Global Sustainability Issues in Energy, Climate, Water, and Environment

September 26-29, 2011
Purdue University
West Lafayette, Indiana USA

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

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The China-US Joint Research Center for Ecosystem and Environmental Change (JRCEEC) was formed in July 2006 with the signing of a framework agreement between scientists from the University of Tennessee (UT) and Oak Ridge National Laboratory (ORNL), and researchers from the Chinese Academy of Sciences (CAS). The center organizes annual workshops held reciprocally in China and the United States. The JRCEEC partners include the Joint Institute for Biological Sciences (UT/ORNL), Institute for a Secure and Sustainable Environment (UT), Institute of Geographic Sciences and Natural Resources (CAS), Research Center for Eco-Environmental Sciences (CAS), Center for the Environment (Purdue University), and the University of Science and Technology of China.

In May of 2011, the US Department of State and the National Development and Reform Commission of the People's Republic of China approved a proposal to establish an EcoPartnership that builds on the success of the JRCEEC. The EcoPartnership includes Purdue University's Center for the Environment, the University of Tennessee's Institute for a Secure and Sustainable Environment, the Joint Institute for Biological Sciences of the University of Tennessee and Oak Ridge National Laboratory, and the Chinese Academy of Sciences' Institute of Geographic Sciences and Natural Resources Research, the Research Center for Eco-environmental Sciences, and the Institute of Applied Ecology.

Since its creation in 2006, the JRCEEC has engaged nearly 1,000 Chinese and US scientists from more than 40 institutions in international workshops, field site visits, and exchange programs for students as well as junior and senior researchers. The EcoPartnership will provide leverage to expand these impressive accomplishments including increased opportunities for academic exchanges, joint research projects, and technology commercialization between US and Chinese partners.

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Introduction: Prospects and Challenges of Growing the Biology-based Economy

by

John W. Bickham

Dr. Bickham was Chair of the Organizing Committee of the China-US 2011 Joint Symposium, "Global Sustainability Issues in Energy, Climate, Water, and Environment." Dr. Bickham was Director of the Center for the Environment, Purdue University from 2006 to 2011, and US Team Leader for the EcoPartnership China-US Joint Research Center for Ecosystem and Environmental Change from 2011 to 2012. He is currently Sr. Industrial Consultant at Battelle Memorial Institute in Houston, Texas.

The 5th annual symposium of the China-US Joint Research Center for Ecosystem and Environmental Change (JRCEEC), and the first meeting of the EcoPartnership, were held at Purdue University in September 2011. In May 2011, the US Department of State and the National Development and Reform Commission of the People's Republic of China approved a proposal to establish an EcoPartnership that builds on the success of JRCEEC. The EcoPartnership includes Purdue University's Center for the Environment, the University of Tennessee's Institute for a Secure and Sustainable Environment, the Joint Institute for Biological Sciences of the University of Tennessee and Oak Ridge National Laboratory, and the Chinese Academy of Sciences' Institute of Geographic Sciences and Natural Resources Research, the Research Center for Eco-environmental Sciences, and the Institute of Applied Ecology.

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The agenda for the meeting included eight keynote addresses, two lunch speakers, 45 technical presentations, a Monday evening Discovery Lecture Series presentation, and a Tuesday evening of entertainment provided by the Confucius Institute at Purdue and the Purdue University Chinese Students and Scholars Association. On Wednesday there was a special presentation by Dr. Arden Bement followed by two workshops/panel discussions—one on the development of the bio-based economy and one on the future of the EcoPartnership—and a lunch presentation by Jay Gore. The symposium ended after noon on Wednesday, but there were two post-symposium activities that day. One was a special networking session with Purdue's Chinese students, and the other was a biofuels workshop funded by the National Science Foundation. Thursday was a full day of tours for our Chinese guests.

I want to express my thanks for the many people who worked so hard to make this event possible. Pankaj Sharma, Jill Wable, and Erica Wilson worked tirelessly to attend to every detail of the planning and organization of the meeting. My wife Pat opened our home for a reception to welcome our Chinese guests and the participants of the meeting. The US-China organizing committee provided technical advice and help in fund raising, and they gave freely of their precious time to develop the conceptual framework for the meeting. Wei Hong and Jonathon Day skillfully arranged post-meeting activities for our guests. The financial help and in-kind support of our sponsors is greatly appreciated. Without their help the meeting would not have been possible. I especially want to thank Shell Oil Company, and chief scientist Jose Bravo, for their generous donation and participation.

ORGANIZING COMMITTEE

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- Purdue University Global Policy Research Institute (GPRI)
- Purdue Water Community
- Shell Oil Company
- The University of Tennessee
- University of Science and Technology of China
- US Department of State
- US National Science Foundation (NSF)

ECOPARTNERSHIPS

On May 10, 2011, US Secretary of State Hillary Rodham Clinton and Chinese Vice Chairman of the National Development and Reform Commission (NDRC) Xie Zhenhua delivered keynote remarks at a US-China EcoPartnerships signing ceremony at the U.S. Department of State.

The United States and China signed the Framework for EcoPartnerships under the US-China Ten Year Framework for Cooperation on Energy and Environment in Beijing in December 2008. The EcoPartnership Framework is aimed at developing new models of mutually beneficial voluntary arrangements between a range of state, local, and private sector organizations, to promote energy security, economic growth, and environmental sustainability in both countries. Six EcoPartnerships were established in 2008 with projects aimed at protecting the environment, developing new clean energy technologies, and sharing innovative techniques to make both nations more energy efficient.

At the second US-China Strategic and Economic Dialogue in Beijing in May 2010, the United States and China signed a Memorandum of Understanding on Implementation of the Framework for EcoPartnerships. This Implementation Plan establishes key policies and procedures of the EcoPartnerships program, including the management framework, selection standards, and procedures for new EcoPartnerships.

The Purdue University/University of Tennessee/Oak Ridge National Laboratory partnership with the Chinese Academy of Sciences will continue a successful five-year collaboration with the China-US Joint Research Center for Ecosystem and Environmental Change. Representing a collection of research centers, this partnership promotes research collaboration among all partnering institutions, faculty and student exchanges, student education, and technology training and transfer in areas of environmental significance including climate change, the environmental aspects of bioenergy production, and sustainability.

Partners: Purdue University (West Lafayette, IN), the University of Tennessee (Knoxville), and Oak Ridge National Laboratory (Oak Ridge, TN) with the Chinese Academy of Sciences, Institute of Geographic Sciences and Natural Resources Research (Beijing, China), Research Center for Eco-Environmental Sciences (Beijing, China), and Institute of Applied Ecology (Shenyang, China).

See JRCEEC at <http://jrceec.utk.edu> and EcoPartnership at <http://www.state.gov/r/pa/prs/ps/2011/05/163178.htm>.

A formal signing ceremony announcing the EcoPartnership agreement was held Tuesday, May 10, in Washington, D.C., in connection with the third annual U.S.-China Strategic and Economic Dialogue event. Secretary of State Hillary Clinton was a guest speaker at the EcoPartnership signing.

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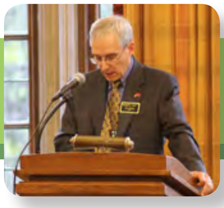

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Welcoming Remarks

INTRODUCTION BY JOHN W. BICKHAM

It is my pleasure to introduce the president of Purdue University, France A. Córdova. Dr. Córdova has distinguished herself as a world-renowned scientist, educator, and administrator. She is a former chief scientist for the National Aeronautics and Space Administration and a Senate-confirmed member of the National Science Board. She was unanimously confirmed by Congress as a citizen member of the Smithsonian Institution Board of Regents. Recently she was elected chairperson of the board for a three-year term beginning January 1st 2012. Today she is leading Purdue through record levels of student success and research achievements with a significant impact in the state of Indiana and beyond.

FRANCE A. CÓRDOVA, PRESIDENT, PURDUE UNIVERSITY

It is a pleasure to see you here in Fowler Hall on the Purdue University campus. The work you are going to do here this week is part of a continuum that began five years ago as part of the China-US Joint Research Center for Ecosystem and Environmental Change. It is also part of a lasting partnership between our two countries and our prestigious research universities. You have come here to address challenges in energy, climate, water, and the environment, all on a global scale. It is critical that we seek solutions to these grand challenges together. The issues of sustainability that you are addressing are of such complexity that no one country can tackle them alone. Each of our institutions has limited resources, both financial and human, and limited access to research instrumentation. Research sharing is required if we are to gain results that make a global impact. The frontiers of science and the nature of grand challenges may appear a little different in different parts of the world, so holistic approaches must take these differences into account. The integration of research with education is critically important. That is one reason we are so pleased to be part of the EcoPartnership. Universities, as you know, are havens of discovery. At Purdue we pride ourselves on our research and our innovations that we hope will impact the world. Our goal as always is to help citizens live better lives. Discovery Park, for example, has been an outstanding success. Currently our faculty are working with 20 strategic global partners from industry, academic institutions, and research institutions. Purdue's global sustainability initiative, including the Center for Environment led by John Bickham, brings together faculty, industry, the public, and the government to respond to environmental challenges. With these varied perspectives, identifying common interests and shared objectives is paramount. This is accomplished through international planning visits, faculty exchange, advanced study institutes, and symposiums like this one. The combined brainpower in this room will help move us towards solutions with greater efficiency and perhaps more intelligent solutions than any of us could accomplish alone. You represent the best of the collaborative spirit, and I am confident that further exchanges like this one will ultimately yield results that better the world. I hope you really enjoy your time.

Hail Purdue.

VIDEO PRESENTATION BY RICHARD G. LUGAR, US SENATOR, INDIANA

I am honored to address this gathering at Purdue University. The first formal meeting of the EcoPartnership brings together some of the brightest minds in the United States and China to address the significant challenges in developing a sustainable world. The economies of the United States and China are the world's dominant drivers of fossil fuel consumption and the release of greenhouse gasses, and as a result our two nations are strategically linked to the challenges of sustainable development. The EcoPartnership builds on five years of success of the China-US Joint Research Center for Ecosystem and Environmental Change, which has created programs that have engaged nearly 1,000 Chinese and US scientists from more than 40 institutions in international workshops, field site visits, and exchange programs for students and researchers.

As the ranking Republican member on the Senate Foreign Relations Committee, I am hopeful this China-US symposium on Purdue's West Lafayette campus will strengthen public and private research and development partnerships in the United States and China through joint initiatives related to our growing economy. I look forward to what this five-year initiative can deliver on these vital issues.

MAOMING CHU, CHINESE DEPUTY CONSUL GENERAL IN CHICAGO

It is my great pleasure to come back to the Purdue University campus and to welcome all of you attending this symposium, particularly those who come so far from China. On behalf of the Chinese Consulate, I want to congratulate Purdue University for convening this symposium. As everyone knows, Chinese President Hu Jintao visited the United States in January 2011. During his visit, he met several times with President Obama, and the Chinese and US governments issued a joint statement. Articles 36 to 39 of the joint statement are focused on the cooperation between our two countries in the fields of energy, environmental protection, and climate change. Also recently the Chinese Ministry of Science and Technology, MOST, has published a document, the 12th Five-Year Plan for International Cooperation in the Field of Science and Technology. Recently in Beijing, a conference was convened to further this kind of cooperation with international partners. These international interactions are excellent opportunities for our countries to further our cooperation in the realm of global sustainability issues.

GARY SAYLER, DIRECTOR OF THE UNIVERSITY OF TENNESSEE-OAK RIDGE NATIONAL LABORATORY JOINT INSTITUTE FOR BIOLOGICAL SCIENCES

Welcome to the 5th joint symposium of the China-US Joint Research Center for Ecosystem and Environmental Change (JRCEEC). The JRCEEC now has a five-year history of international cooperation and interaction in an area that brings us towards a nexus among climate change, sustainability, and bioenergy technologies for the future of the planet. This initiative has its roots in strong cooperative relationships among Chinese investigators in the United States, research scientists at Oak Ridge National Laboratory, and scientists at the Chinese Academy of Sciences, in particular the Institute of Geographic Sciences and Natural Resources in Beijing. This strong initiative was launched in response to global change driven by increasing carbon dioxide concentrations occurring in the northern hemisphere in particular and worldwide in general. At that time the United States and China were tied in a race to see who would be the number one emitter of carbon dioxide to the planet. Right now, China may be winning the race. A recent analysis by the US Energy Information Administration notes that the projected rate of increase of carbon dioxide released due to power generation over the next 25 years is expected to continue at a rate of about two percent a year, a 50 percent increase in the next 25 years. These numbers are particularly disturbing because the source of the carbon dioxide is still largely fossil fuels and coal in particular, and the nexus we are dealing with is largely induced by growing populations and development worldwide.

The JRCEEC has tried to bring the two major players in this arena together in that regard. In China, great research teams have developed tremendous expertise and insight into carbon cycling and biogeochemical cycling. Before the creation of the JRCEEC, we had very little knowledge of this information coming out of China. There are great opportunities for US scientists to continue to partner with our Chinese counterparts in developing new approaches for understanding the impacts of these climate change scenarios on our ecosystem. Since our technologies for carbon capture and sequestration are not advancing rapidly enough, we are also beginning to develop approaches by which biological systems and ecosystems may be manipulated to ameliorate some of these effects. This may be a future direction for this initiative.

We are very pleased that Purdue University spearheaded the effort to create the EcoPartnership Program, and I congratulate them on that successful effort with the State Department. Guirui Yu, the deputy director of the Institute of Geographic Sciences and Natural Resources, and I share confidence that we can continue to move forward. These reciprocal meetings that have been ongoing now for a period of five years are expected to continue. Next year we hope to be back in China. Jie (Joe) Zhang, research director of the University of Tennessee's Institute for a Secure and Sustainable Environment and one of the linchpins in all of these efforts, and I are actively thinking about where the next US initiative should occur, and we are hoping to engage a broad spectrum of US researchers across the country.

In the United States, we have thus far largely focused the China-US workshops at our local institutions, at Oak Ridge, Knoxville, and West Lafayette. It may now be time to bring a broader community of US research scientists forward for these very fruitful and combined discussions across the whole spectrum of energy sustainability and climate change.

We are very pleased to be here at Purdue. Our Purdue organizers have done a marvelous job putting this program together. I want to congratulate them for that effort, and the sponsors that helped bring this whole program to fruition. We are very pleased to have a successful story to tell with respect to the five-year program we have put in place with the JRCEEC initiative, and we hope to continue to grow that with successful opportunities like the EcoPartnership Program that we are also celebrating this week.

Keynote Speakers

Economic and Environmental Impacts of Biofuels: Future US Biofuels and Biomass Demand—Uncertainty Reigns

by Wallace E. Tyner

Dr. Tyner is the James and Lois Ackerman Professor of Agricultural Economics, Purdue University, and Co-chair of the National Academy of Sciences Committee on Economic and Environmental Impacts of Biofuels.

For nearly a year and a half, the 18 members of the National Academy of Sciences (NAS) Committee on Economic and Environmental Impacts of Increasing Biofuel Production have been working to produce a report on the Renewable Fuel Standard (RFS) and the potential economic and environmental effects of US biofuel policy. As a member of that committee, and in my role as a professor of economics (the dismal science), what I have to say may not be viewed as cheerleading for biofuels. My objective is to challenge those of you who work on the technical, logistics, and conversion aspects of biofuels to consider the barriers, uncertainties, and challenges as well as the opportunities for biofuels.

It has become clear to me over the years that, at the end of the day, land is the limiting factor. We are potentially facing increasing demand for biomass for biopower and biofuels. At the same time, there is demand for land for afforestation. We have sometimes conflicting national objectives relating to production of food, fuel, fiber, and environmental amenities. Are we asking the same land to provide all of these goals and over promising the land through the policies we adopt and the plans we make? This is a crucial issue now, and it will become more of an issue in the future.

DEMAND SHOCKS

Over the last five years, we have seen changes on the global scale in the area of land used to produce major crops such as corn, soybean, rapeseed, rice, wheat, millet, and sunflower. From 2006 to 2011, we added 38 million hectares globally to production of these top seven crops. Of that total, 27 million are new hectares; that is, the added area came from pasture or forest or other land not currently in crops. In economics, there is a phenomenon we call market mediated effects: if we use corn for ethanol in the United States, then somebody in another part of the world is likely to produce more corn to make up for that.

Corn, soybeans, and rapeseed are not only the top three crops globally, they are also the first generation biofuel crops. The most dramatic land use change has occurred in China, Sub-Saharan Africa, the former Soviet Union, Argentina, and Brazil, in that order. Major changes in the last five years have been in part due to production of biofuels, but there are many other drivers as well.

A Farm Foundation report, issued in July 2011, examined what happened to food commodity prices in 2011. This report found two big agricultural commodity demand shocks that were different than earlier drivers. These two major shocks served as the catalyst for most of the price increases around the world. From 2005 to 2010, in the United States, we went from using 7.8 million acres to meet ethanol demand to using 23.7 million in 2010, or triple the amount of land. Another big shock for the global market was that US export of soybeans to China required production on 8.3 million acres in 2005, but 22.8 million acres in 2010, an additional 14.5 million acres. Together, the land area needed for ethanol production and Chinese soybean exports rose 189 percent between 2005 and 2010.

China has often been accused of being responsible for the world food crisis because of its increasing consumption of essential agricultural commodities. In fact, China is largely self sufficient in commodities such as corn, wheat, and rice, and the government has policies in place to remain so. But on the soybean, soybean meal, and soybean oil market, China is a big trader. In 2008, China found itself facing a major shortage of soybeans. Its reserve was down to a 14-day supply. Between 2008 and 2011, China changed its policy and imported from the United States a very large quantity of soybeans to build its inventory. That is what triggered the large increase in land use in the United States.

BIOFUELS UNCERTAINTY

Second generation biofuels are facing a very uncertain environment. There are five major sources of uncertainty: future oil prices, feedstock costs and availability by region, conversion costs and efficiencies, environmental impacts of biofuels production, and government policy. This combination of factors makes analysis of biofuels impacts highly uncertain. Add to these uncertainties the condition of the financial markets at present, and investment in cellulosic biofuels becomes quite problematic. Therefore, policies that are going to work will need to be oriented at reducing the risk to the private sector and inducing private sector investment in biofuels.

Future oil prices. The oil price forecast for 2010 to 2035 from the US Department of Energy (DOE) outlines three scenarios, a) a reference case in which the price of oil rises to $125.00 a barrel, b) a low case where the price falls to about $50.00 a barrel, and c) a high case where it rises to $200.00 a barrel by 2035. For a company considering an investment in biofuels to realize a profit without government subsidies, the price of oil would need to be $120.00 a barrel. Would such an investor be willing to make an investment of $200 to $400 million in the face of this kind of uncertainty? If you think that the price of oil will never fall back to $50.00 a barrel, think again. In fact, in January 2009, the price of oil was $34.00 a barrel. On the high side, DOE assumes no discovery of new oil resources and high economic growth. That leaves a huge range, from $50.00 to $200.00. For biofuels investment to happen, it will take private sector investment in the face of huge oil price uncertainty, and the biofuel used for gasoline, diesel, or jet fuel must be competitive with or without subsidies.

Feedstock costs and availability. The next area of uncertainty is feedstock cost and supply. For years, DOE predicted that we could produce biomass feedstocks for $30.00 per dry ton. Today, we expect that the cost to produce corn stover, the residues from corn harvest, will be closer to $80 per ton, and dedicated crops such as miscanthus and switchgrass closer to $110 per ton or more. This means that the raw material needed for these second generation biofuels is going to be much more expensive than previously thought. The 2009 NAS study estimated feedstock availability might be about 500 million tons. That is more than enough to meet the RFS in the United States. The problem is not a resource problem, it is a problem of cost and perhaps environmental issues as well.

Another factor to be considered in feedstock cost, particularly for dedicated energy crops, is that, in all likelihood, cellulosic biomass will be contracted in the long term. Most farmers in Indiana are accustomed to growing corn, soybeans, and wheat, which are one year crops, and farmers are paid after harvest each year. Dedicated energy crops are produced over a period of 10 years or more. We will need contracting mechanisms in place that meet the needs of the farmers and the conversion facilities to determine the appropriate risk sharing between the farmer and the biofuel plant. That is a complicated process.

Conversion costs. Conversion costs are a third area of concern. Most estimates put the cost for biofuels from either biochemical or thermochemical conversion to ethanol well above $3 a gallon of gasoline equivalent. Generally, biochemical and thermochemical technologies are close in cost, but the uncertainty is high. To make cellulosic biofuels competitive with gasoline on a market basis with no government intervention, the cost of crude oil would have to be between $120 and $190 a barrel.

Environmental impacts. The fourth area of uncertainty is environmental impacts. Originally, we thought the environmental impacts of cellulosic biofuels could be positive, with increased wildlife habitat and reductions in soil erosion. Of late, there has been some concern about possible local loss of biodiversity. This could arise if a biofuel plant were located in the center of a 50-mile radius planted mostly in miscanthus or switchgrass, raw materials that must be produced locally, not shipped around the country like corn or soybeans. Environmental impacts depend upon the type of feedstock produced, management practices, and land-use or land-cover changes associated with biofuels production.

We also thought originally that miscanthus, switchgrass, and similar crops would be grown on marginal lands and would not compete with land for food. We were wrong. These crops take a lot of land. If these crops are grown on marginal land, the yields may be lower, and it would take more land to grow them. Current estimates indicate that, particularly for switchgrass, conversion of cropland, pasture, or even land in the Conservation Reserve Program could be quite large.

Government policy. The last area of uncertainty is government policy. The key to adopting government policies to encourage investment is to reduce uncertainty for private sector investors.

One impediment in this arena is known as the blend wall. In the United States, current regulations for ethanol require that it be blended at no more than 10 percent by volume for standard vehicles. We already have the capacity to produce more ethanol than we need to meet that regulation, so we cannot use it all domestically, and excess production is exported. Another domestic outlet for ethanol, E85, consisting of 85 percent ethanol, requires flex-fuel vehicles, and there are very few vehicles so far that can use this fuel. In addition, E85 requires a special pump, and for now there is a very tiny fraction of pumps in the country that can dispense E85, so this fuel will not solve the blend wall problem any time soon.

The US Environmental Protection Agency (EPA) has given preliminary approval for extending the blend limit from 10 to 15 percent, but only cars built since 2001 qualify for that extension, and that blend would not be useable in motorcycles, boats, lawn mowers, chain saws, or any small engines. Most observers assume that even if the EPA finally approves the 15 percent limit, it will not be implemented by industry because it is too risky a venture.

BLEND WALL: CELLULOSE IMPLICATIONS

What does this blending wall mean for cellulose? Even if the EPA raises the wall to 15 percent, corn ethanol and imported sugarcane ethanol production is sufficient to fill that gap, so there will not be much room for cellulose-based ethanol. For that and a number of other reasons, many people think the future is more likely to be drop-in biofuels produced via thermochemical conversion or butanol produced instead of ethanol in a standard refinery

The big remaining RFS issue is enforcement uncertainty. The cellulosic mandate is unlikely to be met in 2022 for a number of reasons. First, there are no commercial facilities today. In addition, the pace of construction would have to be faster than was the case for corn ethanol. Moreover, at present, RFS represents the only a guarantee of market, and that guarantee may not be sufficient for investors.

Consider also the biofuels subsidies. In December 2010, Congress extended the subsidies until end of 2011. For corn ethanol those are set currently at $0.45 a gallon and for cellulosic ethanol at $1.01 a gallon. Given the budget situation, the corn ethanol subsidy is likely to go away, and industry is fighting for alternative uses for at least part of the funds.

BIOFUELS POTENTIAL

In the United States, we have the resource base to meet the Renewable Fuel Standard and beyond for cellulosic biofuels, yet with all the uncertainty in the market today, investors are reluctant to make the plunge into cellulosic biofuels. The only guarantee of a certain market an investor in the United States has available today is through the RFS, but we must ask if any investor would be willing to make a significant investment when tomorrow the government could take that guarantee away. I doubt it.

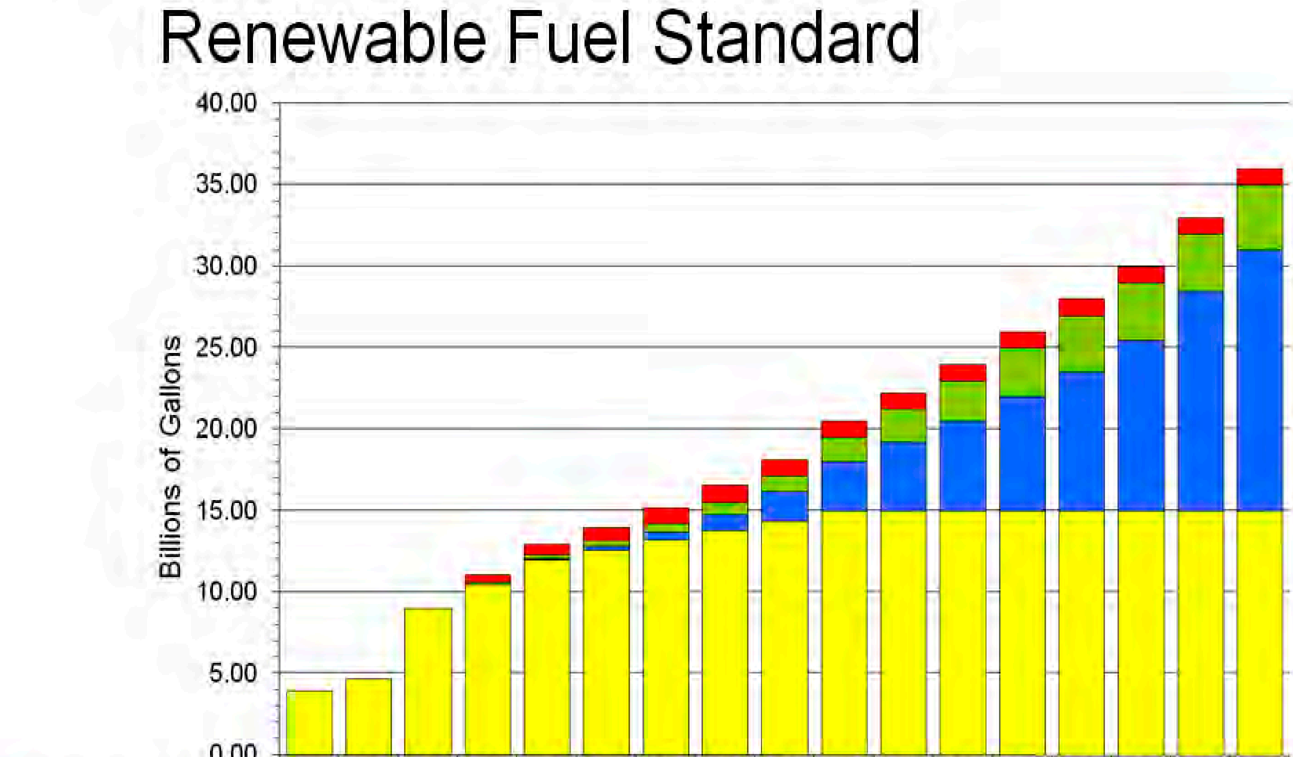
There is one policy option that could be key to advancing cellulosic biofuel production: the reverse auction. With a reverse auction, the government or the military would auction the procurement of biofuels with long-term contracts. This would eliminate price uncertainty, and presumably bidders would take into account their feedstock and conversion costs.

The five uncertainties—oil price, feedstock, conversion technology, environment, and government policies—still loom large, but we might be able to overcome those uncertainties, and at least get some early plants on line in the near future, if we use the reverse auction option.

See: Committee on Economic and Environmental Impacts of Increasing Biofuel Production. 2011. Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy. The National Academies Press. <http://www.nap.edu/catalog.php?record_id=13105>

RENEWABLE FUEL STANDARD DEFINITIONS

- Conventional biofuel: ethanol derived from corn starch with a life-cycle greenhouse-gas (GHG) emission reduction of at least 20 percent compared to petroleum-based gasoline and diesel.
- Biomass-based diesel: fuels must achieve life-cycle GHG-emission reduction of at least 50 percent compared to petroleum-based diesel.
- Advanced biofuels: renewable fuels (excluding conventional biofuel) that achieve life-cycle GHG-emission reduction of at least 50 percent (includes sugarcane ethanol).
- Cellulosic biofuels: fuels derived from any cellulosic material from renewable biomass that achieve life-cycle GHG-emission reduction of at least 60 percent.



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Biomass-based Diesel				0.50	0.65	0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Non-celulosic Advanced				0.10	0.20	0.30	0.50	0.75	1.00	1.50	2.00	2.50	3.00	3.50	3.50	3.50	4.00
Celulosic Advanced					0.10	0.25	0.50	1.00	1.75	3.00	4.25	5.50	7.00	8.50	10.5	13.5	16.0
Conventional Biofuels	4.00	4.70	9.00	10.5	12.0	12.6	13.2	13.8	14.4	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0

From Sustainability to Next Generation Materials: An Integrated Biomass Strategy

by
Martin Keller

Dr. Keller is Associate Laboratory Director, Energy and Environmental Sciences, Oak Ridge National Laboratory.

Oak Ridge National Laboratory (ORNL) evolved from the Manhattan Project, which produced the first atomic bomb. Today, ORNL is the US Department of Energy's (DOE) largest multi-purpose science and energy laboratory. ORNL, which is managed by UT-Battelle, LLC, is the nation's largest concentration of open source materials research, the world's most intense pulsed neutron source, the world's most powerful open scientific computing facility, and it has the nation's most diverse energy portfolio.

The mission of ORNL is to deliver scientific breakthroughs that will accelerate the development and deployment of solutions in clean energy and global security, and in doing so create economic opportunity for the nation.

Looking out to 2030, we know that energy use will continue to rise, led by liquid fuels including biofuels, then coal, natural gas, renewables excluding biofuels, and last, nuclear, which is projected to remain flat. In addition, we know that climate change is real and that it is basically tied to rising temperatures between 1880 and the present.

The warming of the climate system is unequivocal. Global atmospheric concentrations of greenhouse gases have increased markedly as a result of human activities since 1750. Hot extremes, heat waves, and heavy precipitation events will continue to become more frequent. And global temperature and sea level will continue to rise for at least a millennium.

NEW DIRECTIONS FOR ORNL

ORNL has unique capabilities, facilities, and infrastructure to explore and model climate change impacts. We have high-performance computer capabilities, data systems, and networking already in place; established observation networks; and experimental manipulation facilities. Yet even with all these capabilities, our scientists often do not speak the same language. At one end of the spectrum we have biologists involved in disciplines such as environmental studies, and at the other end of the spectrum, the computer simulation modeling people. To bring these people together in one location and foster communication and collaboration, ORNL has created the Climate Change Science Institute.

There is a new scaling and complexity in climate change science. We must consider multiple, interacting factors from the global to the molecular scale, from oceans and continents to the genome of plants, and integrate our efforts across all the different scales and disciplines.

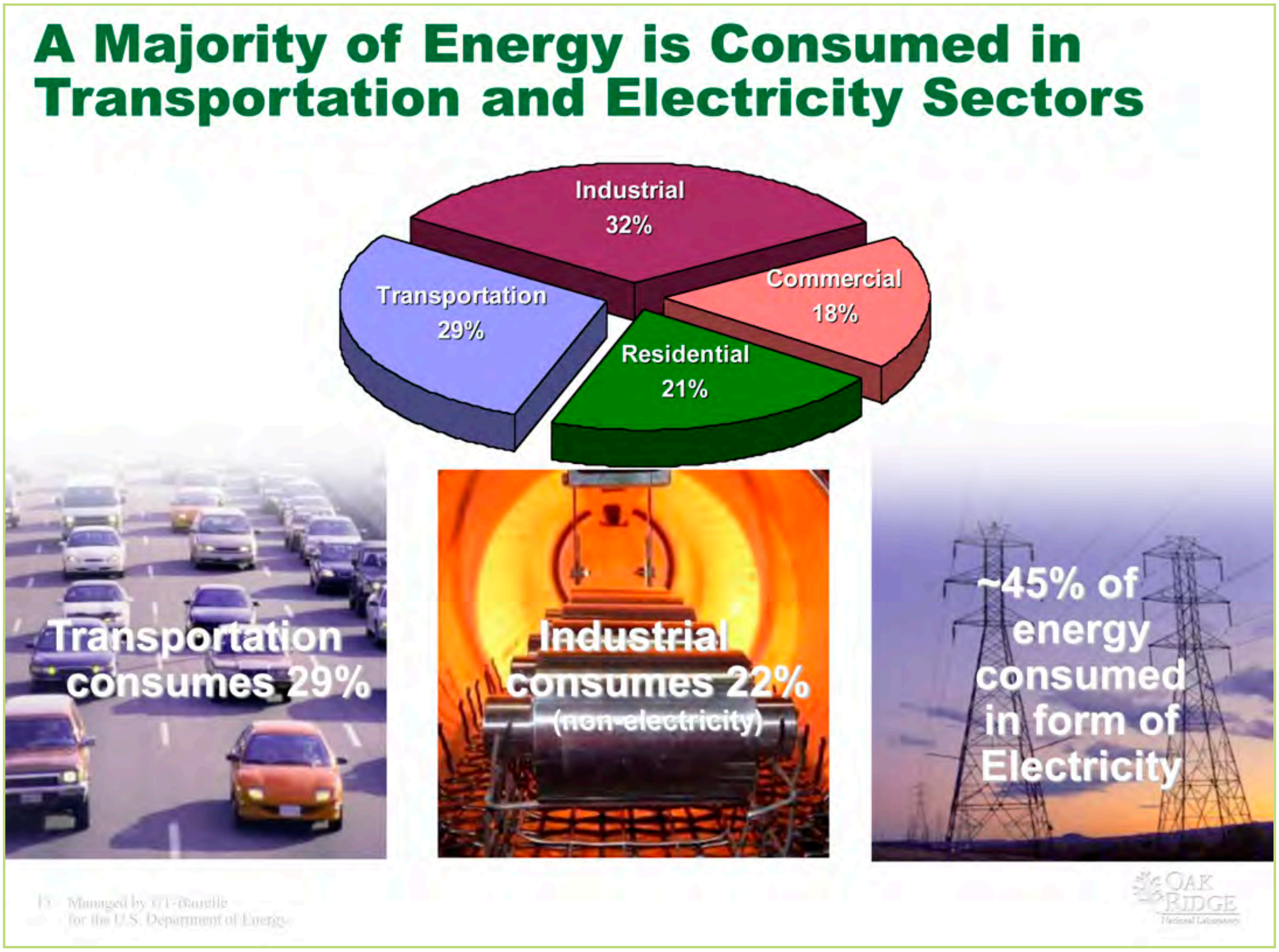
ORNL has also recently formed a new directorate, the Energy and Environmental Sciences Directorate (EESD). EESD is a directorate that spans from basic science to commercialization of technologies in all energy areas except nuclear.

ENERGY PIE: THE TRANSPORTATION SECTOR

In the United States, a majority of energy is consumed in the transportation and electricity sectors. Transportation alone represents 29 percent of the energy pie, and 45 percent of energy is consumed in the form of electricity. From a climate perspective, we could theoretically lower overall carbon emissions by increasing nuclear capacity to generate electricity, but there are obstacles to that approach. Reducing the carbon footprint and the dependence on foreign oil in the transportation sector is one of our top priorities.

What are our options in the transportation sector? Assuming biofuels would not meet this potential, what alternatives would we have to replace liquid transportation fuels? How can we make the transportation segment of the energy pie sustainable? We need to approach this challenge at many different levels and many different scales.

One option is to accelerate electrification of our fleet of automobiles by improving technologies such as advanced batteries that will allow us to drive across country on the interstate system. Electrification will likely play a major role in the future for metropolitan areas and daily commuting, but it is less likely that we will be able to drive trucks across the country on



batteries. A second approach is creating more efficient, lightweight vehicles and more advanced electric/combustion hybrid power trains, in trucks as well as cars. A third angle is to introduce alternative fuels such as drop-in fuels for legacy cars and renewable fuels for newer, advanced engines. Finally, we need to tie it all together by creating intelligent systems and operations. With this approach, we must manage congestion, improve efficiencies in commercial vehicles, make data available for decision making, and improve communication. All these new technologies and processes should aim at creating safe, secure, and affordable vehicles for passengers and freight; increasing domestic production of transportation fuel; reducing environmental impacts of transportation; and making transportation patterns more predictable. This is the challenge we are facing in the United States and worldwide.

HOPE FOR BIOFUELS

ORNL's BioEnergy Science Center (BESC) has been operational for more than four years. BESC is a multi-institutional, DOE, Office of Science, Biological and Environmental Research-funded center performing basic and applied science to enable cost competitive biofuels from cellulosic biomass. In addition to 16 academic institutions and national laboratories, we have three industry partners, ArborGen LLC; Ceres, Incorporated; and Mascoma Corporation.

Developing sustainable biofuels and bioproducts in a cost-effective way requires understanding and modifying plant biomass recalcitrance and delivering new tools and processes for biomass processing and conversion. The current bottleneck for this industry is making the sugars in biomass accessible, and progress will depend on overcoming the recalcitrance problem. We have a number of projects in place to solve this problem. On the feedstock side, in a partnership with the Noble Foundation, we are making significant progress in understanding the lignin pathway so we can genetically modify switchgrass to increase ethanol yield. We have created a transgenic switchgrass that is now growing in greenhouses and also in field trials. Genetic manipulation of lignin improves biofuel production from switchgrass and at the same time reduces the severity of pretreatment and lowers the cost of processing by about 20 percent.

On another front, we are looking at the natural diversity in an important potential feedstock *Populus* to find natural variants of the tree that are more easily digested. We have conducted the largest-ever recalcitrance study of natural variants of *Populus* and gained new insights on the correlation between lignin content and glucose. We found that certain natural variants have unusually high sugar yields with no pretreatment. From northern California, to Oregon, Washington, and Canada, we took about 1200 samples of natural growing *Populus* and investigated in the lab how good they are at releasing sugars. We did this by creating a high-throughput screening pipeline to analyze the amount of cellulose and hemicellulose in the plant and the conversion of these polymers into sugars.

An unexpected finding was the tremendous variation in sugar released in natural variations of *Populus*. As we started this research, we did not know if this variation was due to the environment or genetics, so we put our samples into three common gardens in three locations in the United States. We are now getting data back. The information confirms that the changes are based on genetics, not the environment. We identified 19 genes that control or reduce recalcitrance and six individual genotypes that release 85 percent of the sugar without pretreatment. BESC and its partners are also conducting field tests of improved feedstocks, *Populus* in South Carolina, and genetically improved switchgrass in Texas and Tennessee.

In addition, BESC researchers have engineered a native cellulose-degrading microbe to produce isobutanol. This work demonstrates the ability to combine consolidated bioprocessing with production of next generation fuels.

SUSTAINABLE COMMUNITY

Bioscience and biotechnology for sustainable mobility depend on an integrated biomass strategy. ORNL has several centers and programs that are aimed at implementing that strategy. The Center for BioEnergy Sustainability is tackling the land-use logistics of feedstock selection. BESC is focusing on molecular biology, chemical and structural analysis and characterization, and modeling and simulation. ORNL is also working on catalysis and separations science and technology, using catalytic conversion technology development for biomass separation. The Carbon Fiber Technology Center is working on materials science and engineering that will assist the National Transportation Research Center in its vehicle light-weighting program.

In the final analysis, we are not destined to look at sustainability from a doom and gloom perspective, but we do need to rethink at all levels how we envision our society 100 to 200 years from now. ORNL's vision for a sustainable community includes green, intelligent buildings; high efficiency industrial processes; a smart electric grid; an array of renewable sources of energy; waste reduction and water management; and intelligent transportation systems. Transportation is just one part of this integrated process, and biofuels done right can be a small but significant piece of the puzzle.

Toward a Sustainable Energy Development Strategy from the Perspective of Food Security: Challenges and Opportunities for China

by
Lei Shen

Dr. Shen is a Professor in the Department of Natural Resources and Environmental Security, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing.

In the first decade of the 21st century, China has been faced with many emerging issues related to its energy development. These include rapid population growth, industrialization and urbanization; energy consumption and carbon dioxide (CO_2) emissions; high oil import dependence but a vulnerable oil supply system; the dilemma of decoupling CO_2 emissions from economic growth; high fossil fuel share of overall energy; and the difficulty of increasing renewable energy under the conditions of global financial crisis and transition.

On the one hand, China is carrying out a large campaign of saving energy; on the other hand, the country is supporting new energy development. As we examine the mid- and long-term perspectives of China's primary energy consumption demand, we find that China has to mutually cooperate with developed countries like the United States and Japan in order to deal with its CO_2 emissions and high energy consumption. We also quantitatively measured the extent of sustainability in the realm of energy development. While China had a decent score in terms of the transition to sustainability in its energy policy, it still has far to go on the sustainability path.

IMPACTS OF BIOMASS ENERGY ON FOOD PRODUCTION

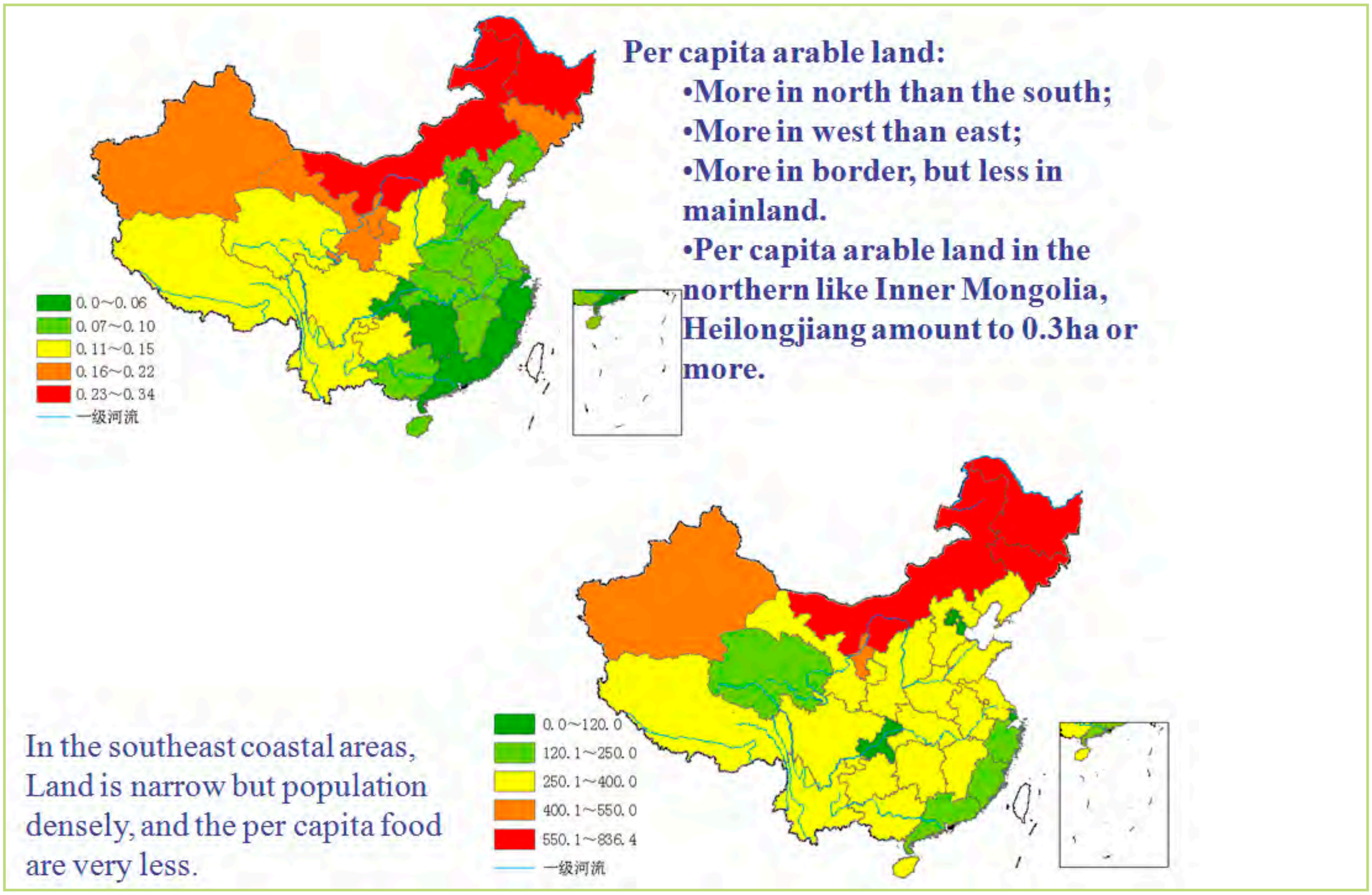
China has great potential but is faced with many challenges for renewable energy development. Over recent years, outputs of biofuels in major countries of the world have been increasing. Many energy crops are used to produce biofuels, including beets, sweet potato, casava, corn, rice, wheat, sorghum, sugarcane, oil palm, and soybean.

There is a perception that global biomass energy development has to some extent caused negative effects on food production and supply, and there is evidence that green-based biofuel will lead to a rise in food price that threatens food security. Many developing countries, therefore, are rethinking the biofuels development initiative.

Worldwide, and in China, arable land and food production are limited, so we have to make decisions in the use of land. Will we feed our mouths or feed our tanks? Biofuel development has primarily been based on the raw materials for food. We are seeing a decrease in the amount of food stuff in the world market and a worldwide increase in the price of grain, which is creating a food crisis for developing countries dependent on importing food. Low-income countries that import more food than they export have been hardest hit; 37 countries, 21 of which are in Africa, are facing a food security crisis. Moreover, high food prices have pushed 100 million people in low-income countries into poverty in the last three years. Despite several record-breaking harvests, world cereal production has fallen short of consumption since 2000, and in 2007, world grain stocks were at their lowest levels in the last 25 years. Global food prices have been rising steadily and were up almost 160 percent in 2011.

Despite these grim statistics, China's biomass energy development has caused little negative effect on its food security. In fact, the increase in China's food prices is not a result of biomass development. Even though food prices in China went up nearly 15 percent in July 2011, China's food security is more significantly determined by its agricultural production conditions rather than competition for biomass energy. In fact, China's arable land is ranked fourth largest in the world.

China's food security future is not optimistic, but this is due less to competition with feedstock for biofuel than to the tension between our people and our land. The Food and Agriculture Organization of the United Nations (FAO) has established a food security line based on per capita arable land. In 2010, FAO statistics showed the amount of per capita arable land in all cities and some provinces like Zhejiang, Fujian, and Guangdong is below the FAO warning line, a point at which food production is 200 kilograms per person or less. The food security situation in southeast China is particularly serious.



Consider the land use efficiency for various biomass crops: corn, corn straw, perennial grasses, and Giant King™ Grass. According to statistics published in 2010 by the clean energy company VIASPACE, biomass yields must exceed 10 metric tons per hectare per year to reach the level of efficiency required to produce ethanol. Cellulosic ethanol from corn straw is not yet commercially viable on a large scale, but the yield is similar to that of corn. For switchgrass, the yield, 25 metric tons, does exceed the level of efficiency required to produce ethanol. Perennial grasses such as switchgrass also lead to less soil depletion and erosion. Giant King Grass makes by far the most efficient use of the land of all these crops, with a yield of 100 metric tons per hectare.

Not only does Giant King Grass have the highest mass and energy yield, it also has the highest financial yield of the energy crops, $US 5,000-6,750 per hectare as compared to switchgrass which yields $US 1,250 per hectare. Switchgrass and Miscanthus are grown in temperate regions and are harvested once a year. Giant King Grass is grown in tropical and subtropical regions with two or more harvests per year. Other crops such as Jatropha and palm oil, which are used for biodiesel, are grown in tropical and subtropical regions. The grasses are suitable for direct combustion, bio-methane production, and cellulosic biofuels such as ethanol. All of these biomass crops are needed to meet China's need for biofuel feedstocks.

TOWARD A CLEAN AND SUSTAINABLE BIOMASS ENERGY

It is clear that we need to minimize the impacts of bioenergy development on food security. There are two basic approaches to this strategy. One is to make the best use of the land; another is to develop the second generation of cellulosic ethanol. All policies should give priority first to ensuring the food supply and then to protecting the future supply of feed and feedstock for bioenergy. In China we have a basic principle that bioenergy should not compete with food for the people, and that we must not fight over land for food. Based on these limitations we have outlined three possible development paths: a) make full use of resources from agricultural and forest waste, b) develop marginal land resources, and c) adjust the farming system.

Waste Resources

One path in China with great potential is exploiting biomass resources. According to the 11th Five-Year Plan for Renewable Energy Development, the total exploitable annual capacity of biomass energy in China was 500 million tons of coal equivalent in 2010, including crop stalk, livestock and poultry manure, firewood and forest biomass energy, and municipal solid and wastewater. All of these biomass resources are used for power generation and production of biogas and bioethanol. One challenge is the uneven distribution of biomass geographically. Nevertheless, China has great potential overall in renewable energy resources, including biomass, wind and solar energy, and geothermal power. According to China's mid- and long-term planning on renewable energy development, the share of renewable energy in total energy consumption was only eight percent in 2005, but this is expected to rise to 10 percent in 2010 and 15 percent in 2020. This policy implementation will aim to reduce 0.6 gigatons (Gt) of CO_2 emissions in 2010 and 1.2 Gt in 2020.

Marginal Land Resources

The second pathway is to develop marginal land resources. At present China's grassland suitable for planting energy crops is about 3.61 million square hectares (hm^2). China plans to grow 13.33 million hm^2 of forests by 2020. China has 136.14 million hm^2 of marginal land, which could be used to plant raw materials for biofuel production. In addition, the existing area of firewood, forest, and shrub woody oil reached 51.76 million hm^2. China's marginal land suitable for bio-energy crop planting includes unused land, existing agricultural land that cannot be cultivated, and forested land. National unused land is 245 million hm^2, and about 60 million hm^2 of the total can be available for biomass, accounting for 24.6 percent of unused land and 6.3 percent of the total land area.

Unused land resources are mainly distributed in northern latitudes or in arid and semi-arid regions with only one crop a year possible, and in some areas with poor production conditions in the western and northern regions. Due to water and temperature constraints, some lands are difficult to develop into arable land, but have potential in the use of energy crops and energy forest. It is estimated that one third of the arable land can be used for bioenergy planting in 10 provinces

China's existing forest land is 282.80 hm^2, which can be divided into forest, woodland, shrub forest, immature forest land, nursery land, and other wooded land. All of this forest land could provide a large amount of biomass resources.

Adjusting the Farming System

The third path is to adjust the farming system. One of the best practices promotes the establishment of deep-rooted perennial species, and their processing for bioenergy has benefits for both the local and global environment. Winter cover crops and food crop/energy crops with long cycle rotations of 10 years or so can improve the yield of lands, and perennial crops and poly-culture cultivation can recover degraded agriculture lands. In addition, some fallow farmland can be converted to green energy production fields, resulting in reductions of CO_2 emissions.

SECOND GENERATION BIOFUEL

The first generation of biofuels used food crops such as corn as raw materials. Between the first and second generation, bioethanol was produced using non-grain crops as raw materials, such as cassava. The second generation bioethanol, cellulosic ethanol, is made from agricultural residues such as cornstalk, forestry residues, cornhusks, wood chips, and other energy crops. This technology could reach maturity and become commercially viable in a very short time,

Cellulosic ethanol has environmental and social advantages and can bring great benefits to China. It is estimated that by 2020, cellulosic ethanol can replace 31 million tons of gasoline per year, reducing China's oil imports by 10 percent. In addition, it can bring in an annual income of 32 billion yuan and create six million job opportunities. Moreover, second generation biofuels can create a value of 90 billion yuan in the domestic engineering and construction market and have potential on the international market. By 2020, cellulosic ethanol can reduce annual CO_2 emissions by about 90 million tons and obtain a favorable economic return.

There are some hurdles to overcome with second generation bioethanol development. In the short term, China needs 90 billion yuan of investment to support bioethanol plant construction. In addition, there is some competition for the biomass supply with cement production and power generation.

CHALLENGES AHEAD

The world faces many challenges, and China is no exception. Some major challenges are of great importance to China's energy development. For example, China is highly dependent on coal and has become increasingly dependent in recent years on imported coal, which raises its CO_2 emissions.

Worldwide, we hear more voices on the question of how to convert grain into bioenergy. Some argue that this may play a limited role in pollution reduction, while leading to higher food prices. China has chosen its specific path of development of non-food biomass, which highly depends on waste resources, marginal land development, and adjustments of farming systems. China's marginal land includes available land, non-agricultural land, and woodland, some of which can be used for bioenergy development sites assuming the appropriate technologies and feasible production costs. We propose that a national multidisciplinary survey of biomass resources should be carried out aiming to find out the types of biomass, distribution, the value of resource use, and scientific evaluation of biomass energy development potential.

ACKNOWLEDGEMENTS

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Bio-based Materials for High-end Electronics Applications

by
Joe Kuczynski

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During the past decade, a shift of focus on greener alternatives to petroleum-based plastics has spurred the development of biobased resins for plastic development. Numerous electronics manufacturers have received overwhelmingly positive press for their strategic initiatives to replace petroluem-based materials in their products. Moreover, major international electronics firms are committed to reducing carbon dioxide (CO_2) emissions and reducing their global footprint by reducing waste and limiting the use of oil-derived plastics in their products.

IBM is actively engaged with our supply chain in an initiative to "green" our product portfolio. The intent of this activity is several fold: a) identify novel biobased plastics for use within IBM products; b) explore potential life cycle and performance impacts of replacing traditional plastics with biobased alternatives; and c) explore novel approaches to electronic design that incorporate biobased or biodegradeable resins. These activities are part of IBM's Smarter Planet initiative. In addition, within IBM we have an Academy of Technology, within which my colleague Dylan Boday and I co-chaired an initiative to evaluate bio-materials.

Although there are numerous areas within a typical server where more sustainable plastics may displace petroleum-based products, only acoustic foam and thermoplastic front/rear covers will be discussed.

IBM'S SMARTER PLANET INITIATIVE

Peak oil depletion scenarios vary widely, but essentially by 2257 we are going to be out of oil. One thousand years before a benchmark date of 2000, agriculture was sustainable, and resources renewable. A thousand years in the future, in states such as Indiana, huge combines, we hope, will be harvesting 2nd and 3rd generation biofuels or feedstocks using fuels such as biodiesel. Looking at progress on this scale, the oil-based economy is just a blip in history.

IBM has recently launched our Smarter Planet initiative with the intent to build one smarter planet, based on the three basic concepts: a) *instrument* the world's systems, b) *interconnect* them, and c) make them *intelligent*.

There are four cornerstones in IBM's Smarter Planet initiative.

- New Intelligence. To manage the mountain of information generated daily by increasingly connected systems, devices, and people, while extracting richer insights and making faster, better decisions.
- Dynamic Infrastructure. To provide the operational efficiency to drive down costs and the flexibility to assimilate change and drive competitive advantage.
- Smart Work. To improve the agility of enterprise business processes and the organization's ability to benefit from and enhance the expertise and creativity of its people.
- Green and Beyond. To support initiatives in response to escalating energy, environment, and sustainability concerns, and stakeholder requirements for social responsibility.

You might ask, what is at stake, and why does IBM care? There is a negative image about the disposal of plastics, with global awareness that the industrialized West is using Asia as its dumping ground. For just IBM alone, plastics usage is about 8-10 million pounds per year. We have a significant opportunity to reduce our environmental footprint by switching to bioplastics.

Within IBM, we launched the Biomaterials Initiative in September 2010, and our Academy of Technology—which includes individuals from our corporate environmental affairs, research staff members, materials designers, and hardware engineers—released a study on biobased materials in January 2011. The project focus areas were to a) determine where"green" alternatives to petroleum-based materials exist for information technology (IT) applications and qualify these new materials at the part and system level, b) establish research in core green technologies via industrial and academia collaboration, and c) establish a road map for a “green” IBM product line.

EVALUATION PROTOCOL: HOW DO WE WAG THE DOG?

There are numerous applications where biomaterials can be used to replace plastics, including foams, thermoplastic covers, packaging foams, cabling, printed circuit boards, fabric-over-foam gaskets, adhesives, and elastomers. The question is: How do we do this? How can IBM, the tail, or bottom, of the supply chain, wag the dog, the raw material suppliers at the top. With regards to foam, we buy the foam from a foam converter, which procures their raw materials from a supplier. With thermoplastics, we purchase the part from a molder, which is typically located in Asia Pacific. Their material is compounded to our specifications, but that compounded plastic comes from the typical raw material supplier. Just how far back in the supply chain do we have to go in order to effect change in our products?

Chemically, the acoustic foam process is based on polyurethane chemistry in which an isocyanate and an alcohol form a urethane crosslink. Acoustic foam is generally manufactured by mixing the raw materials in a mix head then dispensing the mixture onto a conveyor. The reaction proceeds in two stages: the gel reaction and the blow reaction. During the gel reaction, isocyanate reacts with hydroxyl groups on the polyol to form a urethane linkage that builds molecular weight and gels the reaction mixture. The blow reaction is a multi-step process: isocyanate reacts with water to yield an unstable carbamic acid which rapidly decomposes to an amine and CO_2. CO_2 is the actual blowing agent in the reaction mixture responsible for cell formation. The amine subsequently reacts with isocyanate to form urea linkages. The foams with the best acoustic, or sound absorption, performance have a density of about 2 pounds/cubic foot, but more important is the pore count; the magic number seems to be 65-75 pores per inch. The typical ratio of polyols to the isocyanate is about 2:1.

We know that some manufacturers are producing bio-based polyols used in foam polyurethane, though we do not know of any producing bio-based isocyanates. Theoretically, replacing the alcohol with just the bio-based alcohol, we can incorporate about 67 percent green content in the foam.

As I mentioned earlier, we know that bio-based polyols are available, and we want to use them to replace the petroleum-based polyols currently used to make acoustic foam. All servers include an enclosure and front/rear covers. The acoustic foam is placed on the cover and at strategic locations within the enclosure. The foam is necessary because, as we drive these systems faster, the processors are working harder, the components are getting hotter, and more air is blowing through the entire system, generating greater noise. The IT industry in general, and IBM in particular, is working feverishly to absorb some of that noise at the box level. If you have ever been in a data center, you know that it can be difficult to hold a conversation with the person next to you, and ear protection is required. We try to mitigate that noise at the source by using this acoustic foam.

Working back through the supply chain, IBM has been collaborating with two US acoustic foam manufacturers, FXI and WT Burnett, and with a foam converter company, LMC, to assess biobased foam. In a reverberation room at our facility in Poughkeepsie, New York, we can measure how well samples of foam perform acoustically. Basically, we blast sound energy at it and measure how well the material absorbs that sound energy. Comparing the acoustic performance of the traditional, petroleum-based polyurethane with different bio-based materials, including foam made with bio-based polyols, we find the bio-based materials perform better than the petroleum-based materials. In addition, the material needs to be flame retardant since it is installed next to high voltage materials. The bio-based polyols meet our flammability requirement. Moreover, since cost is king at IBM, the bio-based polyols are cost neutral. In sum, the bio-based foams are greener, they are cost neutral, and they actually perform better.

There is, however, a downside. The bio-polyols are currently mixed with petroleum-based polyols at a rate of about 20-30 percent. The foam manufacturing companies acknowledge that an increase of more than 30 percent results in a decrease in mechanical strength. For acoustic foam this may not be a major obstacle since the foam only has to absorb sound energy and so does not need to have any compressive strength. We may therefore be able to drive the bio-content further with existing bio-based polyols.

In late summer 2011, we introduced these bio-based polyols into our products and have been shipping material from the United States, Mexico, and Hungary into the European Union and Asia Pacific regions. IBM is generally reluctant to estimate the amount of CO_2 emissions we might be saving, but we feel we have made a very positive impact on our footprint with regards to acoustic foam.

Another step forward in production of biobased foam has been taken through a joint venture between Ohio State University and PolyGreen Technologies (PGT) to commercialize the production of polyols used in polyurethane synthesis from glycerin, a waste product from the manufacture of biodiesel,which has better properties than the existing polyols obtained from soy or castor bean oil. In June 2011, IBM initiated a collaboration with PGT and FXI for the evaluation of this product for acoustic foams. The price of PGT biobased foam is the lowest for raw materials, since glycerin is a by-product. The foam uses non-food grade oils so there is no pressure on food supplies. In addition, the “green” level is very high, the products perform at a much higher blend ratio, and the material can be used in fabric-over-foam gaskets.

ELECTRONIC ENCLOSURES

The electronics industry has been very enamored for some time with polycarbonate/ABS (acrylonitrile, butadiene, styrene terpolymer). We have been using this material successfully in electronic enclosures for 20 years. Polycarbonate/ABS resin has excellent thermal resistance, and it is very tough. Because these materials are made using injection molding to produce thin wall materials with intricate features, high flow is also important.

At IBM, 95 percent of plastic usage is petroleum based. Looking again at the supply chain, we ask what bio-based material is available in the market today for durable goods that can compete with polycarbonate/ABS. There are, in fact, several compounds based on polylactic acid (PLA). Blends of PLA, a corn-based plastic, are in the commercial pipeline to compete with PC/ABS, and we have forwarded our material requirements to global compounders in the United States, the European Union, and Asia Pacific for applications such as cassette trays and plastic covers. For now, the flammability requirement is the highest hurdle to overcome. We have tested a PLA blend from PolyOne Corporation that meets the wall thickness required for flammability requirements, and preliminary results were excellent. A few questions remain about the material safety data (required by California Proposition 65). Realistically it will take six to nine months for the product to be commercially available because color matching needs to be completed and the material uses a new flame retardant package that must be scaled up.

For the durable goods market, NatureWorks is the largest global supplier of PLA resin, which is derived from biomass fermentation. Virtually all PLA sourced from NatureWorks out of their Nebraska plant is manufactured using corn. A new plant located in Asia Pacific will use instead sugar beets or tapioca root.

ROADMAP TO THE FUTURE

IBM is forming a core group to drive the following activities:

- Covers. We plan to increase PLA content in blends, develop PLA blends with improved properties, and evaluate PLA-based thermoplastics.
- Foam. We will evaluate glycerin-based polyol, drive bio-polyol into polyurethane foam used in our gaskets, and develop novel acoustic foams with 100 percent bio-content.
- Packaging. We will replace IBM packaging materials with “green” polyethylene, evaluate biobased materials as card insulators, and increase biocontent/reduce part weight with novel “green” fillers
- Collaboration. We are initiating a joint effort with Ford on novel fillers, developing nanocellulose fillers, cooperating with Purdue and the China-US joint sustainability effort, and collaborating with major resin suppliers.

Energy Densification: Separations and Other Process Challenges in Biofuels Development

by
Jose L. Bravo

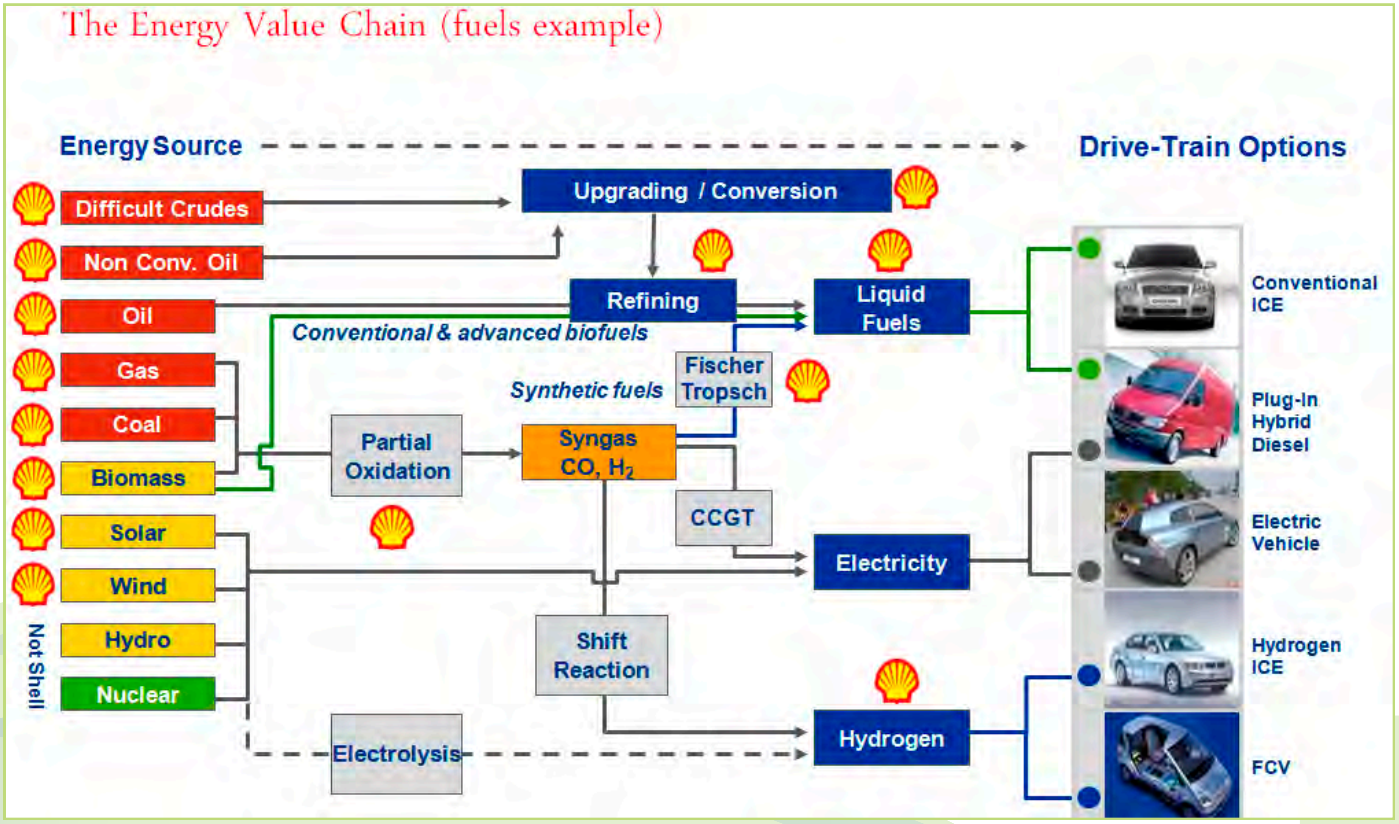
Dr. Bravo is a Chief Scientist at the Royal Dutch Shell Group.

