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Industrial Biotechnology in China Amidst Changing Market Conditions

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Abstract

The increasing use of industrial biotechnology by the Chinese liquid biofuels and chemical industries is expected to help offset energy security and environmental concerns generated by China's robust economic growth. The expanding use of bioprocesses to produce products such as fuel ethanol and bioplastics is also likely to contribute to continued innovation, productivity gains, and cost savings. This, combined with strong government promotion of the country's bio-based economy, coincides with the two industries' growing global prominence; China is currently the world's third largest producer of ethanol and second largest producer of chemicals. This growth has encouraged expanded domestic and foreign investment, including in bio-based projects, and generated related gains in exports, particularly in the chemical industry. Market conditions facing many ongoing and prospective ventures, however, are changing as a result of a combination of factors, including the strength of the Chinese currency, new labor regulations, tax changes, and volatile energy prices.

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Introduction

Industrial biotechnology is often defined as the use of enzymes and micro-organisms[2] to produce goods and services (e.g., through bioprocesses such as fermentation and biocatalysis).[3] This definition, however, does not include the growing trend of converting renewable resources into finished products by any process, including conventional chemical processes (e.g., the production of biodiesel). As such, this article uses the definition used by the U.S. International Trade Commission in its report on industrial biotechnology (2008, 1-4):

> "The manufacture of liquid fuels and chemicals using (1) enzymes or micro-organisms at any stage of the production process, regardless of the type of raw materials used (e.g., renewable, fossil fuel-based, or inorganic); or (2) renewable resources and conventional chemical processing."

Industrial biotechnology is increasingly being utilized by the liquid biofuels and chemical industries in many countries because of its technical, economic, and environmental advantages,[4] including process simplification, lowered greenhouse gas emissions, reduced use of fossil-based inputs and energy, decreased waste generation, and related reductions in production costs and capital expenditures.

In the energy sector, industrial biotechnology is used to produce liquid biofuels (e.g., ethanol and biodiesel**)** from renewable resources for use in

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[2] Enzymes are biologically-derived, biodegradable proteins that initiate or accelerate chemical reactions. Micro-organisms are simple life forms such as bacteria and yeasts. Inasmuch as enzymes are an inherent part of micro-organisms' metabolism, micro-organisms are not only used to generate enzymes but are also themselves used in the manufacture of liquid biofuels and bio-based chemicals.

[3] Biocatalysis and fermentation are two types of bioprocesses. Biocatalysis generally utilizes isolated enzymes and/or micro-organisms to conduct chemical reactions. Fermentation processes, defined by some as a subset of biocatalysis, use micro-organisms to break down complex organic compounds into simpler ones. Ethanol, for example, is produced via a fermentation process in which sugars from corn and other renewable resources are converted by yeasts into ethanol and carbon dioxide. (USITC 2008, v-vii, and 1-4).

[4] Environmental benefits accrue from both the production and use of liquid biofuels and bio-based chemicals but vary by sector. (USITC 2008, 1-1).

blends with or as substitutes for gasoline and diesel. In the chemical industry, in addition to increased use of renewable resources as feedstocks, bioprocesses are used with or instead of conventional chemical processes to produce a wide variety of products ranging from biodegradable biopolymers to specialty chemicals and pharmaceuticals. Industrial biotechnology allows for the production of chemicals that might otherwise not be technically or economically feasible.[5]

China's ongoing use of industrial biotechnology to manufacture liquid biofuels and bio-based chemicals has been spurred in part by its long-standing use of fermentation, a key bioprocess. China produced fermented beverages as early as 9,000 years ago; other fermented products include chemicals and foods (McGovern et al 2006). China's increased use of industrial biotechnology is also attributed to concerns about energy security; the country's increasing energy consumption; volatility in fossil fuel prices, including crude petroleum; a focus on rural development; and environmental concerns (Liu 2005; Latner, O'Kray, and Jiang 2006a, 5; and Jiang 2008, 3, 5, and 6).[6]

