Rural Economic Development and Experimental Sustainability
by Dr. Kelly Tiller 26

Biomass Energy from Complex Carbohydrates
by Dr. Jonathan Mielenz 29

Biofuel Crops: Unforeseen Consequences in Sustainability
by Dr. Daniel Simberloff 32

Current Research on Cellulosic Ethanol in China
by Dr. Guo-Qiang Zhuang 36

Landscape Design for Bioenergy Feedstocks
by Dr. Virginia Dale 38

Carbon Sequestration by Terrestrial Ecosystems and its Role in Biofuel Development in China
by Dr. Sheng-Gong Li 42

Urgent Requirements for Developing a Secure and Sustainable Environment
by Dr. Randall W. Gentry 45

Potential and Development Trends of Bioenergy in Southern China
by Dr. Shao-Qiang Wang. 48

Importance of Collaboration among Government, Academia, Industry, and Environmental Organizations
by Dr. Dennis Ojima. 51

Bioenergy Sustainability Activities at the National Science Foundation
by Dr. Bruce Hamilton 54

International Opportunities at the National Science Foundation
by Dr. Rick Nader 57

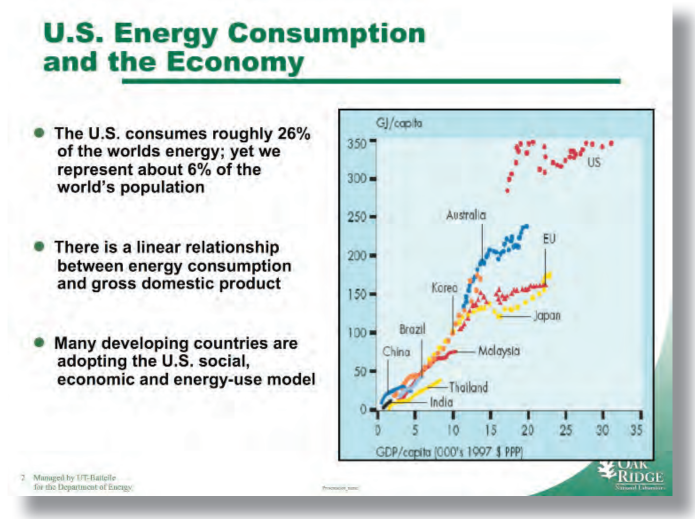
Sustainable Bioenergy: Context, Challenges and Opportunities U.S. Energy Production and Consumption: The Role of Bioenergy

by Dr. Jerry Tuskan

Dr. Jerry Tuskan, *a geneticist by training, is a distinguished scientist with the Environmental Sciences Division, Oak Ridge National Laboratory.*

In the 21st century, we have a societal and environmental need to rearrange our portfolio of energy supply. As our finite supply of fossil fuels dwindles, biomass and bioenergy provide possible solutions to the looming energy crisis. In the broader perspective, we need to consider the entire energy cycle, from the global atmosphere down to the farm, from the farm to the plant, from the plant to the gene, and from the gene back to the global atmosphere.

I have been working in bioenergy since 1978, when I was conducting research, funded by the U.S. Department of Energy (DOE), for my Master's degree on genetic variation in biomass equations. My current research is in the area of poplar genomics and how we can use genomics to help accelerate the domestication of these potential biomass species. This line of research will allow us to leverage the poplar genome to make advances in the production of biomass and transportation fuels from biomass.



Cheap Energy: A Way of Life

Our lifestyle in the United States is predicated on cheap energy. The clothes most of us are wearing today came from somewhere else. The fact that we are all sitting here in this room today exemplifies affordable energy. Many of you traveled halfway around the world to get here, just as many of us travel frequently across the country or the world. We cool our buildings to a comfortable 72° and in the winter heat them to a comfortable 78°. When we talk about changing our energy supply or production we are really talking about affecting the way we live. What we want to do is maintain our standard of living and still have affordable energy.

Worldwide, there is a linear correlation between energy consumption per capita and gross domestic product (GDP). The United States, with only 6 percent of the world's population, consumes 26 percent of all energy produced. We consume more energy than any other country, and our standard of living is high, as is our GDP. China has been near the bottom of the curve of GDP, but it is rapidly moving up the scale. On a global scale, many countries are adopting the U.S. model for economic development and production. This will affect energy supplies and global atmospheric chemistry over the next 50 years.

In the United States, as of 2005, we have four main sources of supply in our energy portfolio—coal, natural gas, crude oil, and nuclear—and we use about 104 quadrillion BTU's of energy annually. We export some energy, but most of our national consumption, about 70 percent, comes from domestic production. The other 30 percent comes from imports. Consumption of the energy supply is fairly equally divided among the residential, commercial, industrial, and transportation sectors. The renewable energy sector of the energy portfolio, in the form of wind, solar, biomass, and hydroelectric power production, is quite small, only about 6 percent.

Transportation Sector

About 98 percent of our consumption of energy in the transportation sector comes from petroleum. Renewable energy accounts for a mere 6.1 percent of transportation consumption. Why then should we look at renewable energy as a source of transportation fuel? The other sectors—industrial, residential, and commercial—consume a wide array of energy sources, while the transportation sector relies almost solely on petroleum. The petroleum supply, of course, is finite. It will run out at some point.

It has been said that we did not leave the Stone Age because we ran out of rocks. We left the Stone Age because we had better technology available. In other words, we need to look at improved technologies, technologies that have a more beneficial effect on our environment, before we reach the point of crisis.

Over the last 40 years, U.S. domestic crude oil production peaked in the mid 1970s at about 9 million barrels a day. That peak occurred when we brought offshore production online, with oil platforms mainly in the Gulf of Mexico. Steadily, since the mid 1970s, domestic oil production has decreased. There was a small uptick in the late 1980s when we brought the Alaskan oil fields online. Ever since, domestic production has been in a steady decline, and this trend will continue over time. Consumption is going up and domestic production is going down. So we are projected to increase our oil imports over the next 20 to 50 years.

Continuing with business as usual has serious economic, environmental, and national security consequences. Much of our oil comes from politically unstable regions of the world and from countries that don't particularly like us. We also have local domestic economic issues. Our agricultural sector is declining. International issues affect decisions on how we produce and consume energy. This relationship between our demand for cheap, affordable energy in the industrial, transportation, residential, and commercial sectors, and our own ability to produce energy, affects the way we live now and how we will live in the future.

The CO_2 Factor and Bioenergy

Over the past 40 years, we have been monitoring and measuring CO_2 in the atmosphere. Some say the relationship between the rise in energy production and the rise of CO_2 is coincidental, but it is fairly well established among distinguished scientists that the rise of CO_2 is due to our increasing consumption of quantities of fossil fuels, both petroleum and coal. With our limited energy supply and the large environmental impact of the United States on the global environment, we need to come up with an energy production scenario that hits the optimum targeted balance between fossil fuels and biomass in the transportation sector.

First, consider emissions. With only 6 percent of the world's population, the United States produces about one fourth of the world's CO_2. China, however, is catching up with us. In fact, in 2008 or early in 2009, China will exceed or surpass us in CO_2 emission. Russia, Japan, India, Germany, Canada, England, South Korea, and Italy's CO_2 production pales in comparison to what our two countries produce. Decisions made soon by the United States and China about the forms and types of energy we choose to consume and produce can have a large influence on world CO_2 emission.

How do we meet our multiple goals of reducing our need for imported oil, maintaining our standard of living, reducing our carbon emissions, preserving our energy security, and maintaining our reliance on affordable transportation fuels? One of the answers is closed-loop domestic production of lignocellulosic biofuels. This is true in the United States, and I believe it will be true in China as well.

The United States has a very small renewable energy portfolio, 6 percent. Solar power provides 1 percent of U.S. energy consumption production, and wood provides 3 percent. Most of that wood biomass, however, does not go to the transportation sector; it comes from the pulp and paper industry, which is basically self-sufficient in energy production and a net supplier of electricity to the grid. Most of this is in direct combustion or gasification during the production of byproducts from the pulp and paper process. Alcohol or liquid transportation fuels represent only 6 percent of the total renewable energy portfolio of 6 percent.

The Cart before the Horse

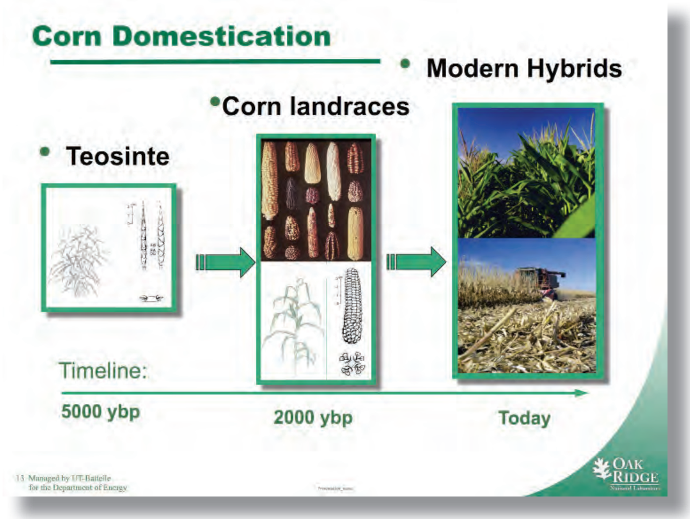
To help spur the development of alternative sources of transportation fuels, the U.S. Congress mandated the production of alternative fuel vehicles. A percentage of all fleet vehicles must be flex fuel vehicles that can switch between conventional fuel and alternative fuels. In 2004, 146,000 thousand vehicles in the United States were capable of burning ethanol as a transportation fuel. We have created a fleet of vehicles that can rely on ethanol in blends up to 85 percent, yet we consume very little ethanol in the transportation sector, 23 million gallons in 2004, compared to 451 million gallons of gasoline. We have a tremendous job in front of us if we are to change the way we supply our fleet vehicles with transportation fuels. We not only have to change this ratio, we also have to develop a source of cheap affordable feedstock that can be economically converted into transportation fuels.

In considering energy options, we have to choose our portfolio carefully. We have only a few options available. In the transportation sector, the only option readily available right now is biofuels. Nuclear, wind, hydrogen, solar, and possibly carbon-free hydrogen for transportation fuels is in the very distant future. That is not technology that we will see deployed over the next 10 to 15 years. The only current and long-term option for transportation fuels is biofuels from biomass.

We currently don't have a portfolio of biomass species or bioenergy crops available to use, but we think that there are species out there that could be suitable. In the United States, poplar is the leading candidate for woody biomass. Switchgrass and reed canary grass are other potential species for the production of feedstocks for the conversion to biofuels. These species—Populus, switchgrass, and reed canary grass—are non-domesticated wild perennial species. To accelerate the domestication process over the next five to 10 years we will need help from modern molecular biology.

Domestication of Maize

The ancient ancestor of corn, 5,000 years ago, was teosinte, a small herbaceous grass species with inedible seed heads and very low productivity. Native Americans, without the benefit of molecular genetics or an understanding of Mendelian inheritance, were able to select candidates, based on phenotype, out of this population and create what was called corn land races, commonly known as Indian Corn. The change was profound. It represented the fixation of a handful of genes that controlled the architecture and production of seeds from this wild relative.



It took the Europeans settlers until about the mid 1950s to make small, incremental changes. Since then we have applied modern breeding techniques and have been able to domesticate corn to the point where it is highly productive, 120 bushels of corn per acre per year, which is much higher than the yield from native land races of corn. One attribute of interest in the domestication of corn is a characteristic inherent in the wild plant. When the seed is mature, the seed head erupts and scatters the seed on the soil. That is known as shedding, or dehiscing. Dehiscing seed is very bad if you're an agronomist and you want to feed your family since you have to scrape all the seeds off the ground.

Modern corn not only does not dehisce; in fact, the sheath around the kernel never opens. The seeds are held tightly onto the cob.

This is something of a double-edged sword, however, at least for the survival of the plant. If some calamity wiped every human off the face of the planet today, corn would die tomorrow. It cannot propagate itself. It is completely domesticated, completely reliant on humans for its survival. Domesticated corn also has no lateral branching. All the biomass that was invested into lateral branching in wild teosinte is now put into the agronomic part. It is soft, so we can eat it, and it has a high yield per acre.

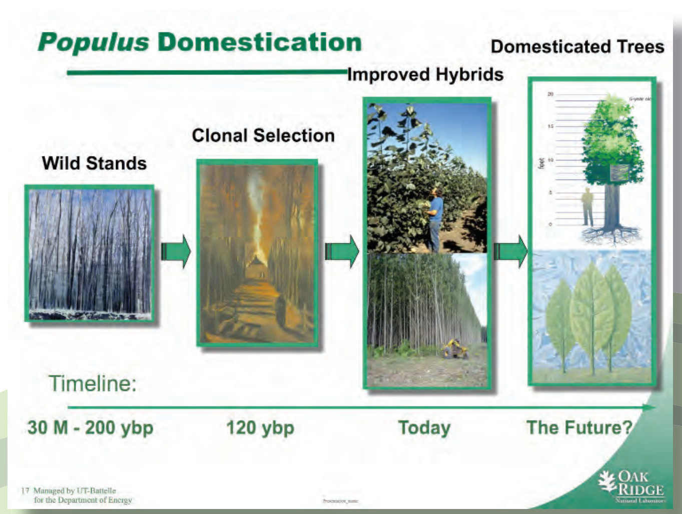
What makes poplar a better candidate for biofuel in the transportation sector than corn? First, poplar is the fastest growing deciduous tree in the temperate regions of the world, including the United States, China, and Europe. The genus covers a broad geographic range. There are native species in China and in the United States. It is perennial and clonal. The perennial trait is important when we consider displacing 20 percent of transportation fuels with biomass-derived ethanol. To meet that goal we must capture a significant portion of agronomic productivity on 20 to 40 million acres of land. We want to deploy this new crop in a way that does not have negative environmental consequences. Perennial crops have lower potential for erosion, lower chemical input, lower soil compaction. These are all aspects of agronomic environmental impact where perennial crops have positive beneficial attributes. In addition, Populus can be grown in plantations, and it grows rapidly.

Genetic Assets of *Populus*

Populus has a number of attributes that make it a good candidate for biomass. It has a small genome, a 485-million base pair. It has a short juvenile period, four years, so we can turn over generations rapidly. There are genetic resources in the forms of pedigrees, genetic maps, and bacterial artificial chromosome (BAC) libraries. We can turn genes on or we can turn genes off based on transformation systems. Moreover, the genome has been sequenced. We have the library of the 45,000 genes in poplar at our disposal on our computers, and we can begin to manipulate and examine how those genes affect productivity.

The process of domesticating poplar is pretty much the same anywhere in the World. Historical records of wild stands of poplar date to 30 million years ago. About 120 years ago Europeans began to domesticate it and plant cuttings from wild poplar along hedgerows.

We already have large poplar plantations here in the United States, China, and many other parts of the world. We have begun to apply modern improvement techniques, but only over the last 10 years or so. We have taken a wild, non-domesticated organism and modified it into clonally propagated, selected individuals. To raise and harvest a tree to five years, 80 feet tall, and 10 feet in diameter using conventional forestry is very expensive, however, about $70.00 per dry ton. Our goal is to



change the architecture of the plant and produce a tree in five years that is only 20 feet tall. It will not have the broad canopy, rather a very narrow crown. All the biomass that was invested in canopy production is now concentrated in the stem, which is where the lignocellulosic feedstock will come from.

This change in the architecture of the tree is important because of the relationship between cost and yield. The cost per dry ton and the tons produced per unit area of land per year follows a curve. As yield per acre increases, cost decreases, whether it's corn, soybeans, tomatoes, walnuts, pears, or poplars. With every generational genetic improvement, yield increases. Ultimately, yield reaches a plateau beyond which it is impossible to lower the cost despite improved yield because of the cost of adding additional nitrogen onto the site. The only way to cross that plateau is through the process of domestication, changing the architecture and the way the plant performs and grows. In other words, we may not actually increase the yield per unit area of land, but we can reduce the cost so that the productivity rises by redistributing the biomass into a harvestable portion. Even without changing the photosynthetic rate, the way the plant captures sunlight and converts it into sugars, we can substantially reduce the cost of biomass. Our target is to get the cost below $50.00 per ton, ideally in the range of $35.00 per dry ton.

Ironically, poplar, which may have a role to play today in national security, was enlisted by a famous French general with his own security concerns. When Napoleon was trying to conquer Europe, he had problems moving his armies in the wintertime because he could not see the roads for the snow. So he instructed his army engineers to design a method for determining where the roads were. His engineers came up with a system of taking poplar cuttings, dormant sticks, which you can drive in the ground. They rooted on their own and produced foliage. In the winter the trees lined the roads and helped Napoleon's armies identify where the gravel roads were and avoid bogging down in the muddy fields.

This project is funded by DOE's Bioenergy Sciences Center, Feedstocks for Bioenergy Project, and Carbon Sequestration Project, and by ORNL's Drought Tolerance Project. The goal is to genetically modify the poplar to produce compact root systems and crowns, reduce height growth, increase efficiency of nutrient inputs and yield per acre, and improve drought and stress tolerance. All these programs are open to international collaboration.

Genomics and Molecular Genetics

Traditionally, researchers looked at phylogenetic relationships between genes on a species level, comparing the genes in poplar and the genes in *Arabidopsis*, a genus that includes cabbage and mustard, to the genes in rice. Because we have sequenced the whole genome we can now look at the expansion of gene families and begin to understand how gene families have differentially expanded or contracted in the various organisms. We can ask how the gene complement that is contained in their genomes allowed those organisms to differentiate and how speciation occurred. With that information we can understand what makes a tree a tree and what makes rice rice.

With these questions answered, we can then target specific genes in poplar that relate to traits we are interested in. One of those traits is gender. Poplar is dioecious; that is, there are male and female poplar trees. Plant breeders want to select the fastest growing, best performing genotypes. As it turns out the majority of those selected superior genotypes are male. If you are doing advanced generation breeding, that puts the breeder in a very bad position. If all you have are male selections there is no next generation. Poplar does not flower until it is 12 to 15 years old. That makes it difficult too perform short rotation selection for a five year production scenario. Tong Min Yin at ORNL began looking at gender determination and found that gender was linked to chromosome 19 in poplar, so certain regions of the genome are unique to the maternal line and absent in the paternal line.

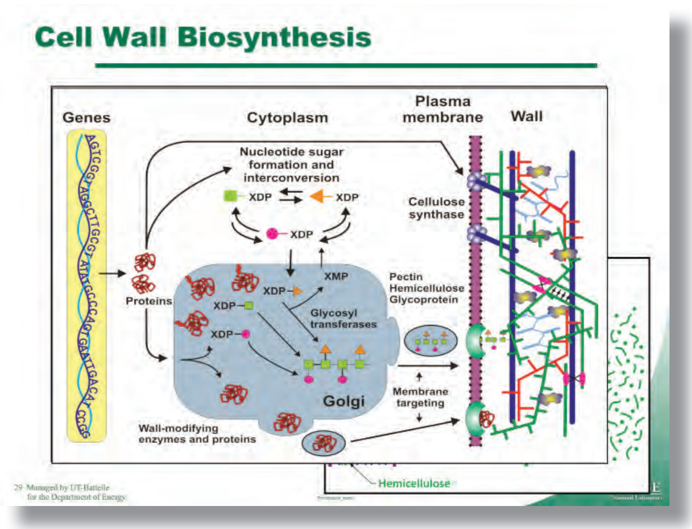
Some regions of the genome on chromosome 19 are shared between males and females, much like the X Y system we see in mammalian systems though this is actually a Z W system because the female is heterozygous. Differentiation of gender is associated with this chromosomal unit. Thanks to the sequencing of the genome, we now have a molecular marker that we can apply upon fertilization. When the pollen and egg cells come together we can begin selecting for gender. This is an example of how we use genomic information to advance selection and improvement.

Our team at ORNL has also begun applying bioinformatics techniques to look for conserved domains and protein prediction motifs. We found 66 genes that had known motifs but in unique combinations, indicating that these are bona fide genes. We then look for unknown motifs that were contained in 134 genes in poplar. It turns out that there were three unknown motifs conserved in these genes that were found in either rice or *Arabidopsis*. We then began looking at what those genes do using a technique called Real Time PCR. We found that some of them are localized to the cytoplasm in stems and leaves and roots. We have no idea what their function is, but we do know they are affecting tissues that we are very interested in. We want to understand how these genes influence the development of stems or roots, roots for carbon sequestration purposes, stems for biofuels purposes.

Biomass to Ethanol

The objective of the poplar team at the Bioenergy Sciences Center is to reduce recalcitrants in woody biomass, that is to make woody biomass more easily converted into ethanol. In order to deconstruct a cell wall, we need to understand how that cell wall is constructed. We do not really know how a cell wall is synthesized, though we do know what lignan is and we do understand the subcomponents of lignan biosynthesis.

We also understand the subcomponents of hemicellulose (polysaccharide) biosynthesis and we understand cellulose biosynthesis, but we are completely ignorant as to how this all happens in concert to derive and produce primary and secondary cell walls. We want to understand this process so that we can take lignocellulosic feedstock and pretreat it in a way that releases the sugars in an economically affordable manner so it can be converted into ethanol through fermentation.



Our main objective is to highlight, define, discover, and understand cell wall biosynthesis. Gene discovery involves a series of studies and steps—some of them gene discovery steps and some of them hypothesis testing steps. Ultimately we will be able to identify a gene and enter it into a transformation pipeline, determine how it affects the biomass, and ultimately determine how that biomass affects conversion of biomass to ethanol.

In summary, the United States consumes about 25 percent of the world's energy, and 85 percent of that consumption comes from fossil fuels. Our transportation sector is the most dependent upon fossil fuels and therefore the target for the development of biomass and renewable energy from biomass in the form of ethanol and other liquid transportation fuels. We think that short rotation poplar offers a plausible means for supplying biomass that is affordable and environmentally sustainable because we can apply modern molecular biology techniques to accelerate domestication, leverage the genes that are now on our computers, and develop a domesticated poplar tree that can be put into a conversion process to produce affordable ethanol and displace our requirements for petroleum in the future.

Eco-environmental Impact of Bioenergy Production

by Dr. John Bickham

Dr. John Bickham *is the director of the Center for the Environment and professor of Forestry and Natural Resources at Purdue University in West Lafayette, Indiana.*

The Center for the Environment (C4E) at Purdue University is one of 11 core centers in Discovery Park, a unique concept for promoting translational research. The role of the C4E is to facilitate large interdisciplinary proposals and projects and to promote new relationships among diverse faculty across Purdue's campus. The C4E, which has 138 faculty participants from 30 university departments, has invested approximately $1 million on 22 seed projects and other related activities.

Two projects funded through the center are particularly germane to the discussion of biofuels production. The first involves carbon sequestration in the Kankakee flood plain, a project headed by Dr. R. Grant of Purdue's Department of Agronomy. The Kankakee River rises in northwestern Indiana and is a tributary of the Illinois River. Kankakee soils are organically rich, and models have shown that these soils sequester significant amounts of carbon. In fact, the amount of carbon contained in these soils dwarfs all other existing carbon sinks in Indiana. This project explores how different agricultural and land-management systems can prevent the loss of carbon from these soils.

A second project, headed by Dr. G. Shao of Purdue's Department of Forestry and Natural Resources, studies carbon sequestration in Indiana forests. Although Indiana is in the heart of the Corn Belt, it also has extensive forest in the southern hilly, non-glaciated part of the state. This project integrates information on forest distribution and structure with climate and soil data to quantify and forecast carbon sequestration.

In addition to these projects, the C4E sets a high priority on promoting campus-wide environmental science and engineering educational programs. The next generation of environmental scientists and engineers is being trained at Purdue in programs like the Ecological Sciences and Engineering interdisciplinary graduate program (http://www.purdue.edu/dp/ese/).

Biofuels are attractive for economic, environmental, and strategic reasons. Reducing our dependency on foreign oil is a key national security issue. Positive environmental effects include reducing emissions of greenhouse gases and other pollutants. Production of biofuels also benefits the economy of rural America, as the money goes back into the pockets of farmers rather than offshore.

The United States derives biofuels from corn to produce ethanol, and soy beans to produce biodiesel. In some tropical countries, sugar cane is used to produce ethanol. Brazil has derived great economic benefit from sugar cane based biofuels and has largely freed itself from dependence on foreign oil. In addition, biodiesel can be derived from palm oil and other plants that grow well in tropical countries.

Although corn and soy beans are excellent sources of biofuels, cellulosic feedstocks clearly are the wave of the future. Poplar, switchgrass, *Miscanthus*, and even managed prairie ecosystems are potential sources of cellulosic biofuels. If we can solve the problems of effectively transforming this biomass into cellulosic ethanol or other fuels, there will be significant environmental gains in greenhouse gas reductions, for example, compared to feedstocks and processes currently available.

Notwithstanding that the environmental and economic effects of biofuels are generally perceived as positive; we should develop our biofuels economy with caution. There exist causes for concern that suggest we must take care in how we manage and develop our biofuels systems in order to ensure that society reaps the maximum benefits with the least risk to the environment.

Causes for Concern

There are currently (in 2008) six existing ethanol refineries in Indiana, six new refineries under construction, and plans for 16 more. Once the 12 plants, existing and under construction, are on line, they will produce 800 million gallons of ethanol per year and consume 300 million bushels of corn; roughly 30 percent of Indiana's crop. If the 16 planned refineries are built, then about 75 percent of Indiana's corn crop will be used to produce biofuels. The potential effect of this on food production would be enormous.

Another cause for concern is simply the scale of our consumption of fuel for transportation. If 100 percent of U.S. corn and soy bean production as it stands today were used to produce biofuels, it would produce only enough to replace 12 percent of gasoline and 6 percent of biodiesel based on current usage (Hill et al., 2006).