When the chief scientists at Shell were appointed in 2005, the CEO of the company at the time met with us and told us what our missions were. When he came to me, an engineer rather than a true scientist, he told me specifically that a good idea that is too expensive is not a good idea. That has always been a guiding light for me.

We need to be sure that when we have good ideas, we are able to take them to implementation, and the path to implementation is usually through the cost competitiveness of the idea.

There are two considerations in the biofuels area that are key to determining that competitive edge: mobility and resources.

There are various options for mobility in the transportation sector, electric cars, fuel cells, combustion engines, hydrogen, or various combinations of these options. On the other end of the equation are the resources available to supply the energy to those mobility elements. Since the discovery of oil, we have become addicted to very high density fuels with a great deal of energy contained within a very small volume. That fact has determined the industrial, social, and economic parameters of



our development, because high density fuels allow airplanes to fly and ships to go very long distances.

THE FUTURE OF BIOFUELS

We have used up much of the easily available, dense energy first and are now faced with energy that is not so easy to get and is less energy dense. We have to go deeper for oil, we have to remove bitumen from sand, and we have to access gas that is contaminated with carbon dioxide (CO_2). Now we have to consider biofuels from biomass, in which the energy component is small. There is a lot of water and air in it. Other available energy sources such as solar and wind are also less energy dense. We are facing a continuously decreasing energy density scenario in resources and are employing new technologies to improve conversion and refining efficiencies to get the most out of the resources available. That is our task at Shell as an energy supplier and the task of you as researchers, investigators, problem solvers, and educators. All of us play different roles in the energy challenge.

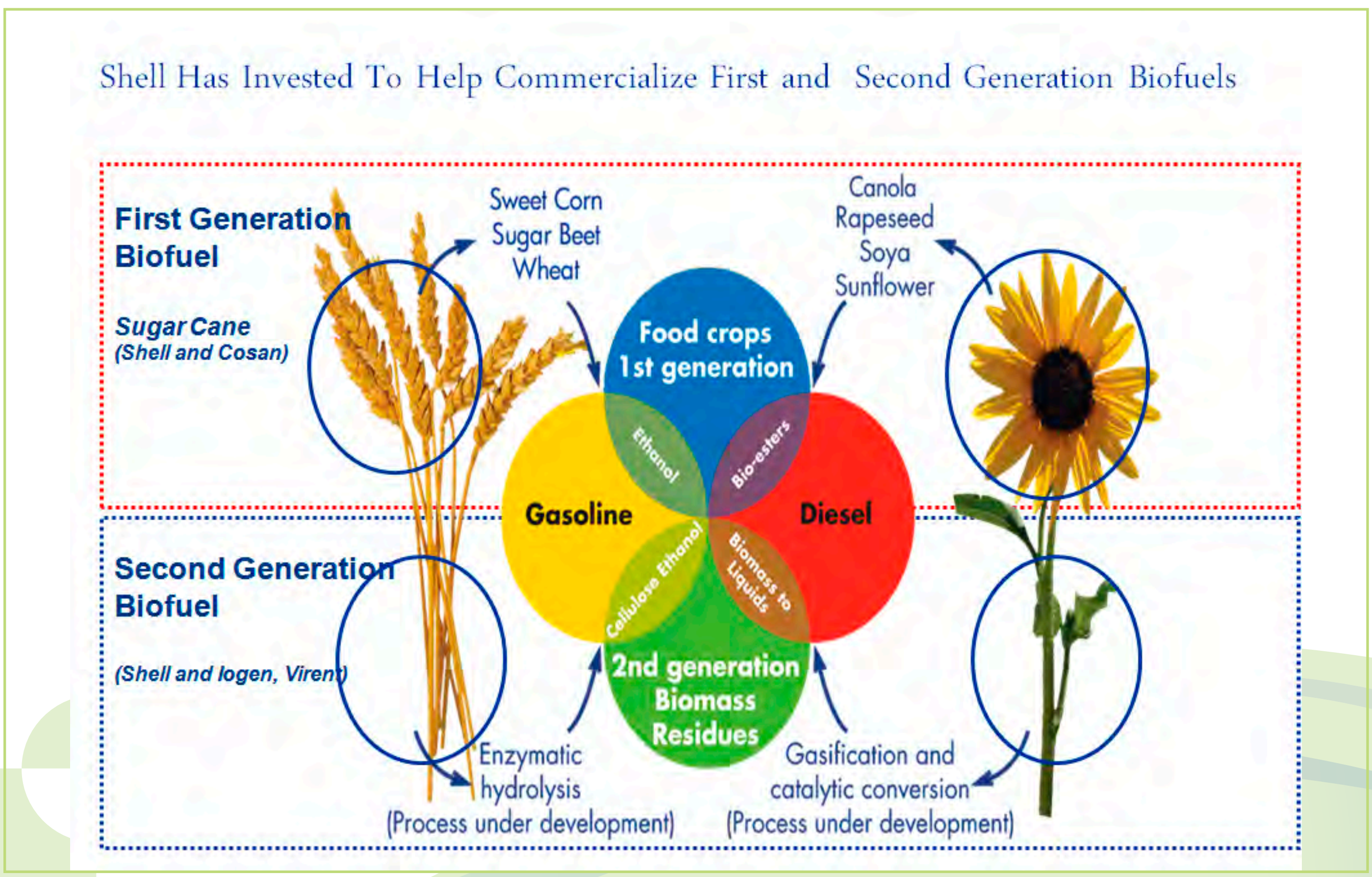
Everybody agrees biofuels are here to stay and will play an increasing role in meeting the energy challenge for a number of reasons, including energy security, environmental concerns, economic development, and ease of implementation. Shell is a leader in first generation biofuels made from sugar cane through our Raizen joint venture in Brazil, but we are now focussing our R&D and strategy on second generation biofuels made from agricultural and forestry residues and have explored algae. The promise of biofuels, however, seems to have a continuously postponed arrrival date. Just a few years ago, people said, second generation biofuels would be available on a massive scale in just five years. Five years later, we are still talking about their becoming available on a large scale in another five to 10 years.

In the meantime, other energy sources suddenly appear. For example, the United States now appears to be awash with natural gas. That is a disruptive event for the biofuels landscape because it has the potential of making electricity the fastest route to CO_2 management and electric mobility. If natural gas delivers electricity, then people will switch to electric vehicles in one fell swoop. So for biofuels to become a reality, there are some challenges and limitations that need to be overcome.

THE DENSITY FACTOR

Biofuels have low energy density and are typically more expensive than petroleum-based fuels. In addition there are as yet unresolved sustainability issues concerning land use, water use, and nutrients. There are also supply chain and logistics challenges.

Many of the problems with biofuels can be approached using fundamental science, but for actual implementation, the main problem with biofuels still revolves around energy density. What makes biofuels an expensive proposition is the effort it takes to densify the energy from the very beginning. The logis-



tics of densification involve trucks to move crops, the amount of water and lignin in the material, and the volumetric density of the materials. The science required to manufacture, purify, and deploy biofuel is also necessary, but it is useless if we don't solve the first problem, densification, which is less a scientific than an engineering issue.

Fuels from energy-dense crude oil, the resource we are equipped to handle, have some environmental and sustainability advantages because they are already so dense. How do we achieve similar energy density using first or second generation alternatives? To extract crude oil from several kilometers under the surface of the ocean or deep in the Earth requires massive engineering. As the easy sources of crude oil become less abundant or subject to political vicissitudes, we turn to other sources, each of which has its challenges.

In terms of energy density, it is revealing to compare some data on newer sources of oil that can be extracted from oil sands and the oil that can be generated from algae.

Oil Sands

Shell is a big producer of bitumen and oil from oil sands in Canada. There is a lot of oil there, some people say more than in the Middle East. The problem is the source is 10 percent oil and 90 percent sand. To separate the oil from the sand is a simple process from the scientific point of view. If you put water on the sand, the oil is released, but the water needs to be heated and the sand needs to be moved. To get a substantial but not enormous amount of oil, 100,000 barrels per day production, for example, the equivalent of what one of the large platforms in the Gulf might produce, you need to move 168,000 tons of sand per day. That takes an enormous amount of energy, equipment, work, logistics, and excavation. An engineer might suggest we could increase the recovery of oil by half a percent if we increase the water temperature for the extraction by 2° C. The amount of energy you get out may not be equivalent to the amount of energy you have to put in just to warm the water a bit because so much water is processed.

Algae

The science of converting algae to oil is very elegant. Researchers working on the biochemistry of the process are learning how to lyse the cells, break them down to get the oil out. However, right now it is very difficult to get naturally occurring algae to grow at more than 100 milligrams (mg) per liter concentration and produce more than 10 percent per weight of diesel precursors. In the lab you can get a lot higher, but we have found at Shell that when you start to scale up, the algae become crowded, and it is very difficult to maintain the colonies. To produce 10,000 barrels of oil, the equivalent of production of a small US diesel refinery, would require an equivalent of 35 million gallons per minute (gpm) of water. The largest municipal wastewater treatment plant ever built processes about 2.8 million gpm. The real challenge in algal fuels is to get that 100 mg per liter to 500 or 600 mg and to get the oil content above 20 percent. Otherwise the magnitude of the process, the sheer amount of concrete and pumping of water, makes the idea unfeasible.

BioCrops

Another challenge for agricultural products destined for second generation biofuels is logistics, the number of trucks it will take to transport biomass on a market scale. A second generation biofuels facility can approach 30,000 trucks a month going into a central location, putting tremendous strain on local infrastructure and requiring very expensive materials handling facilities, all of which are caused by the very low energy density of the biomass.

THE DENSIFICATION CHALLENGE

Energy densification will remain a challenge in the transition to more environmentally sustainable fuels. In spite of the challenges, biofuels have important advantages and will be an increasingly important part of the energy mix. In addition to energy densification and the environmental performance of a fuel, we also need to consider the ease of implementation, that is, the ease of delivery to the customer. In most of the world, we already have infrastructure in place. China is perhaps somewhat of an exception because the country is still growing and building infrastructure, and thus may still have the opportunity to build infrastructure to suit its needs. In the United States, we have what is called legacy infrastructure, which is already in place and has been there for some time. Much of it is covered up under concrete and cement, which makes changing the infrastructure difficult and expensive. So if the environmental performance of fossil-based gasoline and diesel is inferior to that of biofuels, the ease of implementation nevertheless gives conventional fossil fuels an infrastructure advantage. If new oil is discovered, it is very easy to bring that to market thanks to existing refineries, pipelines, and service stations.

Some alternatives to oil-based fuels, however, can offer environmental benefits without large-scale changes in infrastructure. We have, for example, a process called gas-to-liquids (GTL), which converts natural gas through a fairly complicated process into liquid diesel and jet fuel. This is a very easy solution to implement from the product delivery standpoint because it produces exactly the same products we already have on the market, and it produces good quality fuels with no sulfur or particulate emissions. If you could apply the same technology of gasification and produce liquid hydrocarbons from biomass in the same way you can gasify coal, oil, or natural gas, you would have a very elegant solution, achieving very high environmental performance to create products that are fungible with the existing infrastructure. In the oil industry, the term fungibility means that you can mix what you produce with the current fuels, so a fungible fuel is one you can mix into a pool of diesel or gasoline for the customer. Ethanol, for example, is a fungible fuel. We need to make biodiesel fungible. As it stands today, biofuels are in the middle between environmental performance and ease of implementation. We still need better technology to make the products more fungible and thus reduce the cost significantly.

Even some of the competition with biofuels like liquified petroleum gas, compressed natural gas, and hydrogen have ease of implementation issues as well. Hydrogen is a marvelous fuel energy carrier, but we do not yet have the infrastructure to deliver it to the consumer.

Electricity from natural gas, wind, or hydro, but not coal, also has a reasonable environmental profile and potential ease of implementation. In fact, the infrastructure is better than for liquid fuels because of the universal access to existing electrical outlets and the relative ease of expanding on existing electrical infrastructure.

Some of the technologies for alternative fuels are moving up the path of ease of implementation, which is the number one criterion for implementing a new technology with improved environmental performance.

THE WINE ANALOGY

The challenge for production of biofuels such as second generation bioethanol is to increase energy density as close as possible to the point of harvest. Unlike oil, you can't take biomass and put it into a pipeline. Biomass must be pelletized, compressed, dried, and chemically converted to liquid hydrocarbons. Then you have to conceive of a distributed model of energy production totally different from the models we have now where the resource is sent to a central processing location. Imagine that you could turn a crop field into an oil well, with oil coming directly out of the field. The idea of small distributed production for hydrocarbons in the field is a model that is very uncomfortable for a company like Shell. We do it with oil wells, but not with biomass. At some point, that transition needs to happen.

Oil and energy resources are like wine. Oil has the same personality as good and bad wine, old and young. Old wine has been aged for years in the proper environment and so is more desirable. That is what we would call nice sweet, light oil. The older oils have been in the ground the longest time and have been treated for the harshest conditions. Younger oil is viscous and acidic and contains a lot of oxygen, nitrogen, and sulfur, much like a young wine. Bio crude oil from catalytic or thermochemical processes is like just beer. It is very crude, very young, brewed in just one day. It will give you a headache and a bad hangover. We therefore have to find ways to accelerate natural aging over time, going from low to high density material. We have not found an answer for aging wine in an accelerated way, but we have to find a way to age bio material into high energy density fuels.

Production of Cellulosic Lactic Acid as Bioplastic Monomer and the Process Development for the Future Biorefinery Industry

by
Jie Bao

Dr. Bao is a Professor of Biochemical Engineering and Chemical Engineering, State Key Laboratory of Bioreactor Engineering, East China University of Science and Technology, Shanghai, China.

China is a country rich in biomass. Annual production of agricultural residues is 720 million tons per year, and if just half of this resource is used for cellulosic ethanol production, it could replace all the gas consumption in China, which was 0.6 billion tons in 2010. The network required for the cellulosic ethanol industry to achieve 100 percent replacement would include 600 factories with productivity of 100,000 tons annually, about one factory in every three counties in China.

In China, corn stover and other agricultural residues are not utilized efficiently but are often burned as waste. Combustion pollutes the air and can be disastrous in terms of visibility and public health. This is an unnecessary practice considering agricultural residues represent a sustainable supply of cellulosic biomass.

PETROREFINERY VERSUS BIOEFINERY

A petrorefinery converts petroleum to gasoline, diesel, and chemicals, while a biorefinery converts biomass to ethanol, diesel, and chemicals. The most important difference between the feedstocks is the content of lignocellulose in biomass. Petroleum is a simple hydrocarbon mixture and can be separated by distillation to produce gasoline, diesel, kerosene, and heavy oils. Because of the recalcitrance of lignocellulose in biomass, fuel production is a multi-step process.

As we heard yesterday from Wally Tyner, there are negative aspects to biofuels. The future of oil prices is uncertain and could range from $50 to $200 per barrel. Feedstock costs of biomass may increase to $100 dollars per ton, and conversion costs are more than $3 per gallon. In addition, the environmental impacts can be high and suitable land scarce. Government policies and technical limitations also have an impact on decisions related to producing fuel biomass. In the United States, corn is used in ethanol production, and soybeans, another food crop, are exported to China. To be honest, we do need to consider the negative side of biofuels. As a chemical engineer, however, my main concern is the conversion cost.

BARRIERS TO COMMERCIALIZATION

Significant reduction in the cost of cellulosic ethanol is the lifeline of this industry. Cost reductions must be realized in materials, energy usage in the conversion process, and environmental costs such as waste water and solids residue.

Ethanol has been considered the first and almost the only product option of biorefineries using lignocellulose. However, the low value and barriers to entering the biofuel market have made the commercialization of cellulosic ethanol pretty tough, even after decades of extensive research and process development with massive investments. Up to now, no ethanol plant using lignocellulose feedstock is operated in a commercial way, continuously and profitably. On the other hand, the production of value added chemicals using lignocellosic feedstock provides an important option with great commercial potential for the future biorefinery industry.

A chemical like lactic acid is one way to bring down the cost of conversion. Why lactic acid? Lactic acid is generally formed in the valley and upstream of the metabolic pathways, and it is easily modifiable. Lactic acid can be chemically converted to lactide, and from lactide we derive polylactic acid (PLA).

Production of the lactic acid derivative PLA was commercialized by Cargill Dow LLC in 2002. The starting capacity for production was 300 million pounds, and current capacity is one billion pounds. Cargill Dow now projects a possible market of 8 billion tons by 2020. Most of the major producers of lactic acid are in China.

For now, the main problem for lactic acid production is that all producers use corn as the feedstock. If we use a rough cost estimation comparing production of lactic acid instead of ethanol from corn stover, we find the per-ton value added price for ethanol is $154. If we use lactic acid as a chemical, the value of one ton of stover jumps to $360. If we use the monomer grade of PLA, then the value rises to $750 per ton. The difference is in the chemical pathway.

LACTIC ACID: A VALUE-ADDED CHEMICAL

L-lactic acid is one of the candidate value-added building block chemicals in the future of the biorefinery industry due to its importance as the monomer chemical of PLA. At the State Key Laboratory of Bioreactor Engineering, we have designed an innovative process for producing PLA from lignocellulosic materials with corn stover as the starting material. The basic process has been modified into several very simple steps with great reductions in waste water generation and energy consumption.

The corn stover is pretreated with dilute acid, saccharified, and fermented into L-lactic acid using a dry lignocellose process. The reductions in steam consumption and wastewater generation in the pretreatment stage were accomplished in part by regulating two important but rarely noticed parameters, feedstock filling ratios and the solid/liquid presoaking ratio.

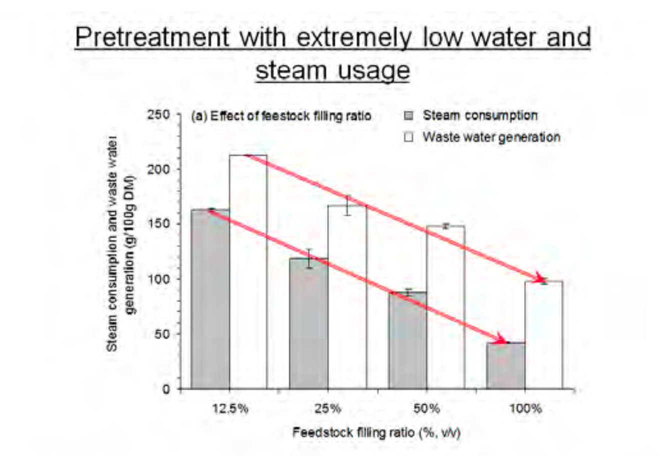
Another innovation is in the detoxification process. Toxins generated during pretreatment of lignocellulose act as inhibitors to fermentation. Traditional means of detoxification require washing and over-liming, which result in low yields, high amounts of waste water, and high energy rates. In our lab, we degrade the inhibitors in the pretreated corn stover material using a newly isolated, "Kerosene" fungus strain, *Amorphotheca resinae* ZN1, which is isolated from the microbial community growing on the material. This produces a higher yield, lower waste water, and lower energy costs. We achieved high solids loading and a high ethanol titer in the simultaneous saccharification and fermentation (SSF) step. We also achieved similar results in our bioreactor using biomass of rice straw and wheat straw. Ethanol concentration reached about 70 grams per liter (g/L), almost the maximal result in this dilute acid pretreatment material with no wastewater generation. Moreover, steam consumption and fresh water usage was cut by about 80 percent.

Another strain we used to boost fermentation of lactic acid fermentation is a newly isolated bacterium from the natural environment of lignocellulose processing, *Pediococcus acidilactici* DQ2. This unique strain demonstrates an unusual property of lignocellulose dependence, showing an obviously better fermentation performance in the lignocellulose processing environment, which is toxic for the majority of bacteria and fungi. The titer and yield of L-lactic acid reached 110 g/L and 87 percent in the SSF under the high solids loading of 25 percent in pretreated corn stover at 50° C, and with moderate cellulose dosage. The preliminary economic evaluation between ethanol production and lactic acid production showed that the profit for lactic acid production was about five-fold greater than the profit for ethanol production.

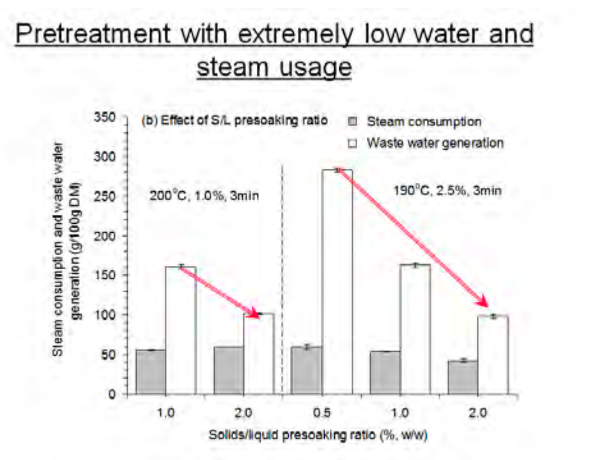
We project that commercialization of cellulosic lactic acid will be feasible by 2015. A pilot and demonstration plant using virgin corn stover is located at the Stove Conversion Park in Luoyang City, Henan Province. Another facility using corncob residue feedstock is a commercial-scale plant capable of processing 10,000 tons of feedstock annually and is located at a corncob xylose plant in Qingdao City, Shandong Province.

The target for the development of the future biorefinery is to achieve full-scale commercialization that is both continuous and profitable. The strategy to achieve that goal is that easy processes take precedence, and that chemicals are a high priority. First, we need to commercialize the production of cellulosic chemicals. Then we must convert the success of the chemicals process into cellulosic ethanol, shaping the real commercial cellulosic chemical industry. Finally, we must convert that success into lipid (biodiesel) and hydrogen processing.

Together, these processes provide a practical strategy for the future biorefinery industry operated continuously and profitably. The engineering practice of the commercial lactic acid plant will provide the lessons for ethanol production using lignocellulose feedstock.



Solids/liquid presoaking ratio of 2.0, 2.5% (w/w) dilute sulfuric acid, 190 °C for 3 min



Full packing, 2.5% (w/w) dilute sulfuric acid, 190 °C for 3 min

Biomass: A Sustainable Solution for Curbing the Fossil Fuel Dependency

by
James Zhang

Mr. Zhang is Group Vice President and Managing Director of FuturaGene Ltd.

In China, people are enthusiastic about cars, and the country has become the biggest automobile market in the world, overtaking the United States in 2009. In 2010, some 18 million vehicles were sold, almost 50,000 cars per day, 32 percent more than in 2009. People predict that in 2011, vehicle sales could reach more than 20 million a year. Edward C. Prescott, a 2004 Nobel Prize winner in Economics, predicts that China's automobile sales will reach 75 million by 2030, an astonishing figure if you consider that today, the total sold in the world is 70 million. China is also rapidly becoming the largest luxury car market in the world.

Can China really maintain this high rate of increase in automobile ownership? I doubt it.

IRREVERSIBLE TRENDS

The surfeit of automobiles in China has become an epidemic urban disease, a super-city disease that is spreading to every city in the country. As a result, China is experiencing a liquid fuel shortage that threatens its national security. The trends in car

ownership are irreversible. Enthusiasm for car purchasing in general and for luxury cars specifically remains high. This urban disease, traffic congestion, is spreading to all cities. Energy demand, especially for liquid fuel, will continue to grow rapidly. These pressures will result in more traffic jams, more liquid fuel shortages, and more environmental damage.

The governments of different cities have established various policies to slow down the car market. In Shanghai, for example, residents have to bid for a license plate before they can buy a car. Beijing, starting in 2011, is establishing a lottery for vehicle licenses prior to purchase. Most cities also currently have traffic restrictions that discourage travel during rush hour or establish restricted areas or parking fees.

China has now overtaken the United States to become the world's largest importer of oil, according to figures released in August 2011 by the Ministry of Industry and Information Technology. In the first five months of 2011, China's oil dependency rate surged to 55.2 percent, surpassing the US rate of 53.5 percent. By 2020, China's oil dependency rate could climb to 60 percent.

In addition to the environmental problems caused by automobile emissions, such as smog, China has other social and environmental problems due to its heavy reliance on coal for energy. China has the third largest coal reserve in the world, after the Russian Federation and the United States. China's coal production, however, is much higher. Under conservative estimates, coal reserves are predicted to be depleted in less than 200 years. Under pessimistic predictions, the reserve will be depleted in less than 50 years.

What will replace coal? China's oil reserve is very small and consumption very high. Imports of fuel oil are heavily dependent on critical sea lanes. Some 80 percent of imported crude oil transits the Strait of Malacca, one of the most unstable and risky sea lanes in the world.

China has the unfortunate distinction of playing the leading role in the world in terms of total energy consumption, coal production, oil dependency, and car production and marketing. As a result, the country is the number one producer of greenhouse gas emissions in the world. This is not a sustainable situation, and changes must be made to tackle the problems.

MAKING CHANGES FOR SUSTAINABILITY

China's current development model is not sustainable. Changes are required to maintain economic development balanced with sound environmental sustainability. Metrics and policies must be changed to make this happen: optimizing China's energy structure, improving energy efficiency, and making investments in new and renewable energy research and development. Clean, renewable energy is the future. The possibilities are endless, as alternative sources are abundantly available, including wind, solar, biomass, geothermal, fuel cells, hydropower, and electric vehicles.

Worldwide, the trend toward biofuels is growing. The US Energy Policy Act of 2005, for example, aggressively pursues cellulosic ethanol. The US target is to reach 20 percent of renewable energy in the primary energy structure by 2020 and 50 percent by 2050. Brazil, the second largest producer and biggest exporter of bioethanol in the world, has set a renewable energy target of increasing production of bioethanol from 17.5 million tons to 320 million tons. The European Union has set a target of 20 percent renewable energy in its primary energy structure by 2020.

CHINA'S ACTION PLANS

China has, in the recent past, set important milestone events, with its Renewable Energy Development Plan (2007), the establishment of the National Energy Bureau (2008), establishment of the National Energy Committee (2010), and its 12th Five-Year Plan on Renewable Energy Development (to be released). The key principles driving these efforts are to slow down the energy market, improve energy efficiency, and optimize China's primary energy structure by increasing the proportion of renewable energy in the structure.

Biomass-based non-food feedstock will play a key role in achieving the goals of China's renewable energy campaign. China has many options for power generation; but for liquid fuel, biomass will be the best and only solution. In his book, *Biomass: Win the Future,* Professor Yuanchun Shi has estimated the total annual quantity of biomass in China at two times the amount of hydroelectric and 3.5 times the amount of wind. Electricity from 422 million tons of crop residues is equivalent to that of two Three-Gorges Power Stations and could generate the equivalent of $16 billion US dollars of income for farmers. Professor Shi's study looked only at marginal land resources for biomass feedstock production.

Bioenergy is considered one of the three key alternatives to fossil fuel use, alongside wind and solar energy, because of its easy acquisition and clean emissions. Biorefining is a conversion process that produces fuel, power, heat, and value-added chemicals from biomass, the biological raw material extracted from organic sources. The consulting firm McKinsey and Company predicts this market will amount to $75-$140 billion annually worldwide by 2020. McKinsey sees this happening as the United States, Europe, China, and others promote biofuels to reduce carbon emissions and oil dependency. In China alone, the firm predicts, cellulosic ethanol fuel use could replace 31 million tons of gasoline by 2020, reduce China's oil dependency by 10 percent, and reduce carbon dioxide emissions 90 million tons annually.

FUTURAGENE GROUP

Sustainable solutions for global forestry, biofuel, and biopower markets...

The FuturaGene Group is focused on supplying low cost feedstock and lowering conversion costs. FuturaGene was first established at Purdue University in 2001. The company went public in 2004, and in 2006 we acquired CBD Technology, an Israeli company focused on biotechnology. In 2010, the company was acquired by Suzano Pulp and Paper. Today, FuturaGene is a wholly owned biotech subsidiary of Suzano with headquarters in London and subsidiaries in Israel, Brazil, the United States, and China.

The vision of FuturaGene is to be a world leader in developing and delivering sustainable biotech solutions for global forestry, biofuel, and biopower markets. FuturaGene is positioned to serve the biotechnological needs of all key players in its strategic market sectors, which include plantation forestry, power generation from biomass, and production of second generation biofuels. Our key scientific platforms are a) enhancement of yield and processability, and b) yield protection. Our key crops right now are eucalyptus, poplar, and other woody species. In the future we will branch out into energy crops like Miscanthus or switchgrass. Our key business is in Brazil, China, and the United States.

Our world class parent company, Suzano, is a global leader in forest based products. It is the lowest cost producer of forests in the world; it is among the top 10 players in the world pulp market; it has 25 percent of market share in white paper, and in 2010 Suzano created its renewables unit to produce wood pellets in Brazil to help supply the increasing demand of European countries for wood pellets as an energy source. Suzano is also a global leader in research on eucalyptus germplasm.

Together, Suzano and FuturaGene are creating the synergy to complete the Biotech Value Chain. Our cooperation with Suzano provides a compelling economical and strategic rationale with clear complementarity of capabilities and the potential for the creation of value. Our job in this enterprise is to supply the market with low cost feedstock and to use our cell wall modification technology to help bring down conversion costs.

FuturaGene also wants to be the leading agribiotech company in China. As far as I know, we are the first biotech company focused on forests in China. We hope to set up a research lab in China specializing in woody crops, especially eucalyptus and poplar. In the future, we may expand into other energy crops like sweet sorghum, switchgrass, and Miscanthus. Our target is the renewable energy and pulp and paper industries. FuturaGene is also interested in technology licensing; since we are a spinoff from a university, we know how to run this kind of business, and we are working very hard to establish our relationships with universities and research institutes. Our abilities in the realm of in-house discovery and our history of partnerships and collaborations with universities and research institutes are crucial assets in inventing new technologies. Sustainable development was defined in *Our Common Future*, the Report of the 1987 World Commission on the Environment and Development—the Brundtland Report—as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Rather than predicting greater environmental decay and hardship in a world of ever-diminishing resources, the report foresees "the possibility of a new era of economic growth, based on policies that sustain and expand the natural environmental resource base."

FuturaGene sees biotechnology as a sustainable solution for a world with diminishing resources. To us, sustainability means enhancing productivity while preserving today's resources for tomorrow. Economic sustainability to every stakeholder involved in the chain is the key to maintaining the sustainability of the whole process.

Direct Solar to Fuel Production Using Photosystem 1: $h\nu \rightarrow H_2$

by
Barry D. Bruce

Dr. Bruce is a Professor in the Department of Biochemistry, Cellular and Molecular Biology, and an Adjunct Professor of Microbiology and Chemical and Biomolecular Engineering at the University of Tennessee.

The National Science Foundation (NSF) supports advanced and cutting edge research through a variety of initiatives. One initiative we have been involved with at the University of Tennessee is the graduate program, Sustainability Through Advanced Interdisciplinary Research (STAIR), part of the NSF's Integrative Graduate Education and Research Traineeship. Tennessee is also one of the states participating in the NSF Experimental Program to Stimulate Competitive Research (EPSCoR). A new program within EPSCoR is the Tennessee Solar Conversion through Outreach, Research and Education (TN Score). With support from STAIR and EPSCoR, we are interested in a taking a radically different angle on the concept of bioenergy.

Plants use photosynthesis to convert energy from the sun—photons—into biomass for energy. In a sense, we want to take a shortcut around biomass, directly converting photons to hydrogen. The idea is if we can directly convert photons into fuel, in this case hydrogen fuel, we can bypass some of the efficiency barriers, such as recalcitrance, inherent in biomass from plants. Basically, we want to use some of the photosynthetic nanostructures found in plants and algae to allow the direct conversion of photons into stored chemical energy or molecular hydrogen.

If we compare the biofuel production and energy conversion efficiency of photosynthetic organisms such as oil palm, sugar cane, and cassava to the electrical production of a photovoltaic cell (PV), we find that the plants' efficiency is two orders of magnitude smaller than that of silicon-based PV. What if we could use plants or algae as self-organizing biofactories to produce the photosynthetic reaction centers that can be used outside the constraints of plant growth and reproduction? This would allow us to use one growth cycle to produce hundreds of photo cycles, where one photo cycle is a solar cycle based on a one day period.

The energy lost between that emitted by the sun and that contained in biomass is huge. For every 1,000 kilojoules (kJs) produced by the sun, 628 are lost before they ever reach the Earth. By the time carbon-fixing C3 and C4 plants have converted photons to biomass, most of the energy, 287 kJs, has been lost due to carbohydrate synthesis. In the end, only 4.5 to 6 percent of the energy is converted, and these are the very best conversion chemistries that exist in nature. The biggest single loss in the plants is that the leaves are not black, they are green, and chlorophyll does not harvest the entire solar spectrum.

One of our hopes is to attain higher efficiencies than those achieved through current approaches using biomass and to move these efficiencies closer to those achievable with some of the photovoltaic based systems. In short, we want to make better use of photons using a biological approach. At a certain point, we will need to move the technology into the material science and electrical engineering fields, combining the best parts of both of these processes. We plan to rewire photosynthesis so it will perform as we want it to.

The first question is whether we can utilize what makes a leaf appear green directly, not via biomass accumulation past or present, to create a new form of sustainable energy. The reaction center we work on is a very interesting structure: photosystem I (PS1), a membrane structure that helps facilitate photosynthesis in plants, algae, and some bacteria. When we extract energy or heat from fossil fuels, the energy was originally created by a reaction in the living plant. We would like to extract the energy directly from a device using PS1 to convert photons to energy in a solid-state, photovoltaic device or to use PS1 as a hydrogen-evolving nanoparticle.

THE HYDROGEN EDGE

Hydrogen has many advantages over conventional sources of energy. It addresses concerns over national security, air quality, and greenhouse gas emissions; it can be derived from diverse domestic resources including fossil, nuclear, and renewable; it is compatible with high-efficiency fuel cells, combustion turbines, and reciprocating engines to produce power with near-zero emissions of criteria pollutants; it produces near-zero emissions of greenhouse gases from renewable and nuclear sources; and it can serve all sectors of the economy, such as transportation, power, industrial, and buildings.

Yet hydrogen production is so far limited. Why? As Frank Zappa, who was a composer and musician and not an energy expert, once said, “There is more stupidity in the universe than hydrogen, and it has a longer shelf life.” So the issue is to find better strategies for making hydrogen.

RE-ENGINEERING PHOTOSYNTHESIS

Two of the existing strategies to create hydrogen involve a) reforming of fixed carbon resources such as natural gas, petroleum, coal, or biomass; and b) thermal dissociation of water from nuclear or solar. There are drawbacks for each of those solutions; they use non-renewable resources, produce low density energy, and with nuclear, there are radiation and security concerns.

Direct solar water splitting has proven so far to yield the best efficiency and improved stability. New opportunities using direct strategies promise a source of energy better than that provided by nature. These involve PV/electrolysis, biological photosynthesis, photoelectrochemical/photocatlysis, bio-inspired catalysis, and re-engineered photosynthesis. All of these are very innovative, but I would like to focus on re-engineering photosynthesis. Nature has made a couple of strategic mistakes, and we want improve on the efficiency of nature by recombining different organisms.

It has been shown that photosynthesis can be used to drive bioreactors to produce hydrogen. If you put algae or cyanobacteria in a bioreactor and give them light, you can trick them into splitting oxygen. They do this very well, but in the process they also generate a little bit of hydrogen, which can be captured to drive fuel cells or even be converted for use in internal combustion engines. All photosynthetic reaction centers, however, are not created equal. They are all evolved from a common progenitor, but only green bacteria and PS1 have the redox strength to directly produce hydrogen.

At the University of Tennessee and Oak Ridge National Laboratory, we have been working with spinach PS1/plastocyanin for more than a decade. That work is now completed, and we have switched our efforts to a different organism, *Thermosynechococcus elongatus*, a thermophilic organism. This extreme thermophile, one of the first cyanobacteria to have its genome sequenced, has become the workhorse for studying the structural biology of membrane proteins.

Even though organisms similar to *T. elongatus*, like tobacco and cyanobacteria, evolved around 2.5 billion years ago, the fundamental core structure of these complexes is quite similar. For example, the same polypeptide backbones and chlorophyll molecules found in *T. elongatus* are also present in both higher order plants and cyanobacteria.

It is easy to isolate these complexes from the cyanobacteria because it is a trimer, having three identical monomer complexes symmetrically arranged. In our lab we have shown that the trimer structure is very pure, with nice clean particles. These are also very thermally stable complexes which are attracting a lot of attention because if you work in a high light environment, you tend to get high thermal gain.

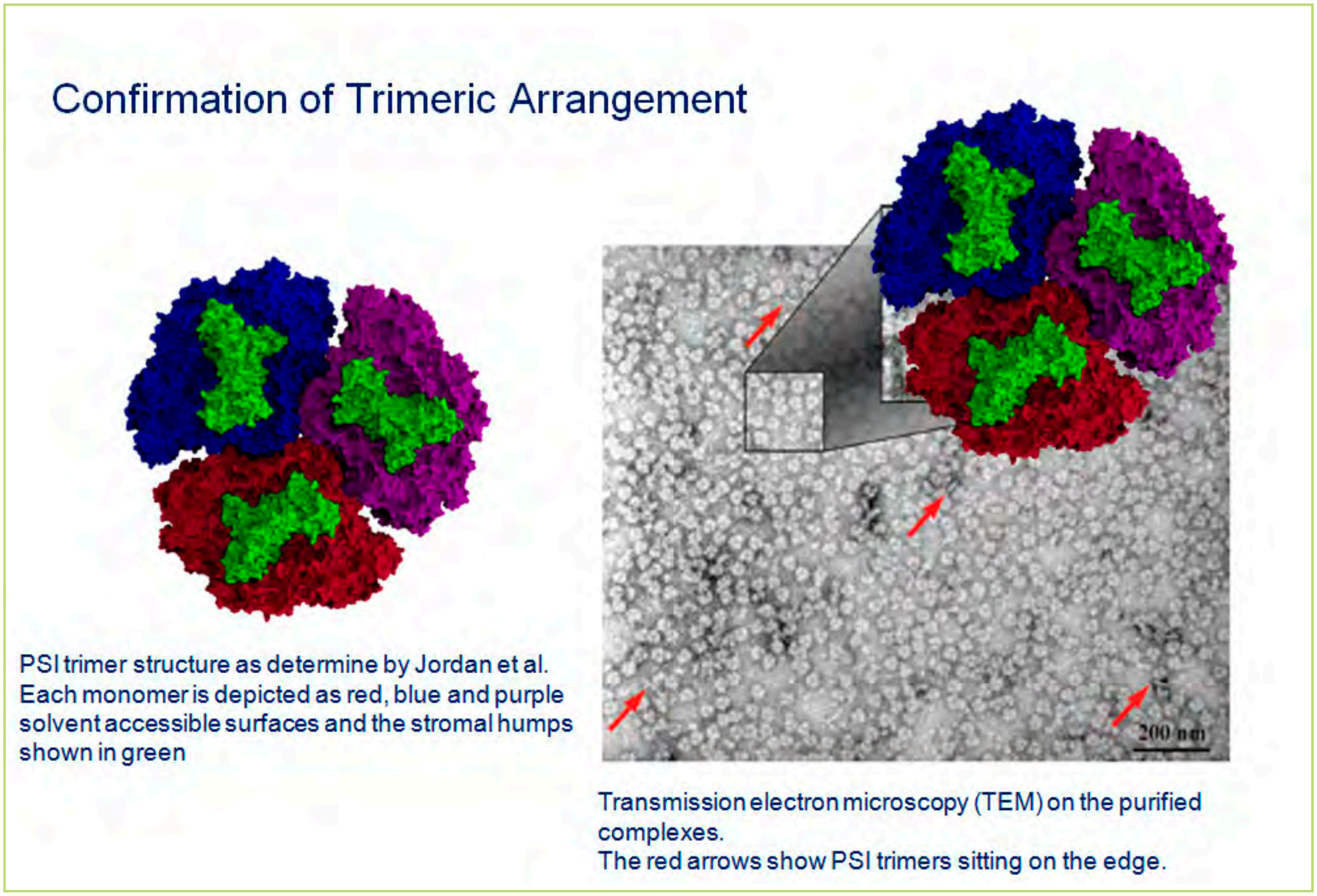
In the PS1 in cyanobacteria, the primary electron donor is a C-type cytochrome. We have therefore developed strategies using *Escherichia coli* to make large quantities of this cytochrome, because this is ultimately going to be our electron donor. Expressing cyanobacterial cytochromes in *E. coli* is a little challenging, but we have tested two different systems and found one that can grow *E. coli* expressing the thermophilic cyanobacteria with the appropriate properties and redox capabilities. It is also very thermal stable.

We simply mix the two purified complexes together (one made in *T. elongatus* and the other made in *E. coli* using molecular biology) followed by the addition of a dilute solution of platinum hexchlorinate and then illuminate with red light. This results in a light driven metallization reaction on the surface of PS1. Upon platinization, the *T. elongatus* photosystem 1 particles get converted from a well dispersed nanoparticle to a cross-linked aggregate structure suggestive of nanowires. The platinum catalyst becomes intimately associated with the surface of the photosynthetic reaction center that will take advantage of the light-generated, low-potential electrons from PS1 and convert them in hydrogen production. We do not know exactly where the platinum nano-catalysts are formed nor the exact size of the nanocluster that self assembles. One of our greatest challenges is to control the formation of the nanocatalyst with the maximum degree of uniformity.

What is the value of this system? As we envision it, with two photons we can generate conversion of two protons to molecular hydrogen. We have done some arithmetic to see what happens if we could scale this system up. What would be its yield compared to other bioenergy strategies? We used a specific fuel value, the equivalent yield in liters of gasoline per hectare per day, using published values that may not be completely accurate just for demonstration purposes. We extrapolated from our small, lab-scale bioplatinum yields for hydrogen production and found we could achieve the equivalent of 300 liters of gasoline per hectare per day, compared to 1.42 for soybean biodiesel, 5.43 for corn ethanol, and 12.1 liters for switchgrass ethanol.

These yields represent very high levels of conversion. Moreover, with this system, it is not necessary to build a massive bioreactor. To produce the equivalent of 300 liters of gasoline per day, the size of the bioreactor could be reduced substantially to a system that is very small, relatively decentralized, and which could generate enough hydrogen to sustain a small home.

Although our platinum metal catalyst has been shown to be an efficient means for production of hydrogen, hydrogenase enzymes can catalyze the same reaction and could potentially displace the requirement of the precious metal platinum. While it is possible to use aqueous in vitro mixtures of PS1 and hydrogenase, the formation of direct fusion proteins of hydrogenase and PS1 have demonstrated five times the hydrogen evolution rate of mixtures of the native complexes. In future research, we therefore seek to replace the platinum catalyst in our current construct with an oxygen tolerant hydrogenase and to form a hybrid protein by engineering a gene to fuse a hydrogenase enzyme from a bacterium, *Ralstonia eutropha* H16, to a subunit of PS1 from *T. elongatus*.



An Overview of Yeast-based Technology for Ethanol Production from Non-food Cellulosic Biomass Developed at Purdue University

by
Nancy W. Y. Ho

Dr. Ho is a Research Professor in the School of Chemical Engineering and Laboratory of Renewable Resources Engineering, Purdue University, West Lafayette, Indiana; and the Founder and President of Green Tech America, Inc., West Lafayette, Indiana.

After the first worldwide energy crisis in the 1970s, US government agencies strongly focused their support on the development of technologies to produce ethanol from non-food renewable cellulosic biomass such as wood, grasses, municipal paper waste, etc. The efficient production of ethanol from cellulosic biomass required microorganisms that could effectively utilize all sugars, particularly the major sugars glucose and xylose, present in all types of cellulosic biomass. Producing ethanol from these new non-food feedstocks also required effective pretreatment with enzymes to break down the sugar polymers in cellulosic biomass to fermentable sugars. As such, the technology to produce these enzymes, particularly various cellulases, also had to be developed.

Today, these required technologies have largely been developed. Since 1980, a group of scientists led by myself at the Laboratory of Renewable Resources Engineering (LORRE), Purdue University, has been developing *Saccharomyces* yeast to efficiently ferment glucose and xylose, as well as the other minor sugars present in cellulosic biomass, to ethanol. This article will highlight our accomplishments in engineering the yeast.

IMPROVING YEAST

Cellulosic biomass is the scientific term for all the non-edible vegetation on Earth. This resource, which includes wood, grasses, and agricultural residues, is the most abundant renewable resource in the world. All cellulosic biomass has the same composition and contains three polymers: cellulose, hemicellulose, and lignin. Using the appropriate enzymes, cellulose and hemicellulose polymers can be converted to a mixture of sugars containing 50-60 percent glucose and 30-40 percent xylose. Early in the development of this technology, it was assumed that these sugars could be fermented into ethanol by microorganisms, particularly by the *Saccharomyces* yeast. This yeast, also known as brewer's yeast, has been used for thousands of years to produce wine from grapes, as well as ethanol from corn (corn starch) on a large scale in the United States. However, there was an unexpected complication; the natural *Saccharomyces* yeast was found unable to ferment xylose to ethanol.

One approach to solving this problem was to use recombinant DNA techniques to clone a xylose isomerase gene from bacteria, such as *E. coli*, into yeast. My group was the first to succeed in accomplishing this. At the time, it was not easy to clone genes into yeast, and unfortunately the enzyme did not function in yeast as well. Following our lead, scientists in Europe at that time also tried to clone the xylose isomerase genes from different bacteria into yeast. They found that no isomerase gene from any bacteria could make the yeast ferment xylose to ethanol.

There was another approach to make the *Saccharomyces* yeast ferment xylose. However, the second approach was more complicated and required the cloning of two genes, the xylose reductase gene and the xylitol dehydrogenase gene, from another yeast (the *Pichia* yeast) into the *Saccharomyces* yeast. Moreover, many scientists believed that this second approach would never work in the *Saccharomyces* yeast. They predicted that cloning these two genes into yeast would still not produce ethanol, but just xylitol. This was the general consensus and the reason why scientists in the United States began to engineer various bacteria to replace yeast for ethanol production.

However, at Purdue University we persisted in modifying the *Saccharomyces* yeast because it was the safest, most effective microorganism for ethanol production. It was also a challenge, one that I felt we could surmount given enough effort. In addition, we found that there was another key enzyme for xylose fermentation, xylulokinase, that the *Saccharomyces* yeast was deficient in. As such, I proposed that if we could supplement these enzymes by cloning the appropriate genes into yeast, we might be able to enable it to produce ethanol from xylose. All told, I predicted that we would have to clone three genes instead of two—the xylose reductase gene (XR), the xylitol dehydrogenase gene (XD), and the xylulokinase gene (XK)—into the yeast.

To make the story short, my group was the first in the world to succeed in making yeast ferment xylose to ethanol by cloning and overexpressing the three genes, XR, XD, and XK, as we proposed. We demonstrated this innovation by cloning the XR, XD, and XK genes into an industrial yeast strain used for industrial corn ethanol production—the 1400 yeast strain. The resulting strain, designated as yeast 1400(LNH32), was able to ferment both glucose and xylose effectively to ethanol. While this work was an important breakthrough, the yeast was not quite ideal for industrial ethanol production as these three genes were cloned on a plasmid.

We believed that integrating (inserting) the three genes into the yeast chromosomes would make them a permanent part of the yeast and ideally suited for industrial ethanol production from cellulosic sugars (sugars extracted from cellulosic biomass). This would allow the engineered yeast to be used for real industrial production. Subsequently, we developed the techniques for integrating (inserting) the XR, XD, and XK genes together into the yeast chromosomes in multiple copies so that the final engineered yeast was "stable," ideally suited for industrial fermentation. This stable strain was designated as yeast 1400 (LNH-ST). We provided the 1400 (LNH-ST) strain to the US Department of Energy National Laboratory (NREL) to test in their demonstration pilot plant, where it was proven that the yeast could continuously ferment both glucose and xylose to ethanol without losing its ability over time. Purdue began licensing this strain to industry for cellulosic ethanol production in 2004, and it is still being used for the production of cellulosic ethanol today.

While the 1400(LNH-ST) strain showed great performance in producing ethanol from sugars extracted from cellulosic biomass, we continued to engineer other yeast strains to search for candidates that could co-ferment glucose and xylose even better. Subsequently, we engineered more than 10 different *Saccharomyces cerevisiae* yeast strains to find the best yeast, designated as Ho-Purdue Yeast 424A(LNH-ST), as the strain we currently provide to industry for cellulosic ethanol production. The above work was accomplished in 2000. We demonstrated that the 424A(LNH-ST) strain could produce cellulosic ethanol at higher concentrations and at faster rates. In general, the Ho-Purdue Yeast produces up to 60 percent more ethanol from cellulosic biomass than the ordinary yeast used for industrial corn ethanol production. It can produce over 9 percent ethanol in 48 hours by converting more than 90 percent of all sugars extracted from any types of cellulosic biomass to ethanol. Although the results were fantastic, we continue to improve the yeast by various innovative approaches. Recently, we have further improved the 424A(LNH-ST) yeast to be more resistant to inhibitors and to be even faster in producing cellulosic ethanol. We now have new derivatives, 424A(LNH-ST)-ER and 424A(LNH-ST)-AR, able to produce more than 9 percent ethanol in 24 hours, twice as fast as the original 424A(LNH-ST).

Recently, scientists in Europe were able to produce *Saccharomyces* yeast that could ferment xylose by cloning the xylose isomerase gene together with the xylulokinase gene (XK). However, their yeast is far less efficient than the Ho-Purdue yeast in producing ethanol from cellulosic biomass. Besides, without incorporating our innovation and including the cloning of the xylulokinase gene (XK) in yeast, their yeast would still not ferment xylose.

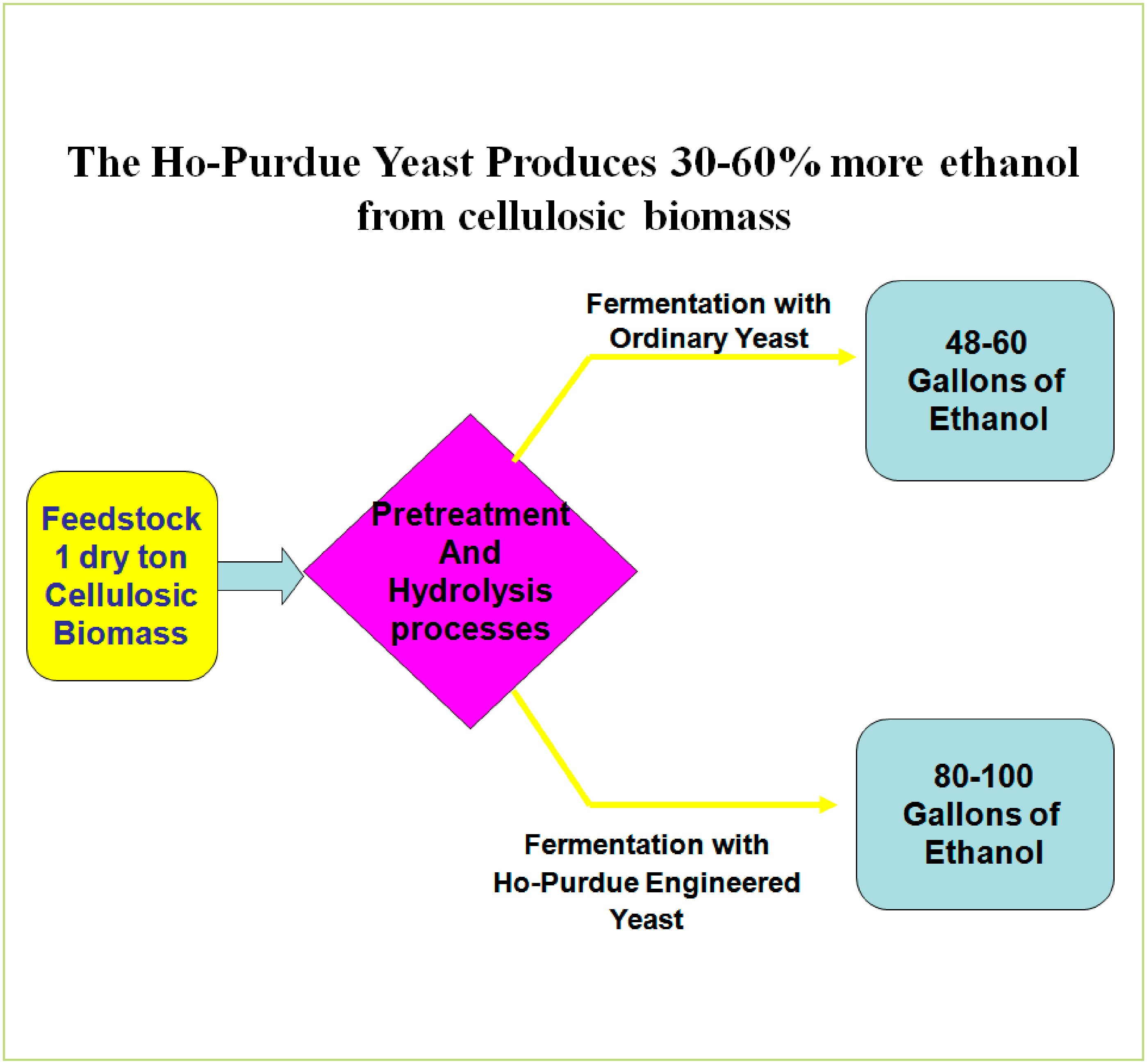
GREEN TECH AMERICA, INC.

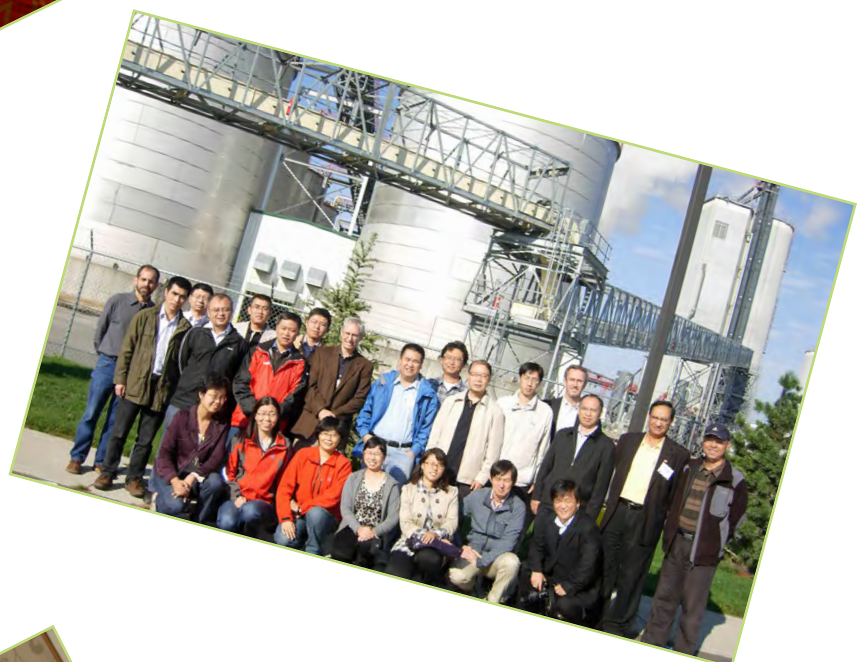
In 2006, Green Tech America, Inc. (GTA) was established in West Lafayette, Indiana, to market the best Ho-Purdue Yeast worldwide for cellulosic ethanol production. The company will also develop new derivatives of the Ho-Purdue Yeast that can produce high value co-products during cellulosic ethanol production. The new yeast will make cellulosic ethanol production much more profitable.

GTA has already been working with companies from many different countries helping them use the Ho-Purdue Yeast to produce cellulosic ethanol from all kinds of cellulosic feedstocks. GTA has also set a goal for producing cellulosic ethanol in the United States. It will work with for-profit and not-for-profit companies and organizations as well as the general public to use corn stalks (corn stovers) as well as other cellulosic feedstocks to produce 5 billion gallons of ethanol as transportation fuel for America.

In addition to marketing the yeast worldwide, GTA scientists have already succeeded in making the Ho-Purdue Yeast simultaneously produce high value co-products during cellulosic ethanol production. The first groups of co-products are different enzymes required for cellulosic ethanol production such as various cellulases. However, our yeast can be engineered to produce any enzymes for commercial applications. Currently GTA is in the process of raising $30 million towards the construction of its demonstration pilot plant for the production of cellulosic ethanol, high value co-products, and algae fuel in a single process. In this process, all carbon from cellulosic biomass will be completely converted to fuels and industrial chemicals. No CO_2 from ethanol production will be released to the atmosphere.

In my view, using the Ho-Purdue Yeast to generate cellulosic ethanol, high valued co-products, and algae fuel through yeast fermentation will be the best way to convert sugars from cellulosic biomass to renewable fuels for years to come. There are very few other options that can produce renewable energy with such efficiency and cost effectiveness.


The Ho-Purdue Yeast Produces 30-60% more ethanol from cellulosic biomass
Feedstock 1 dry ton Cellulosic Biomass
Pretreatment And Hydrolysis processes
Fermentation with Ordinary Yeast
48-60 Gallons of Ethanol
Fermentation with Ho-Purdue Engineered Yeast
80-100 Gallons of Ethanol



Energy & Applications of Hardwood Biomass & Celluose

Forest Service Research at the Northern/East Regional Biomass Center

by Charles Michler

Dr. Michler *is Director of the Hardwood Tree Improvement and Regeneration Center at Purdue University and Program Manager for the US Department of Agriculture Northern Research Station.*

In preparation for legislatively mandated use of plant-based biofuels, the US Department of Agriculture (USDA) has chartered a chain of regional biomass research centers across the United States to target biomass and conversion research. The first of four federal laws that drive the biomass research centers is the Energy Policy Act of 2005, but perhaps the most important is the Energy Independence and Security Act (EISA) of 2007, which set a goal of having a certain percentage of biofuels in our economy by 2022.

The Hardwood Tree Improvement and Regeneration Center (HTIRC) is a collaboration between the USDA Forest Service and Purdue University. The Northern/East Regional Biomass Center, including the HTIRC, was created in 2010 as one of five regional biomass research centers.

The USDA has a number of existing networks of research centers within the Agriculture Research Service and the Forest Service. Over the years, these centers have become very decentralized. The USDA wanted to find a way to improve coordination of these research centers by a) monitoring whether they were on track to meet the federal legislative mandates, b) leveraging current USDA nation-wide capacity to lead sustainable biomass production research, c) coordinating Agriculture Research Service and Forest Service research occurring across different locations into a comprehensive program, and d) promoting coordination of its National Food and Research Institute's Agriculture and Food Research Institute, which has a number of bioenergy Coordinated Agricultural Projects offering competitive grants to fund some of this research.

Research and development mission areas of the Forest Service as part of its Biofuels Growth Platform include

- Sustainable forest bioenergy production and new wood energy crops,
- Efficient and environmentally friendly woody biomass harvesting systems,
- Competitive biofuels conversion technologies that reduce greenhouse gas emissions from fossil fuel use, and
- Life-cycle and sustainability analysis for wood bioenergy systems.

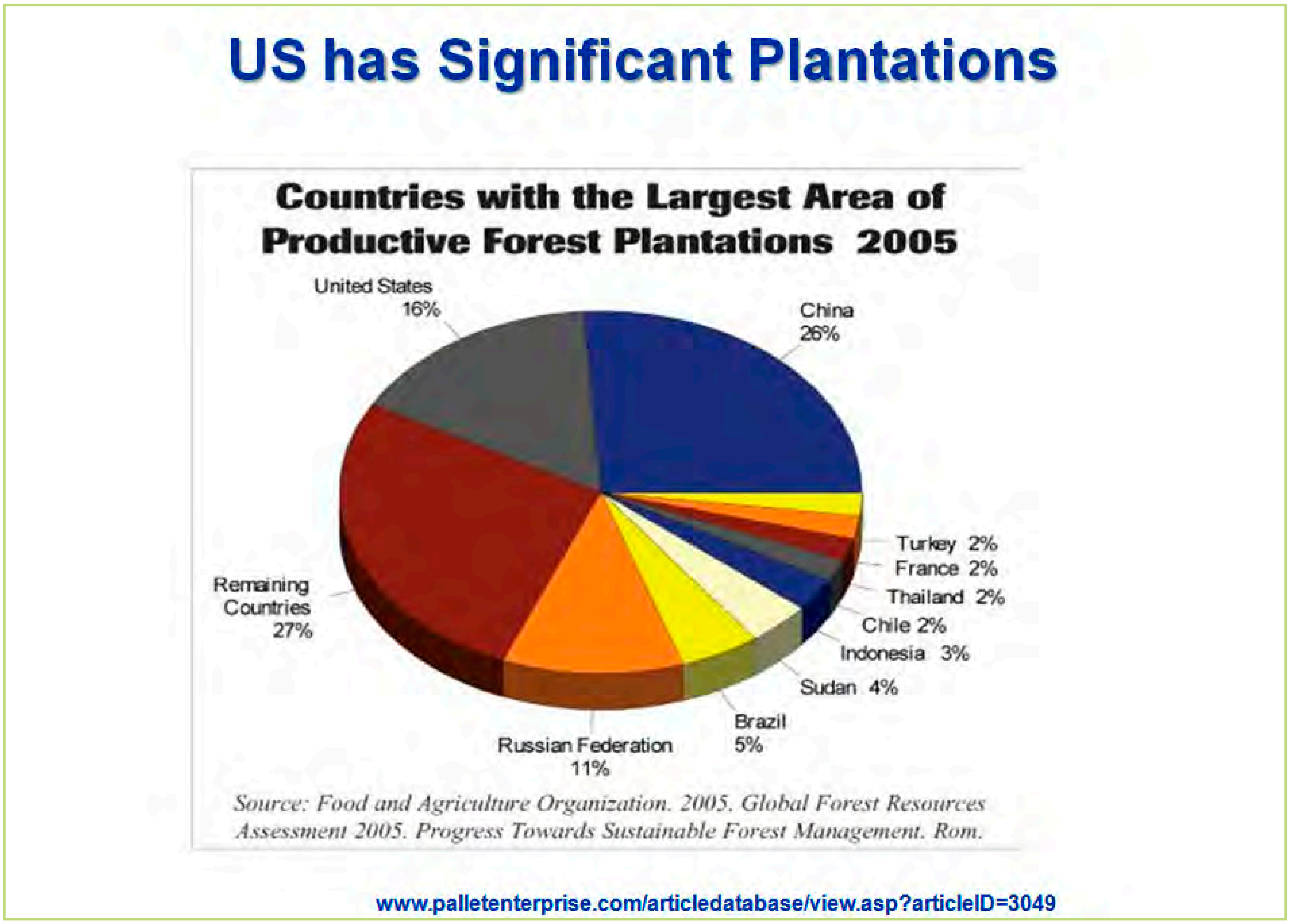
BIOMASS RESEARCH SUPPORTING ADVANCED BIOFUELS

The United States has significant forest plantations, 16 percent of the world's total area. Only China has a greater area of plantations, 26 percent as of 2005. Exploiting these resources to move to the next generation of biofuels economically and sustainably remains a formidable challenge.

Increasing production efficiency through genetic improvement is a proven strategy to support advanced biofuels. Genetic improvement of dedicated feedstocks will be required to increase the amount of production from the same land area, which will help reduce production costs for growers and transaction costs for purchasers of feedstocks, thus reducing pressures to utilize competing lands that are needed for the production of other agricultural and forest-based products and ecosystem services.

Genetic improvement that reduces the costs of purchased inputs, most of which require additional energy to manufacture or deliver, will help reduce the ultimate costs of biofuels and increase their competitiveness with petroleum-based fuels. Yield increases can be expected similar to those achieved with corn and sugarcane. Recent analyses show that some genetic gains may have reached plateaus on average in certain regions. It will therefore be important to track production statistics over time to ensure that specific improvement strategies are working and that high-cost purchased inputs are justified.

