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China's Vision for Renewable Energy: The Status of Bioenergy and Bioproduct Research and Commercialization

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Abstract

The Chinese government is vigorously promoting commercialization of renewable energy and bioproducts, given environmental issues plus food, energy, and national security concerns, according to Chinese industry experts at the August 2010 "China Bioenergy Workshop" and its related technical tours. Goals include replacing 15 percent of conventional energy with renewable energy by 2020 and providing necessary investment of about $800 billion. Government

[1] The views presented are solely those of the authors and do not represent the opinions of the Commission or any of its Commissioners, nor do they represent the opinions of the other authors' organizations. The authors are U.S. Department of Agriculture (USDA)-Washington State University (WSU)-China Agricultural University (CAU) Workshop participants. Affiliations of authors are as follows. Nesbitt: International Trade Analyst for Biotechnology and Nanotechnology, U.S. International Trade Commission (the Commission); Thiers: Washington State University; Gao: CatchLight Energy, LLC, A Chevron/Weyerhaeuser Joint Venture; Shoemaker: Energy Institute, University of California, Davis (UCDavis); Garcia-Perez: Washington State University; Carrier: University of Arkansas; Doran-Peterson: Bioenergy Systems Research Institute, The University of Georgia; Morgan: Purdue University; Wang: University of Hawai'i at Mānoa; Wensel: Washington State University; Chen: Washington State University.

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[3] Shulin Chen was the USDA-WSU-CAU Workshop organizer. Hereinafter called either the "USDA-WSU-CAU Workshop" or "the workshop," it was made possible through a

policies cited include financing (given the lack of venture capital); financial and taxation incentives; carbon taxes and credits; and mandatory usage requirements, but the speakers said more can and will be done. Although not yet released at the time of the workshop, the speakers expected the 12th 5-Year Plan to expand the momentum generated under the 11th 5-Year Plan. This article highlights novel issues gleaned from the experts' unique, "on-the-ground perspective" of current and future bioenergy and bioproduct research and commercialization in China.

Introduction

This article highlights novel information about China's bioenergy and bioproducts industries presented during the Chinese Bioenergy Research Workshop (Beijing, China, August 13–23, 2010). Except for background information about existing grain ethanol facilities and conclusions reached by the workshop participants, almost all the information presented by the workshop speakers is either new, published only in Chinese-language journals, or unpublished. A few highlights are shown below.

For example, workshop speakers confirmed that China is continuing to invest significant resources and funding in renewable energy and biobased chemicals. During the 11th 5-Year Plan, covering 2006 through 2010, renminbi (RMB) 5–10 billion (about $700 million–$1.4 billion) was invested in clean energy, of which 50 percent focused on research and development (R&D) for renewable energy. Workshop speakers indicated that investment in green energy is expected to increase substantially to RMB 5.4 trillion (almost $800 billion) from 2009 through 2020.

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[3] Continued--2008 grant from the USDA International Science and Education Program, National Institute of Food and Agriculture, entitled "Enhancing Bioenergy Education and Business Development Capabilities via Access to International Resources and Technologies." Professor Shulin Chen was also the grant's project director. The authors appreciate the logistical assistance provided by CAU and the insights and helpful input of Professor Dong and Assistant Professor Zhou. The authors also appreciate the comments provided by the editor and the anonymous reviewer, and the input from Andrew David of the Commission.

The speakers and the technical tours also illustrated the growing convergence of the biofuels and chemicals industries, as more companies develop integrated biorefineries to produce biofuels as well as biobased chemicals such as biobutanol and polyethylene.[4] Moreover, biobutanol is being developed in China for chemical applications rather than for use as a liquid biofuel. However, one company's biobutanol plant was temporarily shut down at the time of the workshop because of reduced cost competitiveness, given the high cost of the corn feedstock and the low cost of crude petroleum, a competing end product.

Workshop participants also concluded that restrictions on the use of grain; technical and economic difficulties associated with alternative feedstocks; and potential alternative uses of available biomass, may hinder China's ambitious ethanol expansion targets. The limited amount of available land may also result in a growing reliance on imported cassava and sugarcane as feedstocks.

Workshop background

This USDA-sponsored workshop allowed the authors to meet with prominent industry, association, government, and academic experts in bioenergy and bioproducts who are actively shaping the industry's future and providing input to ongoing Chinese governmental planning and coordination policies and programs. Although not yet released at the time of the workshop, the speakers expected the 12th 5-Year Plan (2011 to 2015) to strengthen and expand upon bioenergy momentum generated under the 11th 5-Year Plan.

The speakers candidly shared their knowledge of technical, economic, and policy-related aspects of China's renewable energy and biobased chemical industries. This information, combined with the two technical tours and the two related scientific conferences, allowed for a unique, "on-the-ground perspective" on current and future research and commercialization in open and productive exchanges. Also, the workshop participants were drawn from academia, industry, and government on the basis of their overall knowledge of China's growing bioeconomy, allowing for further in-depth discussions and sharing of detailed industry information.

The workshop, the main component of a USDA grant awarded to Washington State University (WSU) in 2008, was organized by WSU in collaboration with

[4] Chemical coproducts are expected to make new biofuel ventures more economically feasible.

China Agricultural University (CAU). In addition to presentations by industry experts, the workshop provided technical tours of two state-owned enterprises (SOEs)—Henan Tianguan Enterprise Group Co., Ltd. (Tianguan) and North China Pharmaceutical Group Corporation (NCPC) SINOWIN Co., Ltd.[5] The goal was to ascertain the status of Chinese R&D and deployment of bioenergy and bioproducts, and to develop an international collaboration program in bioenergy research, education, and training with China. The workshop was held in conjunction with two related conferences (the Environment Enhancing Energy Forum (E2 Energy) and the International Conference on Biomass and Energy Technologies (ICBT2010)) to maximize interaction between participants and Chinese experts.

China Agricultural University (CAU)

CAU, the workshop host, is one of the leading universities in China for bioengineering; its Biomass Engineering Center, founded in 2004, is supported by the central government (Dong 2010). In opening comments, Professor Tao Wang, Director of the center, said China's focus on urbanization during the next decade will use bioenergy to offset bottlenecks encountered in extending commercial energy supplies to small towns and cities. Also, under the Renewable Energy Law, the government can buy renewable energy from all sources, including biofuels produced by SOEs such as Sinopec, COFCO, and others.[6] These opportunities are spurring international bioenergy collaborations (Wang 2010).

Organization of the article

The first section of this article describes how Chinese government policies are promoting production and use of renewable energy and reductions in energy consumption. The second section provides examples of research and commercialization in several bioenergy industry segments. The third section discusses the impact of increased use of renewable energy on China's expanding and changing energy infrastructure. The fourth section highlights examples of how research and development in renewable energy is being

[5] See the reference list for speakers' titles and affiliations; the technical tour representatives are listed before the reference list.

[6] Professor Tao Wang, Vice President of China Agricultural University, and Director of the Biomass Engineering Center, CAU.

financed. The last section highlights examples of domestic and international collaborations and strategic alliances at both the industry and university levels.