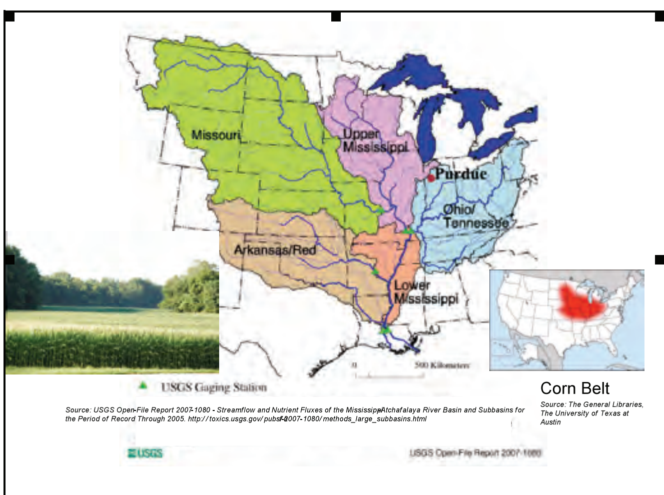
In addition, many of the anticipated environmental benefits will be partially offset by negative impacts, especially if corn is the main source of biofuel. If corn production significantly increases, the result will be more air pollution from the fossil fuels used in farming and transporting. In addition, some ethanol plants use approximately four gallons of water for every gallon of ethanol produced, so water usage will be an important issue in some states until better methods are developed (Keeney and Muller, 2006). As the prices of corn and soy beans rise, there will be pressure to use marginal lands and lands in conservation easements, resulting in a loss of wildlife habitat. And, corn ethanol produced in refineries powered with coal may result in a net increase in greenhouse gas emissions (DOE, 2007). To achieve our ultimate goal of reducing CO_2, we will need to make significant gains in more efficient use of energy and continue to pursue alternative energy sources such as wind and solar, as well as biofuels.

Fertilizer, Pesticides, and Emerging Diseases

Another concern is increased use of fertilizers, insecticides, and herbicides, which will further impair water quality. The Corn Belt is some of the most productive agricultural land in the United States, and a prime target for production of biofuels. The Corn Belt also overlays an area drained by several major tributaries to the Mississippi River, the largest river in the United States. This is the sewage system, if you will, that drains the agricultural heartland of the country. As the biofuels economy grows, there will likely be a need to rely on more intensive use of nitrogen and pesticides which will impact water quality.

In addition to changing agricultural practices related to biofuels, water quality faces an additional challenge. Emerging diseases affect not just public health, they can affect crop plants as well. Soy beans generally require fewer inputs such as fertilizers and pesticides than corn. Nevertheless, Indiana has about 700,000 acres of soy beans that are currently treated with fungicide. An emerging agricultural disease, Asian Soy Bean Rust is already present in the United States and has been detected in Indiana but not yet firmly established. According to Leighanne Hahn of the Office of the Indiana State Chemist, when Asian Soy Bean Rust becomes established, an estimated 5.5 million acres will be treated with fungicides in Indiana alone. The modeled concentrations of off site movement of 14 fungicide active ingredients allowed for control of Asian Soy Bean Rust predict several potential impacts of fungicide use. These impacts include exceeding lethal concentrations to aquatic organisms (fish and aquatic invertebrate species), reproductive effects to specific exposed bird species, and possible respiratory effects on bats depending upon the product applied. A nearly 8-fold increase in the application of pesticides would severely impact water quality in the rivers and streams of the Mississippi Drainage Area.

A hypoxic zone appears each year in the Gulf of Mexico. Thought to be the result of fertilizers from the Corn Belt that drain into the Mississippi River, it is decimating to fisheries in the Gulf and impacting the way of life of those who fish there. The projected increase in agricultural production necessary to satisfy our nation's demand for biofuel will put more pesticides and fertilizers into the Mississippi, reducing water quality and increasing the size of the anoxic zone in the Gulf of Mexico. This will directly subtract from the bottom line of the nation's economic and environmental profitability.



Maps showing the Midwestern Corn Belt and the sub-basins of the Mississippi River which drains it. Midwestern agricultural ecosystems are typically a mosaic of croplands, woodlots, wetlands and other natural areas as seen in the photo (Photo by J. W. Bickham).

Source: Map image produced by Birdnature.com

Photo credit: John W.

The Mississippi flyway is a migratory route for many species of birds, including raptors, waterfowl, and passerines. Many neotropical migrants, such as the Ruby Throated Hummingbird pictured here, cross the Gulf of Mexico on their way to the Yucatan Peninsula of Mexico.

Effects on Wildlife

Wildlife likely will suffer from increased crop production. The central flyway for migratory birds in North America follows the Mississippi River, which funnels migratory birds from Alaska, Canada, the Midwest, and the Great Plains into Louisiana and Texas. The woodlands and wetlands in this corridor represent important habitat for migratory birds including the neotropical migrants, many of which already are highly vulnerable due to deforestation throughout much of their nesting range.

How can we manage agricultural ecosystems to prevent these adverse effects? First, we have to change our perception of ecosystems. An ecosystem is not just a corn field or a woodlot. It is composed of a number of habitats which, altogether, provide invaluable services such as pollination, wildlife habitat, clean water, recreation, and food. Changing any one aspect of the agricultural ecosystem will have a domino effect on these services.

The Midwestern agricultural ecosystem, for example, is highly fragmented. Croplands are interspersed with riparian habitats—rivers and streams—woodlands, and other microhabitats to form a mosaic. This complex landscape provides insects and other pollinators, wetlands to purify the water, habitat for wildlife, and recreation, in addition to providing food. As the price of corn goes up, the value of those lands rises, and much of what is now wildlife habitat could be turned into cropland. Losing this valuable wildlife habitat has its own hidden cost in the loss of ecosystem services. In our deliberations about how to produce the energy crops we need, we must consider all aspects of changing this landscape.

Hummingbird on Life's Edge

*The Ruby-throated Hummingbird (*Archilochus colubris*) is a neotropical migrant common in the eastern United States. Hummingbirds are the most fantastic flyers in the avian world. Adapted for feeding on nectar, they fly up to a flower, and because their wings beat in a figure eight and extremely fast (50-75 beats per second), they can hover, flying forwards and backwards, like a tiny helicopter. They have the highest metabolic rate of any bird, and the nectar they eat is a high energy source. Their metabolic rate is so high that at times, instead of going to sleep at night, they go into torpor to save energy. Torpor is a reduction in their body temperature, metabolic rate, heart beat, etc. and is especially used in times of food shortage. This little bird migrates down the Mississippi Flyway and lands, as do many of the neotropical migrants, at High Island on the coast of Texas near Louisiana. High Island, well known to birdwatchers, is an important resting place before the hummingbirds must fly nonstop across the Gulf of Mexico to the Yucatan Peninsula, a trip of 600 miles. There is nowhere to rest along the way. This is just one example out of a myriad of species of neotropical migrants that do this. If these birds are stressed because of increased contaminants or lack of food, they won't make it. Hummingbirds live on the edge of survival, as do many other species. Changes in agricultural practices related to the biofuels economy could impact populations of neotropical migrants throughout the Corn Belt.*

Integrated Strategies

Best management practices for our changing agricultural landscape will require the development of integrated strategies, for which Purdue University has a number of unique capabilities. The role of the Water Quality Field Station (WQFS), established in 1993, is to test the impact of various farming practices on water quality. Led by Dr. Sylvie Brouder of the Department of Agronomy, the WQFS has gathered nearly 14 years of data on cropping treatments, particularly corn and soybean, as well as native prairie grasses. The instrumentation the WQFS has developed continuously measures weather and soil leachate in different micro-watersheds—hydrologically isolated plots—and periodically measures gas flux at the soil surface on a series of plots that can be manipulated for different treatments, crops, fertilization, pesticides, and harvesting practices. Each of these plots is large enough to be harvested using the mechanized equipment normally used to harvest corn fields and soybean fields. The flux of greenhouse gasses at the soil interface and the water that leaches out of the cropland are monitored over time. During a rain event, water flows through a series of tiled drains into a collection area and is subsequently tested for levels of nitrates, dissolved organic carbon, persistence of bacterial pathogens, and hormones and antibiotics from application of manure.

In 2007, the WQFS began to focus on a variety of biofuel production systems, monitoring plots of crops such as big bluestem, a low-input, native prairie grass; corn and soybean crops in rotation using recommended fertilizer rates; continuous corn cropping with and without removal of residue; and *Miscanthus* and switchgrass, all of which are proposed biofuels feedstocks. The aim is to measure water quality under different cropping systems. This facility is poised to determine the optimal crop rotation system and management practices for producing biofuels.

Purdue is one of the top three university centers in the world for systems engineers. In Discovery Park's Energy Center, a group called the Center for Energy Systems Analysis (CESA) takes a holistic approach to developing next generation energy systems. This includes exploring the overall process of converting from our current energy system based on coal and oil to the future scenario of energy based on biofuels, solar, wind, nuclear, and other systems. CESA estimates the energy conversion will cost the world $60-120 trillion, whereas the world's gross national product is only about $60 trillion. To make those changes, we will have to invest 1-2 years of the world's wealth, which is not possible in the short term. Changes will have to be phased in over time. Systems engineers are working on how best to optimize each step of this conversion. Working together, Discovery Park's Energy Center, C4E, and the Purdue Climate Change Research Center are striving to influence public policy on carbon management to help insure the development of environmentally sustainable energy sources.

Grand Challenges

The environmental challenges we face in converting to biofuels are daunting. How can we mitigate some of the adverse effects on climate change, biodiversity, forests, wildlife, and water and air quality?

As the price of corn and soybeans rises, more of our natural lands will be converted to managed systems for energy production. The United States currently has 14 million hectares (35 million acres) of land in a program called the Conservation Reserve Plan, which sequesters 48 million metric tons of CO_2. In 2010, however, contracts for about 11 million hectares (26 million acres) expire (Food & Water Watch, 2007). If the price of corn is high, much of those lands will revert from wildlife habitat to corn cropland.

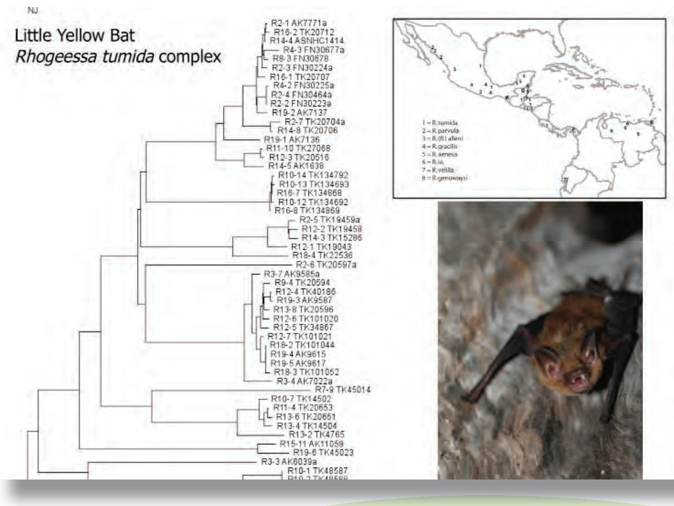
Conversion to cropland will contribute to deforestation, both in the United States and globally. According to 2005 estimates by the United Nation's Food and Agriculture Organization, deforestation is occurring at a world-wide rate of 13 million hectares (32 million acres) per year. Much of that is attributed to conventional agriculture, but biofuel cropping will exacerbate the deforestation problem (FAO, 2006).

Deforestation and crop conversion might also increase the rate of extinction of species. The current extinction rate is nearly 1,000 times the background rate and may reach as high as 10,000 times greater over the next century. There are about 1.6 million species of all organisms formally described by scientists, out of an estimated total of 7 to 10 million species. Most of the biodiversity of the planet has never been described. In fact, most species will never be known before going extinct. At the current rate of extinction, two thirds of all species will disappear in the next 100 years or so. This is an extinction rate the Earth has not experienced for approximately 65 million years, and the reason for the current rate is human impact on global ecosystems.

Recently, the first complete genome sequence of a tree, the black cottonwood, was described making this one of a handful of species for which such a database exists. It is a great step forward to have achieved this level of understanding for a tree with important biofuels implications. But it stands in stark contrast with our understanding of most of the world's species for which we don't even have a name. We have never seen many of them. Nonetheless, every species is of potential benefit to mankind, each a jewel in the crown of Earth.

Many of the areas experiencing high rates of deforestation are located within hotspots of biodiversity, including the Amazon forest, tropical West Africa, and tropical Southeast Asia. The biodiversity hotspots comprise 34 regions covering only 2.3 percent of the Earth's surface but holding 75 percent of the planet's biodiversity. In one of these hotspots, the Amazon, forests are being rapidly cleared for agriculture. In tropical Southeast Asia, many forested areas are being cut to produce palm nuts for biodiesel as well as food. From this, it is likely that the production of biofuels, particularly in the tropics, will increase the risk for loss of biodiversity through deforestation.

To illustrate how little we know about biodiversity and how much work remains to be done, consider the Little Yellow Bat, the smallest bat in the Western hemisphere. It weighs only about 3 grams and is the size of the end of your thumb. When I first started working on this bat about 35 years ago, it was considered a single species, *Rhogeessa tumida*. After a series of genetic studies, there are now eight described and at least two yet to be described species of Little Yellow Bats (Baird et al., 2008). Unlike most species of bats which are highly mobile, Little Yellow Bats don't migrate or disperse very far. Populations have developed genetic and chromosomal differences indicative of species distinction. We were able to determine by chromosomal and molecular genetic studies that there are 10 different lineages of this mammal, each a distinct biological species. The number of species of mammals, recently thought to number about 4,000, has apparently been underestimated by 25 to 50 percent. If the biodiversity of mammals is not yet well documented, imagine then the number species of soil fungi,



The Little Yellow Bat (*Rhogeessa tumida* complex) illustrates the need for continued bio-systematic studies to document biodiversity. Genetic studies in this complex have revealed hidden diversity and increased the number of recognized species 10-fold. The deep branches of the phylogenetic tree, based on mtDNA sequences (modified from Baird et al., 2008) are indicative of species with millions of years of genetic isolation.

rainforest insects, or any of the other obscure groups of organisms that remain to be identified. There is an enormous amount of work to do before we have an adequate inventory of the diversity of life on Earth.

But biodiversity is more than just lists of species, it is also genetic variability within species. In my lab, we are also engaged in studies using genetics to assist efforts at conservation. Since the early 1990s, I have studied Steller sea lions, sampling the animals throughout their range from central California to Alaska, across the Gulf of Alaska and Aleutian Island chain to the Sea of Okhotsk in Russia. We have sampled virtually every population of the species. This species breeds at rookeries, where skin biopsies are taken from the flippers of the pups. We have sequenced mitochondrial DNA (mtDNA) control regions from about 2,500 pups, making this one of the most detailed studies of population genetics for any wild mammal. Three distinct genetic stocks or populations have been identified. These stocks are best managed and conserved as separate entities. A precept guiding conservation biology is the need for preservation of genetic diversity because as genetic diversity declines, the probability of extinction rises. Clearly, conservation goals cannot be achieved without knowledge of the genetic diversity within a species, which is a fact well known to another management group with which I am involved, the International Whaling Commission (IWC).

My research has led me from the smallest of bats to one of the largest organisms on Earth, the Bowhead Whale, which weighs up to 60 tons. It summers in the northern Bering Sea and migrates into the Beaufort Sea, where it feeds along the Canadian eastern Beaufort Sea. In the fall it migrates back to its winter range in the Bering Sea. During the spring and fall migrations it is hunted by Alaskan Eskimo villagers. These communities depend on the bowhead whale as a major component of their subsistence diet. The bowhead hunt is thought to have occurred for the past 2,000 years., For anyone who hunts or fishes or has an interest in traditional Native American culture, this is a truly remarkable event that takes place in Barrow, Alaska, and other villages. The harvest of this Great Whale is regulated by the IWC. As a member of the US delegation to the scientific committee of the IWC, for the past six years my colleagues and I have been conducting an intensive study of the genetics of this population. The goal is to determine whether there are multiple genetic stocks within the population, which could change how these animals are managed and potentially the number of animals allocated to the hunt.

Our lab developed a dataset analyzed by scientists from four U.S. universities and government labs and by scientists from Japan and Norway. No evidence of any stock structure was found, so the quota was renewed for another five-year period after the 2007 IWC meeting. The IWC conducts such similar genetic studies on each species of Great Whale because the conservation of genetic diversity within species is recognized as a fundamental management goal by the organization. Ideally, not just whales but every species needs this kind of attention.

The Lesson from Indiana

Considering all aspects of biodiversity patterns, what can we infer about the future in Indiana or any place that will experience shifts in agricultural production toward biofuel? What are the prospects for protecting biodiversity? I cite Indiana because it is a key location in the central flyway of birds and is also home to other species at risk including many freshwater mollusks that are unique to the area and sensitive to water quality changes. Terrestrial habitats are already highly fragmented and disturbed in most areas.

Growing up in nearby Ohio, I recall reading that George Washington thought it was a most depressing place because he never saw the sun for the trees. At that time, unglaciated Ohio (and Indiana) was covered with virgin forests which have almost completely disappeared. Today the forest is mostly replaced by corn fields. I had no idea what George Washington was talking about until I had the opportunity to visit a virgin oak maple forest, Drew Woods in western Ohio. It was like no place I had ever been, with huge oak trees, many of them up to 300 years old. The biodiversity in that one small woodland exceeded that of anyplace with which I was familiar. I was studying salamanders at the time. Ohio has about half a dozen species of *Ambystoma* salamanders and the most one finds in typical habitats is one or two, whereas six species of this salamander were there in that small, six-hectare (15-acre) forest. Thus, this one small protected woodland preserves an impressive diversity of plants and animals and shows us today what our forests were like prior to the Midwest becoming the Corn Belt (http://www.darkecountyparks.org/pops/parks_drew.htm).

Today, in the Midwest, we are dealing with fragmented and largely disturbed wildlife habitats. Populations of flora and fauna that are still found there are vulnerable to further disturbance. As we convert our agricultural system for the production of bioenergy in hopes of maintaining our way of life, we must consider our responsibility to the environment and the organisms at risk of extinction from pollution, deforestation, and loss of habitat; known consequences of increased agricultural production. We must not overlook our environmental footprint on the largest and most appealing, or even the smallest and least charismatic, of Earth's organisms.

Notwithstanding the environmental issues and concerns raised here, I am optimistic about biofuels and the positive role that they will play in our future economy. Our ability to engineer more efficient refining techniques and develop better strains of corn as well as cellulosic crops will continue to shift the balance towards better environmental effects. At the same time, a clear understanding and dialogue of all the environmental effects of biofuels, positive and negative, is needed.

Literature Cited

Baird, A. B., D. M. Hillis, J. C. Patton and J. W. Bickham. 2008. Evolutionary history of the Genus *Rhogeessa* (Chiroptera:

Vespertilionidae) as revealed by mitochondrial DNA sequences. Journal of Mammalogy 89:744–754.

FAO. 2006 *Global Forest Resources Assessment 2005 – Progress towards sustainable forest management*. FAO Forestry Paper No. 147. Rome.

Food & Water Watch, Network for New Energy Choices, and Institute for Energy and the Environment at Vermont School of Law. 2007. The Rush to Ethanol: Not all Biofuels are Created Equal. www.newenergychoices.org/uploads/RushToEthanol-rep.pdf.

Hill, J., E, Nelson, D. Tillman, S. Polasky, and D. Tiffany. 2006 Enviornmental, economic, and energetic costs and benefits of biodiesel and ethanol fuels. *PNAS*. Vol. 103, no. 30, pp. 11206-11210.

Keeney, D., and M. Muller. 2006. Water Use by Ethanol Plants: Potential Challenges. Institute for Agriculture and Trade Policy, Minneapolis, MN.

Myers N, Mittermeier RA, Mittermeier CG, Da-Fonseca GAB, Kent J,
(2000). Biodiversity hotspots for conservation priorities. Nature 403: 853-858.

Tuskan, G. A., et al. 2006. The genome of black cottonwood, Populus trichocarpa (Torr. & Gray). Science 313:1596-604.

US DOE Publication, 2007 *Ethanol: The Complete Energy Lifecycle Picture*, Second Revised Edition. http://www.transportation.anl.gov/pdfs/TA/345.pdf.

Conversion of Lignocellulose to Ethanol

by Dr. Brian Davison

Dr. Brian Davison *is chief scientist in systems biology and biotechnology at Oak Ridge National Laboratory and involved in the U.S. Department of Energy Bioenergy Science Center at Oak Ridge National Laboratory.*

The vision of the future we are painting in this conference is not a new one. At Oak Ridge National Laboratory (ORNL) we have been working to find alternative sources of fuel for more than 20 years.

Current trends in research raise three questions. Can we convert lignocellulosic biomass to fuel efficiently and economically? Can we produce significant amounts of usable biomass to achieve our future need for fuel? Can we do this sustainably?

We have already made technological progress on the first challenge, whether we can convert biomass economically and efficiently, and I am confident we will be able to start doing this in the next five years or so. We can produce sufficient quantities to answer a significant part but not the total need for reducing dependence on petroleum fuels. The sustainability question is one for which there is insufficient data to answer conclusively.

New Policy Direction

In January 2006, the future of bioenergy got a radical boost when, in his State of the Union Address, President Bush announced that we are addicted to oil, and that bioenergy can play a role in national security. Even before the president announced his plan to implement changes in energy policy, the U.S. Department of Energy (DOE) had set a number of goals that are in sync with the new policy, such as aiming to replace 30 percent of our current transportation fuels derived from petroleum by the year 2030.

In his 2007 State of the Union Address, President Bush proposed increasing our renewable fuels to 35 billion gallons a year by 2030, up from 5 billion gallons annually two years ago. These are ambitious incentive goals that the U.S. government has set as a matter of policy.

Even if we can increase the nation's current grain production, we will still need to start adding cellulosics or other types of biomass for fuel conversion processes to make this plan work.Optimistic estimates by the National Corn Growers Association indicate that, with increases in the current rate of production, we may be able to produce between 15 and 18 billion gallons of fuel a year from grain.

Not by Grain Alone

Currently, the United States produces about 5 billion gallons of ethanol per year from corn and plans to increase production to more than 10 billion gallons by 2012. Part of the driving force behind that goal is the Renewable Fuel Standard adopted by the U.S. Environmental Protection Agency under the Energy Policy Act of 2005. One goal of that standard is to phase out methyl tertiary-butyl ether (MTBE), a gas additive in unleaded gasoline. The standard has recently been revised to increase the amount of biofuel in the gasoline mix in order to achieve this reduction of MTBE. There are limits to what we can do to achieve those goals using grain alone.

Within the biofuels field, whatever type of biomass you choose, there are multifactorial choices to be made. In essence, it's a multiple choice question. What type of land will be dedicated to production of biomass? Will the land be currently marginal crop land, forest land, fallow land, or land now in production for human food and animal feed? Will we be using soft woods, hard woods, or agricultural residues? We must also factor in the production processes we may employ, whether mainstream technologies currently available or promising new technologies that are still in the research and development pipeline. What is the production goal, ethanol, butanol, biodiesel or something else?

Communicating with policy makers is crucial in defining these goals. At times, policy makers get confused when they talk with researchers, each of whom has his or her favorite path to navigate this maze of choices. And, frankly, those of us engaged in our own corners of research tend to embrace our own path as the best way.

As researchers, we have the responsibility to familiarize policy makers not just with our own R & D efforts, but also with the strategy the United States is following for corn ethanol and other biomass. To that end, we need to gather a critical mass of data and to interpret that information for policy makers at every level, local, state, and federal.

Economical Production

Agriculture is a keystone of the economy in Tennessee, but aside from the few large corn and soybean operations that characterize the agricultural sector in West Tennessee, we have a great deal of land that is less productive for these commodities. In February 2007 DOE announced awards to six companies in six different states to build large scale, first-generation cellulosic ethanol plants using different feed stocks and different sorts of processes. These are, in fact, multiple strategies tried out on a very large scale to see if they can actually work. For now, we cannot know for sure which of these processes will ultimately prove most viable

Currently, estimates of the production costs of cellulosic ethanol from those types of plants run about $2 a gallon, so the process is feasible but not economical – if gasoline remains at 2007 levels. Even with current gasoline prices at around $3 a gallon, if you add in the other associated costs—such as transportation, taxes, and profit margin—it's still not economical. Projections based on R&D predict we can bring that cost down to below $1 a gallon if we do our research right, effectively, and fast.

DOE is providing 40 percent of the total cost to build those large plants, about $400 million for all six. Private financing and private companies are investing the remaining $600 million. If the Government puts up 40 percent of the risk capital, the cost return can be pushed down low enough that this strategy will work. In the western economic market, the first plant typically costs two to three times as much as the second plant, in part because a company that builds a risky technology with borrowed money will incur a higher interest rate by the lender.

The Recalcitrance Factor

A 2005 study by ORNL, called the "Billion-Ton Study," predicts that we can produce a sufficient supply of biomass if we make certain assumptions. The Executive Summary clearly states the assumptions needed to increase our productivity. Specifically, the summary posits that we will need multiple sources of biomass, including agricultural residues, but also a large amount in forests and perennial crops. A new generation of agronomic infrastructure will be necessary to actually to bring this about.

The corn ethanol industry has been incrementally and substantially improving its cost structure for the last 25 years and making great strides in producing ethanol more economically. That is one reason for the growth in bioethanol plants in the United States. Just 10 years ago, a 20- to 40-million-gallon-a-year plant would be typical. Today, most plants under construction will have a 100-million-gallon production capacity, because these companies have found ways to produce ethanol better and more economically at a larger scale. To improve the yield of fuel from biomass, we can't rely on the sources available today. We will need to find ways to produce genetically modified plant material and then find ways to break it apart into pieces that we can use.