No one kind of dedicated bioenergy crop or purpose-grown woody species will be able to provide all of the required biomass needed to meet or exceed the 2007 US Environmental Protection Agency's Renewable Fuel Standard (RFS2) targets established by the EISA, 36 billion gallons per year by 2022, so different species options may be available depending on the needs of the biorefineries and local production conditions. There are many kinds and sources of feedstocks that can be converted into biofuels. It is important that the limitations to performance of different feedstocks be considered within a context of regional adaptation, and in comparison to the productivity of other feedstocks at the same time. Preference and previous investment decisions should give way to longer-term pragmatism. To develop high-performance supply chains that result in sustainable biofuel production, choices will need to be made and efforts concentrated for best use of the regional resources that are available.



Toward this end, in 2010, the President's Biofuels Interagency Working Group issued a report, *Growing America's Fuels*, outlining strategies to meet the higher standards. The report recognizes a suite of five classes of dedicated feedstocks, some more productive than others even when grown under optimal conditions:

- sugarcane – also known as energy cane, a high biomass form of sugarcane that is optimized for sugar and cellulose content;
- woody biomass – from purpose-grown woody species such as poplar, residues left after timber harvest, and harvest of diseased and insect damaged trees;
- perennial grasses – e.g., switchgrass, *Miscanthus*, and native prairie species;
- biomass sorghum (including sweet sorghum); and
- oil producing crops – e.g., industrial canola, *Camelina*, soybean, and algae.

These five classes are in addition to corn grain starch and crop residues such as corn stover and cereal straw, but do not include other potential sources of feedstocks with significant potential, such as municipal solid waste, waste vegetable oil and tallow, and animal manure.

In addition, economic, environmental, and social issues need to be addressed up front as the advanced biofuel sector expands. Regional feedstock production systems should be designed, implemented, and monitored in ways that lead to management practices that reduce disruption to the existing food, feed, and fiber markets; that maintain or even enhance the quality of soil, air, and water natural resources, while at the same time preserving or restoring the function of closely associated natural ecosystems; and that provide new economic opportunities benefiting land owners and rural communities, as well as the expanded biofuels industry. With these specifications in mind, all regional supply chain components should be considered together to ensure that the resulting systems are productive, profitable, and done with good stewardship of all resources, including both natural and human capital.

Domestic and international shifts have already occurred across agriculture in response to the growth of the corn grain starch ethanol industry, and changes will likely continue for many years as new advanced biofuels markets expand. Lessons learned from the ethanol biofuels industry, including collateral changes to commodity markets, should be considered and applied as the new advanced biofuels industry begins to expand.

REGIONAL SOLUTION

Within the national network of five USDA-supported research centers, the Northern/East Regional Biomass Center covers the Midwest and upper Midwest. We have several programs within the Northern Research Station and the Forest Products Laboratory in Madison, Wisconsin, aimed at supporting advanced biofuels.

In the arena of the forest bioenergy and bioproducts supply chain, one project is looking at short rotation woody crops such as poplar and willow. There are several steps in the supply chain. First is production of the crops, which are then harvested, collected, and transported. Biofuels and byproducts are created using a variety of technologies such as co-firing, combustion, gasification, and digesting, among others. The products—including ethanol, other liquid fuels, electricity and heat, and specialty products—are then distributed and finally reach the end users as transportation fuels, chemicals, and other products.

On another front, a genetics and energy crop production team is exploring the link between energy, climate, and tree genetics. The goal of this project is to 1) develop fast-growing tree crops as energy feedstocks; 2) develop sustainable forest biomass removal strategies; 3) understand climate change effects on natural and plantation forests; and 4) fill critical knowledge gaps in 1), 2), and 3). The research also explores short rotation woody crops for their energy, fiber, and environmental benefits; the ecological sustainability of using forest residues for energy; and carbon sequestration and climate change adaptation of conifers.

One research team is breeding and selecting poplar and midwestern hardwoods for biofuels, bioenergy, and byproducts. This effort involves

- Breeding, testing, and selecting protocols so that new, superior genotypes can replace older varieties no longer suited to the productivity and wood quality standards needed for increasing biofuels, bioenergy, and bioproducts production;
- Investigating pollen viability, comparing traditional and nontraditional grafting methods, and assessing species incompatibility based on reciprocal crossing matrices, and inbreeding depression as a result of crossing siblings; and
- Focusing efforts on quantitative genetic and physiological analyses, as well as the development of practical tree breeding techniques.

Another team is exploring the genotype/environment interaction of poplar energy crops for multiple benefits. Quantifying the response of genotypes to sites where they are grown is critical for informing breeding programs, successful crop deployment, and increasing operational flexibility in using existing and emerging genotypes.

NATIONAL BIOREFINERY SITING MODEL

A project funded by the US Department of Energy Office of Biomass, released in spring 2010, builds on the Western Governors' Association Western Assessment Model to conduct a supply chain analysis on biofuels production in the entire United States. This National Bioefinery Siting Model provides county level resource availability data for a variety of biomass feedstocks. A Geographic Information System-based model provides an optimized network of biorefineries based on cost and demand. The project also creates a platform for biofuels policy analysis. An impact assessment study includes a life-cycle assessment at various project locations and establishes an economic modeling and business concept assessment.

As part of the national effort, the Forest Products Laboratory is proposing and developing a USDA Northern-East Regional pilot-scale facility that will have multi-feedstock capabilities, a modular design, and three conversion pathways: thermochemical, biochemical, and chemical. The portable facility, which can be rented, will be focused on forest products industry interactions.

BIOFUELS KNOWLEDGE GAPS

At the present time, techniques for biomass harvesting and transportation to conversion facilities are underdeveloped. We need to develop the ability to economically harvest and transport feedstock. In addition, the metrics to compare the performance of various feedstocks and conversion technologies, and key metrics of raw materials like physical/chemical composition and conversion efficiency, are not sufficiently available.

It is a challenging goal to economically make biofuels from wood. Huge amounts of wood exist as standing timber, but not all is available for economic, social, and political reasons. Moreover, EISA restrictions on forest biomass sources make plantation and short rotation woody crops important.

Several types of technologies exist to make biofuels from forest biomass, with varying raw material input requirements, but we do not know when biofuels from forest biomass will become economical without subsidies. We also do not know the impacts that biofuels from forest biomass will have on existing wood use markets. Forest managers and land owners have just begun to contemplate biofuel wood supply issues.

Forecasting Carbon Storage of Eastern Forests: Can American Chestnut Restoration Improve Storage Potential in an Uncertain Future?

by Harmony J. Dalgleish

Dr. Dalgleish *is a Postdoctoral Research Associate at Purdue University.*

The question I am posing here, whether or not restoration of the chestnut tree to eastern deciduous forests can improve the storage potential of carbon in an uncertain future, is not one that I can answer today, but is an important question that needs to be addressed now and in the future. To that end, an interdisciplinary team of scientists from five institutions—Purdue University, the US Forest Service, Wayne State University, Wilkes University, and the University of Wisconsin, Madison—is working together to find the answer. The team includes people with expertise in tree physiology, landscape modeling, carbon cycle science, forest ecology, and statistics. Our goal is to bring together a suite of scenarios that will allow us to forecast carbon storage potential in forests of the eastern United States.

EASTERN FORESTS: A CARBON SINK

Global climate change due to human activities has driven an interest in determining not just global carbon budgets but also regional carbon budgets and their drivers. Our team is particularly interested in the carbon budget of eastern US forests, which are currently a carbon sink. The largest component of carbon influxes is from live trees that fix carbon, especially the deciduous forests prevalent in many eastern states. These deciduous forests are a carbon sink today largely due to historical land use changes. Current efforts to restore the chestnut tree in eastern forests have the potential to affect the carbon budget.

The proportion of land area under cultivation has changed since 1890, when much of the cultivated land was located in the East. By 1990, agriculture had shifted west, while in the East, much of the land has reverted to forest composed of second growth trees. These historical changes have created a carbon sink, but current and future disturbances increase the risk of significant carbon loss over the long term. These disturbances include climate change, insect pests such as the gypsy moth, and changes in fire management.

The integrated effect of these disturbances on carbon storage in eastern forests is not well understood, but an understanding of the processes will be vital for setting effective forest management policies for carbon sequestration and ecosystem services.

In eastern deciduous forests, fire management has caused a shift from oak dominated forests to maple dominated forests. Beginning in the early 20th century, fire suppression increased canopy closure and allowed more shade-tolerant species such as maple to establish. With continued fire suppression, the canopy continues to close and maple develops in the mid-story. This creates a positive feedback loop; where maples establish, they create humid, cool conditions, which decreases the probability of fire ignition due to the more moist shady conditions. Oak, a shade-intolerant species, has trouble regenerating and reestablishing without fire.

Exotic insects and diseases also threaten to reduce or extirpate many tree species. Two of the main insect pests are the gypsy moth and the hemlock woolly adelgid. The consequences of compositional changes due to insect damage on carbon storage are likely profound but not well understood. Hemlock woolly adelgid, for example, causes short-term loss of carbon but may result in long-term gain as more productive trees—trees that store more carbon—replace hemlock. That is where the chestnut tree enters the picture.

THE AMERICAN CHESTNUT

The American chestnut (*Castanea dentata*) was a wide ranging species in the eastern United States. In its historic range, it covered approximately 800,000 square kilometers and was considered dominant in many forest types until the 1900s. Pure stands were probably uncommon, although some were documented, notably by Thoreau in the 19th century. This tree can grow up to huge sizes, 12 feet or greater in diameter and more than 200 feet high.

When I first started studying the chestnut, I began to wonder what the term dominant, which occurs often in the literature, especially the older literature, really means. To get an idea of the quantitative data, I went through the historical literature and found 12 studies with data, either basal area or canopy area, that could tell how much of a particular area was chestnut. The studies included data from seven states ranging from the southern to the northern portion of the range, from North Carolina to Connecticut. In some studies, the proportion of chestnut was quite low, only five percent chestnut, but ranged all the way up to 80 percent. The average of these 12 studies was about 40 percent, which correlated pretty well with the estimate of one in four trees commonly cited in the historical literature.

The American chestnut has also been called a foundation species in the ecological literature. This means that it is a species that can control population and community dynamics; for example, it can influence wildlife populations because of its highly nutritious and edible chestnut seeds. It can also stabilize ecosystem processes such as productivity because of its long lifespan, which can affect carbon cycling. Economically, the chestnut was also a very important logging species. It had very rot-resistant wood and was highly prized for building materials, telephone poles, and mine supports.

This all changed around about 1900, when the chestnut blight was accidentally introduced through nursery stock of ornamental trees. It was first documented in 1904 in New York City. The disease causes cankers which girdle the stem. The canker does not affect the root systems, however, so even though the main stem is killed, the tree can re-sprout; in fact, it is quite a prolific re-sprouter.

The chestnut blight resulted in about 4 billion dead trees in a little less than four years. The disease quickly spread from New York City even as government agencies tried to discover a treatment or establish quarantine zones. There was a massive effort to either stop the disease or stem its spread. In Pennsylvania, for example, whole swaths of the forest were cut in an attempt to prevent the spread, but nothing worked. When the disease was discovered in North Carolina and Georgia in 1914 at the beginning of World War I, the efforts were halted.

The idea of breeding the chestnut for blight resistance, however, had already begun in the early 1900s. The notion sprang from the knowledge that the Asian chestnut evolved with the pathogen and is fairly blight resistant, but the idea only came to fruition in the 1980s. At that time, the American Chestnut Foundation (TAFC) started a backcross breeding program. Their idea was to bring two parent trees, the American chestnut and the Chinese chestnut, to create a generation that would be about 50 percent American chestnut, then to breed that back to the American chestnut to create three levels of backcross and increase the percentage of American chestnut genes and character. By fixing the allele for blight resistance and breeding back successive generations several times, it is possible to create a hybrid species that is 94 percent American chestnut genetically but has a high level of blight resistance.

This is the stage where TAFC is now, with a strain that is likely blight resistant but mostly American in character. We are arguably on the cusp of one of the largest restoration efforts in history. The goal of TAFC is to introduce it into eastern forests, an effort they began in 1983.

How might the restoration of American chestnut affect carbon storage? Chestnuts have a high carbon storage potential because they grow very large very quickly. A 2009 study by Jacobs et al. in the journal *Forest Ecology and Management* demonstrated that in plantation settings planted in black walnut, northern red oak, and blight resistant chestnut, bole carbon, the carbon in the mainstem plus all the branches that are greater than 20 centimeters in diameter, was highest in chestnut at three different ages. In another study that included pine trees in comparable locations, even at just under 20 years old, the chestnut rivaled some of the pines that were 10 years older.

A MODELING APPROACH

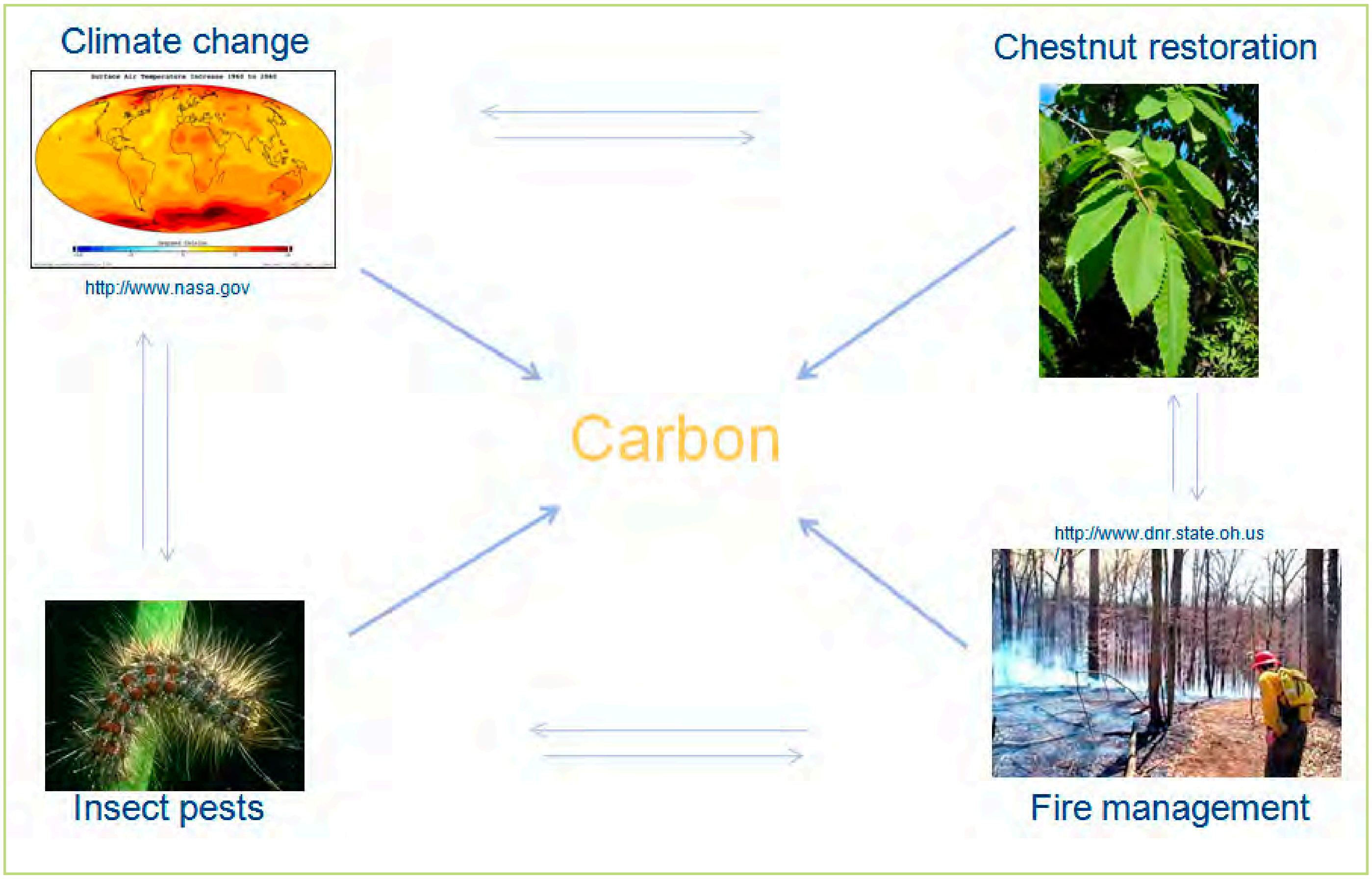
Individually, each of four drivers—climate change, chestnut restoration, insect pests, and fire management—could have large effects on forest carbon. Our research team wants to examine the critical question of carbon storage in eastern forests at a time when all of the drivers interact. To do this we need a species-specific modeling approach that incorporates information about climate and information about the physiology of different species. We will then feed that information into a landscape model, scale it up, and look at carbon changes at the landscape level.

We will be using a species-specific model called PnET-II, a forest ecosystem process model developed at the Complex Systems Research Center, a division of the Institute for the Study of Earth, Oceans, and Space at the University of New Hampshire. PnET-II takes climate variables such as carbon dioxide, temperature, and precipitation and then specifies physiological and life history traits to predict aboveground net primary productivity and establishment probabilities.

We will then combine those results with other landscape information into the LANDIS-II model, a spatially dynamic forest and succession model that simulates forest growth and regeneration at large spatial (more than 100,000 hectares) and long time (centuries) scales. LANDIS-II was developed at the Forest Landscape Ecology Laboratory at the University of Wisconsin-Madison, the US Forest Service Northern Research Station, and Portland State University. This model gives us the flexibility to look at how the different drivers may interact.

We will be using two study locations, both in western Maryland and both in the heart of the historic chestnut range, Savage River State Forest and Green Ridge State Forest. Even though these sites are only about 40 kilometers apart, they are separated by a ridge of the Appalachian Mountains and so have very different physiographies. Savage River has the highest precipitation in Maryland and is dominated by mesophytic oaks. Green Ridge has the lowest annual rainfall in Maryland and is characterized by xeric oak forests with less maple and more pine. Stand reconstructions indicate that both of these areas had American chestnut as a historically important part of their composition.

Another advantage to these sites is the large amount of site specific data available, thanks to prior work by our collaborators. We have data on species-specific life histories, physiology, and phenology for nearly every tree species at these locations except for the American chestnut. The demise of the American chestnut occurred before the advent of modern forest ecology. Renewed interest and the possibility for restoration have led to more research, and there is quite a bit of information in the gray literature and in the historical literature as well. I have



recently amassed about 200 publications dealing with American chestnuts. With these resources, we should have the data to address the question of how reintroduced American chestnut might interact on the landscape, a possibility not available just 10 years ago.

With this data, we will perform a factorial simulation experiment. One factor will be prescribed fire under three scenarios: none, a restricted program realistically in line with current policy restrictions, and an aggressive one using the type of burning needed for long-term oak restoration. Another factor is climate change at two levels, moderate and extreme, based on two of the scenarios of the Intergovernmental Panel on Climate Change. A third factor will be the current level of disturbance of existing insect pests, the gypsy moth and the hemlock woolly adelgid. A fourth factor includes several novel pests at three levels: none, assuming no new invasives; impending, which is the emerald ash borer that is already decimating ash populations in northern Indiana and spreading; and other potential sources of mortality including sudden oak death pathogen and the Asian longhorn beetle, another insect. The final factor will be chestnut restoration at three levels, none, restricted, and aggressive.

We will then incorporate climate change into the multifactorial model by simply putting the data into PnET-II and changing the climate inputs. Insects and fire parameters will be implemented in the LANDIS-II disturbance model. Chestnut restoration will be implemented in the LANDIS-II harvest module through planting, though restoration scenarios with chestnut will likely include some disturbance, with fire and harvesting potentially used as restoration enhancements. We will also be using the disturbance module to simulate human-assisted dispersal.

Finally, we want to quantify uncertainty. Parameter uncertainty combined with uncertainty in model structure will contribute to uncertainties in output parameters. We are particularly interested in the uncertainty associated with biomass and species composition predictions, particularly the amount of maple, chestnut, and oak on the landscape with these different drivers.

In conclusion, in our research, we aim to project the potential impacts of critical threats to future carbon storage and to evaluate the feasibility of a promising mitigation approach that would have been unimaginable merely a decade ago: restoration of the American chestnut on the landscape.

Influences of Forest Restoration on Soil Organic Carbon and Carbon Cycling Potential

by Zhiyun Ouyang (with Yun Wang and Jizhong Zhou)

Dr. Ouyang *is a Professor with the State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences.*

Ecosystem degradation is one the biggest challenges in China. There are many ways to restore degraded ecosystems, for example, using natural processes or with artificial plantations, which are widely used in China and in other parts of the world. In the last decade, 4.2 million hectares of forest per year were planted worldwide. China planted about two million hectares a year, nearly half of the world's total. Most of these new plantations are not natural but artificial forests.

Different forest restoration approaches have different plant community and soil physiochemical characteristics. A great deal of research has been carried out on the impacts of forest restoration approaches on soil fertility, yet little is known about the consequences of artificial plantations on regional and global biochemical cycling and carbon. In 2004, David Wardle and colleagues published a very detailed discussion in *Science* magazine about the drivers of ecosystems with high and low fertility and how those levels of fertility impact animal and plant communities, litter, the soil-food web, and soil processes.

DATA COLLECTION AND ANALYSIS

Our research at the Research Center for Eco-Environmental Sciences focused on the consequences of artificial plantations on regional biochemical cycling, including carbon, nitrogen, and phosphorous, but one of our main focuses is on carbon. As we know, soil microorganisms mediate the degradation, transformation, and mineralization of soil organic carbon. The recently developed functional microarray has the advantages of high-throughput, quantitative analysis, and linking the structure and function of the soil microbial community. This microarray is a powerful tool for studying the soil microbial community.

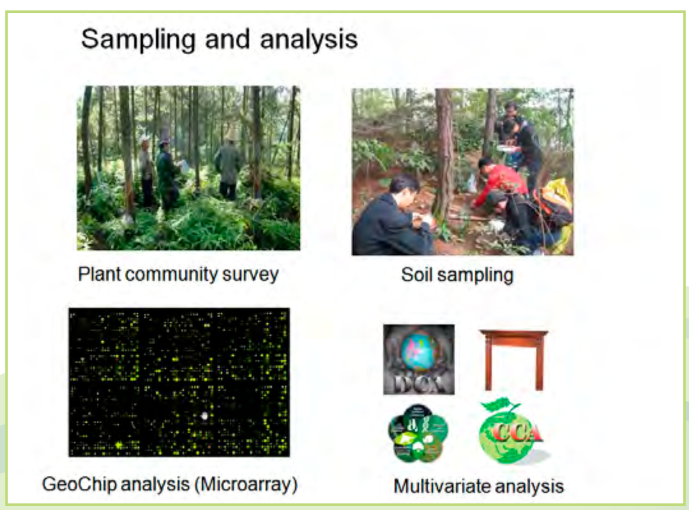
Our trials were conducted at three sites in Southern China characterized by a subtropical monsoon moist climate, an average annual temperature between 17.9° and -18.9° C (64.22° and -2.02° F), an annual precipitation of 1452-1950 millimeters (57 to 76 inches), and red (acidic) soil with a pH between 4.2 and 4.5.

In this area, there are typically three types of forest restoration: artificial restoration using Masson pine plantations, a native species; artificial restoration using slash pine, an introduced species; and natural restoration with secondary forest. The time period for restoration was about 20-25 years.

In our plant community structure survey, each plot was divided into two to three subplots about 10 x 10 meters (m) for the tree layer, four 5 x 5 m subplots for the shrub layer, and six 1 x 1 m subplots for the herb layer. A total of 39 soil samples were collected, each with three subsamples. Each soil sample contained three subsamples collected from three tree subplots. Each soil subsample was randomly collected within the subplot, with a composite of five cores of 0 to 10 centimeters of the soil layer.

Our microbial community structure analysis was performed with GeoChip 3.0, a functional microarray. The solid substrate contains genes carrying special functions. GeoChip3.0 can perform 28,000 probes from 292 functional gene families involved in nutrient cycling and other processes. We performed 5,196 probes from 41 gene families involved in carbon cycling to gain as much information as possible. There are four types of genes: carbon fixation genes, carbon degradation genes, and methane production and oxidation genes.

In our data processing, we used a one way analysis of variation (ANOVA) to analyze the effects of forest restoration approaches on soil microbial community characteristics, plant characteristics, and soil characteristics; a detrended correspondence analysis for carbon cycling soil microbial community structure; and redundancy analysis (RDA) and partial RDA to analyze the relationship between the carbon cycling microbial community and soil and vegetation factors respectively. A Monte Carlo permutation test with 999 permutations was used to pre-select



factors that significantly influence carbon cycling microbial community structure. We actually collected too much information to analyze it all. A lot of research remains to be done to develop the methods to find useful information for such a huge data set.

With these methods we can answer questions about plant community structure, soil physiochemical characteristics, and carbon cycling genes and how they influence each other under different forest restoration approaches. This will help determine the best ecosystem restoration strategy.

RESULTS

We analyzed differences in the three forest restoration approaches using four characteristics: 1) plant communities, 2) soil physicochemical characteristics, 3) soil organic carbon content and composition, and 4) community of carbon cycling genes. Furthermore we analyzed 5) the relationship between carbon cycling genes and environmental factors and 6) the relationship between soil carbon content and carbon cycling genes.

Plant community structure. Our analysis of the species richness, or diversity of plant communities, among the three different forest restoration approaches showed that the diversity of the natural secondary forest was significantly higher than for the artificial plantations, and that between the Masson and slash pine plantations, there were no differences in diversity index. We found no significant differences among the three approaches in terms of tree layer biomass and root biomass. There were also no significant differences in the amount of litter stock.

Soil physical characteristics. For the natural secondary forest, soil water content was higher than for the artificial types, and bulk density was lower. We also looked at soil particle composition, which can have important effects on the soil microbial community. We found clay content was the highest for slash pine plantation, while sand content was highest for Masson pine plantation. There were no significant differences in silt content among the three approaches.

Soil chemical characteristics. Looking at nitrogen, phosphorus, and potassium content, it is very clear that the overall soil fertility of the natural forest is higher than that of the artificial plantation. Contents of total nitrogen, available nitrogen, total phosphorous, available phosphorous and available potassium were higher in natural forest than those in artificial plantations, and there were no differences between the Masson pine and the slash pine plantations. There were no significant differences in total potassium among the three forest types.

Soil organic carbon and composition. Soil organic carbon and composition were significantly affected by the restoration approach. Natural secondary forest soil stored more organic carbon more stably than the two artificial plantations. In addition, we found that soil organic carbon content showed significant positive correlations with the tree layer diversity index and surface area of thin roots.

Community of carbon cycling genes. The abundance of carbon cycling genes, carbon fixation genes, and degradation genes of natural secondary forest were all higher than those of the Masson pine plantation and slash pine plantation. For methane cycling genes abundance, there were no significant differences among the three types. Gene abundance correlated well with the biochemistry process, indicating that carbon cycling under natural restoration was faster than under artificial restoration.

Relationship between carbon cycling genes and environmental factors. Positive relationships were found between the diversity of carbon cycling genes and the tree layer diversity index, available nitrogen content, and available phosphorus content. These factors all provided nutrient sources and inter space for soil microbial diversity. Low soil fertility and low plant diversity contribute to the low diversity of soil microbial diversity in artificial plantations.

Relationship between soil organic carbon content and carbon cycling genes. A positive relationship was found between soil organic carbon content and carbon cycling genes. The low diversity of carbon cycling genes in artificial plantations might contribute to the low soil organic carbon content. A positive relationship was found between carbon fixation genes and soil organic carbon content. Microbial carbon fixation is an important way to increase soil organic carbon content. The low diversity of carbon cycling genes in artificial plantations might contribute to the low soil organic carbon content.

NATURAL PLANTATION BENEFITS

Our abundant data, most of which has not yet been analyzed, has led us to conclude that overall, natural plantation may be superior in many ways to artificial plantation in forest restoration projects. Moreover, the native species Masson plantation generally outperformed the introduced species, slash pine, plantation. Artificial plantations significantly reduced soil organic content and its stability, as well as the diversity of carbon cycling genes. Plant factors and soil factors explained 65.8 percent of the variation in the carbon cycling of the soil microbial community. The low tree layer diversity index, available nitrogen content, and available phosphorus content might contribute to the low diversity of carbon cycling genes in the artificial plantations. A positive relationship was found between carbon content and carbon cycling genes. The reduced diversity of carbon cycling microorganisms in artificial plantations might contribute to the low soil organic carbon content.

In conclusion, compared with natural restoration, artificial plantations have significantly lower soil organic carbon content and carbon cycling functional gene diversity. These results have important implications on forest restoration and the corresponding ecosystem services of carbon maintenance and the carbon cycling potential.

Isolation of Highly Purfied Cellulose from Wheat Straw and Preparation of Cellulose Aqueous Solution

by Lifeng Yan

Dr. Yan *is an Associate Professor in the Department of Chemical Physics, University of Science and Technology of China.*

New industrial uses of biomass span many spectrums, but they have one thing in common. All biomass feedstocks must undergo some sort of conversion process to produce fuels, power, or chemicals. Many of these processes are either very expensive or are detrimental to the environment. At the University of Science and Technology of China, my research has focused on biomass conversion for energy and chemicals, the chemistry and physics of cellulose, green chemistry synthesis of materials, and the synthesis and application of biomaterials.

Structurally, biomass contains lignin, hemicellulose, and cellulose at different concentrations depending on the different kinds of feedstocks employed. It can be difficult to convert the cellulose using green methods.

We need a better understanding of the relationships and interactions among these components in order to convert the cellulose efficiently and with minimal impacts on the environment.

CELLULOSE SOLUTION

Cellulose is a basic polymer and also the most common organic molecule in the world, yet its uses remain very limited due primarily to the difficulty of finding new and better solvents to extract it. Most of the solvent compounds available are not only expensive but also have adverse environmental effects. Solvent systems for cotton, for example, which are used to produce cloth, are very toxic, and researchers are looking for a better and more environmentally friendly replacement. One key question is whether it is possible to separate cellulose directly from biomass and then prepare the cellulose in a homogenous solution.

The molecular structure of cellulose is very complex. Glucose molecules aggregate to form a crystalline structure that forms small fibers. The microfibers then form thick fibers and finally a plant cell wall. Because of the crystalline structure of cellulose, it is very difficult to dissolve in common solvents, as the bonds between the molecules are very strong.

The idea of developing new, greener solvents such as ionic liquid and aqueous solutions of sodium hydroxide (NaOH) with or without urea or thiourea is very attractive. We have focused on aqueous solutions because ionic liquid is too expensive for use at the commercial scale. The aqueous system is quite simple and may turn out to be a better choice for applications in the real world.

Research has shown that an aqueous solution of NaOH can directly dissolve cellulose but requires a very low temperature. Freezing the suspension overnight at -12° C and then thawing it under strong stirring can dissolve the cellulose, but this method is not suitable for every molecular form of cellulose. If the molecular weight is high, which is the case with natural cellulose, the available solvents are not suitable. In 1998, researchers found that adding compounds such as urea and thiourea to the aqueous system can stabilize the solution and dissolve cellulose with high molecular weight.

We have conducted a topochemical investigation of cellulose dissolved in an aqueous solution of NaOH and thiourea. Using scanning electron and energy dispersive X-ray microscopy (SEM-EDX) and atomic force microscopy (AFM), we were able to directly observe the orientation of the molecules of cellulose in solution and show the changes in the shape of the microcrystalline cellulose on a mica substrate before and after treatment in the solution and subsequent cleansing in pure water. The SEM-EDX and AFM studies showed a homogenous distribution of NaOH and thiourea around the cellulose fibers during the process of dissolving.

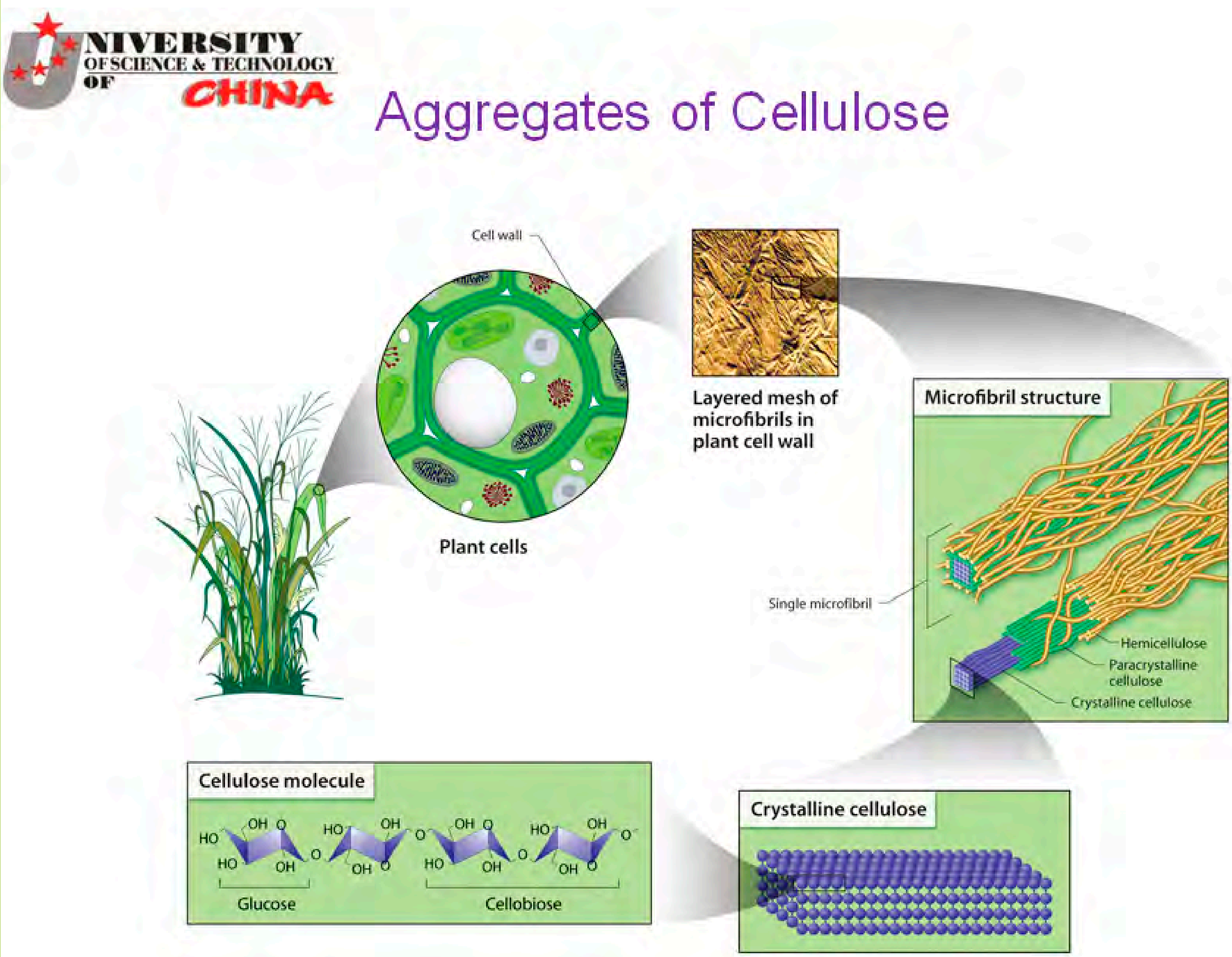
We have also reported on a new solvent system for cellulose: a mixed aqueous solution of poly(ethylene glycol) (PEG) and NaOH. Cellulose powder was added to the mixture at room temperature. Then the solution was frozen to -15° C for 12 hours and thawed to room temperature under strong stirring. We found the cellulose solution in the new solvent to be stable, even after 30 days of storage at room temperature.

ISOLATION OF CELLULOSE

We have also explored methods for isolating purified cellulose from wheat straw biomass powder. One method used an inorganic acid and an alkali. The biomass powder was washed with dilute water and ethanol, and then filtrated. The residue, dehemicellulose, was then washed and diluted again, producing cellulose (delignin), which was then bleached.

A second method used dilute acid and PEG. Eight cellulose samples with various molecular weights were obtained from wheat straw by a two-stage process without further bleaching. The dewaxed wheat straw was pretreated with hydrochloric acid aqueous solution, followed by delignification using a PEG-based aqueous biphasic system. The yield of cellulose was in the range of 48.9-55.5 percent, which contained 1.2-3.2 percent hemicelluloses and 0.97-3.47 percent lignin. All the isolated cellulose samples could be directly dissolved in a NaOH/ urea aqueous solution through a precooling-thaw process. The isolation process, the obtained cellulose, and their solution were studied by Fourier transform infrared spectroscopy, SEM-EDX, and X-ray diffraction respectively.

The results reveal that it is possible to directly prepare cellulose aqueous solution from wheat straw using only aqueous solution. This suite of experiments shows that it is indeed possible to directly prepare cloth and chemicals from waste biomass such as wheat straw in an efficient and more environmentally friendly way.



Potential Nanotechnology Applications with Hardwood Biomass

by Robert Moon

Dr. Moon *is a Materials Research Engineer in the Performance Enhanced Biopolymers group at the US Forest Service – Forest Products Laboratory in Madison, Wisconsin; and an Adjunct Assistant Professor in the School of Materials Engineering and member of the Birck Nanotechnology Center at Purdue University.*

Consumers, industry, and governments are increasingly demanding products made from renewable and sustainable resources that are biodegradable, non-petroleum based, carbon neutral, and have low environmental and animal/human health and safety risks. Natural cellulose-based materials (wood, hemp, cotton, linen, etc.) have been used by our society as engineering materials for thousands of years and their use continues today, as verified by the enormity of the world wide industries in forest products, paper, textiles, etc. However, the properties, functionality, durability, and uniformity that will be required for the next generation of cellulose-based products and their engineering applications cannot be achieved with traditional cellulosic materials.

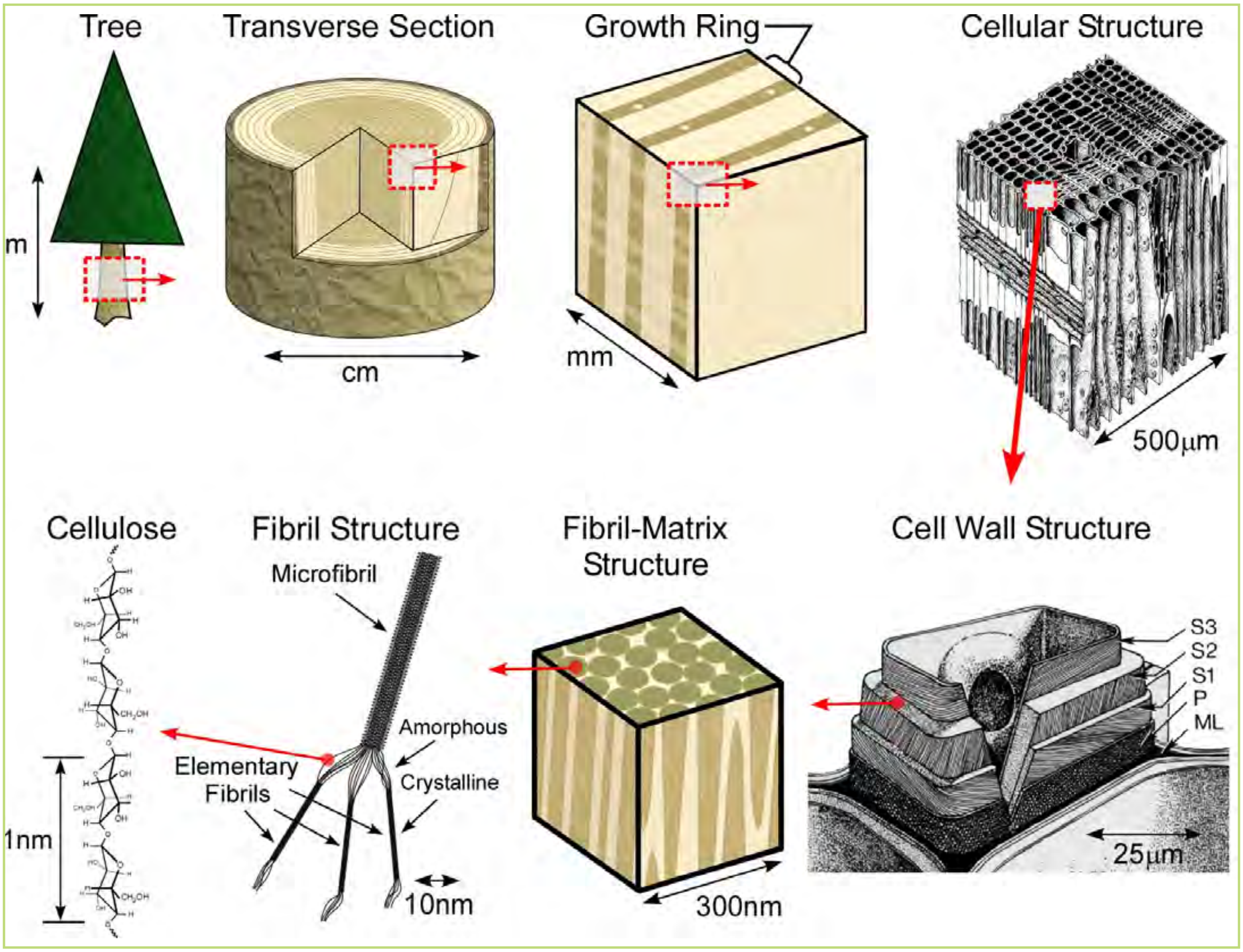
Fortunately, there is a base fundamental reinforcement unit that is used to strengthen all subsequent structures within trees, plants, some marine creatures, and algae: cellulose nanomaterials (CNs). By extracting cellulose at the nanoscale, new cellulose based "building blocks" are available for the next generation of cellulose-based composites.

Emerging CN-based technologies offer potential development of composite materials with a wide range of new properties that have applications in products once considered improbable with biobased materials (wood, plants, etc.). Crystalline cellulose has a greater axial elastic modulus than Kevlar and its mechanical properties are within the range of other reinforcement materials. CNs have high aspect ratio, low density (1.6 g cm-3), and a reactive surface of –OH side groups that facilitates grafting chemical species to achieve different surface properties (surface functionalization).

A variety of CN composites have been produced—films, fibers and plates—and have had transparencies greater than 80 percent with tensile strengths greater than cast iron and a very low coefficient of thermal expansion similar to fused silica. Potential applications include but are not limited to barrier films, antimicrobial films, transparent films, flexible displays, templates for electronic components, reinforcing fillers for polymers, biomedical implants, pharmaceuticals, drug delivery, bio-encapsulation, fibers and textiles, separation membranes, food packaging, batteries, supercapacitors, electroactive polymers, sensors, construction materials, etc.

To date the majority of CN-based research can be considered fundamental in nature but the field is transitioning to more applied research for product development. The first step in this has already begun with development of several pilot plant CN processing facilities. The increased quantities (as compared to laboratory scale) give an opportunity for researchers and companies to conduct applied research in the processing of larger sized CN-composite specimens, which is necessary for most potential consumer and military applications.

See: R. J. Moon, A. Martini, J. Nairn, J. Simonsen, and J. Youngblood. 2011. Cellulose nanomaterials review: Structure, properties and nanocomposites. *Chemical Society Reviews* 40 (7): 3941-3994.



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Realities and Potentials of Wood Energy: A Geospatial Perspective

by Goufan Shao

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

As demand grows for renewable energy, wood fuel, one of the oldest energy sources on the planet, could become the newest market commodity. The question is, how?

The European Union policy target, 20 percent of energy coming from renewable sources in gross energy consumption by 2020, is a predominant driver for future biomass and waste demand. Wood and wood waste have a major share in the category "biomass and waste."

WOOD PELLETS: WHAT AND WHY

Wood pellets are a biomass substance produced from sawdust and wood chips. They are very pure and natural and have very high density. Wood pellets are now considered an efficient alternative to traditional oil-based fuels. They have less volume and less moisture content and are easy to transport; they can serve multiple purpose uses; they produce fewer emissions; they are easy to use, and most importantly, wood pellets contribute to local economies.

One report on the current status and future prospects for the European wood pellet markets for 2020 showed a great deal of import activity. For example, in 2009, the United States exported half a million tons of wood pellets to European countries, and there is even more import/export activity within European countries. As we get closer to 2020, and demand for renewable energy grows, the US industrial pellet sector will too. Currently, the United States is the second largest producer of wood pellets in the world. Wood pellet production in the United States in 2008 amounted to 1.8 million tons. From 2008-2010, total US wood pellet exports to Europe alone grew from 85,000 tons to more than 600,000 tons per year.

Looking at the other side of the world, China's demand for biomass is supplied domestically, but Korea will likely become an important and competitive market in the future. Renewable energy mandates are in place throughout Korea, encouraging the generation of power from biomass. Malaysia, Canada, and Chile export biomass pellets to Korea.

In the United States today, petroleum is still the number one energy source, followed by natural gas and coal. US use of biomass is not high, but is roughly equivalent to hydropower. Slightly more than 70 percent of the volume of current US wood removal is roundwood, with the remainder consisting of logging residues and other removals, which currently amount to nearly 93 million dry tons annually—68 million dry tons of logging residue and 25 million dry tons of other removal residue. Primary processing mills—facilities that convert roundwood into products such as lumber, plywood, and wood pulp—produced about 87 million dry tons of residues in the form of bark, sawmill slabs and edgings, sawdust, and peeler log cores in 2002.

Also to be counted in the existing forestry biomass inventory are the short-rotation woody crops such as poplar, pine, eucalyptus, and willow, which will produce a lot of biomass for the future. In addition, by 2020, US biomass from corn stover, wheat and grass straw, hay, dedicated energy crops, woody crops, animal manure, and municipal solid waste will total 548 tons. The global biomass potential by 2030 is estimated to be even higher: 1.4 billion dry tons for the United States and 1.7 for China and India together.

In short, woody biomass is not in short supply, but very little of it is being used. A major question is how to take this theoretical biomass potential to a sustainable biomass potential. The theoretical potential is based on biophysical and agro-ecological factors, biomass extension and growth, and residue production ratios. The techno-economical biomass potential is based on accessibility, resources competition, biomass logistics, and production costs.

A GIS APPROACH

A sustainable biomass potential depends on a number of social and environmental constraints. One method to go from potential to reality is to use geospatial technology to narrow down the possibilities and feasibility of woody biomass. A first step is to assess the biomass potential for power production using a geographic information system (GIS) approach.

Basically, the GIS approach uses a series of map layers. One layer assesses regional attributes such as land use, land cover, crop area, residue yield, and residue characteristics. The next map layer identifies candidate power plant sites based on factors such as capacity, efficiency, and plant costs. The next three map layers a) identify biomass collection areas and selection of power plant sites, taking into consideration the maximum allowable transportation distance; b) map the existing road networks; and c) assess the electric grid, including connection and expansion costs. Together, these three layers allow an estimation of electricity production costs and help identify the prime sites for feasible power plants and estimate overall electricity production costs and internal rate of return (IRR).

CASE STUDIES

In the last 30 years, GIS technology has improved dramatically. It is a powerful tool to perform spatial calculations, as long as the data are available. In the United States, thanks to remote sensing data gathered from satellites and airplanes, there is a lot of high resolution, free data available. We have therefore been able to put together a few case studies to estimate the potential of siting wood-based energy plants.

The state of California wanted to narrow down the most suitable areas for producing wood-based energy plants, so they used map layers to identify service areas by distance from the biomass source and the type of land area, from agricultural to rangeland to urban areas. It was then possible to add cost information by road class and feedstock type in order to optimize the facility scale or size by satisfying different well-defined objective functions such as minimizing total delivered feedstock cost to the facility or maximizing facility profit, including distribution of product (e.g., ethanol, electricity, composite materials, and other products).

Another case study was conducted for more than 10 states in the southern United States. This study included an economic analysis to select the most feasible areas, and 27 counties were identified that have high potential for energy generation from woody biomass. The ArcGIS Network Analyst extension was used in assessing the economic availability of woody biomass resources to these communities.

Japan has developed a GIS package not for economic, but for social and environmental analysis for Asian countries. The Central Research Institute of Electric Power Industry (CRIEPI) researched natural and social conditions in Asian countries while defining potential food crop, field, and primary forest to develop a Biomass Energy Use Business Evaluation GIS Software in the Asian region.

While an increase in the use of wood energy could result in a reduction of CO_2 equivalent emissions, there are considerations about environmental impacts associated with the production and transportation of wood pellets. Geospatial technology can help with optimizing what, where, and how big a new wood energy facility should be developed within a region.

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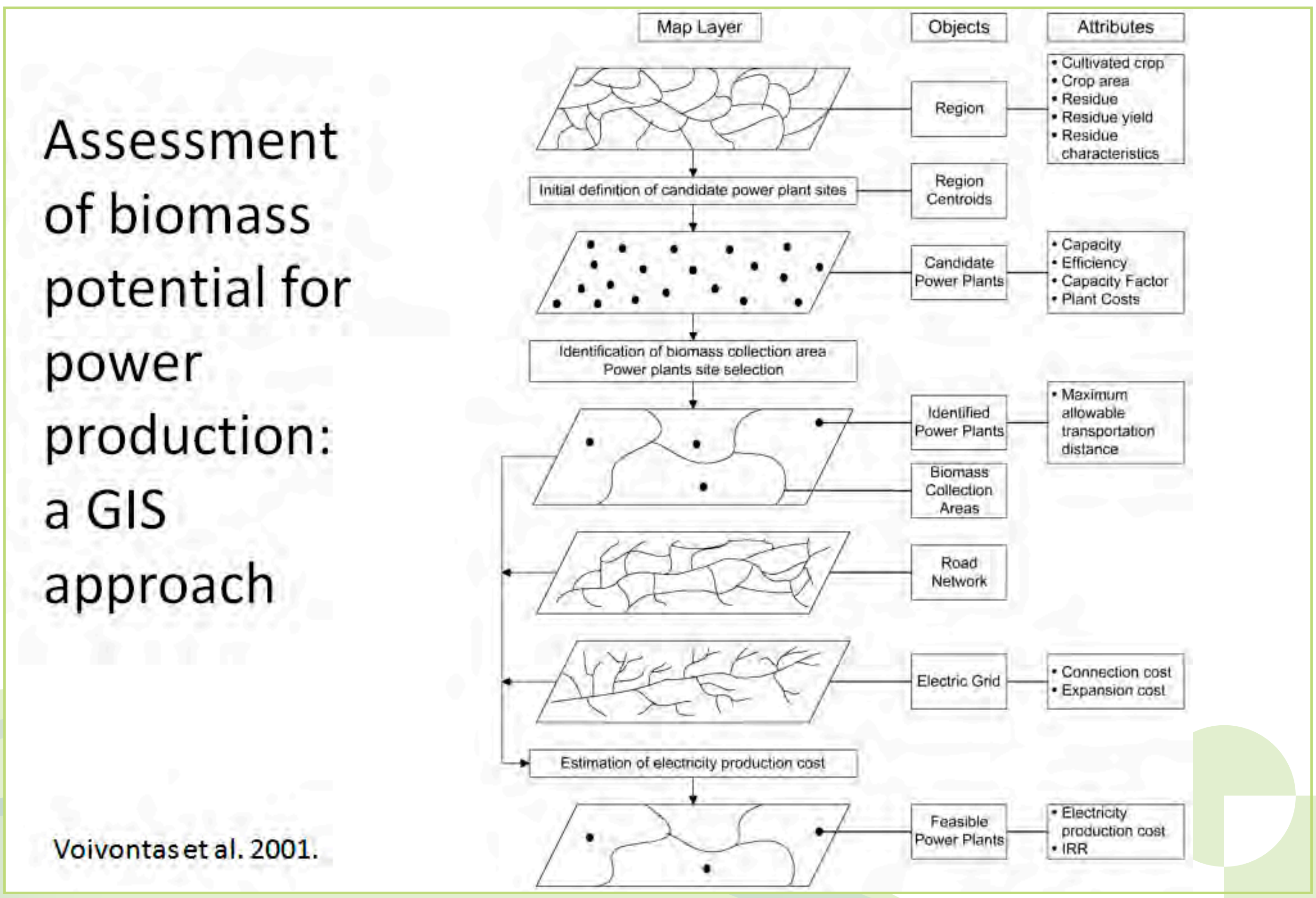


Genetic Improvement of Biomass Quality & Sustainability Factors

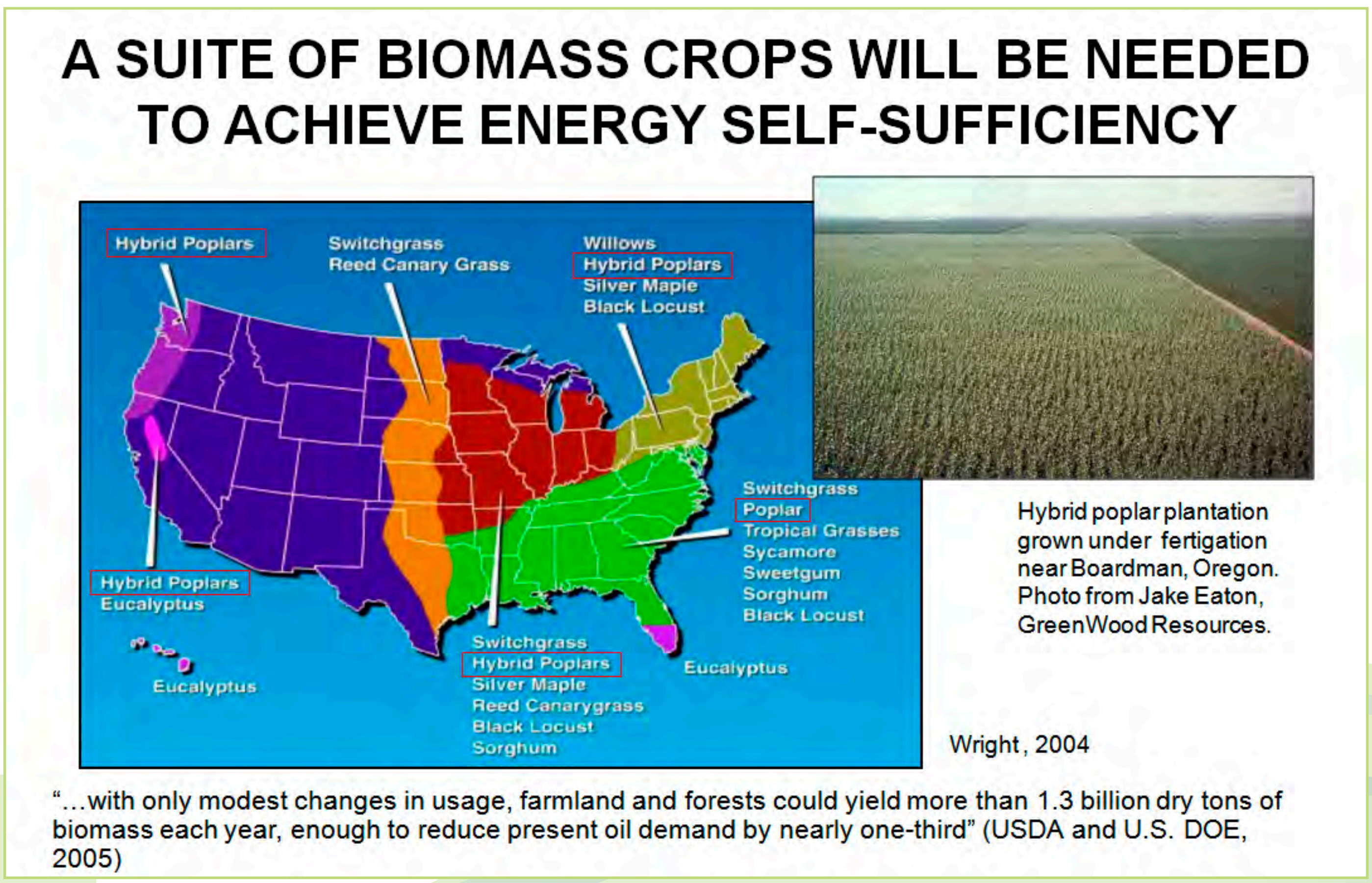
Engineering Poplar for Use as a Cellulosic Feedstock

by Rick Meilan

Dr. Meilan *is an Associate Professor of Molecular Tree Physiology in the Department of Forestry and Natural Resources, Purdue University.*

The US Department of Energy has set a goal to replace 20 percent of our liquid transportation fuels by the year 2020. In 2006, A. E. Ferrell and colleagues published in *Science* magazine an article in which they predicted there would be a large increase in the demand for ethanol in the United States. Two federal actions supported their prediction, one policy driven and the other economic driven. The Energy Policy Act (EPACT) of 2005 set a requirement that 7.5 billion gallons of "renewable fuel" be used in gasoline by 2012, and to provide incentive for people to do that, EPACT included a corn alcohol subsidy of $0.51 cents for every gallon of ethanol that was blended with petroleum as a transportation fuel.

These actions led to a rapid increase in the construction of biorefineries and a lot of investment in infrastructure. Within two years, the United States had achieved the goal. In 2007, we produced more than eight billion gallons of ethanol, exceeding the original goal of 7.5 billion gallons. In the latest Farm Bill passed in December 2010, the corn subsidy went from $0.51 cents a gallon to $0.45 cents a gallon. These incentives, however, were based on corn as feedstock, which is unsustainable. The corn subsidy may eventually be eliminated entirely, but the economic incentive proved so effective that Congress decided to implement a subsidy of $1.01 for any ethanol that is derived from a cellulosic feedstock and blended as a liquid transportation fuel.



In 2004, Lynn L. Wright with Oak Ridge National Laboratory published a report in which she recognized that a suite of biomass crops will be needed for the United States to achieve energy self-sufficiency. Wright looked at land availability, soil type, climate, and rainfall patterns county by county and in each state. She also looked at the growing requirements of various potential bioenergy crops, particularly cellulosic crops, and made some recommendations about which crop would do best in different regions of the country. In virtually every one of these regions, she found that poplar would be a suitable bioenergy crop. There are about 30 different species of poplar within the genus *Populus*; these genotypes are adapted to growing across a very wide range of climatic zones and geographic regions.

A wish list for the desired traits for bioenergy crops would include: vegetative propagation, rapid growth, high conversion efficiency, reproductive sterility, and ease of harvesting.

TRANSGENIC POPLAR

During the years when trees are investing energy in the reproductive effort, there is a measureable decrease in the concentric growth rings, leaf size, and internode distances. If we can prevent a plant from flowering, all the plant's carbohydrates will be invested in vegetative structures and, therefore, the plant will exhibit more rapid vegetative growth. Equally important is the need for transgene confinement. The US Department of Agriculture's Animal and Plant Health Inspection Service (APHIS) has overarching regulatory authority with regard to the commercial deployment of transgenic plants. In its current regulatory framework, APHIS states that before we can deploy a transgenic plant or tree commercially, we have to develop a strategy for mitigating the risk of transgene spread and persistence in the environment. One way of achieving that objective is to prevent the plants from flowering entirely. To do so, we need to control the onset of maturation.

MicroRNAs (miRNAs) control developmental timing in a number of plant and animal systems. These miRNAs are expressed in a stage- or tissue-specific fashion. With regard to post-transcriptional control, after the miRNA's gene is expressed, a hairpin loop is formed as a result of a process called inverted repeat; it gets cleaved to produce a mature miRNA that is 20 to 25 nucleotides in length. After the short, double-stranded segment of RNA is unraveled, it can bind to a homologous site on its target message. The resulting double-stranded RNA is susceptible to degradation by a complex called RISC (RNA-induced silencing complex).

George Chuck, a post-doctoral researcher in Sarah Hake's Lab at the Plant Gene Expression Center, identified a gene called *CORNGRASS1* (*Cg1*) while screening a mutant maize population. He later found it to be a member of the miRNA156 family. The miRNAs that he isolated from *Zea mays* targets plants or sequences that contain what is called the SBP (*SQUAMOSA* promoter binding protein) box. The *Squamosa* is a floral meristem identity gene that was originally identified in *Antirrhinum*. This miRNA controls the fate of meristems as well as lateral organs in a number of plants. The maize *Cg1* mutants exhibited adventitious root formation, produced a number of shoots rather than having a central stem, and were sterile.

Chuck cloned the *Cg1* gene and built a binary vector in which the gene was under the control of a constitutive promoter, and transformed it into three different heterologous herbaceous species: maize, tobacco, and an *Arabidopsis*. In all those transgenic plants he found consistent phenotypes. They produced multiple stems, had faster rates of vegetative growth, contained less lignin, had higher carbohydrate levels, and they either had delayed flowering or none at all.

Based on Chuck's results, we decided to test *Cg1* in poplar. Using a hybrid aspen genotype with a high transformation efficiency, we produced about 30 independent lines and verified the presence of the transgene with the standard polymerase chain reaction technique. We also verified that the *Cg1* message was processed to produce a mature miRNA. So far, these transgenic poplars are only about a year and a half old, so they are not ready to produce flowers, but they exhibit all the other phenotypes that were seen in the heterologous, herbaceous species transformed with the same *Cg1* construct.

Our transgenic poplars produced enlarged, dark green stipules. In addition, dormant lateral buds elongated, resulting in sylleptic branches. When selecting trees for rapid growth, one of the phenotypes we look for is production of sylleptic branches because of the increase in photosynthetic capacity as a result of increased leaf surface area.

Below is a summary of the phenotypic characters we have measured.

- The severity of the phenotype related to *Cg1* expression level. We found an inverse relationship between the level of transgene expression and the height of the plant; that is, the highest expressing transgenic plants were the shortest.
- The internode length. While in most cases there was no significant difference in the number of nodes on the transgenic plants regardless of expression level, there was a difference in the length of the internode. In the intermediate- and high-expressing lines, the internode lengths were shorter. In addition, the plastochron duration, which is a measure of the rate at which new leaves are initiated, was not significantly different for even the highest expressing lines; so the rate at which the plant is initiating new leaves has not changed, but the total leaf area has increased as a result of the syllpetic branches that were produced.
- Branching and *Cg1* expression. The branching phenotype was more severe in lines that had the highest transgene expression, while those lines with the lowest transgene expression did not show the branching phenotype.
- Lignin analysis. As we have seen in other plants, we found that when *Cg1* is over-expressed, there is a change in the lig-

nin content as well as in the lignin composition (S:G ratio). The low-expressing line had 20 percent less lignin, while in the high-expressing line there was a 40 percent reduction in total lignin. At the time we did these analyses, the primary transformants were just one year old. There is some evidence, and cause for concern, that when a transgenic plant is regenerated or is vegetatively propagated, the transgene may become silent. To explore this possibility, we vegetatively propagated the primary transformants and analyzed the propagules for lignin. Our results revealed that the propagules remained true to type; again, there was a significant reduction in total lignin present in the transgenic lines.

In another project, a post-doctoral researcher in my lab found 14 genes in the poplar genome that contain an SBP box. However, none of these potential target sequences has been annotated. Determining the tissues in which these 14 genes are expressed and the developmental stage at which they are expressed will give us some clues about their function.

LOOKING AHEAD

Poplars expressing *Cg1* may have commercial value as a cellulosic feedstock for biofuel production and in the paper-making industry. It is yet to be determined whether miR156 directly regulates lignin biosynthesis. It is possible that the observed changes in lignin could be an indirect consequence of the developmental changes caused by *Cg1* over-expression. Nevertheless, over-expression of *Cg1* may offer a novel approach to altering lignin content and composition in poplar.

Other traits regulated by miRNAs may also be commercially useful. These include:

- Multiple stems (ease of harvesting, less need for growers to purchase new equipment)
- Rapid growth (biomass yield)
- Better rooting (ease of establishment)
- Higher sugar levels (better conversion efficiency)
- Flowering control (regulatory requirement)

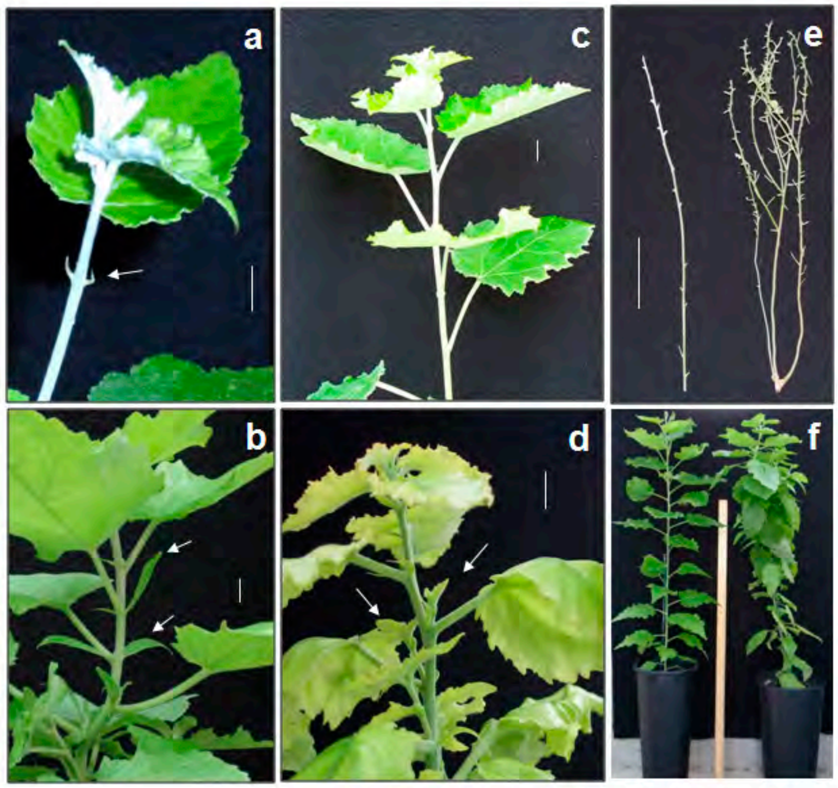
- Much work remains to be done in order to assess the potential of transgenic poplar. We need to a) conduct a complete lignin analysis on the rest of existing lines, b) assess the carbohydrate status of existing lines, c) perform target-gene expression analysis in various tissues of transgenics over time, and d) conduct a transgenic field test to determine total biomass produced by Cg1 over-expressing trees.