> ***Renewable energies*** are generally derived from "sustainable raw materials and waste products" (Bug 2010). The term "conventional energy" usually refers to fossil fuels such as gasoline and diesel. In China, the terms "renewable energy" and "green energy" include not only hydropower, solar, wind, and biomass/biofuels, but also nuclear energy. Biorefineries—production facilities for liquid biofuels such as bioethanol and co-products (e.g., biobased chemicals)—can be considered analogous to petroleum refineries but use renewable resources as inputs instead of fossil fuels. Examples of renewable biomass inputs include agricultural and forestry residues, municipal waste, and energy crops.

Government policies/goals promoting renewable energy

China is proactively promoting production and use of renewable energy and reductions in energy consumption.[7] Acknowledging China as a leading source of global greenhouse gases (GHG) in 2009, particularly from energy consumption,[8] Professor Dinghuan Shi said that China's growing economy has driven increased energy consumption and GHG emissions, primarily by the coal-fired plants and other industrial energy sources essential to China's economic development (see figure 1 for sectoral energy consumption during 2000–2050 under two energy reduction scenarios[9]). Large increases in the number of vehicles and in consumption of manufactured goods have exacerbated the situation (Lin 2010 and Shi 2010). This thirst for energy is currently satisfied by coal[10] —which accounts for 70 percent of China's energy consumption—and crude petroleum; China imported almost 55 percent of its consumption of crude

[7] Unless otherwise noted, comments in this section were made by Professor Dinghuan Shi.

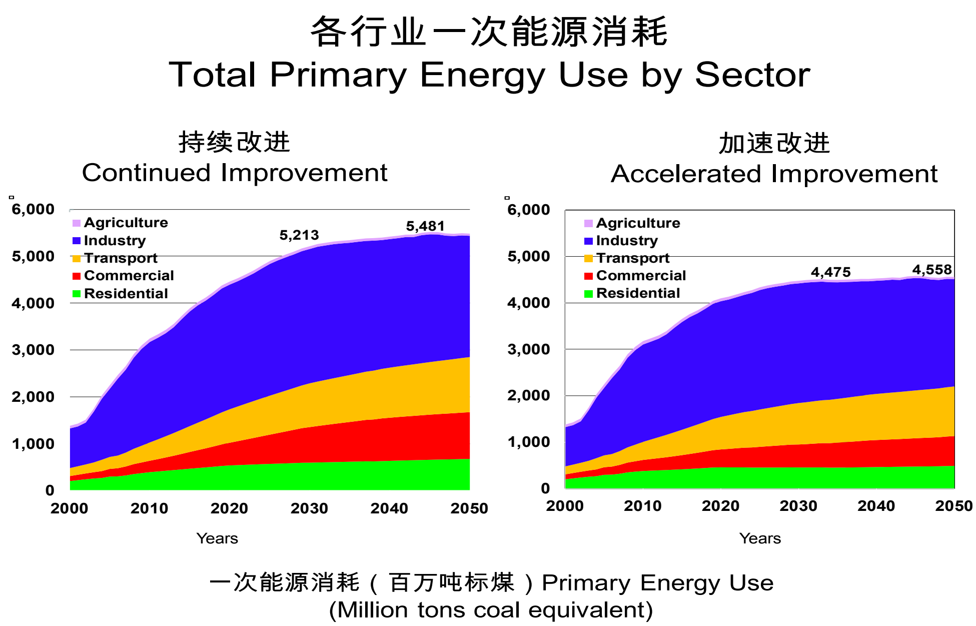
[8] See also U.S. Energy Information Administration (EIA), "International energy statistics," January 2011.

[9] According to Dr. Mark Levine of the Zhou et al. report team, "continued improvement" refers to the future progression of energy efficiency of products and industrial processes progresses at the same rate as in the past few decades. In comparison, "accelerated improvement" addresses a "much more rapid move to greater energy efficiency in products and industrial processes . . . reaching today's most efficient products within two decades or less." (Pers. comm., April 29, 2011)

[10] Coal is considered to be a nonsustainable energy source. It is not only nonrenewable but it also emits pollutants and GHGs—including a significant amount of carbon dioxide (CO2)—when burned.

petroleum in the first quarter of 2010 (Lin 2010). This is considered a threat to energy security and national security, as well as to the environment.

FIGURE 1 China's Total Primary Energy Use from 2000 through 2050 under Two Energy Reduction Scenarios



Source: Zhou et al., *China's Energy and Carbon Emissions Outlook to 2050*, April 2011, 32; Levine, "Will China Overwhelm the World with Its Greenhouse Gas Emissions?" April 5, 2011, 32. Reprinted with permission.

Policy goals

These scenarios prompted China's top leaders to set a goal of replacing 15 percent of conventional energy with renewable energy by 2020, with parallel goals of increasing energy efficiency and reducing energy consumption (Shi 2010). The Renewable Energy Law, for example, implemented January 1, 2006, is intended to increase energy supplies, enhance energy security, and protect the environment (Huang 2010). The 2007 Medium and Long-Term Development Plan for Renewable Energy enumerated renewable energy targets for 2010 and 2020 (box 1). Speakers considered it likely that the 12th 5-Year Plan would expand policy support for renewable energy.

Box 1 Some goals of the 2007 Medium- and Long-term Development Plan for Renewable Energy

	2010 target	2020 target
Biodiesel	0.2 million ton/year (t/year)	2 million t/year
Fuel ethanol	2 million t/year	10 million t/year
Biomass power generation:		
– From agricultural and forestry residue and energy crops:	4 gigawatts	24 gigawatts
– From municipal solid waste:	500 megawatts	3 gigawatts

Source: Sun, "Biomass Energy Development in China," 2010.

China is said by one source to be the "global manufacturing leader of most renewable energy technologies, and the largest user of clean energy" (EESI/WRI 2011). It also became the world's leader in installed clean energy capacity in 2009, followed by the United States, the previous leader, and Germany (Pew 2011). Renewable energies emphasized during 2009 through 2020 include hydro and wind power (the two largest in terms of Chinese capacity in 2009), solar, biomass, biogas, and nuclear. Installed Chinese hydropower capacity exceeds that of the United States and Canada combined (Shi 2010). Also, Chinese wind energy capacity has more than doubled each year during 2006 and 2009, exhibiting a faster average annual growth rate than that of the United States. China manufactures most of the turbines used domestically, including small ones used in cities and villages, but is currently a limited exporter of the products.

Professor Shi said that the many solar heaters on Chinese roofs have reduced carbon dioxide (CO_2) emissions and, since 2008, central government stimulus spending "subsidized" the adoption of solar energy in rural areas.[11] China accounts for 50 percent of the world's solar water heaters and is promoting new policies that bring electricity to rural areas and, in some regions, integrate multiple power sources (e.g., biogas with solar; wind energy with solar-

[11] Workshop speakers generally referred to various types of monetary support and incentives as "subsidies."

powered batteries). China is also the world's largest producer of photovoltaic modules, exporting 90 percent of output (Shi and J. Zhang, 2010).