Government support, characterized by Jiang (2008) as "strong," plays an important role in promoting China's development of a bio-based economy, particularly in regard to biofuels. Long-term support of industrial biotechnology and related strategic planning are reflected in the country's 11th Five-Year Plan. The Chinese government's approach has been expansive in scope, addressing research and development (R&D) as well as measures supporting supply and demand. In addition to promoting the use of renewable resources, the government has focused on the supply side by providing various types of financial support, including monetary incentives and preferential taxation policies (Ke 2006; author, pers. comm., December 18, 2006; and Embassy of the People's Republic of China in the United States of America 2006). China has also implemented mandatory use programs for ethanol, stimulating demand.

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[5] Also called "white biotechnology," industrial biotechnology is often referred to as the "third wave" of biotechnology following upon the relatively longer-term use of biotechnology in the healthcare sector ("red biotechnology") and the agricultural sector ("green biotechnology"). Biotechnology processes generally used in red and green biotechnology (e.g., genetic engineering) will not be addressed in this article.

[6] As noted by Jiang, China's rural residents–about two-thirds of China's population, or 800 million people–earn a net annual income of less than $500. Industrial biotechnology has the potential to provide additional income for farmers (e.g., for agricultural residue) and create rural employment. Jiang also notes that one of China's environmental goals is to reduce greenhouse gas emissions by 1.4 billion metric tons. (2008, 3, 5, and 6).

This article first presents information about China's liquid biofuels and chemical industries and their use of industrial biotechnology. Related business strategies are then discussed, followed by information regarding government policies. Each industry discussion concludes with an outlook as to potential outcomes within the context of changes in market conditions affecting each industry.

Liquid Biofuels

China's methodical progression towards the development of a national biofuels program began in the mid-1980s with ongoing R&D related to ethanol. This program then expanded into the formulation of a legislative framework, the 2001 launch of an ethanol initiative, and inclusion of "The Bioethanol Utilization Plan" in the country's 11th Five-year Plan.

China is the second largest energy consumer behind the United States. After having doubled from 1996 to 2006, its energy consumption is expected to nearly double again by 2020. Consumption of crude petroleum alone increased to 6.5 million barrels per day in 2004, an increase of more than 100 percent since 1994, before growing to 7.6 million barrels in 2007. Imports account for a growing share of the total, increasing from 19 percent of the total in 1999 to 43 percent in 2005 and projected to continue increasing to 60 percent by 2010 (EIA 2008 and Jiang 2008). As a result, China, a net importer of crude petroleum since 1993, has been actively searching for energy supplies to meet its steadily growing energy needs stemming from its population growth, robust economic growth, and burgeoning number of vehicles.[7] This search for energy has influenced China's foreign policy efforts, spurring numerous alliances with energy- and resource-rich countries (Earth Policy Institute 2005; Leggett 2005, A1; and Rohter 2008, 1).

China is the world's second largest market for automobiles. After growing by almost 47 percent in the first half of 2006 alone compared with the like period in 2005, sales grew by 24 percent in 2007 and continued to exhibit strong growth through early 2008, resulting in a corresponding increase in gasoline consumption. In 2005, China mandated that ethanol blends (mostly E10, a gasoline blend containing 10 percent ethanol) would

[7] See, Wang et al. 2006, 9 and 17; InfoPlease 2004; GreenCar Congress 2006c; and Cha 2008, A1.

replace conventional gasoline for all vehicles nationwide. Since that time, the use of pure gasoline has leveled off while consumption of E10 has increased (Sanchez and Junyang 2008). The National Development and Reform Commission (NDRC), the agency that oversees biofuels and other energy products, projects in its “Mid- and Long-Term Renewable Energy Development Plan” that the E10 plan is expected to be implemented on a national basis by 2020 (Speckman 2008).