The groundwork for future progress has already been laid. Several ramets (i.e., genetically identical copies) of each transgenic line have been propagated, a field site has already been prepared, and a permit amendment has been granted by APHIS. We are also regenerating additional, unique transgenic events.

In our research, we have demonstrated for the first time that over-expression in poplar of a MIR156-class miRNA has dramatic effects on its development, and that miRNA over-expression represents a novel approach to altering lignin content and composition in poplar. It is yet to be determined whether MIR156 directly regulates lignin biosynthesis or if the observed lignin changes were indirect consequences of the developmental changes caused by *Cg1* over-expression. Nevertheless, plants expressing *Cg1* exhibit many of the traits needed for commercial production of cellulosic feedstocks to generate biofuels.

35S::Cg1 POPLAR PHENOTYPE

- **Enlarged, darkened stipules**
- **Increase in the number of branches (sylleptic shoots) and leaves**
- **Number of nodes unchanged in many of the transgenic lines**



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Capturing the Genetic Diversity of Maize and Sorghum for Improving Bioenergy Grasses

by Nicholas C. Carpita

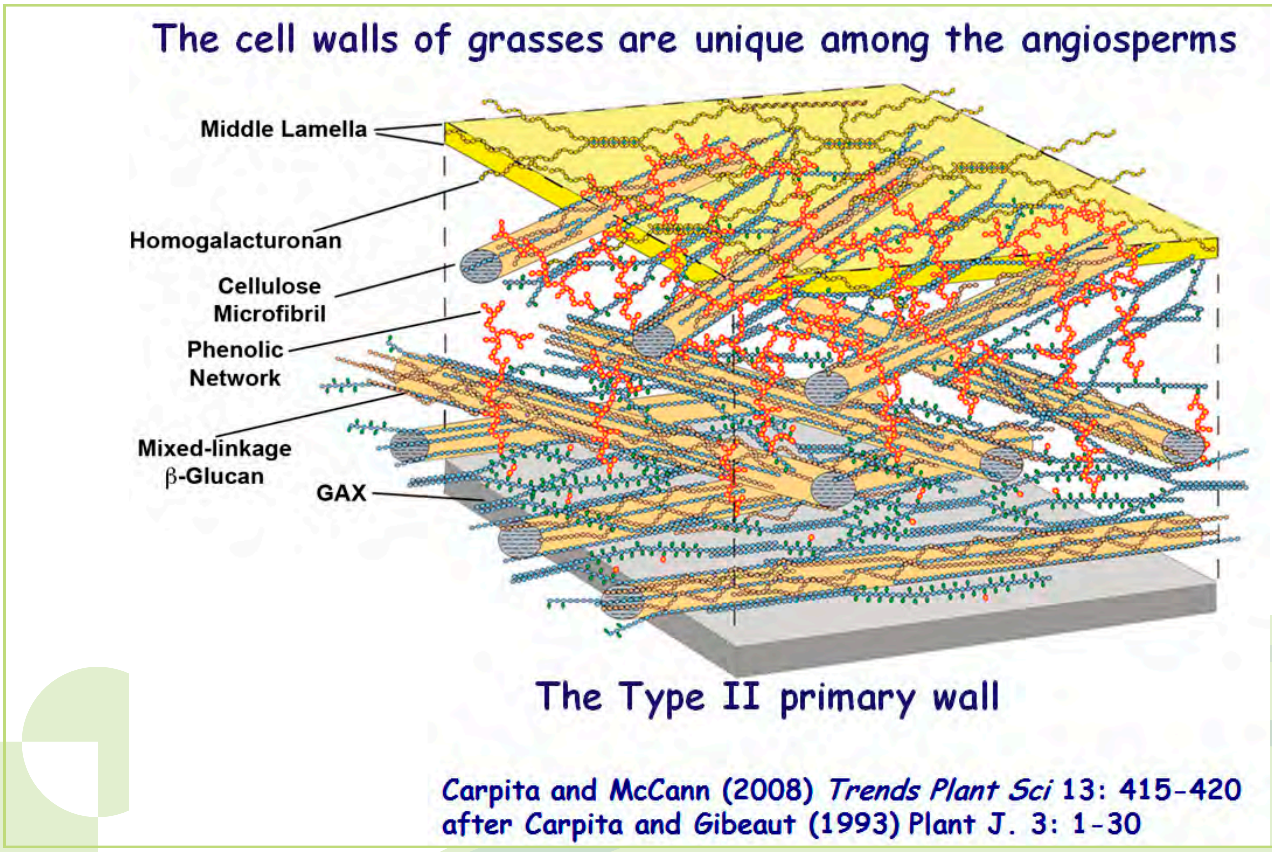
Dr. Carpita *is a Professor in the Department of Botany and Plant Pathology, Purdue University.*

The lignocellulosic cell walls of annual and perennial grass species such as Miscanthus, sugarcane, sweet sorghum, and tropical maize represent major feedstocks for biofuel production. Grasses possess a completely different kind of cell wall from those of all other flowering plant species. We have classified cell wall-related genes in maize and sorghum that underpin a fundamental understanding of the synthesis of cell wall biomass during growth and development. Comparative genomics between closely related maize, rice, and sorghum, and a reference eudicot, Arabidopsis, reveal differences in gene family structure between the grass species and dicots that explain fundamental differences in wall structure. These differences in gene family structure and expression between Arabidopsis and the grasses underscore the requirement for a grass-specific genetic model for functional analyses.

CELL WALL STRUCTURE OF GRASSES

The commelinid monocots have cellulose microfibrils like the dicots, but they are also interlaced with different molecules, mostly the polymers of xylose, called xylans. The xylans are cross-linked with a phenylpropanoid network of hydroxycinnamic acids and lignin. Grass cell walls have true lignin in the secondary walls of the xylem and fiber cells, which contribute most of the biomass to the plant, but it is these xylan-phenylpropanoid networks that set the grasses apart from walls of all other plants.

Because of the close evolutionary relationship to the future bioenergy grasses, maize and sorghum genomes promise to be



important engines of discovery for improvement of all bioenergy grasses. They also have complex genomes similar to those of other C4 grasses, and their genetic diversity gives great potential for improved agricultural traits of interest. In addition, there is a long history of genetic discoveries and breeding success and a wealth of genetic tools that is ever growing. Moreover, tropical maize and sweet sorghum could become transitional if not the optimal bioenergy crops.

FUTURE OF MAIZE AND SORGHUM

Maize has quality traits for advances not only in grain yield, but also in biomass accumulation and sugar accumulation. The estimated genetic diversity of maize is estimated at nearly two percent. Maize genetic diversity permits selection of a great many desirable traits; the focus on improvements to grain production has increased yields almost eight-fold since the advent of hybrid corn.

Genetic diversity is of great importance, as we have seen in the some of the ancestors of our modern hybrid corn. We have a long history of genetic discoveries and breeding success with hybrid corn, and now having the genomic sequences for maize and sorghum opens up many possibilities to capture that diversity. One of the genetic improvements in hybrid corn is related to traits of a particular line, B73, which spreads its leaves to form a very tight solar collector with very little shading. This trait allowed us to seed plants much closer together, which greatly increased yield. The tropical lines of maize, however, flowered too late to be used in the Midwest, so they were discarded from the breeding programs. If producing ears of corn is the goal, this is not a desirable trait. But if the goal is to grow biomass, then a late-flowering trait is advantageous. Likewise, grain production is not the goal in sweet sorghum, since late flowering leads to increased sugar production in the stem.

For grasses to become optimal energy crops, selection of the diversity will involve a transformation from grain to biomass production. The grain-producing corn plant was never designed to produce biomass; it was designed to remobilize carbon and nitrogen to the grain. So there is a much greater potential for biomass accumulation in crops such as tropical maize and sorghum. Other features may make certain tropical maize and sorghum hybrids advantageous. As an annual crop, tropical maize and sorghum hybrids give growers greater flexibility by avoiding the problem of dedicating the land to a perennial crop year after year.

Many have made the case that perennial grasses have more benefits over annual crops because the nitrogen and other inputs challenge sustainability. However, while large amounts of nitrogen are required for grain protein, many field studies, from Texas to Nebraska to Kansas to our own plots in Indiana, show that optimal stem biomass of an annual energy grass is not greater than recommended for perennials. The ability to grow a legume in the subsequent year mitigates the sustainability problem further. Both sorghum and some of the tropical maize varieties also have higher water use efficiency, which greatly extends the range where the crop can be grown.

LOGISTICS OF ENERGY COPS

The principal limiting factor for launching a biofuels industry is always to be the lack of a dedicated crop in the ground and the lack of biorefineries where the crops are to be grown. In envisioning a new cellulosic biofuels industry based on dedicated perennial grasses, a great lesson can be learned from the grain industry of the midwestern Corn Belt. This development began with the advent of hybrid corn in the 1930s. As growers planted improved varieties that increased yield from 20 to 160 bushels an acre, an extensive rail system developed to move the grain to market. Rail shuttle transfer stations emerged throughout the Midwest, where small rail takes products from local grain elevators and consolidates it onto larger trains that deliver coast to coast. The success of the corn ethanol plants is in part because they are co-located within this rail infrastructure.

If bioenergy is to become viable, we will have to use existing infrastructure to make it happen. No one is rushing to build a half billion dollar refinery if they cannot guarantee themselves a product, and no grower is willing to commit land to a bioenergy crop like Miscanthus if there is no factory to process it. The existing ethanol plants are in an enviable position to take advantage of other energy crops located near the existing ethanol plants, which can be retooled and expanded to include cellulosic stock. That is not to say that there is not a place for Miscanthus or switchgrass, depending on the region where it grows best, but the grower needs a guaranteed market for the crop.

NEXT STEP: OPTIMIZING EFFICIENCIES

What else can plant biologists do to help optimize carbon and energy conservation efficiencies? We can 1) modify biomass composition by mutation or by genetic engineering, 2) exploit natural genetic diversity, and 3) build novel genetic circuits in synthetic biology approaches. Capturing the diversity of maize and sorghum is the route to identifying the genes for biomass quantity and quality that are translatable to all bioenergy grasses. It is too early to write off annual grasses, such as maize and sorghum, as end-use bioenergy crops. In fact they have great advantages over perennials. We will undoubtedly make the advances necessary to produce sugar and biomass in a sustainable way, but we really need to advance our downstream technologies to make "drop-in" fuels. Gaining control of carbohydrate and lignin composition and architecture is the key to providing the optimal feedstock regardless of end use, whether direct conversion of sugar to ethanol, direct catalytic conversion of lignocellulosic biomass to energy-dense fuels, to high-value products or production of biopower.

See: I. Dweikat et al. In press. Envisioning the transition to a next-generation biofuels industry in the US midwest. *Biofuels, Bioproducts and Biorefining.*

Genomics Insights into Enhanced Cellulosic Bioethanol Fermentation

by Qiang He

Dr. He *is an Assistant Professor in the Department of Civil and Environmental Engineering at the University of Tennessee.*

Economic considerations dominate the feasibility of bioethanol production. Improving the efficiency of cellulosic bioethanol production is therefore key to lowering the associated costs. In 2008, a team of researchers from Oak Ridge National Laboratory and other institutions reported in *Nature Biotechnology* that consolidated bioprocessing (CBP) could achieve a significantly higher increase in the yield of sugar than other methods, nearly doubling the yield obtained by eliminating pretreatment. CBP is thus one of the more promising ways to increase production efficiency of cellulosic bioethanol.

A couple of strategies for CBP are commonly mentioned. One is to use synthetic biology to create new genetic circuits. For example, we have made some progress in incorporating genetic capacities into the microbes that ferment cellulose into bioethanol. Another approach, which is not really new, is co-cultivation of existing microbes having different capacities without changing the genetics. In our laboratory at the Department of Civil and Environmental Engineering at the University of Tennessee, we are using several strains of bacteria to determine the best combinations to achieve efficient conversion of cellulose to ethanol.

The process of converting sugar into ethanol is not always efficient. Some bacterial strains are more efficient than others in converting sugar into ethanol directly, and there are several possible combinations of cellulolytic bacteria. One of the model organisms that is widely studied is the cellulolytic bacterium *Clostridium thermocellum* (CT). CT by itself, however, is not an efficient converter of cellulose to ethanol. We have also performed preliminary screening on several different strains of saccharolytic *Thermoanaerobacter*. We have found one or two very promising combinations: CT plus a strain called X514 and CT plus the strain 39E.

These strains, X514 and 39E, are not cellulolytic bacteria, and so cannot degrade cellulose, but they are very efficient in converting sugar into bioethanol. When you add these partner strains to CT, the percentage of conversion increases dramatically. We wanted to know why these strains, which are of the same species and are essentially very similar, are so different in their capacity to produce ethanol in partnership with CT.

CO-CULTIVATION FOR CELLULOSE CONVERSION

We designed a fairly simple study to look at these strains in more detail, at the physiological level. Using batch cultures, we measured the amount of ethanol and sugar that were produced, and also the amount of cellulose utilized in the process. Compared to the control, the cellulose fermenting culture with CT alone, ethanol production in batches containing CT plus the saccharolytic *Thermoanaerobacter* strains X514 and 39E was higher. We also found that the co-culture with the X514 strain increased ethanol production more than the co-culture with the 39E strain. Cellulose utilization in the co-cultures was also higher than in the monoculture. The co-culture with the 39E strain uses more cellulose, but leaves more sugar in the culture broth than the co-culture with the X514 strain and does not have the capacity to utilize the remaining sugar.

There is a linkage between soluble sugar accumulation and production of ethanol, but we wanted to find further clues to explain why the 39E co-culture was not producing more ethanol. We therefore looked at the role in ethanol production of the non-cellulolytic fermentative partners in the co-culture system.

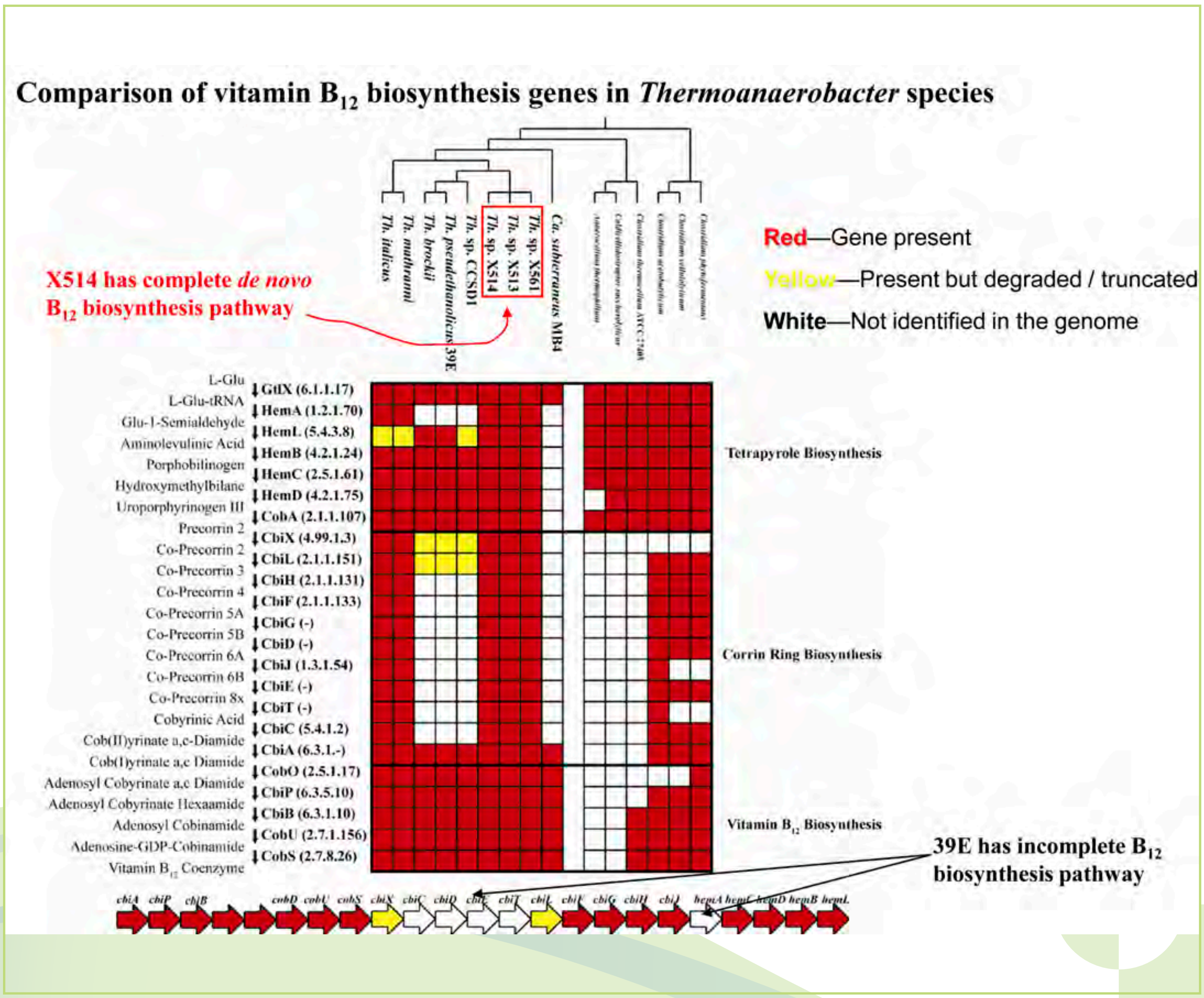
When we measured the utilization rate and growth rate for two sugar substrates, glucose and xylose, we clearly saw that the X514 co-culture grows faster than the 39E co-culture on both substrates. To find out why, we sent cultures to a researcher at Washington University in St. Louis, Missouri, who looked at the carbon flux distribution in X514 and 39E using ^{13}C labeled substrates. Even though there were major differences in the rate of conversion from sugar into ethanol, the percentage of carbon flux distribution was almost exactly the same. This was the case for glucose, and the results for xylose were very similar. This helped us determine that the differences in ability to convert sugar into ethanol between the two strains of co-cultures is not due to differences in metabolism, rather the difference is in the rate of flux.

We also wanted to see what effect the addition of yeast would have on ethanol production. We expected the ethanol yield to be higher, but an unexpected result was that there were differences in the two co-cultures. Without the yeast, X514 outperformed 39E, but with the added yeast, the superiority of X514 disappeared.

We also added different amounts of cellulose to see if that would make a difference. For X514, the more cellulose, the higher the ethanol production. For 39E ethanol production increases up to a point, after which it drops. With the same amount of yeast extract, a certain nutrient growth factor is essentially exhausted, becoming the limiting factor to 39E. For X514 that is not the case.

We then looked at the genomes of the two strains. One of the major differences we found between X514 and 39E is in the pathway for the biosynthesis of vitamin B_{12}, an important growth factor. X514 has the whole pathway in the genome sequence, but the 39E strain is missing key critical components of the pathway. X514 has the capacity to produce vitamin B_{12} from the medium itself, while with 39E it is necessary to provide exogenous vitamin B_{12} to support the growth of bacteria. So it appears that the difference between the X514 and 39E based co-culture may be attributed to the inability of 39E to make vitamin B_{12} in the cell from a defined culture. Essentially vitamin B_{12} production pathways seem to be critical in enhancing ethanol production.

The availability of whole genome sequences and comparative genomics tools for multiple *Thermoanaerobacter* strains made it possible to investigate the genomic characteristics underlying enhanced ethanol fermentation capacity. Genome analysis revealed that the higher ethanolic fermentation efficiency was associated with the presence of a complete vitamin B_{12} biosynthesis pathway, providing a valuable biomarker for selecting metabolically robust strains for bioethanol production.



Strategies to Generate Economically Viable Biofuels from Cellulosic Biomass: Approaches from the Bioenergy Science Center

by Paul Gilna (presented by Steven D. Brown)

Dr. Gilna *is the Director of the BioEnergy Research Center (BESC) at Oak Ridge National Laboratory.* **Dr. Brown** *is a Research Scientist in the Biosciences Division and BESC, Oak Ridge National Laboratory.*

The BioEnergy Science Center (BESC) at Oak Ridge National Laboratory is one of three bioenergy research centers widely distributed across the United States and funded by the US Department of Energy (DOE): the Joint BioEnergy Institute (JBEI), the Great Lakes Bioenergy Research Center (GLBRC), and BESC. These three centers, which were launched in 2007 to pursue transformational science for new, sustainable biofuels, are multi-institutional partnerships with multi-disciplinary teams.

BESC is a multi-institutional center performing basic and applied science dedicated to improving yields of biofuels from cellulosic biomass. Nineteen institutions participate, including industrial partners, university partners, and the National Renewable Energy Laboratory (NREL).

Since BESC is funded by DOE's Office of Science, we are focused on basic, fundamental research, but considering our affiliations with industrial partners, we also think it is important to translate our basic science findings into practical applications. Indeed, our industrial partners facilitate strategic commercialization of basic research.

A primary technical focus of BESC is trying to understand and overcome biomass recalcitrance. Unlocking the sugars in lignocellulosic biomass is key to enhancing the potential of the plants through various routes, whether to produce ethanol via the conventional route or to achieve consolidated bioprocessing, which produces fuel and other useful co-products.

Another key mission of BESC, beyond the fundamental science, is to train the next generation of scientists and researchers. BESC researchers have partnered with National Geographic and the Jason Project—a non-profit organization to provide students with mentored, authentic, and enriching science learning experiences—to produce a film and generate an educational module on bioenergy. In addition, BESC created an interactive biofuels outreach lesson for students in grades three through eight. This effort involves piloting more than 220 lessons, which reached over 6,000 students. BESC has also piloted 10 Biofuels Family Science Nights with an average attendance of 250 people each. If BESC is to have a lasting impact, education of the next generation of scientists and researchers is an important component.

BIOMASS FORMATION AND MODIFICATION

BESC takes a two-pronged approach to increase the accessibility of biomass sugars. The first prong is to modify the plant cell wall structure to increase accessibility, and the second prong is to improve combined microbial approaches that release sugars and ferment them into fuels. Both approaches utilize rapid screening for relevant traits followed by detailed analysis of selected samples.

We work primarily with two model plants, switchgrass and poplar, and a number of microorganisms. In switchgrass, we have found we can change a single gene in the lignin biosynthetic pathway and have profound impacts on cellulosic ethanol. Working with the Samuel Roberts Noble Foundation, we are creating a transgenic switchgrass that can dramatically increase the amount of ethanol produced by the mutant strain compared to the wild type switchgrass. This research is now at the field-trial stage.

Genetic manipulation of lignin in switchgrass can also increase the yield of the crop from a given land area by improving the enzyme levels required to break down the lignocellulosic material. This development, which was recently published in the *Proceedings of the National Academy of Sciences*, will have a significant impact on costs associated with the biomass.

BESC is not studying just a single gene, however. A number of other transgenic switchgrass lines within the biosynthetic pathway for lignin are also being targeted and are entering the transformation pipeline for characterization and study. We are also looking at other pathways and other genes as well. One of the strengths of this particular activity is that scientists and students work together to propose different gene targets. Their proposals are then evaluated by a committee, and based on the evidence and data that are presented, constructs are then chosen to enter the pipeline.

One team, in a project supported by the Nobel Foundation, has found that a mutation of a key transcriptional factor increases the cell wall thickness of pith. This single gene mutation opens up the possibility of significantly increasing the mass of fermentable cell wall components in bioenergy crops and generating more biomass per area of land dedicated to the plant.

BESC is also exploring the natural diversity of *Populus* across quite a wide range of the western United States, from British Columbia to the San Francisco/San Diego area. We are identifying key genes in biomass composition and sugar release. So far we have collected more than 1,300 samples and submitted them to a high-throughput screening pipeline to create a genetic marker map to identify allelic variation and marker trait associations that affect the release of sugar. The plants are then established in a common garden so we can distinguish between genetic versus environmental effects. These experiments will help the team decide which lines to propagate.

Another team is exploring the ways that lignin content and composition in natural *Populus* variants affect sugar release. This is one of the largest studies of its kind on the natural variants of *Populus*. Certain natural variants yielded unusually high sugar yields with no pretreatment. This new knowledge will help us design biomass with reduced recalcitrance, leading to more-efficient biofuels production.

Another key component of research at BESC is high-throughput characterization pipelines to assess the recalcitrance phenotype. BESC and its partner, NREL, have screened thousands of samples of species of candidate feedstock plants to screen their chemical and structural compositions. The samples were subjected to a new pretreatment method using dilute acid and steam and then analyzed for enzyme digestibility and sugar release using a number of different enzyme cocktails. In three years, the high-throughput pretreatment and hydrolysis system has been used to analyze more than 10,000 samples from BESC, industrial, international, and external collaborators for composition and digestibility.

In addition to the high-throughput pipelines, we also have more-detailed, lower throughput studies with which we can obtain a better understanding of certain genes or components. We can use various imaging techniques and others such as mass spectrometry to understand key genes in very fine detail and determine the different rates of delignification that may reflect differences in pretreatment so we can begin to optimize those treatments.

BESC also maintains a laboratory information science system that underlies much of the analytical work we do in biomass characterization. The results from the NREL, for example, are entered into the system and tracked with a barcode. If we send a sample for nuclear magnetic resonance spectroscopy, the sample is tracked along with the data.

These various projects and lines of research at BESC have broader implications in terms of biorefining. We have established that some native biofeedstocks have a high amount of variability in composition and digestibility. This finding offers the promise of identifying, breeding, or modifying the plants for improved conversion or compositional traits. In addition, biomass can be intentionally modified in key plant cell wall pathways, and some lignin-modified plants show improved digestibility. Detailed analysis of these samples by a range of techniques provides preliminary clues to recalcitrance, and cross-linkages appear critical.

BIOLOGICAL CATALYSTS TO OVERCOME RECALCITRANCE

A fundamental issue behind devising a strategy for biomass deconstruction and conversion is to develop an understanding of cellulose hydrolysis at the microbial rather than the enzymatic level. To that end, there are a couple of possible strategies. A native strategy might entail using metabolic engineering to improve product yields and tolerance using a bacterium such as *Clostridium thermocellum*, which is a powerful agent to hydrolyze biomass and access the sugars, but not so good at actually making ethanol or biofuels. Another approach is a recombinant strategy using heterologous enzyme expression to enable cell wall fermentation. With either strategy, the applied objective is to engineer industrial strains capable of producing high yield without added enzymes, which are expensive. At BESC, we are pursuing both strategies. One of our major goals is to use microbial hydrolysis, instead of the classical approach using enzymatic hydrolysis, for consolidated bioprocessing (CBP). There is a fundamental difference between microbial and enzymatic hydrolysis and a fundamentally different relationship between microbes and cellulose.

BESC is seeking to revolutionize how biomass is produced by developing an advanced new process. The first step in the process is based on modification of biomass using genetically manipulated plants such as a switchgrass mutant. The next step is CBP using a reduced pretreatment process or no pretreatment at all. The unseparated biomass is then exposed to a CBP yeast we are developing to produce a significant reduction in the addition of cellulose. The end product will be a next generation fuel such as butanol, isobutanol, or hydrocarbons.

BESC is also combining improved switchgrass feedstock with CBP microbes to enhance potential yield. We are finding that transgenic pretreated switchgrass continues to perform significantly better than the wild type. Using an improved cellulolytic Mascoma yeast we obtained a slightly higher ethanol yield on both the wild type and the mutant switchgrass, but the results using the CBP yeast with a modified lignin switchgrass were dramatic, achieving a 67 percent improvement in ethanol yield. These preliminary results, which still need to be optimized in the future, demonstrate the synergy between feedstock modification and conversion.

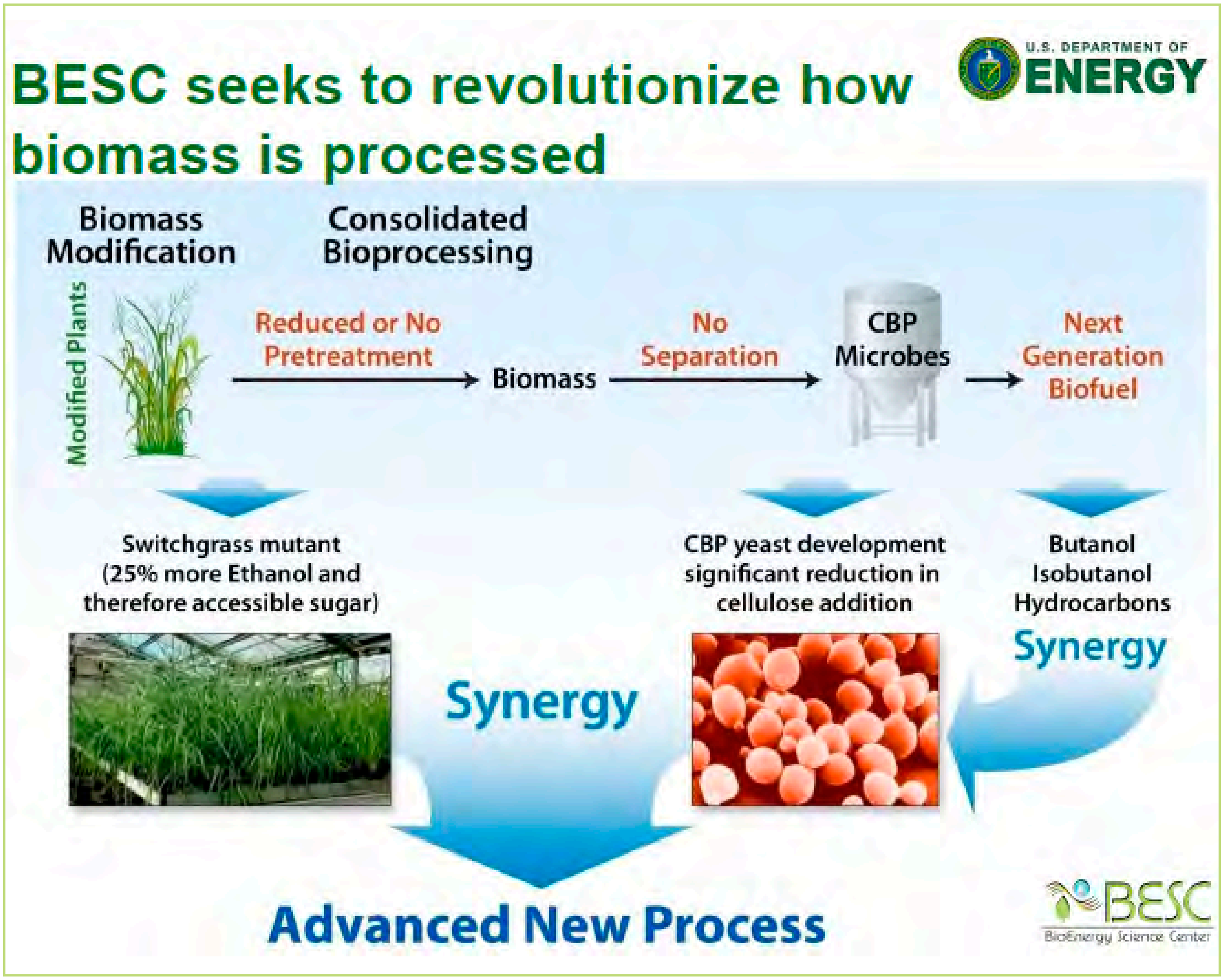
Other research pathways for BESC and its partners include

- exploring *Clostridium thermocellum* as a model system for cellulose hydrolysis,
- understanding the structure of the cellulolytic enzyme cellulosome,

- sequencing the multiple members of the genera *Caldicellulosiruptor*, an extremely thermophilic bacterium capable of fermenting cellulose,
- developing a suite of genetic tools for thermophiles, and
- engineering a microbe to produce isobutanol directly from cellulose.

The challenge of producing and converting sustainable cellulosic biomass into fuels presents the opportunity for science and technology to make an appreciable national and indeed global impact in the next 20 years. However, overcoming recalcitrance—the inability to easily access the sugars and other monomers in order to make fuels or other products—is one of the major challenges to cost-effective biofuel production. This is a central theme of BESC. Transformative advances to understand biomass recalcitrance require detailed scientific knowledge of 1) the chemical and physical properties of biomass that influence recalcitrance, 2) how these properties can be altered by engineering plant biosynthetic pathways, and 3) how such changes affect biomass-biocatalyst interactions during deconstruction by enzymes and microorganisms. The BESC team is applying the knowledge gained from these activities to develop a set of approaches on both the plant and microbial components to improve the generation of fuels from biomass resources.

The BioEnergy Science Center is supported by the Office of Biological and Environmental Research in the DOE Office of Science and is a US DOE Bioenergy Research Center. ORNL is managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract no. DE-AC05-00OR22725.


BESC seeks to revolutionize how biomass is processed
U.S. DEPARTMENT OF ENERGY
Biomass Modification
Consolidated Bioprocessing
Modified Plants
Reduced or No Pretreatment
Biomass
No Separation
CBP Microbes
Next Generation Biofuel
Switchgrass mutant (25% more Ethanol and therefore accessible sugar)
CBP yeast development significant reduction in cellulose addition
Butanol Isobutanol Hydrocarbons
Synergy
Synergy
Advanced New Process
BESC
BioEnergy Science Center

Gene Flow Matters in Switchgrass (*Panicum virgatum* L.): Potential Widespread Biofuel Feedstock

by Charles Kwit

Dr. Kwit *is a Research Assistant Professor in the Department of Plant Sciences at the University of Tennessee.*

In the past few decades, there has been a large push for the use, improvement, and expansion of dedicated biofuel crops in the United States and in many other parts of the world. Some observers have voiced ecological concerns about these crops because many of them exhibit characteristics associated with invasiveness. The agribusiness sector has registered concern about seed purity of biofuel feedstock cultivars whose seeds would be harvested in agronomic fields. The common thread for both concerns, which have regulatory implications, is gene flow; thus detailed knowledge of gene flow in biofuel crop plants is important in the formulation of environmental risk management plans.

At the University of Tennessee's (UT) Department of Plant Science, we are working to synthesize the current state of knowledge of gene flow in an exemplary biofuel crop, switchgrass (*Panicum virgatum* L.), which is native to eastern North America and is currently experiencing conventional and technological advances in biomass yields and ethanol production. Yet surprisingly little is known regarding aspects of pollen flow and seed dispersal, and whether native populations of conspecific or congeneric relatives will readily cross with current agronomic switchgrass cultivars. Filling these important knowledge gaps will be required to confront the sustainability challenges of widespread planting of biofuel feedstocks, both in areas where the feedstock is native and where it is non-native.

GENE FLOW AND HYBRIDIZATION: WHY CARE?

Switchgrass, as we know, is a very attractive bioenergy feedstock from a number of standpoints. The US Department of Energy has expressed interest in switchgrass production since the late 1970s. Interest in its potential is also driven by current energy-related legislation.

Efforts to improve switchgrass include conventional breeding programs and transgenic efforts as well. This line of research proposes to boost the rapid spring growth of the crop, its high water-use efficiency, and the partitioning of nutrients to roots. In the process, we are manipulating gene flow and hybridization of switchgrass. Some might ask why we should even care about gene flow and hybridization in switchgrass. At the heart of the question are two causes for concern about switchgrass and other biofuel feedstocks: their ability to become invasive and the purity of the seed available.

INVASIBILITY

Species considered invasive species are those that a) may negatively affect ecosystem processes and functionality and b) may cause economic losses.

Some traits of switchgrass that are desirable also lead its ability to become invasive. It is a C_4 plant with a competitive edge over C_3 plants in terms of water efficiency and drought resistance. It is a perennial with a long canopy duration, no known, significant pests or diseases, and rapid spring growth that lets it out-compete weeds. It partitions nutrients to belowground components in the fall, and its seeds are sterile. These are the ideal traits of biomass energy crops, but all these characteristics other than perennial growth and seed sterility are also known to contribute to invasiveness. Plants may become invasive through two mechanisms: planting in a novel environment and escape via seed.

We need to think hard about introducing switchgrass into US agronomic systems, especially in terms of the gene flow of this particular biofuel feedstock. Switchgrass populations are native especially in eastern US habitats. Historically, it has been used as an ornamental, for erosion control, for forage, and as wildlife habitat. As a *Panicum* it has a history of hybridization and introgression. Two potential risks following transgene introgression from crops to their wild or weedy relatives are 1) invasive hybrid populations from introgressed weedy or wild populations through seed dispersal brought about by positive selection and/or evolution, and 2) extinction of the wild relative population brought about by demographic swamping and negative selection. In short, wide-scale planting of agronomic switchgrass may carry a risk of invasiveness and extinction of related wild populations.

Researchers have identified targeted areas where we know switchgrass can grow very well. Many of those target areas overlap with preexisting collections of native populations. We need to consider these spatial juxtapositions to determine how far apart we can keep these populations if we don't want intermixing of genes from our agronomic crop. Even if we do trials showing containment measures for gene flow, many people are still very concerned about how far pollen travels, because pollen flow from an agronomic crop may inundate a wild relative nearby, whether the agronomic plant is transgenic or not; pollen flow to these wild relative populations will result in hybridization if the conditions are right.

SO LITTLE IS KNOWN, SO MUCH ASSUMED

To date, there remain significant information gaps in our understanding of seed dispersal, pollen dispersal distances and viability, and the potential for crossing and hybridization.

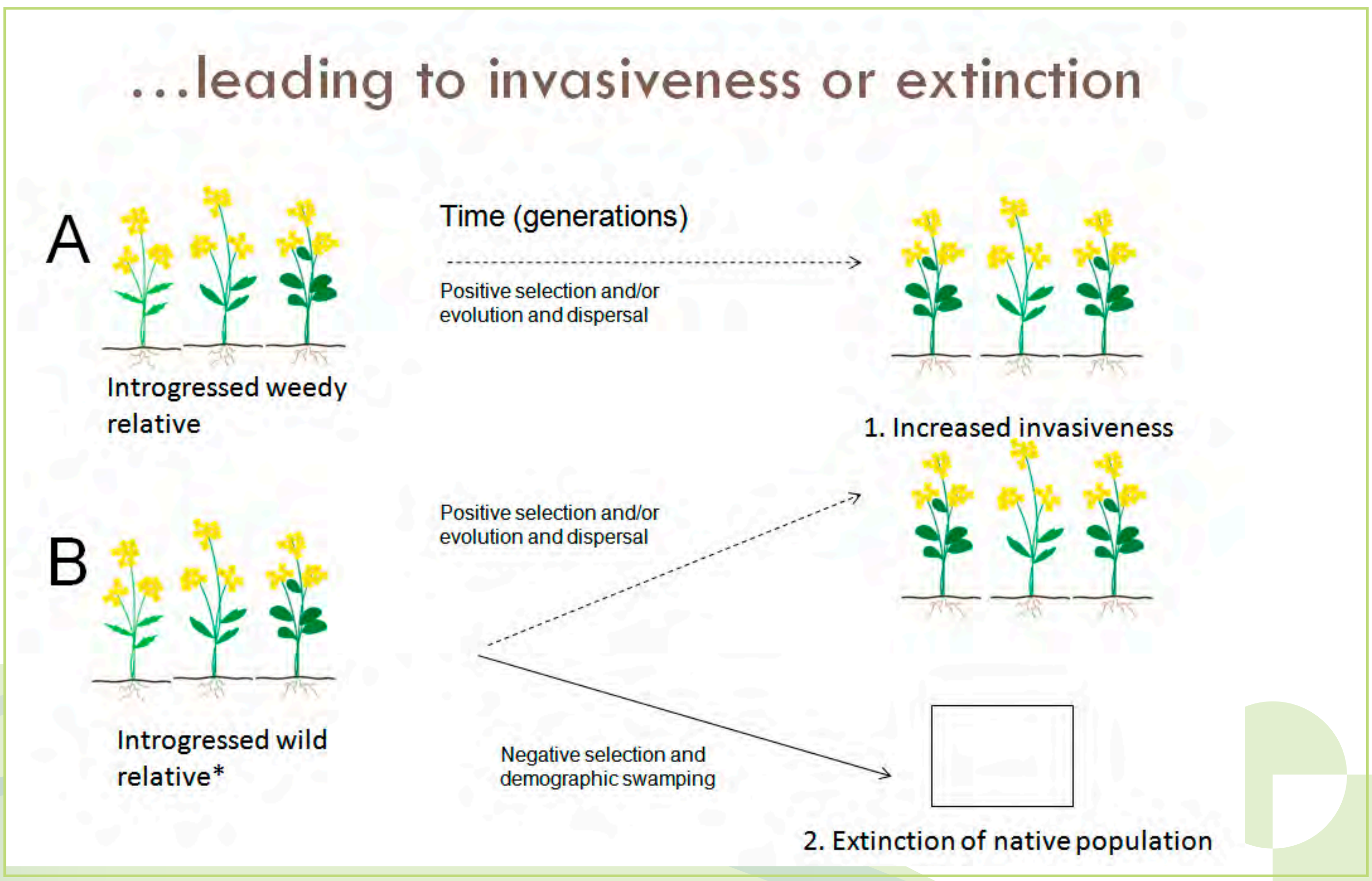
There are certain preconditions necessary for successful introgression. Flowering phenologies need to overlap. In the case of switchgrass, cultivar crosses will probably need similar ploidy levels—the number of complete chromosome sets in the cell—in the agronomic crop and its wild relatives that would result in the formation of hybrids. After several generations of contact between the agronomic crop and native varieties, we might have hybrids interspersed in the wild population, if the agronomic crop continues to supply ample pollen into the wild with repeated back crosses, resulting in introgression. Pollen is the primary player in this scenario. So far there are no published accounts of agronomic and wild crosses, or interspecific hybridization, and few examples of any hybridization of *Panicum*. The crossing and hybridization potential may be limited to intraspecific crosses involving similar ploidy levels.

Depending on the fitness of those hybrids and the trait involved from the agronomic field, once we have an introgressed wild relative population with the agronomic traits, one or more things can happen. If there is positive selection in the new environment, and/or evolution and dispersal of seeds into another location, we could indeed see the end result of increased invasiveness. If we have negative selection and continued demographic swamping, these plants may not be able to handle the new environment. To a degree, the outcome will depend on the actual selection pressures of the improved traits.

So far, there has also been little research on seed dispersal of switchgrass. We do know that we are dealing with very small seeds that are gravity dispersed; that is they fall to the ground, and they may be moved from there by birds or small mammals or by water. It would be nice to have a little bit more information if we are to model how far genes can actually flow in these systems. Some research is underway on pollen dispersal and viability once it leaves the anther. This is important information if we are going to model how far the pollen can travel.

STEPS UNDERWAY

My colleague in UT's Department of Plant Sciences, Neal Stewart, and I have a few ongoing projects to address some of the issues I have raised today. We have received a grant from the US Department of Agriculture Biotechnology Risk Assessment program to answer some very fundamental questions



on switchgrass pollen dispersal and intra- and interspecific hybridization possibilities.

One of the studies examines field-to-field pollen dispersal distances between agronomic cultivars of switchgrass. Switchgrass feedstocks are being grown on farms within a 50-mile radius of a demonstration biorefinery created by DuPont Cellulosic Ethanol in partnership with Genera Energy LLC, a for-profit venture of the university. In 2008/2009, the cultivar of choice for farmers was Alamo Switchgrass. In 2010, some producers planted new cultivars, including EG1102, which is an improved Kanlow cultivar. This new kid on the block is not being planted in high quantities, but it is present in the fields. Dr. Stewart and I are analyzing diagnostic molecular markers of the offspring from maternal Alamo plants at numerous distances from the Kanlow cultivar to determine the probability of outcrossing. This study will help answer questions about seed purity. We hope to be able to distinguish our newly planted Kanlow from the standard Alamo. We are collecting and growing seed from the Alamo fields at known distances from the Kanlow to see whether hybrids are forming as a result of pollen movement from the EG1102 field to nearby fields. We want to know if there is a distance-related function to the pollen dispersal curve that may affect the probability of outcrossing. Farmers and seed distributors who may harvest, advertise, and sell the seed need to know what the purity of the product is and whether they can sell it under the commercial name of Alamo or Kanlow.

Another way to determine pollen movement and distances is by using a Nelder wheel design. We are planting, with approval of the USDA Animal and Plant Inspection Service, a transgenic switchgrass clone with a red fluorescent protein inserted and allowing it to flower. Traps are set up at our receptor clones to catch the pollen, and perhaps late next year we will be able to look at pollen specimens under a microscope to see if they are fluorescing red.

Some of my collaborators and I are also looking at the intricacies of pollen movement by incorporating atmospheric data to model pollen deposition at local and large scales. In terms of intra- and interspecific hybridization, we have access to native switchgrass seed that we will germinate and attempt to cross agronomic cultivars with native populations of switchgrass from Tennessee. One native variety shares the same number of chromosomes as the tetraploid *Panicum virgatum.* If we think *Panicum virgatum* might hybridize with another *Panicum*, such as the widespread native *Panicum dichotomiflorum* we owe it to ourselves to do our homework.

We hope that our research efforts in UT's Department of Plant Sciences will contribute to the state of knowledge of gene flow in switchgrass and help guide efforts at environmental management of a potentially important biofuel crop.

Fast Assessment of Lignocellulosic Biomass Property for Biomass Energy Production

by Laigeng Li

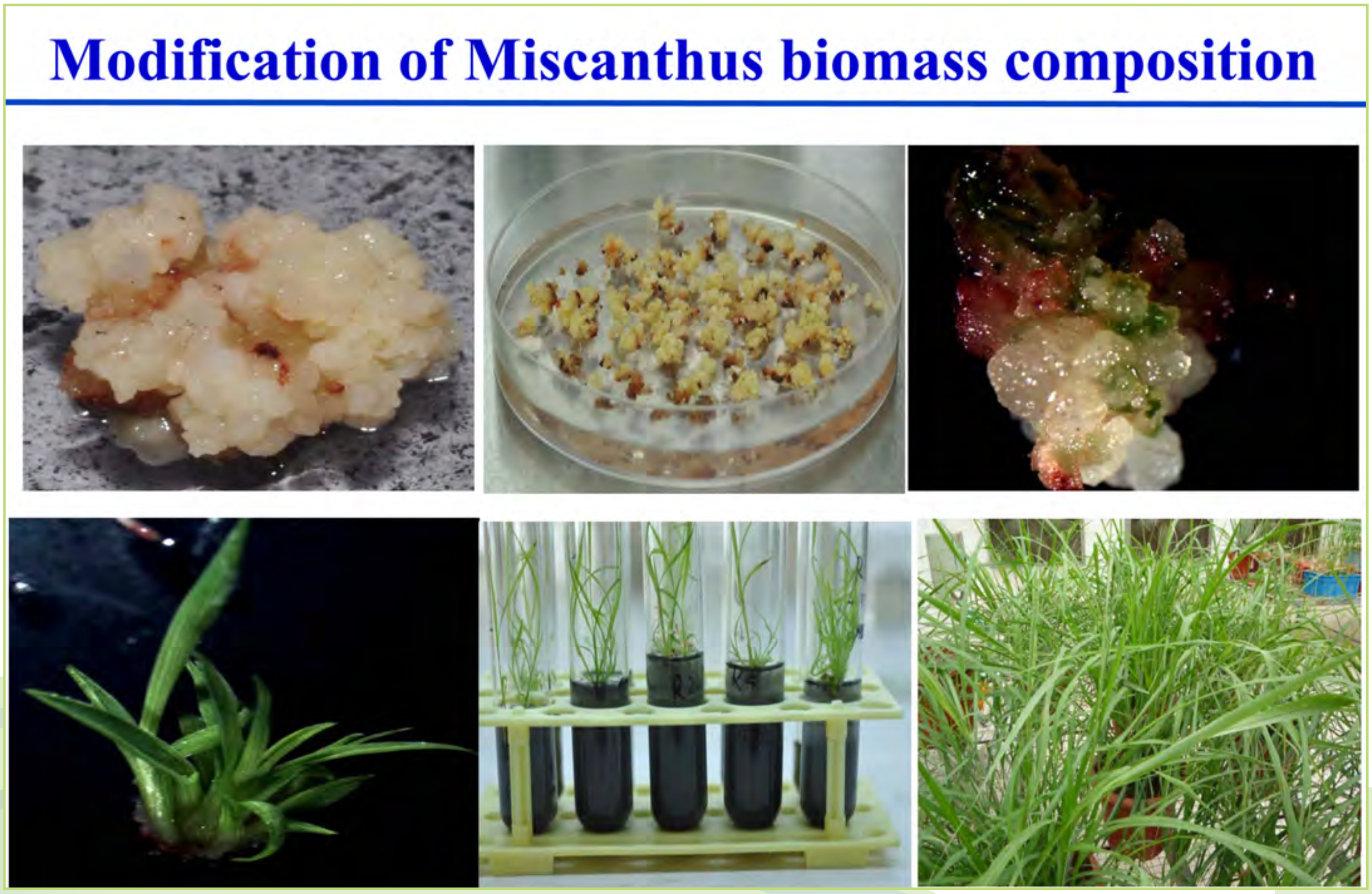
Dr. Li is a Professor at the Institute of Plant Physiology and Ecology, Shanghai Institutes for Biological Sciences, Chinese Academy of Sciences.

When we talk about biomass or lignocellulosic energy, basically we are talking about the material of the primary and secondary cell walls. The primary cell wall is composed of cellulose, hemicellulose, and pectin. The secondary cell wall is composed of cellulose, hemicellulose, and lignin. When we use this material to obtain biofuel, we use the cellulose primarily to produce glucose and finally ethanol.

Lignin is a different component than cellulose, and it has a different effect on the production of sugar or glucose from cell wall material. Different plants, such as herbaceous and woody species, have different lignin content and constituting unit composition. My past research has mainly focused on the modification of lignin biosynthesis in poplar trees.

In trees, we can manipulate the lignin biosynthesis pathway using different genes. The lignins of poplar trees have different ratios of the guaiacyl (G) and syringyl (S) units. In our laboratory we have been able to modify both lignin content and structure by manipulating the 4CL gene and the Cald5H gene. In so doing we reduced lignin content by up to 50 percent, increased the S/G ratio threefold, and augmented cellulose content by 30 percent.

With this modified material, we can improve the efficiency of lignocellulosic biomass conversion, and improve the efficiencies of hydrolysis and fermentation processes to achieve ethanol purification. Compared to the control, the transgenic material reduced enzyme production by 33 percent, boosted hydrolysis efficiency by 30 percent, and increased the concentration of



ethanol by 21 percent. We have also worked on the genetic modification of Miscanthus composition to increase its biomass conversion efficiency.

HIGH-THROUGHPUT ANALYSIS

Various plants have diverse biomass lignocellulosic materials and composition of cellulose content, lignin content, and S/G ratio. The question is how we can quickly evaluate the composition of the material so we can improve it by choosing different genes to manipulate. This calls for high-throughput biomass analysis.

Conventional chemical analysis is traditionally very slow—it takes about a week to get results—and it is also costly. Fast development of bio-energy research and industry requires establishment of a rapid and high-throughput analysis technology for biomass production. To that end, we are using near-infrared (NIR) technology to perform these assessments. This technology is already widely used in a number of areas, such as airport screening and pharmaceutical and agricultural applications.

The critical issue for using NIR for evaluation of biomass material is to establish a calibration model to convert the NIR information to chemical composition information. To that end, we collect samples for calibration, collect the NIR spectrum from the sample, and chemically analyze it. In this way, we can take a sample from an unknown material and run it through the calibration model to get our results.

The calibration process is comprised of several steps. The sample preparation undergoes spectrum collection and chemical analysis. The data analysis is fed into the calibration model for validation. If the sample meets the established criteria, it is subject to a routine analysis. If abnormal samples do not meet the criteria, they are rejected, but the information will go back to the calibration model to adjust the model performance. Thus the model is periodically verified and improved.

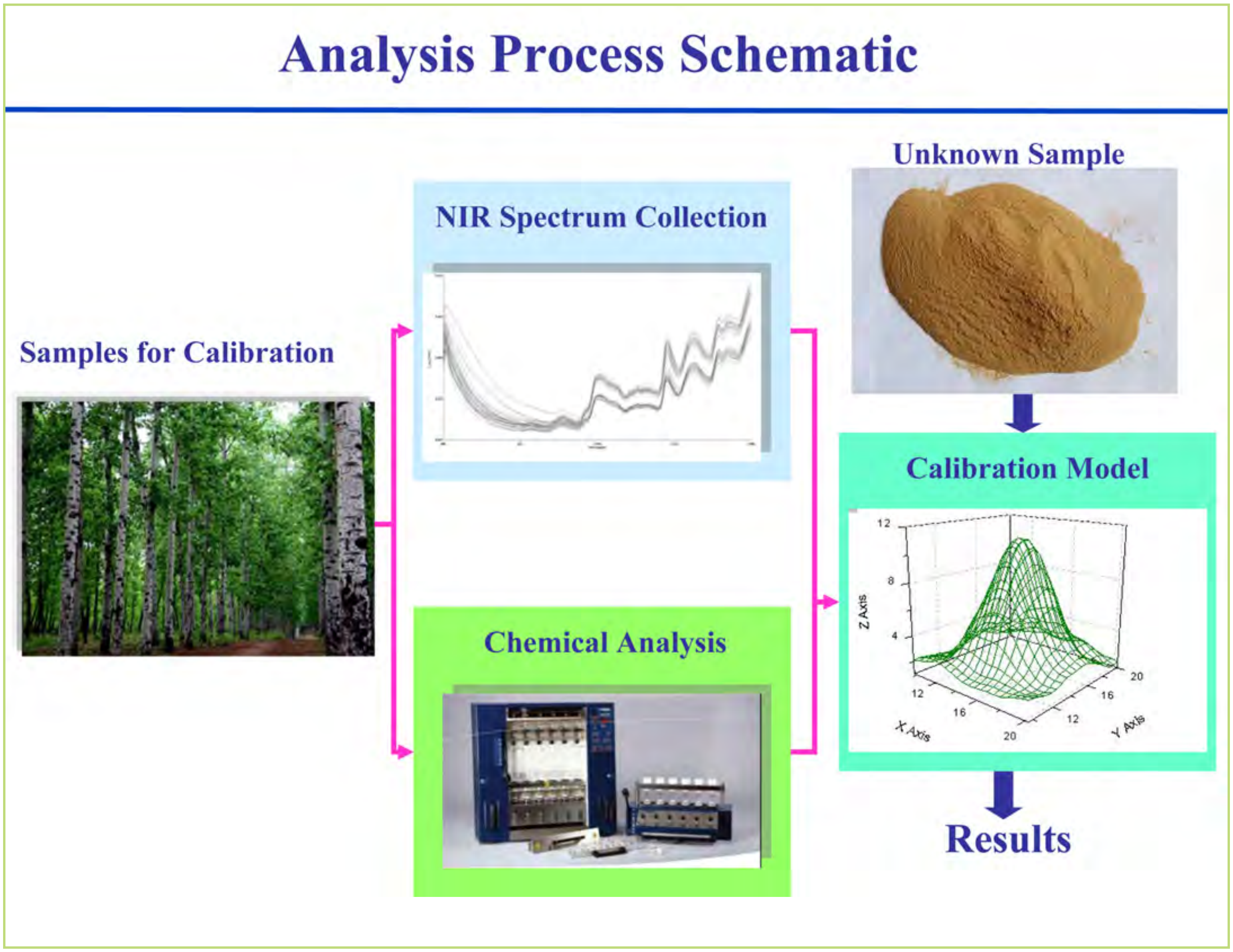
The NIR spectrum analysis is performed with an instrument, the FOSS XDS, that scans a whole range of information on the scale of 400 to 2500 nanometers. The samples were dried and milled to a specific particle size of 30 mesh. In addition, every sample was scanned three times to account for packing density and in random sequence in order to minimize instrumental and operational bias.

Using this technique, a combination of chemical analysis and the NIR information, we analyzed the biomass components of samples of poplar, eucalyptus, and Miscanthus. The analysis of poplar showed the lignin content is negatively correlated to the release of sugar: the higher the lignin content the less efficient the sugar release. With holocellulose, we found a positive correlation: the higher the content the greater the efficiency of sugar release. For the alpha cellulose proportion we found a negative correlation: the higher the ratio the lower the sugar release efficiency. For the lignin S/G ratio, the higher the ratio the higher the sugar release in the cell walls.

We also found that NIR can predict the lignin and holocellulose content of eucalyptus. Our work with Miscanthus is still ongoing, but the data indicate so far that NIR can likewise be used to predict the holocellulose and lignin content of this plant material. We have found so far that the lignin and holocellulose content of Miscanthus is much lower compared to poplar or eucalyptus.

When we assessed the lignocellulosic material, we wanted to predict the content, but also we wanted to see if we could predict the sugar conversion efficiency. We were able to predict with accuracy the digestibility and final amount of sugar released using NIR information.

In sum, we were able to determine by NIR analysis the lignin, holocellulose, and cellulose content of poplar, eucalyptus, and Miscanthus as well as the efficiency of sugar release. We were able to process 30 to 40 samples per hour, much faster than traditional chemical analysis. We found, however, that it is necessary to standardize the sample treatment; we had to dry the samples and mill the sample particles to a uniform size of 30 mesh. We also had to perform model calibrations for each species. Fitting of the NIR information with chemical properties and digestibility by partial least-squares (PLS) regression generated a group of NIR models that we were able to use for rapid biomass measurement. Applying the models for biomass measurements led to a reliable evaluation of the chemical composition and digestibility, suggesting the feasibility of using NIR spectroscopy in the rapid characterization of biomass properties. We eventually want to find the most efficient way to do this type of screening in the field so we can quickly assess the efficiencies of transgenic plants as bioenergy feedstocks.


Analysis Process Schematic
Samples for Calibration
NIR Spectrum Collection
Chemical Analysis
Unknown Sample
Calibration Model
12
8
4
Z Axis
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16
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X Axis
20
16
12
Y Axis
Results

Climate Change Mitigation & Water Conservation

Business-as-Usual Spells Trouble: Long-term Implications for China of Extended Global Warming

by Matt Huber

Dr. Huber *is a Professor in the Earth and Atmospheric Sciences Department at Purdue University and Associate Director of the Purdue Climate Change Research Center.*

Unlike most researchers in the field of climate change, my long-term interests are in the ways that very large releases of greenhouses gases over fairly long time scales affect the climate system. I am less interested in what happens in 10, 20, or even 50 years than what happens beyond 100 years. That is the point where the science really starts getting interesting…when the climate change signal becomes substantially bigger than the noise of natural variability.

Simulations of global temperature in relation to atmospheric carbon dioxide (CO_2) concentrations predict future climate using a variety of relatively simplistic models of climate and carbon cycle interactions. Most climate models track a specific path of emissions from about 1800 to 2300. Many researchers in the climate change field use the year 2100 as a stopping point. But we should also consider what happens after the year 2100.

If we follow the business-as-usual (BAU) type of trajectory, in which we burn through all the easily accessible sources of carbon such as oil and coal, we wind up with CO_2 concentrations in 2300 of around 1,500 parts per million (ppm). CO_2 is a very long-lived molecule in the Earth system, and some substantial fraction of it remains in the atmosphere for tens of thousands of years. If we use a model to simulate out to 6,500 years, CO_2 concentrations first increase and then decrease to about 1,000 ppm. This is just one type of scenario projected if we do what I call a committed burn, continuing to burn fossil fuels for the next couple hundred years as we do now.

There are different models predicting global mean surface temperatures under that kind of scenario, and there is a lot of variability and a wide spread among the models. We usually simplify the figures to find one number that we call climate sensitivity. This sensitivity number for warming is based on global mean temperature change for a doubling of CO_2. The medium sensitivity models for that amount of CO_2 show a spread of temperature change scenarios between 5 and 8° C. Again, we do not know if these figures are correct or whether this amount of warming will happen; there is always a spread on the temperature values depending on the sensitivity of the model.

Under the BAU scenario, global emissions of carbon between 2000 and 2100 will increase from 40 to 80 gigatons per year. If we want to stabilize atmospheric CO_2 at something substantially less than that high value, we might pick among different thresholds. Stabilizing CO_2 below 450 ppm would be required for emissions to peak by 2010, with a six to 10 percent decline per year thereafter. If emissions peak in 2020, we can stabilize below 550 ppm only if we achieve annual declines of one to 2.5 percent per year afterwards. A 10-year delay almost doubles the annual rate of decline required to achieve a peak.

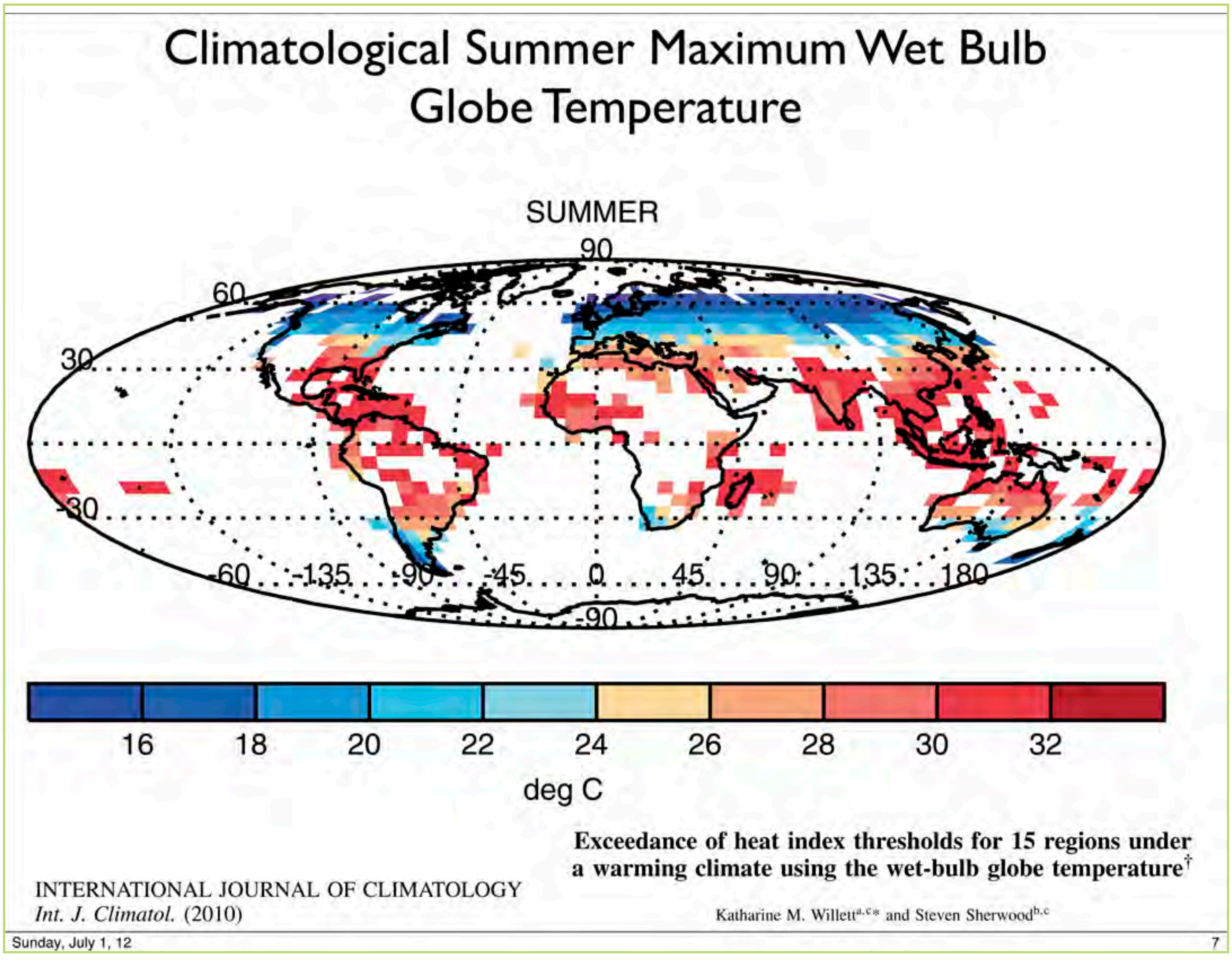
Unfortunately, neither of these scenarios is realistic considering recent trends in global emissions, so the first scenario is unlikely to occur and is basically irrelevant. That ship has sailed. If we are lucky and can follow the second trajectory, we may start decreasing emissions by 2020. In my opinion, we will probably follow a BAU scenario for a significant span of time.