China invested RMB 5–10 billion (about $700 million–$1.4 billion) in clean energy during the 11th 5-Year Plan with 50 percent focused on R&D for renewable energy (Shi 2010)[12] Speakers confirmed that the government would continue to invest substantial amounts in renewable energy in 2009 through 2020. Dr. Jie Zhang's comments, in particular, provided a window onto the National Development Reform Commission's (NDRC) interest in attracting outside investment to help it accomplish the country's bioenergy goals. Investment of RMB 5.4 trillion (almost $800 billion) is expected, with about one-third dedicated to China's smart grid and the largest shares thereafter to hydro, wind, and nuclear power, respectively (J. Zhang 2010).[13] Projected "green energy" capacity and investment levels in these years are shown in figures 2 and 3, respectively.

Policy measures to promote bioenergy production and consumption

The Chinese government has implemented several measures supporting supply and demand of biofuels. For example, on the supply side, government-authorized biofuel producers receive a variety of operating incentives, including monetary incentives. Demand side measures include mandatory use regulations for E10.[14] Expected increases in the production and consumption of bioenergy, including biofuels, will require the following measures (Shi 2010):

- ✓ R&D investment in renewable energy needs to be increased;
- ✓ More demonstration projects need to be constructed;
- ✓ Standards need to be formulated;

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[12] Currencies were converted using the time period's average of about RMB 7.2 per U.S. dollar (IMF, "Exchange Rate Query"). Currency conversions later in this article were obtained from this source for the specified time periods.

[13] Dr. J. Zhang said that China will become the largest market for clean energy within the next decade; China welcomes international collaboration; and that the Energy Research and Development Center provides energy advice and policy information to the NDRC.

[14] E10 is a gasoline blend containing 10 percent ethanol.

- ✓ An environmental monitoring system needs to be established;
- ✓ State renewable energy programs are needed; and
- ✓ New rules and regulations are needed to encourage venture capital.

FIGURE 2 Green power capacity, 2009 and 2020

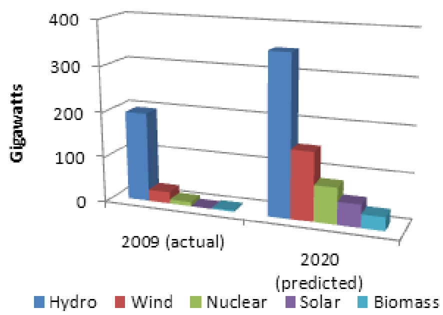
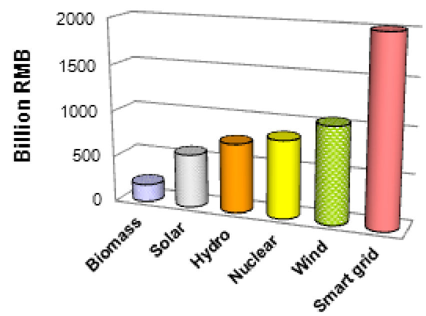


FIGURE 3 Green power investment: Total 2009–20 (5.4 trillion RMB)



Note: China includes nuclear energy in its green power and renewable energy classifications.

Source: Capacity and investment data, J. Zhang, "Green Energy: Development and Investment Opportunities in China." 2010.

In regard to bioenergy projects in general, workshop speakers cited "policy-related subsidies" provided by the National Development and Reform Commission (NDRC) and the Ministry of Finance for "large-scale engineering" projects and the provision of tax-free status for power projects utilizing renewable energy (Huang 2010). In early 2010, the NDRC also identified the bioindustry as a "Strategic Energy Industry" to support a sustainable industry/economy (*People's Daily Online 2010*).

Research and Commercialization

Several industry segments, including starch-based ethanol, alternative feedstocks, other biofuels, and biobased chemicals, are under study and/or being commercialized. As with other countries, in regard to biofuels and biobased chemicals, most of China's activities and policies relate to biofuels despite significant domestic production of biobased chemicals. In 2007, the value of biobased chemicals manufactured in China using industrial biotechnology reportedly exceeded $60.5 billion (versus about $2.5 billion in 2003), with annual sales expected to grow thereafter by about 10 percent (Nesbitt, 2009).

Research

Workshop speakers emphasized the importance of basic and applied research to the Chinese bioenergy program, noting that it builds upon the country's long history of using fermentation (e.g., in the manufacture of beverages, food, and chemicals). The technology being commercialized originated in the Chinese Academy of Sciences (CAS),[15] universities within China, individual companies, and international sources. Workshop participants considered the official systematic reporting of the current status of Chinese bioenergy a relatively new development.

Ongoing industrial and academic research in China addresses a wide variety of topics, ranging from feedstocks to process development (Lin 2010). Substantial research is underway on production of 2nd generation ethanol from nongrain and cellulosic biomass feedstocks, including development of biomass pretreatment; enzyme systems and microorganisms (e.g., those metabolizing a variety of sugars besides glucose); and fermentation processes. Although scaled-up from lab bench to demonstration-scale facilities, this research has not been commercialized yet (Xing 2010). Professor Tianwei Tan (2010) described another promising technology: a fungal lipid production system (35–60 percent intracellular lipid content), which could be easily converted to biodiesel using a standard conversion technology.

In addition to grain-based ethanol, commercialized feedstocks and technologies include alternative fuels such as cassava. For example, cassava is the main feedstock for a commercial fuel ethanol plant built in 2006 with a capacity of 200,000 metric tons per year (t/year) of ethanol (or about 67 million gallons per year). Other technologies already commercialized include biomass for electricity and biodiesel from waste oil.

[15] Workshop speakers said that the CAS is a government institution comparable to the U.S. National Laboratories.

Commercial production of starch-based fuel ethanol in China

China, like other countries, has produced ethanol for chemical use for decades. The focus on fuel ethanol, however, developed largely during the last decade. As of 2010, there were five authorized state-owned commercial-scale fuel ethanol plants using starch-based feedstocks such as corn and wheat grains or cassava. Several speakers mentioned that these facilities receive a variety of operating incentives, including government "subsidies" estimated at about $0.45 per gallon of ethanol and about $0.10 per gallon of biodiesel. Also, workshop speakers considered it unlikely that more fuel ethanol producers would be designated as "authorized," with its associated incentives, even those developing 2nd-generation feedstocks and technologies. This was an interesting observation for two reasons: (1) this information has not been widely disseminated outside China; and (2) it was unexpected, given the amount of work underway on 2nd–generation technologies. It is not deterring 2nd–generation development; however, most of this development is by currently authorized starch-based ethanol producers and their partner companies, all SOEs.

The starch-based ethanol facilities are located along the east and southeast coasts of China, largely because of feedstock availability (Lin 2010). Their output amounted to 1.72 million metric tons in 2009, or about 576 million gallons.[16] All but one are joint ventures between large SOEs such as COFCO, PetroChina, and Sinopec (Fu 2010).[17] The technology is essentially like that used in the United States: starch hydrolysis, fermentation of the resulting monomeric sugars into ethanol, and distillation of the ethanol-containing fermentation broth. Fuel ethanol has not been exported since 2006, largely because the export tax rebate was revoked (X. Zhang, 2010). Tianguan's grain ethanol facility is shown in figure 4.