The increase in energy costs through the first half of 2008 was said to be curbing domestic sales of larger, “gas-guzzling” vehicles such as sedans, sport utility vehicles, and light trucks. Sales of such vehicles slowed in July 2008, increasing by only 6.8 percent compared with July 2007, continuing a 4-month trend. In August 2008, in a reported effort to reduce increasing consumption of gasoline, the Chinese government doubled the sales tax on larger cars from 20 to 40 percent and reduced taxes on smaller cars. Moreover, the cascading progression of the global economic slowdown resulted in a downward revision in October 2008 of growth in sales of light vehicles in 2008 (including passenger cars and light commercial vehicles) to 9.7 percent, less than half that of 2007 (*IHT* 2008; EIU.com 2008; GreenCar Congress, 2006c; Cha 2008, A1; and Schuster 2008).

Industry Profile

Ethanol[8]

China is the third largest producer of ethanol worldwide, accounting for about 5 percent of world biofuel production. The importance of biofuels to the country’s goals is reflected in the highly concentrated nature of the sector. According to the Foreign Agricultural Service (FAS) of the U.S. Department of Agriculture (USDA), although China has numerous companies producing food-grade ethanol, the country has to date limited its fuel ethanol production and, in turn, its production incentives, to five state-owned companies: China Resources Alcohol Co. (CRAC); Jilin Fuel Ethanol Co.; Henan TianGuan Fuel-Ethanol Co.; Anhui BBCA Biochemical Co.; and Guangxi COFCO Bio-Energy Co. The marketing and distribution of ethanol is also controlled by the government; state-owned entities China Petroleum and Chemical Corporation (Sinopec) and China National

[8] Except as noted, much of the information in this section was compiled from the Foreign Agricultural Service’s annual reports on biofuels in China (Sanchez and Junyang 2008, 5-6; Latner, Wagner, and Junyang 2007, 5 and 9; Latner, O’Kray, and Jiang 2006a, 11, 12 and 14; and Latner, O’Kray, and Jiang 2006b).

Petroleum Corporation (CNPC) are the only companies authorized to blend ethanol with gasoline and distribute the blend.

Official production of fuel ethanol began in 2004. The FAS reports that annual production increased from initial levels of about 101 million gallons in 2004 to 469 million gallons in 2007, an increase of 367 percent.[9] Annual growth has been slowing. Following increases of 1400 percent (2004), 206 percent (2005), and 41 percent (2006), production grew by only 8 percent in 2007. Most of the ethanol produced in China is derived from corn. One company–Henan TianGuan Fuel-Ethanol Co.–has been using stale wheat as its primary feedstock but supplies of stale grains are reportedly running low. China's promotion of stale grain as an ethanol feedstock allowed for the eradication of a large stockpile of outdated grain that had accumulated because of overproduction resulting from policies promoting agricultural production (Sanchez and Junyang 2008, 5, 2007, 5, 6, and 9, and 2006, 9; Bilin 2007; Cao 2006; and Liu 2005).[10] Another company, Guangxi COFCO Bio-Energy Co., which started commercial production in April 2008, uses cassava as a feedstock. It is the first large-scale, commercial nongrain project approved in China.[11]

Biodiesel[12]

Information about the size and composition of the Chinese biodiesel industry varies. The industry is very fragmented. Most of the estimated 100 companies producing biodiesel have only about 30,000 to 6 million gallons capacity. Although China is the world's largest importer of soybeans, edible vegetable oils are used primarily for food, reducing the supply for biodiesel consumption. As such, many companies face insufficient supplies of the renewable resources used as feedstocks (i.e., animal fat or vegetable oil feedstocks) and have to limit production to a few months a year. Biodiesel production in 2007 reportedly amounted to about 90 million gallons,

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[9] In comparison, according to the U.S. Department of Energy, U.S. shipments of ethanol in 2007 amounted to 6.5 billion gallons. (USITC 2008, 2-5).

[10] Fuel ethanol production costs vary depending on the input; if a company using stale wheat as a feedstock has to convert to new wheat, production costs will increase. It costs about $1.68 per gallon of ethanol if stale grain is used as the input versus about $1.56 per gallon for cassava or about $1.95 per gallon for corn.