The challenges are twofold. First, lignocellulosic biomass is complicated and heterogenous. Second, even though people have known about and used the fermentation process for thousands of years, it's not a simple one. Yeasts have been doing it for 6,000 for humanity, but fermentation still is a complicated process.

Current baseline technology of a biomass refinery involves multiple steps. The challenge is to combine these steps with the ultimate goal of consolidated bioprocessing, achieving hydrolysis and fermentation of all the sugars in one step.

ORNL's Bioenergy Science Center has a number of partners—including the University of Tennessee, the National Nuclear Energy Laboratory, and the University of Georgia—that are targeting the recalcitrance problem. Why is biomass so difficult to break apart? If we can more easily extract the sugars from biomass, we will be able to find ways to use them expeditiously as fuels. There are a number of solutions in the pipeline to convert sugars to fuels, if we can leap the recalcitrance barrier.

One strategy to simplify the more complicated processes is to grow and harvest native plants such as switchgrass, pre-treat them with chemicals or heat or both, subject them to a multiple fermentation process using enzymes and hydrolysis to produce fuel. Another vision is to use genetically modified plants, which will be engineered to require less structural pretreatment. These can be converted into the ultimate fuel product using a consolidated reaction and hydrolysis process.

The focus of the Bioenergy Science Center is on three major areas, 1) the formation and modification of the plant material and how it is made, 2) the characterization and modeling of the material and the pathways itself, and 3) the process through which the material gets deconstructed and converted by microbes and enzymes into the end fuel products.

We can overcome the recalcitrance barrier by genetically modifying the cell wall and using microbes and enzymes to perform low-cost hydrolysis and fermentation. Our hope is to find ways to combine the good features of both of these processes in a synergistic combination, where the whole is greater than the sum of the parts.

Genetic modification of the plant cell wall is a key challenge. We need a better understanding of which genes control biomass production and cell wall synthesis. We need to know what happens at the molecular level and how heterogeneity and structure relate to recalcitrance and deconstruction of the cell wall. And we must learn the mechanisms by which microbes and enzymes attack the biomass substrates.

The Bioenergy Science Center project is finding ways to make the conversion of biomass to fuel more efficient. We also take a long-term view of sustainability. In the context of producing biomass for conversion to fuels, sustainability means using the same land for 100 years to efficiently produce biomass for conversion to fuel, with no external inputs and no degradation of the land quality. Many will say this is impossible. Our challenge as a group is to come up with data that will support the vision of sustainability. Public policy must be driven by good scientific data. Otherwise, we will not move forward to reach our goal of a sustainable, renewable source of biomass to supply our increasing consumption of fuel.



Photos courtesy of UT Bioenergy Program

Status of Bioenergy Development in China: An Overview

by Dr. Giu-Rui Yu

Dr. Giu-Rui Yu *is the director of the Synthesis Research Center of the Chinese Ecosystem Research Network and vice-director and professor at the Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences*

In 2006, China's consumption of energy accounted for 15.5 percent of total global consumption. While this represents a significant portion of the world's use of energy, the average per capita consumption of energy in China is still quite low, only 40 percent of the world average. Nevertheless, China has recently become a net importer of energy. In 2005, coal production in China was at 2.06 billion tons, while consumption had risen to 2.25 billion tons. The demand for coal is expected to rise at a rapid pace, reaching 3 billion tons by 2020.

As the country's own fossil fuels become depleted, China is looking at renewable sources of energy, including biomass, to meet its need for economic development. At the same time, China recognizes the need to balance concern for the economy with concern for the environment, and biomass has some serious environmental drawbacks.

King Coal

China relies primarily on coal, and to a lesser extent crude oil and natural gas, to provide most of its energy needs. Very little energy is currently available from renewable sources, and to compound our energy crisis, our efficiency at delivering energy from the producer to the consumer is among the lowest in the world.

Coal is the major source of energy in China, accounting for 80 percent of the total energy supply, 40 percent above the world average. An energy supply dominated by coal leads to severe pollution. Other sources of energy include crude oil, natural gas, hydro power and nuclear energy. Renewable sources of energy are a small portion of the overall energy supply, only 8 percent in 2006.

Crude oil consumption is expected to rise from 323 million tons in 2006 to 375 million tons in 2010, which will make China the second largest oil consumer in the world. Natural gas is supplied to more than 60 cities; by 2010, 270 cities will need natural gas.

China has potentially significant resources of renewable energy from hydro-power, but so far less than 20 percent of hydropower resources have been exploited. Exploration of renewable energy resources is the direction the Chinese government is taking to meet its growing energy needs. In addition, energy use efficiency in China is only 32 percent. A major challenge for the Chinese government is to increase energy efficiency, use less coal, and reduce sulfur and carbon dioxide emissions by 20 percent by 2010 even as energy consumption increases.

Renewable Energy Sources

One promising source of renewable energy in China is hydropower. In 2006, national hydropower generation capacity stood at 124 million kilowatts (kW). By 2020, planned generation capacity will more than double, reaching 300 million kW. The total estimated potential to produce electricity from wind resources is 1,000 gigawatts a year. By 2004, China had installed turbines capable of producing 760 miliwatts of electricity annually, and development of more wind turbines is slated for the coming years.

China is rich in solar energy resources, with more than two thirds of the country suitable for the use of of photovoltaic cells. China is already the third largest country in the world in the use of solar energy. In recent years, the Chinese government has put great effort into developing solar energy. In 2004, capacity of photovoltaic generation stood at 65,000 kW. Solar energy is particularly attractive in remote areas and in special industries.

Many families use solar water heaters in their homes. About 90 meters^2 (968 feet^2) of photovoltaic cells had been installed at the end of 2006, and annual production capacity is 15 million meters^2 (161 million feet^2). If we can produce 150 million meters^2 (1,615 million feet^2) of solar heaters by 2010, we can replace 10.8 million tons of coal each year.

Geothermal resources such as hot springs are mainly distributed in the Hengduan Mountains region, mostly in Tibet. Geothermal energy is primarily used for heating, bathing, and gardening, and could replace about 32 million tons of coal per year. Geothermal pumping is also used mainly in the provinces. More than 30 million meters^2 (322 million feet^2) of geothermal pumping systems have been installed nationwide. Beijing is expected to see a jump in these systems from about 8 million meters^2 to 35 meters^2 (86 million feet^2 to 376 million feet^2) by 2010.

Biomass Resources

Biomass energy production uses crop stalks, domestic animal waste, forest waste, and organic garbage as raw materials that are subjected to treatment technologies. In 2006, China approved 39 projects using biomass power generation. Production capacity of these units is 2.2 million kW per year. Each year, the amount of usable biomass energy produced in China is equivalent to that produced from 500 million tons of coal.

- Annual production of agricultural stalks stands at 800 million tons, the equivalent of the energy produced from about 150 million tons of coal.
- Approximately 80 billion meters^3 of industrial organic waste water can produce the same amount of energy as can be produced from 57 million tons of coal.
- Annual forest product waste, 900 million tons, provides the energy of about 300 million tons of coal.
- Urban garbage, 120 million tons, can produce the same amount of power generation as about 13 million tons of coal for power generation.
- Biomass gas derived from raw materials such as stalks, wood residues, rice shells, and branches can be used to replace natural gas in kitchen ranges and could provide fuel for 80 million people in rural areas.
- Raw materials such as sugar cane, cassava, and corn; crossbred grain sorghum with high sugar content and high production capacity; and sorghum juice and corn fibrin can be used to extract ethanol.
- The production of biomass diesel oil is still in the experimental stage in small-scale production processes. The focus in the future will be to shift toward using renewable oily plants to produce biomass diesel oil.

Renewable Energy Planning: 20/20 vision

China's Renewable Energy Law took effect in January 2006. This law will facilitate the development of renewable energy in China, with its currently available and as yet untapped renewable resources.

The four basic principles of the law are to

- Combine government responsibilities with public support
- Combine government guidance and market forces
- Combine current demand and long-term goals
- Combine international experience and domestic practices.

The long-term goal is to increase consumption of renewable energy from water, wind, biomass, and solar 16 percent by 2020. Renewable energy capacity will replace 530 million tons of coal. The new law also requires reducing 1.1 billion tons of CO_2 and 8 million tons of SO_2 emissions.

The policy also speeds up development of small- and medium-sized hydropower plants and installation of large-scale wind power plants in coastal areas and northern areas, and small- and medium-sized wind power plants in other areas.

To increase the use of solar energy in cities, the plan is to develop centralized energy plants using photovoltaic cells and to distribute hot water and heating in densely populated areas. In rural areas and small towns, solar water heaters and kitchen ranges will provide energy for individual households.

The goals for biomass include increasing the total from all sources—agricultural and forest biomass, burning of garbage, methane power from landfills, and methane power generation in large-and medium-scaled project—to 3 million kW.

Pilot sites producing biomass solid fuel will provide 50 million tons, and methane consumption in rural households will rise to 18 billion meters^3 The policy also aims to replace 10 million tons of refined petroleum with biomass liquid fuel produced from sorghum, sugar cane, and cassava. Annual production of biodiesel oil from Barbados nut and Tung-oil tree will rise to 1 million tons per year.

To produce biomass for energy production, the Chinese government plans to grow more trees and other woody plants in desert areas. By 2020, 13 million hectares (32 million acres) of bioenergy forests will be planted, providing raw materials for production of 6 million tons of biodiesel oil and 15 million kW in annual power generation.

The key requirement for adding agricultural biomass is to minimize the conflict between food requirements and energy production, placing top priority on national food security. The basic premise is that cultivating bioenergy crops must not infringe on grain crops for human. This will require technological innovation and exploration in the development of agricultural biomass, and coordinated development between the biomass and related industries.

Measuring Success

A number of nation-wide initiatives are establishing guidelines and setting benchmarks to guide and measure the status of bioenergy development in China.

The National Development and Reform Commission (NDRC), a planning agency of the Chinese Government, recently issued a circular on implementing high-tech biomass industrialization. The commission's stated target is to encourage industrialization of biomass exploitation technologies for wider applications and to promote large-scale production of non-grain bioenergy, up to 100,000 tons.

In 2006, together with the Ministry of Finance (MOF), NDRC also issued a circular on enhancing the management of developing ethanol biofuel projects. This circular addresses the initiatives of some provinces to replace lead-free gasoline with ethanol oil in cars. Rising petroleum prices and a short supply of corn have led to uncontrolled development of ethanol production and rising corn prices.

A joint meeting on biomass development and use was held in 2006, with NDRC, MOF, and the State Forestry Administration (SFA) to implement the law on renewable energy. They identified four priority areas in the next 15 years: biomass power generation, bio-liquid fuel, marsh gas and power generation, and bio-solid fuel. Five strategic products include fuel ethanol, industrial methane, biodiesel oil, compacted fuel, and bioplastics.

In addition, the Chinese oil company PetroChina works with SFA and local governments to develop biomass energy. From 2005 to 2010, 0.8 million hectares (2 million acres) of biomass forests will be planted to produce 6 million tons of biodiesel fuel and 15 million kW of power generation.

By 2010, the annual production of non-grain ethanol by PetroChina will exceed 2 million tons. PetroChina is cooperating with local governments in five provinces: Sichuan, Yunnan, Shangdong, Hebei, and Hainan to achieve these goals.

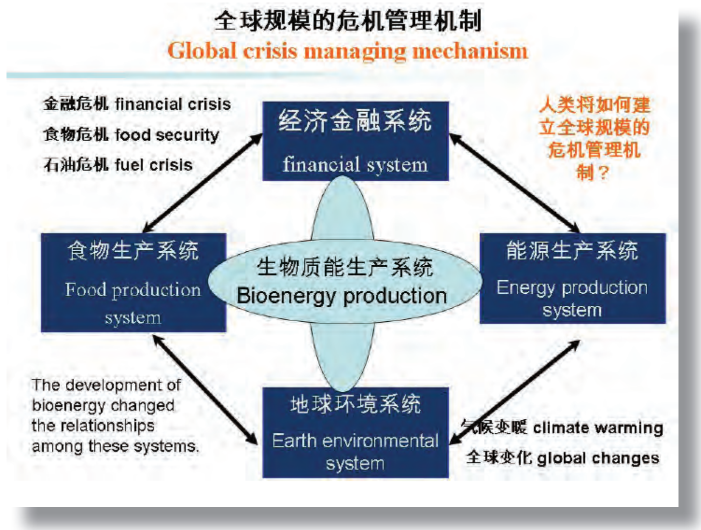
There will continue be competition between energy and food crops, but the Chinese government has now switched the bioenergy focus to nonfood resources. These efforts are in the very early stages. Moreover, the marketing system is not mature yet, and no one knows the size of the market.

Ecological Concerns

The ecological and environmental issues in developing biomass energy are likewise difficult to solve. Four major questions arise.

- Will the use of agricultural and forestry waste alter the lifecycle of ecosystems?
- The use of crop stalks will definitely reduce the content of organic matter in cropland. How can we maintain soil fertility and the carbon cycle?
- Most biofuel plants demand large areas of land. Will the large-scaled cropping of these plants change the nutrient balance of ecosystems?
- In non-grain production areas, does the development of bioenergy plants mean we will lose more wetlands, grasslands, waste lands, and forests that support the existing environment?

In addition, there are doubts about whether biomass energy is fully renewable. If we resort to artificial means to produce biomass energy in a competitive environment, we may produce more greenhouse emissions than is produced from food production. Given a competitive economic environment, it is unsure whether we can develop bioenergy wisely and sustainably. We have already depleted our geological energy sources. Continuing, intensive human activities may pose future threats to environmental recovery and improvement.



We are now at a major crossroads in managing the four systems affected by bioenergy production: the financial system, the food production system, the Earth's environmental system, and the energy production system. Our decisions today will have significant and long-term influences on the economy, the fuel crisis, and food security.

We convened in Knoxville at this China-U.S. Joint Research Center workshop to face these crucial issues together. Over the next days, we will be seeking answers to two basic questions. First, is there a good chance that China and the United States can work together for the common goal of ensuring the future of humanity? Second, can we create new wisdom by combining the best of ancient and modern civilizations, and by combining the intellectual and technological resources of our two modern civilizations? My hope is that we will find a practical and effective approach for our countries to address the complex issues of bioenergy.

China's Energy Demand and the Potential of Bioenergy Production in China's Terrestrial Ecosystem

by Dr. Ming Xu

Dr. Ming Xu *is an ecologist and professor with the Chinese Ecosystem Research Network, Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences.*

The first thing that comes to mind when you think of China is its high population density. With a population of 12.3 billion, we have no shortage of people. Nearly everywhere you go, it is crowded… not on the Tibetan Plateau, of course, but in most of the rest of the country. To support this huge population and fuel our economic growth, we need a steady supply of energy for heating, cooling, transportation, and cooking. A much touted source of energy today is bioenergy.

Bioenergy is nothing new; it is the oldest energy source on Earth. In China, our traditional food preparation used bioenergy, and that tradition continues today. Shared meals are at the very heart of Chinese culture, and cooking relies on bioenergy, whether from a wood fire or modern stove. We are just now rediscovering bioenergy.

Growing Pains

China has seen dramatic economic growth in the past few decades. Gross domestic product (GDP) has doubled almost every 10 years in the past 30 years. Another important phenomenon in the last few decades is urbanization. On average, in China, a person who lives in urban area consumes 3.5 times more energy than a someone living in a rural area. As GDP grows, so does our consumption of energy

About 70 percent of China's primary energy, the energy in raw materials, is from coal, 21 percent from oil, 1.7 percent from natural gas, and 6 percent from hydropower. The amount of primary energy from bioenergy sources is currently very small. China has an energy self sufficiency rate of about 92 percent. The deficit must be made up by importing energy.

In 1994, China became a net oil importer, and demand is rising dramatically. The percentage of oil imported to meet demand for total consumption today is about 50 percent, so we are already highly dependent on imported oil. As living standards continue to improve, more and more people, especially in the cities, drive their own vehicles. As the number of vehicles increases, the gap between domestic production and consumption will widen, especially after we reach peak production in 2010. China's growing dependency on oil for transportation is a major driver of our increasing energy deficit.

As economic development progresses and urbanization increases, heavy industry will continue to be a major part of China's economy. Energy demand for industry and construction will increase 50 percent by 2020 and slowly decrease to about 40 percent by 2050. As our GDP continues to rise, we must meet that demand.

With our total proven energy reserves, we have roughly enough coal to last about 50 years, oil for 10 years, natural gas about 45 years, and hydro barely one year. The energy supply is clearly a security issue. From 2000 to 2020, GDP will quadruple. In 2020, China's annual energy demand is estimated to be 3.1 billion tons of coal equivalent (TCE). This is about 1.4 times our consumption, a huge challenge to our energy supply.

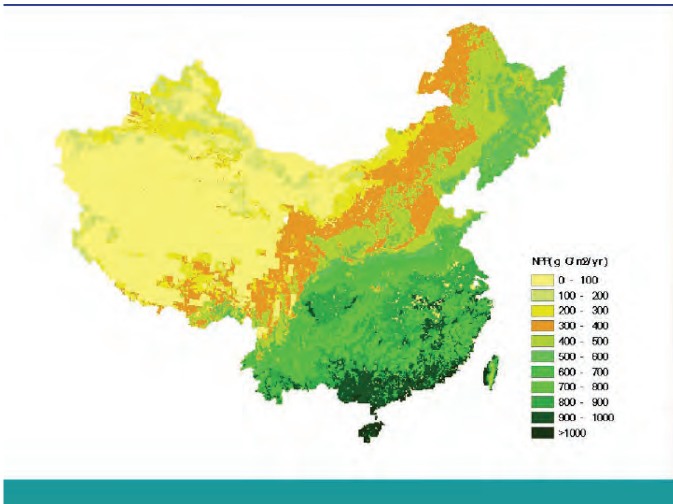
How are we going to meet that demand? Will bioenergy be a solution? My research takes a global look at the role of bioenergy in the overall energy supply, calculating the total solar energy fixed in China's terrestrial ecosystem.

Modeling the Future

Biomass resources are derived either from corn-based technologies such as ethanol production, or from biomass-combustion power plants. Available resources for biomass include agricultural residues, forestry residues, animal waste, industrial solid waste, urban water waste, and energy crops.

The benefits of bioenergy are well known and often cited. Sources are abundant and renewable, emissions are clean and low in carbon compared with fossil fuels, and the cost, if not currently at least in the future, can be low.

Based on current economic and urbanization trends, energy consumption in China will continue to increase to about 3.0 TCE in 2020, according to the National Development and Reform Commission. By 2020, the percentage of total energy consumption from bioenergy will account for 4 percent.



Net Primary Productivity: Yellow-Low, Green-High

For the past 20 years, the Chinese Ecosystem Research Network has been running different ecosystem models to measure a number of variables that contribute to the carbon cycle for the whole terrestrial ecosystem of China. We can model changes, and track and predict climate change, from 50 years in the past to 100 years in the future. Taking into account the complexities of carbon exchange, we can estimate total ecosystem productivity, or net primary productivity (NPP), to see how much energy in the ecosystem, or carbon, we can harvest or fix each year. We also use satellite remote sensing models to directly measure biological and climate variables. We are finding results among the various models are very similar, which gives us some confidence in predicting the course of climate change.

China's terrestrial ecosystem is divided into 14 categories, from bare ground to water, from evergreen forests to cropland, from desert to subtropical forest. Distribution of vegetation varies widely. Most of the country has very low NPP, including the Tibetan Plateau, with high NPP in the southern part of China with its subtropical forests. There are also some forests in the northeast with high NPP.

China's total terrestrial ecosystem productivity is 3.3 PgC (petrograms of carbon). The most productive vegetation types are cropland, grassland, and open shrubland. The least productive are deciduous needleleaf forest and evergreen needleleaf and broadleaf forest. There are vast expanses of grassland in the Tibetan Plateau area, so although the productivity is low, the total productivity over such a huge area is high. .

Much of China's agricultural land, grassland, and shrubland is remote, with low population density. Some of the areas are too steep for easy access. If we want to convert crop land to bioenergy production, we need to determine the best soils on the lower and flatter areas. The plateau area of the Gobi desert, for example, has very steep slopes and is unsuitable for agriculture, including biomass production. The government has already placed restrictions on farming in that area.

Where's the Land?

Bioenergy consumption in China will represent just 4 percent of overall energy consumption by 2020. To meet the additional demand for bioenergy, we will need to dramatically increase the area of production of all vegetative types.

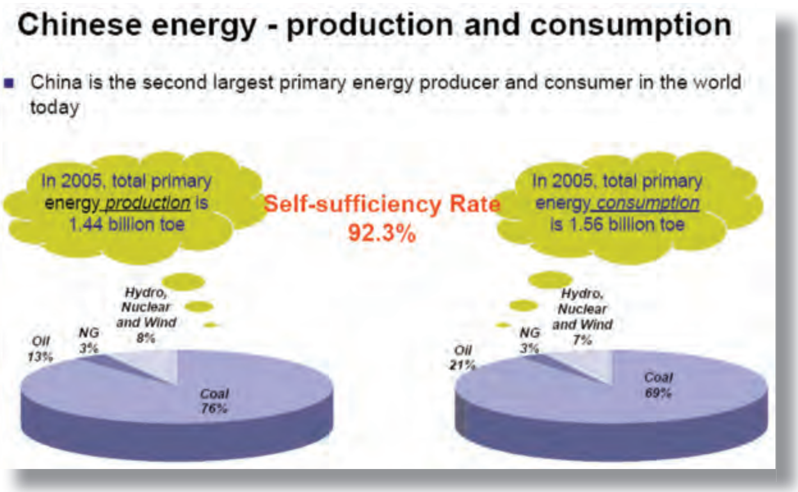
Evergreen needleleaf forest alone will need to be increased 63 percent by 2020. If we plant those crops on agricultural land, we will need to increase cropland by about 12.5 percent, which is impossible. Nearly every inch of arable land is already being fully used. To cite an example, winter wheat is grown on narrow highway median strips. In southern China, the situation is even crazier; every single piece of land, even the size of a conference table, is a rice patty.

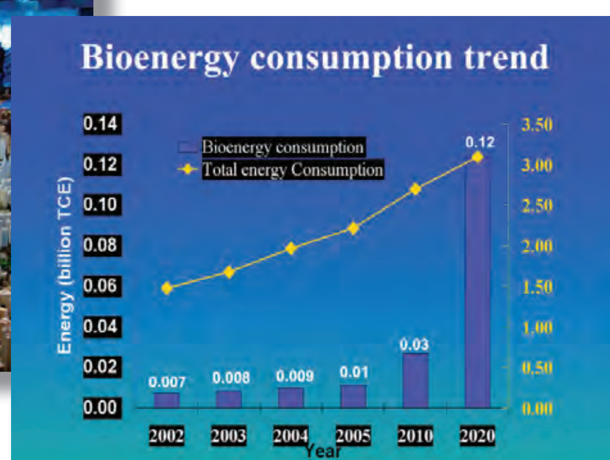
We need large amounts of land to produce bioenergy. Where will we find it? Cropland is not feasible. Grasslands are already a highly fragile ecosystem. In addition, the government has already spent billions of dollars on the national forest protection plan, launched about 10 years ago. We wanted to turn steep land back into forest. Now we want to cut back the forest for energy crops. The obstacles and limitations are overwhelming. Even if we could turn the Gobi Desert into bioenergy plantations, the crop would not be accessible for harvest due to its remoteness.

Even crop residuals from agricultural production are very expensive. Currently we have a number of biomass combustion power plants. Laborers collect the biomass for about 7 Chinese cents an hour, about 1 U.S. cent per pound (0.45 kilograms) of biomass. That is very cheap labor. To collect and deliver materials, you also need energy. Agricultural residues such as stalks, which everyone says are plentiful, are traditionally used as fodder for animals or returned back to the soil as organic fertilizer. Yet one of the goals of bioenergy is to reduce carbon emissions and solve the global warming problem. If we reduce the amount of organic carbon going back to the soil, soil respiration is going to increase, releasing more carbon to the atmosphere. You are just moving the carbon from one place to another. In short, bioenergy has limited potential to meet China's future energy demand, because most of the productive land is currently used for food and fodder.

We need to think more deeply about why bioenergy is still a hot topic globally as well as in China. The trend is driven by politics and economics. In China, as elsewhere, biomass and ethanol plants are funded by government subsidies. These subsidies result in increases in the price of power, which is already quite high, and increases in food prices, which have risen dramatically in the past two years in China. The Chinese government has already begun to apply the brakes on ethanol projects. Another hot topic is risk investment, as government and private industry want to bank on a return on investment in unproven technologies.

The future of bioenergy is spatially dependent. In the United States, Brazil, or Cuba, with high productivity, large unused areas of land, and low population density, it may be possible to increase production of bioenergy. China simply does not have enough land. Perhaps future technology will allow us to farm in the desert or on the Tibetan Plateau, but I don't see this possibility in the near future. An old Chinese saying cautions that you cannot put out a fire on a huge chunk of firewood with a small cup of water.





The Tennessee Biofuels Initiative: A Model for Rural Economic Development and Experimental Sustainability

by Dr. Kelly Tiller

Dr. Kelly Tiller *is an agricultural economist in the Agricultural Policy Analysis Center at the University of Tennessee's Institute of Agriculture and director of External Operations for the new Office of Bioenergy Programs, Tennessee Biofuels Initiative.*

In the United States, 97 percent of transportation fuel is derived from petroleum sources. Like China, the United States has outlined a long-term vision for an energy future that will rely on increased domestic production of renewable energy. This comprises not just one target but a number of targets.

One goal is to ensure that by 2025, America's farms, ranches, and forests will provide 25 percent of the total energy consumed while continuing to produce safe, abundant, and affordable food, feed, and fiber. President Bush, in his 2007 State of the Union Address, set the goal of replacing 20 percent of our transportation fuels with renewable sources by 2017. In addition, the U.S. Department of Energy (DOE) has set a goal of replacing 30 percent of our energy use with renewable sources in 30 years.