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16 Production of 576 million gallons of starch-based ethanol requires about 200 million bushels of grain, harvested from over 1.4 million acres.

17 When asked about job creation related to bioethanol production, Dr. Lin (COFCO) said that the number of jobs created is limited but, with about 600 people per plant, some growth is likely; other speakers said that such data were not collected. Also cited was a 2009 Novozymes-McKinsey report stating that China's conversion of agricultural residues to bioethanol could reduce gasoline consumption and CO2 emissions, and create about 6 million direct jobs and income of about RMB 32 billion (or about $4.7 billion). See also Novozymes, "Commercial production of cellulosic biofuel on fast track in China," May 27, 2010.

Figure 4. Henan Tianguan Enterprise Group Co., Ltd.'s commercial fuel ethanol biorefinery. The feedstocks are grain (corn and wheat), molasses, and cassava. Tianguan plans to upgrade this facility to produce bioethylene, biogas and biodegradable plastics. (Reprinted with permission from Tianguan.)

Alternative feedstocks

Although most commercial ethanol production in China is from corn, food security concerns have led to the central government implementing policies that cap the use of corn for biofuels and restrict expansion of food grains for fuel ethanol production.[18] During the workshop, Professor Shi characterized the initial emphasis in China on corn as a feedstock for fuel ethanol as "a mistake." The feedstock restrictions have spurred development of alternative inputs such as cassava and sweet sorghum, and 2nd generation cellulosic feedstocks (e.g., agricultural residues, such as corn stover and wheat straw, and forestry residues; box 2). The workshop speakers did not express support of using herbaceous energy crops, such as switchgrass, perhaps because of the limited amount of available land.

[18] Land use is limited; only 14 percent of land in China is arable. Moreover, China's population is about 1.3 billion and most food produced is consumed domestically.

Box 2 Examples of agronomy studies and some findings

Given the restrictions on using corn, use of alternative feedstocks such as sweet sorghum and agricultural residues have been studied by many organizations. As reported by Dr. Lin, several studies have been undertaken regarding sweet sorghum. Solid and liquid fermentation pilot studies addressing sweet sorghum were conducted at Tsinghua University and Guangxi Science and Technology Institute for Light Industry, respectively. The reported results were that, as in the United States, fresh sorghum conversion has limited usefulness as a feedstock because the freshly extracted juices can be contaminated by other microorganisms, depleting the sugars. Fresh stalks are limited to a 2 month storage period; and concentrated syrup storage is limited to 8 months (Lin 2010). Another study, conducted by British Petroleum and the Hebei Agro-Science Institute, examined parameters such as variety selection, planting density, and fertilizer and irrigation requirements; however, no results were reported in the workshop.

Although demonstration-scale 2nd–generation ethanol plants are rapidly being deployed, commercial production is not expected for at least 3–5 years (Lin 2010) because of the high processing costs. Despite lower feedstock costs for 2nd–generation production, estimated at about RMB 200–300 (about $29–44) per ton corn stover and wheat straw (Fu 2010), the cost of producing corn-stover ethanol in China is currently about 1.5–2 times the cost of corn ethanol, largely because of pre-treatment and enzyme costs (Fu, Xing 2010). The tabulation below, entitled "Comparison of Transportation Fuels Policy and Practice," presents a uniquely detailed comparison of current and future production of liquid transportation fuels (bioethanol and biodiesel) in China and the United States, juxtaposed with national consumption and policy information. In the next 10 years, bioethanol production is projected to increase in China at twice the rate it is projected to increase in the United States.

Tianguan operates a state-of-the-art 2nd-generation ethanol facility which uses corn stover and wheat straw feedstocks, the major agricultural residues in its geographical area (box 3). Another 2nd-generation ethanol facility producing about 3 million gallons per year of ethanol from corn stover will be brought onstream in late 2011 by Sinopec, COFCO, and Novozymes (Novozymes 2010). The process will be based on the technology used at COFCO's existing 2nd-generation facility located in Zhaodong, which is somewhat similar to that of the National Renewable Energy Laboratory's (NREL; Golden, CO) dilute acid process. The biofuel production process can also create value-added chemicals as co-products.

Comparison of Transportation Fuels Policy and Practice

	China[1]	USA[1,2]
TODAY		
Population	1300 M	300 M
Number of Vehicles	200 M	256 M
PETROLEUM Consumption		
Today	24 BG (72 MT)	140 BG
Gasoline	46 BG (140 MT)	40 BG
Diesel		
BIOFUELS Consumption Today	As E10, B10	As E6, E10, E85, B5, B20
In Gasoline	0.4 BG (1.2 MT)	9.6 BG
In Diesel	0.0001 BG (0.37 MT)	0.3 BG
BIOFUELS Production Today		
BioEthanol	0.56 BG (1.7 MT)	10 BG
BioDiesel	0.17 BG (0.5 MT)	0.7 BG
TOMORROW Production	Non-grain	Cellulosic EtOH
By 2010-2012	0.73 BG (2.2 MT) EtOH	
By 2020-2022	4 BG (10 MT) EtOH 0.7 BG (2 MT) Biodiesel	36 BG** EtOH
By 2030		60 BG EtOH (30% total demand)
**Breakdown of 36BG EtOH		
1st gen: Conventional Biofuels		
Ethanol from cornstarch		15 BG by 2022
Biomass-based diesel		1 BG by 2022
2nd gen: Cellulosic Biofuels		16 BG by 2022
3rd gen: Other Adv Biofuels		4 BG by 2022

Notes:
Numbers are estimates and are on an annual basis. (BG = billion gallons; MT = million tons; E5.7 = 5.7% ethanol in petroleum, etc.; B5 = 5% biodiesel in petroleum; EtOH is ethanol; etc.)

Color code: Targets from Policy/law, Consumption, Production.
Primary references: [1] USDA-WSU-CAU Workshop, 2010; [2] EISA of 2007.

***Source*:** Shoemaker 2010. Reprinted with permission.

Box 3 Tianguan Cellulosic Ethanol Production: A Leading-Edge Demonstration-Scale Plant in China

Infrastructure--In addition to producing commercial amounts of ethanol from grain, Henan Tianguan Enterprise Group Co., Ltd., (Tianguan) is currently operating a pilot demonstration-scale 2nd generation plant, using corn stover and wheat straws as feedstock and steam-explosion pretreatment, with a reported capacity of 10,000 t/year. The facility currently uses residual lignin and commercially-purchased coal to fuel the pretreatment. The capital needed to build the cellulosic ethanol demonstration plant was about RMB 85 million, or about $12.5 million (compared with about RMB 1 billion for the company's commercial-scale grain ethanol facility—with a capacity of 500,000 t/year). Tianguan started construction of the demonstration plant in 2006 and brought it onstream in 2008.