What does this mean in terms of median temperature change? If we stabilize at around 540 to 560 ppm of CO_2, some more sensitive models predict that global mean surface temperature will increase 3° C. Other, relatively insensitive, models would predict a 3° change for 760 parts per million. Yet other models would predict crossing the 3° threshold at 440 ppm. This is just one range of possibilities. If we do not start diminishing emissions until 2050, we end up with CO_2 of at least about 840 ppm, which corresponds to about 5° global warming in equilibrium. That 5° is an important number to keep in mind.

Unfortunately, the range of possibilities goes from frankly ridiculous to just mildly depressing. The Intergovernmental Panel on Climate Change predicts, using a consensus of the models, that the hottest summers on record historically will become normal summers in the future.

THE HUMAN HEAT BALANCE

If summers get hotter, what will this mean for life on Earth? One of my special interests is in the thermal tolerances of humans, animals, and plants, but especially humans. An important concept in thermal tolerance is what we call the wet-bulb globe temperature, which is a multi-parameter measurement. Those parameters are temperature, atmospheric pressure, humidity, and radiation either directly from the sun or reflected in the atmosphere. Wet-bulb globe temperature, an attempt to estimate the amount of heat gain by something or somebody at rest, is a weighted mean of the real, sensible temperature; the amount of radiation the body receives; and the ability to sweat away heat. Katharine P. Willett and Steven Sherwood have plotted the exceedance of heat index thresholds in summertime for 15 regions around the globe under a warming climate scenario using observations of the wet-bulb globe temperature. (*International Journal of Climatology* 2010). This scale runs from a cool 16º C to a hot 32º C. Most places on Earth even during summer don't usually exceed about 30º on that scale. Indiana is in the 26-28º range.



The United States has good statistics on deaths resulting from heat stress. Heat-related deaths are broken down by age group. These statistics show that the elderly, infants, and other sensitive groups are more likely to suffer from to heat stress than the young and healthy. As summer temperatures rise, so will mortality from heat stress.

The heat balance of humans is dependent on heat from the sun, solar radiation, and infrared radiation rising up from the ground or other reflective surfaces. Conduction, air that is moving against you, can also transfer sensible and latent heat. Another factor is clothing. What we often forget is that people also generate internal heat, metabolic heat from burning calories. All these factors affect a person's energy balance.

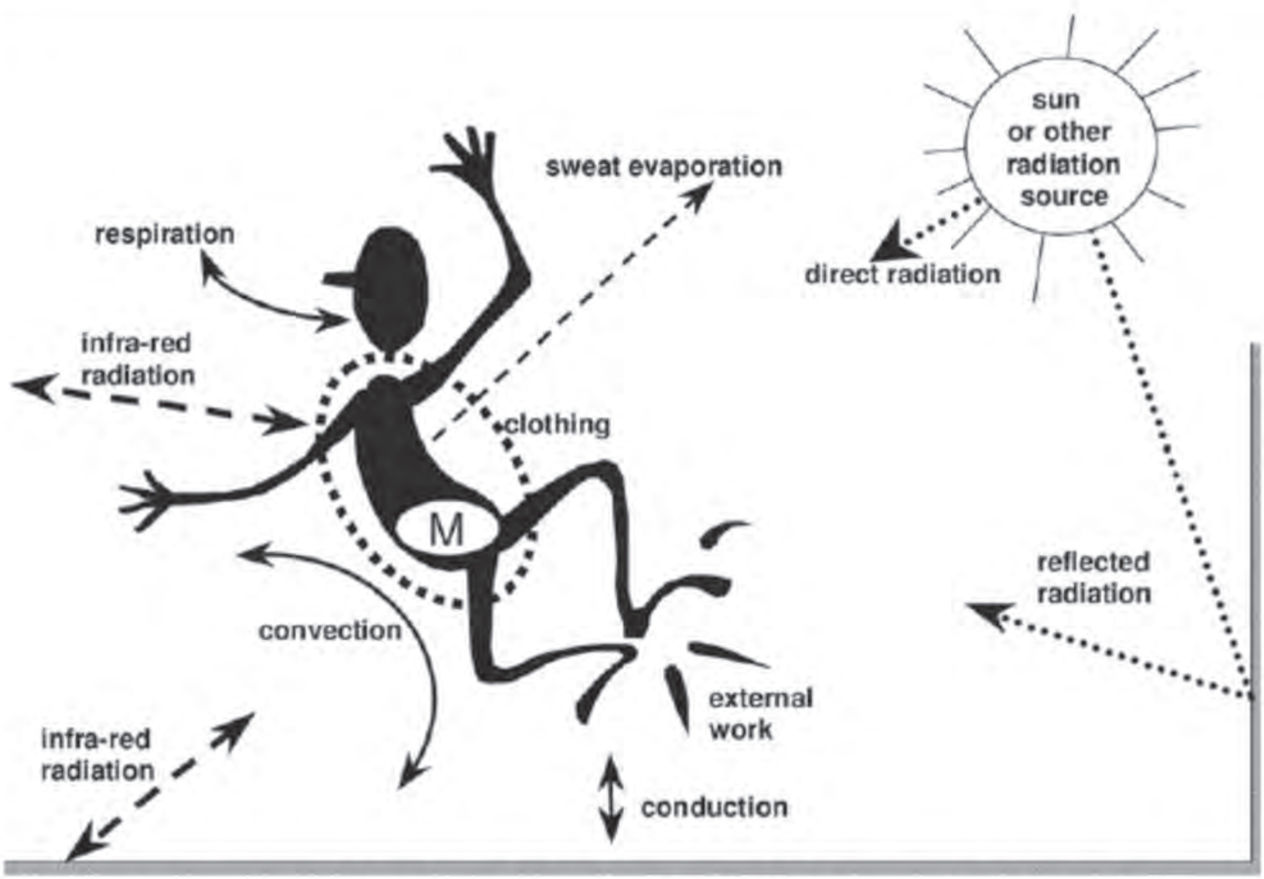
One way to measure the heat balance of humans is with the web-bulb temperature (T_w), a value that is slightly different than wet-bulb globe temperature. T_w includes wet-bulb globe temperature, but it has other dynamics. The average human body at rest generates about 100 watts of metabolic heat, the equivalent of one and a half light bulbs. This heat, in addition to any heat from absorbed solar heating, must be carried away via a combination of heat conduction, evaporative cooling, and net infrared radiative cooling. Conductive cooling is inhibited by high temperature, and evaporation is limited by high relative humidity. Net (latent plus sensible) cooling can occur only if an object is warmer than the environmental wet-bulb temperature (T_w), which is measured by covering a standard thermometer bulb with a wetted cloth and fully ventilating it. The second law of thermodynamics does not allow an object to lose heat to an environment whose T_w exceeds the object's temperature, no matter how wet or well ventilated.

Even on the hottest day of the year, there is no place on Earth where T_w is greater than 32º or 33º C. Even in the Sahara desert, T_w is low because the atmospheric humidity is low, so if you are standing in the shade with a wind blowing on you, evaporation would cool you quite a bit. The places where T_w is a little high are essentially hot humid zones. This has very important implications for China. If you go to a world that is 10˚ C warmer than it is today, which may happen by 2100 or even 2050 in some parts of the world, it would be so hot that if you were outside in the shade drinking infinite amounts of water with a fan blowing on you, you would die of heat stroke in three hours.

This scenario applies to most of Asia in general, where today 50 percent of the world's population lives, and China in particular. With a 10˚ warming, using a variety of models and scenarios, we find that the T_w increases linearly with tropical mean temperature. For a large but feasible warming, regions with more than half the world's current population will experience lethal temperatures. Large parts of China would be completely uninhabitable for human beings if they have to go outside. This, of course, applies to all mammals.

HOT WORK

On a less theoretical note, Chinese researchers have conducted a study on the physiological and psychological effects of heat acclimatization in extremely hot environments. Volunteers were allowed to rest in a preparation room, where their original parameters were measured. The subjects then entered a chamber room, basically a big metal box with heaters, and were left for 15 minutes to adjust to the new, hotter, environment. They were then subjected to a variety of physiological stressors including high humidity and exercise at a prescribed speed. After leaving the chamber, the subjects' physiological parameters were measured and they were asked to answer questions about their



Schematic representation of the pathways for heat loss from the body. M = metabolic heat production (reproduced with permission, Havenith, 1999) thermal sensations and feelings of fatigue. The subjects then were allowed to rest and drink as much water as they wished, and these steps were repeated five times.

This study allowed the researchers to design a new environmental heat stress index for indoor hot and humid environments. The T_w values ranged from 30º C to 40º C at five step increments and were used to measure the safe working time of light and hard work in hot and humid environments. The study showed how many minutes passed before the subjects stopped working or just collapsed. At around a T_w of 38º C, people started dropping out after a just a couple of minutes of light work. For heavy work, on the other hand, people started dropping out around 34º C, and almost no one was capable of working. For heavy labor, once the 32º C T_w threshold was crossed, it was basically very difficult for someone to do much work.

Today, in Southeast and Northeast China, for a couple of weeks in summer, there is already enough heat stress that people should probably not work. There are a few exceedances of wet-bulb global mean temperature in the 35º range, but there are some areas where exceedances cross the 32º threshold. In a world that is warmer by 1˚, 2˚, 3˚, or 5˚ C, conditions will deteriorate. In a very bad, 5˚ warming scenario, the 35˚ threshold will be exceeded 80 percent of the time in summer. This means that about 80 percent of the time in coastal China, even healthy people will not be able to work outside, and many won't be able to work inside.

Our research shows that under a BAU strategy for the next 50 years, large parts of Southeast China may eventually be too hot during the summer for heavy labor. Such a strategy beyond 100 years may eventually lead to uninhabitable conditions over most of coastal China.

If we continue a long, sustained burn of fossil fuels, large parts of the world—including significant portions of China and the United States—may become regions in which unprotected mammals, including humans, would suffer from lethal heat stress. While these projected conditions are far in the future, and entirely avoidable, the long residence time of carbon in the atmosphere suggests that careful consideration of large, long-term risks may provide guidance on decisions in the near-term.

Global Spatial-temporal Patterns of Carbon-use Efficiency

by Yangjian Zhang

Dr. Zhang *is a Research Professor at the Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, and an Adjunct Research Assistant Professor at Rutgers University, New Jersey.*

Worldwide, the United States and Brazil are leaders in the production of biofuels, with China a distant third. A basic requirement for biofuel production is primary productivity of biomass, whether gross or net, which is highest in tropical forests. Gross primary productivity (GPP) is the rate at which plants sequester energy, or carbon, from photosynthesis. Plants sequester carbon in their leaves, trunks, and roots. Net primary production (NPP), which is more relevant to the production of biofuel, basically is a measurement of the amount of carbon we can actually use, since a certain amount of carbon returns to the atmosphere through processes such as decomposition of organic matter. The return of this carbon to the soil or the atmosphere is called heterotrophic respiration. That is, NPP equals GPP minus the amount of carbon that is returned to the atmosphere.

One common parameter in the models of global geochemical cycle studies is that of carbon use efficiency (CUE), the proportion of GPP that is used for NPP, expressed by the equation CUE=NPP/GPP, which indicates the amount of energy that is saved in the plant body. CUE is commonly used in many models because it is intuitive, it is easily comparable among different ecosystem types, it is applicable to total NPP or to the NPP of the different tree organs separately, it is applicable at different temporal scales, and it is readily usable in models.

When this concept was formed, it was very important for biofuels because it determines where carbon is sequestered. Carbon allocation crucially determines the long-term rate of ecosystem respiration and determines the usable biomass. Carbon used for maintenance respiration returns to the atmosphere within a few hours or a few days. Carbon allocated to structural biomass of organs with high turnover and decomposition rate, such as deciduous leaves, returns to the atmosphere after a few months to a few years. Carbon allocated to organs with lower turnover and decomposition rate, such as stem wood, returns to the atmosphere only after decades or centuries. The carbon in organs is the most useful source of biomass.

VALUE OF CUE

Since GPP and NPP are always difficult to measure, what is the value of CUE as a measurement? Researchers first hypothesized that NPP should be proportionate to GPP, and that it should be constant, meaning that autotrophic respiration (Ra) should be proportional to GPP in a constant way. This theory was based on the idea that Ra is regulated by the availability of sugars from photosynthesis and the demand for adenosine triphosphate (ATP) by existing and developing tissues. These two processes should remain in balance when integrated over long periods, which means that Ra should be constrained by or proportional to GPP. But many modeling studies assume a constant CUE. If Ra is proportional to GPP for forest stands that vary in species composition or age, or that are exposed to different climates or soil fertility, then CUE should be constant. Alternatively, if Ra is proportional to biomass then CUE should vary with differences in allocation. Ra ultimately depends on sugars from photosynthesis. This theory, that Ra is proportional to biomass, has been tested on small herbaceous plants and tree saplings. Its applicability on large trees is in doubt.

CHALLENGING THE ASSUMPTION

Based on my research, a global scale analysis using recently generated MODIS NPP and GPP data, I challenge this conventional hypothesis.

When I looked at CUE at a global scale, comparing the southern hemisphere with the northern hemisphere, I found that CUE is not consistent on the temporal scale, and it is not consistent when temperature is factored in.

A researcher in China has observed the effects of temperature based not on model results but on field plot measurements. He found that Ra decreases with increased temperature, but the data were only taken at temperatures lower than 11° C. There are no data between 11º and 29° C. This researcher thinks that Ra should increase in a linear fashion, but based on my findings the trend should not be linear; rather CUE would stabilize and then increase.

Global modeling results also show that when precipitation is less than 2,000 millimeters, CUE decreases. With an increase in precipitation, CUE becomes stable. CUE for ecosystems in extreme environments, like the Tibetan plateau and in the western United States, is fairly high. In a more amenable environment like the tropics, CUE is normally lower.

If we calculate according to ecosystem type, we find that crops such as grass have higher CUE than forests. Even between forest types there are differences in CUE. A paper published in 2007 in the journal *Global Change Biology* and based on field analysis of several different ecosystems reported large differences between types. In some ecosystems like boreal forests, CUE is extremely low, while it is much higher in systems such as temperate deciduous forests. We can infer from this research that there is a difference, but we are not so confident about the variables for some ecosystems. Nevertheless, these results are consistent with our model research findings.

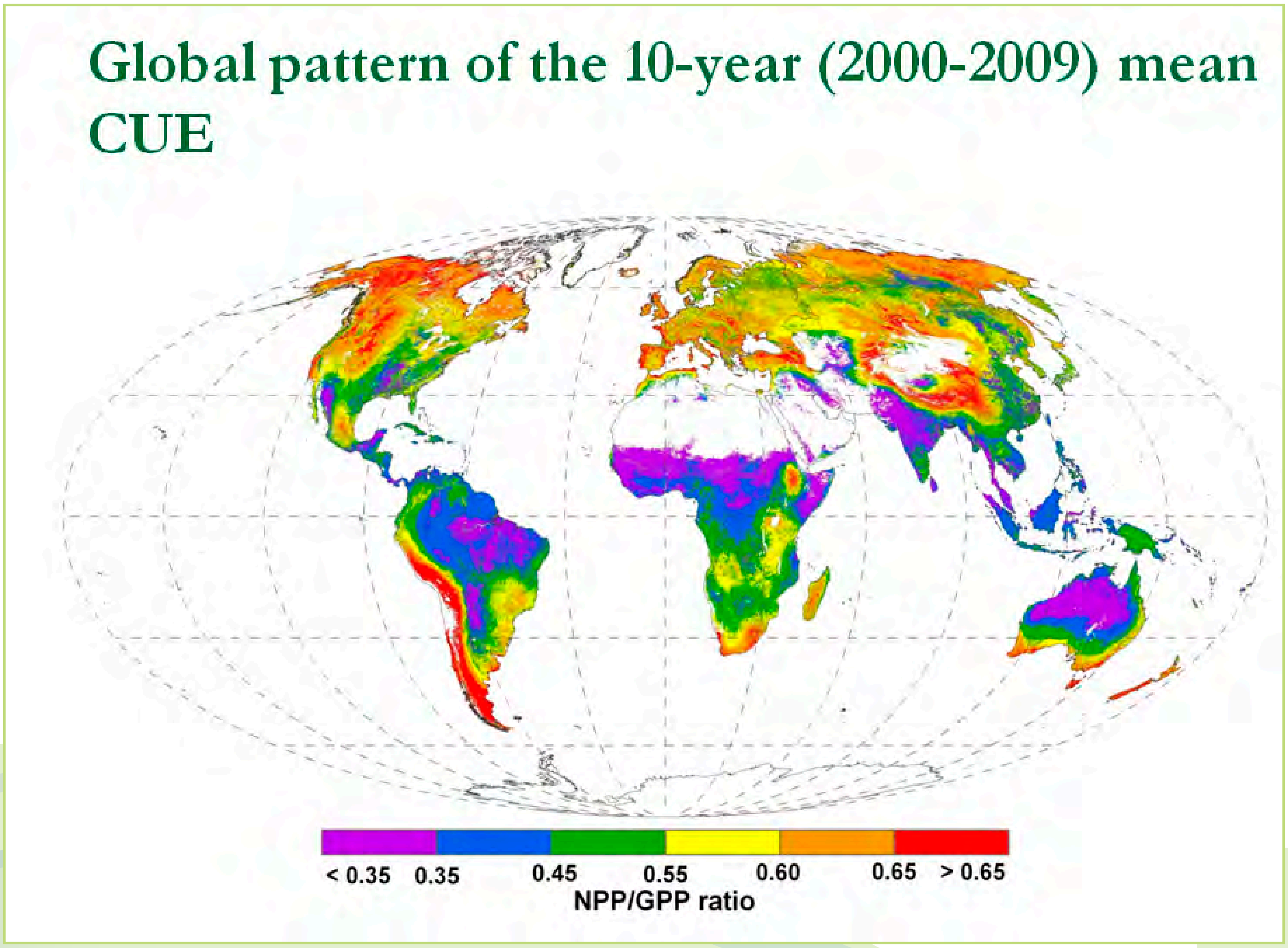
Our modeling of the global spatial patterns of the CUE trend from 2000 to 2009 reveals changes in CUE over time. CUE has increased in the midwestern United States in the past 10 years, while in southern China, CUE has decreased.

In examining the patterns of NPP, CUE, GPP, and the growth rate of CO_2 we find that when the global ecosystem is more productive, the growth rate of CO_2 production will decrease. Global temperature trends over the same 10-year period, 2000 to 2009, indicate a decrease of CUE in the midwestern United States and an increase in the Tibetan plateau. We also find precipitation decreased in southern China, while it increased in the United States. Using a correlation analysis between the NPP and GPP ratio and climate, I found that higher temperature will drive CUE lower and that increased precipitation will drive CUE higher.

I also performed a statistical analysis for each of the ecosystem types, including the different forest types and herbaceous type systems. I primarily found a negative trend in CUE with rising temperatures in most ecosystem types, and a positive trend between precipitation and CUE. This held true in systems such as needle leaved evergreen and needle leaved deciduous forests, but the relationship in other ecosystems was not significant.

I have also mapped the globe into eight zones of equal intervals and analyzed precipitation and temperature trends for the past 10 years. In each of the eight zones, CUE increased as temperature decreased and precipitation increased.

It is clear from these modeling studies that at a temporal dimension, CUE increased in areas where temperature has been decreasing or precipitation has been increasing. These findings challenge the conventional viewpoint that CUE is consistent along the climatic gradient and independent from ecosystem type. In addition, the findings will advance out understanding of ecosystem carbon cycling.



Identification & Quantification of Subsurface Lateral Flow & its Contribution to Nutrient Loading in Streams in an Agricultural Catchment in Subtropical China

by Bin Zhang

Dr. Zhang *is a Professor of Soil Biophysics and Soil Fertility in the Institute of Soil Science, Chinese Academy of Sciences.*

Soil erosion is a global issue with local implications that are understood at the smaller scale. Soil erosion and water pollution are increasingly large issues in China as in other regions of the world. However, subsurface lateral flow from agricultural hillslopes is often overlooked compared with overland flow and tile drain flow, partly due to the difficulties in monitoring and quantifying the flow. The Institute of Soil Science of the Chinese Academy of Sciences is conducting soil hydrology research specifically related to the subsurface lateral flow of water from rainfall and its contributions to environmental issues.

The study site is located in southeastern China near the city of Yingtan in Jiangxi Province. This is a typical agricultural catchment in the subtropical region of China. The study was carried out at different temporal and spatial scales to examine how subsurface lateral flow generates through soil pedons—layers of soil horizon from the surface to the roots of plants—from cropped hillslopes and to quantify its contribution to nitrate loading in the streams.

Generation of subsurface lateral flow was identified from the profiles of soil water potential along hillslopes during simulated rainfalls and its comparison with hydro-chemographs during two heavy rainstorm events. Subsurface lateral flow was estimated by direct measurement for the simulated rainfall on the cropped hillslopes, by modeling using Hydrus-2D software on the cropped hillslopes, a chemical mixing model for the stream flows through the catchment, and the WaSIM model for the whole catchment.

The annual soil moisture regime showed soil water saturation in deeper soils at the lower slope positions and the difference between different land uses. The dynamics of soil water potential during typical rainstorms showed positive soil water potential over an impermeable soil layer at 0.6 to 1.50 meters depth, indicating earlier soil water saturation in the deeper soil than in the surface soil and drainage processes along the hillslopes irrespective of land uses.

Dye tracing experiments before and during simulated rainfall showed the different paths of preferential flow between two land uses, one shallow rooted peanut cropping system and another agroforestry system with peanut crops intercropped with deep rooted citrus. The hydro-chemographs in the streams, one trenched below a cropped hillslope and one at the catchment outlet, showed that the concentrations of particulate nitrogen (N) and phosphorus corresponded well to stream flow during the storm, while the nitrate concentration increased on the recession limbs of the hydrographs after the end of storm.

All the synchronous data revealed that nitrate was delivered from the cropped hillslope through subsurface lateral flow to the streams during and after the end of the rainstorms. Water balance during the simulated rainfall revealed that subsurface lateral flow accounted for 5-38 percent of rainfall in the agroforestry system and for 40-62 percent in the peanut cropping system.

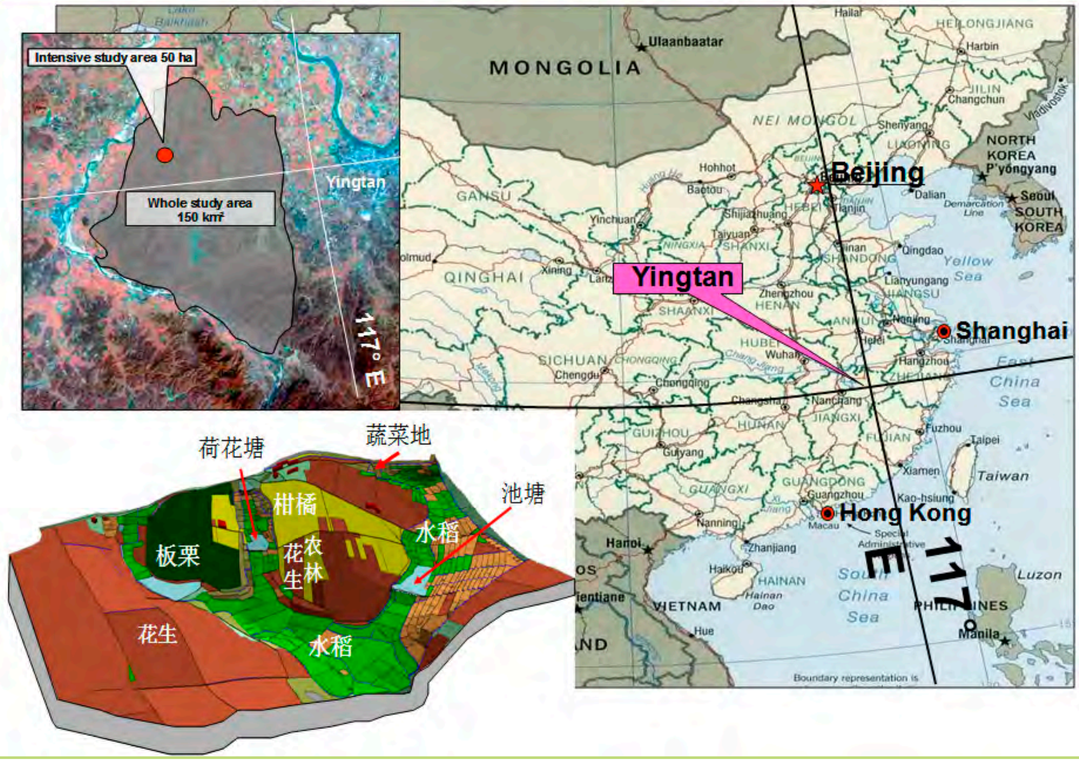
The chemical mixing model based on electricity conductivity (EC) and H+ concentration showed that the subsurface lateral flow accounted for 29-45 percent of total stream flow in the stream trenched below the peanut hillslope and for 5.7-7.3 percent of total stream flow at the catchment outlet during two typical storm events.

The Hydrus-2D modeling estimated that annual subsurface lateral flow accounted for 14-34 percent of annual rainfall in the agroforestry system and for 25-42 percent in the peanut cropping system. The European catchment hydrological modeling WaSIM estimated that subsurface lateral flow from the whole catchment accounted for 35-39 percent of annual rainfall. The Hydrus-2D estimated that nitrate lost with subsurface lateral flow accounted for 15-49 percent of total annual nitrate loss or 10-30 percent of applied N fertilizer in the agroforestry system, and for 40-64 percent of total annual nitrate loss, or 31-40 percent of applied N fertilizer in the peanut cropping system.

The chemical mixing model estimated that the subsurface lateral flow is responsible for 86 percent of total nitrate loss (or 26 percent of total N loss), and for about 69 percent of total nitrate loss (or 28 percent of total N loss) during two storms.

The results suggest that for controlling non-point source surface water pollution from an intensive agricultural catchment, we need to pay more attention to subsurface lateral flow through hydraulically stratified soil pedons. In addition, to control nutrient loss through subsurface lateral flow, deep rooted crops should be introduced to the landscape.

Introduction

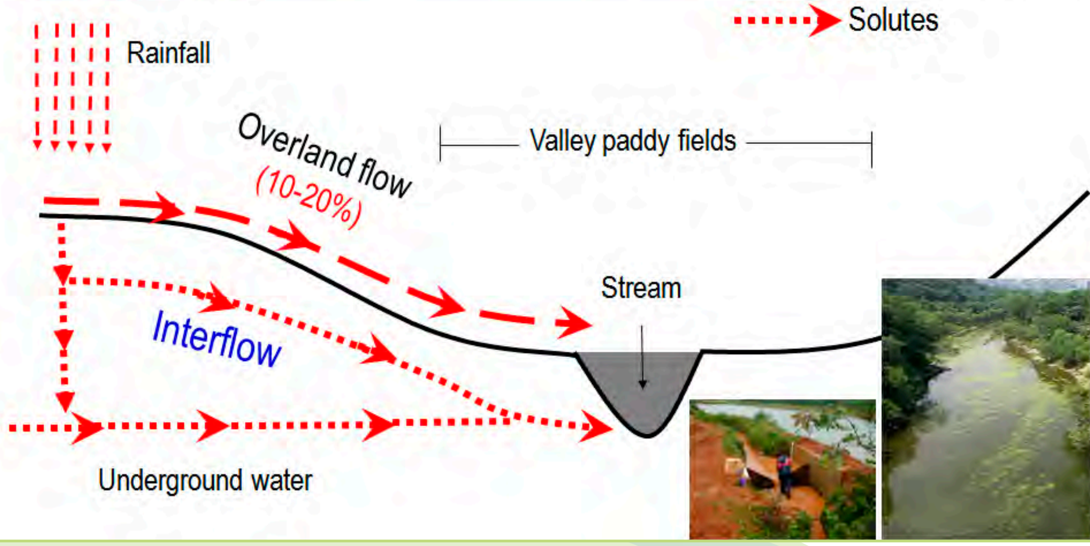


Introduction

Subsurface lateral flow or interflow:

Lateral flow over impermeable soil layer

Generation and contribution to stream flow and nutrient loading?



Biomass Conversion
Science & Technology

Biomass to Clean Energy by Thermal Chemical Conversion Processes

by Zhongyang Luo

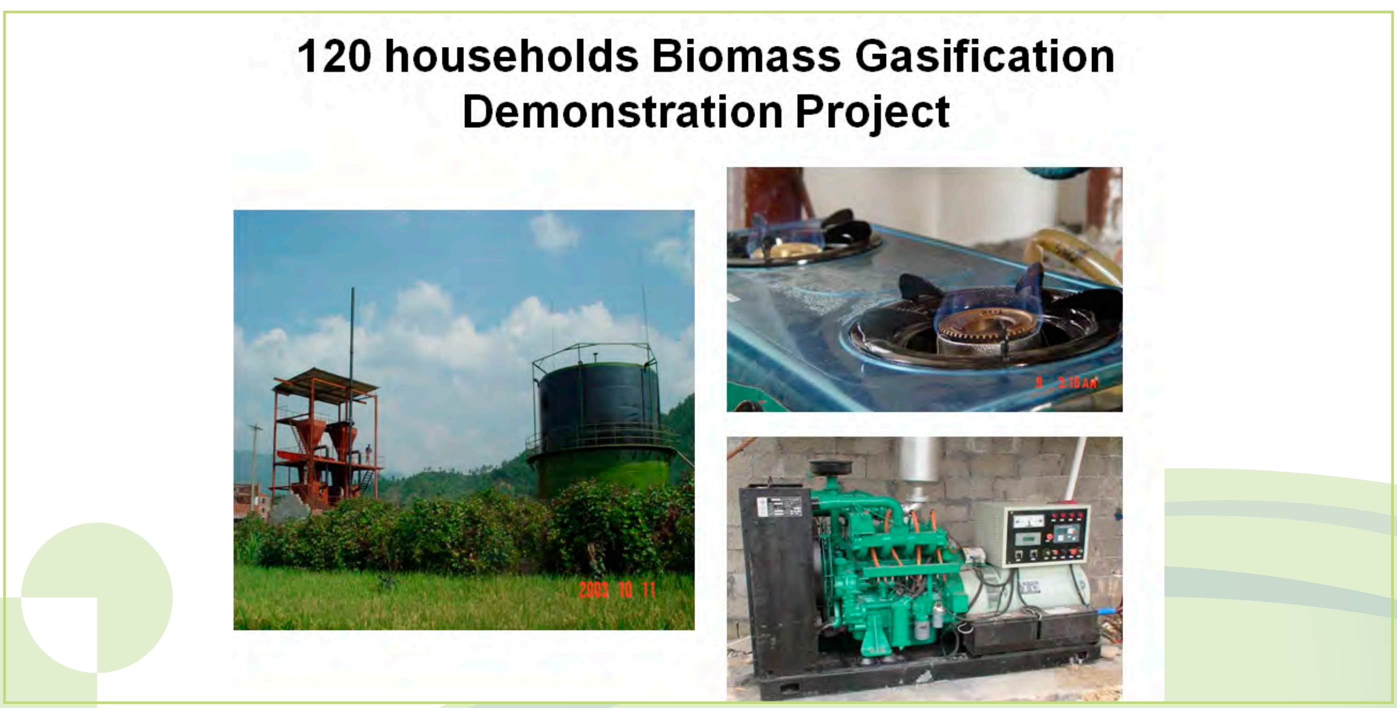
Dr. Luo *is the Director of the State Key Laboratory of Clean Energy Utilization and Dean of the Department of Energy Engineering at Zhejiang University.*

Though biomass energy represents more than 15 percent of China's primary energy structure, the utilization level of commercial biomass is still very low. However, due to the shortage of conventional energy resources and the crisis caused by environmental pollution, biomass utilization, especially high quality conversion of biomass to clean energy, has caused increasing attention from government, universities, institutes, and enterprises in China. In addition, the exploitation of biomass means recycling mobile carbon to reduce emissions of carbon dioxide.

In the last century in China, the most familiar biomass utilization technology is methane production by fermentation. This technology also solves the problem caused by the shortage of electricity and fuel gas in rural areas. Moreover, the char produced from firewood is clean and convenient to use. However, with the popularization of commercial energy in rural areas, traditional biomass energy conversion, such as direct combustion and domestic methane production, is being substituted for commercial energy, for example electricity and LPG. China is now rich in biomass resources, especially the residues from agriculture and forestry

In order to realize a high quality conversion of biomass to clean commercial energy, several advanced technologies have been developed, such as direct combustion, biomass gasification of syngas, and pyrolysis for liquid fuel. We have developed circulating fluidized bed technology for biomass direct combustion plants in China, and also set up fixed bed gasification and elutriated bed gasification for domestic use or synthesis. In addition, we have developed a process using fluidized bed pyrolysis followed by a bio-oil upgrading process to produce high-quality liquid fuel.

The development of direct combustion of biomass power has a large social and environmental benefit with the technical feasibility to solve energy and environmental problems at this stage. For the long term, the technical development of converting lignocellulosic biomass to liquid transportation fuel will be an important route to abate the oil shortage and environmental degradation.



Kinetic Model of Klebsiella pneumoniae 1,3-propanediol Oxidoreductase

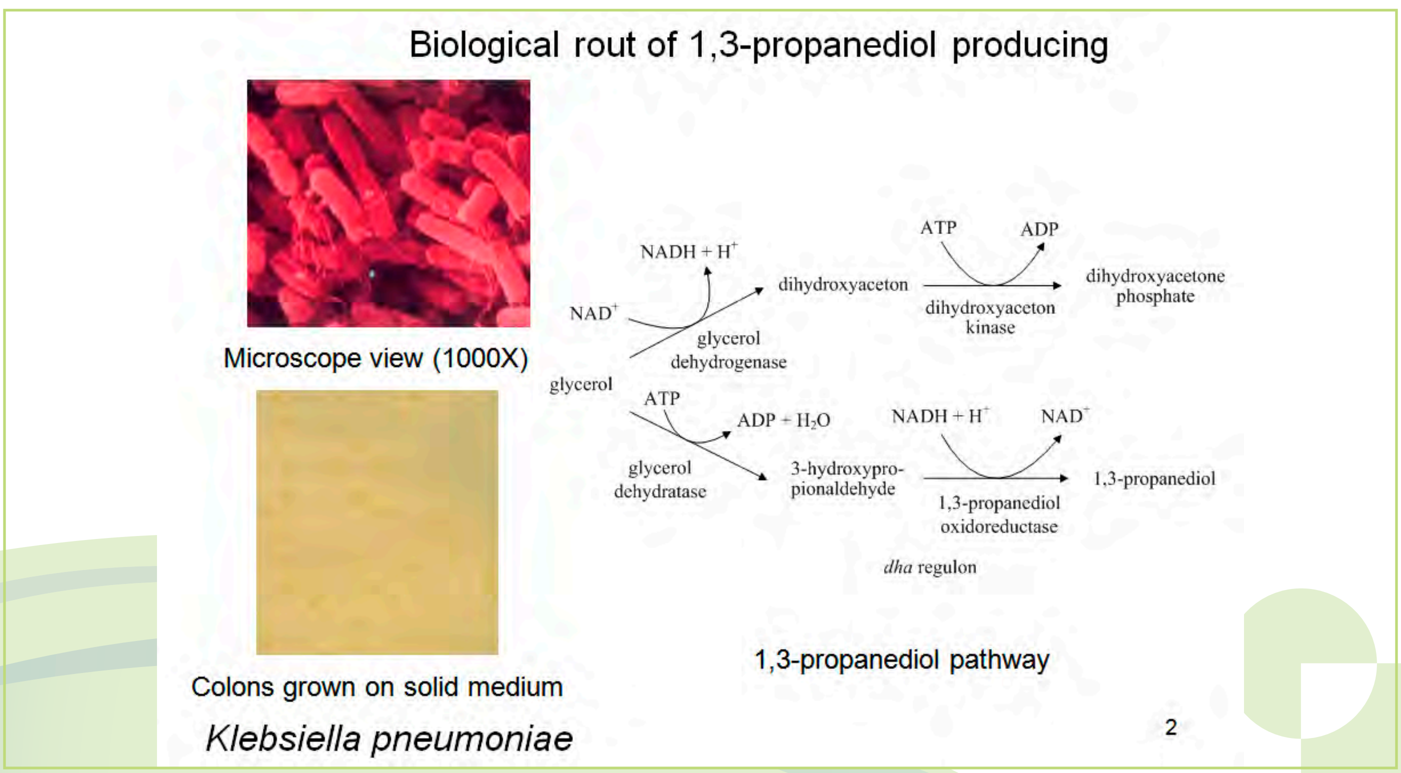
by Jian Hao

Dr. Hao *is an Associate Professor in the Laboratory of Biorefinery Engineering, Shanghai Advanced Research Institute, Chinese Academic of Sciences.*

Glycerol can be biologically converted to 1,3-propanediol, a key raw material required for the synthesis of polytrimethylene terephthalate and other polyester fibers. In the 1,3-propanediol synthesis pathway, the reaction of 3-hydroxypropionaldehyde converted to 1,3-propanediol was catalyzed by 1,3-propanediol oxidoreductase. This reaction was a reversible reaction with double substrates and double products. The kinetic model of this reaction was constructed following the BiBi PingPang mode. 1,3-propanediol oxidoreductase was purified from the lysate of a constructed *E. coli*, which contain a dhaT over-expressing plasmid. The dhaT gene was cloned from *Klebsiella pneumoniae*, a 1,3-propanediol producing microorganism.

Nine parameters in the model were identified via linear plotting and nonlinear regression step-by-step. First, the model was simplified to an un-reversible reaction model, and six parameters were identified by linear plotting using the data of initial reaction ratio. Second, the preliminary value of $Km_{(NADH)}$, $Km_{(HPA)}$, Kf, $Km_{(PDO)}$, $Km_{(NAD)}$, and Kr obtained in the first step were fixed in the model, and then the unknown parameters were reduced to three. Using the data of reaction progress via nonlinear regression, the preliminary value of the last three parameters Keq, $Ki_{(NADH)}$ and $Ki_{(PDO)}$ were obtained. In the last step, all the preliminary values of the nine parameters were used as guesses for the final parameters' estimation, using the data of reaction progress via nonlinear regression. The final value of $Km_{(NADH)}$, $Km_{(HPA)}$, Kf, $Km_{(PDO)}$, $Km_{(NAD)}$, Kr, Keq, $Ki_{(NADH)}$, and $Ki_{(PDO)}$ obtained were 8.47 umol/L, 904.31 umol/L, 358565.18 umol/(L.min), 487.12 umol/L, 461.69 umol/L, 769.67 umol/(L.min), 1261.10, 2107975.42 umol/L, and 7810.24 umol/L, respectively.

Source: Abstract. China-US Program Book. China-US 2011 Joint Symposium



Hydrogen Production from Biomass with Chemical Looping Gasification Technology

by Qinhui Wang

Dr. Wang *is a Professor at the State Key Laboratory of Clean Energy Utilization at Zhejiang University in China.*

Biomass is one of the most important energy resources available. It is renewable and abundant, produces low emissions of greenhouse gases, and can be carbon neutral if the capture process is balanced with production of carbon dioxide (CO_2). For now, however, it has a low utilization efficiency. In the future, high efficiency systems will be a developing trend, and one option will be using biomass for hydrogen production.

Hydrogen (H_2) has been widely considered as the ideal energy carrier in the future due to its advantages of high utilization efficiency and zero emissions of pollutants including the greenhouse gas CO_2. Biomass is clean, renewable, abundant, and carbon neutral, thus it is a suitable source for the production of "zero carbon" hydrogen. Biomass gasification has the potential to produce hydrogen at a large scale compared to other processes such as biological conversion methods, the potential for uses in fuel cells and hydrogen turbines, and uses as a transportation fuel in fuel cell cars or hydrogen engines.

The advantages of using hydrogen include the possibility of constructing a power generation system with high efficiency, higher than 60 percent for coal or biomass, while it is 45 percent for an ultra supercritical power plant. Moreover, China is second in the world in the supply of biomass in China, 8 million tons per year. In the future, hydrogen production with CO_2 capture will be an important option for the use of biomass.

CHEMICAL LOOPING GASIFICATION

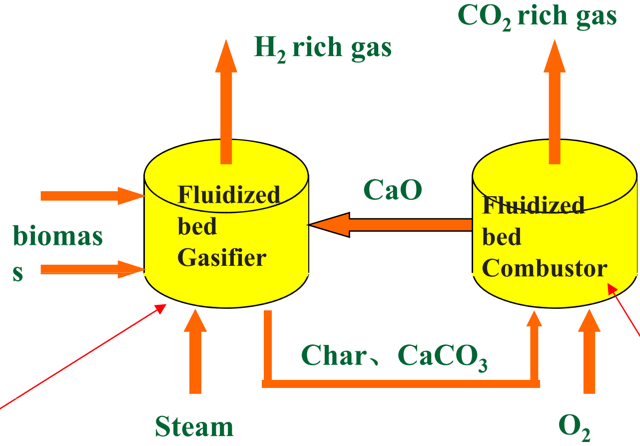
The chemical looping gasification process with biomass and calcium oxide (CaO) is relatively simple. There are two main reaction chambers, a fluidized bed gasifier (FBG) and a fluidized bed combuster (FBC). Biomass is gasified partly with steam in the FBG. As CaO is used as the CO_2 acceptor to absorb CO_2 and release the heat for the gasification processes in the gasifier, CO is depleted from the gas phase by the water-gas shift reaction. Methane (CH_4) produced during the coal pyrolysis and the gasification process is converted to CO and H_2 by reforming reaction. The high hydrogen content gas may be obtained from FBG. CaCO3 produced in the gasifier and unconverted char are transported to the FBC. The unconverted char and opportunity fuel are burned in the combustor and supply the heat required by the CaCO3 calcination reaction. The produced CaO is transported back to the gasifier for recycle use. The CO_2-rich gas may be obtained from the combustor for disposal if pure oxygen is used.

This process represents several advances in gasification technology. First, it reduces the requirements for gasification as only the part of the biomass with high activity is gasified, and the char with lower activity is burned in the FBC combustor. In addition, the process accomplishes anaerobic hydrogen production with CO_2 acceptor gasification and a high concentration of CO_2 for disposal in the combustor. Moreover, the process produces near zero emissions; the very small quantity of ammonia generated during gasification may be easily removed, and the sulfuric acid is captured by CaO in the gasifier and transformed into calcium sulfate in the combustor. Other polluting gases may be disposed of in the CO_2 gas stream. In 2006, this technology received an invention patent from China: Hydrogen from solid fuel with near zero emission by anaerobic gasification.

Biomass chemical looping gasification technology is a prospective system shown by the primary research works at Zhejiang University as follows,

- systems analysis and calculation,
- experiments on a high pressure thermogravimetric analyzer (TGA) using typical biomass such as rice straw, wood, and wheat straw, and
- construction and experiments on pressure facilities, including the effects of [CaO]/[C], [H_2O]/[C], pressure, and temperature on the biomass chemical looping gasification process.

Chemical Looping Gasification Processes with CaO



$$CaO + C + H_2O(L) \longrightarrow CaCO_3 + 2H_2 + 0.6kJ/molC$$

- **Main reactions in gasifier:**

$C+H_2O=CO+H_2$-131.6kJ/mol

CH_4+H2O=$CO+3H_2$-206.3kJ/mol(reforming reaction)

$CO+H_2O=CO_2+H_2$+41.5kJ/mol (water-gas shift)

$CaO+CO_2=CaCO_3$+178.1kJ/mol (carbonation reaction)

$H_2S+CaO=CaS+H_2O$

Main reactions in CFB combustor:

$CaCO_3=CaO+CO_2$-178.1kJ/mol

$C+O_2=CO_2$+393.791kJ/mol

$H_2+1/2O_2=H_2O$+286kj/mol

Chinese patent: ZL20031108667.5, Authorized in Jan. 2006

Optimization of Acetone-butanol Fermentation Using Non-grain Feedstock

by Jiping Shi

Dr. Shi *is Deputy Director of the Sustainable Technology Research Center of the Shanghai Advanced Research Institute, Chinese Academy of Sciences.*

Shanghai Advanced Research Institute is a new institute located in the Zhangjiang Hi-Tech Park in Pudong. The institute has five major research areas: frontier studies and advanced material, information science and technology, space and marine, energy and environment, and life science and technology.

The mission of the center is to provide sustainable energy conservation and emission reduction technologies for climate change, ecological environment, and resource efficiency. We want to improve our ability to cope with global environmental change and enhance the understanding of emission reduction of greenhouse gasses. The ultimate goal of our work is to improve the quality of people's lives.

BIOPRODUCTION OF BUTANOL

Butanol is a chemical with many applications. It is used as solvent in the food industry and has potential for use as an additive for biofuels. Compared to ethanol, it has a higher energy content and a higher boiling point and thus lower volatility, so it is very safe when used as a biofuel. It also less hydrophilic, so it can be mixed with gasoline in a higher percentage than ethanol, and it has a higher octane number. These attributes give butanol many advantages as a biofuel. The disadvantage is the very high price, so for now butanol is not a good candidate as a biofuel.

There are two methods for producing butanol, petrochemical synthesis and a biological process that uses a microorganism to ferment starches from food grains. The organism is *Clostridium acetobutylicum*. The clostridial solvent produced contains not only butanol but also acetone and ethanol, so this kind of fermentation is called Acetone-Butanol-Ethanol (ABE fermentation).

Feedstock price dominates the total production cost of butanol, with 75 percent of cost from corn and the other 25 percent from the steam, water, electricity, environmental protection, and waste mash treatment.

To achieve cost reductions, in our research we have tried to produce butanol using non-grain feedstocks such as B-granule type wheat starch, cassava, corn fiber, sweet potato, and wheat bran.

COST COMPARISONS

Using maize, the common substrate for butanol production, as a control for the experiments, we compared maize with wheat bran and corn fiber substrates in fermentation and found the wheat bran and corn fiber yielded comparable total solvents. Using potato and sweet potato as a feedstock, we found maize generally yielded slightly higher concentrations of acetone, ethanol, and butanol except that ethanol yield was just slightly higher for sweet potato. Cassava, a typical substrate that grows in southern China and other southern Asian countries, also has a significantly lower yield of acetone, ethanol, and butanol compared to maize.

The last feedstock we tried was wheat B-type starch granules. Wheat B-starch is commonly used in animal feeds, but it is not very suitable for use in ethanol fermentation. We found that it did produce significant amounts of butanol, but was still not quite as productive as maize.

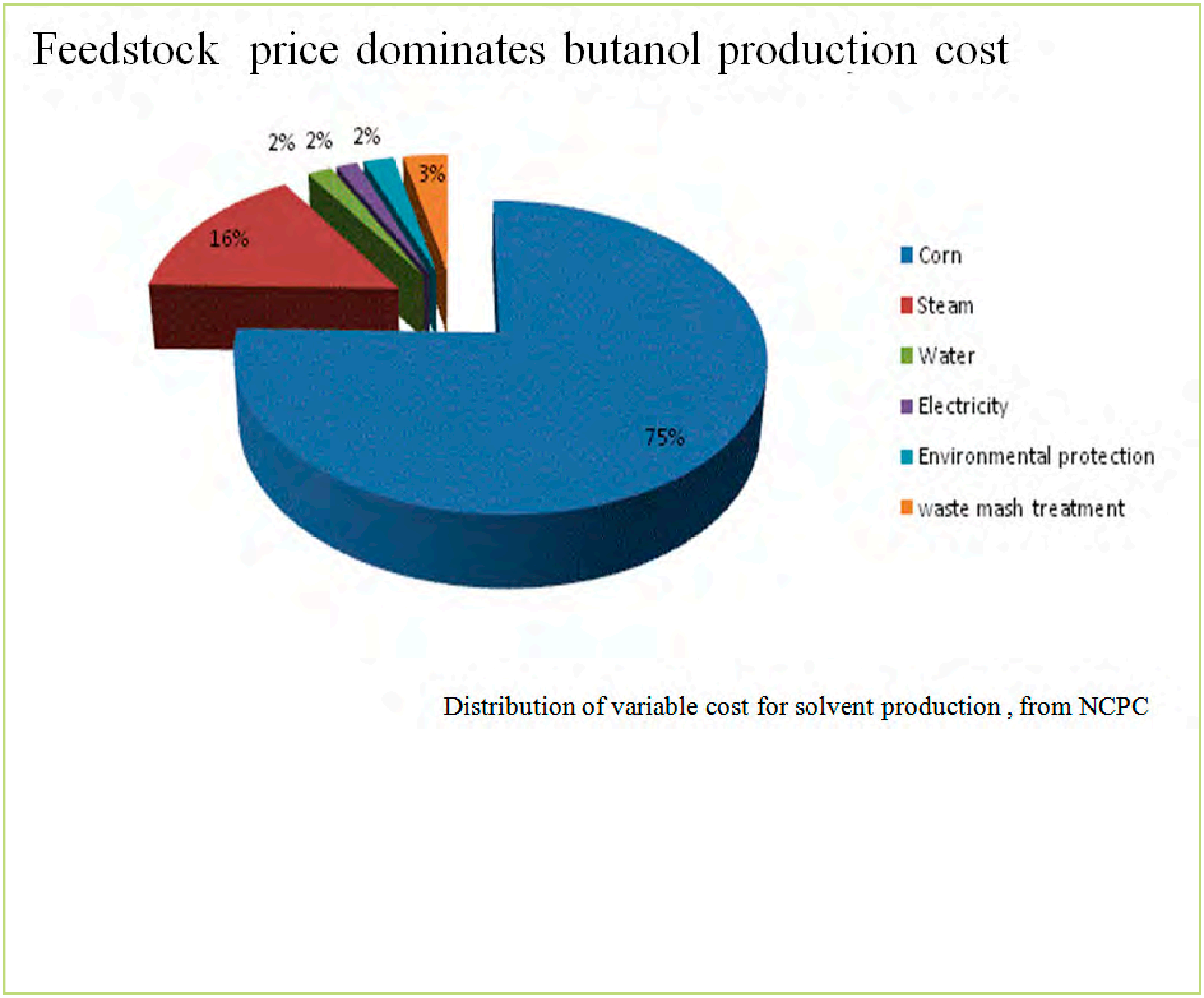
We then combined B-starch with other non-grain feedstocks because we suspected that there may be some nutritional limitations with B-starch alone. When we added wheat bran and corn fiber to the B-starch, production of all three solvents increased to levels comparable to maize. Adding ammonia water to B-starch also increased total solvents to levels comparable to maize.

We also tested cassava with additions of nitrogen sources: ammonium sulfate, urea, soy bean meal, and wheat bran. These additions also brought total solvent levels close to those of maize. Additions of ammonium sulfate to potatoes and sweet potatoes also boosted total solvents to levels similar to maize compared to potatoes and sweet potatoes without ammonium sulfate.

SCALING UP

After completing these experiments in our laboratory, we scaled the trials up in a commercial factory using a 50-ton fermentor for maize, wheat B-starch, cassava, sweet potato, wheat bran, and corn fiber substrates. The medium was optimized not solely using B-starch but also with the addition of other nitrogen resources so that the total solvents reached the level of maize. We then made economic calculations of relative costs. Since the price of butanol used as a fuel is very high, the cost of substrates calculated in this study is lower than for maize.

Previous studies have shown that there is not enough nitrogen present in wheat B-starch as a substrate to increase the production of solvents comparable to maize, and that organic or inorganic nitrogen should be added to the medium. Extra nitrogen resources supplemented from ammonium salts increased the total solvent yield. After optimization of the fermentation process, the final yield of butanol using non-food starches reaches the level of 13-14 grams per liter, close to the level achieved using maize starch. Our experimental results in the laboratory have been assessed in a pilot plant using a 50-ton fermentor showing that scaled-up production of butanol from ABE fermentation is possible. We found that the production cost of butanol made from non-food grain starch is lower than using maize starch; therefore, bio-production of butanol from non-food starch sources is comparatively economically feasible and sustainable.



Development of a Novel Bioelectrochemical Membrane Reactor for Energy Generation

by Guoping Sheng

Dr. Sheng *is an Associate Professor in the Department of Chemistry, University of Science and Technology of China.*

At this symposium, many people have reported research results on the ways in which biomass can be converted to hydrogen, biofuels, and the like, but we often overlook an abundant energy resource, wastewater, when in fact there is plenty of organic matter in wastewater. We simply need to find ways to extract energy from this ubiquitous resource. The objective of our study is to find a way to harvest energy from wastewater.

There are currently two processes used for harvesting energy from wastewater. One process widely used around the world is anaerobic treatment for methane or hydrogen production. This method, however, is only for high strength wastewater, and it has disadvantages such as the low quality of the effluent, which means that post treatment such as aerobic treatment is always needed. Another treatment is the microbial fuel cell for electricity production. It can be used for high-strength or low-strength wastewater and is cost effective, but it is still in development.

THE MICROBIAL FUEL CELL

A microbial fuel cell (MFC) is a device that uses bacteria to oxidize organic matter and produce electricity. An MFC consists of two chambers, the anode and the cathode chamber, which are separated by a membrane. The bacteria grow on the anode, oxidizing organic matter and releasing electrons to the anode and protons to the solution. The cathode is sparged with air to provide dissolved oxygen for the reactions of electrons, protons, and oxygen at the cathode, with a wire (and load) completing the circuit and producing power. There are many configurations of MFCs, but even after 20 years of development, many problems remain, such as high construction costs and bad effluent quality.

In order to guarantee effluent quality, an MFC system used for wastewater treatment and energy generation should be integrated with a conventional wastewater treatment bioreactor in a combined treatment system. There are several types of combined wastewater treatment processes: a) an MFC combined with a downstream solids contact tank, sludge recycle line, and clarifier; b) an MFC combined with a membrane bioreactor (MBR) as a post-treatment process; and c) an MFC submerged into the aerobic tank of an existing activated sludge process. However, if you simply connect two individual reactors in sequence, the operation efficiencies are not as good as expected.

THE BIO-ELECTRIC MEMBRANE REACTOR

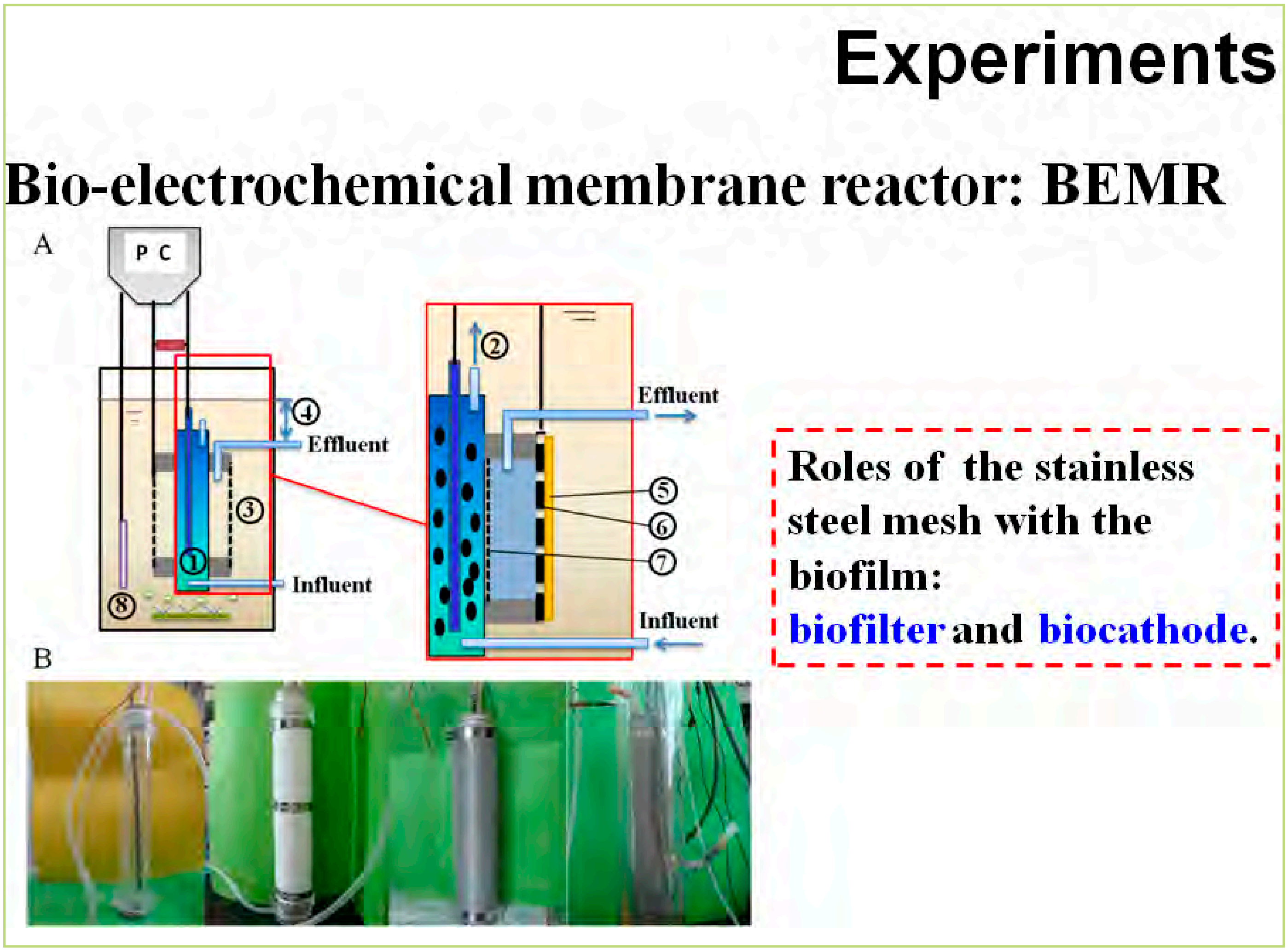
In our study, we have demonstrated a novel bioreactor that provides effective integration of the MBR and the MFC. The bio-electrochemical membrane reactor (BEMR) has advantages of both the MBR and the MFC for wastewater treatment and energy recovery: good biomass retention, high quality effluent, low operational cost, and good electricity generation. The distinguishing feature of the BEMR is that it uses a stainless steel mesh with the biofilm formed on it, which serves as both cathode and filtration material. The effluent flows to the anode chamber and then discharges into the larger chamber, the cathode chamber. The bacteria cling to the biofilm attached to the steel mesh, reducing the bacteria so the water passes through the steel mesh, and clean water is discharged from the system. Electricity generation performance was closely associated with the formation and detachment of biofilm, which drive the catalysis of oxygen reduction.

We have evaluated the performance of a BEMR system for a synthetic wastewater treatment and energy recovery system. We found the average concentration of chemical oxygen demand (COD) removal efficiency to be 92.4 percent over a 140 day period, and average ammonium removal efficiency 95.6 percent. These represent very high removal efficiencies.

In evaluating system performance during different experimental periods, we found that an increase in hydraulic retention time and a decrease in loading rate and external resistor could enhance system performance. Performance was best at very long hydraulic retention time; under those conditions, the power density of the system was about 4.35 watts per cubic meter.

The main feature of the reactor is the biofilm attached on the steel mesh, which can serve as a biofilter or a biocathode. To explain the connection between biofilm formation and electrochemical activity, we used the trans-membrane pressure (TMP) as an indicator for biofilm growth. As TMP increased, the biofilm grew thicker, and when TMP was sharply increased, the biofilm would grow too thick. At first, with increasing pressure, more electricity is produced, but when the biofilm grows too thick, the electricity is reduced and the biofilm should be cleaned, something of a double edged sword.

In conclusion, our study shows that a) the BMER system integrates the advantages of both MBR for nutrient removal and MFC for energy recovery; b) the stainless steel mesh with the biofilm formed on it plays the roles of filter and biocathode; and c) with an increase in hydraulic retention time and a decrease in the loading rate, system performance was enhanced. These results indicate that the system holds great promise for efficient and cost-effective treatment of wastewater and energy recovery.



The ABC, Ag, Biology, and Chemistry of Biomass Conversion

by Mahdi Abu-Omar

Dr. Abu-Omar *is a Professor in the Department of Chemistry and a University Faculty Scholar at Purdue University.*

The first commandment in biomass conversion is "Thou shall conserve every carbon atom."

Two of the grand challenges for this century are the utilization of renewable resources and environmental remediation. In the United States alone, approximately 1.4 billion tons of lignocellulosic biomass represents an annually renewable source of energy and feedstock.

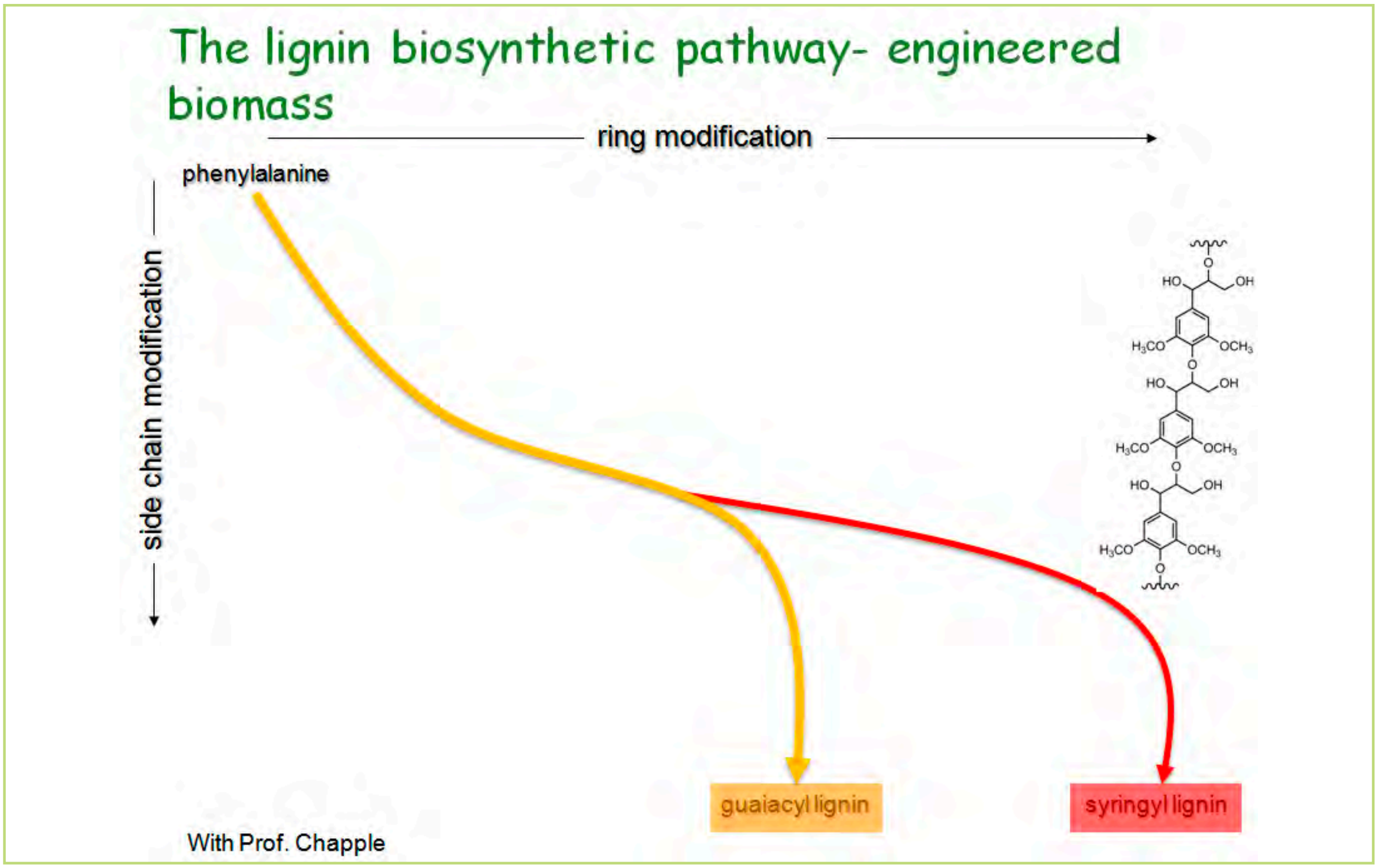
The vision of the Center for Direct Catalytic Conversion of Biomass to Biofuels (C3Bio) at Purdue University is to develop new technologies that maximize the energy and carbon efficiencies of biofuel production by the rational and synergistic design of both physical and chemical conversion processes and the biomass itself. One goal of C3Bio is to apply and optimize catalytic transformations to a range of biomass components and genetic variants.

The biological conversion of biomass to biofuel is a multi-step process. Biomass is harvested and delivered to the bio-refinery. The biomass is then cut into shreds and pretreated with heat and chemicals to make cellulose accessible to enzymes. The enzymes break cellulose chains down into sugars. Microbes ferment the sugars into ethanol. The ethanol is then purified through distillation and prepared for distribution.

Cellulose and hemicellulose undergo hydrolysis, producing glucose and xylose. When these sugars subsequently are subjected to dehydration, two types of the chemical feedstock furfural are produced, but there are also unusable tars produced as well due to degradation of the material. In my research I have focused on using a selective hydrolysis and conversion process to produce furfural without the production of tars. This process allows biomass to be fractionated into lignin, cellulose, and hemicellulose. The latter can be hydrolyzed to xylose and subsequently dehydrated efficiently.