Most of our efforts thus far have been based on ethanol derived from corn-based sources and have largely been located in the midwestern United States, the Corn Belt. Corn-based ethanol production has increased rapidly over the last few years, and we have made tremendous gains in increasing production and use of ethanol. But we will certainly approach some limits to production before very long and face difficult choices about substituting fuel and other uses of corn products for food uses. By 2012, we could potentially double corn-based ethanol capacity, but there is a limit to the amount of corn-based ethanol we can sustainably produce without disrupting the agricultural sector. The need for increased capacity and increased use over time are good reasons to look closely at the promise of cellulosic ethanol.

Production of biomass and cellulose for energy conversion will depend on forest biomass resources and on potential dedicated energy crops such as switchgrass. The Southeast is a promising source for both kinds of materials. Production of cellulosic fuels is sustainably and economically feasible in the longer run with the capacity to produce well over a billion tons of biomass resources from agricultural sources, forest sources, and other industrial sources.

The state of Tennessee places a high priority on decreasing the nation's dependency on foreign oil while spurring rural economic development. With financial support from the state, the University of Tennessee (UT) launched the Tennessee Biofuels Initiative (TBI). A strong focus on transportation fuel motivates much of this work. As we continue to gain momentum, we must ask ourselves what results to expect in the near future from this initiative.

Our Comparative Advantage

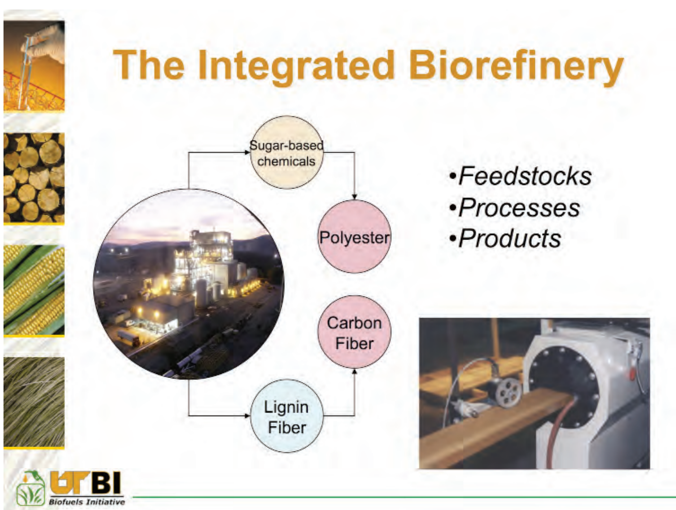
The state of Tennessee, with its biocentric economic focus, is poised to move forward into a leadership role in contributing to the future biofuels economy. The state has the opportunity to leverage some of the strengths of the university, Oak Ridge National Laboratory (ORNL), and other active programs. It is a wise investment for the state to make now with potential benefits in terms of rural economic development, job growth, new economic opportunities, and new agricultural income. In addition, new opportunities for intellectual property development can yield benefits for the state and create a market with virtually unlimited demand.

To jumpstart this new bioeconomy, three elements must come together simultaneously. First, we need to encourage farmers to produce cellulosic feedstock in a manner that is sustainable and economically competitive. Second, we must ensure production of a sufficient quantity of that material to supply the manufacturing sector so that it can convert that material economically, sustainably, and efficiently into useful products, fuels, and energy. Third, to complete the cycle, we need to encourage widespread consumer acceptance and use of renewable biofuel products in the economy.

To begin moving this agenda forward, we must focus on two elements of the cycle: the farming sector and the manufacturing sector. To that end, we propose a two-pronged strategy with a business component and a research agenda. This strategy will require a commitment of more than $70 million from the state of Tennessee. In June 2007, the state legislature approved the funding for the TBI. The package includes more than $8 million as a feedstock production incentive payment that will be made available to local farmers who will produce switchgrass. It includes another $40 million for construction of a pilot-scale biorefinery that can produce 22 million liters (5 million gallons) per year of cellulosic fuel. Additional funding will support research and leverage a number of partnerships to meet the goals of establishing a viable biofuel economy.

Refining the existing system to allocate local resources will work best in this region, taking into account geographic constraints. We are therefore looking primarily at switchgrass, short rotation woody crops, and other forest residues. The ultimate goal of the initiative is to ramp the project up to the commercial scale. The proposed technology platform is the biochemical platform. Converting switchgrass or other biomass feedstock into fuel is a proven, not very sophisticated, technology, at least initially. Pretreatment involves using steam acid hydrolysis. Then the treated biomass moves into an enzymatic conversion process. There are many proven combined bioprocessing technologies, and some newer technologies on the horizon. These can be tested in the pilot-scale facility. Initially, the design of this facility, with a proven track record, will likely assure the highest probability of near-term success in producing Grassoline™ from switchgrass. Today, the capacity of the pilot facility is about 10 percent of the scale for a commercial facility.

It's not just high-volume, fairly-low value biofuels that will result from this initiative. In the long run, the economics of commercial facilities will be driven largely by products and side-stream chemicals and materials that can be co-produced with the biofuels. The integrated biorefinery concept of this pilot scale facility allows us to test and to improve productivity over time. You might, for example pull the lignan stream out and use lignan fibers to ultimately develop carbon fibers and sugar-based chemical building blocks for other products that currently are petroleum based.



The Switchgrass Promise

Switchgrass, of course, is well suited to the Southeast and is the feedstock we are developing for this project. As a warm season, native perennial grass, it is well suited to local conditions of the area. It is also very resistant to many of the diseases, pests, and other problems such as the weather that often plague agriculture. Therefore it requires fairly limited amounts of chemicals, fertilizers, and other inputs, and so provides environmental benefits as well. In addition, it does not require irrigation. With very little water use, even in the drought of 2007, switchgrass performed exceptionally well compared to other crops.

Research trials over several years have proven the productivity of switchgrass. As of 2007, a fairly large-scale set of trials was in the third and fourth years. In these trials, we consistently produced 6-8 tons per acre of mature switchgrass. Even in the record dry season of 2007, we estimate slightly higher yields, around 8-10 tons per acre. Moreover, very little work has been done to improve the yield on this crop, especially for energy purposes. With routine research over the next couple of years, we hope to improve yield in this region to about 12 tons per acre.

Once switchgrass is planted, it takes about two to three years to reach its full yield potential. At that point, we estimate the crop will be productive without reseeding for at least 10 years or more. In that respect it is much like hay produced to feed livestock on farms right now. For the present, we recommend production practices very similar to the way that we harvest and store a traditional hay crop. We are, however, seeking opportunities to significantly improve the current harvesting, storage, and transportation process, which is not very efficient for a hay crop, much less for production of biofuels. This initiative is designed to allow us to conduct research at a scale that will improve these efficiencies.

The Pathway Forward

In the short term, what are our expectations for progress with these projects? In 2007, we began selecting a number of technology partners for the biofuels initiative. We have taken steps to acquire a site for the pilot-scale facility. We are moving forward with the permitting and other issues that will lead to groundbreaking by the end of 2007 . We also expect to finalize a farmer incentive program that will enroll farmers who want to participate in switchgrass production. We will offer them contracts to eventually produce up to 3,200 hectares (8,000 acres) of switchgrass.

We have procured a good supply of switchgrass seed for the next several years and will be ramping that production up as seed becomes available and as farmers enroll in the program. Assuming the best case scenario, production of switchgrass would be sufficient that we could begin construction in 2008. Within about 18 months, we hope to complete the construction process and begin generating Grassoline™ and ethanol fuel by the end of 2009. In 2010, we aim to be at full production capacity and ready for scale up and development within about a three- to four-year period.

Synergy in Energy

Our vision for the state of Tennessee is based on the successful demonstration of this facility. Though there is no firm, long-term timeline, in about 20 years Tennessee could be producing about 3.8 billion liters (billion gallons) of cellulosic biofuels per year, at a very competitive price compared with petroleum-based fuels. We could have 10 or more of these large scale biorefineries located in the state, mostly in rural areas. These refineries could create about 4,000 new jobs directly and support a number of additional jobs as well, perhaps up to 16,000 total. There are tremendous opportunities for farmer cooperatives to have ownership stakes in these facilities, not only as producers and suppliers of the commodity but also as stakeholders in production facilities. Such buy-in would retain more income in local economies and provide significant economic development opportunities.

In addition to generating fuel, tremendous opportunities could open up for satellite manufacturing facilities to locate near those biorefineries to take advantage of some of the side stream products that could be produced, bringing more jobs and more revenue. Opportunities for 20,000 or more farmers to invest in these new dedicated energy crops could generate significant levels of farm-based income.

We are also pursuing the acquisition of a site for the facility in Monroe County in southeastern Tennessee. Located about 35 miles from Knoxville, the site is very close to the university and Oak Ridge National Laboratory (ORNL). This means we can send our researchers there on a regular basis to work and conduct research in the facility. The site is in the heart of a very productive farming region, and a number of farmers are willing to work with us to supply the switchgrass that will be required. The site boasts a well developed infrastructure, including rail access, a port on Tellico Lake that can handle barge traffic, and access to truck traffic near the intersection of I-75 and I-40. The necessary utilities and services are also very close to end users.

In the longer term, some of the research efforts at ORNL, UT, and elsewhere have significant potential to be tested in this facility and to improve the entire process and the entire system over time. Research efforts to supply feedstock to a facility like this include improvements in agricultural practices; agronomics; and harvesting, transportation, and storage logistics. Poplars, hybrid poplars, and other sources of improved potential feedstock can be added to the university's research on switchgrass and new pretreatment technologies.

The opportunities for progress are numerous, but we will need to do a better job at leveraging partnerships that are already in place, such as the TBI and the joint UT/ORNL Bioenergy Science Center (BSC). The BSC focuses primarily on fundamental research in this area. Having a pilot facility available and working in partnership with UT will allow BSC to test some of the results of that basic research and move the technologies toward a commercially viable system.

The Southeast Sun Grant Initiative is another important partnership already in place. UT is the hub for this federal initiative, which aims to improve biomass feedstocks region by region and develop systems for providing large-scale biomass for bioenergy uses. Much of the five-year, $10 million dollar investment will be awarded to partner institutions in the Southeast for various research projects related to biomass conversion. We are also working on several projects to build partnerships with DOE National Laboratories through faculty fellowships for joint projects with researchers in national labs. In addition, graduate research assistantship funding will be available to improve the skills of those entering the workforce to work in this field in the future.

UT is also developing a coordinated bioenergy curriculum for a graduate program that will be shared and available publicly. We are also continuing to improve our educational resource, the Bio Web, an online repository for a large volume of peer reviewed work that spans the breadth of bioenergy, including biofuels, biopower, bioproducts, and biorefineries. (See http:bioweb.sungrant.org)

In short, the state of Tennessee has established a very ambitious task, an initiative that is, however, achievable. Many of the pieces are already in place, and others are coming together to make this initiative a success and a real opportunity to propel this entire industry forward, especially in the Southeast.

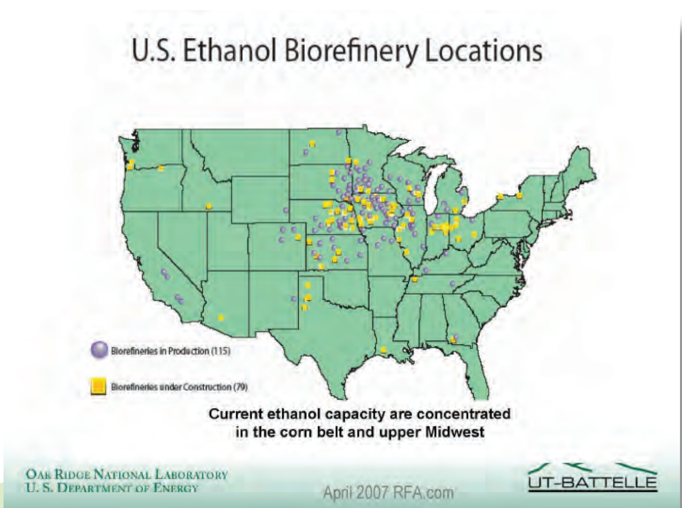
Biomass Energy from Complex Carbohydrates

by Dr. Jonathan Mielenz

Dr. Jonathan Mielenz *is manager of the Biomass Program and group leader of Bioconversion Science and Technology, Biosciences Division, at Oak Ridge National Laboratory*

The advantages of biofuels produced from biomass are many. Production of these fuels reduces dependence on foreign petroleum sources, which require costly infrastructure support and are often imported from countries in turmoil. Our supply of fossil fuels is finite. As biofuels begin to displace petroleum, we can extend the supply well into the future. The environmental benefits of ethanol and biofuels include reduced emissions of CO^2 and particulates and lower greenhouse gas emissions relative to fossil fuel,

Today, most of the ethanol produced in the United States comes from a common agricultural commodity, corn. According to the Renewable Fuels Association, between 1990 and 2006, production of ethanol in the United States went from nearly zero up to 25.36 billion liters (6.7 billions gallons) per year. Considering current capacity and future capacity under construction, we are quickly approaching annual production of 49 billion liters (13 billion gallons) of ethanol, primarily from corn.



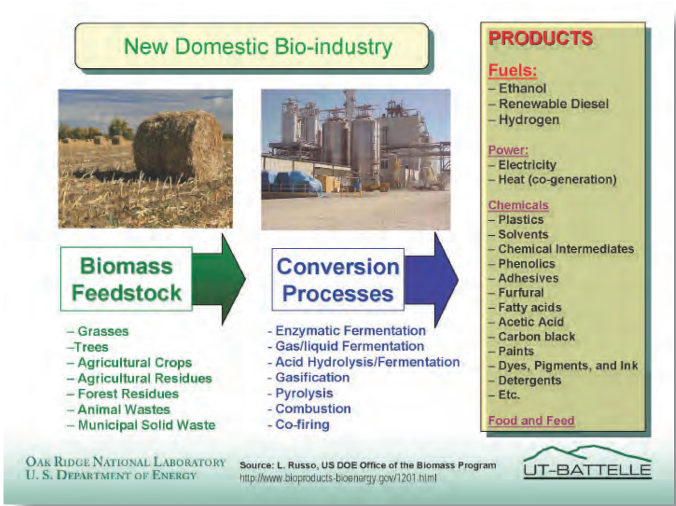
As the number of plants producing ethanol increases, corn growers are cautiously optimistic about the market. The National Corn Growers Association (NCGA) has set a goal of producing 15 billion bushels of corn by 2015. Only 11 percent of corn produced in the United States goes directly for human consumption. Most corn goes for domestic animal feed with some going to the export market. The NCGA estimates about one third of the future crop will be used in ethanol production. Even with increased production of ethanol from this crop, there will still be sufficient corn available for human consumption and livestock feed.

At a production rate of 57 billion liters (15 billion gallons), we can foresee that ethanol will replace approximately 10 percent of our current petroleum uses, which stands at about 530 billion liters (140 billion gallons) per year in the United States.

Processing Corn for Ethanol

Corn processing is pretty straight forward. The simplest process, and the one most rapidly adopted by plants currently being built, is the corn dry mill. Essentially the dry mill process involves milling the corn, adding water and heating the mix to gelatinize the starch, adding enzymes that break the starch down to glucose, fermenting it, and removing the ethanol by distillation or dehydration.

A more complex system is the wet mill process. Though it is still relatively simple, it is a more complex refining system similar to that found in the petroleum industry. The corn is soaked with water, called steeping, to swell the kernel, followed by mechanical separation of the starch from the seed coat and germ. The germ is refined to yield corn oil, and protein residues are separated from the granules of starch. The protein residues can be sold as animal feed products or further upgraded by fermentation of the cellulose portion of the feed to produce both ethanol and a higher-value feed. The starch extracted from the steeping process can be processed in a variety of ways. Alpha-amylase and glucoamylase enzymes can be used to produce sweeteners and syrups, and glucose. Glucose itself can be converted to high fructose corn syrup through the action of a glucose isomerase. Alternately, the glucose is available as a final product, or used as a fermentation feedstock to produce high values products like amino acids and organic acids, or also produce ethanol by a yeast fermentation. So, unlike the dry mill refinery, the wet mill process yields many more co-product possibilities and therefore the potential for greater profits.

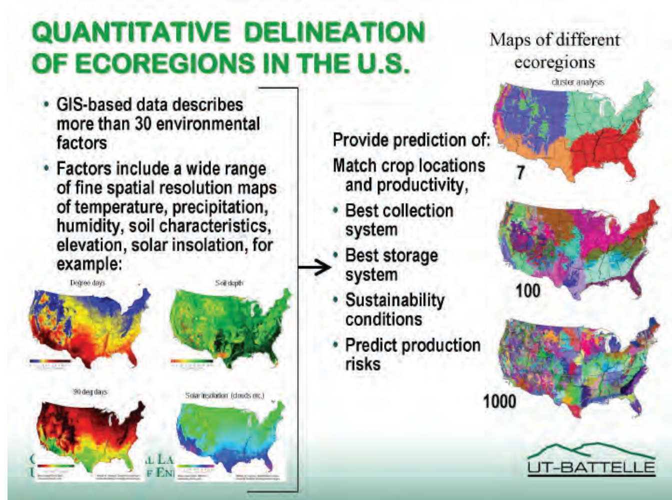


The wet mill process is also very flexible. In 1995, for example, when corn prices were lower than they are today, there was a significant shift away from ethanol towards production of high fructose corn syrup, which is a higher value compound. This built-in flexibility makes wet mill operations more sensitive to market forces than the dry mill process, which produces only ethanol, as production can shift in response to the price of corn and the demand for multiple products such as corn oil, wet animal feed, dry gluten meal, starches, ethanol chemicals, or high-fructose corn syrup.

Where's the Biomass?

As biomass feedstock—whether agricultural crops or residues, trees, grasses, or animal wastes—is converted to end products such as fuels, power, or chemicals, we need to ask where the biomass is going to be grown. Research funded by the U.S. Department of Energy (DOE) at Oak Ridge National Laboratory (ORNL) and the Idaho National Laboratory (INL) aims to determine the potential yield in tons per acre, the cost of production, and how soon a new feedstock could be introduced. We are also analyzing data to find the best locations for production of the biomass and for siting of future biorefineries. DOE will not build the refineries, but this information will help assist commercial entities. The ultimate goal, of course, is a low cost and environmentally sustainable supply of biomass, whatever the source.

The joint ORNL/INL biomass program is conducting a quantitative analysis to determine the best ecoregions in the United States for introducing new biomass crops that are not already being grown in large quantities anywhere. Geographical information system (GIS) data describe more than 30 environmental factors—including temperature, precipitation, humidity, soil characteristics, and elevation. These maps help predict the best collection system, storage system, conditions, and production risks for these crops. Biomass delivered at the biorefinery represents about a third to half of the total cost of the production of ethanol. One advantage of corn over other biomass sources is that corn kernels have a very high bulk density, so there is a lot of weight per unit in a train or truck load. Bales of switchgrass are much lighter, and therefore occupy a lot of space. DOE is funding efforts to improve the costs and logistics for moving biomass from the field to the biorefinery. We are mining a lot of data to answer very complex and sophisticated questions regarding production and transportation of biomass to the biorefinery



Conversion Costs

While dry mill and wet mill facilities are already producing ethanol, we are trying to find more efficient and cost-effective ways to convert biomass to ethanol and other useful products. Ideally, we will find a simple biological solution, whereby a natural process will inexpensively do the conversion with fewer associated costs.

The current biological process for production of ethanol is fairly complex. Pretreatment is essential to start to break apart the plant material. Enzymes are added to boost the fermentation process and complete the breakdown of the cellulose. Other sugars, or complex carbohydrates, are present in the mix, plus an ethanol-producing microorganism to ferment the sugars from the biomass which are not just glucose sugar, but include the sugars xylose, arabinose, and mannose. The resulting ethanol is then purified.

Pretreatment is a thermochemical process, usually mild acid levels and 150+ °C temperatures, This process starts the deconstruction of the biomass components—the carbohydrates cellulose and hemicellulose, and a non-carbohydrate, lignin—from each other to make the carbohydrates available for fermentation, The next step is the saccharification and fermentation process, which uses enzymatic hydrolysis to convert cellulose to glucose. The glucose can then be easily fermented by microbes—yeast or bacteria—that convert sugar to ethanol. Ongoing research in microbiology development aims to produce a microorganism that can use xylose, a monosaccharide from hemicellulose, and the other aforementioned sugars, directly as a source of fermentation of sugars. It is crucial to use all the sugars very efficiently to minimize the costs of the resulting products. For this process to be economically viable, a very high conversion rate, 92+ percent, of glucose to ethanol is required. The yield of xylose to ethanol should be 85 percent. Those rates of conversion are necessary to approach a cost of $0.25 per liter ($1 per gallon). Information from the U. S. Department of Agriculture's Office of the Chief Economist, which accounts for every component of cost from plant construction to transportation costs per gallon of ethanol produced from corn, pushes the cost closer to $0.62 pre liter ($2.50 per gallon). The price per gallon at the pump, of course, would be much higher as cost of distribution and taxes are added to the cost.

The Biotech Approach

To simplify the fermentation process, we would like to find an organism that produces its own enzymes and directly ferments the resulting sugars. The high cost of enzymes, which contribute as much as 18 percent to the cost of production of ethanol, makes this an economic imperative. The goal is to find a totally biological pretreatment process.

Nature has made a very common organism that can convert cellulose directly into ethanol, *Clostridium thermocellum*. ORNL's Bioconversion Science and Technology Group is investigating this organism as a consolidated bioprocessing organism. *C. thermocellum* is a strictly anaerobic bacterium that produces ethanol and byproducts from cellulose using its own cellulase enzymes, yet little is known about its biology during this fermentation process. Our group at ORNL is trying to find the expression rate of key enzymes in this process. We want to see, during the process of breaking cellulose down into ethanol, what genes are being expressed and what proteins are present. The advantage of *C. thermocellum* is that its final genome sequence is known. It has over 3,000 genes, which is complex enough for our thinking. We have also developed a microarray process that can detect which combinations of genes are turned on or off in a fermentation process, which are active or inactive during the process. We want to know how the expression of those genes changes during the fermentation process.

In the future, after we have examined expression of combinations of genes, we want to complete the analysis at the single gene level. We are also looking closely at the total number of proteins produced by this microorganism, again during cellulose fermentation. We recently received a critical set of data on the total number of proteins expressed during this process with a number of fermentations. A number of genes won't be expressed so the proteins won't be present but there will be surprises. In fact, initial data revealed some new genes expressed that we did not anticipate.

The eventual goal of working on *C. thermocellum* with the BioEnergy Science Center, Dartmouth College, and others is to find the best genes that are over-expressed so we can bioengineer a microorganism that is much more efficient in converting cellulose directly to ethanol. To reach the goals of ethanol production set by DOE, even with the most efficient technologies of the future, we will need biorefineries that operate 24/7, every day of the year, using the least expensive biomass sources and conversion processes. This will be the future story of biomass.

Biofuel Crops: Unforeseen Consequences in Sustainability

by Dr. Daniel Simberloff

Dr. Daniel Simberloff *is the Gore Hunger Professor of Environmental Science and serves on the faculty of the University of Tennessee Department of Ecology & Evolutionary Biology.*

As we begin to evaluate plant species suitable for biofuels production, we must go beyond examining candidates based solely on their potential for producing fuels and also assess threats they may pose to ecosystems. To allow our zeal for producing affordable, renewable fuels to blind us to the very real threat of invasive plants could have tragic consequences for the health of our natural systems.

I first became interested in biofuels production about six years ago while at a conference. One of the speakers discussed plants that would be useful for producing biofuels and introduced a list of the ideal traits of those plants. Much of my work involves studying introduced species and their impacts on various aspects of native ecosystems, which helped shape my response to the speaker's list. Except for plant sterility, the listed desirable traits for a biofuels plant and those for a horrible invasive weed were the same.

I got even more worried when, a few minutes later, the same speaker offered the giant reed *Arundo donax* as an example of a potential biofuel source. *Arundo donax* is well known in the United States, particularly in California, as one of the more invasive plants.

The plant invades wetlands and, as it spreads, blocks streams, chokes roadsides, and completely changes the ecosystem. Among other damaging effects, the plant's rampant spread has threatened the Least Bell's Vireo, which is on the U.S. endangered species list.

Clearly, this plant poses a very real threat, yet the speaker was promoting it as potential biofuel crop. The plant has created extensive damage in the United States even though outside its native range (the Indian subcontinent and parts of Asia and eastern Europe) it is sterile. In the United States, the plant reproduces through fragmentation of its rhizomes and production of new roots from stems.

Although *Arundo donax* has been recognized as a significant problem in California for about a century, it has been touted as a potentially useful biofuel crop, and some have proposed planting about 1,200 hectares (3,000 acres) of it in Alabama. A proposal to plant 6,000 hectares (15,000 acres) of *Arundo donax* in Florida has resulted in a major court case.

Alien Invaders

Another troublesome invasive plant, reed canary grass (*Phalaris arundinacea*) was introduced into the United States by the mid-19th century for forage and, chiefly, erosion control because it grows rapidly in a wide variety of settings where erosion is a problem. Reed canary grass out-competes many native plants, including some that are of conservation concern, and it has created a huge challenge for people in ecological restoration because it makes certain wetland mitigations almost impossible.

Meanwhile, few species eat it, and it provides poor habitat for birds and wildlife; the plant is so dense that they cannot penetrate it. It also greatly increases siltation in many wetlands and is a serious allergen, producing copious amounts of pollen.

For many years, reed canary grass was thought to be an exotic species of Eurasian origin, but we now are almost certain that there are native North American varieties. We don't fully understand the genetic basis for invasiveness, but we do know that this invasion was caused by introduced varieties.

Reed canary grass exemplifies two major misconceptions about introduced species. First, many people mistakenly assume that, if we are deliberately introducing species, we have conducted sufficient research and can conclude, with some assurance, that these species will not become troublesome invasives.