Feedstock--The company's corn stover collection, which is purchased on a spot basis at market prices, uses about one-third of the corn stover available within a 20–25 kilometer radius. It was mentioned that distributors who transport the corn stover from the farm to the storage facilities have entered the market. During the workshop, however, Dr. Lin (COFCO) indicated that these distributors profited more than the farmers. He added that a new system is being considered that would be more beneficial for the farmers.

Expected cellulosic expansion--Given the decentralization of feedstock supplies, Tianguan plans to build a few new cellulosic ethanol plants before 2013, with a total cellulosic ethanol capacity of up to 120,000 metric tons. These plants could be south of the existing demonstration plant and located near feedstock supplies. The company is applying for construction permits but, according to the Tianguan representative, the economic feasibility of the project will depend on the availability of subsidies from the Chinese government because otherwise the plants won't be profitable (company officials estimated that ethanol fuel prices would have to rise by nearly 30 percent before their current production would be commercially viable). The facilities will be relatively small, about 10,000-30,000 metric tons depending on the financial resources, making it easier to collect feedstock from farmers. The production of biobased chemical coproducts could make the venture feasible.

Future biorefinery plans--Tianguan is also planning for the future. The Tianguan representatives stated that whereas the current biorefinery produces fuel ethanol, protein meals, animal feed, dietary fiber, and fertilizer, planned expansions would allow for the production of chemicals such as 1,4-butanediol, biodegradable plastics, and ethylene from ethanol. It was stated that production of ethylene from bioethanol is at an early stage; to be profitable, 1 million t/year would need to be produced.

Source: Tianguan representatives, technical tour, August 17, 2010.

The Chinese government projects production of 3.6 billion gallons per year of fuel ethanol by 2020. With the ambitious ethanol expansion targets, restrictions on the use of grain, and technical and economic difficulties associated with alternative feedstocks, 3.1 billion gallons will need to be produced from nongrain and 2nd–generation ethanol processes since starch-based ethanol production is capped at 525 million gallons. Throughout the workshop, the value of available biomass in China was estimated at around 300 million tons, translating to potential production of about 25 billion gallons of ethanol.[19] However, it is not clear how much would be available for fuel ethanol, given competition from other uses, including other bioenergy applications. The continued dependence of most pilot facilities on steam explosion pretreatment also indicates that financial and energy costs will be difficult to overcome without significant technical breakthroughs. The steam explosion process still needs to be optimized and its efficiency validated in a precommercial stage before expansion to commercial scale.

In light of these constraints, a continued and growing reliance on imported cassava and sugarcane seems likely, as land pressure within China will limit domestic supplies of these alternatives. Several speakers confirmed that importation of cassava is already underway; for example, 30–50 percent of the cassava used at the Beihai ethanol facility in Guangxi is imported from Thailand and Vietnam.[20] This information was of great interest to workshop participants who, until now, had to rely on informal reports of such imports. Efforts are also underway to increase Chinese supplies of jatropha, but consumption demands are also likely to be met with imports during the near term.

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[19] Using a conversion factor of 1 ton of biomass produces 80 gallons of ethanol.

[20] In 2010, Thailand, the world's largest cassava supplier, is said to have marketed 98 percent of its cassava chip exports to China for use in biofuels. This demand has contributed to substantial growth in Thailand's exports of cassava chips since 2008, as well as in the price of cassava (Rosenthal 2011, A1).

Other biofuels/sources of energy

The Chinese Ministry of Agriculture has promoted family-scale biogas production and consumption since the 1960s, making biogas a small, but significant, source of energy in rural China. Professor Dong and others stated that large-scale commercialization of biogas is only now occurring, as reflected by a few large projects coming onstream in 2009 and 2010. The Chinese government invested about RMB 20 billion (about $3 billion) in biogas production from 2003 through 2009 (Huang 2010).

Biogas uses waste materials as inputs, including animal waste. The first and largest of China's high profile, large-scale biogas demonstration projects is the Anaerobic System at the Chicken Farm of MinHe, in Shandong Province, which has 2–4 million chickens (Sun 2010). The grid-connected project's capacity is about 6,000 kilowatt hours per day from the anaerobic digestion of 300 tons of manure and 500 tons of waste water; the residue can be used as a fertilizer. U.S. and Chinese technology are used (e.g., General Electric (GE) Energy, a partner, provided three turbines that generate electricity from the biogas; GE is also working with a second Chinese farm on another biogas project) (GE 2009, Sun and J. Zhang 2010).

An egg production farm in northwestern Beijing—Beijing DQY Agriculture Technology Co., Ltd., with almost 3 million chickens—uses four large biodigesters to generate electricity for the grid (Shi 2010). This plant was constructed by a Chinese company using German technology. Both the Shandong and Beijing plants receive feed-in tariff subsidies mandated by the central government and GHG emission reduction payments through the Clean Development Mechanism of the Kyoto Protocol.

Aviation biofuels are also being studied. PetroChina, Tianguan, and NCPC all mentioned that they are entering the aviation biofuels market. Although one feedstock will be algae, NCPC is also looking at biobutanol with DuPont as a biofuel and potential hydrocarbon for jet fuel use (NCPC 2010).

As for biodiesel, China is planting oil plants such as jatropha and *Pistacia chinensis* that could eventually produce as much as 5 million t/year (1.5 billion gallon/year) of the fuel (Tan 2010). Although biodiesel capacity and production data vary, production capacity reportedly amounted to about 200,000 t/year (60 million gallon/year) in 2008 with chemical conversion accounting for the majority because of the low costs (Tan 2010). Professor Tan described biodiesel production from waste oil, estimating that enough waste oil and fats exist to eventually produce 2 million t/year (600 million gallon/year) of the fuel. Most Chinese biodiesel is exported (Sun 2010).

New technology also plays a role in biodiesel production. Enzymatic conversion processes are being studied, and a facility using lipase as a catalyst and waste oil as a feedstock was started up in October 2007 (Tan 2010). Although more costly, the enzymatic conversion process is considered environmentally friendly (in comparison, the chemical process reportedly results in waste water and high energy consumption). There isn't much production yet of biodiesel from microalgae.

Production of biobased chemicals and other bioproducts in China

Biobased chemicals are often not only more environmentally sustainable than their fossil-fuel counterparts but may also make the production of liquid biofuels more economically feasible as coproducts. Companies are increasingly integrating production capability for downstream biobased chemicals into biorefineries, including biobutanol.[21] For example, Tianguan is upgrading its grain ethanol facility in Henan Province by adding a biobutanol production facility, with plans to import the needed grain. The product is, however, like many other such biobutanol ventures in China, intended for chemical use; the Tianguan representative (2010) mentioned that the company is focusing on a "more cost-effective application; biofuels are still too expensive an application" for biobutanol. Another upgrade to Tianguan's grain ethanol facility is to increase the size of the recovery unit for CO_2 to increase CO_2 capture to as much as 40 percent, versus 10 percent currently; some of the recovered CO_2 will be used to make biodegradable plastics, significantly reducing petroleum use.