We are also investigating the use of maleic acid as a catalyst in biomass conversion to improve the concentration of furfural in the final product. In addition, many years of fundamental research on lignin structure and its biological synthesis has resulted in a better understanding of the lignin biosynthetic pathway allowing access to engineered biomass. We have access to tailored biomass that is rich in a specific kind of lignin. These developments present an excellent opportunity for selective chemical conversion strategies.

Transition metal catalysts have been an integral part of the success story of the petrochemical industry in the past century. In my laboratory, we are exploring catalytic processes based on cheap and abundant materials that can be employed in tandem to unravel polymeric biomass into soluble components and their subsequent transformation into fuels and/or high value organics.


The lignin biosynthetic pathway- engineered biomass
ring modification
side chain modification
phenylalanine
guaiacyl lignin
syringyl lignin
With Prof. Chapple

Agro-ecological Knowledge Needs for Deploying Bioenergy Cropping Systems

Comparative Agro-ecological Performance of Perennial and Annual Biomass Systems: Metrics and Data Workflows

by Sylvie Brouder

Dr. Brouder *is a Professor in the Department of Agronomy and the Director of the Water Quality Field Station at Pudue University.*

As the US bioenergy agenda continues to evolve, several important challenges remain for the objective of sustainable bioenergy crop production. Among the greatest challenges to understanding the energy yielding potential of nonfood biofuels crops is a dearth of field data. In order to project yields and judiciously allocate agricultural land among competing food, feed, and fuel objectives, we must use models that can accurately predict production potential across varied landscapes.

Development, calibration, and verification of reliable models require high quality data from experiments in management manipulation and/or on-farm monitoring. Indeed, new and high quality data are an essential prerequisite if we are to apply models to understand yields of novel or emerging crops as well as existing crops that may be repurposed from their current use to a bioenergy objective.

The imperative for developing new databases for *novel* bioenergy crops is, perhaps, obvious but it is equally critical for crop species that have been grown in the United States for some time. This need for new research and data on familiar crops reflects both the change in end use which will likely be associated with important changes in managements, but also a culture among agronomic researchers that does not preserve data for future use.

To date, agronomic research has been conducted by individuals or small groups of researchers addressing locally relevant questions through the development of a site-specific and relatively small database. In addition, data output has been considered dedicated to the original objective and of little intrinsic or enduring value beyond the initial purpose; thus, "used" data were typically discarded at the completion of a discrete project. Historically, this approach has severely hampered the development and application of the agronomic models required to extend the inference base of agronomic findings to other environments and managements. The success of US bioenergy crop initiatives requires a concerted effort to identify, standardize, and share a core set of plant and soil metrics and protocols that are universally useful and informative to agronomists engaged in empirical research and to sustainability modelers alike.

PROJECTING PRODUCTION POTENTIALS: EXISTING AND NOVEL CROPS ON MARGINAL LANDS

Yield potentials as a function of land capability are important when we consider serious efforts to produce enough energy on agricultural lands to justify using land resources for this purpose. Over the past few years, several crops have been identified and advocated for in both scientific literature and the popular press, but knowledge of species-specific yield potential across varied environments remains sparse. Switchgrass is the candidate crop of choice for many of the state and federal agencies promoting energy security through agricultural production.

Switchgrass is a native perennial that has been improved for use as animal forage. Because of this end use, switchgrass research to date has mostly focused on producing a high yield of digestible nutrients and high levels of protein achieved with a higher proportion of low biomass—leaves—and a low proportion of high biomass—stem—tissues, an objective not necessarily in keeping with producing highest possible quantities of liquid fuels per unit land area. Likewise, sweet sorghums have been improved for US agricultural soils but with the objective of optimizing sugar production; although sugar content may be a common goal for both uses, when sorghum is grown for biofuel, lignocellulosic content is a major additional consideration. Thus, while existing literature may provide some insight into agronomic performance, data may not be sufficient or appropriately targeted toward bioenergy yield to parameterize models for simulating energy production with crop models at field to landscape scales.

Certainly, much less is known about novel species. Novel crops anticipated to have high energy yielding potential include Miscanthus, high biomass sorghums, and energy cane; we are only now getting mature stands in field trials, so model simulations are highly uncertain as there continues to be insufficient data to parameterize and calibrate models; full validation of model projections remains many years away.

In the United States, an important aspect of bioenergy crop forecasting is the expectation of high energy production on soils considered marginal for food/feed production; the US Bioenergy Agenda is founded on the assumption that prime lands will continue to be used for food crops, and we will take advantage of poorer lands for bioenergy crops. The United States has a significant area of lands with high erodibility, shallow topsoil, poor water storage capacity, and other physical limitations such as soil structure and texture, and these have been explicitly targeted for bioenergy crop production. Additional key assumptions to present bioenergy forecasts are that candidate, non-food bioenergy crops will have higher nutrient use efficiency and water use efficiency as compared to food/feed crops currently being grown. This is theorized to allow bioenergy crops to produce a positive net energy balance on marginal soils with few inputs. Further, native species on unmanaged lands are assumed to have sufficient energy production to warrant harvesting as they are assumed to require little to no management inputs, especially fertilizer, to detract from the net energy balance. Such assumptions about production potentials on marginal lands are far from trivial, and forecasts of US bioenergy crop production will remain purely theoretical and highly uncertain until we have more data to fully test hypotheses and verify assumptions.

MAKING DATABASES USEFUL: METRICS, STANDARDS, AND ACCESSIBILITY

Regardless of whether the objective is for food, feed, or fuel production, for experimental work on crop sustainability, data and data accessibility from empirical studies are considered foundational by crop modelers. According to a recent survey conducted CGIAR (Consultative Group on International Agriculture Research) on behalf of the "Climate Change, Agriculture and Food Security" Challenge, key limitations to further improvement of crop models are the lack of high quality data and the unavailability or inaccessibility of shared databases. The need for seamless interfacing between empirical experimentation and modeling highlighted by the CGIAR report is most certainly reflective of what is needed to realize sustainable bioenergy crop production at landscape scales. Sound use of crop models to forecast energy production will depend on open access to agronomic data as well as data from related disciplines and the creation of virtual, multi-disciplinary research partnerships of field researchers and modelers that may be asynchronous in both time and space.

It should be noted that simply making data available from field research (e.g. Web posting) will not ensure data accessibility by others. To achieve such virtual partnerships and repurpose data, we need standard measurements, explicit derived metrics, and mechanisms for sharing. Field researchers are the measurement makers and data generators, and our measurement protocols are standardized according to very internal and culture-specific criteria. However, measurement protocols are not adequately standardized across the agronomic disciplines. Such non-standardization can lead to erroneous interpretation of values within databases; when secondary data (e.g. a crop growth rate estimated from several field measurements) derived with an erroneous interpretation of the primary data has inadequate provenance (records documenting origin), the error can become imbedded in a dataset shared among unsuspecting modelers and widely propagated throughout the cycle of use of the data. Lack of measurement standardization is a common and significant barrier to data sharing. At present, only a small fraction of collected agronomic data is readily discoverable, accessible, or reusable, and the lack of standardization is a key reason.

For seamless integration of field and modeling research and data longevity, we also need to identify a common core of measurements that adequately capture the key system attributes but are not overly onerous or too costly. These core measurements must accurately characterize the inference space or the critical bounding conditions. For example, precipitation patterns (intensity, duration, and seasonal distribution of rainfall are a key driver of plant growth) and data capturing this environmental attribute must be sufficiently precise and accurate to characterize what matters to the plant. Ideally, there is agreement among all potential data users regarding what data are actually needed to identify the inference space. However, such agreement can be difficult to achieve as researchers are typically working in different regions of the country or world. These researchers are also working in a large number of different disciplines resulting in different perspectives on what system attributes are most important. Moreover, they often have vastly different budgets with which to conduct their sampling campaigns. Further, modelers may have developed unique and extremely mechanism-intensive models and overlooked the challenges of acquiring the data to broadly calibrate and apply the model. Regardless, if we are to make progress on complex problems such as ensuring sustainable bioenergy crop production at landscape scales, scientists must make a concerted effort to identify a core of measurements and appropriate standards for measurement collection.

CORE MEASUREMENTS

The following constitute some initial thoughts on developing a core of standardized measurements for field research that would facilitate the aggregation of data across experiments and downstream reuse of data in crop models. From a global yield perspective, not necessarily specific to bioenergy crops, there are four essential measurements to make:

- *Soil information* includes texture and classification of soil type and sampling for fertility characterization and carbon/nitrogen stocks;
- *Management information* includes a) fertilizer…the type, rate of application, timing, method of application, and location; b) cultivar name and gross characteristics such as growing degree days, maturity group, and spring versus winter planting or harvest; c) seeding rate, planting date, and other input such as tillage, previous crop, and crop sequence;
- *Crop growth and development information* such as benchmark development and phenology stages including timing of emergence;
- *Daily weather and climate information* including daily maximum and minimum temperature, precipitation, relative humidity, solar radiation, and wind speed, and others such as derived greenhouse gas emissions.

Important caveats to consider:

- *Data are expensive:* Measurements vary in cost and the ease of collection for quality data. Data collection should focus on the key drivers of the results or outcomes of interest in the broadest possible context. These drivers may vary in space and time, and developing a robust data core necessitates some careful conversation among field researchers and their modeling colleagues. While it should be presumed that key drivers of realized crop performance will be the same as in the modeling simulations, a better outcome for aggregation and reuse of disparate field data will be possible when careful prior plans and data collection and management are made an explicit objective versus only post hoc synthesis of previously entirely uncoordinated data.
- *Inference is spatio-temporal*: Given that data are expensive, efficient field data collection strategies are essential to maximize the inference space. Historically, field researchers have typically used one of the following approaches:
    - Collect data intensively at a small number of locations (typically expensive);
    - Include more locations with fully replicated experiments and less intensive routine measures and targeted sampling campaigns (approach taken by the Chinese Maize Network); or
    - Sample a highly distributed field network across a major growing region but with only a minimum number of measurements at each location ("adaptive" management approach often used to study near-term impacts of a change in farmer practice).

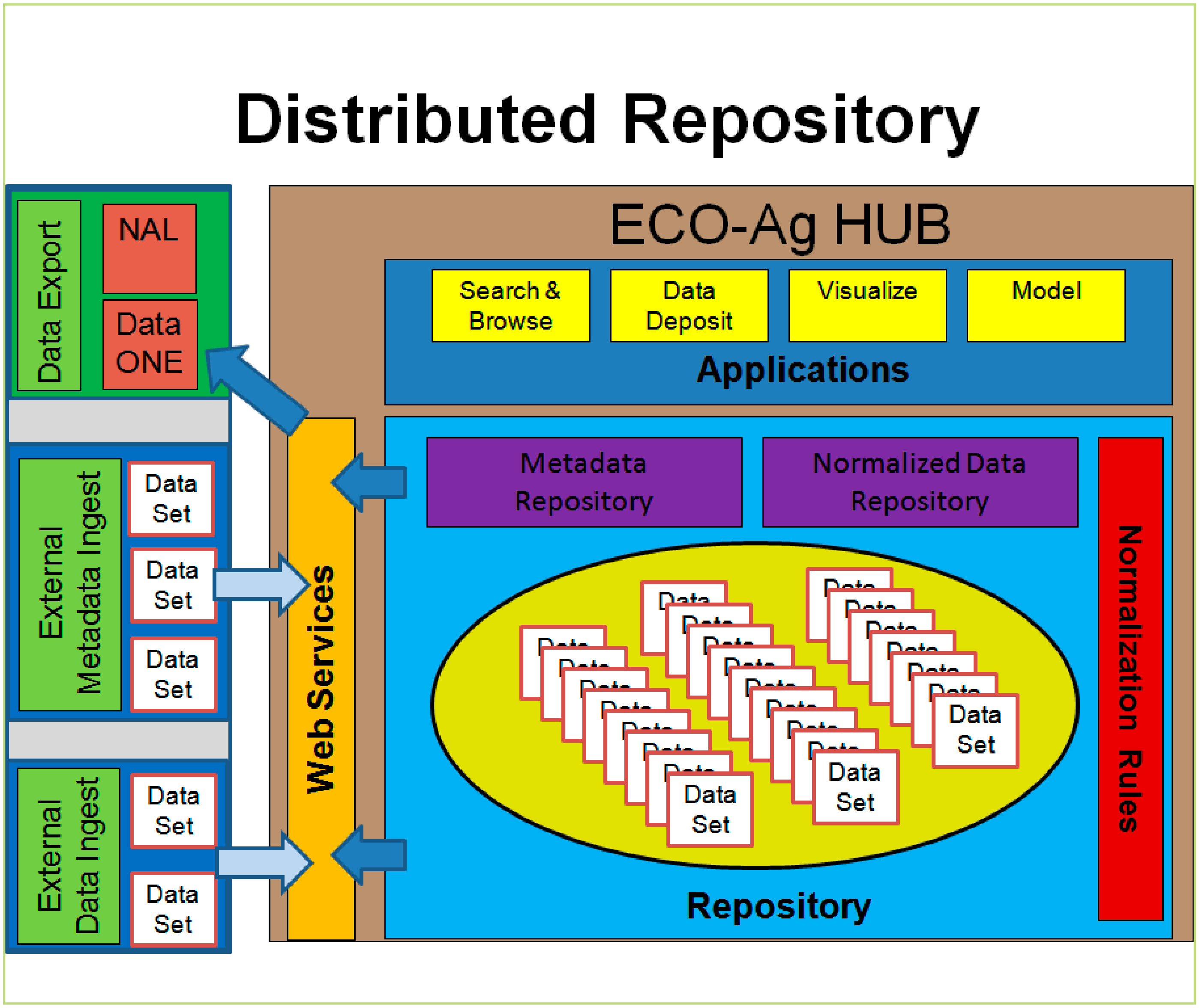
Ultimately, the most efficient approach to capturing important aspects of inference space of entire agro-ecozones may be a nested, hierarchical array that carefully links all three approaches.

DATA SHARING

Ultimately, we need effective ways to discover, access, integrate, curate, and analyze a range and volume of disparate, currently disaggregated data. Assuming a core dataset can be identified and measurements are standardized sufficiently to permit their aggregation, mechanisms are needed to facilitate data sharing. Data hubs are one way of sharing information among multiple users using off-shelf technologies for a cyber-infrastructure. There are, however, pressing technological challenges to informatics for all agronomic efforts that concern workflows for data sharing. One challenge is data dispersion: how best to take advantage of small datasets collected by many researchers. Another challenge is data heterogeneity. There are varied protocols reflecting local culture and variations in the prime purpose of each dataset (lack of measurement standardization, discussed above, is just one facet of heterogeneity). A third challenge is data provenance, or the need to track data through a multi-step process of aggregation, modeling, and analysis.

Such data dilemmas seem particularly challenging to disciplines that predate cyber-infrastructure for managing data (e.g. agronomy vs. genomics) but the new cyber-cataloging tools that are emerging will eventually revolutionize research on cropping system sustainability. At present, barriers to their use include money, motivation, and workflow mechanics. Workflows for agronomic data have not been established in any global sense. Vast distances can exist across surprisingly short geographic and disciplinary space. We are at a point where it is critical to address these gaps, and there are efforts underway to do so. The actual handling and preservation of the data, however, lags behind.

I would like to issue a challenge to our research librarians and bioinformatics centers. Data workflow done right is critical to ensuring that project data requirements are not overbearing, that they are doable, and that provenance traces can be stitched together. As research is conducted, the data produced needs to be audited, metadata need to be generated, standards need to be applied, vocabulary needs to be controlled, and means of curation need to be determined. Such a process can ensure that data from many sources and formats can be available, accessible, and usable by others. Data in this form becomes an institutional asset that retains or can gain in value versus the current situation where data have almost no value beyond the individual research program.


Distributed Repository
ECO-Ag HUB
Search & Browse
Data Deposit
Visualize
Model
Applications
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External Data Ingest
Data Set
Data Set
Web Services
Metadata Repository
Normalized Data Repository
Normalization Rules
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Landscape Design for Bioenergy Cropping Systems

by Esther S. Parish

Mrs. Parish *is a Geographer at the Center for BioEnergy Sustainability, Environmental Sciences Division, Oak Ridge National Laboratory.*

There are many different definitions of sustainability, but we would all likely agree that sustainability is the capacity of an activity to continue while maintaining options for future generations. The Center for BioEnergy Sustainability (CBES) at Oak Ridge National Laboratory (ORNL) has been developing a suite of indicators, or metrics, for assessing the overall sustainability of a bioenergy production system.

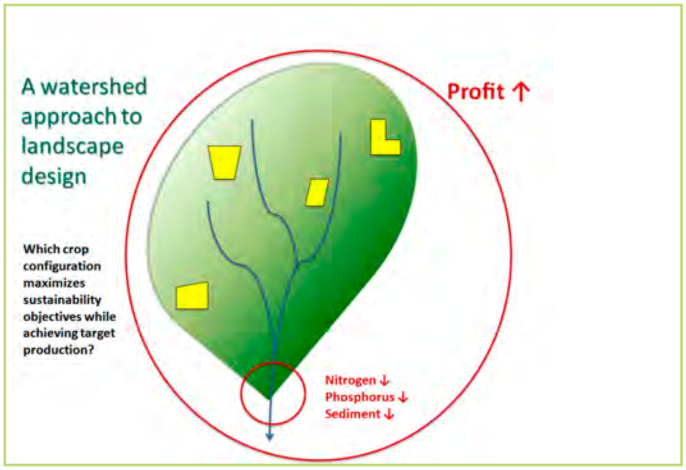
Under the leadership of CBES Director, Dr. Virginia Dale, interdisciplinary teams of researchers at ORNL have been developing a suite of environmental and socioeconomic indicators that might be used to assess the sustainability of biofuel production according to a common framework. We have identified 19 environmental indicators related to soil quality, water quality and quantity, greenhouse gases, biodiversity, air quality, and productivity (McBride et al. 2011), and 16 socioeconomic indicators dealing with social well-being, energy security, trade, profitability, resource conservation, and social acceptability (Dale et al., in review). We have tried to recommend indicators that may be measured in a standard way across different agencies at a relatively low expense. We are currently exploring ways each specific indicator could vary depending on spatiotemporal settings and other considerations of context (Efroymson et al., in review). We are also researching the tradeoffs that might occur as multiple sustainability goals are implemented.

THEORETICAL FRAMEWORK FOR LANDSCAPE DESIGN

We hypothesize that cellulosic crops dedicated to biofuel production can be planted according to a landscape design so that a shift in land use may have positive impacts on indicators of sustainability. By landscape design, we mean that the crop type, location, and management techniques may be selected with the goal of improving a particular set of sustainability indicators for a given location.

Biofuels are typically derived from agricultural feedstocks produced within a context of particular environmental conditions and socioeconomic constraints. Farmers desire to generate profits but may also strive to achieve co-benefits, such as the protection or improvement of ecosystem services like water and air quality. Farm choices inevitably involve tradeoffs. For instance, increasing profits through application of fertilizer may also result in runoff of excess nitrogen, phosphorous, and sediment into surrounding stream channels.

We have chosen to use a watershed approach to landscape design in the development of our Biomass Location for Optimal Sustainability (BLOSM) model so that we might examine potential changes in water quality resulting from bioenergy production. We have configured BLOSM to test the idea that bioenergy crops may be planted across a watershed in a spatial configuration that may simultaneously reduce nitrogen, phosphorous, and sediment concentrations at the outlet of the watershed while simultaneously realizing an overall economic profit and feedstock production goal.

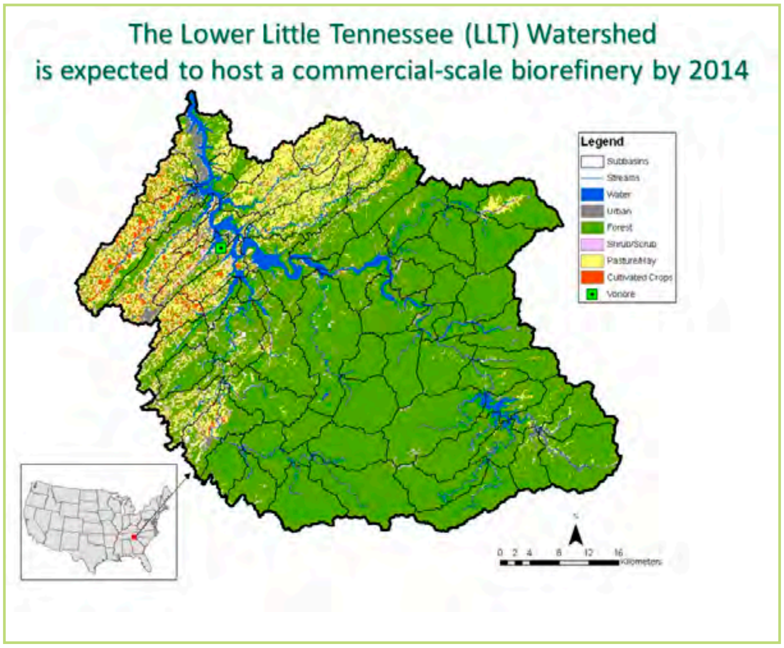


CASE STUDY

We have used a local case study of *Panicum virgatum* (switchgrass) production to illustrate the challenges of exploring tradeoffs between socioeconomic and environmental indicators of sustainability within a bioenergy system:

ORNL is located near a demonstration-scale (250 Mgal/yr) cellulosic biorefinery in Vonore, Tennessee, managed by Genera Energy LLC. Three years in advance of ethanol production from the Vonore facility, local farmers were contracted to establish a feedstock supply of perennial switchgrass. In 2008, ORNL began collaborating with the University of Tennessee's Institute of Agriculture in order to incorporate environmental design criteria (e.g., distance from streams, site slope) into the farmer selection process. From 2008 to 2010, total switchgrass production from 63 farms across a 10-county supply area has risen from 1,000 tons to 15,000 tons per year. Switchgrass production is expected to increase even more substantially when a commercial-scale biorefinery locates within the vicinity of the Lower Little Tennessee (LLT) watershed in 2014.

Building from our experience with the Vonore-area experiment, we have used BLOSM to test the effects of converting land from traditional corn and hay-land/pastureland production to dedicated switchgrass plantings in order to supply 65,000 tons/year of feedstock to the anticipated commercial biorefinery (Parish *et al.* 2012). BLOSM integrates outputs from a hydrological model, the Soil and Water Assessment Tool (SWAT) parameterized for perennial switchgrass growth (Baskaran *et al.* 2010) and an economic model known as the Policy Analysis System (POLYSYS), to select switchgrass planting locations from available hydrologic response units (HRUs). The combined BLOSM tool can consider objective functions such as farm profit and water quality impacts at the sub-basin level under certain assumptions; for example, that it is possible to meet switchgrass production targets and that only agricultural or hay land will be converted to switchgrass production. These assumptions place certain constraints on the total quantity of land converted. The final output of BLOSM is an assessment of the optimal spatial locations for planting bioenergy crops to meet specific balanced objectives. During this case study, our aim was to predict maximum achievable goals for each of the four sustainability criteria on an individual basis—namely increase profit and reduce in-stream concentrations of nitrogen, phosphorus, and sediment—and then to examine the planting configurations that might simultaneously realize all four of these goals to the extent possible.



We used BLOSM to explore six possible scenarios for the LLT watershed: 1) minimizing nitrogen, 2) minimizing phosphorous, 3) minimizing sediment, 4) maximizing profit, 5) achieving balanced objectives, and 6) achieving balanced objectives while limiting agricultural land conversion to 25 percent of available cropland. In our model runs we assumed that only current pasture/hay land and agricultural land were eligible for conversion. We performed a comparison of local net revenues and crop yields for each HRU. Also, we tracked the potential flow of pollutants in the sub-basin and stream-flow networks.

BLOSM results indicate that a combined economic and environmental optimization approach can achieve multiple sustainability objectives simultaneously. Near maximum reductions in nitrogen, phosphorus and sediment concentrations were achieved simultaneously with realizing 90 percent of the maximum achievable profit when a small proportion of the LLT watershed was planted with perennial switchgrass. Real-world data will be critical to validating the success of these landscape designs. We are planning to validate our results with data collected from eight LLT watershed subbasins under the Integrated Bioenergy Supply System (IBSS) project recently funded through the US Department of Agriculture's support to the Southeastern US Regional Partnership. Once validated, the landscape design approach described here may be modified to incorporate other feedstocks, sustainability objectives, and regions.

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Root Morphological Responses to Phosphorus Application & Water Stress Conditions of *Bothriochloa ischaemum* Intercropped with *Lespedeza davurica*

by Bingcheng Xu

Dr. Xu *is a a Research Professor with the State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources.*

The Loess Plateau is located in the center of China. It encompasses about 640,000 square kilometers mostly in the semiarid to arid region and has a population of about 70 million. The plateau is characterized by low and highly variable rainfall, with most precipitation occurring in summer between July and September. Yearly evaporation losses are high in part because of high runoff during the rainy season and high winds. The soil quality is poor, and vegetation coverage is scarce.

The most serious environmental issues in this area are soil erosion, degraded vegetation, and desertification. Attempts at vegetation rehabilitation are difficult due to the variety of soils and structure of the grassland. In addition, there is a lack of adaptive species, which is the reason we have introduced switchgrass from America and some species from other countries. We need more research on soil and water conservation and more work on plant regional productivity and long-term eco-adaptation.

THE INTERCROPPING APPROACH

In earlier research, we focused too much on above-ground concerns, especially biomass production, and too little on what was occurring below ground, especially with the roots. Plant root systems can hold topsoil in place and thus prevent soil erosion. Our most recent research focus is on intercropping of different species. Intercropping has many benefits, especially in meeting water requirements, nutrient demand, and resource use efficiency needs, and achieving yield stability and sustainability.

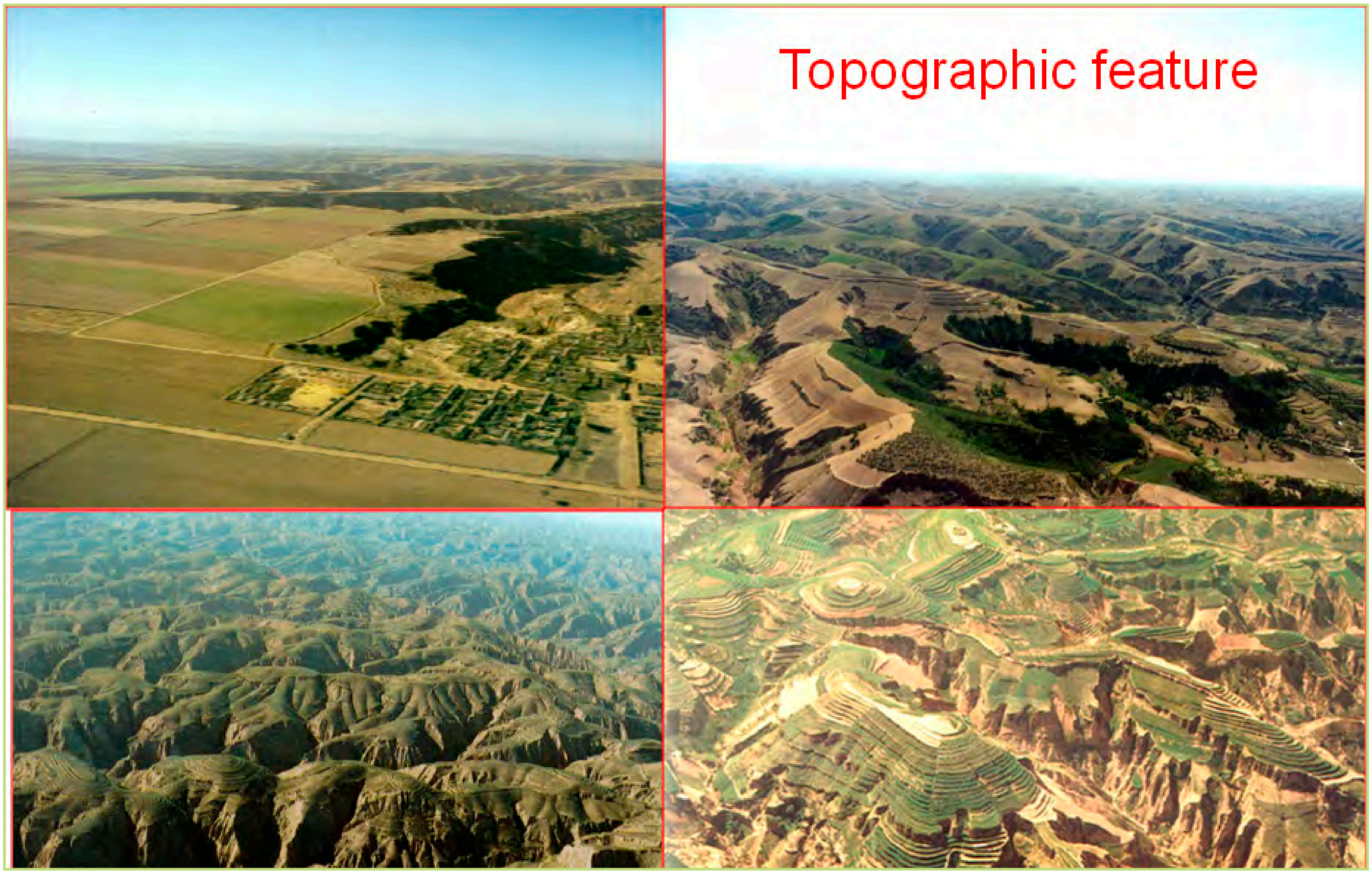
The first crop in the intercropping system is old world bluestem (*Bothriochloa ischaemum*), also called yellow bluestem, which is widely distributed in America and China. It is a C_4 perennial, herbaceous grass with high resistance to close grazing and is good forage for goats and cattle. Widely distributed in the semiarid Loess plateau, this bluestem grass was introduced because of its ability to control soil and water erosion. The second crop is *Lespedeza davurica,* a C_3 perennial legume which is also good forage for goats and cattle. This crop, which is widely distributed in the region, is also very good at controlling soil and water erosion. Both are dominant species in natural grasslands.

We planted these two species together in a potted experiment for two years using a replacement series design in which we varied the mixture ratio of the two plants. Twelve plants of the two species were grown in the same pot at several different plant density ratios. We applied three different water treatments—high, medium, and low, where HW is similar to sufficient water, MW similar to moderate water stress, and LW similar to severe water stress. We also used two different phosphorus (P) treatments, 0 and 0.1 gram of phosphorus pentoxide (P_2O_5) per kilogram of dry soil. The total design included more than 300 pots. Our results showed that:

- Water stress significantly decreased the single plant root surface area (RSA) values of *B. ischaemum*
- Total root length (TRL) per plant followed a similar trend as RSA and decreased as the proportion of *B. ischaemum* increased in the mixtures
- There were no obvious trends in the root average diameter (RAD) of *B. ischaemum* in the mixtures under either water or P treatments, and RAD values were significantly higher in the monoculture without P application under both HW and MW than under LW treatments
- Without P treatment, specific root area (SRA) averaged values were lower as the level of water treatment declined, while with P treatment, MW treatment had significantly higher SRA, and there was no difference between HW and LW treatments
- HW treatment without P addition had significantly higher SRA, and with P treatment, MW and LW produced significantly higher SRA
- Mean specific root length (SRL) followed similar trends to SRA.

Overall, we conclude that under serious water deficit, the addition of P may reduce root:shoot ratio. Regardless of the mixture ratio and water regimes, P addition decreased root average diameter and increased root biomass, total root length, and root surface area, two mechanisms for *B. ischaemum* to increase fine root length and thus increase the absorption surface area. Moreover, P addition decreased root density thus increasing metabolic activity.

Our results suggest that water was the primary limiting factor affecting root growth and morphology of *B. ischaemum*, but that species competition from *L. davurica* also plays an important role.


Topographic feature

Heavy Metal Contaminations in a Soil-Rice System: Identification of Spatial Dependence in Relation to Soil Properties of Paddy Field

by Jianming Xu

Dr. Xu *is the Director of Soil and Water Resources and Environmental Science at Zhejiang University, and the Chair of the Soil Chemistry Division of the Soil Science Society of China.*

Heavy metals enter the human food chain through soils, where they are absorbed by edible plants and then consumed by people, and through aquatic systems, where they can accumulate in fish and also be eaten by humans. Food safety health risks are a major environmental concern in China and worldwide. Rice is a dominant agricultural product in China, and this food crop ranks second by quantity in the world, so the potential for heavy metals to enter the food chain through the consumption of rice is quite high. Whether heavy metal contamination enters the food chain through soil, water, or the air, the quality of the environment has a great impact on food safety.

In China, heavy metal contamination in rice paddy soil has attracted a great deal of attention. Understanding the mechanism of transfer of heavy metals in the soil-rice system can be a key challenge to evaluating the uptake of pollution from soils to plants.

Substantial research has been carried out to investigate the transfer of heavy metals in soil-plant systems on the basis of plot or field experiments, sometimes at contamination sites of special concern such as agricultural areas near industrial regions. Little information is available, however, on the transfer of heavy metals in soil-rice systems in paddy fields and spatial aspects of the bioavailability of heavy metals to rice plants. Researchers in the department of Soil and Water Resources and Environmental Science at Zhejiang University therefore wanted to evaluate this issue on a regional scale.

The study area was in Zhejiang Province, which is very close to Shanghai, one of the most developed regions in China and one in which pollution is a serious problem. Within Zhejiang Province, we selected three rice production counties from the north, the middle, and the southeast: Nanxun, Shengzhou, and Wenling. These are not only representative rice production areas but are also within highly industrialized areas in Zhejiang Province.

We took soil samples and rice samples from these three counties, collecting nearly 100 samples from each of the three sites ranging from 70 to 100 square kilometers.

We analyzed plants of two cultivars, a hybrid rice and Japonica rice. In China, hybrid rice is predominant in Nanxun, Japonica rice in Shengzhou, and both cultivars in Wenling.

For the soil samples, we measured the total concentration of five heavy metals: cadmium (Cd), copper (Cu), nickel (Ni), zinc (Zn), and lead (Pb), and we quantified the metal fractions of the heavy metals. In addition, we measured soil properties such as soil pH, organic matter, electrical conductivity, soil texture, and iron oxide. For the rice grain samples we measured the concentrations of Cd, Cu, Ni, and Zn. We found that lead could not be detected in rice grains.

The objectives of our present research are to

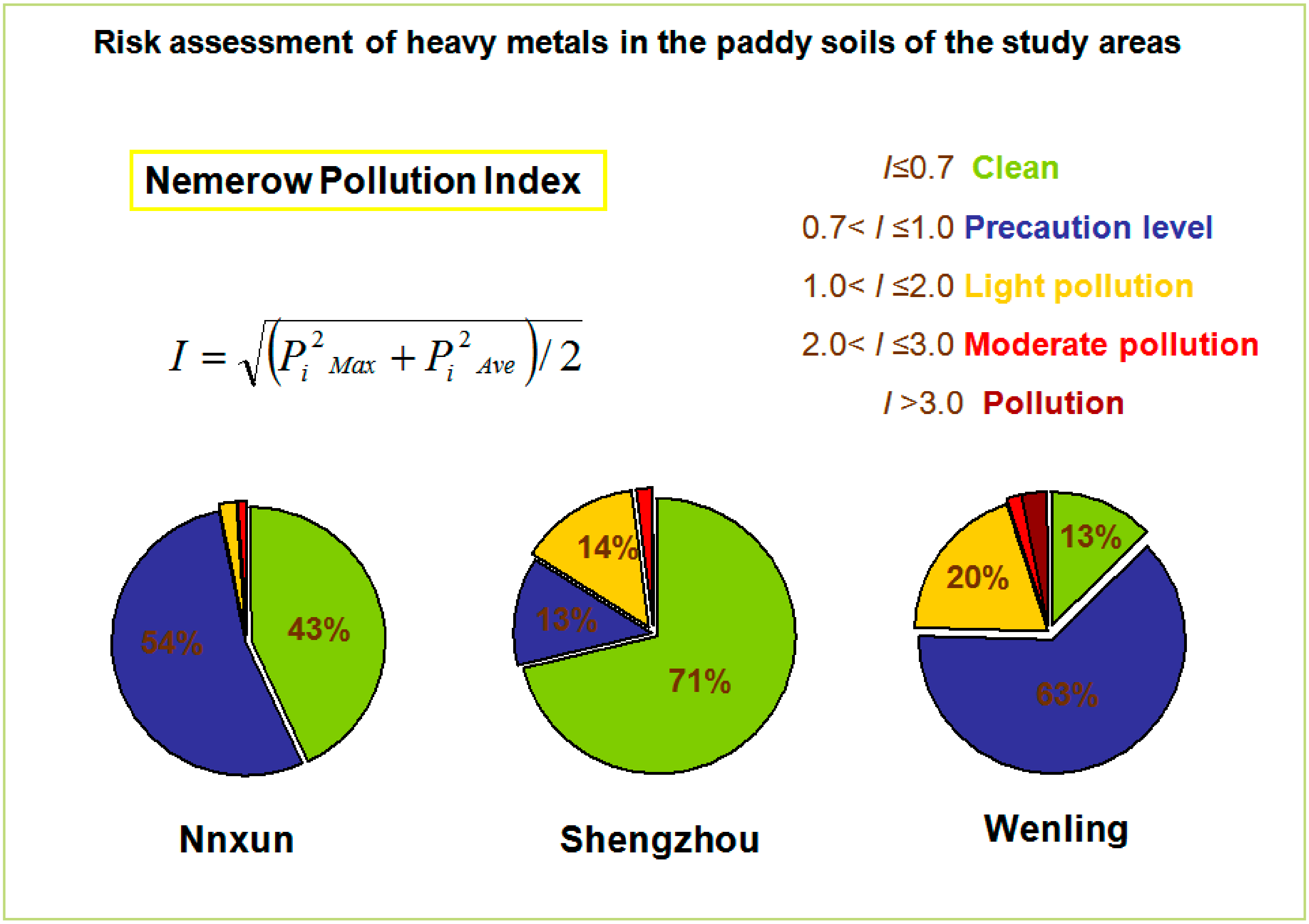
- study the spatial variability of heavy metals in paddy soil and rice grains in rice-production areas at regional scales,
- investigate metal fractions in paddy fields and their spatial correlation with uptake by rice, and
- develop the transfer models of heavy metals in soil-rice system in rice production areas.

TRANSFER AND BIOAVAILABILITY OF HEAVY METALS IN SOIL-RICE SYSTEMS

We compared the mean concentration of heavy metals from paddy soils in the different study areas against the background values in the soils of Zhejiang Province and the threshold value used as the benchmark of soil contamination recommended by the Ministry of Environmental Protection of China (1995). Our data show that in Wenling, contamination is a more serious problem than in the other two study areas.

In the rice grain samples, we found that the concentration of Cd exceeds the Maximum Levels of Contaminants in Foods in China established by the Ministry of Health (1995) in some samples from Shengzhou and Wenling, with higher concentrations in Wengling.

Our risk assessment of heavy metals in paddy soils in the study areas, using the Nemerow Pollution Index, showed Shengzhou to be the least contaminated, with a lower percentage of the soil samples registering at the precautionary level, with higher levels found in Nanxun and Wenling. In the Wengling location, we classified the different soil types and also plotted the different industrial and electronic waste disposal sites. When



we measured heavy metals in soil and paddy rice, we found concentrations of Cd, Cu, and Zn in higher concentrations in the northwest, but Ni did not follow a similar pattern, indicating that Cd, Cu, and Zn concentrations were probably greatly influenced by human activities, especially from industrial discharge. For Ni, the concentration level was close to natural levels.

Using the Wengling samples, we divided the heavy metals into different fractions in paddy soils and looked at the spatial distribution of metal fractions in soil and heavy metals in rice. Using Cd as an example, we found that the spatial pattern in rice was strongly similar to those of the exchangeable fraction, with high concentrations in the northwest and low concentrations in the southeast.

In order to understand the relative bioavailability of heavy metals in soil-rice systems, we used the enrichment index (EI). The EI provides a useful indication of the metal availability from soil to plants. The EI varied significantly with the different heavy metals in the soils, with Cd having the highest EI followed by Zn, Cu, and Ni.

We also looked at the distribution of heavy metals in fractions as percentages of the total. About 92.8 percent of total Cd was associated with non-residual fractions, which had significant availability to rice plants, so that the Cd exhibited higher bioavailability to plants compared to other heavy metals. Cu, Ni, Pb, and Zn were predominantly associated with residual fractions, and the lowest associated with the exchangeable fraction, indicating these heavy metals, unlike Cd, were stable in paddy fields.

In soil-rice systems in the study areas, different EIs of the same metal were observed between the studied areas, and EI values in Shengzhou were significantly higher than those in other areas. This result indicated that heavy metal availability to rice may be affected by other factors such as soil properties and rice genotypes.

In order to study the spatial variance of bioavailability of heavy metals and the influence of environmental factors, spatial distribution maps were plotted out in the study areas, based on analysis of spatial distribution maps of heavy metals in soil and rice. The observed spatial patterns of EIs indicated the transfer and bioavailability of heavy metals in soil-rice system exhibited spatial variances in the study area. The results indicated that soil properties did affect the availability of heavy metals in paddy fields.

The spatial distribution of the total heavy metal concentrations in soil and rice presented similarities to some degree; however, the total concentrations in soil alone could not reliably estimate the availability of most heavy metals to rice plant. Generally, the spatial correlation of heavy metals in soil-rice systems was in the order of exchangeable fraction>organic bound fraction>Fe-Mn oxide bound fraction>residual fraction, indicating that the exchangeable fraction had the highest bioavailability, while the residual fraction was not considered to create a bioavailability pool. The distribution of heavy metals in fractions varied with the specific heavy metal. Cd occurred primarily in the non-residual fractions while the other heavy metals were predominantly associated with the residual fraction. Thus, Cd had high solubility in the paddy soils and exhibited higher bioavailability in soil-rice systems.

In conclusion, the transfer and bioavailability of heavy metals in soil-rice systems showed significant differences between study areas. Soil properties and rice genotypes played some role on influencing the transfer of heavy metals in soil-rice systems. Among these factors, genotype combined with environmental interactions exhibited the largest influence, followed by the environmental effects alone, then the rice genotype effect. Using information on heavy metal fractions and soil properties for different genotypes of rice, we could well predict the transfer and bioavailability of heavy metals in soil-rice systems of rice production areas.

Scaling Biomass Production from the Field to the Watershed Scales

by Indrajeet Chaubey

Dr. Chaubey *is a Professor of Ecohydrology in the Departments of Agricultural and Biological Engineering and Earth and Atmospheric Sciences at Purdue University.*

The Renewable Fuel Standard of the Energy Independence and Security Act of 2007 mandates an increase in production of biofuels from 4.7 billion gallons in 2007 to 36 billion gallons by 2022. Of all major categories of biofeedstocks to meet production goals, the most prominent is corn starch ethanol. The next most prominent are dedicated energy crops such as switchgrass or Miscanthus, followed by crop residue—primarily corn stover—then by woody biomass. Oil seeds are expected to play a relatively minor role.

The US Department of Energy's Billion Ton Update of 2011 has estimated how many dry tons we are utilizing now and what the potential for production will be as we progress from 2012 to 2030. There are four major categories included in the estimates, 1) forest land resources currently used, 2) forestland biomass and waste resource potential, 3) agricultural resources currently used, 4) agricultural land biomass and waste resource potential, and 5) dedicated energy crops. Of all these categories, dedicated energy crops will certainly be very significant as we approach 2030. Currently, despite much discussion, the contribution of dedicated energy crops is virtually nonexistent, but in future we will start to see significant contributions from dedicated energy crops, which will grow exponentially through 2030.

LANDSCAPE CHANGES

What will such large changes mean to the landscape? Most of our bioenergy feedstock production is currently concentrated in the Midwest, which is expected to continue to play a significant role in the future. In 2010, most ethanol power plants were concentrated in the Midwest, a major agricultural region. Land use change is expected to take place because of the shift in biofeedstock production, resulting in major changes in land use from the co-production of food and energy crops.

What will such changes mean for sustainability in terms of soil and water resources? Some of the key questions we ask are:

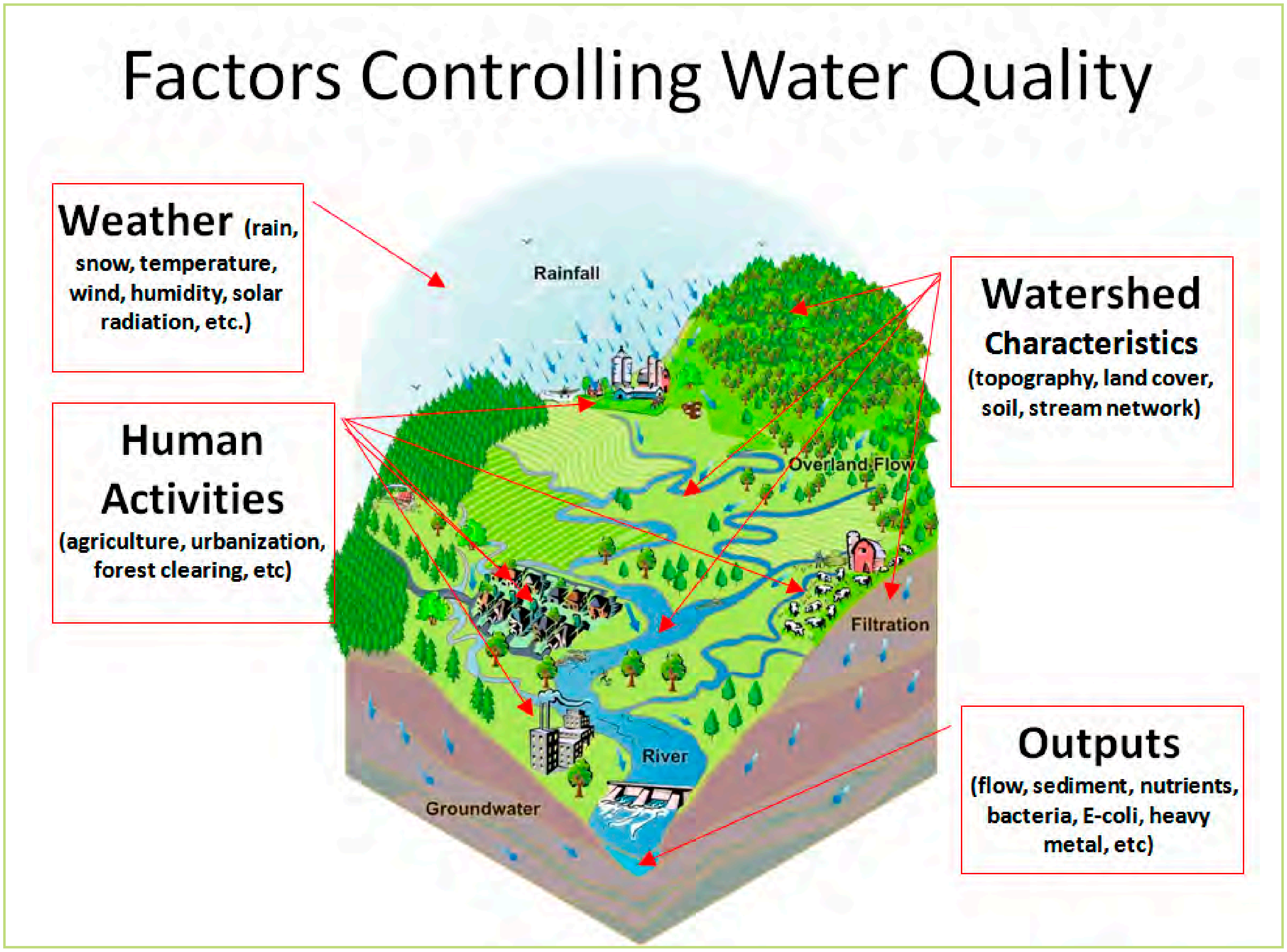
- What are the environmental impacts of various biofeedstocks production systems to meet cellulosic ethanol demands? These include corn stover, switchgrass, Miscanthus, mixed grasses, and fast growing trees such as hybrid poplar.
- How do these impacts vary at different spatial and temporal scales of assessment, from the edge of the field to the watershed and large catchment scale?
- How can selection and placement of various energy crops be optimized to ensure environmental, production, and economic sustainability?
- How can decision support tools be developed to help minimize negative impacts and promote positive impacts?

In order to look at different specialty scales, from field to watershed scales, let us look at a bit of background on processes and factors that control environmental quality, especially water quality. A watershed typically has rolling hills with forested areas. Some of these forests may be managed for bioenergy production. There are also crop areas, either for food or bioenergy production, pasture fields, and urban areas. This landscape is intersected by a series of streams and rivers.

What happens in the watershed affects the quantity and quality of water, as well as the quality of soil resources. One factor is the weather—rain, snow, temperature, wind, humidity, solar radiation, etc.—over which we have no control. Another factor we have little control over are watershed characteristics such as topography, soil, and the stream network. A very important factor is human activity, over which we do have control. Our selection of land management combined with other factors will affect the amount of flow and the quality of the flow including sediment, nutrients, bacteria, and heavy metals.

When we look at hydrologic processes at the field scale, the picture becomes more complicated. In the Midwest, a relatively high water table depth results in easily saturated soils. Farmers often install tile drains to lower the water table so that a crop can be grown. Precipitation and other weather variables along with crop management, type of tillage, and amount, method, and timing of fertilizer application all affect not only the pathways for different amounts of water but also water quality and how much nutrient sediment moves through different pathways.

At the catchment scale, all those factors along with what happens in the channel itself determine watershed scale processes. Channel processes include both dissolved and sediment-attached pollutants, sediment deposition, sediment contribution



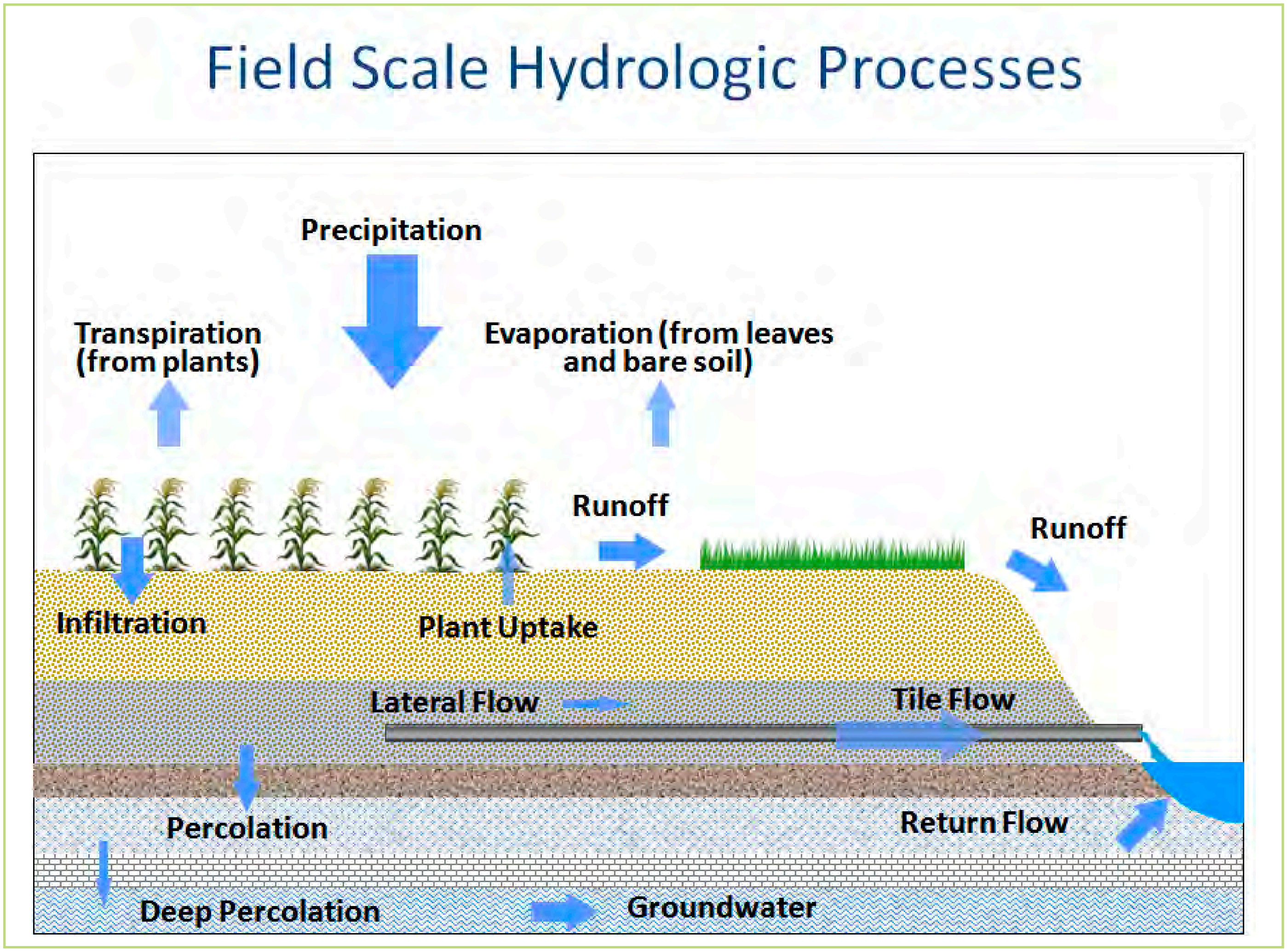
to the chemistry of the overlying water column, the amount and makeup of nutrients, and other processes. How do we evaluate all these complexities and interactions? To do so we must look at the field scale and the watershed scale using a multidisciplinary approach combining monitoring and modeling to consider the impacts at both scales.

MODELING WATERSHEDS

One of the models we use to look at the field scale impact is the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model. The GLEAMS model is used to characterize a field where crops are grown. The model accounts for the different nutrients and pesticides applied and, depending upon weather characteristics, can determine the amount of evaporation and transpiration that occurs, the amount of pesticides intercepted by foliage or washed off into the soil, how those pesticides are distributed in the root zone, and how much will be lost to runoff.

To look at watershed scale impacts, we use the soil and water assessment tool (SWAT) model. With SWAT, a watershed is divided into sub-watersheds depending on the stream or river network. Each sub-watershed is further divided into hydrologic response units (HRUs), an area conceptually similar to the field but not quite matching the field boundary. HRUs combine unique land uses, unique soils, and unique slope characteristics. The SWAT model also requires inputs such as solar radiation, rainfall, maximum and minimum temperature, relative humidity, and wind speed. Other inputs required by the model include the type of tillage, type of crop, crop rotation, amount of inorganic or organic fertilizer applied, and timing of fertilizer application. The model then takes all that information and quantifies watershed response such as the amount of biomass or yield that can be expected for different crops, the amount of surface and groundwater stream flow, the amount of evapotranspiration, and water quality—such as the concentration and loads of sediment, nitrogen, phosphorous, and pesticides at any point within the watershed. With SWAT, we can also perform a time series to model changes in the watershed and how those changes will affect the watershed over a certain time period.

We have defined six different measures of sustainability: soil erosion, water quantity, water quality, biomass and crop production, profitability, and aquatic biodiversity. We are now collect-



ing and synthesizing data needed to improve the SWAT model, specifically incorporating energy crops into the model. We can then take information on the watershed scale to calibrate and validate the model to make sure that it represents the watershed we are trying to simulate. The calibrated SWAT model quantifies the six indices of sustainability.

We look at the watershed in the context of alternative watershed landscape scenarios. The scenarios could be affected by different policies at the national, regional, or local scale. They could be affected by the economics of energy crop production or of alternative crops, or different individual stakeholder goals, such as the goals of a farmer. We then translate that information using the calibrated SWAT model and quantify sustainability metrics of these alternative watershed landscape scenarios. Finally, we compare the effects of potential changes compared to the baseline conditions.

One more factor we consider is climate change and climate variability, because absent any other changes in the watershed, climate variability and climate change can affect sustainability.

FIELD DATA

The field data we use to improve the models come from a number of sites. The goal is to make GLEAMS and SWAT as representative of the Midwest conditions as possible. We therefore look at different soil types, from very poorly drained to well drained soils, very flat to high slopes, very productive soils to marginal soils, representing different ecoregions in the Midwest and different drainage management conditions. We want the parameter values of the models to be applicable to the entire region, not just one site.

At the Purdue University Water Quality Field Station (WQFS), researchers are collecting data on a number of treatments to assess different energy crops and different management of those energy crops. The data collected are used to evaluate and improve the SWAT model and to bring new energy crops such as switchgrass and Miscanthus into the model.

This research facility is a unique, highly instrumented field lab for integrated studies of agricultural productivity and environmental impact. At WQFS, we can conduct field scale analysis of the cropping system level of different energy crops and their environmental impacts in terms of water use efficiency, carbon and nitrogen dynamics, and greenhouse gas production. We evaluate the model carefully and then target measurements to coincide with model crop growth parameter development.

In 2007 we focused our efforts on switchgrass. A Miscanthus crop was established in 2008. A big bluestem mix has been established since 1996, and a hybrid poplar crop was established in 2011. To help us validate the model parameter values, we performed a detailed sustainability analysis of the model and looked at measurements that would improve the model parameters. These measurements include leaf area index, accumulated heat units, canopy height, fraction of above ground biomass, crop growth rate, fraction of nitrogen and phosphorous in the biomass and other factors.

We then take the data at the watershed scale and calibrate the model to make sure it represents the watershed response characteristics satisfactorily. For example, we tested the SWAT model performance in a 2,000 square kilometer watershed, Wildcat Creek in north central Indiana, where there are a number of gauging stations for which the flow data and water quality data are available. We run the model, calibrate it, and validate it to look at different model performance statistics. We are consistently getting values that agree with what the model simulated, so we are very pleased with model performance.

We used the calibrated models to determine impacts of increased corn production at both the field scale and watershed scale. We looked, for example, at field scale results for different crop rotations, from corn-soybean to corn-corn-soybean to continuous corn, and measured the impacts of each rotation. Generally erosion losses would be greater when the rotation is switched from corn-soybean to continuous corn. The extent of erosion may depend upon the soil type. This finding agrees with a consensus in the scientific community about negative environmental impacts of increased corn production.

We then evaluated the environmental consequences of unprocessed agricultural residue removal. We found that there are tradeoffs in the removal of corn stover. Removal of residues leads to faster warming soils in spring, but soil organic carbon declines because the biomass is removed. There may also be faster losses of soil moisture because of the lack of cover. Other effects include increases in soil erosion, and increased need for fertilizer input due to the loss of nutrients though removal of biomass. All these factors will affect nitrogen and phosphorous mineralization in the soil profile. Removal of stover generally results in increased erosion losses, but those losses may or may not be statistically significant depending on the type of soil. We see similar results for other water quality parameters.

Moving from the field to the watershed scale, the results of stover removal is not all negative, so our results are giving us a really mixed signal. For example, at the watershed scale, the flow and losses of organic phosphorous, nitrates, and mineral phosphorous may decrease, but losses of sediment and organic matter may increase. We may see more sediment losses and more organic nitrogen losses when we remove 30, 52, or 70 percent of stover, but in other cases we may actually see a decrease in these losses. In order to understand this, we have to look at detailed processes.

If we look at the impact of residue removal on soil water over a year's time, comparing the baseline of no removal and a removal of 70 percent of residue, we find that during the growing period, there is very little difference in soil water. In the non-growing period, however, there is less soil water present with residue removal. These differences are primarily due to differences in evapotranspiration. These soil water losses result in less stream flow at the watershed outlet.

We also wanted to ask if there are some characteristics that we need to be careful about. For example, will removal of residue have different impacts according to land slope? We found that slope does matter; in some of the higher slope conditions, the relative loss of sediment can be greater.

MANAGEMENT CHOICES BASED ON GOOD INFORMATION

Most studies on perennial energy crops have focused on the agronomic potential and soil-nutrient dynamics. Little information is currently available quantifying watershed-scale hydrologic and water quality impacts. However, it is generally acknowledged that perennial crops will lead to reduced nutrient, sediment, and greenhouse gas losses, and such crops could be grown on less productive and highly erodible lands. Planting cellulosic feedstock on croplands currently used for ethanol production could increase ethanol production by 85 percent and reduce nitrogen leaching and greenhouse gas emissions. From the land management standpoint, we need to optimize the selection and placement of energy crops in the landscape to maximize sustainability. We need to develop decision support tools to evaluate the impacts of energy crop production.

In summary, unprecedented land use and management changes will result from bioenergy crop demand. We therefore need to perform a systematic assessment of the sustainability of biofeedstock production in order to make informed production and management decisions. So far, our results indicate that in the future, land management will play a significant role affecting the sustainability of biofeedstock sustainability compared to land use changes. What we decide to do now can have a very profound impact far into the future.

Conversion Technologies
& Soil Carbon

Mixed Volatile Fatty Acids as Substrates for Electricity Generation

by Zhonghua Tong

Dr. Tong *is an Assistant Professor at the University of Science and Technology of China.*

The energy crisis affects most of our essential resources, including water, gasoline, coal, and electricity. Increasingly, people have been turning to new sources of energy and trying to find new ways to use wind, water, nuclear energy, terrestrial heat, solar power, and even biomass.

At the University of Science and Technology of China, we have been exploring the field of fermentative hydrogen production. This method has drawn a lot of attention because it is environmentally friendly and can be used to recover clean energy from wastewater or biomass. The process has limited applications, however, because of the incomplete conversion of the substrate. For example, only 15-33 percent of the energy from glucose can be extracted as hydrogen. Most of the remaining energy exists as volatile fatty acids (VFAs) such as acetate, propionate, and butyrate. Researchers are therefore looking to adopt a suitable secondary process to further recover energy from the remaining acids. Photosynthetic hydrogen production is a secondary process for energy recovery; however, for this process, the load rate and production yield limit its application. A microbial electrohydrogenesis process has also been proposed for energy recovery. In this process additional energy is required to drive the hydrogen from the cathode.

MIXED VFAS IN MICROBIAL FUEL CELLS

Microbial fuel cells (MFCs) are a bio-electrochemical process system developed to use microbial organisms to oxidize organic matter and generate electricity. A variety of substrates can be used for this process, including organic compounds such as acetate, butyrate, starch, glucose, and even complex organics in wastewater plant residues. Research has shown that different substrates used in the MFC can result in different efficiencies, and fermentative hydrogen production will result in different concentrations of these acids.

The objective of our study was to investigate the effectiveness of using mixed VFAs in wastewater as a substrate for MFCs. We also wanted to interpret the relative contribution and possible interactions among these different components.

For our experimental design, a mixture of acetate, proprionate, and butyrate was used as the substrate. In the experimental setup, the relative contribution and possible interactions of the three components on electricity generation were investigated with response surface methodology, a collection of mathematical and statistical methods used for multifactor experimental design. From our previous work on fermentative hydrogen production, we set a fraction range of these three acids. The total concentration of the three components of the substrate added up to 500 milligrams of chemical oxygen demand per liter (COD/L). We used 10 reactors with different fractions of these components, which was determined using a simplex-centroid design method.

For the MFC construction and operation, we used a single chamber configuration. The air cathode was connected to carbon paper with a platinum film coating. The anode was a carbon fiber. We put anaerobic sludge collected from the local wastewater treatment plant into the chambers, each of which was supplemented with a different composition of the acids, and added 100 milliliters of the nutrient media. The MFC was operated in batch mode.