The fact is, in the United States, we have about 7,000 introduced species, and about 1,500 of those are plants. About 10 percent—about 150 species—are viewed as problem invaders, and about half of them were deliberately introduced. Many were introduced as horticultural varieties and many others for erosion control. In many cases, those species introduced for erosion control were selected for the same traits—rapid growth, perennial, ability to flourish in a variety of habitats—that tend to make species invasive.

Indeed, plants introduced for erosion control have been among the very worst invaders in the United States. Our most famous invader, kudzu, was introduced into this country, not from its native home, China, but from Japan. It arrived in the United States 100 years ago for use as an ornamental, but within about a decade it was being used for erosion control. In fact, the plant was widely distributed by the federal Soil Conservation Service, now known as the Natural Resources Conservation Service. The agency distributed 85 million cuttings of this plant to farmers in the Southeast in the early 20th century. The agency paid farmers to grow the plant for erosion control. Today, as many as 10 million U.S. hectares (25 million acres) are heavily infested with the plant.

Another plant, pampas grass from Argentina, was widely introduced by state departments of transportation for erosion control along roads and highways, and it also has become invasive in a number of areas.

Native Invaders

The second misconception about invasive species is that if a plant is native it is of no concern. The thinking here is that all natives have co-evolved with other plants and animals in the ecosystem and that natural enemies will keep them in check.

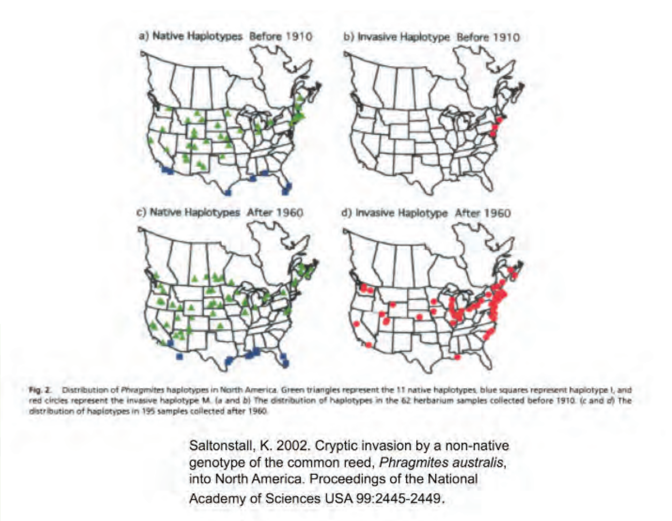


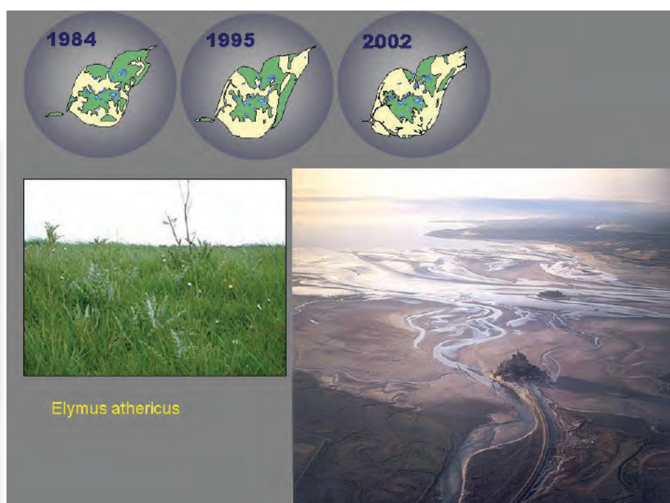
Fig. 2. Distribution of *Phragmites* haplotypes in North America. Green triangles represent the 11 native haplotypes, blue squares represent haplotype I, and red circles represent the invasive haplotype M. (*a* and *b*) The distribution of haplotypes in the 62 herbarium samples collected before 1910. (*c* and *d*) The distribution of haplotypes in 195 samples collected after 1960.

Saltonstall, K. 2002. Cryptic invasion by a non-native genotype of the common reed, *Phragmites australis*, into North America. Proceedings of the National Academy of Sciences USA 99:2445-2449.

This assumption is flawed on two counts. As in the case of reed canary grass, we know that some native species become invasive only after cultivars from other regions are introduced, creating new, invasive genotypes.

Common reed, *Phragmites australis*, is native to North America and has been in parts of our Southwest for at least 40,000 years and along the East Coast for at least 3,000 years. It was a totally innocuous plant, not terribly common in any region. Then about 150 years ago it exploded and started to get into wetlands, beginning with disturbed wetlands. From there, it began to invade intact wetlands. Researcher Kristin Saltonstall discovered that the entire invasion was caused by one or more introduced cultivars. One main exotic haplotype is involved, and it has totally replaced the native haplotypes in many areas. I could offer other examples, but this makes the point that introducing new genes can render what had been a perfectly normal plant into an invasive problem.

Not nearly as many native plants are viewed as invasive as exotic ones, but there are a few, and we can learn quite a bit about the problem from examining them. Among natives considered as invasive are several conifers, including Douglas fir, white fir, and western juniper. All three of these species are invasive in grasslands in the West under some circumstances. The trees begin as part of a forest then, in certain circumstances, rather quickly begin to spread into native prairie. The spread seems to result from suppression of fire, which allows them to spread into areas where frequent burns would have killed the seedlings and where greatly increased grazing favored them over the prairie plants. The one-seed juniper in northern Arizona is more mysterious. About 20 or 30 years ago, it started invading shrub and grass lands, and we suspect it has something to do with fire suppression.



Another example from the East, Virginia pine, has been invading grassy areas in Maryland and Ohio that have species of conservation concern. Apparently, these grassy areas had been maintained for at least 150 years through grazing. The saplings were either trampled or eaten by grazing livestock. But when grazing ended, the Virginia pine began to invade.

Elymus athericus is a grassy plant that grows in the intertidal zone of Normandy and other parts of Europe. Until about 50 years ago, the plant was restricted to a relatively narrow strip at the back of the intertidal zone. Then, about 30 or 40 years ago, it began to spread further down into the low intertidal zone and then into places like around Mont Saint-Michel, a rocky tidal island in Normandy. The plant feeds on aerial nitrogen deposition as well as nitrogen runoff from fertilizer, which allows the plant to osmoregulate much more efficiently and grow at lower elevations where it is submerged by seawater longer.

The plant's invasion has had tremendous economic impacts. The lambs that produce pré-salé (salt-marsh) mutton can no longer breed in the Normandy marshes because the animals don't eat *Elymus athericus*.

All of these invasions share two unifying characteristics: First, they all occurred in areas where humans had changed the physical or biological environment. Second, these plants behaved in a way we would not have predicted and didn't fully understand at the time. Today, however, with substantial experimental work, we can explain almost all of these cases quite well.

Metamorphosis

It's important to note that large nations like the United States and China contend with species that are native to one region but invasive in another. In the United States, the most famous example is cordgrass (*Spartina alterniflora*). A native of the eastern United States, cordgrass has created a huge invasion problem in California, Oregon, and Washington.

Miscanthus giganteus, a sterile hybrid of two Asian parental species, is one of the two carbon-fixing (C4) plants that have received the most attention as potential biofuel crops in the United States. The possible use of *Miscanthus* as a feedstock for biofuels is cause for concern among invasion biologists. *Miscanthus* is a sterile allopolyploid hybrid, and both of its parental species are invasive in some circumstances. One of the parents is *Miscanthus sinensis*, which is listed as an invader by several states and state agencies. In fact, the Tennessee Exotic Pest Plant Council lists this as a potential invasive problem with cited actual invasions in certain settings in the state. But Tennessee is not the most threatened area. *Miscanthus sinensis* escapes from various ornamental plantings and forms large, highly-flammable clumps that then spread.

The other parent of that hybrid is *Miscanthus sacchariflorus*, which is banned in Massachusetts because of its invasive characteristics. Those who are excited about the *Miscanthus* hybrid point out that it has been grown in Denmark for over 20 years without becoming invasive, contending that it won't become an invasive elsewhere. Anyone who knows anything about biological invasions knows that there is often a lag time—lasting decades or even centuries—between the time the species are introduced and the point at which they become invasive. Often, the transition from innocuous plant to aggressive invader occurs rapidly and the plant suddenly explodes and spreads across the landscape.

Consider the case of Brazilian pepper, *Schinus terebinthifolius*, which was introduced to South Florida, including the Everglades, in the mid-19th Century. The plant grew as a harmless ornamental in people's backyards until around 1900, when it began to spread rapidly. It is now the most troublesome invasive plant in Florida and one of the most invasive plants in the entire nation. In Florida it dominates about 300,000 hectares (740,000 acres). What likely triggered the spread was the lowering of the water table through provision of water for human use and agriculture.

Wild lettuce varieties, *Lactuca scariola* and *L. virosa*, were introduced to Great Britain by the 16th century and existed for 300 years as a harmless roadside weed. Then, in the early 20th century, wild lettuce began to spread rapidly and is now one of Great Britain's major weeds.

Because *Miscanthus* is a sterile allopolyploid that does not set seed, people assume there is nothing to worry about, but as I have pointed out, through vegetative reproduction, even a totally sterile plant can become invasive. *Spartina anglica* was originally a sterile hybrid. It was first noticed in the late-18th century in Great Britain after our *Spartina alterniflora*, cordgrass, was introduced by accident. Every so often it would hybridize with the native *Spartina maritima* and produce a rather large plant. It's worth noting that such hybrids are often very vigorous and larger that the original plant species. The plant grew harmlessly for almost 100 years, until 1890, when one of these sterile plants underwent a spontaneous mutation, doubling its number of chromosomes. Instantly, it became fertile, because each chromosome now could pair with another one, and spread like wildfire around Great Britain. It converted gently sloping mud flats into badly drained marshes and destroyed a number of important conservation habitats and changed a number of industries.

Spartina anglica has since been released accidentally in Washington and California. It is spreading rapidly and destroying shell fisheries.

In view of how these plants, once regarded as innocuous, have become troublesome pests, we should be concerned about the *Miscanthus* hybrid, particularly since we know that both parents are invasive in some circumstances and that sterile allopolyploids sometimes become fertile.

The University of Illinois is now pursuing research on use of *Miscanthus* as a biofuel crop, while we in Tennessee have turned to switchgrass, with support of the president and our governor. Unfortunately, switchgrass has many of the same characteristics I have noted among these other plants, and it is also completely fertile. It's important to note that switchgrass is not invasive in its native range, the eastern United States. Tennessee has acres and acres of switchgrass, and we could have more. The plant is, however, invasive west of the Rockies where it has been introduced, and it is on pest-plant lists in at least two of western states. Switchgrass has at least two ecotypes. One is tetraploid (four sets of chromosomes) and the other is hexaploid (six sets) and octoploid (eight sets). So it is sort of a typical polyploid weed and grows really rapidly in a variety of habitats.

Even though this plant has been recognized as invasive in parts of the West, we have not carefully studied the circumstances under which it becomes invasive. I am not saying that we should not proceed to explore biofuel crops, but I am suggesting that we must consider a plant's potential for invasiveness along with its other—more desirable—characteristics. If we fail in this endeavor, the resultant invasion will not be trivial to redress, particularly where grasses are involved. Biological control (control through introduction of insects or pathogens) of grasses is difficult and there's always the risk that a biocontol agent would begin eating grassy food crops. Use of herbicides to halt the spread of these crops would involve huge tracts of land at enormous expense and at potential risk to the environment.

Many people believe that if a plant is sterile it doesn't pose a threat. That is clearly not the case. Another sterile plant that threatens aquatic ecosystems is Caulerpa taxifolia, *the famous algae killer native to the Western Pacific off Australia. This hardy pest's use as an aquarium plant led to its release into the Mediterranean Sea, where it has since spread quickly. The plant made its way from the Stuttgart Aquarium to the Oceanographic Museum of Monaco. The staff at the Monaco aquarium purged their tanks by dumping the water out the window into the Mediterranean. In 1984 scientists discovered an area of the plant about the size of a speaker's podium. Today, the plant covers about 1500 hectares (3,700 acres) off the coast of Spain, France, Monaco, Italy, and Croatia and has devastated the fisheries. It's worth noting that this plant is a male clone produced by mutation in the late 70s or early 80s in the Stuttgart Aquarium. The plant is expected to continue to spread.*

Current Research on Cellulosic Ethanol in China

by Guo-Qiang Zhuang

Guo-Qiang Zhuang *is a professor with the Laboratory of Environmental Biotechnology, Research Center for Eco-Environmental Studies, Chinese Academy of Sciences.*

In the past two decades, China has gone from being independent of imported petroleum to becoming a net importer. In 2006, China imported about 180 million tons of petroleum, or 47 percent of total consumption. In the next 20 years, according to projections by the International Energy Agency's World Energy Outlook, oil production in China will not increase, but demand will rise dramatically.

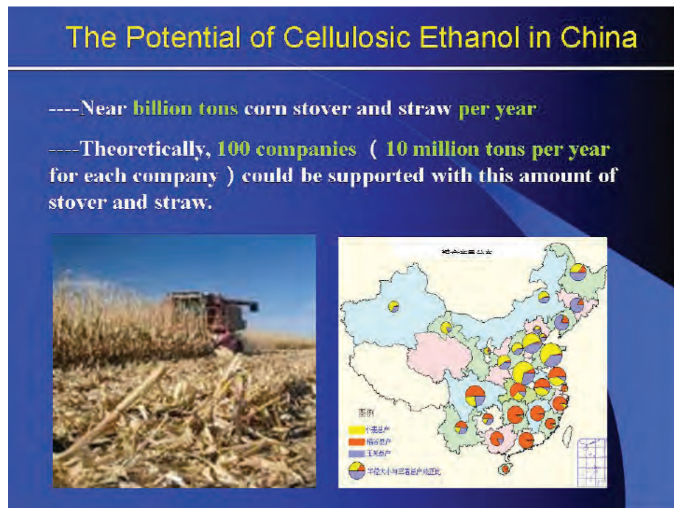
By 2030, petroleum imports are projected to peak at about 70 percent of total consumption, assuming that oil is available for import. Energy shortages represent an emerging threat to China's national security and long-term economic development. Development of biomass energy will therefore be necessary to move the country beyond a petroleum based economy. China, however, due to its large population, is limited in the amount of biomass that can be diverted from the food supply.

In 2000, China granted licenses to five plants owned by four companies to produce corn ethanol in the provinces. Annual production of ethanol by these plants is 1 million tons. At this rate, if all the fuel produced in China were to contain 10 percent ethanol, there would still be a shortage of 4 million tons. To prevent a shortage of affordable crops for human consumption, China must look to other forms of biomass for fuel production.

Of the many potential sources of biomass available in China, one of the most promising is lignocellulose, which can be converted to energy. China already produces nearly one billion tons of corn stover and straw per year. With this amount of available biomass, 100 companies could theoretically produce 10 million tons of cellulosic ethanol per year, creating new jobs and increasing the income of farmers.

R & D of Cellulosic Ethanol

Though the basic system of producing liquid fuel from biomass is fairly simple, involving the fermentation of lignocellulosic biomass and extraction of ethanol, there are a number of challenges to perfecting the technology and making the process economically feasible. One difficulty is that the sugars that are fermented to make the ethanol, a form of alcohol, are difficult to extract from the lignocellulose.



In recent years, several laboratories in China have focused on the research and development of cellulosic ethanol. Two of these labs have started up experimental-scale pilot plants, and this year three more will perform pilot scale experiments.

- The first laboratory in China to focus on cellulose is led by Professors Peiji Gao and Yinbo Qu at Shandong University. Their research explores the interactions between the cellulose binding domain and cellulose, and the short fiber generating factor.
- At the Institute of Process Engineering of the Chinese Academy of Sciences (CAS), a group led by Professor Hongzhang Chen has devised a means to create textile products from the long fibers of cellulose while separating the short fibers unsuitable for textile production to produce cellulosic ethanol.
- Professor Fukun Zhao, with the Institute of Biochemistry and Cell Biology at the CAS, is exploring the structure and function of animal cellulase.
- Professor Qiang Yong at Nanjing Forestry University is exploring the pentose-hexoses simultaneous fermentation, and genetic modification of pentose-fermenting strains.
- Professors Yanhe Ma and Keqian Yang with the Institute of Microbiology at the CAS are using metabolic engineering to perform cellulosic conversion by *Clostridia* bacteria.

- Professor Xiaomong Bao at Shandong University has explored the conversion of wood sugar, or xylose, using recombinant yeast.
- At the Research Center for Eco-Environmental Sciences, Professors Hong He and Guoqiang Zhuang are exploring the conversion of cellulose into sugar alcohols.

At the pilot-plant scale, two major research efforts are underway exploring two basic approaches to finding economically and technically feasible processes to produce liquid fuel from lignocellulose.

Researchers led by Professor Hongzhang Chen at the CAS are working to perfect a technique to convert cellulose into ethanol using enzyme hydrolysis. Four laboratories at the CAS are part of the collaborative research group, including Professor Chen's group at the Institute of Process Engineering (IPE), the Research Center for Eco-Environmental Sciences group led by Guoqian Zhuang, a group led by Yinhua Wan at IPE, and a group led by Keqian Yang at the Institute of Microbiology.

This process uses steam explosion—exposure to high pressure steam—to produce cellulase and initiate the saccharinization and fermentation stage of ethanol production. Though we find this a promising approach to converting biomass to ethanol, we have encountered a number of barriers to making the process technically and economically feasible.

- Enzyme activity is low.
- Temperature is not suitable for hydrolysis due to the sensitivity of yeast used in the process.
- Energy consumption in the process is high relative to the low amounts of ethanol produced.

The cost to produce a gallon of ethanol is between $2.40 and $2.60, while the cost to produce corn ethanol is about $1.80 a gallon.

In addition, we are exploring ecological studies at different regions across China to screen and identify cellulose-utilizing micro-organisms from which we can find some promising strains with high enzymatic activity. Our hope is to make the new process using steam explosion and hydrolysis to convert lignocellulose to ethanol profitably in five to 10 years.

Another research team involving partners with the East China University of Science and Technology and the Tinguan Group is exploring a slightly different technique using acid hydrolysis to convert lignocellulose to ethanol.

The Chinese government considers these endeavors extremely important and has offered financial backing through the Ministry of Finance, the National Development and Reform Commission, the Ministry of Science and Technology, and the National Natural Science Foundation of China. Private companies are backing the research as well, including COFCO, a Chinese food company, and the Tianquan Group, which wants to invest in basic research and in a pilot plant scale experiment of cellulosic ethanol.

In short, cellulosic ethanol may be the most promising solution in China as a substitute for petroleum products in the near future. If we continue to make progress at the current rate and solve some of the technical and economic problems, by 2020, China could derive 15 percent of its fuel from cellulosic ethanol.

Landscape Design for Bioenergy Feedstocks

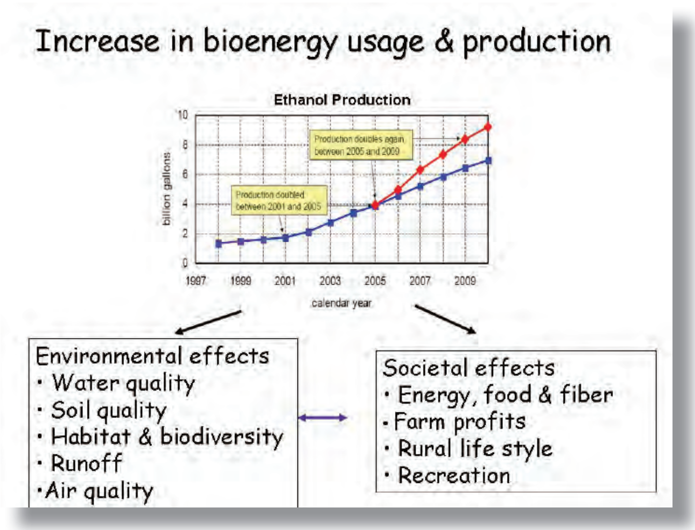
By Virginia Dale

Dr. Virginia H. Dale *is a group leader of Landscape Ecology and Regional Analysis in the Environmental Sciences Division of Oak Ridge National Laboratory.*

As researchers in China and the United States, we are at an important juncture in terms of developing new and better ways to produce energy.

As we explore the future of bioenergy crops, we're moving from examination of individual crops and farms to a study of how feedstocks lay out on the landscape—their patterns and implications for ecological processes.

Bioenergy usage and production—chiefly ethanol—is expected to increase. In fact, projections of ethanol production have had to be revised upward based on new data and because of changes in U.S. energy policy. Bioenergy production and use doubled between 2001 and 2005 and is expected to double again between 2005 and 2009.



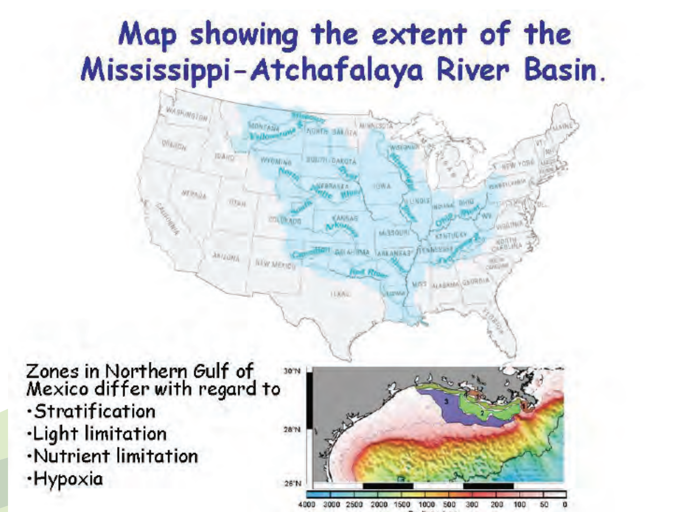
Larger-scale effects are also associated with bioenergy production. Many of the decisions about what to plant and how to plant it are made at the field scale. But as a landscape ecologist, I want to encourage us to think not just at the field scale but on the scale of an entire watershed.

The Big Picture

The University of Tennessee currently has a study at the Milan Experiment Station, which focuses on a small watershed in West Tennessee. By studying this smaller watershed within the context of the entire Tennessee Valley, we are hoping to understand what takes place in much larger watersheds.

The Mississippi-Atchafalaya River Basin—covering 41 percent of the entire United States and much of the area east of the Rocky Mountains—drains into the Gulf of Mexico. The Gulf is experiencing hypoxia, a condition reflecting very low dissolved oxygen concentrations in the water. Hypoxia typically begins with excessive nutrients buildup—caused by agriculture as well as from atmospheric deposition. Opportunistic bacteria—cyanobacteria and algae—consume these available nutrients. The nutrients are then sequestered into the organismal biomass, and then these algal blooms die. As the algae decompose, they deplete the oxygen in the water, causing hypoxia. Subsequently, those marine organisms that can swim to healthier waters do, but those that cannot die. For this reason, hypoxia has severe economic consequences for fisheries.

The hypoxic zone created by the Mississippi-Atchafalaya drainage changes in size and location from year to year but has grown progressively larger in recent years.



I chaired the hypoxia advisory panel of the U.S. Environmental Protection Agency (EPA) Science Advisory Board, which included 24 international scientists who worked for more than a year to determine the best solutions for the problems that we're observing in the Gulf of Mexico. Our 300-page report has just been released. (http://www.epa.gov/sab/panels/hypoxia_adv_panel.htm)

Our leading recommendations for reducing the nitrogen and phosphorus factors that influence hypoxia are 1) conversion to alternative cropping systems, using perennials or alternative rotation systems and 2) promotion of environmentally sustainable approaches to biofuels production. We focused on biofuels production because there currently is a huge push toward biofuels produced from corn. What we are recommending is sustainable perennial cropping systems.

The challenges for thinking about a landscape design for biofuels feedstocks are large. One issue is that the data on the environmental impacts are available only at the farm scale and at the very large watershed scale. What is lacking is information on the in-between scales. This dearth of information is of concern because the effects at the different scales are not linear. In short, we cannot sum up all the farm effects and come up with the effects across the entire watershed; there are very few metrics for cross-scale comparison.

The landscape design considers human needs as well as how decisions are laid out on the land, including the type of feedstock and where the feedstocks are planted as well as the use of fertilizers, insecticides, herbicides, and management systems. In exploring how those patterns affect the overall processes, benefits to ecosystems services as well as the environmental costs need to be considered.

Richard Forman, a premier landscape ecologist and a professor at Harvard University, did a study of how land management decisions should be laid out. He said the very first thing that should be considered is water and biodiversity concerns. Then we should look at cultivation, grazing, and wood products, and clearly bioenergy fits in here. Next we should consider the location of sewage and waste. And finally, we should look at the locations of homes and industrial facilities.

In short, Forman recommends that, in a pristine world, we should think about water and biodiversity first. But this is not a pristine world, particularly in China, where people have been occupying the land for thousands of years. The reality is that planting under pristine conditions is hardly ever possible. Indeed, existing development often constrains opportunities for land management. Since the land is already in human use and given that food production occupies much of the land, we are not starting with a pristine system.

With biofuels feedstocks, there is an opportunity to start anew. We must contend with existing conditions, but we can strive to design a landscape that best accommodates our energy needs as well as our concerns about the environment.

Landscape Design

Our bioenergy choices include such considerations as production levels, soil quality, weather conditions, past land-use practices, farming systems and practices, plowing techniques, and use of fertilizer, which are all influenced by societal choices and demands.

All of these many choices together combine to form what I call the landscape design. Often it is the water-quality impacts of these landscape decisions that have the greatest impact on environmental conditions.

When bioenergy use and the spatial implications are considered, it is useful to expand considerations beyond feedstock production. The other spatial parts of the equation involve harvesting, transport, conversion, production, separation, and the downstream markets. Numerous studies have shown that the spatial co-location of all of these has a great influence on economic viability and sustainability.