Workshop participants visited NCPC SINOWIN's sorbitol and biobutanol facility in Shijiazhuang; again, the biobutanol produced is for chemical use. Company representatives stated that the corn-based biobutanol plant had been temporarily shut down because of the high cost of corn and the low cost of crude petroleum (which makes their product less cost competitive). Alternative feedstocks such as sweet potatoes, cassava, and molasses are being considered. But the NCPC representatives added that the separation of

[21] Biobased chemicals are usually either produced in a biorefinery as coproducts of a biofuel or produced using biobased inputs.

the biobutanol is one of the main costs and that this is likely to remain so until a microorganism is developed that will produce higher yields of biobutanol, thereby reducing the separation costs. Box 4 highlights novel aspects of Tianguan's and NCPC's development of biobased chemicals.

The NCPC SINOWIN representatives stated that whereas subsidies are needed for ethanol production, they are not needed for biobutanol, and that the Chinese government is studying how to address biobutanol demand in China. In their opinion, it is price dependent: if the price of biobutanol is very similar to that of ethanol then biobutanol will have a market in China and its costs could be offset by the production of hydrogen and CO_2, each of which can be used as inputs to produce other chemicals within the company (NCPC SINOWIN 2010). Workshop participants noted that the companies' production of biobutanol as a chemical also means they are not subject to Chinese biofuel restrictions.

One example of biobased chemical production mentioned by several workshop speakers, the conversion of glucose to succinic acid, is garnering attention worldwide because of its potential as an intermediate for several downstream chemicals, including biodegradable plastics (Xing 2010). Another biobased chemical produced by fermentation is 2,3-butanediol.[22] Other biobased chemicals mentioned in the workshop as being either studied or produced in China include bioethylene, acrylamide, lactic acid, 1,3-propanediol, sorbitol, and bioplastics such as polylactic acid and polyhydroxyalkenoates. In addition to the major bioprocess currently used (fermentation), enzymatic biocatalysis is being studied, with input from foreign collaborators.[23]

Infrastructure

China's energy infrastructure is expanding and changing, particularly in response to the increased use of renewable energy. Achieving the 2020 goal of replacing 15 percent of energy consumption with clean energy will require increased renewable energy capacity (e.g., hydropower is projected to increase to 350 gigawatts; wind to 150 gigawatts; and solar to 50 gigawatts)

[22] The fermentation steps would be glucose or xylose to 2,3-butanediol followed by esterification to 1,3-butdiene or followed by dehydration to 2-butanone.

[23] In biocatalysis, enzymatic bioprocesses are used either in lieu of or in addition to conventional chemical processes. The production processes for several pharmaceuticals in the United States and the European Union, for example, including those for some blockbuster products, integrate biocatalytic processes. USITC, Industrial Biotechnology, 2008, 2-7 and 3-15.

Box 4 Current and future production of biobased chemicals by Tianguan and NCPC

Tianguan's Future Biorefinery Production--Tianguan's industrial grain ethanol plant (400,000–500,000 t/year) uses starch-rich materials such as corn, wheat, and cassava as feedstocks. During the technical tour, Mr. Xiao Yang Zhang (the president of the company) spoke of plans to convert the company's grain ethanol plant into an integrated cellulosic biorefinery producing several high-value products (e.g., biodegradable plastics, ethylene, polyethylene, biobutanol, polytrimethylene terephthalate, and biodiesel). Tianguan is developing many of the emerging technologies needed. Novel perspectives about three products from the proposed biorefinery are:

> *Polyethylene from ethanol:* The Chinese ethylene market in 2010 amounted to more than 2.6 million tons but China's current ethylene production is less than 50 percent of demand, resulting in significant import dependency. Thus, according to Tianguan representatives, converting their ethanol production (current market price $810–830 per metric ton) to ethylene ($1,220–1,310 per metric ton) and then to polyethylene ($1,400–1,500 per metric ton) could be economically feasible. Bioethylene production is also considered a critical step in developing the polyethylene industry in central China. Moreover, Sinopec (a Tianguan stakeholder) reportedly built a 9,000 t/year pilot plant in the 1980's to produce ethylene from ethanol and is said to be planning to upgrade this plant as part of a consortium to develop bioethylene biorefineries. Chinese universities and research centers are also working to address reported technical problems associated with the production of ethylene from ethanol.
>
> *Biobutanol:* Tianguan plans to import the needed grain for its biobutanol production facility. The product is intended for chemical use as "biofuels are still too expensive an application" for biobutanol.
>
> *CO_2:* Will increase CO_2 recovery to 40 percent and to use some of the CO_2 to produce biodegradable plastics would reduce use of petroleum-based plastics significantly.

NCPC SINOWIN Co., Ltd.–The company is the biofuels subsidiary of the North China Pharmaceutical Group Corporation (NCPC), an SOE. NCPC SINOWIN is both a drug development center and an environmental research center. Its annual commercial-scale production capacity for biobutanol is about 12,000 t/year. The company temporarily stopped biobutanol production in 2010 because the price of its corn feedstock became too high and the price of crude petroleum was too low (the company representatives candidly noted that their biobutanol is price competitive at crude petroleum prices of more than $120 per barrel). Among other process modifications, the company is studying alternative feedstocks for biobutanol, including cassava, sweet potato, and molasses, to help offset price swings in corn; they found, however, that sweet sorghum is not an effective alternative.

Box 4 Current and future production of biobased chemicals by Tianguan and NCPC-Continued

NCPC SINOWIN uses a *Clostridium* organism that has the ability to release the glucose from the starch feedstock and then convert it to acetone, butanol, and ethanol (ABE). The process yields about 23 percent by weight on the sugar substrate—3 parts acetone; 6 parts butanol; and 1 part ethanol. Sixteen fermenters are used, each having 300,000 liter capacity. Feedstock costs account for the largest share of total production costs (60-70 percent), followed by separation costs (20–30 percent). NCPC's goal is to develop a microorganism that will yield a higher concentration of butanol, thereby reducing separation costs. They said that U.S. companies use membrane separation but this is very costly.

Speaking of the future of biobutanol in China, the NCPC representatives said biobutanol will have a place in China if its price is similar to that of ethanol. But, they said, China's version of the U.S. Environmental Protection Agency would have to approve it before use and that blending approval would also be needed. They stated that the production costs for the biofuels could be offset by coproducts such as CO_2 and hydrogen; CO_2 can be used as a precursor for some of the petrochemicals to be produced and hydrogen can be used directly in the company's sorbitol production process.

Sources: Technical tours: Tianguan, August 17, 2010, and NCPC, August 20, 2010; various workshop speakers; Professor Pingkai Ouyang (president, Nanjing University of Technology), plenary speech at ICBT 2010; "ICIS Pricing: Ethanol (Asia)," May 5, 2010, "ICIS Pricing: Ethylene (Asia Pacific)," April 30, 2010, "ICIS Pricing: Polyethylene (Asia Pacific)," April 30, 2010.

(J. Zhang 2010). Meeting the goals is also likely to require changes to the existing energy production and distribution infrastructure to accept new sources of energy.