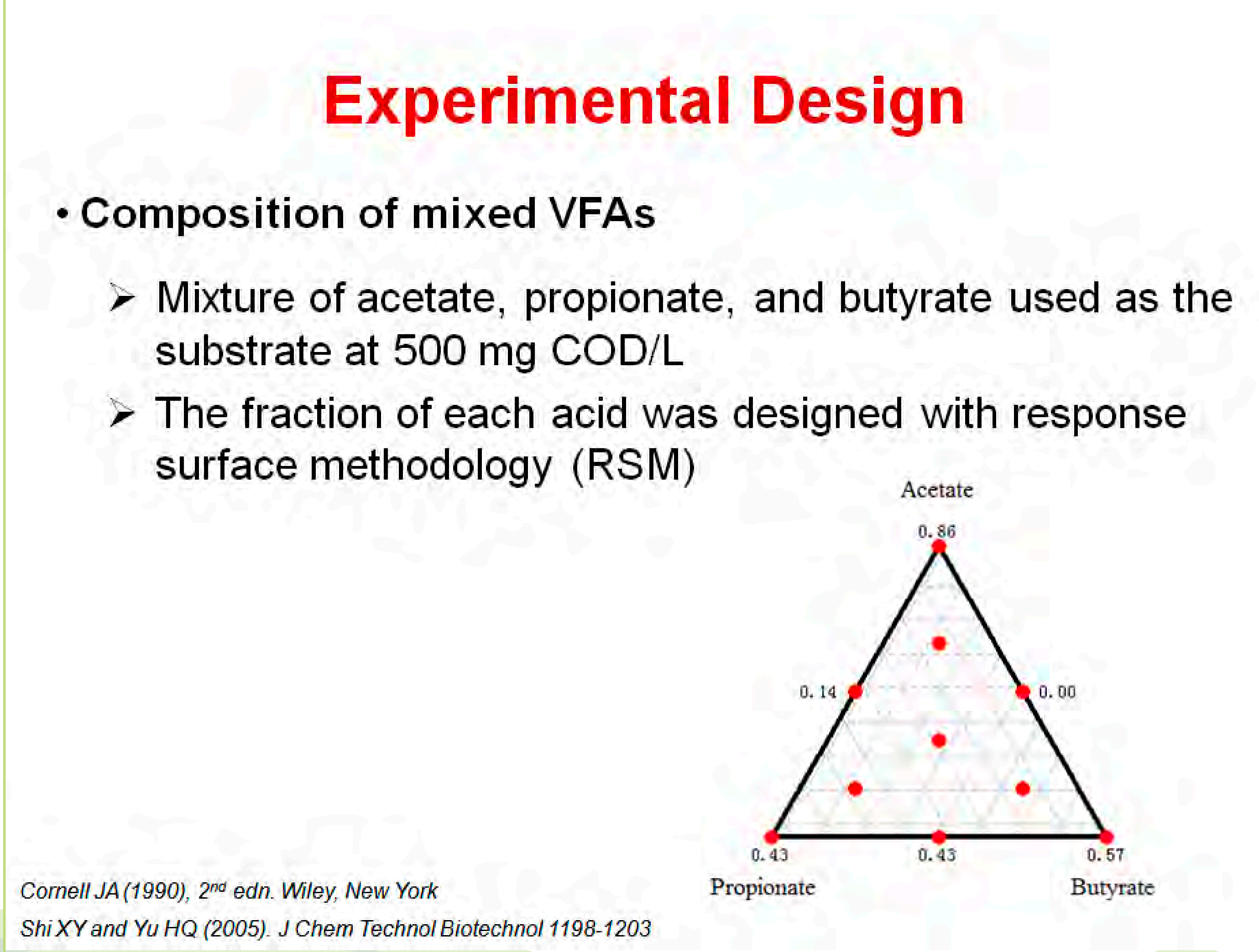
A Scheffé multiple regression model was used to analyze the effect of mixture composition on electricity recovery. For the data analysis, the power density was normalized to the liquid volume of the anode chamber, and the coulombic efficiency was calculated according to this equation. The microbial community structure of the anode microbial film was analyzed based on the16S rDNA-based PCR-DGGE method (polymerase chain reaction—denaturing gradient gel electrophoresis). Bands of interest were cut and suspended in sterile water to release DNA for sequencing. Similarity of community profile was analyzed with Quantity One software.

RESULTS

We found that stable electricity was generated after the enrichment process. Analysis showed that power density was more sensitive to the composition change of mixed VFAs than coulombic efficiency, and that electricity generation could mainly be attributed to the portion of acetate and propionate. However, acetate and propionate showed an antagonistic effect when the fraction of propionate exceeded 19 percent, causing a decrease in coulombic efficiency.

Butyrate was found to exert a negative impact on both power density and coulombic efficiency. DGGE profiles revealed the enrichment of electrochemically active bacteria from the inoculum sludge. Proteobacteria (Beta-, Delta-) and Bacteroidetes were predominant in all VFA-fed MFCs. Shifts in bacterial community structures were observed with different compositions of VFA mixtures as the electron donor. The overall electron recovery efficiency could increase from 15.7 to 27.4 percent if fermentative hydrogen production and MFC processes are integrated.

In conclusion, sustainable voltage output can be achieved in MFCs using mixed VFAs as substrates. This proposed integration process provides an application potential for MFCs.



Catalytic Conversion of Biomass to Fuels and Chemicals

by Ying Zhang

Dr. Zhang *is an Associate Professor in the Department of Chemistry at the University of Science and Technology of China.*

Biomass is the only renewable substitute for petroleum to produce liquid fuels and chemicals. A large amount of low-cost, or even free, biomass is currently available in China as waste material. Today, we sow a seed, next month or next year, we have a big plant.

Biomass has several advantages over petroleum. Biomass is clean. Theoretically, it is CO_2 neutral. Compared with other energy resources, biomass can supply renewable organic carbon, making it very important for energy and material sustainability.

BIO-OIL TO LIQUID FUEL

Phenolic compounds in biomass can be catalytically converted to liquid fuels. These phenolic compounds are first converted from the lignin of lignocellulosic biomass by hydrolysis or a thermal decomposition process. These compounds preserve higher energy density than other components from cellulose or hemicellulose because there is less oxygen in the compounds. A great deal of research has been conducted on the hydrogenation of phenolic compounds; so far, however, conversion of phenolic compounds from biomass has proven very difficult to accomplish.

About two years ago, researchers at the University of Science and Technology of China tried to upgrade the pyrolysis of crude bio-oil in supercritical ethanol under a hydrogen atmosphere by using the palladium catalyst $Pd/SO_4^{2-}/ZrO_2$/SBA-15 at 260°C. The upgrading was successful. We were able to convert most of the acids to esters and to remove almost all the aldehydes and many of the ketones, which are very unstable. But less phenolic compounds were converted. Some researchers reported that the phenolic compounds in bio-oil can be converted only at temperatures above 350°C. If we can remove the aldehydes and ketones, which cannot polymerize with phenolic compounds, then we can improve the properties of the bio-oil without converting phenolic compounds.

Two reports changed our mind. One researcher found that phenol can be hydrogenated to cyclohexanone at very low temperatures, about 80° C, with a palladium catalyst in a hydrogen atmosphere. Another group working on complex phenolic compounds was able to convert phenol at 250° C to alkanes. This led us to think that if we could find a good catalytic system to convert those compounds in biomass to desired fuels, we might be able to convert phenolic compounds at low temperatures.

Because there are hundreds of compounds in pyrolysis bio-oil, and some of them are highly thermo-instable, if we do direct upgrading, the high treatment temperatures will cause a polymerization reaction and deactivate the catalyst. Clogging of the reactor can also occur. To deal with these considerations, we decided to separate the phenolic compounds from the complex at the pretreatment stage and then select a suitable catalytic system to convert them to liquid fuels. Considering that oxygen-contained compounds may have better combustion properties, and the conversion needs milder conditions, we developed an efficient method for hydro-treating either pure phenolic compounds, or the ones separated from bio-oil to alcohols.

First we had to find an efficient way to separate these phenolic compounds from bio-oil. Even in traditional distillation, separation of these compounds is difficult to achieve. We decided to use glycerol in the distillation process to separate bio-oil into three fractions. The first mainly consisted of low-molecular-weight volatile compounds plus about 70 percent water. With this material we were able to use traditional separation and purification to get value-added chemicals. The third fraction, the residue, consists mostly of pyrolysis lignin. We can use hydrocracking with catalysts to convert this material into liquid fuels. The second fraction is where we concentrated our efforts. This material consists of phenolic compounds plus about 25 percent water. We were able to use catalysis and hydrogenation to convert them to alcohols.

To achieve hydrogenation of phenolic compounds separated from the bio-oil, we developed a ruthenium-based catalyst that we used in the reaction mixture at 170° C. We then modified the catalyst by adding titanium. Using this method, we found that phenolic compounds separated from bio-oil can be completely converted into cyclohexanol and derivatives under mild conditions. It is also possible to transform bio-oil into high-heating-value liquid fuel or fuel additives. Another highlight of this work is that the hydrogenated products can be easily separated from water, the greenest solvent, and conserve energy in the process.

CONVERSION OF BIOMASS TO LGO

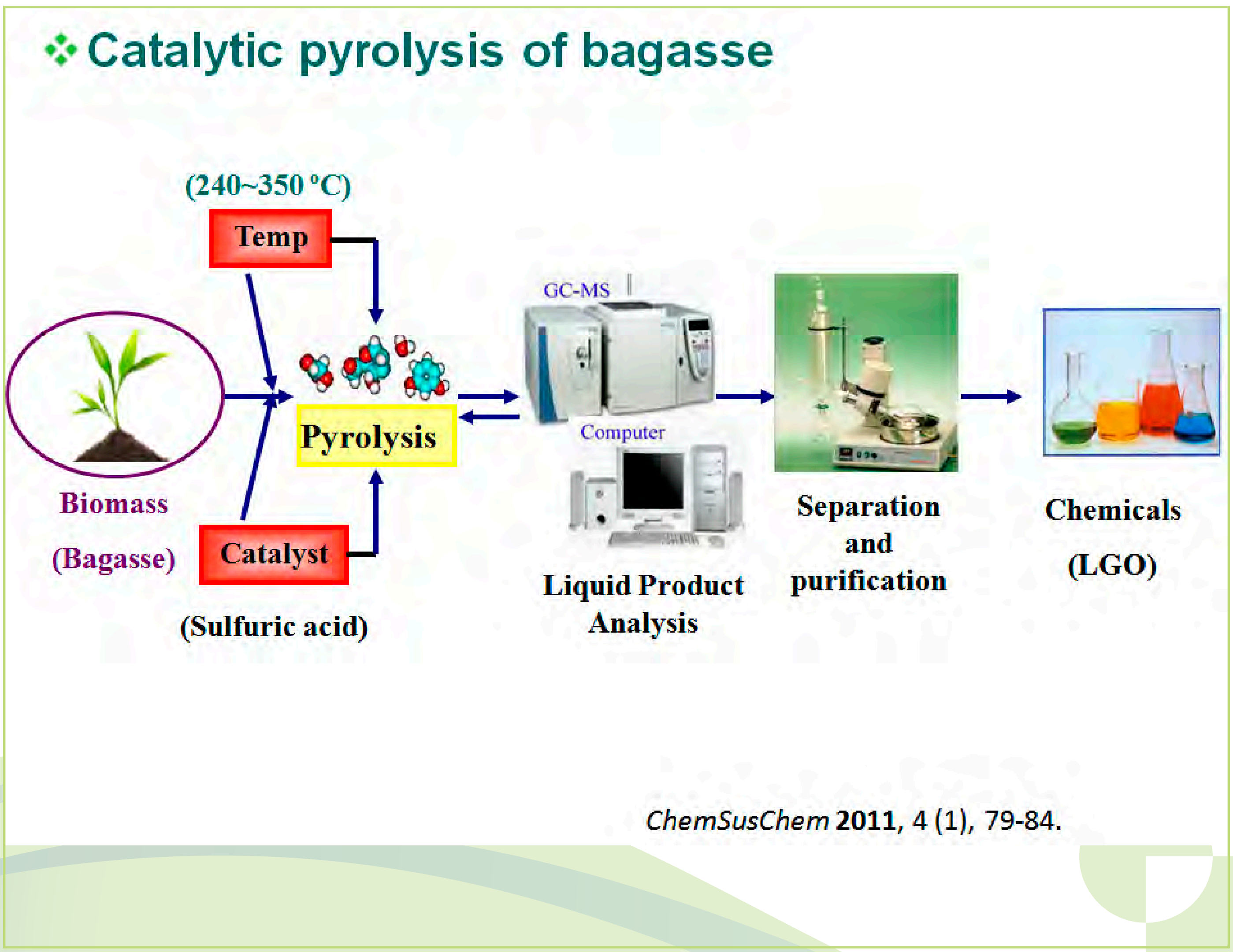
Another part of our work is the catalytic conversion of biomass to levoglucosenone (LGO). LGO is an optically active compound which has been widely investigated as chiral synthons and intermediates in organic synthesis. LGO can be used as chiral building blocks for the synthesis of many analogs of complex natural products. Originally LGO was produced by organic synthesis from glucose. This process is complex, and the cost is very high.

In recent years, researchers have found that LGO can be produced by pyrolysis of cellulosic raw materials. Pyrolysis of cellulose is the most economical and effective method for the production of LGO, but the yield is very low and the process expensive. We wanted to find an efficient process to produce LGO at a lower cost, with higher yield and higher selectivity under mild conditions. Based on our experience with catalytic pyrolysis, we decided to use a cheaper and stronger acid, in this case sulfuric acid, and a cheaper source of biomass or cellulosic resources such as bagasse—a residue of sugar cane and sorghum—and waste paper as the study materials.

In the catalytic pyrolysis of biomass, we first chose one kind of biomass, we then used different catalysts to perform pyrolysis at different temperatures, and finally we analysed product distribution with gas chromatography or mass spectroscopy to help guide further experiments. Lastly, we separated and purified the liquid to produce LGO.

In one trial, we used bagasse as the starting material and sulfuric acid as the catalyst. The pyrolysis temperature was around 240°C to 350°C, lower than the traditional, high temperature of 500°C for fast pyrolysis. At such high temperature, many kinds of reactions can happen; for example, lignin, cellulose, and hemicellulose can undergo different pathways for degradation, so we cannot control the products. If we lower the pyrolysis temperature, the product distribution will be very narrow.

In our experiments, we measured the yield of the target chemical LGO using three sulfuric acid pretreatment concentrations at different temperatures from 240°C to 350°C. The optimal yield of LGO (7.58 percent) was obtained at 270°C with a sulfuric acid pretreatment molar (M) concentration of 0.05M. With traditional, high temperature fast pyrolysis, as I men-



tioned, we cannot control the products. When we performed pyrolysis at 400˚C with bagasse and no catalyst, the major products were acetic acid, furfural, and phenolic compounds, but there were also minute amounts of other compounds, making it difficult to separate them out. When we lowered the pyrolysis temperature to 270˚C, with no catalyst, the product distribution became quite narrow; the major compounds were acetic acid, furfural, phenolic compounds, and a lot of levoglucosan (LGA). When we pretreated the bagasse with sulfuric acid, we still got acetic acid, furfural, and a lot of LGO, but almost all the LGA disappeared. We therefore have shown that by changing the temperature or adding certain catalysts during pyrolysis, we can get target products that can be separated from the bio-oil.

We also compared LGO production from three materials—microcrystallinecellulose, bagasse, and filter paper—pretreated with 0.05 M of sulfuric acid at temperatures between 270ºC and 320˚C. Because bagasse is about 50 percent cellulose, and we believe that LGO is produced from the cellulose, we thought that if we used pure cellulose, we could produce more LGO. However, when we tried using microcrystalline cellulose with pyrolysis temperatures from 270˚C to 320˚C, the best LGO yield we achieved was about 5.84 percent, which is about 50 percent lower than when we used bagasse

We think this lower yield of LGO with pure cellulose may be due to the fact that microcrystalline cellulose has a larger crystal size than bagasse and is more resistant to pyrolysis. We also used filter paper pretreated with sulphuric acid and got a similar result as with bagasse.

To produce LGO, some think that phosphoric acid is better than sulfuric acid, so we also compared bagasse pretreated with phosphoric acid. When we did so, we found that the yield of LGO was about 30 percent lower than with sulphuric acid and that higher pyrolysis temperatures were required to increase the yield of LGO.

From this suite of experiments, we concluded that sulfuric acid is more effective than phosphoric acid to catalyze pyrolysis of bagasse to form LGO. We also found that bagasse is better than microcrystalline cellulose for LGO production when sulfuric acid is the catalyst. We were able to develop a more economical process to produce LGO, since the materials of bagasse and sulfuric acid are easily available and cheap. Moreover, we developed a high energy efficiency process to produce LGO with pyrolysis temperatures as low as 270˚C.

Carbon Budget and Management for Eastern Asian Grasslands

by Yuling Fu

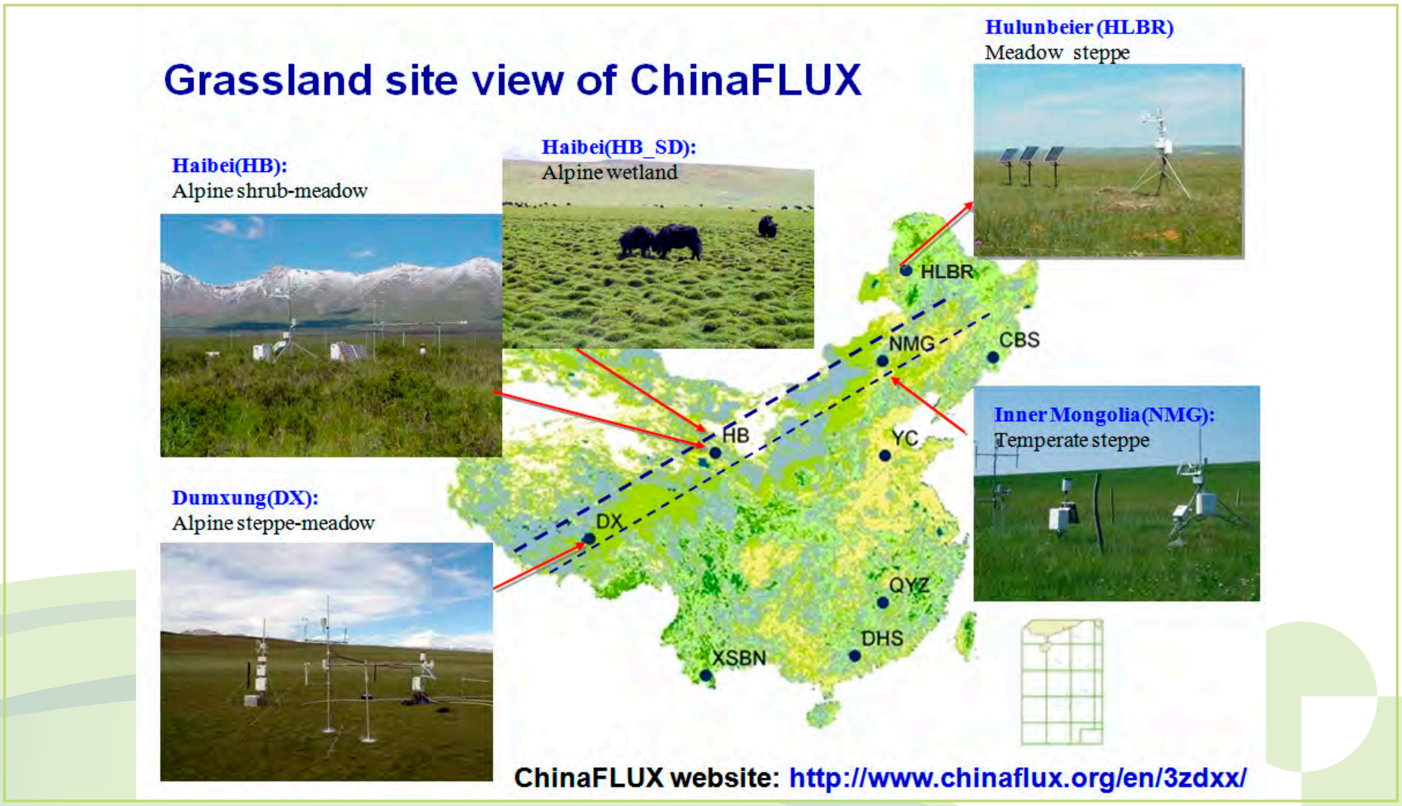
Dr. Fu *is an Associate Professor at the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences.*

There is clearly a great deal of uncertainty regarding the role of grasslands in the global carbon budget, and the drivers of CO_2 flux dynamics differ among a range of grasslands under various climatic conditions and management practices.

There is evidence that some grasslands can be significant sources or sinks of atmospheric CO_2, while others are carbon neutral. Studies have shown that the annual amount and the timing of precipitation remain dominant factors in the CO_2 exchange in temperate semiarid and Mediterranean grasslands.

There are large areas of temperate and alpine grasslands in East Asia. The temperate steppe represents one of the typical vegetation types on the Eurasian continent. This ecosystem is more xeric and water stressed than many other ecosystems and is ecologically fragile and sensitive to climate change (Li et al., 2005; Niu et al., 2008). An experimental study has found reductions in CO_2 flux under warming, whereas increased precipitation stimulated ecosystem CO_2 fluxes and also alleviated the negative effects of warming on net ecosystem exchange (Niu et al., 2008). Meanwhile, alpine meadow ecosystems also cover a large area with high soil carbon density (Ni, 2002), which may have played an important role in global carbon cycles.

Studies have indicated that alpine meadows are highly sensitive to temperature change (Kato et al., 2006) and may have significant potential for releasing CO_2 under climatic warming because of the sensitivity of frigid soil to warming (Wang et al., 2002). In our presentation, we give a general overview of carbon budgets in grassland ecosystems and the effects of climate change and human disturbance on the carbon budget of grasslands in eastern Asia, which will help provide scientific support for sustainable management on grasslands in East Asia.



Refractory Organic Components in Chinese Arable Soil: Indication for Carbon Sequestration

by Xudong Zhang

Dr. Zhang *is a Professor at the Institute of Applied Ecology, Chinese Academy of Sciences.*

Historically, before people began to farm the land, soil organic carbon (SOC) content was relatively constant. With the introduction of intensive agriculture and conversion of grassland to agricultural land, levels of SOC declined over time along with management changes. At some point, we should see improvements in agricultural practices that will allow SOC to rebound. The level of improvement will depend on system management and offsetting practices such as no-till agriculture, cover crops, and diverse crop rotation. Without offsetting practices, SOC will continue to decline.

The Chinese agricultural ecosystem has used conventional tillage systems for a long time, 50 years or more. Our conventional tillage system is very different from that of the United States, where most plant residues remain in the soil. In China, almost all plant residues are removed from the land, especially in northern China, where winter is very cold, there are few other energy sources, and farmers have to burn plant residues for cooking and heating. This removal of materials from the land leads to soil degradation. In the soil horizon, the sequence of organic matter is rising. Once, this soil horizon was very thick, about one meter. After cultivation for 20, 40, or 80 years that horizon has shrunk significantly. The same was true in the United States in the 1930s.

Wind and water erosion are particularly severe in northeastern China, which has what is called a monsoon climate. Most precipitation occurs in summer during June, July, and August. Heavy rain and strong winds lead to serious soil erosion. Because the land is bare, even when the slope is not steep, if there is no vegetation cover, water flows easily. The soil quality along that slope is different from top to bottom, but the soil is tilled all along the slope, leading to serious erosion.

To meet the need for increased agricultural productivity, and since the land is so degraded, farmers over time have used a great deal of chemical fertilizer. From 1961 until the present, the amount of fertilizer applied to the soil increased dramatically and is expected to continue to rise through 2021. Before 2000, increases in the yield of crops paralleled increases in fertilizer application. After 2000, crop yield did not keep pace with increased levels of fertilizer. Even though chemical fertilizer use increased, production began to fall.

In the future, as our population continues to increase, we will need to produce more food. There are limits to our ability to increase food product, however. We can use more fertilizer or perhaps we can use new technologies. I do not think just by adding fertilizer we will see increases in production like those we saw over the last five decades. Instead, we must find ways to restore soil quality and soil fertility.

Increased use of nitrate fertilizer has led to eutrophication of water and nitrate accumulation in groundwater in addition to soil degradation. We see widespread eutrophication of water throughout China, even in very large lakes. More than 70 or 80 percent of groundwater is contaminated by nitrates.

To solve these problems, we have to find new ways to manage the land. Consider that in China no-till agriculture is very limited, and only small experimental areas are being used to test the method. The practice has not been adopted by real farmers.

To restore soil organic matter (SOM), we can either apply organic manure or we can change our tillage system from conventional to no-till systems. We can, of course, quantify the total SOC, but we can only know the amount of carbon retained and sequestered, not how the carbon may have changed, which affects the ability of plants to use the carbon. If we want to understand more about what is happening to SOC, we need to study different organic compounds from different sources that are indicative of the transformation processes.

CARBON RETENTION AND SEQUESTRATION

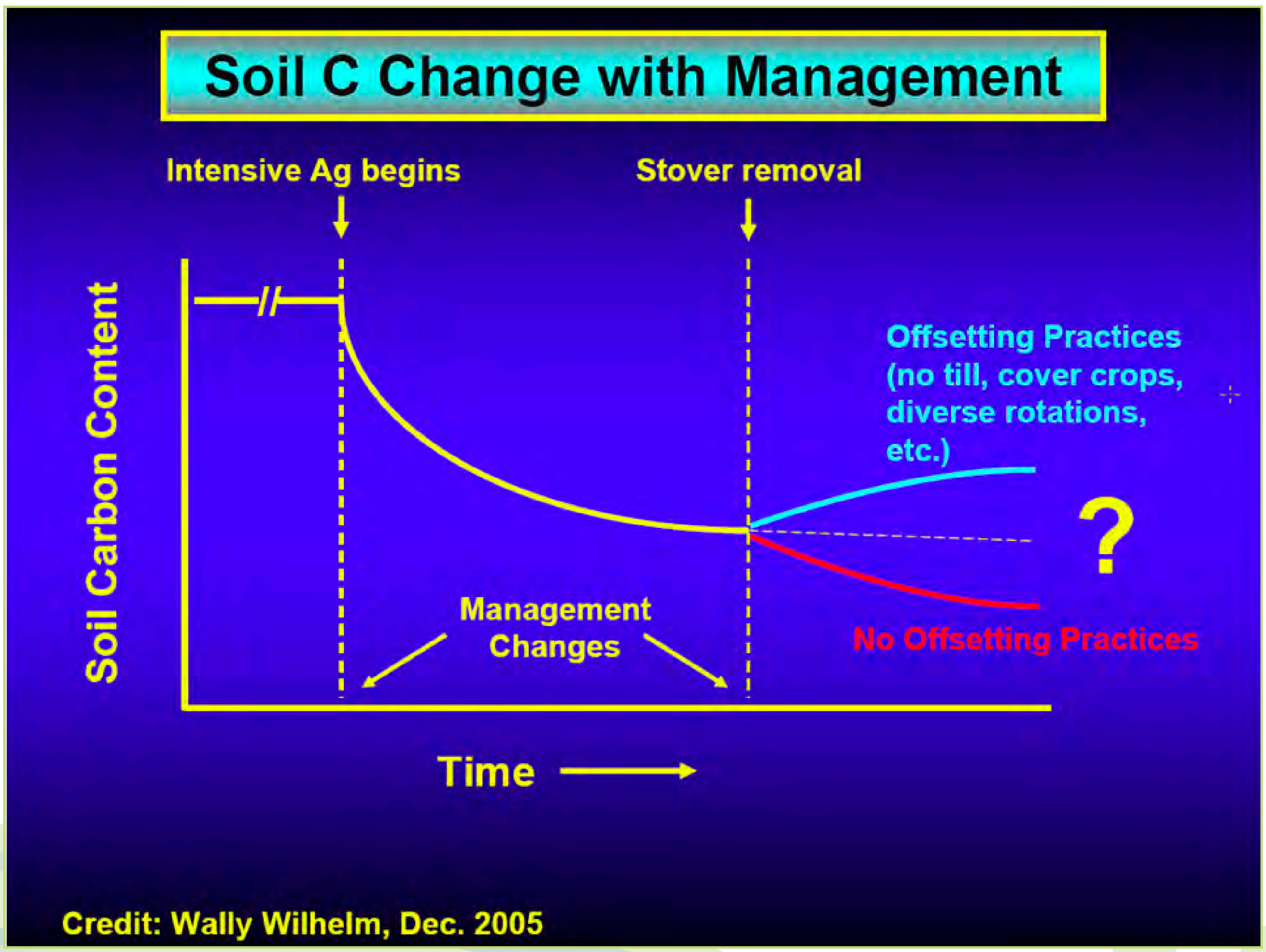
Researchers with the Institute of Applied Ecology have for a long time been studying SOC in the Chinese Mollisol region of northeastern China. Mollisols are soils typical of prairies and, prior to intensive agriculture, had high levels of organic matter. Farming over the past decades has led to declines in SOM and SOC. In a recent study, we collected about 1,050 samples from the whole Mollisol area and determined the SOC concentration. We found an abnormal distribution of carbon and nitrogen in the samples, an indication of changes in SOC.

As one of the essential management approaches to maintain and increase SOC sequestration in agroecosystems, fertilizer applications influence the turnover of both labile and refractory SOC components significantly. Refractory SOC components especially are crucial to carbon cycling and sequestration.

Lignin is a predominant component of the refractory SOC pool; thus, the dynamics of lignin in response to fertilization regimes were used to examine the stabilization of plant-derived carbon in arable soils. We have investigated the impacts of long-term fertilizations, for approximately 30 years, on lignin content, distribution, and degree of degradation in Chinese Mollisols in northeastern China under a cropping system of continuous maize.

Long-term inorganic fertilizer applications exhibited no significant effect on either lignin content in soil or on the relative accumulation of lignin in SOC in 0-20 centimeters of soil depth. However, the accumulation of lignin was markedly enhanced, while degradation was evidently retarded, after long-term organic fertilization and combined applications of inorganic and organic fertilizers, suggesting the stabilization of lignin in these cases. Simultaneously, the degradation of lignin in the Mollisols was evidently retarded after organic fertilizer application.

We also found that the turnover kinetics of soil lignin was particle-size specific. Regardless of fertilizer management, the silt fraction was the predominant storage pool, representing over half of the lignin phenols. The undecomposed lignin phenols derived from root stubble and manure were inclined to be preserved in course fractions, while the lignin monomers decomposed by soil microorganisms and ligninolytic enzyme preferred to be stabilized in fine fractions. This suggested that the transformation of lignin mainly occurred in the clay fraction and thus the stability of lignin was enhanced through the interaction between SOC and soil minerals. In conclusion, stabilization of lignin in course fractions is crucial in terms of carbon sequestration in arable soil.



Clostridium thermocellum Ethanol Stress Responses and Tolerance Mechanisms

by Steven D. Brown

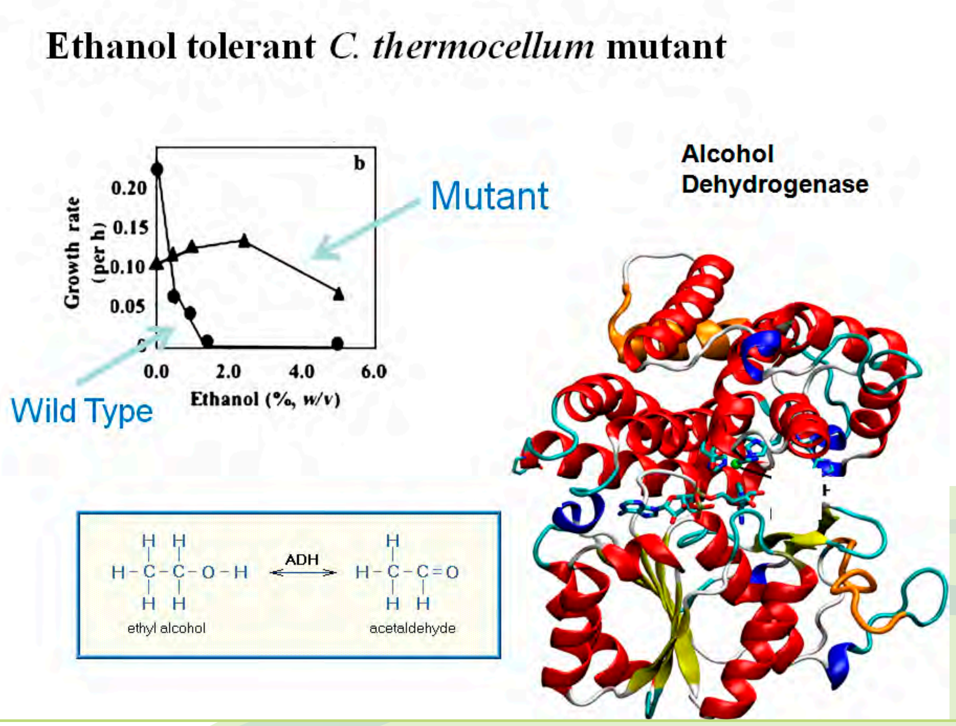
Dr. Brown *is a Research Scientist in the Biosciences Division and the BioEnergy Research Center, Oak Ridge National Laboratory.*

Clostridium thermocellum, a candidate industrial biocatalyst for cellulosic fuel ethanol production, is relatively sensitive to ethanol compared to current industrial yeast, and relatively little is known about its physiological response and the coordinate regulatory response to ethanol. In this study, the wild-type *C. thermocellum* ethanol stress response was dynamic and involved about 500 genes that were significantly differentially expressed between different conditions over time via microarray, which represented every functional category.

Cellobiose was accumulated within the ethanol-shocked *C. thermocellum* cells, as well as the sugar phosphates such as fructose-6-P and glucose-6-P. The comparison between intracellular metabolites, proteomic, and transcriptomics profiles is discussed. The integrated responses lead us to propose that *C. thermocellum* may utilize nitrogen metabolism to bypass the arrested carbon and energy metabolism in responding to ethanol stress shock, and the nitrogen metabolic pathway—especially the urease genes and redox balance—may be the key targets for ethanol tolerance and production improvement.

We also resequenced the genomes of several independent ethanol tolerant mutant strains using microarray comparative genome sequencing (CGS) and next generation sequencing (NGS)-based approaches to gain fundamental insights into process related traits and compare approaches. Genetics data showed mutations within the alcohol dehydrogenase gene (*adhE*) conferred the enhanced mutant ethanol tolerance phenotype and provide insights into this complex phenotype. AdhE biochemical and modeling studies are underway to provide further mechanistic insights into ethanol tolerance.

Source: Abstract. China-US Program Book. China-US 2011 Joint Symposium.



Assessment & Design of Sustainable Processes

Resilience Analysis of Biofuel Production Systems

by Suresh Rao

Dr. Rao *is the Lee A. Rieth Distinguished Professor (Ecological Engineering) in the School of Civil Engineering, with a joint appointment as Distinguished Professor (Ecohydrology) in the School of Agriculture, at Purdue University.*

The Fukushima nuclear power plant disaster, flooding caused by Hurricane Katrina, major flooding of the Mississippi River, the *Deepwater Horizon* oil spill, the mortgage derivatives crisis, and failure of a major biofuels company are all examples of natural and man-made crises. These events have renewed interest in the concept of *resilience*, especially as it relates to complex, coupled systems vulnerable to multiple or cascading failures.

Most of these events have catastrophic and long-lasting consequences as a result of unexpected (low probability), high-magnitude, high-consequence events. Here, the complex system of specific interest is the industrial system for biofuels production, which is closely connected to, inter-dependent on, and/or has direct or indirect impacts on several other complex systems: 1) hydro-climatic systems such as rainfall patterns and net radiation; 2) biomass production systems such as landscape and cropping systems used to grow biomass; 3) aquatic and terrestrial ecological systems; and 4) socio-economic systems such as energy markets and subsidies. External drivers of each of these systems are comprised of deterministic and stochastic controls, and as such the internal dynamics of these systems and the emergent overall dynamics are subject to stochastic variations, making predictions uncertain.

The definition of resilience of a particular biofuels production plant or the entire industry is adopted from an ecological context: resilience is the capacity of a complex, coupled system to adapt to changing conditions without catastrophic loss of function outside acceptable bounds. I depart from other approaches to engineering resilience by more clearly differentiating the concept of resilience from that of risk analysis as a design principle. In addition, I contrast ecological resilience strategies with those typical of engineering resilience.

An idealized model of resilience management includes: sensing, anticipating, learning, and adapting. From this perspective, resilience analysis can be understood as differentiable and complementary to risk analysis, with important implications for the adaptive management of complex, coupled ecological-engineering systems. In a companion paper, we present a mathematical analysis of a biofuels plant, and show how resilience analysis helps in design and management of biofuels plants.

See: Jeryang Park, Modeling Resilience of Biofuels Production as a Complex, Coupled System: Implications for Design and Management (next page).

Modeling Resilience of Biofuels Production as a Complex, Coupled System: Implications for Design and Management

by Jeryang Park

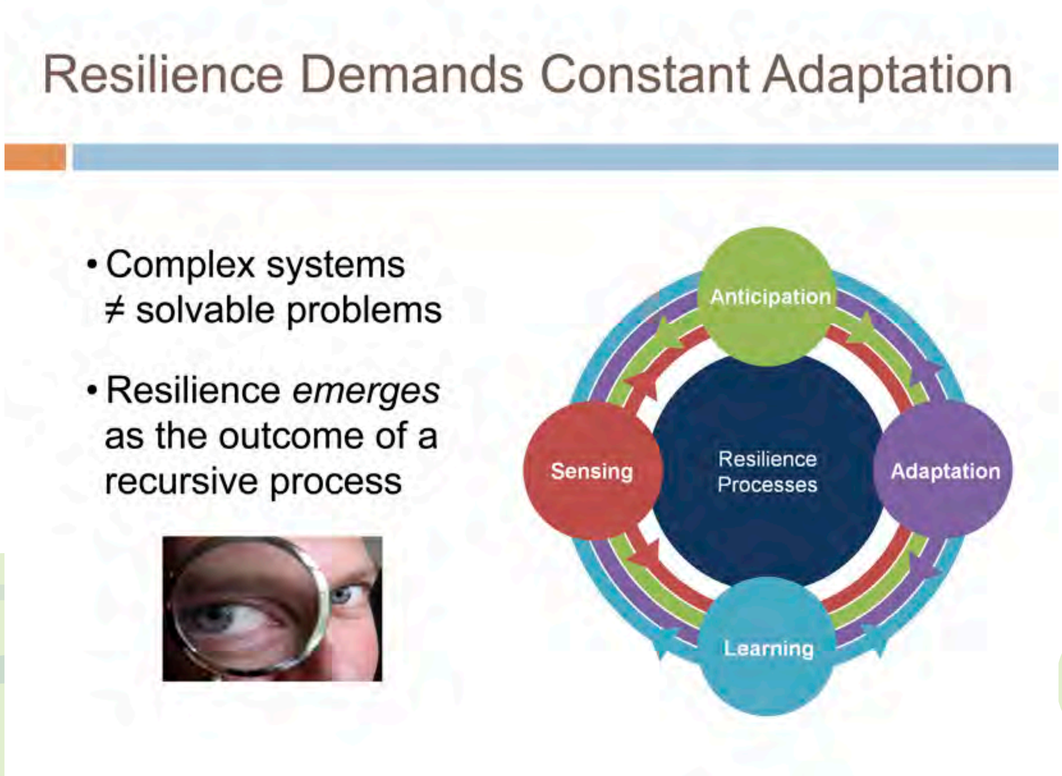
Mr. Park *is a Ph.D. student in the School of Civil Engineering at Purdue University.*

Resilience represents an alternate design and management strategy for responding to unknown and unexpected threats by adaptation and anticipation. In highly complex and turbulent environments, the classical approaches, such as risk management and optimization for eco-efficiency—which form the basis for risk predictability and system stability—are not sufficient for designing a sustainable industrial system.

Recent failures of rigidly built industrial systems caused by unpredicted natural and man-made disasters highlight the inadequacy of conventional approaches and call for a resilience-based approach. Accordingly, resilience has been increasingly acknowledged as an essential feature of complex, coupled systems for sustainability. Nonetheless, it has not yet resulted in practical methods for application of the concept within existing design approach.

We propose an adaptability of a system as a critical factor that maintains the system's crucial functions under chronic and acute perturbations, and thereby determines the system's resilience. We propose a model prototype for measuring the adaptability of complex industrial systems. The model is inspired by ecological analogs. The biofuels system is conceptualized as multiple, inter-connected filters, all of which have inherent ability to *adapt* and absorb unpredicted external perturbations.

A simple model is introduced for describing the system dynamics to examine its adaptability and the resulting resilience. Since specific adaptability strategies are contingent upon variations in system structure, diverse and flexible approaches are needed for process design and operations to facilitate different degrees and types of adaptability. We present initial results for biofuels production as the case study, and discuss the implications of our model simulations.



Life Cycle Assessment of Potential Aviation Biofuels Production in the United States

by Datu Agusdinata

Dr. Agusdinata *is a Research Scientist at Purdue's System-of-Systems Laboratory and the Division of Environmental and Ecological Engineering.*

The percentage contribution to greenhouse gases (GHGs) by the aviation sector in the United States is currently not very large, about three percent, compared to the contribution by the total US transportation sector of about 11 percent. Aviation emissions, however, could have a very significant impact on GHGs in the future for two reasons. First, the impacts of emissions, especially particulate emissions, at high altitudes are poorly understood. We do not know, for example, what effect the condensation trail that aircraft produce will have on climate change. Second, aviation is one of the fastest growing sectors of the worldwide transportation industry. China's contribution alone to the growth of aviation between 2010 and 2030 will outpace that of most other countries. Therefore, though contributions of aviation to GHGs are relatively small for now, the fast growth of the industry and the uncertainties of high altitude emissions will rapidly become more significant.

BIO-JET FUEL

There is consensus that aviation biofuels will be instrumental in achieving the proposed US government's 2050 goal to reduce emissions of GHGs by 50 percent compared to the 2005 baseline level. Some flight tests have been successfully conducted using bio-jet fuels; however, no commercial-scale aviation biofuels production facility yet exists.

The chemical composition of typical jet fuel includes paraffins, aromatics, and olefins. The airline industry requires a replacement or drop-in fuel with a similar composition so there will be no changes to engine design. The current aviation biofuels lack certain compounds found in petroleum-based fuels, especially the aromatics. That causes some problems. First, although the aviation biofuels have higher energy content per mass of volume, they have lower density; second, without aromatics there could be some leakage problems in the fuel tank of an aircraft. The standard specification for aviation turbine fuel containing synthesized hydrocarbons is a fuel that consists of a 50/50 blend of aviation biofuels and petroleum-based jet fuels, the formula that has been used in successful test flights.

In our study we considered the next generations of biofeedstocks. Second and third generation feedstocks include those that contain oil, such as camelina and algae, and lignocellulosic biomass feedstocks such as corn stover, switchgrass, and short rotation woody cops. We also considered for production purposes only marginal agricultural lands. These marginal lands are estimated to produce only half the yield of more-productive land.

LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) is an accounting tool used to measure the environmental impacts of a product or service from cradle to grave. To cite a simple example, this methodology can be used to compare the environmental impact from the lifecycle perspective of using paper towels or an electrical hand dryer to dry your hands. An LCA for aviation biofuels takes into account the life cycle stages, all the processes needed to produce bio-jet fuel, including carbon and nitrogen cycles.

A traditional LCA, however, is technology oriented; that is, it can determine a good technology from an environmental point of view, but it cannot say whether or not the technology will be adopted by consumers or users. To address this issue we proposed a Multi-Actor Lifecycle Assessment, which allowed us to explicitly consider the decision-making criteria of all the actors in the life cycle stages of the aviation biofuels. The expected result of this assessment is a better estimate of the level of adoption rate and emissions impacts.

At Purdue, we have also developed a model of bio-jet supply and demand. The actors in this model, in other words the people and organizations that make decisions, include policy makers, airlines, biorefineries, and farmers. Other factors to consider are international policy drivers such as global emission reduction targets and international carbon prices. National policy measures that factor into the model are legislation, regulations, the national carbon price, market incentives, subsidies, and fuel certification standards.

This is essentially a top down model. It also includes the technological learning curve, which implies that as more fuel is produced, production costs will decline. Furthermore, the model considers land constraints and time-delay variables to assess other dynamics in the calculation of GHGs emission impact.

Our first results assess unit emissions of GHGs as measured in a functional unit: grams of carbon dioxide equivalent per megajoule of energy (CO_2 e /MJoule). Emissions drivers include fertilizer (camelina), fossil fuel (algae), soil organic carbon sequestration (switchgrass and short-rotation woody crops), and carbon credits from co-products (all feedstocks). The benchmark for the typical petroleum-based jet fuel is lower than 85 CO_2 e /MJoule.

Looking at production cost results per unit, we consider land costs for five feedstocks: camelina, corn stover, switchgrass, short-rotation woody crops, and algae. For camelina, land cost is a major driver. For algae, capital cost is a prime driver. In all these considerations, uncertainties are high, but they are highest for switchgrass and short-rotation woody crops.

Results for our economic viability assessment included profitability measures such as production cost, net present value, and internal rate of return. The viability of a certain feedstock for aviation biofuels production is highly dependent on the price of oil. Based on the criteria for the economic viability assessment, we used our model to simulate the penetration level for each feedstock under a high oil price scenario through 2050. In this baseline case, corn stover will be the most dominant feedstock over the course of this century. Camelina, like corn stover and camelina, has lower production costs and is therefore more viable early in the 21st century, but algae will become more viable as a feedstock by 2040, and the woody crops will remain fairly low in viability through 2050.

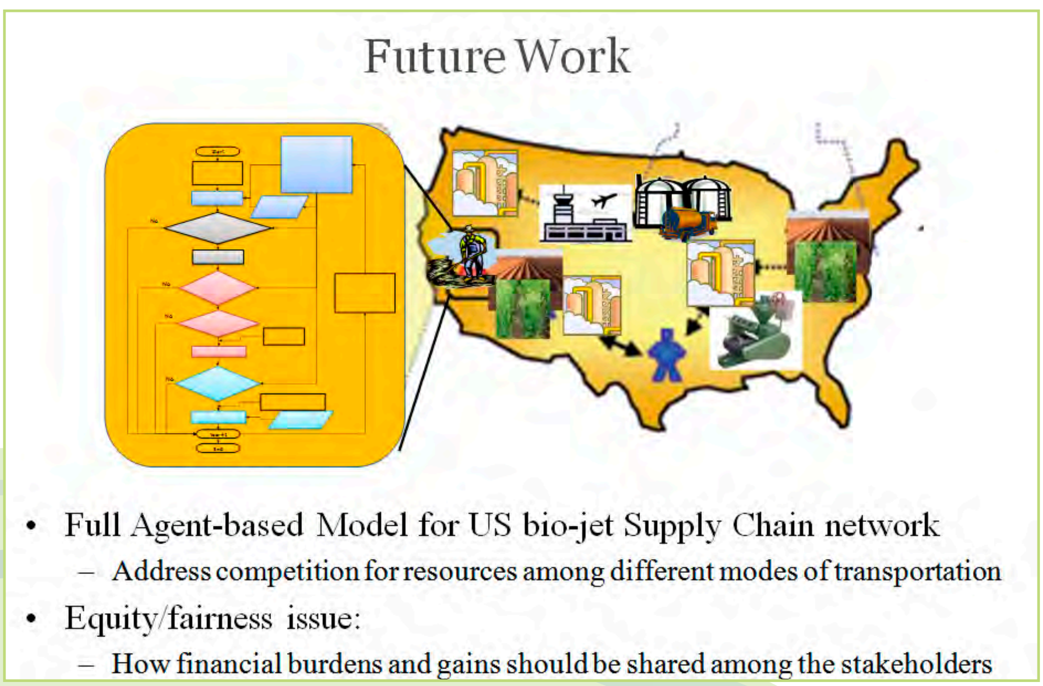
We also looked at the evolution of US future aviation life cycle emissions under three projections using historical trends in oil prices and a low and high oil price scenario. By 2050, emissions levels are projected to be 71 percent of the 2005 baseline level if oil prices are high, 128 percent if oil prices continue their current trends and assuming the fuel will be derived from camelina. If oil prices are low, there will be no viable aviation biofuels.

Our uncertainty analysis under the high oil price scenario indicated that by 2050 the target of a 50 percent reduction in emissions cannot be achieved by bio-jet fuels alone. These are the kinds of results we obtain using supply/demand logic that includes actor decision criteria in the models.

In conclusion, it is obvious that aviation biofuels alone cannot lead to achievement of the US policy goal. The most influential factors are the price of oil and the availability of land. In our study, we looked only at marginal lands with low productivity and low yield. In the future, we might develop better strains of feedstocks for these marginal lands. If aviation biofuels are to become viable, we may need to relax the 50/50 blend requirement. To that end, we should address the problem of lower density and lack of aromatics compounds of potential bio-jet fuels.

We also need to mention some of the limitations of our model, which looked only at next-generation feedstock and US production capacity. Some of these feedstocks might be imported from Canada or overseas. We also cannot rule out the continuing contributions of first generation feedstocks. And lastly, farmers' decisions might play into future scenarios, for example if they decide to grow feedstocks on more productive agricultural cropland rather than on marginal lands.

Our work at the System-of-Systems Laboratory at Purdue gives us a basis to develop a fully agent-based model for a US bio-jet supply-chain network, a system that would also address competition for resources among different modes of transportation. Such a model would also allow us to address equity and fairness issues. Consider, for example, the current assumption that additional costs from rising oil prices initially fall on the airline industry but are passed on to the ticket buyer. Is that fair? We can use this new framework to explore ways in which financial burdens and gains should be shared among multiple stakeholders.



Tunable Catalysts for a Sustainable Future

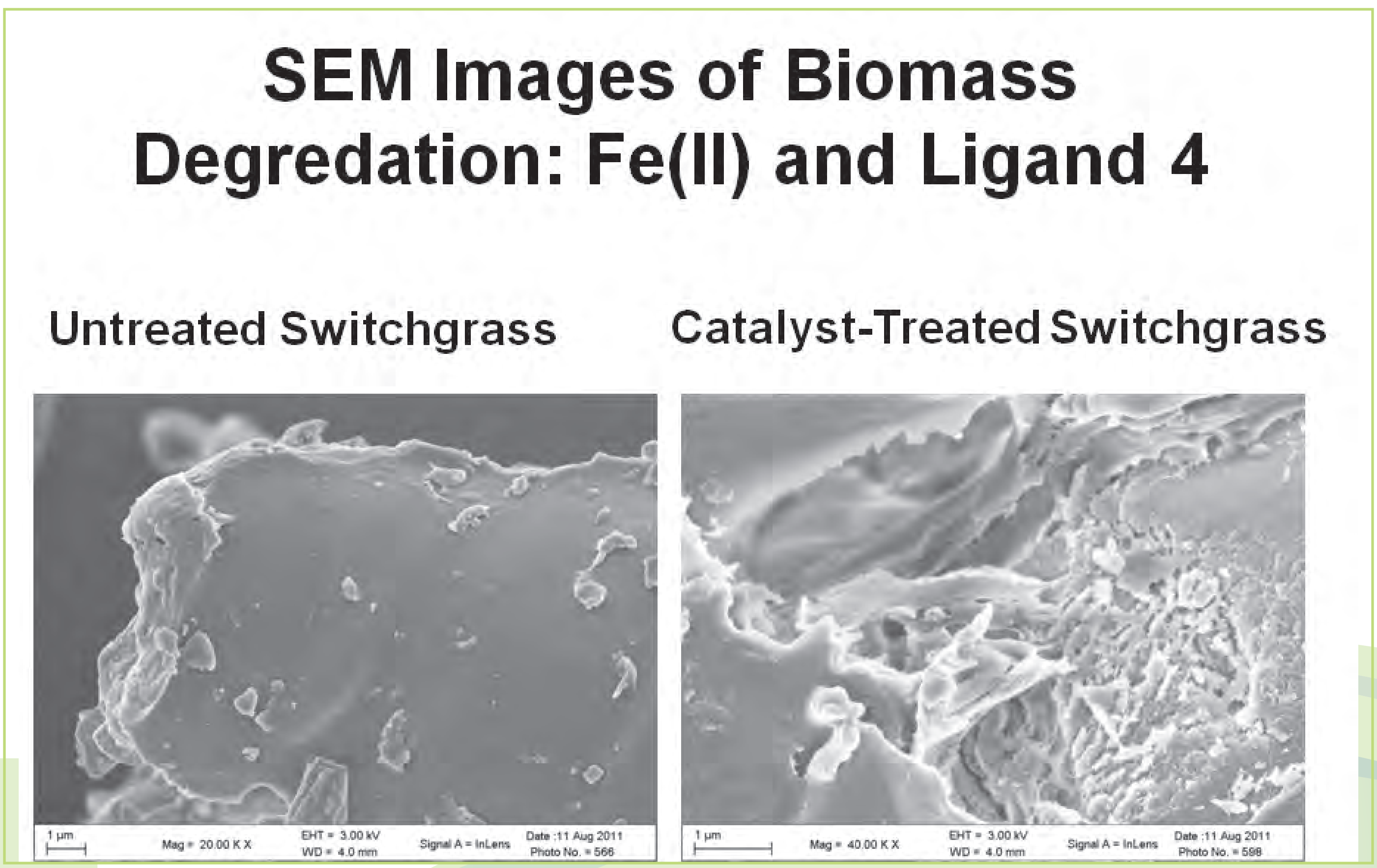
by Shane Foister

Dr. Foister *is an Assistant Professor of Organic Chemistry in the Department of Chemistry at the University of Tennessee.*

One of the greatest challenges facing contemporary science is the development of sustainable processes for the production of fuels and materials currently derived from non-renewable resources. Ideally, this move to sustainable inputs should also address the environmental impacts of new processes on the environment. My colleagues and I are conducting research on the development of functionally distinct families of catalysts derived from complexes of structurally-related heterocyclic ligands with non-precious transition metals (NPMs).

The chemical features of the ligands and the identity of the bound metals govern the selectivity and activity of a particular catalyst for a particular chemical process. Thus far we have identified catalysts for a diverse array of processes including synthetically-useful cycloadditions, hydrocarbon oxidation, and biomass conversion, all derived from a conserved set of ligands.

Our most promising catalysts for the conversion of biomass are derived from complexes of 1,2,4-triazoles with manganese and iron. We hypothesize that these species function via an oxidative depolymerization of the lignin components of biomass, yielding value-added organic products in addition to cellulosic materials suitable for existing downstream applications. Reactions with several types of raw biomass, including switchgrass, hardwoods, and softwoods, as well as with isolated lignins have been conducted in aqueous solutions at temperatures at or below 60 °C, using hydrogen peroxide or molecular oxygen as co-oxidants. Substrate preferences, optimal reaction conditions, and product distributions seem to be inherent to particular classes of catalysts.



Societal Issues in Achieving a Sustainable World

The Relationship Between Narrative, Patterns of Thought, and Public Policy: Changing the Ecological Debate by Re-narrating Human Subjects as Inhabitants

by Robert Marzec

Dr. Marzec *is a Professor of Ecocriticism, Postcolonialism, and Global Studies in the Department of English; and a Faculty Participant in the Center for the Environment, Discovery Park, Purdue University.*

Ecocriticism is an interdisciplinary area of study that applies the techniques of literary analysis to environmental issues. One aspect of the field is an attempt to generate analysis of the environmental movement in relation to public policy. In my research, I study narrative—the way in which information is collected and disseminated to the public—and the reaction of the public to that information. This also involves an examination of the ways in which narratives generate patterns of thought, and philosophies or "world views" of how a culture, a political regime, a nation, and an international community relate to, constitute, and change their ecosystems. Two forms of ecological world views I will address stem from two different locations: one local and one global.

The particular example of a global world view informed by a particular narrative or pattern of thought that I will consider arises from the narrative of climate change generated by the United Nations Intergovernmental Panel on Climate Change (IPCC)—specifically its Fourth Assessment Report, *Climate Change 2007*, an extremely important document that attempts to generate a global consciousness of ecological concern about climate change. The IPCC has taken a scientific approach to this goal and yet has had, due to the continuing pressures of climate change deniers, little success in convincing the public that climate change is undeniable. The inefficacy of the IPCC's narrative is due, in part, to 1) the relentless counter-narrative being deployed by climate change deniers, and 2) the equally powerful narrative of what we might clumsily call the "hearing all sides of the argument" narrative. This second narrative controls and directs the public consciousness when it comes to many political concerns, and suggests that all narratives and the world views they generate that depict and influence reality are equally justified.

In my work, I engage in an ontological and historical analysis of these various narratives and the patterns of thought that generate them, in order to reveal their potentialities and limitations. In doing so, we can more successfully generate a public consciousness that attends to the needs of our current ecological situation. More specifically, I explore what I refer to as the concept of inhabitancy—that is how humans relate to, and are indissolubly part of, an ecosystem—as one way to reconcile the conflicts and barriers to producing a more ecologically sound public consciousness and political policy. The concept of inhabitancy is important because it speaks more directly to an understanding of how to think about human beings in relation to a "whole systems" approach to reality. It constitutes an alternative to customary conceptions of human subjectivity as atomized "individuals" that stand outside or above their environments, a world view that, obviously, inevitably damages ecosystems.

I will briefly discuss how current scientific climate change reports, which attempt to change public and political environmental policy, tend to overlook this crucial element of human subjectivity, and the significant influence that narratives and world views of ecological representation have on people's relations to the issue of climate change.

A GLOBAL APPROACH

I will focus on one climate change report, the Fourth Assessment Report produced by the IPCC. The product of some 500 scientists, the Fourth Assessment Report is perhaps one of the best examples of peer-reviewed documents ever produced. The report was subject to the scrutiny of 2,000 expert reviewers representing over 50 nations and more than a dozen international organizations. The report confirms that global warming is unequivocal, and that it is the result primarily of human activities.

The report was produced in part to give concrete, authoritative advice to the international body established to address global warming, the United Nations Framework Convention on Climate Change. Many of its projections are grim. By 2020 some 75 to 250 million people in Africa will be exposed to increased water stress. In some African countries, agricultural yields may be reduced by 50 percent. Water security will intensify in southern and eastern Australia and in New Zealand. Water resources will decrease in sections of Africa, Asia, Europe, and elsewhere. By the middle of the 21st century, the eastern Amazonian forest will become a savannah. The melting of polar ice caps will cause sea levels to rise and produce a flood of migrants, of "climate change refugees" across the planet. The Maldive Islands, home to some 400,000 people, will soon be the first nation on the planet redefined—in its very disappearance—by this new category of environmentally dispossessed human subjectivity. At the 2010 Cancun Climate Change Conference, 43 island nations announced they face the end of history. These issues are at the forefront of a number of human concerns in relation to global climate change. They raise the question of what it means to be an inhabitant on a planet facing unprecedented anthropologically engendered ecosystem transformation.

One might think that the IPCC report would have a profound effect on those in charge of public policy governing social and environmental matters, and on public consciousness; however, political structures, social discourse, and economic interests continue to thwart efforts to legislate environmentally friendly policies.[1] The assessment report, in spite of its attempt to surmount these restraints, oddly contributes to this inability to make a difference. The authors describe the report as "a remarkable achievement, the product of enthusiastic and dedicated scientists devoted to providing scientific information to policy makers." The report, however, is also consciously framed by a series of apologetic statements. These statements are designed to alleviate any anxiety that the conclusions drawn and the suggestions made for policy makers might be contaminated by any particular political agenda. In this way the report overlooks the counterproductive influence of the "hearing all sides" worldview on public and political consciousness, and unconsciously contributes to the continuing generation of an atomized subjectivity that assumes to stand objectively "above," "beyond," and "outside" the fray of "particular interests" that attempt to change an individual's relationship to his or her environment.

We can begin to notice these unexamined forces influencing the character of the report when we look more closely at the general rhetoric of the IPCC. On its website's home page, the IPCC characterizes itself as an organization that produces information that is "policy relevant yet also policy neutral and never policy prescriptive." This declared political neutrality is, on the one hand, the result of the objective, fact-oriented work of the broad scientific community. But there is something else in operation here. The rhetoric of the report attempts to say that the authors have not succumbed to any particular ideological vision of human ordering; instead, the report is supposed to transcend ideological agendas.

In its attempt to urge governments to work together, the IPCC presumes to speak across nations and across the planet about the environmental crisis, a worldwide phenomenon. This interpretation, however, misses something crucial about the ontological makeup of our contemporary global, ecological occasion. The report should more precisely be read as symptomatic of a larger structural problem: the inability to theorize the significant influence that world views and particular (anti-ecological) forms of human subjectivity (such as the anthropocentric individual who cares little for complex ecological relations) have on our ability to produce genuine political change.

In my discipline, when we use the term political, we are referring to: 1) the common understanding of politics (party politics, conflicting political agendas, legislation, etc.), but also more importantly 2) a kind of activity that transcends the limitations of an established mode of existence (that is, "the political realm" is ostensibly the realm that promises us all that we can make a change, hopefully a change for the better). So the report wishes to be political in the sense that it wants to produce a change, but at the same time the authors want to avoid being accused of espousing a political agenda. This neutrality—no political agenda—is part of the pattern of thought that assumes change can only be made from a standpoint that lies above particular beliefs. I suggest that this particular standpoint is part of the problem, not part of the solution. I want to suggest that *every* report has an agenda or standpoint, and that having an agenda should not be interpreted as an unwanted method of procuring political transformation. In fact, the more one foregrounds their agenda, the more one reveals the limitations of the other fellow's agenda—in this case, the agenda that attempts to deny the impact that humans have had on our environment, which is also the agenda of the atomized, anthropocentric individual, not the agenda of inhabitants who understand themselves to be intimately connected to and influencing their environments.

Most people are suspicious of politicians because they have an agenda that is not based on scientific fact. This stems from the two different meanings or interpretations of the term political, and the particular understanding of the political as always being overtaken by a counterproductive agenda, creating a deadlock between making real political change and attempting to transcend a political agenda.

As an eco-critic working in the humanities, I examine patterns of thought that are operative at certain moments in history and in certain communities, patterns that inform, create, and in many cases limit what a culture can do at any particular moment. For instance, we can scientifically gather data on, and analyze the effects of, consumer culture and ecosystems, urban expansion, and the increase in wastes and toxins it brings. But habitualized patterns of thought have created and continue to support the consumer culture that leads to ecosystem degradation. In my work, I analyze the patterns of thought that block real political change, and the pattern of thought that connects productive empirical research and the results of analyses to political neutrality is one mode of thinking that forestalls making changes in policy.

GLOBAL MISCONCEPTIONS

In order to crack this suspension of real political change, we can take two approaches to thinking about policy. One way is to take a scientific stance: gather all the evidence and make an informed rational decision as far as possible in the face of uncertainty. In this way, the IPCC report is exemplary. In attempting to understand the origin of the apologetic tenor in the report, one might attribute it to the extreme pressures put on the IPCC over the course of the last 15 years by conservative politicians, fossil-fuel dependent corporations, and think tanks supported by oil companies that are not concerned about environmental alternatives. Scientists with the George C. Marshall Institute, for example, deny that there is any hard evidence of human caused warming. In 1995, the Wall Street Journal stated that a key scientist working for the IPCC deliberately cleansed uncertainties from his findings to make global warming appear more indisputable. This accusation was proven to be inaccurate.[2] However, the impression that the IPCC cannot be trusted persists, and the fiction that global warming may be a hoax remains solidly planted in the public mind.

How can we break through these limitations and start speaking across these divides to produce a more holistic view without giving up an informed understanding of specifics of the science? First, we need to characterize the IPCC report as a narrative for a population, a story based on the accumulated scientific evidence. As a humanist, I deal with narratives and how they function and influence the ways people think. A story has a frame, a certain selectivity. As narrative, the IPCC report as a story is not neutral; rather, it offers a particular selection of the total story of the effects of climate change across every ecosystem across the planet. It has a clear agenda: change policy so as to address the negative anthropological effects on ecosystems across the planet. Such an agenda, it seems to me, is one that many people would find worthy of espousing. Here the point is not to shy away from being "policy prescriptive," but rather to more forcefully articulate the limitations of a policy that denies our climate is in the process of undergoing dramatic change. One can do this by attending to the situation of those inhabitants living and struggling on the front lines of climate change.

LOCAL ACTIVISM OF THE INHABITANT

Consider a different example of an attempt to change policy, a form of activism we find playing itself out on the local level in various locations around the planet. One example is the environmental activism of Sajida Kahn, a South African Muslim woman and political activist who had spent most of her life in the struggle against apartheid. In the post-apartheid era, she struggled against the ecological and climate policies of the Kyoto Accord, which paradoxically ensured that a toxic landfill just across her street in Durban, South Africa, would continue to remain fully functional. This landfill, known as the Bisasar Road Landfill, is South Africa's largest formal garbage dump. The landfill was created by apartheid bureaucrats in 1980 on the site of what was formerly a nature reserve in a mixed race neighborhood.

The Bisasar site is one of the most active landfills on the planet today. It substantially exceeds the amount of waste emissions considered to be hazardous. Sewage sludge is dumped into the site daily. The decomposition of landfill waste produces heavy concentrations of methane, benzene, toluene, formaldehyde, and other toxic materials, each of which poses short-term and long-term problems to the local community. At high doses, benzene, for instance, causes dizziness, tremors, confusion, unconsciousness, and death. Moreover, long-term exposure to high levels of benzene in the air, according the US Department of Health and Human Services, can cause leukemia. Woman in particular who live near landfills have a fourfold increased susceptibility to cancer. Khan herself died of cancer in 2007 at the age of 55. A survey found that seven out of 10 households in the area reported cases of tumors.

In 1987, the City of Durban promised to close the dump, but it continues to operate to this day. In 2002, a team from the World Bank met with Durban officials, and under the official carbon trading credit system of the Kyoto Accord, the World Bank team convinced local officials to keep the landfill operating an additional seven to 20 years. The World Bank delegates argued that the landfill should remain open because the toxins it produces, such as methane, are a "clean development mechanism." Methane can be reclaimed to produce electricity, a more "environmentally sound" method of producing energy than coal, which produces greenhouse gases.

THINKING INHABITANCY

What can we say about both the IPCC report and its relation to policy, and Sajida Khan's struggle to change policy? The narrative of the IPCC report, of course, is more global in nature, while the second is clearly grounded in the specific environment and community. More importantly, however, the narrative embodies the concept of inhabitancy, a term that arises out of a pattern of thought that at one time was dominant in the West in English common law.