Sustainable feedstock production requires modeling of these multiple components. The feedstock must be placed onto a truck or train or other transportation system and delivered to a feedstock refinery. The design approach should incorporate all of these components, interactions, and changes at different scales and examine how these conditions contribute to sustainable environmental and socioeconomic conditions. We have to sustain the environment, but we also have to be able to sustain the choices society makes.

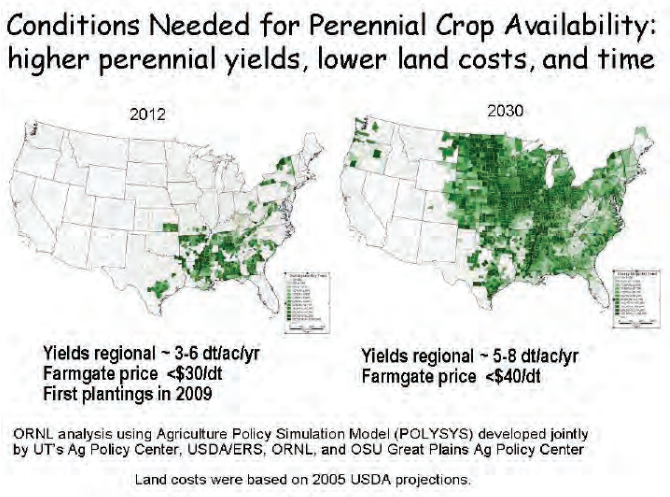
The innovations of this landscape design involve not just thinking at the farm level but also at the watershed and the regional perspective. Integrated environmental and socioeconomic dynamics, alternative regimens and policies, spatial optimization, and scale must all be considered.

By putting options in models and then interfacing them with field experiments at a fairly large scale, we can learn about some of our options before we implement them. This combination of modeling and field scale experiments provides an opportunity to gauge the effects of our decisions at multiple scales. We are just now at the point where we can pursue this modeling approach to improving our understanding of bioenergy systems.

Landscape design involves thinking about multiple factors: crop selection and location, type and location of the bioenergy conversion facilities, the trade off between energy and food crops, land cover, and carbon storage.

The use of lignocellulosic biomass from perennial crops, corn stover, or cotton stocks depends on the crop-management approach, how you're plowing or not plowing, initial soil carbon levels and soil types, and temperature ranges. There is a gradient in temperature and moisture across the United States, so different optimal conditions across the landscape can be identified as places where it is better to collect the corn stover or cotton stocks for lignocellulosic biomass.

Studies have shown that there is great variability in the collection of corn stover in the United States, and I imagine the same is true in China, in terms of gross production versus collectable stover. If we look at perennial crop availability, we must consider yield, land cost, and the time required for a perennial crop to grow and mature. When considering projections of lignoceelulosic potential in 2012 and 2030, the map of potential yield for 2012 is very different from the map for 2030 because of the time for the crop to be established and grow.



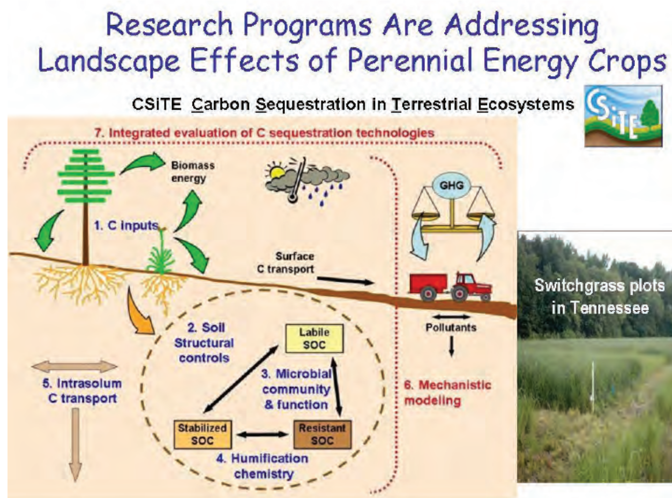
I am focusing on perennial crops because, in order to be sustainable, landscape designs should move toward perennial crops where possible. The corn option and even the corn stover option is not going to be as environmentally suitable in places where we can grow perennial crops, particularly in terms of soil carbon resulting from deeper root distribution. Improvements in both soil carbon and root distribution are experienced as farming moves from traditional crops to no-till and perennial crops. Switchgrass in particular improves carbon storage in the upper 10 centimeters of the soil, and root penetration increases soil porosity and infiltration and reduces compaction. These factors are compromised as we take corn stover off the land. The positive landscape effects of perennial energy crops occur under certain conditions when we replace annual crops or pastures, not necessarily forest land.

It's most beneficial to grow these perennial crops where we can use minimal tillage and support a cover-crop management system. In such situations, these perennial crops will require fewer nutrient and chemical applications than annual crops. Where possible, the use of native or noninvasive species should be encouraged and the harvest should be scheduled so as not to conflict with bird nesting times. There is no question that birds will occupy these perennial systems.

A number of research programs are tackling these landscape issues, including ORNL's Carbon Sequestration in Terrestrial Ecosystem study (CSiTE). CSiTE is studying switchgrass plots in West Tennessee and looking at elements such as carbon inputs, soil structure, the microbial community, the chemistry of the soils, and carbon transport.

Perennial Issues

Among the challenges being addressed is determining conditions under which the bioenergy crop systems are sustainable. In response, researchers at Oak Ridge National Laboratory have identified some landscape characteristics and stream and soil conditions that we think represent candidate metrics for measuring the sustainability of these systems over time.



In many cases, cultivation of bioenergy crops represents a dramatic change in agricultural systems, and once these systems have been altered, they are rarely restored to their previous forms. Ultimately, farmers can manage the initial landscape conditions, the change, or the historical restoration, but the latter represents a difficult proposition. Or farmers can adapt to the new conditions and try to manage them to meet environmental goals.

One of the critical decisions farmers make involves choice of crop. Researchers are trying to identify crops that can be used for bioenergy and that are compatible with the existing characteristics of the ecosystem in which they'll be planted. If farmers are planting a field of annuals, also planting a buffer of perennials around the field can improve the soil conditions, reduce runoff, and improve water quality. There are also benefits in restricting land-use changes to hardy locations and avoiding alterations to more sensitive areas.

Ecological restoration is costly and in many cases impossible to achieve; a more reasonable option involves adapting to new conditions. Land managers should plan our adaptation strategies before making changes to the system through the introduction of perennial crop systems. These altered systems are not natural, but they often possess properties that make them important to continuation of desirable ecological conditions.

The changes that are being made to the landscape in growing perennial biofuel crops can have significant impacts that extend well beyond the edge of the field. Indeed, landscape changes occur simultaneously with other environmental changes. In evaluating bioenergy strategies, we need to think more widely about biodiversity, invasive species, air pollution, acid deposition, climate change, and the combined effects of these factors.

Many of the farm decisions are made at the farm scale, but the effects extend well beyond the edge of the field. The cross-scale effects can be large and difficult to understand and measure, particularly in the context of how they are related and combined. Thoughtful landscape design offers a way to minimize environmental impacts associated with bioenergy production. There will be environmental impacts, but we need to work at minimizing them. The emerging ecosystems that will support bioenergy feedstocks require a lot of attention, but they also promise opportunities for producing fuels that reduce many of the environmental impacts associated with the continued dominance of petroleum-based products.

Acknowledgement: *This research was sponsored by the Laboratory Directed Research and Development Program of Oak Ridge National Laboratory (ORNL), managed by UT-Battelle, LLC for the U. S. Department of Energy.*

Carbon Sequestration by Terrestrial Ecosystems and its Role in Biofuel Development in China

by Dr. Sheng-Gong Li

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

The major concern of the Synthesis Research Center of the Chinese Ecosystem Research Network is the sequestration of carbon or CO_2 by ecosystems. We are exploring whether we can alleviate or offset global warming, directly reducing atmospheric CO_2 if photosynthesis exceeds respiration. We also want to know whether we can provide sufficient biomass for bioenergy production, indirectly reducing carbon emissions from fossil fuel combustion by using bioenergy as a sustainable source of energy.

China is a major consumer of fossil fuel, second only to the United States, and carbon emissions contribute greatly to global warming, which is caused by an imbalance between carbon emissions and carbon sinks. Terrestrial ecosystems are a large carbon sink, but there are considerable annual variability and uncertainty about the critical role the ecosystem can play in balancing the global carbon budget.

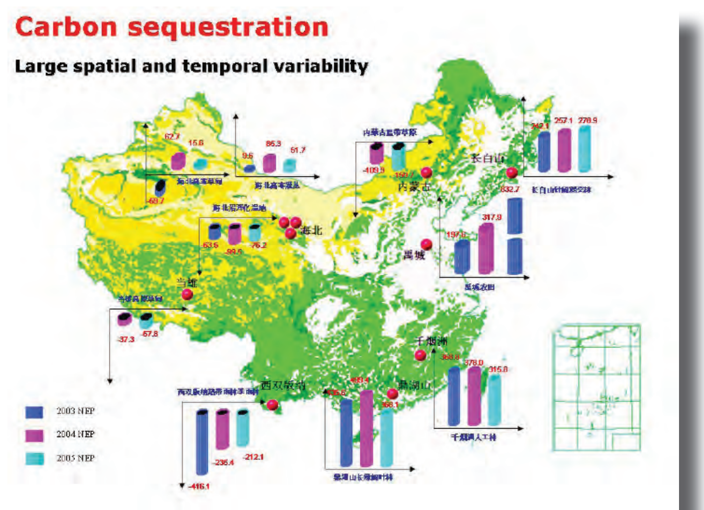
China is a country with diverse ecosystems, a dense population, and a shortage of energy to meet its needs. China has shown impressive economic development over the past 30 years, with a growth rate of gross domestic product of 8 percent annually. That progress has been accompanied by intensive human activities and extensive eco-environmental pressure. Some of the environmental impacts include loss of biodiversity, drought and flooding, ecosystem degradation such as land desertification, acid rain and nitrogen deposition, air pollution, soil erosion by wind and water, and montane glacier melting and treeline retreat. But the key issue is the energy shortage, which is a bottleneck for economic development.

Carbon Sequestration Challenges

A number of questions remain unanswered concerning the role that carbon sequestration plays in China. For example, what is the role played by terrestrial ecosystems? What are the temporal and spatial patterns of carbon sources or sinks and what are the driving forces? What are the responses and feedback of ecosystems to global change? Are there any efficient countermeasures to mitigate the effects and adapt to global warming?

China's diverse ecosystems fall into four categories. The forest occupies only 16 percent of total land area, or 160 million hectares (396 million acres), and 29 percent of that, 47 million hectares (116 acres), is artificial forest. We have 400 million hectares (988 million acres) of grassland, or 40 percent of the total land area. Farmland accounts for about 14 percent, or 133 million hectares (328 million acres), and wetlands 38.5 million hectares (95 million acres) or 4 percent of total land area.

Carbon storage as measured in billions of tons varies from system to system. Above-ground carbon storage is far less than below-ground storage, about 3 percent of the total. Carbon storage in the soil is by far the greatest at 185.7 billion tons. Total above-ground storage by vegetation type—which includes forest, woodland and shrubs, grassland, farmland, and wetland—amounts to 5.7 billion tons. If carbon is released from the soil, it will be a very big contributor to global warming. We therefore need a better understanding of sequestration by typical terrestrial ecosystems in China.



To better understand how the ecosystem functions, a large regional network was established in 2002 under the leadership of the Chinese Terrestrial Ecosystem Flux Observational Research Network (ChinaFLUX). After five years of research, we found large spatial and temporal variability in carbon sequestration. Some variation is due to the type of land cover. We also found variability in carbon sequestration related to temperature and precipitation.

Our major concern is to determine what will happen in a period of global climate change, specifically what factors will be predominant, and how climate change may affect production of bioenergy. To date, we have only preliminary results in the form of a biometrical estimate. At present, for the entire Chinese terrestrial ecosystems, the carbon sink size is 4.3 billion tons. We found that forest sink size is decreasing, due to plantation harvesting, deforestation, and reforestation over the past 50 years. The grassland sink is marginal, and farmland and wetland sinks neutral. Computer models predict that in the next 50 years the carbon sink will gradually decrease.

There Are Choices

China has begun and will continue to make efforts to green the landscape. What are the options we have to deal with global change and sustainability in China?

China encourages the production of bioenergy as a substitute for oil to meet the needs of its growing economy and to build an environmentally friendly society. In January 2006, China implemented a national law on renewable energy. We are also developing biofuels such as biodiesel, ethanol, and gasohol, and building biomass-burning power plants for remote areas without electricity. We are in a state of transition from traditional uses of biomass, such as cook stoves, to modern energy uses of biomass, and we are adopting new energy-efficient technologies. We must reduce the amount of carbon in the atmosphere, and at the same time produce bioenergy from plant biomass.

The actions we can take now to mitigate and adapt to the effects of global warming are threefold. First is to increase the carbon sink by storing carbon in the soil through afforestation and reforestation and restore the ecosystem by removing grazing and converting farmlands into grasslands or forests. Second is to store carbon reserves. Third is to reduce emissions of greenhouse gasses, mainly CO^2, and develop renewable and alternative energy sources including biofuels.

In 1998, the Chinese Government issued a National Natural Forest Protection Project. The goal is to increase reforestation and afforestation and restrict harvesting of lumber, increasing carbon uptake. Together, the increased carbon sink will be about 44 tons, or 1.5 percent of CO^2 emissions in China. Forests are critical for long-term carbon sequestration, but the accumulation of carbon in forests is very slow. The selection of reforestation and afforestation for maximal carbon sequestration is still a challenge. We still need a cost/benefit analysis of carbon sequestration by forestation.

Another effort is to convert cropland to forest and grassland and protect grasslands from grazing. Over the past four years, the Chinese government has made great efforts to restore vegetation across the whole country. This has resulted in significant improvements to the environment. The contribution of this effort to carbon reduction has not yet been calculated. This is an area in which we need more research, but we can already see visible results. About 10 years ago, I visited a project area to control desertification by fencing livestock out. At the time, the land was barren and dry. It's still dry, but on a recent visit, farmers had successfully planted the fenced-in area in crops.

Objectives for Biofuel Development in China

There are three main goals for biofuel development in China. The most important objective is to reduce carbon emissions. The second is to alleviate poverty in rural areas. China is still a developing country, and 10 percent of the population still has no accessible electricity. The third purpose is to decrease energy dependence on imported fossil fuels.

At present China is next only to Brazil and the United States as a major player in biofuels in terms of net biofuels production and consumption. China currently produces about 1 million tons of bioethanol fuel each year. By 2010, bioenergy production will account for 1 percent of China's renewable energy consumption, and 15 percent by 2020. Key areas in biofuel development include

- Biogas from biowaste, such as methane production in rural areas
- Biomass gasification and solidification from agro-straws
- Biomass-to-liquid fuel, such as biodiesel and ethanol
- Straw-fired heat and power generation.

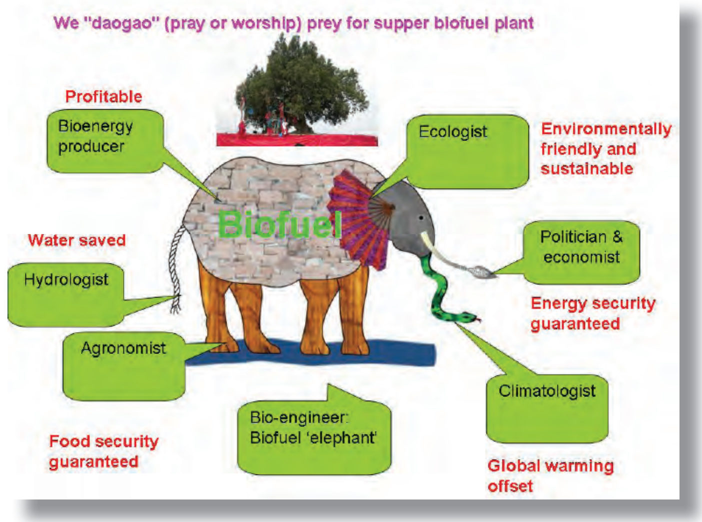
More than 200 species are potential biofuel plants. These include biofuels derived from forest species such as poplar and willow; grassland species such as bamboo and switchgrass; farmland species such as corn, sugarcane, sweet potatoes, and transgenic plants; wetland species such as the common reed and narrow-leaf cattail; aquatic species such as algae. In many areas of China, there are climate, nutrient, and water limitations to the production of biofuels. The northwestern and northeastern regions are primarily dry to semi-dry zones. The northwestern highlands are also dry to semi-dry, the more southerly highlands humid and semi-humid. Much of the northeastern coastal and interior zone is semi-humid. The most promising, humid, zone stretches from the northeastern seacoast to most of southern China.

We know the Panda likes to eat bamboo, but some researchers think bamboo is a good candidate for biofuels development, though the bioethanol is still difficult to extract.

Recent research estimates the potential of biofuel farmland production from grain sorghum at 7.6 million hectares (19 million acres), which could produce 28.5 million tons of ethanol and 28.5 million tons of biodiesel per year. Potential biofuel forest, about 7.6 million hectares (19 million acres), could produce 200 million tons of biodiesel from Chinese pistache and Barbadosnut.

Critical Issues

In China, we "daogao"—pray or worship—for super biofuel plants. Six general considerations are crucial in selecting the right plants. They must be profitable, they must be hydrologically benign in order to conserve water, they must not be grown at the expense of food crops so we can guarantee food security, they must be environmentally friendly and sustainable, they must guarantee energy security, and they must help offset global warming.



China is just beginning to address the technology required to produce alternative sources of energy. Moreover, energy use efficiency is very low, about 60 percent that of the United States and about 20 percent that of Japan, so there is a lot of room to improve efficiency and reduce carbon emissions.

We need time to determine if biofuel production will work or not. In terms of profitability, if the global price of oil remained at $70 a gallon, production of biofuels would be profitable. According to some reports, our oil reserves will be depleted within the next 39 years. Under that scenario, with no oil available from our reserves, biofuels could become very competitive. Other renewable sources for alternative fuels may be identified in the meantime, but for now, biofuel is a good choice.

The reality is that we require carbon sequestration in any event, not just to offset global warming, but also for our own survival. If there is no energy, there is no life, human, animal, or plant.

Urgent Requirements for Developing a Secure and Sustainable Environment

by Dr. Randall W. Gentry

Dr. Randall W. Gentry *is director of the Institute for a Secure and Sustainable Environment at the University of Tennessee (UT) and an associate professor of civil and environmental engineering at UT.*

Sustainability is a relatively new term that dates back to the Bruntland Report entitled Our Common Future. Gro Harlem Bruntland was prime minister of Norway and led the Commission that created this report in 1987.

When someone asks me to define what sustainability is, I like to go back and look at how the Commission defined sustainability, or rather the term sustainable development: development that meets the needs of the present without compromising the ability of future generations to meet their own needs. That is really what sustainability means, but many details lie behind that simple definition, for example, further understanding on how much variance may be allowed in terms of a process that may not be sustainable in the short term but that might lead to a further sustainable process in the long term.

I also like to mention Garrett Harden's "Tragedy of the Commons," his 1968 article in *Science*, where he used the analogy of the commons as a community-shared grazing field. Our commons are natural resources. Though Harden also addressed controversial issues such as population control, the simple message of the paper was this: in an unmanaged system, benefits are shared by a select few, whereas negative impacts are shared by all. For instance, reduced mitigation standards, leading to negative effects such as resource depletion, are shared by all. This is an obvious economic dis-equity. The problem is whether we can capture the extent of the lack of equity through modeling in a policy framework.

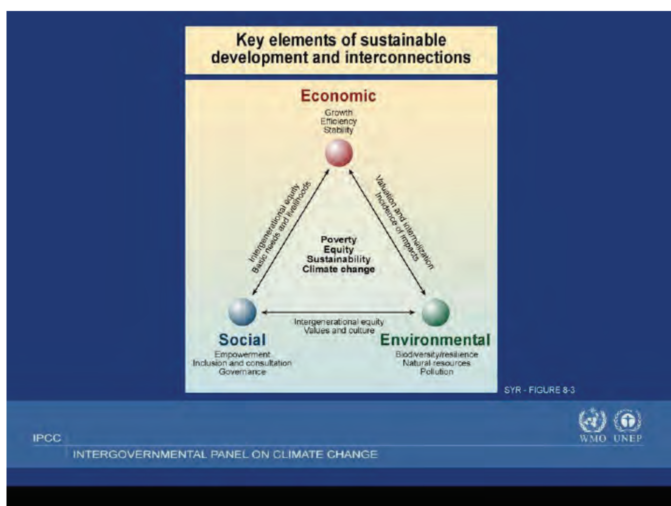
Coming of Age: Sustainability as Science

In recent years, sustainability is being taken much more seriously as a science than at the time of the Bruntland Report. Sustainability, in other words, should not be viewed as just some renaissance of the environmental movement. Sustainability is being viewed within a room of its own, to use recent language from the Proceedings of the National Academies of Science (PNAS). The National Academies have recently established a Science and Technology for Sustainability Program and a sustainability gateway on their Web site, an indication that they are taking seriously many of the issues we are addressing in this workshop. How then do we use science and technology to arrive at sustainable processes?

PNAS also recently published an editorial based upon a description of science based research by Arnold Stokes of the different motivations behind scientific research. Basic research, such as the work of physicist Niels Bohr, is motivated by a quest for a fundamental understanding of science without regard to any ultimate use of the knowledge. At the other end of the spectrum is applied research, as exemplified by the work of Thomas Edison.

The intersection of fundamental and applied research falls into a third category of motivation, like the use-inspired basic research of the French microbiologist Louis Pasteur. This is something of a hybrid category of research, which is a part of the quest for understanding of the fundamental processes of the behavior of natural systems and what is required to sustain them.

The Intergovernmental Panel on Climate Change (IPCC) has captured some of the elements of sustainability in the context of climate change.

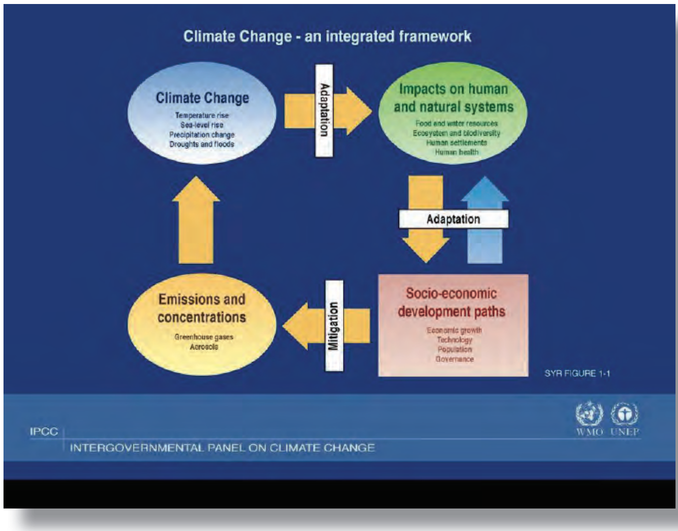


Sustainability encompasses three principal parts: economic, social, and environmental. We in the sustainability community are trying to understand the dynamic behavior among these pieces. When we talk about policy interactions, though, we tend to envisage some static, as opposed to dynamic, arrangement. That is not the way it should be, but it is the way we often implement it.

Most of us involved in decision making from an engineering or science perspective have really looked along just one axis, the economic/environmental axis. We have dealt a lot with economic and environmental issues, but I don't know that we have truly captured most of the social issues, or even completely understood what the dynamic response function among those different groups may be.

I am a groundwater hydrologist and engineer by training, so I do not work directly in the social aspects of sustainability, but I am becoming a bit more aware of the complex ways the social piece fits into the framework of research. Most engineers or scientists, in talking about decision making, use the term optimization a great deal. There is a point on a curve where we would like to be that is optimal for operating behavior. When we start addressing some of the social aspects, the dynamic feedback shifts. It may still be optimal, we can still use that language, but it is more of a Pareto surface that represents the best state at which we can operate. There are no better solutions, but as things change dynamically with these interactions, that Pareto curve moves about quite a bit.

Again in the context of climate change, the IPCC has developed a model useful to conceptualize the processes of adaptation and mitigation. As the climate changes, it affects human and natural systems. These systems respond to change by adapting, altering socio-economic developmental pathways and also by developing strategies to mitigate climate change, for example by trying to lower emissions and concentrations of greenhouse gases.



Most of our research within the sustainability community has fallen into one single area, or perhaps two, of these spheres. We don't very well know how to model these behaviors or these response functions among these spheres. If we do so, many times we do it in a static fashion that is not as dynamic as the process should be.

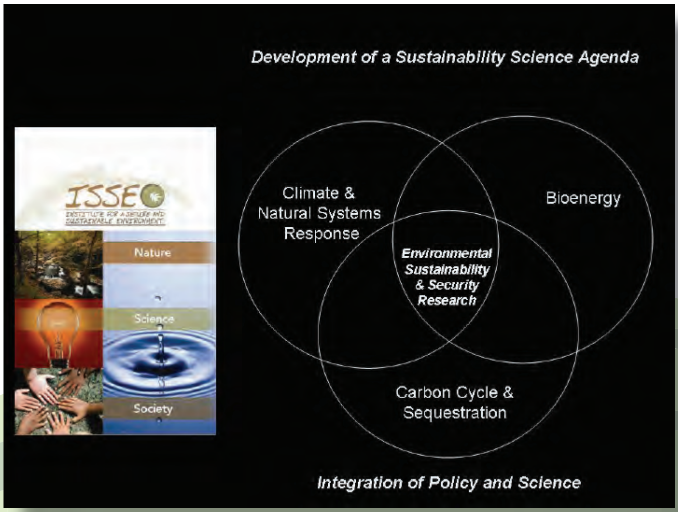
One step for integrating science and policy is to go beyond just optimization of a process to using a decision-making framework. If we take a step back and look at earlier research in the environmental risk sector, it seems that research had a much more dynamic framework for decision making than where we are today. We can go back and revisit some of those models and think about how they worked.