Infrastructure expansion efforts underway in rural and urban areas are diverse, ranging from household solar and biogas projects to commercial-scale ventures, and each has its own challenges. For example, ethanol is extremely hygroscopic and will easily absorb water, affecting storage and distribution. As such, one infrastructure question related to the national rollout of E10 is whether high humidity levels in southern China would require a new infrastructure for distribution and use, rather than using existing gasoline distribution networks. In contrast, biobutanol, if used as a transportation fuel, is far less hygroscopic and can be more easily integrated into existing networks.

New biofuel production facilities are also being brought onstream. As with other technologies, China is rapidly developing such sites, particularly 2nd-generation, and standardizing them to the extent possible.[24] This speed parallels the development of fossil fuel refineries in China; 6 new 200,000 barrels per day refineries (or about 8.4 million gallons per day)[25] will be built by 2020, with one built every 18 months using a "cookie cutter" approach (Fu 2010).[26]

Financial considerations

Professor Shi stressed the importance of funding R&D if China's renewable energy goals are to be met, mentioning that RMB 5–10 billion (about $700 million–$1.4 billion) has been invested in clean energy during the 11th 5-Year Plan, with 50 percent focused on R&D for renewable energy. Investment in clean energy will have to increase as capacity grows. Chinese investment levels in green energy from 2009 through 2020 are expected to total RMB 5.4 trillion (about $800 billion) (J. Zhang 2010).

As in other countries, capital is necessary for the construction of precommercial and commercial facilities and, for some companies, in crossing the "Valley of Death" while bringing a product to market.[27] Funding sources in China vary, especially given the relative lack of domestic venture capital.[28] Tianguan, for example, an SOE, said it funds its own facilities. Another avenue for financing is foreign investment. Many foreign investors are said to have shown great interest in China's "inviting market" (Shi 2010), and there is considerable foreign investment in the bioenergy and biobased chemicals industries. Although, per the "Industrial Catalog for Foreign Investment (2007 Amendment)," foregin

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[24] Although this speed could reflect efficient coordination of projects and use of high-quality imported technology, such as the world-class fermentation plant control systems produced by Siemens and used in the Tianguan facility, quality may become an issue if it is not controlled well. One workshop participant said that China needs to monitor such situations closely.

[25] Using a conversion factor of 1 barrel of crude petroleum equals 42 gallons.

[26] China is also focusing on establishing and expanding industrial production sites. One proposal calls for the development of a "green valley" (an industrial park) near the Great Wall that will have solar, biomass, and other clean energy projects.

[27] The "Valley of Death" is the "funding gap" in the transition from research to commercialization of a product. Ford, Koutsky, and Spiwak, "A Valley Of Death In The Innovation Sequence: An Economic Investigation," September 2007.

[28] Professor Shi said that new rules and regulations are needed to encourage venture capital.

investment in the production of liquid biofuels such as bioethanol and biodiesel is restricted in that the Chinese partner must hold the majority of the venture, at the time this article was prepared the 2007 catalog was expected to be updated but specific information was not yet available. Another source of funding—stimulus funding—was also said to be available for infrastructure projects during the economic downturn.[29] Also, as detailed more fully in an article from a Chinese journal, the CAS's "BiotechnologyInnovation & Bio-Industry Promotion Program" is expected to increase collaborative synergy between government, industry, academia, and finance.[30]

Government funding is available for research and commercialization. Examples include the National Basic Research Program 973, which covers the extension into applied research, and the National High-Tech Program 863, which supplies funding for applied research and then the next level—pilot scale tests. The National Supporting Program and the National Development and Reform Commission also provide funding for pilot plants and, in combination with company funding, support commercialization. Government funding to universities has also increased. In regard to CAU's funding for R&D, for example, Professor Dong stated that CAU received almost eight times more funding in 2009 than in 2001, a total of RMB 890 million (about $131 million) versus RMB 102 million (about $12 million).

Government funding methods cited by workshop speakers for commercial-scale projects include monetary incentives for biogas and ethanol projects and tax incentives for clean energy power projects, including biomass power generation (Huang and Shi 2010). In 2006, for example, the subsidy for fuel ethanol from grain was RMB 1,373 per ton of ethanol (or about $172 per ton) (J. Zhang 2010). In 2009, the government increased the subsidy to RMB 2,056 (about $302) before decreasing it to RMB 1,659 (about $244) in 2010. In addition to the facility's annual performance, one factor that affects the amount of the subsidy is whether companies are exceeding the allowed levels of grain; those that are will receive lower subsidies (J. Zhang 2010).

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[29] China reportedly allocated about $47 billion in stimulus spending in 2008–09 to clean energy, versus about $67 billion in the United States. It was projected that much of the allocated funds would be spent in 2010–11. The Pew Charitable Trusts, "Who's winning the clean energy race?" March 2010, 11, 14, 20.

[30] *Science and Technology Daily,* "中科院生物技术创新与生物产业促进计划初显成效," June 17, 2010. The article was shared with the authors in follow-up discussions to the workshop.

Although some sources have speculated about the future removal of such monetary incentives, they continue to be an important factor affecting the competitiveness of biofuels. When asked about the break-even point past which E10 would be considered competitive, a representative of Henan Tianguan Enterprise Group Co., Ltd., stated about RMB 9,000 per ton (with the observation that they are currently at about RMB 7,000 (about $1,029 at the time of the workshop)).[31] While this figure is an estimate for only one facility, it was considered an unusually candid conformation of the continued significance of monetary incentives and support to the industry. The production of co-products such as bio-based chemicals is also expected to make the biorefineries more cost-effective.

Carbon credits and a carbon tax are other sources of clean energy funding in China. GE, referring to the Anaerobic System in the Chicken Farm of MinHe project, says, "Backed by the International Bank for Reconstruction and Development, the project is receiving financial support through the sale of carbon credits called Certified Emission Reductions (CERs)."[32] Dr. J. Zhang said that a carbon tax was collected in 2009 from petroleum and coal companies to subsidize clean energy projects. He added that the government has not developed such policies for nongrain production, though, because such projects are "currently part of the energy mix" and that good policies are needed to strengthen the biomass industry and to meet the 2020 goals. Dr. Xingguo Fu (2010) also stated that the National Bureau of Energy is interested in an aviation fuel program and it is likely there will be a carbon tax of about RMB 500 (about $74) per metric ton of CO_2 if biofuels are not used.

Funding for clean energy projects is also available through the Investment Association of China's Energy Research and Development Center, the public face of investment in NDRC-supported programs. Presenting information new to many of the workshop participants, Dr. J. Zhang said the projects are considered low risk for investors because they are NDRC projects. He added that RMB 300 million (about $44 million) was invested in 2009, much of it in solar energy projects.

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[31] Tianguan representatives, technical tour, August 17, 2010. In this instance, the "break-even point" can generally be defined as the price point at which production or sales equals operating expenses without a profit or loss. Prices above the "break-even" point would generate a profit.

[32] "GE powers China's largest chicken waste biogas plant," September 25, 2009. In addition to being eligible for tax incentives, biomass power generation companies are also eligible for the sale of CER credits under the Kyoto Protocol.