This dominant ontology structured social and agricultural systems during the pre-enclosure era in England. Before the enclosure movement, certain parts of the land under private ownership were considered common land, and by tradition, inhabitants other than the landowner had certain rights to use the land, such as grazing, haying, or gathering fire wood. Through a series of enclosure acts, property owners sought to prohibit such traditional uses.

In the early 17th century, Stephen Gateward began championing the cause of people who had been denied access to the land because of an enclosure act. The enclosure movement allowed landowners to turn the land into private property in order to produce a higher yield. This is a very different view of how people relate to an ecosystem than the traditional view, which ideally encouraged a more sustainable use of the land.

On many occasions, Gateward brought those dispossessed of their land—the result of an act of enclosure by an individual attempting to generate a higher yield for profit—before the court to explain to the judge that they were "inhabitants," that they "had inhabited the land since time immemorial" and on that basis should not be thrown off the land. In most earlier cases, the court decided for the inhabitant, for the dispossessed. Inhabitancy was at the time a legal term and a concept of how people relate to an ecosystem; their subjectivity was thought of in relation to a *habitation*. In the particular case that Gateward pursued in 1603, the court decided the term inhabitant was too vague, too meaningless, and that it should no longer be accepted in the judicial system as a legal term. Gateward and the people he represented lost that case, and from then on Gateward and other litigants lost all cases. The term inhabitant was struck from the judicial system, and over the course of the next century the idea of inhabitant was erased from historical consciousness.

The word inhabitant, from the French, means one who has dealings with, cohabits, dwells, or inhabits a place. The Latin word from which it is derived—habera—means "to be constituted," "to be created," "to be." In other words, in the word inhabitant, the self and an ecosystem are not thought of as unrelated entities. They are thought of as indissolubly related, not as separate but as flowing in and out of one another. The subject is constituted by the environment and also constitutes the environment. Thus the concept of a subjectivity based on the idea of inhabitancy also contains an ethical element—a care for a habitation.

This concept needs to be coupled with the more global approaches currently dominating the issue of climate change. Sajida Kahn's struggle was a struggle to make a global structure recognize its blindness to inhabitance. We are always local even when we are dealing with global issues, and we have to remember this when thinking about the relationship between scientific data and the narratives that constitute our political lives. We should not see this as a limitation, but should in fact use it to our advantage. Sajida Kahn's struggle for a livable inhabitancy is symptomatic of a fundamental limitation that rules in today's world of geopolitics and policy, an ontological framework that I define as environmentality.

ENVIRONMENTALITY

Environmentality refers to the larger, global, structural administration of environmental matters by state organizations and national global actors. Without going into this in detail, basically the term arises from a complex history, extending back to the material and ontological development of post-Enlightenment colonial land relations. The enclosure movement that spread across the planet turned land into private property and changed people into atomized individuals deprived of understanding their meaningful connections to others and a habitation, and destined to live a life of overconsumption in relation to the ecosystems they inhabit. In the face of dwindling resources, the Earth, which has been seen in this discourse of overconsumption as a thing that exists to produce energy for humans, is transformed into an object defined solely in terms of energy security. This environmentality does not include the concept of inhabitancy.

A couple of examples illustrate the way that policy confronts local populations. When politicians deal with their constituency, the local populations are suspicious that global actors are at work. No matter how much information you give them, no matter how much expert knowledge you disseminate, hoping it will trickle down to a lower level, there is always a huge gap and great suspicion. At the local level, people need to think about themselves in relation to the larger circulatory system of an environment. Once we begin to talk to people in those terms, we can change their suspicions about the ways in which new technology could help them meet local needs.

When we begin to think this way, progress is possible. I'll offer one example. The Chesapeake Bay Foundation (CBF) in the Mid-Atlantic region was very successful in getting the word out about environmental threats to the bay. The CBF managed to change the way people thought of themselves as individuals—as subjects disconnected from the environment, as anthropocentric organisms that did not care how they related to their ecosystems. The CBF, for instance, realized that people did not understand that if they lived in New York State and put toxins into their local streams, such toxins would filter down into the Chesapeake Bay. The CBF began to talk in terms of the "watershed" and the "air shed." It also began to foreground the importance of "riparian forests"—a concept that generates a narrative that compels people to think about a space, a location, and an object as indissolubly connected to the expansiveness of an environment.

The idea of inhabitancy encourages human subjects to think of themselves as indissolubly related to their environment. It invites a population to consider new narratives and new forms of technology that can address our current ecological situation, and begins to break through the world views that produce a generalized suspicion of technology. A riparian forest is a complex ecosystem which serves as a transition between the aquatic and the terrestrial. The forest floor bacteria enable denitrification to take place. Shade trees keep water cool and enable streams to retain more oxygen, which in turn encourages growth of algae and aquatic insects. The riparian forest is a buffer system reducing pollutants by 30-90 percent. It is also a functional last line of defense against agro-production and urban development. If we think of inhabitancy in the same conceptual framework that we have of a riparian forest, we could think of new constitution of public subjectivity—of inhabitants—as a last line of defense against the problem of climate change.

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[1] One political body, however, has taken the report quite seriously: the US Military. For specifics on this see my article "Environmentality" in *Radical History Review,* Fall 2011, and the forthcoming article "Environmentality: Military Maneuvers, the Ecosystem, and the Accidental" in *Postmodern Culture.*

[2] The question of "uncertainty" in any analysis is important, for the general public misunderstands the force of uncertainties inherent in any experiment. However, this is an element of the problem of changing policy that unfortunately I don't have the time today to address.

Landscape Ecology and the End of Antiquity: The Archeology of Deforestation in South Coastal Turkey

by Nicholas K. Rauh

Dr. Rauh *is a Professor of Classics at Purdue University and Director of the Rough Cilicia Archaeological Survey.*

Since 2000, the Rough Cilicia Archaeological Survey Project has incorporated research on landscape transformation as a component to its regional survey of ancient Rough Cilicia, located in southern coastal Turkey opposite Cyprus. The project has been funded three times by the National Science Foundation (1996, 2000, 2003) and most recently (2011) by the National Geographic Society.

The region of western Rough Cilicia was celebrated during antiquity for pristine cedar forests that stood between 1,500 and 1,800 meters in altitude along the slopes of the Taurus Mountains. Today, along the front range of these mountains, the forest is completely denuded or otherwise replanted with recent growth in the past 80 years.

The region is very rugged, rising rapidly from sea level to over 2,000 meters at the top of the Taurus Mountains. In terms of agricultural production, it is marginal, but it was famous for its forests, in particular cedar forests, which grow in a very fragile environment near the top of the slope and just below a plateau which is part of the Anatolian Plateau.

The fame of Rough Cilicia is recorded by several sources, including the ancient geographer Strabo, who said that Hamaxia, a town in our study area, "is a settlement on a hill with a harbor where shipbuilding timber is brought down. Most of this timber is cedar. For it appears that this region surpasses all others in cedar wood for ships. For this reason Antony assigned the region to Cleopatra, who used it to construct her fleets." Cedar was very useful for ship building because it is naturally rot resistant.

The current environment in the ecological region of the cedar forest between 1,500 and 1,800 meters is one of extreme deforestation. The area has been replanted, but relic, old-growth cedar forests are rare. The question is, when did the cedar forest disappear?

In the published literature, we find a good deal of ideological bias in answering that question. For example, the current view of most scholars is that deforestation is a recent phenomenon. We know that timber was cleared here just before the advent of World War I to build the Turkish railway that crossed Palestine. Timber was also used to build the Suez Canal at the end of the 19th Century. So the contemporary view is that most of the deforestation has occurred in the last two centuries as a result of mechanization of the timbering industry. In 1980, the Turkish government outlawed the clear cutting of cedar forests. Since then, the government has been replanting cedar.

Another interpretation is that Rough Cilicia might have become eroded during the Middle Ages by various nomadic people, or pastoralists, the Arabs, Turks, and Mongols who migrated into the region at that time. This interpretation relies on a notion that pastoralism is bad and agricultural settlement is good for the environment. It is interesting, though a bit counterintuitive, that there is a perception in both of these views that somehow the ancient society lived in Halcyon times, practicing proper methods and maintenance of the landscape for agricultural and other purposes. This bias presents the ancients as somehow more reasonable than modern people living in the same region. In light of these varying interpretations, we set out to determine when exactly the highland cedar forest of Rough Cilicia disappeared.

CANARY IN THE COAL MINE

We use cedars in our research as the canary in the coal mine, in that we can examine the tree rings of ancient cedar trees and see how many old trees still survive in the Taurus Mountains, and how old they are.

What do we actually know about cedar forest regeneration? First, cedars trees live in a very fragile environment. If left undisturbed, they will live more than 1,000 years. Clearing of cedar trees results in erosion. Topsoil is lost because the environment is very steep and fragile. The land becomes barren rock, after which there is a process of regeneration by colonizing plants, in particular juniper, a tall shrub or tree that is very invasive. In many regions of the Taurus Mountains, juniper remains the dominant species today. Over time, juniper creates a canopy, allowing cedars to return and eventually eclipse the junipers, cutting out the sunlight and creating their own canopy. The question is how long does this take to occur?

Contemporary Turkish forestry scholars who look at this question in laboratory conditions say that under perfectly controlled environments, with no animals getting in to eat the understory, and no wood cutting, it takes somewhere between 160 and 180 years for the cedars to return. Other estimates indicate that, if left to natural restoration, it may take as long as 500 to 600 years for a cedar forest to regenerate.

ARCHEOLOGICAL CLUES

To determine how long the cedar forest would have taken to rebound after it was eliminated, we turn to our own archeological data of development, human and urban, of the region, using evidence obtained from our pedestrian survey of surface pottery remains, or sherds. Based on processed sherd counts, we see that the region was minimally inhabited before the pre-Roman era (ca. 800 to 67 B.C.E.). During this period, Rough Cilicia was inhabited primarily by pastoralists who left no evidence of permanent structures or significant remains.

Following the Roman conquest we see an enormous spike of development during the early Roman era (67 B.C.E. – 250 C.E.) as measured by our counts and by the dramatic rise in the number of occupied sites. In the late Roman era (250-650 C.E.), there is a decline in the numbers of both of these, but enough remains to indicate a significant occupation. By the Byzantine era (900-1100 C.E.), the number of datable sherds and sites declines dramatically.

Relying on a recent theory framed by the 20th century British scholar John Bryan Ward-Perkins (hereafter referred to as the "theory of comfort"), we attempt to assess the accomplishments of Roman civilization partly by looking at the quality of creature comfort it provided to its inhabitants, not only vertically from rich to poor—that is, whether even poor people enjoyed permanent dwellings and other amenities—but also horizontally, or geographically, across great distances, from big cities like Athens to backwaters of the Mediterranean such as Rough Cilicia.

From that perspective, we see that in the Roman era in Rough Cilicia, there were numerous, but relatively small, cities, on the order of 1,000 to 5,000 people. In the built environments we have been mapping, we notice that there are numerous monumental building complexes such as public baths. These all required the construction of permanent architectural space using terracotta roof tiles; baths likewise employed hypocaust systems of furnaces and raised ceramic pylons that enabled warm air to flow beneath the floor to furnish interior heating. Based on the widespread finds of ceramic roof tiles in these built environments, structures large and small, from large bath complexes to domestic houses and animal pens, were constructed with solid tile roofs capable of lasting for centuries. To produce quantities of large roof tiles required heavy reliance on firing technology, that is, ceramic kilns, several of which have been identified in the vicinity.

Another example of the heavy reliance on firing technology in Roman Rough Cilicia concerns mortar-based building construction. It so happens that urban development in our study area came simultaneously with the advent of the use of lime mortar, which was produced by burning limestone, a resource that is readily available in the outcrops of the mountains in the lowlands. Almost all of the buildings in our region were constructed with mortar and rubble aggregate, so again burning was going on in connection with this activity as well.

In addition to terracotta tile for local use, we have found large concentrations of ceramic amphoras, which were used to ship wine and oil produced in this region overseas. These jars show up in Rome and Carthage and even as far away as Oman and the Red Sea. So this region, in the Roman era, was a major exporter of surplus agricultural commodities that were transshipped in locally produced transport jars. We have identified at least three amphora kiln sites in the survey region that produced these jars along with roof tiles , and ceramic basins. In fact, our ceramics specialists have identified more than 160 forms (bowls, mugs, pitchers, basins, pots, fry pans, and casseroles) that were produced in this region.

In addition, we have found evidence of iron mining in the region (including fragments of slag and finished ingots), a technology that requires even higher temperature burning, probably using charcoal. Typically charcoal production in pre-industrial societies required seven units of wood to produce a single unit of charcoal. In short, I think we have underestimated the dependency of urban societies in the Roman Mediterranean and elsewhere on firing technologies to build their permanent habitats. In Rough Cilicia the fuel for this was generated almost exclusively by harvesting the region's available timber.

PALEO-ENVIRONMENT OF WESTERN ROUGH CILICIA

This archaeological evidence of abundant ship and architectural construction, and heavy reliance on firing technology, still does not tell us whether the inhabitants of Rough Cilicia exhausted the available supply of timber. We cannot analyze the forest cover of the lowlands, because those forests (pine, oak, and hardwood) have experienced dramatic changes over time with no relic survivals. All lowland forests are relatively new growth in other words. We rely on the survival of aged cedar trees, a specialized tree that was reserved for unique purposes, as the canary in the coal mine. If it disappeared, we can be fairly certain that the forest in the lowlands disappeared as well.

In our ecological survey, conducted from 2000-2011, we used a number of geo-archeological methods to solve this question: dendrochronology, river basin geomorphology, and palynology, the change in pollen over time as the landscape changes.

Working with Dr. Unal Akkemik, a forestry specialist in dendrochronology at the University of Istanbul, and local forestry agents to lead us to relic forests, little patches of the oldest forests in the mountains, we have examined tree ring samples of more than 50 aged cedar trees at two highland areas, both at 1,700 meters elevation. One site, the Gurcam Karatepe Mountains, is just 15 kilometers from the coast and was connected to a harbor on the coast by a system of roads. The second site, the Biçkici Canyon, is in a more remote area in the back country of the Taurus Mountains.

According to our dendrochronological sampling, the oldest trees in the region are less than 400 years old and represent relatively new growth. Their early dates (by modern standards) nonetheless demonstrate that regional deforestation occurred long before the advent of modern technological logging. The forest was instead depleted at the latest in the late Middle Ages, at least in the niches we documented. Although there are not a lot of these older trees, we did find some clusters that tend to have the same age, within 20 years of each other in terms of their regeneration.

Natural forest regeneration should be stochastic. When trees are found growing all at one time, it could mean that a fire wiped them out. The problem with that scenario is that when cedar trees exceed about 1.5 meters in diameter they are basically impervious to fire.

A more reasonable explanation for these even-aged clusters of trees is clear cutting, which seems more likely in this region. The oldest trees up in the deep part of the mountains are about 100 years older than the ones in the mountains closer to the coast, which would also make sense in that regard. In any event, we were able to show through dendrochronology that deforestation in the area is not a modern phenomenon; though the old growth forests were probably finished off in modern times, their depletion occurred well before modern times.

Another clue to the timing of deforestation survives in changes to the natural landscape, the second focus in our dating efforts. When a cedar tree is cut down, the roots disintegrate within 25 years. The topsoil they are holding on to in this fragile environment comes loose, and especially during periodic flooding, the soil enters the bed load and works its way down to the coast. Accordingly, we have dug geomorphologic trenches in relic river terraces and ancient lagoons in the Gazipasha coastal plain as well as in the tree zone of the Biçkici highland to get a record of alluvial deposition. We try to find carbon, pollen, and macrobotanical residues in addition to a stratigraphical record of alluvial deposition. Only four of these trenches have given results because of very frequent disturbances in recent times, so this is an expensive, hit-or-miss venture, but we do have some results that give a partial answer to our questions. Based on the surviving depositional record, we estimate that about three meters of alluvium have been deposited in the river basin since about 500 C.E.

The information from these trench excavations indicates what possibly occurred at the end of antiquity. Again some things are counterintuitive in the sense that the evidence suggests that alluvial deposition occurred in a time frame when the Roman era population was declining. Some geologists view erosion as a direct and simultaneous consequence of anthropogenic activity such as urban development. In the Rough Cilicia Roman era inhabitants cleared and converted the landscape in the lowlands to an agricultural landscape of orchards and vineyards. They created artificial terraces to maintain the landscape. We hypothesize that once the regional population declined, there would be fewer people to maintain the artificial landscape, and the terraced landscape would have gradually started to erode over time. In other words, Rough Cilician population collapse between 500-600 C.E. possibly triggered landscape erosion due to lack of maintenance. This at least is what our preliminary data seems to indicate. If we tabulate the data in a mathematical way, we find that the overall rate of deposition occurred at a rate of 0.128 centimeters (cm) per century. If we separate the carbon data for the period 654 B.C.E. to 1007 C.E. from the data for the period 1007 to 2007 C.E. (based on our available carbon dates), we see that the rate of deposition during the "ancient period" (654 B.C.E. to 1007 C.E.) occurred at a rate of 0.8 cm per century as opposed to a rate of about 0.13 cm per century in "modern times" (1000 C.E. to present). What strikes me about these numbers is how, in the modern era with loggers employing equipment such as chainsaws, railroads, and trucks, the rate of soil deposition commensurate with regional deforestation is not even double that of the ancient rate of deposition. This suggests again that despite their limited means of technology, the inhabitants of ancient Rough Cilicia made a surprisingly large impact on the landscape before 1000 C.E.

Our geoarchaeological field investigation aims to explore the relationship between forest depletion in the Rough Cilician highlands and the "anthropogene process" over time. Overall, our results show that three forms of anthropogenic disturbance are likely to have influenced the ecology of this highland landscape: expansion and abatement of land clearance for agricultural purposes; demand for shipbuilding timber by Mediterranean maritime societies; and the likelihood that heavy reliance on wood-fueled firing technologies depleted the regional forest cover during the Roman era (1-6th centuries C.E.). Preliminary results indicate that current perspectives about the timing of deforestation in this region are flawed, and that the initial deforestation and erosion coincided with regional site abandonment and population decline at the end of antiquity.


Bickici Kiln Site
Ceramic Production
SPACE IMAGING
Roman Tower
BICKICI KILN SITE


Permanent Structures:
Terracotta Roof Tiles
Local Production

Fighting Poverty with Respect to Land -use Efficiency: An Example from the Most Impoverished Place in China

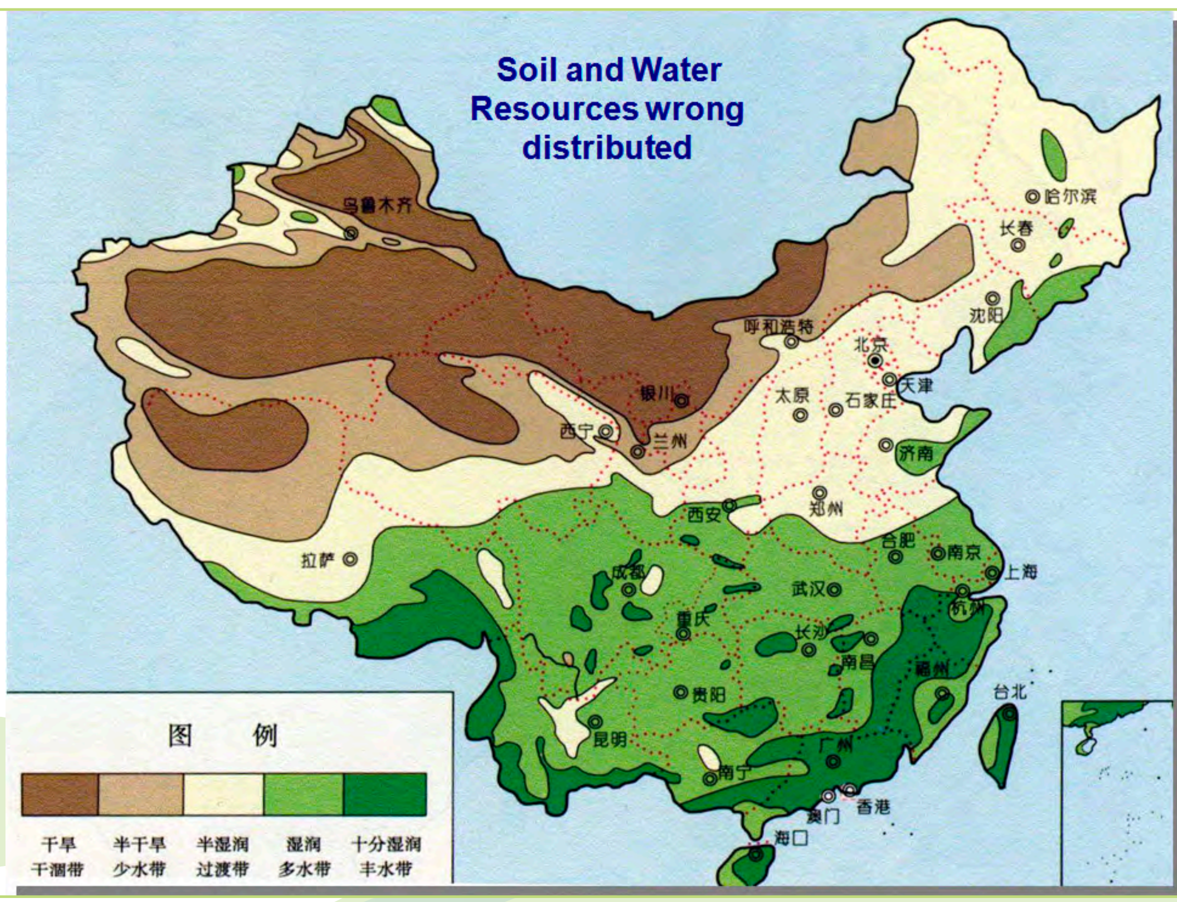
by Yongqing Ma

Dr. Ma *is a Professor in the Department of Watershed Ecology, Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources; and a Professor in the Institute of Soil and Water Conservation, Northwest A & F University, Yangling, Shaanxi Province, China.*

It is an unfortunate fact that soil and water resources in China are poorly distributed. The southern part of China is blessed with a lot of rain, but not much land. In the north, there is a lot of land but not much rainfall. Northern China has 65 percent of the land but only 40 percent of the population. It also contains 51 percent of the cultivated land but only 20 percent of the country's water resources.

Researchers with the Institute of Soil and Water Conservation are working at an ecological research station on the Loess Plateau. The Guyuan Ecological Station was established in 1986 by the Chinese Academy of Sciences (CAS) and has been managed jointly since 1996 by the CAS and the government of Ningxia Hui Autonomous Region. The station has been a scientific research center and student study and experimental base for Northwest A & F University since 2009.

So far, more than 100 scientists have worked at the Guyuan Station, which is located at an elevation of 1,750 meters above sea level. The topography of the area consists of hills and valleys. The annual average temperature is 6.2° C, the hottest month is July, and the monthly summer average is 18.9°C. The coldest month is January, and the monthly average winter temperature is -8.3° C. In this region, except for the wet area of the Liupan Mountains, annual precipitation is around 400 millimeters (mm), and it decreases to 240 mm from south to north. The rainy season is between June and September. Because it is located in a dry area, evaporation is very high, and there is not much ground water for wells. The average water resource per



person is 370 cubic meters, only half of the average for the Yellow River region and only 14 percent of the Chinese national average.

The South Ningxia hilly region includes eight counties with a total land area of 30,500 square kilometers (km^2). The population in 2002 was 2.38 million, of which 60 percent are Muslim. The main social, ecological, and economic problems are soil and water loss, drought, low agricultural yield, population expansion, and poverty. In this region, population density increased from 28.6 persons per km^2 in 1949 to 160 persons per km^2 in 2004. In such a region, the standard population density should be 24, according to the definitions of the United Nations.

Because of heavy population pressures, in the 1980s the local residents could not produce enough grain to feed themselves and so relied on grain support from the national government. In addition, agricultural production has been mainly focused on grain production. The average yield is very low. It is common that in some years the yield is not enough for the next year's seeds for growing spring wheat. This region is the poorest place in all of China.

THE SHANGHUANG EXPERIENCE

From 1980 to 1985, scientists from our institute focused in several different stages on the main problems and restrictions for local development in this region. We first suggested adjusting the proportion of agriculture, forestry, and animal husbandry. Because of the grain shortage, we suggested that farmers apply fertilizer deep in the soil, but there was still more grain production than the land could support.

Five years later, in 1985, as agriculture and animal husbandry increased, a shortage of forage appeared to be the main restriction for development. At that time we suggested artificial cultivation of forage. From 1991 to 1995, a continuous drought occurred, so scientists focused on harvesting rain water with the construction of storage facilities. From 1996 to 2000, because of global warming and frequent spring droughts, we suggested that the local farmers cultivate winter wheat instead of spring wheat. In addition, we encouraged them to use inter-cropping techniques with crops such as vegetables and artificial pasture planted among pear and apricot trees.

From 2001 to 2005, scientists from our institute summarized strategies for development in such a harsh area. Called the "Shanghuang Experiences," the document consists of the following suggestions. At the top of the hilly area, trees should be planted to control erosion. On the sloping land, flat terraces should be built to make dry land farming feasible. In the flat lands and valleys, where the land is more fertile and more easily irrigated, cash crops such as vegetables and fruit trees should be grown. An added advantage is that by doing so, the local farmers could improve their scientific knowledge and increase their income.

The provincial government liked our plan, and the local governor of Ningxia wrote a letter to the CAS saying we were doing a good job and that they wanted the Shanghuang Experience to be popularized throughout the whole province.

About 20 years ago, however, our scientists began to recognize that in the harshest environments, we should not be growing crops at all, but instead should maintain the natural vegetation. We asked the local governor to set aside certain places where farmers are not allowed to graze livestock. These areas where grazing has been excluded have been restored through natural rehabilitation. Because of our contributions, the local government has donated a building for our station staff to conduct research.

Today, local residents understand their environment better. Ten years ago, the central government recognized this, and the Grain-for-Green policy was established. In the South Ningxia hilly region, much of the land devoted to crop cultivation was returned to grassland. Most cultivated grass is alfalfa, however, and there was no local perennial grass to feed animals over the winter. It is well known that cattle and sheep should not be fed a straight diet of alfalfa for long periods of time. Alfalfa is a rich forage legume that can induce illness in livestock. Grass with more fiber is needed to supplement alfalfa.

SWITCHING TO SWITCHGRASS

In 1988, a Japanese professor from Utsunomiya University began to address this problem. Since May 1988, Professor Nobumasa Ichizen has introduced 400 kinds of Gramineae (Poaceae) plants into the Guyuanarea of the Loess Plateau. Switchgrass, a perennial grass, is the only plant that can survive in very dry conditions, and it has emerged as a promising herbaceous perennial feedstock because of its very wide adaptability, high biomass yield, and newly improved varieties.

In 1996, switchgrass cultivation on the Loess Plateau in Shaanxi Province and Ningxia Autonomous Region in northwestern of China began. The area has highly degraded soil in a semi-arid environment (300–400 mm annual rainfall). An extensive selection test of domesticated plant species was performed, and the best growing plant was found to be switchgrass. These efforts to establish switchgrass cultivation have provided a new source of forage for cattle and sheep.

As a supplement to the germanous forage grasses, good varieties of switchgrass can enhance the diversity of local forages and improve soil productivity on the Loess Plateau. Besides increasing forage sources, it can also prevent soil erosion. In 2006, nine cultivars of switchgrass—Alamo, Black Well, Cave-in-Rock, Dakota, Forestberg, Kanlow, Nebraska 28, Pathfinder, and Sunburst—provided by professor Ichizen, were sown by drilling with a soil depth of 3-4 cm in 2006.

Among nine cultivars, most germinated except two lowland, tetraploid cultivars, which did not germinate the following spring. In the spring of 2007, Guyuan experienced a severe, 50-year drought. It was so dry that while switchgrass was being planted, a carrier pigeon from Yinchuan, 330 kilometers away, come to the field and drank tap water that was used for irrigation of transplanted switchgrass. This indicated that there was no surface water available for the carrier pigeon from Yinchuan to Guyuan.

Despite the drought, in fall 2007, local farmers were able to harvest switchgrass plants to feed their livestock.

LESSONS LEARNED

Historically, agriculture in the South Ningxia hilly region was adapted for raising livestock. Population pressure led to destruction of natural vegetation, and government policy forced the local farmers to destroy the forest and grassland and change cropland to grain production, which resulted in an ecological disaster. The government has since recognized the problem and has made efforts to correct it.

Most of the local residents of the region are Muslims, who have a good understanding of their environment. Chinese traditional agriculture puts emphasis on grain crop production, but much of the South Ningxia hilly region is not suitable for grain production.

The local residents realized that intercropping vegetables among fruit trees would not work in such dry conditions, and they gave up halfway through the project. They also found that wheat could not survive drought, but switchgrass grows well even in a dry environment.

The local Muslims are very skillful at marketing livestock. The local village governor told me that with one sheep they can make three families rich. They can raise a lamb for half a year and sell it at a profit to the next farmer who is skillful at making the sheep grow. That farmer can make a profit by selling to a third farmer who has plenty of forage and grains to add more meat and muscle, so by the time the third farmer sends the sheep to market, the profit is even greater.

Over several decades, researchers have tried different approaches to improve agricultural systems, and thus the lives of local residents, in this most impoverished region of China. Our efforts, and the feedback from local farmers, have taught us that it is not possible to return to extensive animal husbandry and uncontrolled grazing. At present, the development of agriculture should be based on a combination of approaches, including production of drought-adapted animal forage that can be fed to facility-raised livestock.

The Efficiency Trap: Why New Technologies Can Never Save the World (and Why Efficiency is No Substitute for Sex)

by Steve Hallett

Dr. Hallett *is an Associate Professor in the Department of Botany and Plant Pathology, Purdue University.*

I believe that one ought have only as much market efficiency as one needs, because everything we value in human life is within the realm of inefficiency—love, family, attachment, community, culture, old habits, comfortable old shoes. —Edward Luttwak

In the modern world, we face a whole slew of problems, but to be simplistic, we can boil them down to two major crises: a looming energy crisis and the poster child of all our environmental crises, global climate change caused by greenhouse gas emissions, principally carbon dioxide.

If you look at a civilization-level perspective, the Roman Empire had what can be called the forest interval, when wood was the main resource driving the economy. In the modern world, we are currently in what I call the petroleum interval. The modern world appeared when it did and as quickly as it did because we suddenly discovered fossil fuels. We entered the industrial revolution with coal, and then we transitioned into oil and natural gas. This interval appeared in a century and will be gone in a century. We sit right now at the very peak, just as it is about to enter a decline.

We are confronted with twin problems, an impending decline of fossil fuels that threatens our economies and global climate change. The logical solution to the first of these problems, of course, is to save fossil fuels, particularly oil. The environmental crisis of global warming is also all linked to fossil fuels since, when we burn them, we release carbon dioxide into the atmosphere.

The solution, according to conventional wisdom, seems to have emerged: efficiency. We need to kill two birds with one stone. The more efficient we are, the more we conserve fossil fuels and the less carbon dioxide we release.

But there is a brand new idea out there, only 150 years old. In 1856, the British economist William Stanley Jevons published a wonderful book, which can be downloaded from Google for free. In his book, *The Coal Question,* Jevons says this about coal: "It is very commonly urged that the failing supply of coal will be met by new modes of using it efficiently [and that] the coal thus saved would be, for the most part, laid up for the use of posterity. It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth…" Today, you can replace the word coal with the word oil.

The conventional wisdom Jevons was challenging is that increased efficiency leads to diminished consumption. Today we keep hearing that we need more efficient cars, more efficient refrigerators, more efficient biofuels, and so on. That is all we need to do to save fuels and reduce our emissions. But 150 years ago Jevons said, no, the very opposite is the truth.

THE EFFICIENCY PARADOX

When coal was first used in the industrial revolution, it was used by clunky, super inefficient engines that wasted tons of coal and released tons of carbon dioxide. People became very worried that there might not be as much coal as we thought, so we needed to use it more efficiently, by creating better engines. But Jevons argued that every time we get a better engine, our consumption increases. He reported a 30-times efficiency increase over the life of the steam engine, but these efficiency improvements, and there were many of them, didn't reduce consumption, they spurred the industrial revolution.

A better engine helped open more coal mines. As the system became more efficient, the coal could be moved by train, and more locomotives led to construction of more train tracks. With more tracks you could build more trains, and then you could put the coal on ships. The British Empire was powered by coal, and its coal consumption was powered by efficiency. Britain eventually started using less coal for one reason only… it was gone. Incidentally, efficiency continues to improve today because to dig the very dregs out of very deep mines requires being really efficient.

There are four possible outcomes from an improvement in efficiency: conservation, rebound, backfire, and system backfire. Efficiency improvement does not have to refer just to a replacement technology. It can apply to a service or just about anything you want. It can be the way an automobile company runs its business, for example.

The first thing that happens when we start to use that replacement is that we conserve energy, because we are doing the same thing with a more efficient machine. I bet that by the end of this talk, if you try to think of one example where that has ever happened, you will come up with absolutely nothing.

As we become more efficient, of course, we reduce the price, and we get a rebound effect. We use the thing, like the car or refrigerator, more, giving up some of that conservation. The thing is better or nicer, so we use it a lot more or we use it to do more things. We not only get rebound, we get backfire. So this more efficient technology overall consumes more energy than the original one ever did.

Take the refrigerator, for example. In the United States, between 1950 and 2000, refrigerator efficiency increased 170 percent, while volume increased 175 percent. Electricity consumption per unit increased, while the number of units increased a lot.

This idea, a system backfire, is important because new technology can permeate through other aspects of the economy and cause changes in all manner of things that are related to it. Grocery stores don't look like they used to anymore because refrigerators are starting to do a different job and changing society as well. Trucks or airplanes with refrigerated containers can zoom across the desert or across oceans, shipping milk or groceries and contributing to globalization. In the middle of winter, you can buy organic, environmentally friendly, asparagus grown in Chile.

The system backfire driven by efficiency improvements holds true with cars. We don't use less fuel as cars become more efficient or as road systems link us more efficiently. If we were all still driving Model T Fords and we had not made them efficient, would we have as many cars as we do, as many roads as we do? No, we would have a lot less consumption. As you make the car more efficient, consumption does not go down.

So why are we demanding more-efficient cars when it won't save fuel; we will use still more fuel, and we will use it faster. And as we have more-efficient cars that work more efficiently and cost less, we need more roads. As we need more roads, we get more cars, and as we get more cars we need more roads. What causes the worst traffic jams in the world is a new road. Traffic jams don't happen in the middle of nowhere, they happen in big cities with the most roads and the most cars. Applied to anything, efficiency is a massive trap. This is the simple and easy message: efficiency does not tend to conserve energy, it tends to increase consumption.

RESILIENCE

The next message is a lot harder to understand. Efficiency tends to simplify systems and make them less resilient to change. This is a systems concept that may be better approached illustratively rather than scientifically. Let's go back to the refrigeration example, message number one, since the increase in efficiency of refrigerators is easy to understand.

Refrigerators now consume more energy than ever, but they also changed systems. They simplified grocery retail into big box stores, which you may think is good for society, or if you are

like me you may think is bad for society. But they also changed wholesale systems, they changed agricultural regions, making them more specialized and more efficient, but much simpler and potentially a lot less resilient to change, which is where sex will soon come into the picture.

With agriculture, which is my area of study, there is a great dilemma. Efficiency tells us that with a global population expected to reach nine billion in another few decades, we need more efficient agriculture to raise yields. This means more fertilizer, better plant varieties, genetic engineering, more agricultural land, more water. But that is not the solution. Perhaps efficient production of calories has been part of the problem. There are a billion people starving on the planet, and ironically there are a billion obese people on the planet. In agriculture, we like to say how much we have improved agriculture and reduced hunger, but today there are a billion people starving. At the beginning of the Green Revolution there were only two billion people on the planet. Many more people are starving now than there have ever been on the planet.

These agricultural improvements have been horrendous for the environment. We have the dead zone in the Gulf of Mexico. We have severe erosion on the Loess Plateau. The classic example is the Aral Sea which, thanks to the Soviet Union's efficient use of water to raise cotton, has largely crashed, though it may be recovering a little now. We have an image of agriculture with the sheep gamboling in the pasture, the chickens clucking in the barn, but that is not what agriculture is like in the modern world at all, and certainly not in the United States. Today, we have large feedlots in Colorado, huge ammonia plants where we get our nutrients, and silos from which grain is shipped all around the country. The idea is that to produce corn and cows in the same part of the country is totally inefficient. We have efficient agriculture, with efficient use of water from the Ogallala Aquifer, which is declining. We have efficient use of diesel to drive the big machinery around at the peak of the petroleum interval, and efficient use of fertilizer which nearly all comes from natural gas. This is an efficient fast track to disaster. This is where it all goes wrong.

My last example will be that of sex, but before we talk about sex we need to talk about fire. Take our good friend Smokey the Bear, for example. Smokey causes wildfires. His job is to put out fires, of course, but only you can prevent wildfires. Smokey causes wildfires by trying to make a dynamic system static. He supports productivity over resilience. Many forests, and prairies too, need to burn, they are cyclical systems that go through phases of growth and increases in productivity. Then they burn, they recover, and they renew as part of a cycle. What we often try to do, especially when we have planted our $2 million house on the edge of the forest, is assume that fire is entirely a bad thing, so we prevent fires, the fuel builds up, we continue to prevent fires, and the fuel builds up more. Then when the fire does happen it is not just a little brush fire that trickles through the forest, it is a wildfire. Smokey the Bear does not necessarily cause fire, but he sure does cause wildfire. What we do with efficiency is try and maintain and push systems to the limits to keep them productive. We make them strong like glass. Glass is very strong, but when it gives way it shatters. We need our systems to be strong like rubber, which bends without breaking. So many of our systems in the modern world at the moment are strong like glass. When they go, they are going to go, just like the Roman Empire did. Only you can prevent it.

SEX AS A MODEL OF SYSTEM RESILIENCE

The long term survival of systems depends on diversity, redundancy, complexity, and feedbacks. These characteristics are eroded by efficiency. My last illustration to help make sense of this system analysis is sex, a global example.

Natural selection is the quintessential engine of efficiency. The speed of the cheetah is constantly tested by the speed of the antelope or other potential meal. A cheetah that is not fast enough is not as likely to pass its genes on to the next generation. In every generation, the speed of the antelope is also tested by the speed of the cheetah If they are not efficient enough, they are out. The albatross, with its incredibly efficient wing design, makes transcontinental voyages over the ocean. This efficient winged evolution allows it to travel over the ocean with barely a flap of its wings. It picks up little bits of updraft coming off the ocean and goes forever. We are always trying to make solar power more efficient, but think about plants. The lowliest little plant in a hot environment or a cold environment or a dry environment or a wet environment converts sunlight into chemical energy silently with virtually no waste every day. Nature almost seems perfect sometimes, but of course it is not.

Natural selection is only one of the stories of evolution. The other story, of course, is sex. Sex is ridiculous. It is very inefficient. It is expensive. It wastes huge amounts of energy, and it is extremely risky. Sex requires at least two individuals, and often three. Sex is not even necessary for reproduction.

Consider the leatherback turtle, which putts around in the Arctic and the Antarctic, then when it wants to lay its eggs, it swims thousands of miles back to the tropics. This is a ridiculously expensive system in terms of energy. Sex wastes huge amounts of energy.

Sex is also extremely risky, just ask the male praying mantis. Actually very few species do this, but while praying mantises have sex, the female bites the head off the male. The peacock, a predator-ready package, wanders around the forest constantly looking over its shoulder because it worries about getting eaten. But when it comes time to have sex, it spreads a massive array of feathers to say, "Here I am!" to find the peahens.

Sex requires two individuals and often three. With some plants, for example, when two flowers want to have sex, they often need a third member of the party such as a bee. In addition, sex is not really necessary. There are lots of ways to reproduce asexually.

So why, a billion years after sex first evolved, do all the big organisms on earth have sex? The efficiency of natural selection made the cheetah fast, but it would be even faster if it did not carry certain appendages that get in the way when it runs. What about the hummingbird that flits from place to place? Why does it waste energy on coloration to make it attractive to the opposite sex? You would think that such a ridiculous system would have been removed by natural selection. One reason is variability.

But what does that mean? While natural selection is honing organisms for the utmost degree of efficiency in their environment, sex is constantly making their existence precarious. Efficiency perfects organisms for the environment as it is. Sex ensures the capability of organisms to adapt should the environment change.

The environment has changed a lot in the last billion years. Any large organism that abandons sex is eventually doomed. This is intuitively obvious; all the big organisms on the planet have sex, and any creature that gave it up is long since gone. The same principle applies in the human-made world. Efficiency, we may also call it productivity, works in a stable world, but it ultimately ends in disaster because it erodes resilience. Resilience comes from diversity and redundancy, which are inherently inefficient.

For a species, for an ecosystem, for any human-made system, there needs to be a feedback that brings in diversity, which in turn brings in complexity, which brings in redundancy and maintains the system constantly in a cycle. Efficiency is the most massive trap on the planet. We constantly fall into this trap when we make the argument that we need efficiency now to reduce carbon dioxide emissions and save our energy. The very opposite is the truth.

Back to message number one. Efficiency does not do what it is supposed to, it actually increases consumption. The second message is that efficiency tends to simplify systems and make them more brittle, less resilient to change. So as researchers, what in the world are we doing, with 99 percent of our research aimed in the direction of efficiency?

We need to rein in our desire to make systems more efficient. What we actually need to do is admit that we are in trouble. We may be heading for a big cliff, but we cannot avoid it by increasing efficiency. We need to think about these systems in a completely new way and find the means not to make them more efficient, but to make them more resilient.

Efficiency has been claimed as one of the most urgent needs in a warming world facing peak oil. Efficiency has even been called "the sixth fuel." It is not. Efficiency is part and parcel of the problem…and it's certainly no substitute for sex).

Biogas in China: Energy, Ecology, or Multi-Opportunity

by Renjie Dong

Dr. Dong *is Professor and Executive Director of the Biomass Engineering Center, and Head of the Energy Engineering and Low Carbon Technology Laboratory, China Agricultural University.*

The correlation between energy consumption and standard of living is well documented. A higher standard of living leads to increasing consumption of energy. All the developed countries enjoy devices, equipment, or vehicles with high energy efficiency, while the less developed countries use less energy-efficient technologies. If we want a better life, statistics tell us, we have to consume higher amounts of energy. In the past 100 years or so, only a limited number of countries, the developed countries, had a very high standard of living and could consume a high amount of energy per capita. Today, however, more countries such as China, India, Brazil, and Africa, countries with huge populations, strive for a higher living standard.

Where is the new energy going to be found? Nuclear power is one option, but after the tsunami disaster in Japan, there has been strong concern and even criticism of nuclear power. Just one or two months after that disaster, several big countries' governments announced that they will continue to use nuclear power, probably because there are very limited options for new energy production. Other sources include renewable energies like solar and wind. China is the largest market and producer for photovoltaic cells and wind turbines, but if we do a lifecycle analysis, there are still some questions and arguments on net energy generation from these renewables.

Another option is bioenergy, but even with energy from biomass, questions remain. There may also be other options, but we still need to find new energy sources to support development and to help the developing countries improve their living standard.

Countries like the United States and the European nations have reached a point where the pollution they generate can be mitigated because they have enough money to treat the pollution and return to a green or clean environment. Some scientists suppose that the whole planet can support or sustain this temporary pollution and that, as countries like China or India develop, they will go through a period of serious pollution followed by environmental remediation, as the developed countries have. But in the past, there were a limited number of developed countries and fewer people. Most researchers maintain that today, the whole planet, the whole population has no excuse to first pollute and then restore the environment. We need a new green way to reduce pollution as our economies develop.

ORGANIC WASTE TO BIOMASS

One of many solutions to protect the environment in developing countries is organic waste treatment. In China, for example, organic waste pollution is becoming the number one problem. If we combine technologies to treat organic waste and produce energy, we may have solved two problems. One type of bioenergy from organic waste is biogas.

The central government has supported biogas development in China since New China was set up. In the beginning, biogas was generated from household biogas plants (household biogas reactors). China's leaders have repeatedly visited demonstrations of biogas production. China even has a national standard system to guide household biogas plant construction.

Household biogas plants contribute very much to the energy supply and mineral energy resource savings if we think about it on the country scale. In one year, a small biogas plant can save a half ton of standard coal. Considering the number of these household biogas plants in China in 2005, about 25 million plants and more recently 30-40 million, that represents a huge amount of coal diverted from energy production.

Yet challenges remain in increasing the use of biogas from organic waste. One issue is the origin of the feedstock material. In the past, the material used in these household biogas plants came from cattle, pig, or chicken manure, but now fewer and fewer farmers raise animals in the back yard, so finding the feedstock is a challenge, which complicates household biogas plants' construction and maintenance.

Household biogas plants, on average, produce about one cubic meter of biogas a day, which can be used for lighting and cooking. Those used to be very attractive to farmers in rural areas because 20 years ago there was not enough electricity for lighting and not enough easy energy for cooking in the rural regions. Today however, electricity has reached even very remote villages, easy energy like coal and natural gas are popular in the countryside, and biomass cook stoves are well installed in rural regions for the less rich farmers to cook and heat. So although household biogas is still strongly encouraged and welcome in underdeveloped regions, in more and more regions it is predicted to decline. Larger biogas plants are going to take the place of biomass cook stoves.

LARGER PLANTS, MORE CENTRAL BIOGAS

One promising route for biogas is the development of medium- and large-size biogas plants (MLBPs). These have developed very fast since 1999, when there were fewer than 100. Four years ago there were around 9,000, and today more than 10,000 biogas plants. The government plays a crucial role in the promotion of these larger plants.

There are still some technical problems associated with MLBPs. The average size of the MLBP has remained relatively small, around 250 to 280 cubic meters on average, and productivity has lagged in the past 12 years.

Theoretically a large biogas plant has five components, a) feedstock pretreatment; b) an anaerobic digester; c) biogas cleaning, storage, and distribution; d) digestate treatment and disposal; and e) biogas utilization. Any organic material can be used as the main feedstock of a biogas plant, but the best source is one with abundant amounts that can be easily collected and transported, with high organic concentration and good degradability. Dairy and beef cattle are the number one potential source of manure in China, followed by pigs and chickens, but much of the manure generated throughout the country cannot be used directly as a feedstock because it is generated across a huge area. To collect it for MLBPs would lead to additional energy consumption.

FARM-BASED POWER STATIONS

In some cases, very large biogas plants are constructed on big livestock or crop farms. One example is a dairy power station that produces electricity from manure-derived biogas. The farm has 10,000 head of dairy cattle that produce 280 tons per day of manure, producing 20,000 kilowatt hours of electricity per day. Compared to coal, the anaerobic digestion process results in an annual reduction of 30,000 tons of CO_2 equivalent greenhouse gases (GHGs).

Another example is a plant on an intensive poultry production farm, called Minhe, that also uses anaerobic fermentation technology to treat the manure and produce biogas. The company that owns the plant sells credits of GHGs emission reduction (CERs) through the Clean Development Mechanism (CDM) of the Kyoto Protocol.

A third example is from Guangxi; by a special technology of UASB-TLP (Up-flow Anaerobic Sludge Bed/ Turbulent, Laminar, and Pulsation), biogas is efficiently generated from the high organic concentrations, 120,000mg/L COD, of wastewater from molasses-ethanol production. 1,300 cubic meters of wastewater per day produces 40,000 cubic meters of biogas a day.

A pretreatment of the feedstock to guarantee the acids are degraded into biogas is the key technology in high organic concentration feedstock conversion. This technology can also be used in smaller plants that can support the energy needs of a village. One such biogas plant is used to supply clean cooking fuel for one village, which buys manure from a local pig farm. The villagers still use coal to heat during the winter, but the substitution of cooking fuel for coal does provide a benefit to the farmers and the village's environment.

THE ROLE OF MLBPS

The challenge in developing MLBPs is to determine the core role of biogas plants. Of course, a primary role is to produce energy. A second important goal is the ecological benefit, treating organic wastes and reducing GHGs. Ideally, MLBPs can achieve both goals simultaneously. But if we analyze the energy balance, the results sometimes would not be so positive.

Currently, China has decided to support development of MLBPs. We need to determine the most appropriate technology, whether with traditional feedstocks such as manure, or some new technology which needs to be proved first. Feedstocks for these MLBPs should be easily degradable biowastes. Cellulosic materials are easy to get, but some research on the materials' treatment should be done before such materials become real potential feedstock for biogas production.

Currently, more than 97 percent of biogas plants in China produce biogas only for on-site use as an alternative to coal. Most plants are not economically beneficial, but they are ecologically beneficial for local regions, which is why biogas plants deserve governmental support.

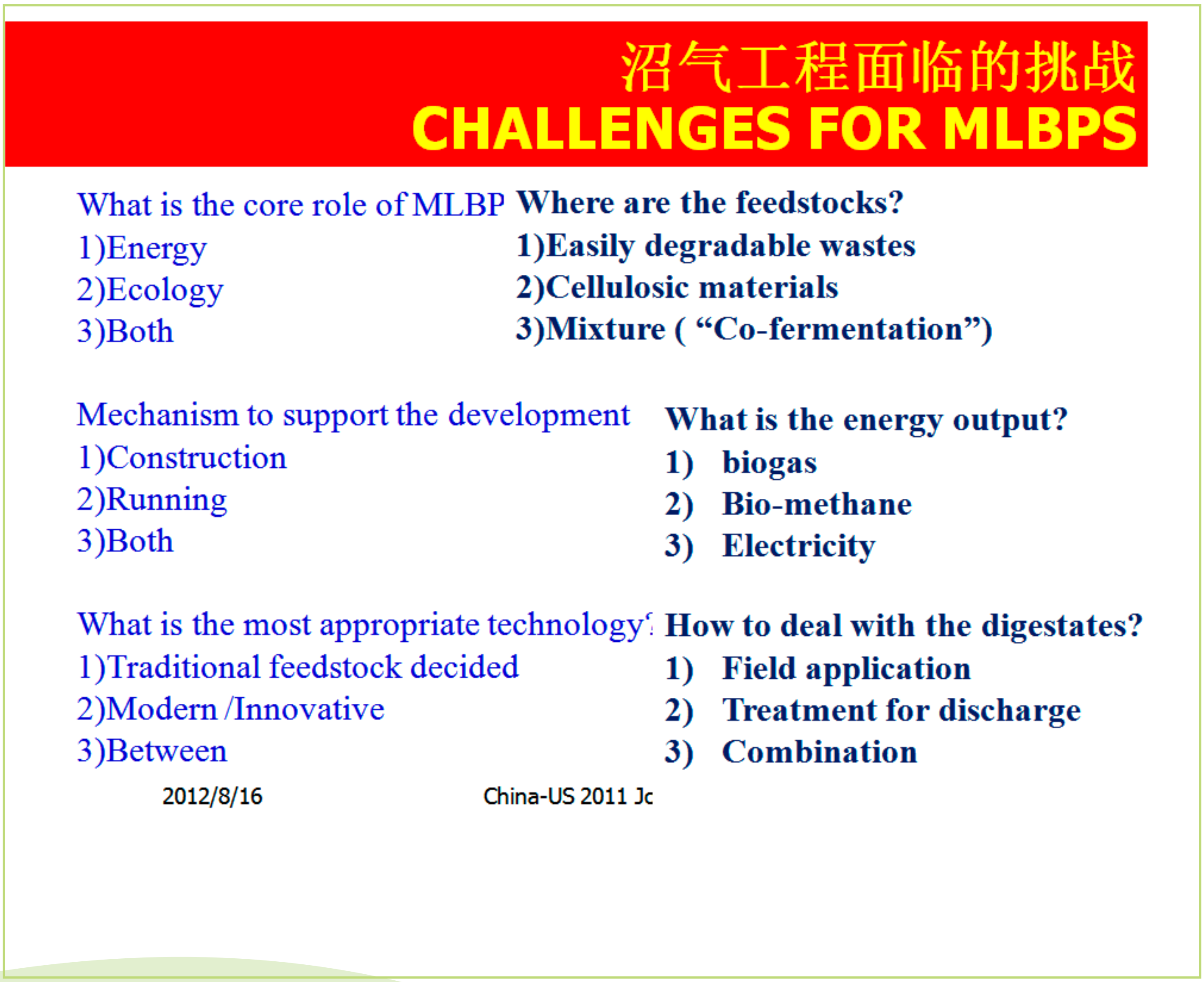
We also still need to determine what type of energy output is best, whether biogas or bio-methane, which is produced when the biogas is purified. We can also consider using biogas to generate electricity, which is economically possible with very large-scale biogas plants.

As a primary conclusion, in the overall bioenergy mix, biogas has received good support from the Chinese government. There are already millions of household biogas plants and more than 10,000 medium- and large-scale biogas plants, with an accelerated development rate. The construction cost of large, modern, and efficient biogas plants is very high, which could represent an obstacle for their development if governmental subsidies are not sufficient. With reasonable design, construction, and management, biogas plants generate clean energy, provide environmental protection, and contribute to global GHGs emission reduction.

UTILIZATION OF BIOGAS PLANTS DIGESTATES: ONE FOCUS OF CHINA AGRICULTURAL UNIVERSITY

Biogas plants are claimed to be good facilities to treat organic waste to convert into energy and to prevent the waste from polluting the environment. For the household biogas plant, the solid and liquid residues from the biogas plant, called biogas digestates, are transferred to the crop field to be used as fertilizer. However, in many cases, especially in China, MLBPs do not fulfill that promise. The biogas plants treat the organic waste but pollute the environment again. In fact, biogas fermentation only converts carbon into biogas, and almost all the nitrogen, phosphorous, and potassium remains in the residues. Researchers at the BioEnergy Engineering and Low Carbon Technology Laboratory of China Agricultural University have been addressing and trying to solve this problem by defining the nutrient content in the digestates, especially in the liquid phase.

The effluent from the biogas plant is quite valuable. It has lots of nutrients and components that are beneficial to plants, including indole acetic acid (IAA), a plant hormone that can increase the tolerance of plants against drought and disease. IAA concentration in the effluent is higher than the threshold the plants need to derive benefits. This explains why we need to dilute the effluent with water before applying it to crops. To derive commercial products from the digestate, we can, in fact, use the diluted effluent in soilless production of vegetables. When the nutrients in the effluent are condensed, they could be a commercial product for crop production. For the solid digestate, special technology has been developed to convert it into an artificial medium for agricultural production. The cost should be taken into account when we try to commercialize biogas digestates.



WORKSHOPS OVERVIEW

Two workshops were held on Wednesday, September 28, 2011.

The objective of the first workshop was to establish an "Agenda for the development of an environmentally sustainable economy: expanding research, industry and policy collaboration." The workshop was moderated by Mark Van Fleet, Executive Director of Purdue University's Global Business Engagement Initiative. The objective of this workshop was to develop recommendations for industry and government on how to move toward a sustainable economy and fashion a closer collaboration between university research, industry, and policymakers.

The second workshop session "Barriers to Sustainable Photosynthetic Production of Biofuels and Bioenergy," was funded by the US National Science Foundation and moderated by Nathan S. Mosier, an Associate Professor in Agricultural and Biological Engineering at Purdue University. The objectives of this session were to identify critical knowledge gaps in the field, to identify potential research collaborations and partnerships between US and Chinese institutions, and to develop recommendations for areas of funding needed to advance this research area.

Agenda for Sustainability: A Tall Order

by Arden L. Bement

Dr. Bement *is the Director of the Purdue Global Policy Research Center and Former Director of the National Science Foundation.*

The mission of the Purdue Global Policy Research Center (GPRI) is to provide unique solutions in the policy world by using Purdue's strengths in research, modeling, and analysis to develop policy options within our areas of excellence; to share that knowledge with policy makers; and to explore the relationship among research, ethics, and public policy.

To accomplish this mission GPRI affiliates with over 40 research centers and institutes of excellence throughout Purdue in seeking opportunities to find new approaches for solving the world's most challenging problems.

We focus on seven areas, namely: health, energy systems, agriculture, economy, society and leadership, security, and environment.

The sustainability of energy, biodiversity, the environment, and the economy represent a complex interconnected system. One cannot achieve sustainable energy without a sustainable environment. Likewise, one cannot sustain either one without assuring a sustainable economy. To achieve any of these aims requires educating our youth and the public at large on the importance of conserving energy, sustaining natural resources, and mitigating climate change.

The purpose of the first workshop session, to set the "Agenda for the Development of the Bio-Economy," invokes the GPRI theme of society and leadership. This is where technical, economic, and social factors converge. It's also where interdisciplinary research between the natural and social sciences is paramount to develop a better understanding of these complex, interactive, global problems. A starting point for our consideration is ecosystem services. These services are basic to the sustenance and quality of human life. They represent a common capital for all human beings. Unfortunately these services are taken for granted and ceded as private capital by governments for economic development. Consequently, they are not adequately regulated nor managed in a sustainable way.

Rather, the value of ecosystem services is often exploited for private gain in the economic balance sheets between producers and consumers. Public policy makers throughout the world have not yet come to grips with the incentives and disincentives needed to regulate the sustainability of these services. A fundamental causal factor for this situation is a lack of understanding by the public at large of the importance and economic value inherent in these services. Also lacking is the responsibility of governments, industries, and consumers to accept their respective responsibilities in protecting these services as a public good.

It is instructive for our purpose in this workshop to reflect on the root causes for the degradation of ecosystem services. Rising population growth and the affluence of emerging economies are by far the greatest challenges to ecosystem services. The ever increasing demands for natural raw materials by a growing world economy has resulted in exploitive practices in extracting minerals; bio-products; and oil, gas, and coal for energy production. These along with the overfishing of natural marine life and overgrazing of pastures are among the root causes of the degradation of ecosystems beyond sustainable yield. These practices are also responsible for the loss of biodiversity on our planet.

The introduction of invasive organisms, emissions of harmful substances, and the impacts of global climate change exacerbate the inability of ecosystems to sustain themselves. This is a train wreck that is occurring before our eyes, crying out for better corrective measures and accountabilities.

The challenges that confront the world need government intervention. Without such intervention, individuals and firms are able to capture the benefits of ecosystem services without having to be accountable for their damage and degradation.

Protection of common-property resources is a fundamental responsibility of government. This responsibility carries with it the need to impose disincentives for negatively impacting common-property resources. Most nations reserve lands, parks, marine sanctuaries, and territorial waters to protect these essential resources. However, governments need to be attentive to adding to their reserves if warranted based on projected trends.

In some instances it will be necessary to restore resources that have become degraded. Proper management and stewardship should seek to maximize benefit flows consistent with sustainability. They should be attentive to developing new understandings, data, and models that facilitate these aims.

All of these actions require new public investments and increased R&D budgets, which are difficult to appropriate in today's constrained economies. Public awareness is essential to reallocate existing financial resources in a focused way to address these problems.

President Obama's Council of Advisors on Science and Technology has addressed these issues in its executive report "Sustaining Environmental Capital: Protecting Society and the Economy." They have put forth an action plan consisting in part of the following points:

- **Institute and fund a Quadrennial Ecosystems Services Trends Assessment.** The aim of this assessment would be to characterize the condition of US ecosystems in sufficient detail to predict ecosystem changes.
- **Develop interagency science-policy platforms on biodiversity and ecosystem services.** These would provide regular assessments of biosphere and ecosystem changes and inform coordinated interagency approaches to solving problems resulting from these changes.
- **Carefully target conservation programs and prioritize expenditures based on cost efficiency.**
- **Improve capabilities for valuating ecosystem services** as well as generate new knowledge for assessing impacts resulting from activities on both private and public lands.
- **Identify the most important data gaps** and clarify agency roles for filling these gaps.
- **Establish an open-source and machine accessible information base** to inform decisions and encourage both public-private partnerships and international cooperation in developing innovative tools for data synthesis, integration, and decision making.

Throughout all US government studies of ecosystem issues and corrective measures, there has been a consistent theme: the magnitude of the problem of protecting ecosystems is well beyond the resources, both financial and intellectual, of any one country no matter how large or prosperous. This is a global issue that requires the cooperation and best efforts of all nations around the world.

Both private companies and state economic development offices have recognized the economic potential of sustainability and "green technologies."

Different people concerned about sustainable development often interpret the term "green" differently. To some it means a striving for a simpler, less consumptive lifestyle. To others it means applying technology to achieve a smarter lifestyle that prevents damage to the environment. Henry David Thoreau, the 19th Century philosopher and iconoclast, advocated striking a balance between staying connected with both civilization and nature. I believe that striking this balance applies to "green technology".

The list of new potential innovation drivers for economic development is long. Some examples identified by the chemical industry are:

- Light-weight transportation materials, especially engineered polymers;
- Affordable water filtration technologies, especially to provide potable water in poor rural areas; and
- Products and technologies for CO_2 capture or conversion.

In addition, other industries are focusing on such possibilities as:

- Energy conservation and storage,
- "Zero carbon" houses and buildings,
- Smart electrical meters and power grids,
- Hybrid vehicles, and
- Precision agriculture.

Industry is also accepting an active role for sustainable development. The American Institute of Chemical Engineers has developed an index for responsible sustainability for the chemical industry. This is to be an ongoing tool to benchmark industry improvements in sustainability based on seven well defined sets of metrics:

- **Strategic commitment**: which includes public commitment to excellence, commitment to voluntary codes and standards, timely public sustainability reporting, setting challenging sustainability goals and programs, and seeking objective third-party ratings from respected agencies;
- **Sustainability Innovation**: which includes corporate commitment to sustainability R&D, developing products and processes with superior environmental and social performance, use of sustainability decision-support tools in R&D, and measuring the effectiveness of R&D in terms of new products that enhance environmental and social sustainability;
- **Environmental performance**: which measures the use of renewable sources of energy and materials, greenhouse gas emissions, emissions or releases of wastewater and hazardous waste, and compliance management to minimize environmental liabilities;
- **Safety Performance**: which measures employee safety, process safety, and plant security;
- **Product Stewardship**: which measures product assurance policies and engagement of value-chain partners to assure product safety, responsible risk communication policies, and involvement in legal procedures related to product safety and environmental damage;
- **Social Responsibility**: which takes into account stakeholder partnerships, social investment, and community image; and,

- **Value-chain management**: which relates to environmental management systems, supply chain management, and the establishment of a responsible care management system. Both systems are becoming new standards for responsible environment management in the chemical industry.

There is abundant evidence to show that good ecosystem stewardship innovations in green technologies can lead to substantial business gains through economic development as well as the creation of new jobs. This brings me to the role of universities.

Since most of this conference has highlighted the role of universities and national research institutes in sustaining energy, climate, water, and the environment, I need only to make a short reprise of Purdue's activities in "green" research, education, and entrepreneurship. Examples of renewable energy research projects alone, some of which you have heard about in this symposium, include:

- Improving ethanol production using modified yeast,
- Improving wind turbine performance,
- Producing hydrogen on demand,
- Direct catalytic conversion of biomass to biofuels,
- Nanotechnology approaches for improving the efficiency of thin solar cells,
- Modeling and simulations to improve solar cells,
- Developing a hydrogen storage system for cars,
- Biodiesel production from algae, and
- Optimizing energy conversion through "smart metering."

Purdue University is only one of many US universities engaged in renewable energy, climate, water, food security, and "green technology" research. These research programs provide a solid base for international partnerships in finding global solutions for the sustainability of Earth's ecosystems.

I will conclude with a short "punch list" of possible considerations, which are at once needs, opportunities, and barriers to begin our workshop discussion. They are:

- Public awareness and action;
- Education and workforce development;
- Holistic system models to improve understanding;
- Integrated ecosystem monitoring, to include space, high altitude and ground systems;
- Quantitative metrics that are adequate to both measure change and make projections;
- Open data bases of current conditions and trends;
- International partnerships involving governments, industries, and universities working together;
- R&D strategic roadmaps and priorities;
- Targeted R&D investments that get beyond the "give me more" syndrome;
- Scaled policy innovations at the international, national, regional, state, and local levels; and
- Policy mechanisms to counter or mitigate volatilities.

This I admit is a tall order, but I am sure even more considerations will surface during our discussion.

2011 WORKSHOP
Sponsors and Hosts

This meeting is the 5th annual symposium of the **China-US Joint Research Center for Ecosystem and Environmental Change** (JRCEEC) and the first meeting of the **EcoPartnership**.

The 2011 workshop was held September 26-29, 2011, at Purdue University, West Lafayette, Indiana (USA). The theme of this year's workshop was Global Sustainability Issues in Energy, Climate, Water, and Environment.

The primary sponsors of the 5th Annual China-US Workshop were the Center for International Business Education and Research (CIBER), Purdue University; Chinese Academy of Sciences; Confucius Institute, Purdue University; FuturaGene; Green Tech America; Institute for a Secure and Sustainable Environment (UT); International Programs Office, Purdue University; Joint Institute for Biological Sciences (UT?ORNL); Oak Ridge National Laboratory (ORNL); Purdue University Chinese Students and Scholars Association (PUCSSA); Purdue University Global Policy Research Institute (GPRI); Purdue Water Community; Shell Oil Company; The University of Tennessee (UT); University of Science and Technology of China; US National Science Foundation (NSF); and the US Department of State.

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