Let's consider, for example, that funding is available for a new area of research in bioenergy, and we have five different processes that we would like to evaluate. A concept of how policy and science could work together is the scenario of a policy framework that does not allow any research dollars or research direction that results in a process that is not sustainable. In that case, we have to pick some metric to define sustainable processes, perform some sort of life cycle analysis or full life-cycle analysis.

We capture all of the pieces that are pertinent to that process and we look at the energy budgets, the resource budgets. We determine whether there are any net losses or carbon neutrality issues in that process. If we don't view three of the five processes as ever being sustainable from that life cycle analysis, we won't invest in them.

But what if we approach near sustainability? The problem at this point is that we have a life-cycle cost. Are we willing to compromise to achieve a goal that is less than 100 percent sustainable? We can put a percentage on it. Perhaps we will allow this net loss because we think in 20 years, technology will catch up with the process, it will be improved, and the investment will have a payback.

We view the world through the prism of these two end goals or results: fossil fuel dependence and fossil fuel independence. We need to start thinking about the transitional states between those two. What will we allow over small time steps in order to get to that more independent framework? Can we accept quasi-sustainability for some short period of time? And what does that actually mean?



One approach may be to use the market system, working again through the policy framework and looking at market incentives for certain types of programs. To wean ourselves off gasoline, we might allow markets to shift to more of an ethanol-based market. We invest in corn ethanol for a period of time to allow market diversion into ethanol-based products. At some point we may begin putting incentives out for what we consider to be more sustainable processes, lignocellulosic ethanol.

As we consider the interactions between sustainability science and policy frameworks in the context of biofuels, we must keep our sights on the distant goal of achieving energy independence from the starting point of energy dependence, and work toward establishing not just one path to the future, but outlining all possible scenarios along the way using all the means at hand.

We are at the nexus between climate and natural systems response, bioenergy, and carbon cycle and sequestration. This is the area in which we can provide some help. But we also have to tie policy and science together and come up with a framework to do that. Though we don't have a solution for that yet, we have a number of researchers looking at the relationships.

ISSE's Niche

The Institute for a Secure and Sustainable Environment (ISSE) focuses on developing a sustainability science agenda. This is our perceived niche in advancing sustainability and security research.

ISSE's has a number of active program areas and researchers in various fields of expertise. In addition to our core group, the team includes faculty members and research faculty members across campus. These are think-tank type people who come together and look at the all the relevant resources on campus and the resources that exist within ISSE. They then form teams to address some of the issues that we have been talking about.

Program areas include agriculture and natural resources, education and social perspectives, energy and environmental policy research, environmental security—not just from the threat perspective but also from the perspective of resource scarcity, protection of the resource, and environmental sustainability—and water resources.

Within that framework we also have a group of centers that are housed within the institute. The Center for Clean products and Clean Technologies has been working with the U.S. Green Building Council and the U.S. Environmental Protection Agency on developing green building materials, databases.

Our Community Partnership Center is trying to integrate some of these new ideas into the rural community. Part of that work is in the biofuels initiative; you cannot have biofuels if the agricultural community does not buy into it.

The Southern Appalachian Information Node and the Southern Appalachian Man and the Biosphere Program is also located under ISSE's umbrella.

Every state has a Water Resources Research Center, and this is our U.S. Geological Survey, a U.S. Department of Interior-based center. Within that group is the Southeastern Water Resources Institute. One issue of concern is whether to allow bioenergy crops that are require irrigation, a policy decision. What if a farmer converts to a crop that has to be irrigated or requires additional agricultural inputs? Should we only invest in crops that don't require additional nutrients or water resources? Those are policy-based decisions. Once the policy is established we can determine the optimal solution.

Potential and Development Trends of Bioenergy in Southern China

by Dr. Shao-Qiang Wang

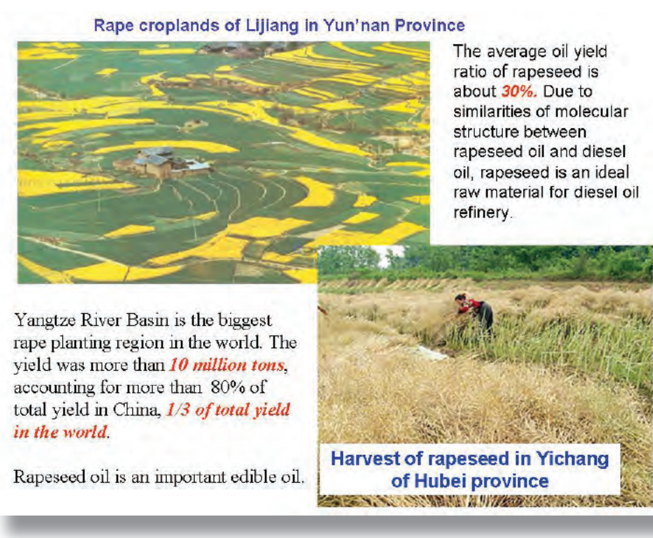
Dr. Shao-Qiang Wang *is the director of the Qianyanzhou Ecological Research Station, Chinese Ecosystem Research Network; the director of the Office of Research, and an associate professor at the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences.*

China has a large population with a small amount of crop land per inhabitant. Exploitation of non-grain bioenergy crops in China is therefore crucial in order to ensure security in the food supply. One of the most productive and promising agricultural regions in terms of cultivating biomass to produce bioenergy is southern China, which occupies one fourth of the total land area of China and enjoys abundant natural resources. Water is plentiful, annual precipitation is high, and the weather is warm in the summer and mild to cool in the winter. The area also enjoys a rich diversity of animal and plant species and has a huge potential for developing bioenergy.

Food Crops with Biomass Potential

Many crops that grow well in southern China have potential as biomass crops, whether the source is the edible portion of food crop plants; byproducts such as stems, stalks, and leaves; or non-food crops. Agricultural resources that hold potential as bioenergy crops include straw stalk, rapeseed, sugar cane, potato species, and forest resources.

- **Straw stover.** The byproduct of corn production, straw stalk is a clean and renewable source of bioenergy. The energy potential of 2 tons of straw stalk equals that of a ton of coal. Research on straw stalk focuses on three areas: gasification, production of solid fuel from the stalks, and generation of electricity from straw. The area devoted to cultivating maize, primarily concentrated in the Yangtze River Basin, represents 90 percent of the total area planted in rice in southern China, and the yield of straw stalk is about 150 million tons per year.
- **Rapeseed oil.** The Yangtze River Basin is also the biggest rape producing region in the world, with a yield of more than 10 million tons per year. This accounts for more than 80 percent of total annual production in China and one third of the total in the world. Rapeseed oil is an important source of edible oil. Average oil yield ratio of rapeseed is about 30 percent. In addition, due to the similarities of the molecular structure between rapeseed oil and diesel oil, rapeseed is an ideal raw material for diesel oil refinery.



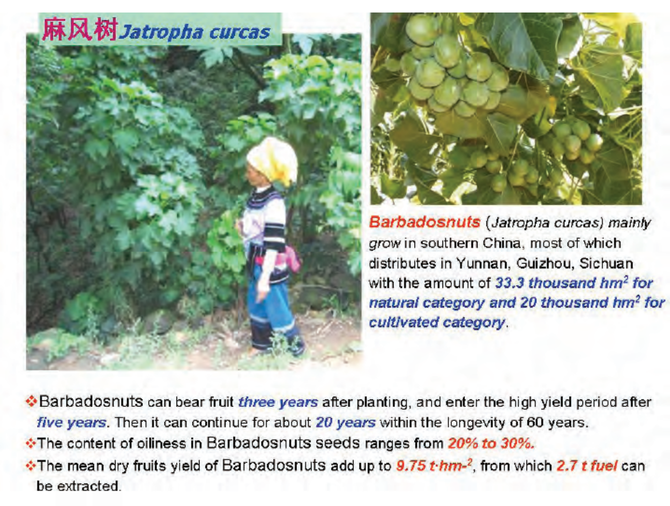
- **Sugarcane.** Grown primarily in nine provinces of southern China, sugarcane is another potential source of biomass to produce fuel. The total area of land planted in sugarcane from just four of those provinces—Guangdong, Guangxi, Hainan, and Yunnan—approaches 1.7 million hectares (4.2 million acres) with a yield of nearly 100 million tons. In addition to the sugar that can be refined from cane, syrup derived from sugarcane can be used to produce about 800,000 tons of alcoholic fuel. It takes about 20 tons of sugarcane to produce 1 ton of alcohol. Bagasse, the residue left after the sugar is extracted from the cane, can be used to produce biodiesel oil.

- **Cassava.** A tropical plant grown in eight provinces in southern China, cassava is a starchy tuber that is an important food crop and also a potential source of biomass. In 2005, the yield from 438,000 hectares (1.08 million acres) was more than 7 million tons. The starch ratio of fresh cassava roots is about 30 to 35 percent, and it takes about 7 tons of roots to produce 1 ton of alcoholic fuel.
- **Sweet potato.** While sweet potato grows well throughout southern China, the highest yield occurs in Sichuan Province. In 2004, sweet potato cultivation was about 800,000 hectares (1,977,000 acres), and total yield was 1.7 million tons, or 15 percent of the total yield in China. Sweet potato is easily adaptable as a source of fuel; 1 ton of alcohol can be made from about 10 tons of sweet potato.

Energy Forests

In addition to arable farmland in southern China, there are also areas of marginal lands suitable for developing energy forests. Many species of these trees have low soil fertility requirements and can grow on wasteland, mountain land, and in soils with high alkalinity unsuitable for other crops. These marginal lands can be productive for bioenergy without competing for land in valuable rice producing areas. Forest biomass energy plays an important role in exploiting and using biomass energy in the southern region of China.

- **Barbadosnut.** The Barbadosnut (*Jatropha curcas*) grows mainly in three provinces in southern China: Yunnan, Guizhou, and Sichauan. The natural, or wild variety, thrives on about 33,300 hectares (82,290 acres), while 20,000 hectares (49,420 acres) of land are devoted to the cultivated variety. After planting, the tree takes only three years to begin bearing fruit, and at five years it is highly productive.



The oil content of the Barbadosnut seed ranges from 20 to 30 percent, and 2.7 tons of fuel can be extracted from a yield of 9.7 tons per hectare (3.9 tons per acre).

- **Guangpishus.** The Guangpishus tree (*Cornus wilsoniana*) grows in the Changjang River basin and in limestone areas of southwestern China. The oil yield ranges from 25 to 30 percent. Guangpishus bears fruit two to three years after insemination with inoculation, has a high yield for more than 50 years, and can live as long as 200 years. One tree can produce 50 to 150 kilograms (110 to 330 pounds) of fruit per year.
- **Oil camellia.** Found primarily in southern China, the oil camellia tree (*Camellia oleifer Abel*) bears fruit in the fifth year and produces a rich harvest by the eighth year. Gross yield from about 3.7 million hectares (9.14 acres) can reach 220,000 tons per year. The oiliness rate of the fruit is about 30 percent, and it yields 400 kilograms of oil per hectare (880 pounds per acre).
- **Tung oil tree.** Grown mainly in the Yangtze River area and southern provinces, the Tung oil tree (*Vernicia fordii*) has a special place in the economy of China. It mainly grows in the southern zones of the Yangtze River Basin, especially in Sichuan, Hunan, Hubei, and Guizhou provinces. Distributed over about 2 million hectares (5 million acres), the tree produces an annual yield of 120,000 tons of fruit, about 70 percent of the whole world's yield. The oiliness rate of the fruit is more than 70 percent, it bears fruit in three years, and it can produce fruit for 20 to 30 years.
- **Mastic tree.** Widely distributed throughout China, including the reaches of the Yellow River and Guangdong and Guangxi provinces of southwestern China, the mastic tree (*Pistacia lentiscus*) bears fruit in five to seven years and can live hundreds of years. The oil content is 42.5 percent and oil production rate 20 to 30 percent. The length of the carbon chains of the oil is similar to that of ordinary diesel oil, so it is highly suitable for production of biodiesel oil.

There are 6.3 million hectares (15.57 million acres) of winter fallow fields suitable for rapeseed production alone, with a potential yield of 10 million tons of biodiesel in southern China. In addition, most plants with potential for energy production are highly adaptable to a range of environmental conditions and can be planted extensively in wasteland and marginal lands, which are abundant in southern China. In Guangxi, Guangdong, Hainan, Fujian, and Yunnan provinces there are currently 13.3 million hectares (32.87 acres) of unused land where these energy plants could be grown.

Better Breeds, Higher Yield

To guarantee the industrialization of bioenergy, we must improve the quality and yield of energy crops by seed selection, breeding, and planting, and by expanding gross production by putting marginal lands into production.

At present, energy plants grow in the wild or under extensive management, which leads to degradation of the breeds and low productivity. By improving the breeds and enhancing cultivation methods, we can potentially achieve high increases in productivity.

In sugarcane production, for example, by selecting and fostering three new breeds that produce both energy biomass and sugar, we could realize a yield of more than 120 tons of stems per hectare (50 tons per acre) and 45 tons of fermented sugar per hectare (18 tons per acre). New rapeseed breeds selected and managed for high oil content could produce 55 percent more oil than current yield in the agriculturally rich middle reaches of the Yangtze River Basin.

While the promise of energy forestry is high, almost all the potential tree species for bioenergy are scattered in areas of southern China with low productivity. To reduce the cost of production and ensure a reliable supply of raw material in the future, we must first establish a base of energy forest located near transportation arteries and refineries.

In recent years, technologies have developed rapidly, and some companies in southern China have already started production of bioenergy. Although research studies on bioenergy were launched in China several years ago, we now need to conduct pilot testing comparing efficiencies of processing technologies. One factory established in Maoming, Guangdong Province, has been using vegetable oils from plants such as rapeseed, cottonseed, and beans as raw materials to produce vegetative diesel oil. This facility is already delivering biodiesel fuel used in ships, cars, and mining machinery. In Guangxi Province, about 30 manufacturers produce 0.7 million tons per year of alcohol from cassava, hardly enough to achieve benefits on a large scale. In 2006, the Chinese food company COFCO founded a 0.2 million ton fuel alcohol project in Beibu Gulf, Guangxi Province, using materials such as cassava. We need to conduct more research to determine which are the most technologically and economically feasible among these emerging technologies.

Production Scale, Production Cost

At present, biomass sources available to energy crops can't meet the needs for mass production of biofuel. At the same time, we lack measures to boost development of the energy industry, which leads to the high cost of biological energy products. In short, biological energy products have no competitive advantage in the marketplace. We need to put in place measures to breed more-productive energy crops, cultivate a base of energy plants, and implement supporting policy to accomplish these goals.

To increase production of energy products, we need to encourage rapid expansion of the area available for cultivation of these crops. Currently, there are several projects underway to meet that goal by 1) establishing a 400,000 hectare (988,400 acre) plantation for Barbadosnut in Yunnan, Sichuan, and Guizhou provinces in 2006-2010, 2) establishing a 50,000 hectare (123 600 acre) plantation for Guangpishus in Hunan and Jiangxi provinces in 2006-2010, 3) cultivating more than 6 million hectares (14.83 million acres) of high-quality rapeseed on winter fallow fields in southern China, and 4) expanding cultivation of sugarcane to 2 million hectares (5 million acres), and 1 million hectares (2.5 million acres) of energy sugarcane.

This increase in area under cultivation should result in an increase in output of 100,000 tons of fuel ethanol and 2 million tons of biodiesel.

Production of biomass from multiple sources—food crops other than the Chinese staple of rice, byproducts of these food crops, and forest products grown on marginal lands—must increase to help meet the growing energy needs of China without compromising food security. While significant progress is being made to improve yield of potential bioenergy crops, we must fine-tune the production technologies, overcome strategic infrastructure barriers to efficient distribution of biomass to refineries, and expand the amount of land in production for forestry biomass products. We will also need refinements in energy policy to ensure that China remains on target to meet its dual goal of increasing fuel production while guaranteeing food security.

Importance of Collaboration among Government, Academia, Industry, and Environmental Organizations

by Dr. Dennis Ojima

Dr. Dennis Ojima *is a senior scholar with the H. John Heinz III Center for Science, Economics and the Environment.*

The Heinz Center is a non-profit organization which is committed to providing objective scientific information to decision makers at the national and international level (www.heinzctr.org).

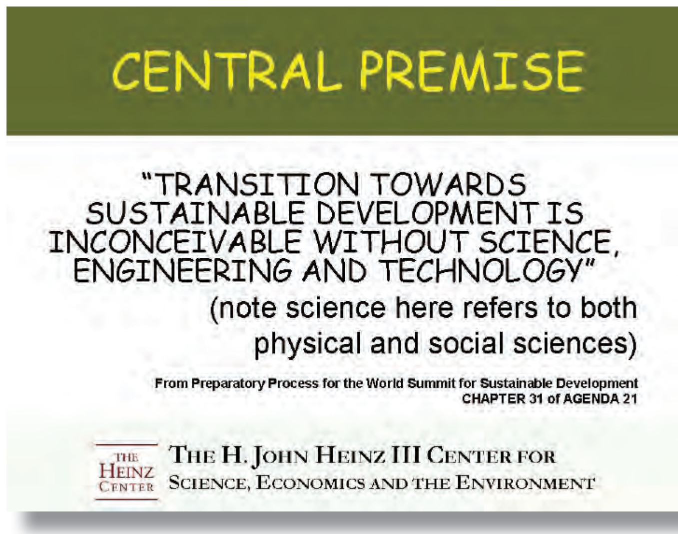
I am a research scientist who deals with carbon sequestration and biogeochemistry, but my new position at the Heinz Center involves using this science background to inform decision makers both in private and public sectors about environmental issues related to their interests.

In the area of global change, I am working with Bob Corell, director of the Global Change Program at the Heinz Center. He served as assistant director for geo-sciences at the National Science Foundation and has been a leader in global change science for more than 30 years. Bob has been promoting global change research nationally and internationally and is one of the founders of the US Global Change Research Program (www.usgcrp.gov).

Tom Lovejoy is the president of the Heinz Center and has been a leader in conservation and biodiversity for many, many years. I feel fortunate to work with these leaders in the environmental sciences and to be able to work with other leaders internationally and nationally to build greater understanding and to strengthen collaboration. I intend to share with you some of the insight I have gained over the last several months in dealing with energy strategies and the nuances within the current science-policy discussion of bioenergy development. I have incorporated some discussions related to sustainable development and concerns throughout the world about how we should develop bioenergy in a way that does least harm to the environment and to society.

Making the Transition

Beginning with the 1987 Brundtland Report and continuing with the 2002 World Summit on Sustainable Development in Johannesburg, it is clear that this transition towards sustainability is really built upon our ability to work together to harness and to use what we know scientifically and technologically in shaping a better future. And this will necessitate a melding of science and policy. Many of us who are trained as scientists don't really participate in the policy or decision making area as much as we should. We have, however, seen a growing body of engineers becoming involved with technology transfer, though the scientific community has been lagging in that regard.



As we investigate the environmental impacts of bioenergy development, we face several complex issues. Among them are potential impacts to ecosystems, biodiversity, water usage, and biochemistry related to nitrogen effects, as well as the impacts of invasive species. The linkage between social and environmental concerns is at the nexus of how we ought to move forward prudently in developing bioenergy strategies.

As we look at social concerns, technological capacity, and development strategies in the international context, we find that different regions of the world have very different concerns. Indeed, the concerns that we may have in the United States or Tennessee would be different from those for the arid lands of the high plateau in China, or in southern China or the China Plains. Clearly, strategies must be tailored to the specific characteristics of each region. Beyond the physical features, these regions differ in terms of the cost structures associated with technological transfers, R & D, and the impacts on local economies.

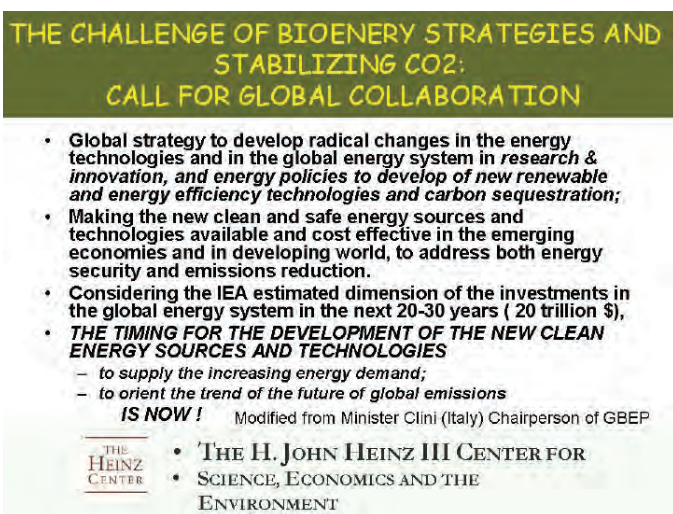
Policy and institutional structures play out at local, national, and global levels. Currently, scientists and policymakers are exploring various frameworks for policy development and potential roles for nongovernmental organizations (NGOs) and other institutions. These organizations are motivated because of the global interest in bioenergy's role in reducing greenhouse gas emissions—particularly carbon.

Major decisions are being made, but to date they have not been well coordinated. In fact, some of these institutions are actually tripping over each other. In response, the Heinz Center and other NGOs are trying to navigate through policy-related complexities and develop an appropriate road map. Such a road map would present a set of best practices or certification schemes to guide bioenergy development on the global scale.

As we look at the international landscape of bioenergy opportunities and constraints, we are in fact trying to determine what is feasible within particular countries and regions. China and the United States are defining different pathways to sustainable production of biofuels, which is appropriate because there is no one pathway. This is true despite the reality that bioenergy is relatively specific in terms of the overall energy domain. Nevertheless, there is quite a diversity in pathways and strategies that one might take, and these strategies must be tailored to fit the needs, environmental conditions, technologies, social structure, and resources available to each region.

Global Collaboration

While bioenergy strategies must reflect regional realities, there must also be overarching global collaboration.



Corrado Clini is chairman of the Global Bioenergy Partnership (GBEP), an international organization whose charter members include the G8 (the United States, France, the Russian Federation, the United Kingdom, Germany, Japan, Italy, and Canada) plus Brazil, China, India, Mexico, and South Africa (www.globalbioenergy.org/).

Clini insists that it takes a global partnership to really pursue innovative energy research and reduce fossil fuel emissions in terms of science, technology, and political frameworks.

Clean energy technologies must be cost effective if developing countries are to play a role in promoting sustainable development. These developing nations will require new energy sources that will allow them to be self-reliant.

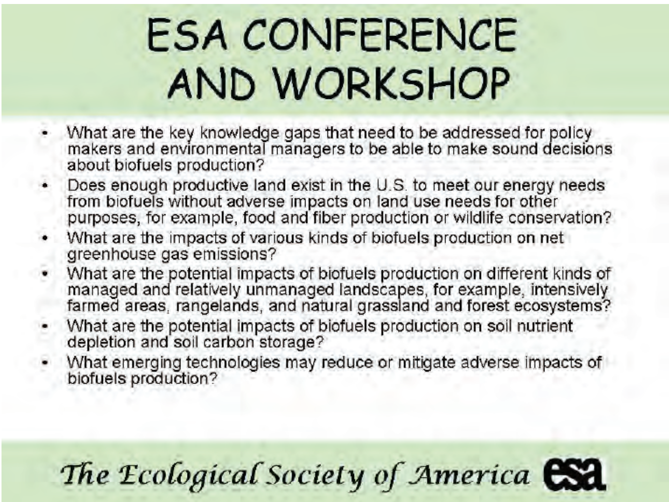
Globally, there are potentially large investments in bioenergy development, but we need to use these resources effectively and disburse them equitably throughout the world. And the time for action is now. In fact, Clini maintains that new clean energy sources and technologies are not being developed fast enough.

In developing these technologies, we are looking at a new energy framework that is not based on fossil fuels and at the limited areas where they are available. Indeed, in developing bioenergy resources, we're looking at a whole new set of markets and a whole new framework of doing business across the world. This reality has certain industrial groups and major decision makers quite worried because it will change the way we distribute power—both political power and energy. This change will have many ramifications in the political world and also in the private sector. Across the globe, all sovereign nations seek energy independence, and bioenergy can help them move toward that goal. But we're not talking about total independence. In fact, we're talking about biofuels use as a modest percentage of overall energy consumption, but one that is expected to grow significantly over coming decades.

Bioenergy will help developing countries transition away from some of the more greenhouse gas-emitting technologies toward ones that may provide better carbon sequestration. Many projections suggest that we will exceed the target cap of 550 parts per million (ppm) of carbon dioxide in the atmosphere, and we are already seeing the impacts of climate change at 385 ppm. Impacts will only increase as we move toward 450 to 550 ppm.

The Heinz Center is involved in several efforts related to global energy assessment and bioenergy partnerships. One is the Global Energy Assessment (GEA) Council, which essentially is an intergovernmental panel of experts on climate change. The GEA Secretariat is based at the International Institute for Applied Systems Analysis (IIASA) in Laxenberg, Austria. The Heinz Center has been asked to serve as the U.S. Support Office for the assessment, and Bob Corell is leading that effort.

The operating premise for a global energy partnership is based on how we make technological and scientific contributions to meeting our energy needs while reducing our greenhouse gas emissions. Currently, biofuels account for 1 percent of our road-transport energy consumption, and we are moving toward boosting that to 7 percent by 2030, according to an alternative scenario advanced by the International Energy Agency. Ethanol is expected to be an important bioenergy source, as is biodiesel. The Global Bioenergy Partnership is helping to address how best to move forward in our efforts to produce biofuels, as well as the related trade issues. Much of the organization's discussion has dealt with issues related to national and global security, and it hopes to move us toward certification and creation of best practice guidelines for biofuel production. The partnership's discussions also address such issues as biodiversity, changes in water or nitrogen applications, social equity, the risk of altering indigenous activities that might, in turn, change social and cultural patterns.