Domestic and International Collaborations and Strategic Alliances

Domestic and international collaborations exist at the industry level, at universities, and in many combinations thereof. As is the case with many research-intensive high-technology industries (e.g., pharmaceuticals), such collaborations are initiated for numerous reasons, including: (1) efforts to mitigate the risks and costs involved in developing new technology; (2) the enhanced ability to share knowledge and technology within ongoing collaborations; and (3) the synergy generated by pooling individual companies/entities' specializations along the value chain, ranging from process technology to marketing.

Collaborations are underway at many Chinese universities. CAU is actively focusing on numerous international collaborations; it has "close relations" with USDA and research collaborations with many U.S. universities (Wang 2010). In 2006, Tianguan built a joint R&D center with Zhongshan University to develop biodegradable plastics from CO_2.[33] COFCO has collaborations with Tsinghua University, East China University of Science and Technology, Tianjin University, Harbin University of Technology, and others. CAS has also provided key contributions to the development of biofuels.

Chinese companies are participating in domestic and international strategic alliances, including 2nd-generation biofuel ventures, in part to defray costs and offset risks. International R&D collaboration is strongly promoted in China; China has historically entered into many collaborative ventures with countries such as Germany and the United States.[34] Professor Shi said that China and the United States should confront the "mutual crisis" by promoting renewable energy development, citing the U.S.-Chinese agreement to construct a clean energy research center as a step towards future sustainable development.

In one of NCPC's ongoing collaborations with DuPont, although not confirmed, the NCPC SINOWIN representatives said they sold the DuPont/BP biofuels venture its cell line—and the related details—for $500,000 (the cell line was developed by CAS). Tianguan is also very interested in establishing international collaborations outside China (Tianguan 2010). Foreign entities

[33] Henan Tianguan, "Science," (accessed various dates).

[34] China has had projects with Germany since 1979; China also introduced U.S. technology converting sweet sorghum in the 1980s and has since improved the technology advancement process (Shi 2010).

active in Chinese bioenergy and biobased chemicals technology exchange and alliances include Novozymes, Genencor,[35] UOP, and NREL, among others. In one example of information published in Chinese journals, international collaboration is also a focus of CAS' "Biotechnology Innovation & Bio-Industry Promotion Program."[36] Although China's recent indigenous innovation policies may impact innovations in bioenergy, several of the Chinese experts stated that China's international intellectual property collaboration will not be held up by such policies. When asked if these policies will affect joint ventures, representatives of NCPC SINOWIN, a bio-based chemicals producer, said that there are many mechanisms that can be used to enter the market.

In regard to collaborations and intellectual property rights, Dr. Lin of COFCO mentioned that work was underway on patenting the sweet sorghum varieties. He also mentioned Chinese and European patent activity related to COFCO's 2nd- generation ethanol production at its Zhaodong facility (feedstocks include straw or agricultural waste), with projected patent activity and/or technological development in India, Brazil, and the United States.

Conclusion

Speakers at the USDA-WSU-CAU Bioenergy Workshop and the technical tour representatives, all experts in bioenergy and bioproducts such as bio-based chemicals, provided a unique, "on-the-ground perspective" on current and future Chinese bioenergy and bioproduct research and commercialization. Drawing upon centuries of fermentation expertise, China is strongly promoting its bioeconomy, spurred in part by environmental issues, as well as food, energy, and national security concerns:

- ✓ China's primary energy source—coal—does not promote environmentally sustainable development;
- ✓ China's crude petroleum reserves are likely to be depleted after 11 years;
- ✓ As of the first quarter 2010, China's imports of crude petroleum reached 55 percent of its consumption;
- ✓ The country's burgeoning economy has boosted energy consumption

[35] A Genencor press release, dated January 10, 2011, stated that DuPont had made a binding offer for Danisco A/S. Genencor is a division of Danisco.

[36] *Scientific Times,* "张知彬谈"中科院生物技术创新与生物产业促进计划," April 12, 2010. The article was shared with the authors in follow-up discussions to the workshop.

significantly in many ways, ranging from increased manufacturing to use of a growing number of vehicles;
- ✓ China is not only providing electricity to rural areas but is also increasing power generation to towns and cities as the country undergoes continuing urbanization.

China is focusing on several types of renewable energy, including hydro, wind, solar, nuclear,[37] biomass, and biogas power generation, as well as liquid biofuels. The workshop speakers affirmed that China is investing heavily in renewable energy, with investment levels projected to increase to a total of RMB 5.4 trillion (about $800 billion) for the period 2009 through 2020. The central government is promoting supply-and-demand measures for bioenergy, as well as national funding programs to foster applied research and the transition to commercialization of bioenergy and other high-technology products. The NDRC also provides funding for pilot plants and, in combination with funding from companies, supports commercialization. The technology being commercialized originated in the CAS, in universities within China, in companies, or from international sources, as well as many combinations of these sources.

The cap on corn use in China because of food security concerns has spurred exploration and promotion of alternative feedstocks as biomass inputs for liquid biofuels, including, for ethanol, cassava and sweet sorghum and lignocellulosic inputs such as agricultural and forestry residue; various oil plants for biodiesel; and algae for aviation biofuels. Given the limited land available to supply many alternative crops, however, workshop speakers confirmed that imported feedstocks are also being used to meet Chinese demand in the near term (e.g., cassava). Throughout the workshop, the amount of available biomass in China was estimated at around 300 million tons, translating to potential production of about 25 billion gallons of ethanol.[38] However, it is not clear how much of this biomass would be available for fuel ethanol, given competition for other uses, including other bioenergy applications. The continued dependence of many pilot facilities on steam explosion pretreatment also indicates that financial and energy costs will be difficult to overcome without significant technical breakthroughs.

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[37] China includes nuclear energy in its green power and renewable energy classifications. In comparison, the EIA defines nuclear energy as "nonrenewable." EIA, "Energy Kids," n.d.

[38] Using a conversion factor of 1 ton of biomass produces 80 gallons of ethanol,

The production of biobased chemicals is being emphasized and expanded, either as co-products of biofuel production in integrated biorefineries or as stand-alone products with biobased inputs. In addition to the major bioprocess currently used (fermentation), enzymatic biocatalysis is being studied, with input from foreign collaborators. Biobutanol is increasingly being produced for chemical applications as companies do not consider it cost-effective as a biofuel.

The Chinese infrastructure for these products is growing accordingly, as is financing (with an emphasis on promoting venture capital) and standards development. Workshop speakers provided an unusually candid confirmation of the continued importance of monetary incentives and support, stating that E10 prices at the time of the workshop were still RMB 2,000 per ton (or almost $300 per ton) below the break-even point. They also stated that feed-in tariff subsidies mandated by the central government and GHG emission reduction payments are provided through the Clean Development Mechanism of the Kyoto Protocol. Carbon credits and a carbon tax are other sources of clean energy funding in China.

Demonstration plants in biofuels are also being brought onstream rapidly; biogas is being commercialized; and various sources of bioenergy are being combined to optimize power generation, particularly in rural areas. Domestic and international collaborations are expanding, spurring current and future innovations in liquid biofuels, bioenergy, and bioproducts, both for use in China and for export.

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