Currently there is quite a bit of concern related to sugarcane-based ethanol in Brazil and its effects on increasing deforestation rates. In response to these issues, the Dutch have moved to boycott or embargo ethanol imports into Holland or into Europe.

At its annual conference in March in Washington, DC, the Ecological Society of America (http://www.esa.org/) addressed the "Ecological Dimensions of Biofuels" and highlighted many of the issues that we have discussed at this workshop.

As a follow up, about 30-40 researchers, managers, technicians, and policymakers will work to establish a framework to guide various agencies and the private sector in incorporating ecological concerns into decisions regarding biofuel production.

The transition toward sustainable energy production and use is not possible without social, political, and scientific partnerships. Interdisciplinary and international partnerships like the China-U.S. Joint Research Center for Ecosystem and Environmental Change and others like it will help ensure that we move forward in developing a sustainable global strategy for developing biofuels production.

Bioenergy Sustainability Activities at the National Science Foundation

by Dr. Bruce Hamilton

Dr. Bruce Hamilton *is program director of the Environmental Sustainability Program at the National Science Foundation.*

Mission of the National Science Foundation

The National Science Foundation (NSF) is a federal agency with an annual budget of about $6 billion dollars. The mission of the NSF is to advance the frontiers of science and engineering through support of basic research and education. The NSF is at the front lines of research and integrating education into that research in a number of fields. In the context of bioenergy sustainability research and education, we have a number of technological programs in the works.

First, though, let me explain that the NSF essentially does not have any laboratories of its own. Almost all of its funding goes to universities in the form of grants and cooperative agreements to support projects at universities. We do, however, have a small business program, and a little more than $100 million dollars a year does go to small businesses through the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs.

The NSF is organized much like a university, with various departments, or directorates, for example the Engineering Directorate of which I am a member, the Directorate for Biological Sciences, and the Office of International Science and Engineering. Within each of these directorates and offices are various programs led by at least one program officer.

The Engineering Directorate has, for example, a program for biotechnology, biochemical, and biomass engineering; the catalysis and biocatalysis program; and a new environmental sustainability program, of which I am the program director. We also have programs related to bioenergy sustainability within the Biological Sciences Directorate, the Mathematical and Physical Sciences Directorate with its other divisions of chemistry and materials research, and in the Office of International Science and Engineering.

Grants Supporting Bioenergy and Sustainability

One of the areas that NSF has worked to develop over about the past 10 years is metabolic engineering, which is cited as an area for research support in Acts of Congress, including the U.S. Biomass Research and Development Act of 2000, which was renewed in 2005 by the U.S. Energy Policy Act. The Act calls for research on "metabolic engineering of biological systems to produce novel products, especially commodity products, or to increase product selectivity and tolerance with a research priority for the development of biobased industrial products that can compete in cost and performance with fossil based products." Over the past 10 years, NSF has led an interagency opportunity in metabolic engineering solicitation, calling for proposals from universities requesting research support. NSF is the host agency for this effort. Seven other federal agencies have participated in this call for proposals, including the U.S. Departments of Energy (DOE), Agriculture (USDA), the Environmental Protection Agency (EPA), and NASA.

One of the grants that has resulted from that call for proposals in metabolic engineering involves exploring genomic approaches to metabolic engineering of solventogenic *Clostridium*, which may one day be used as a fermentation agent to produce butanol as a biofuel. In addition, a number of large companies are working on this technology today.

Within NSF we have individual programs such as the biotechnology, biochemical, and biomass engineering effort led by Fred Heineken. We invest about $10 million dollars per year in grants for that program. One example is research in metabolic engineering of *E. coli* sugar utilization and regulatory systems for the consumption of plant biomass sugars, with Ramon Gonzalez, a faculty member at Rice University as principal investigator. This grant is funded at a little over $200,000 for two years. Another research effort in this field explores the functional and structural analysis of algal hydrogenase combinatory mutants. The principal investigator was Dianne Ahman at the Colorado School of Mines in Golden Colorado, home to the National Renewable Energy Laboratory (NREL), one of the sister laboratories of Oak Ridge National Laboratory (ORNL). Researchers at NREL collaborated with Dianne on this work. That is the type of collaboration between university and National Laboratories that we encourage at NSF.

Career Paths

A special category of grants is available to new assistant professors just starting out in research: career grants. As an example, one of these grants is to encourage research to harness fermentative metabolism to glycerol in *E. coli*, a new path to biofuels and biochemicals. Principal investigator Ramon Gonzalez from Rice won this grant, for a five-year project funded at $400,000.

Another project that involved the field of metabolic engineering resulted from a solicitation of a 10-year partnership with EPA on technology for a sustainable environment. A grant was awarded to explore biological hydrogen production as a sustainable green technology for pollution prevention. The principle investigator, Bruce Logan at Penn State University, submitted a proposal to our Small Grants for Exploratory Research (SGER) program. These SGER grants are not peer reviewed; instead we make decisions on these internally at NSF.

SGERs are relatively small, short-term grants for outside-the-box ideas. Logan won $100,000 for a one-year project to conduct a feasibility study on the potential for direct generation of electricity from waste water using a microbial fuel cell involving a living system rather than a chemical fuel cell. He was able to use the data he submitted to our peer review process to win a larger grant, more than $500,000 for a three-year study on improving power generation in microbial fuel cells.

NSF also has a fairly major plant genome research program, which also relates to bioenergy sustainability. One grant will support research on the genes required to make a soybean seed—think biodiesel. Some of my colleagues at NSF will protest, saying, "No, Bruce, we were not thinking of biodiesel when we made that grant," but in fact it potentially does relate to applications in biodiesel. This is a relatively large award for NSF: $12 million dollars. In addition, NSF is partnering with DOE and USDA on the corn genome sequencing project which is underway. About $30 million is being invested over three years in that project.

MUSES Grants

The Engineering Directorate was the main impetus behind a special program relating to sustainability and bioenergy. Materials Use: Science, Engineering, and Society (MUSES) funds research on understanding the supply, treatment, use, and reuse of resources not just of natural systems, but the environmental effects of introducing alternative materials or new processes as well. Over the past five years, the Engineering Directorate has invested $4-6 million per year in MUSES, which calls for interdisciplinary proposals that cover not only technological issues such as environmentally benign process redesign and manufacturing, but also behavioral factors such as social science, economics, and social forces relating to the adoption of new technologies and new products. Under the MUSES program, in summer 2003, we sponsored an international workshop at the University of Oklahoma on assessing the sustainability of bio-based products. Following that workshop we made a number of grants in numerous bioenergy and sustainability areas including the following:

- **Complexity and the bioeconomy**, the natural and industrial ecology of biobased products, funded at $2 million over five years. The principal investigator is an engineer at Iowa State University. Co-principal investigators include engineers from other universities, a sociologist, and an economist, illustrating the multidisciplinary nature of the grants.
- **Renewable energy from forest resources** and investigation into the viability of large-scale reduction of sustainable transportation fuels from lignocellulosic biomass, a $2 million grant over five years. The principal investigator is a forest resources specialist at Michigan Technological University. Her team includes a chemical engineer and two social scientists.
- **Materials use, infrastructure change, and environmental impacts** for alternative fuels in vehicles, $1.5 million over five years. The principal investigator is an economist at Carnegie Mellon University. His team includes three engineers—civil, environmental, and mechanical—and a researcher from the Green Design Initiative at Carnage Melon.
- **Life-cycle assessment**, a multi-scale statistical framework for assessing the biocomplexity of materials used as transportation fuels and life cycle assessment of gasoline, ethanol, biodiesel, and hydrogen, $1.6 million. This team is led by a chemical engineer and includes a statistician, an environmental health scientist, and an economist.

These grants illustrate the importance to NSF of engaging multidisciplinary teams to work in the fields of bioenergy and sustainability.

Back to Basics

NSF has a number of programs related to education and the integration of education into research. Our Integrative Graduate Education and Research Traineeships (IGERT) program emphasizes interdisciplinary research and education. Each of these grants is typically $2.5 to $3 million over five years. Most of that money supports a group of perhaps15 graduate students who work together in an interdisciplinary topic area. These traineeships are located at about 150 sites across the country. One of these grants, a $2.5 million award to the University of Delaware, supports research trainees in sustainable solar hydrogen energy as well as hydrogen from biomass.

Our Experimental Program to Stimulate Competitive Research (EPSCoR) program is supporting an award on research on sustainable forest bioproducts. This is a fairly large grant for NSF, almost $7 million over three years. The University of Maine is the lead institution, and the research is focused on work involving conversion of wood chips to biofuels and bioproducts.

Our small business program also makes grants that relate to bioenergy and sustainability. A phase II SBIR grant to a small business on designer cellulases for biomass conversion provides $500,000 over two years with the aim of moving that research towards commercialization, which is the primary goal of the small business program. In the biotech area NSF is investing about $20 million per year in small biotech businesses.

Through our catalysis and biocatalysis program, we have funded a proposal on "Selective Production of Large Water Soluble Organics from Biomass." The principal investigator, Jim Dumesic at the University of Wisconsin, published a paper in *Science*, "Production of liquid alkanes by aqueous phase processing of biomass-derived carbohydrates." This paper addresses the catalytic conversion of biomass, not to ethanol, not to butanol, but rather to alkanes, which are hydrocarbons. There are some advantages to converting biomass to hydrocarbons, though this a somewhat radical departure from the conventional bioenergy approach. This might be possible through two routes, a biocatalytic route perhaps involving synthetic biology, or an alternative route, involving more traditional chemical engineering heterogeneous catalysis.

In keeping with our mission to foster education in the realm of bioenergy sustainability, NSF has an Education Directorate which is investing in sustainability education. The directorate is investing $1.7 million in the Center for Sustainable Engineering, a consortium co-funded by EPA. The institutions are Carnegie Mellon University, the University of Texas at Austin, and Arizona State University. The consortium is aiming very high. Its target is to develop and implement activities to enhance education in sustainable engineering at colleges and universities around the world.

The U.S. government is working on a plan, the U.S. National Biofuels Action Plan, which is led by DOE and the USDA. In line with its mission to support basic research related to biofuels, NSF is participating in formulating this National Action Plan, fostering basic research in fields such as metabolic engineering, plant genome research, catalysis, and biocatalysis.

NSF has a strong tradition of supporting basic and applied research in science and engineering and fostering the educational endeavors of the next generation of researchers. By funding projects as diverse as exploring the basics of plant genomics to turning wastewater into electricity, NSF represents one of the driving engines of innovation in the United States. NSF support for research in the realms of bioenergy and sustainability will inform technological progress in the near and distant future.

International Opportunities at the National Science Foundation

by Dr. Rick Nader

Dr. Rick Nader *is a program manager in the Office of International Science and Engineering (OISE) at the National Science Foundation. He has a background in science policy, and his research interests include the cultural impacts on public perceptions of controversial technologies such as genetically modified organisms and nanotechnology.*

Program managers in the Office of International Science and Engineering (OISE) focus on countries or regions within the portfolio of grant opportunities offered. I concentrate primarily on China. Focusing on a specific country allows each of us to keep abreast of the political and scientific developments in our countries in order to best serve the U.S. community interested in doing collaborative research.

I first traveled to China in 1989, backpacking and spending some time with one of my father-in-law's colleagues, who at the time was a director of geophysics in the Geological Institute of the Chinese Academy of Sciences (CAS). Thus, I have a connection to China going back almost 20 years. I am very pleased to be able to continually renew my involvement in China through involvement in these types of collaborations. It continues to be a lot of fun working to promote China-U.S. collaboration.

OISE's Goals

OISE is an integral part of the National Science Foundation (NSF). OISE moved to the Office of Director a few years ago, and funding international research was made a priority across the foundation. It is not the job of OISE to fund international research, though until around 2000, it had been doing so largely through small research awards. Now, funding international research is the job of the research divisions. There has, in fact, been something of a paradigm shift in the thinking about what OISE should do.

Our mission, consistent with that of NSF, is to advance the frontiers of research. We provide grants to seed collaborations; provide access to sites, facilities, people, and ideas abroad; and foster U.S. talent capable of successfully working globally. OISE funds projects to provide international experiences early in the careers of our principle investigators, and also in the careers of students, high school teachers, and others.

OISE allows them to travel overseas so they can see the excellent work being done in other countries, and perhaps interest students in careers in science, technology, engineering, and mathematics through the international Science, Technology, Engineering, and Mathematics (STEM) Education Coalition experience.

We also strive to build effective collaborations and partnerships to address problems on the regional and global scale, such as climate change, energy, and human and social dynamics. To that end, OISE enlists the help of other countries' scientific counterparts. Addressing grand global challenges for science cannot, and should not, be the responsibility of one country. We need to prepare a globally engaged U.S. workforce in science and engineering. If these goals resonate with your objectives, I encourage you to seek our support.

Keep in mind, OISE does not have a foreign affairs or foreign assistance mission. We do, however, recognize, that increasing capacity in developing countries to fund basic research is important to addressing the challenges we face as a global community of scientists. We try whenever possible, on a case by case basis, to support those scientists to work with the United States to advance the frontiers of science.

From the NSF perspective, any country, anywhere around the world is a welcomed partner. There are, of course, practical considerations and realities.

Although OISE does not require a formal Memorandum of Agreement to fund collaboration, we do want to ensure there is somebody on the other side, whose talents are known and whose contribution to the project is clear.

We need to know for example, what resources will be brought to bear and how partners will work together. This is especially important since we do not normally support the cost of the foreign collaborators, although there are some exceptions made on a case by case, country by country basis. OISE takes into consideration the importance of the foreign investigators' participation in a meeting or project.

OISE is organized in four regional clusters, 1)Africa, Near East, and South Asia; 2) Americas; 3) East Asia and Pacific; and 4) Global Initiative, with overseas offices for each region. OISE maintains three overseas offices. Our first office was established in 1960 in Paris and serves the European Union. Twenty years later we opened the office in Japan. With the opening of the new Beijing office, we are opening a new office about every 20 years.

The NSF Beijing office officially opened in May 2006. The leaders of CAS and the Natural Science Foundation of China (NSFC) have done a superb job of working with NSF to establish the office, and this office continues to be a major conduit for information and cooperation. We owe our excellent relationships to our long term commitment to building the institutional linkages at NSF between our counterparts, not just at the executive level but also at the program level.

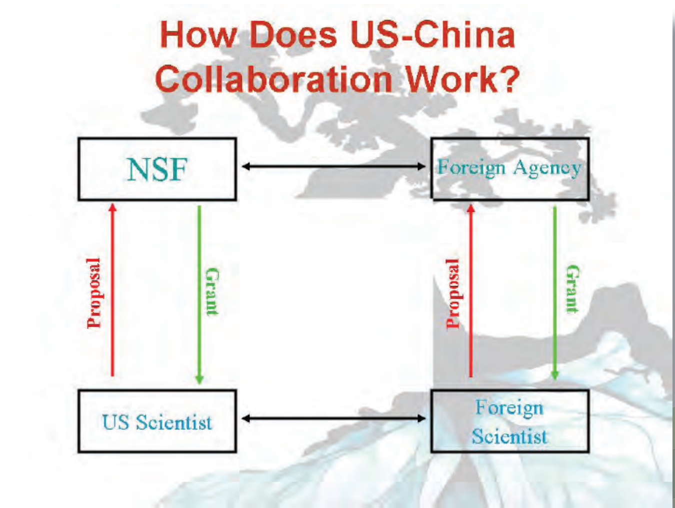
Dr. Bill Chang is the director of the office. He receives a lot of visitors in the Beijing office. He also analyzes and reports on proposed and new policies that affect science and research trends in China. Of course, if there were fewer visitors, he might do more analysis and reporting, but his role in creating international liaisons with agencies and institutions is critical to the success of our endeavors. The overseas offices do not make grants. All proposals must be processed at NSF headquarters. Dr. Chang does, however, give us great advice, and if we have questions about certain issues we greatly value his opinion.

The goals of the Beijing office are to 1) facilitate and strengthen collaborations between the United States and China in science and engineering to further U.S. science and technology, 2) analyze and report on science and technology developments in China, and 3) create liaisons with Chinese agencies and institutions.

Building Networks

NSF and the foreign agencies are in regular communication via telephone, e-mail, and meetings sponsored at the ministerial level and through bilateral China-US Commission Meetings on S&T.

U.S. scientists and Chinese scientists also work together one-on-one in a variety of scenarios. Sometimes they meet for the first time at a conference, or perhaps they have worked together for a few years. Sometimes communications with U.S. researchers continue after a graduate student goes back to China. These relationships often lead to collaborative research proposals that require funding. Typically, foreign researchers submit proposals to their own national funding agency, and U.S. scientists submit their proposals to NSF.



These proposals go through the regular, separate review channels. There is no coordinated joint review for NSF solicitations. However, some programs, such as Materials or Chemistry, have coordination between NSF and the foreign counterpart agency.

NSF program managers choose reviewers with competence, expertise, and experience in the specific topics. We select reviewers from anywhere in the world. In fact, soliciting reviewers from another country is more important with China than in other regions.

In Europe, for example, U.S. scientists typically know whom to contact concerning certain topics, but in Asia and in China particularly, we need to improve our awareness of the research currently being pursued and familiarize ourselves with talented scientists in Asia. After the separate reviews and grant processes are completed, the next step is to negotiate and carry out the projects, which occurs at the institutional level.

Collaboration, Catalysis, and Early Career

OISE is comprised of people with both technical backgrounds and country-expertise. Our staff rely heavily on the technical divisions, such as Ann Russell in the Environmental Biology Program and/or Bruce Hamilton in the Sustainable Engineering Program. Their expertise guides OISE in determining where the research frontiers are and whether a specific proposal will ultimately benefit the field.

Aside from technical merit, OISE looks at three elements crucial to the success of a request for funding: mutual collaboration, catalytic effect, and early career experiences. Collaboration may seem an overused word, but OISE has some bells and whistles we like to see in collaborative proposals. We are interested in funding mutual intellectual collaborative research proposals. We don't typically fund scientists to solely conduct field work, for example those who go for a couple of weeks to collect rocks and return to their lab in the United States to analyze them. There is nothing wrong with this; we just don't consider that the type of international collaboration OISE likes to promote. We prefer, instead, to foster a catalytic or joint intellectual project.

The next step is to determine whether the project will actually be catalytic to research and whether it involves early-career students and researchers. The presence or absence of these elements can determine the fate of a proposal. The early-career scientists and students need to be involved in meaningful ways, not just included to help ensure the proposal will be funded.

When I call principle investigators and ask what the students are going to do, they sometimes answer, "We will figure that out when we get there." That is not what we consider meaningful integration. OISE prefers to fund student involvement that is integral to the project and technically sound on its merits.

Setting Priorities

The priorities for the U.S Cooperative in Science in Engineering in China are often congruent with both national science agendas. These include fundamental aspects of climate change, energy and sustainable technologies, energy security, long-term ecological research, pollution, environment, integrated Earth observation systems, sustainable engineering, cyber-enabled discovery and innovation, and data sharing and exchange, among others

Fundamental aspects of climate change are very relevant to our agenda and there are enormous opportunities for collaboration in that field. The Cyber-Enabled Discovery and Innovation is an evolving initiative that addresses getting the connections in place to collaborate and create virtual laboratories. Cyber encourages research that occurs synchronously or asynchronously. The speed of the networks is already amazing, and the speed and capacity of the networks is evolving at a rapid pace. Some of the next generation improvements will be cyber-enabled and Internet-enabled research and discovery, opening doors for new ways of working together. One recent development within the Cyber-Enabled Discovery and Innovation initiative is the Global Ring Network for Advanced Science and Education (GLORIAD).

This is now a complete-loop, high-speed bandwidth for scientists to work together across the Northern Hemisphere. It provides another great pathway for NSF, which wants to take down barriers and put up roads, even if they are cyber roads, to bring researchers from around the world together.

Seeds of Research

OISE is involved in the early stages of fostering the catalytic goals of collaborative ventures, including planning visits; workshops; partnerships for international research and education; and post-doctorate, graduate, and undergraduate student projects. Planning visits are at the low end of the spectrum in terms of moneys granted. At the other end of the spectrum are high-dollar grants for research and education, called the Partnership for International Research and Education (PIRE).

- **Planning visits**. The budget for planning trips is usually about $20,000 for trips involving one, two, or three people and single or multiple U.S. institutions. These short trips by U.S. researchers focus on promising areas for collaborative research. The visits allow the researchers to assess the expertise and facilities of the potential partners in the foreign country. The visits don't need to include a cast of thousands; rather, these may be targeted for individual investigators with great ideas who want to get started on a project with their foreign counterparts, but cannot plan in detail without face-to-face time.
- **Workshops.** Workshops are designed to bring together early career researchers in new catalytic areas and are funded at a slightly higher level. This year, we were able to fund 20 workshops in China with the help of the NSF research directorates. Typically the workshops are co-organized by U.S. and foreign investigators and are held in a foreign country. NSF supports U.S. participants, and the host country supports its researchers. The aim is to identify new areas of joint research, catalyze new ideas for future research, and stimulate dialogue on major bilateral science and technology issues. These workshops have a two-year maximum duration and a targeted budget of $50,000.
- In November 2006, we sponsored a joint workshop with Argonne National Laboratory, the Massachusetts Institute of Technology, and the Chinese Academy of Sciences, Institute for High Energy Physics to discuss future research and exchange between U.S. researchers and Chinese counterparts at the Beijing Neutron Spallation Source, a $10-million facility, expected to be complete by 2011. NSF

appreciates the chance to fund two scientific communities who really do not know each other yet, to discuss upcoming research opportunities.

- **Partnerships for International Research and Education (PIRE)**. So far we have funded two cohorts (32 active projects) of international partnerships aimed at advanced, cutting edge scientific research and excellent international collaboration. These partnerships require contributions by strong international partners. The five-year awards are funded up to $2.5 million each. PIRE requires meaningful involvement of students and junior researchers and expects innovative models for international cooperation. They are highly competitive. In 2007, we received 520 pre-proposals, invited 71 of those to submit full proposals, and funded 20 awards. The next round of funding will be dispersed in 2009, and we are hoping to receive many excellent pre-proposals in late summer of 2008. More information on the competition may be found at www.nsf.gov/oise.
- ***International Research Fellowships (Post-doc)***. These fellowships support researchers working outside the United States for nine to 24 months. Support for fellows includes salary, research, and dependent expenses, plus generous allotments for travel to conferences and visiting U.S. institutions. This can be important as extended travel abroad can make it hard for recipients to retain ties to their local research community. Candidates must be U.S. citizens or permanent residents who have completed their Ph.D. no more than two years before application. We especially encourage work in developing countries. Awards range from $60,000 to $200,000. For more information, see www.nsf.gov/oise.
- ***Support for Graduate Students***. We have a number of programs to support graduate students. The Integrative Graduate Education and Research Traineeship (IGERT) program supports graduate research fellowships for interdisciplinary research. These awards, which encourage a multidisciplinary, problem-oriented focus, fund graduate students through the principle investigator at the student's institution Up to 10 IGERT awards may expressly include international collaborations, which provide an additional $200,000 over 4 years (starting in year 2) for sending U.S. students abroad. The Doctoral Dissertation Enhancement Program (DDEP) supports doctoral student research in a foreign country on projects that involve collaborative research. The U.S. faculty mentor is the principle investigator on the proposal. These are funded at $12,000 to $15,000 per award for up to two years. For more information: www.nsf.gov/oise.
- In addition to these programs, NSF supports a number of other initiatives aimed at encouraging international travel and research by students. The East Asia and Pacific Summer Institutes (EAPSI) for U.S. graduate students allow students in science and engineering to spend eight weeks in a research setting in the Asia-Pacific region. The hope is that these encounters will initiate scientific relationships that will facilitate future international collaborations. Students study the language and the culture of the country before and after their arrival. NSF provides travel funds as well, and the host country picks up the cost of students' local, in-country living, expenses.
- ***Support for Undergraduate Students***. NSF also offers programs for undergraduate research experiences abroad. International Research Experiences for Students (IRES) allows small groups of undergraduates, graduate students, teachers, and principle investigators to be embedded in a focused research environment overseas. The Research Experience for Undergraduates (REU) supports research experiences for undergraduates on the domestic level, but we also have international versions of those. For more information, see "Looking beyond the Borders: A Project Director's Handbook of Best Practices for International REUs" at www.nsf.gov/pubs/2006/nsf06204/index.html

To reiterate, OISE criteria for co-funding include 1) true intellectual collaboration with a foreign partner; 2) new international collaborations, as opposed to well-established ones; 3) benefits to be realized from the expertise and specialized skills, facilities, and/or resources of the foreign collaborator; and 4) active research engagement of U.S. students and junior researchers at the foreign site.

All international activities that OISE supports are geared toward making it possible for U.S. institutions to carry-out innovative, catalytic, and highly meritorious research via international collaboration, and to develop the next generation of globally engaged U.S. scientists and engineers.

We look forward to receiving proposals that meet these criteria and encourage anyone interested in any of these programs to consult OISE and the relevant disciplinary program manager early in the application process.

THE UNIVERSITY of TENNESSEE UT

中国科学院
CHINESE ACADEMY OF SCIENCES

JiBS
JOINT INSTITUTE FOR BIOLOGICAL SCIENCES
UNIVERSITY OF TENNESSEE
OAK RIDGE NATIONAL LABORATORY

PURDUE UNIVERSITY
Discovery Park

ISSE
INSTITUTE FOR A SECURE AND SUSTAINABLE ENVIRONMENT

1958
University of Science and Technology of China

OAK RIDGE
National Laboratory