[11] See, Sanchez and Junyang 2008, 5 and 7, and author, pers. comm., November 30, 2008. The Guangxi ethanol production facility's feedstock requirements were said to provide additional income for 1.1 million farmers (*The Standard* 2006).

[12] The information and data in this section were compiled from various sources including Wang 2007; Wang et al. 2006; Sanchez and Junyang 2008, 9; and Latner, Wagner, and Junyang 2007, 7.

although it has been reported that it often did not meet quality standards for fuel-use biodiesel. Unlike ethanol, biodiesel is marketed directly to end users.[13]

Business strategies

Ethanol

Ethanol production capacity is expected to increase to slightly over 1 billion gallons per year by 2010 and to about 3.3 billion gallons by 2020. Given food security concerns, however, a cap has been put on the amount of corn that can be used as a feedstock. New fuel ethanol projects being approved focus on nongrain feedstocks such as cassava and sweet potato; studies are also underway addressing the use of other nongrain feedstocks such as sweet sorghum and sugar beet. Tiger Ethanol, for example, has proposed using sugar beet at its majority-owned joint venture in Fujian Province to produce both ethanol and refined sugar, and has signed an agreement with the local government to cultivate an estimated 1.5 million tons of sugar beet by 2014. The use of sugar beets will give Tiger Ethanol flexibility to shift ethanol and sugar production levels depending on world prices. It will also provide additional income to farmers of as much as $100 per acre (for a total of about $250 per acre), as they will be able to grow two crops each year–barley from March through June and sugar beets from July to October.[14]

China is also emphasizing the use of lignocellulosic feedstocks such as agricultural and forestry residue, energy crops (e.g., switchgrass), and municipal waste for ethanol production with commercial production expected to start during 2011-15. Existing corn starch production plants are expected to be retrofitted to produce cellulosic ethanol once the technology becomes feasible. The industry is expected to produce an estimated 3 billion gallons of ethanol from lignocellulose by 2015-20, or one-half of total projected ethanol production from all sources.[15]

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[13] In comparison, U.S. shipments of biodiesel in 2005 amounted to slightly over 106 million gallons and increased to more than 495 million gallons in 2007. (USITC 2008, 2-4 and 2-5).

[14] See, *Farms.com* 2006; GreenCar Congress 2006b and 2006e; Latner, O'Kray, and Jiang 2006a and Latner, Wagner, and Junyang 2007, 4 and 5; Kojima, Mitchell, and Ward 2007, 93; Bilin 2007; Garten Rothkopf LLC n.d., 373, and *BioFuelsBusiness.com* 2008 and *Biomass Magazine* 2008.

[15] Latner, O'Kray, and Jiang 2006a, 19; Li, Shi-Zhong, 2007; Embassy of the People's Republic of China in the United States of America, 2006; *Forbes* 2007; Bilin 2007; and Speckman 2008.

China is working with domestic research institutes and foreign entities to develop cellulosic ethanol production. Two demonstration-scale[16] plants are currently operating in Henan and Heilongjiang Provinces (Sanchez and Junyang 2008, 8). In 2006, state-owned CRAC, the second largest producer of ethanol in China and a unit of COFCO Limited (formerly China National Cereals, Oils & Foodstuffs Corp.), brought onstream a corn stover cellulosic ethanol pilot plant in Heilongjiang Province through an agreement with SunOpta (Canada) and Novozymes A/S (Denmark) with plans to expand operations.[17] Another ethanol producer, Tianguan Group, has converted 40 percent of its grain-based production in Henan Province to nongrain inputs such as cassava and sorghum following the government's directives of June 2007. It also operates a demonstration scale plant that converts wheat straw into cellulosic ethanol that is expected to be a model for plants built within the province through 2020. The company chairman cites a focus on creating "clusters" of smaller-scale plants given logistical and infrastructure limitations such as collecting and transporting the wheat straw feedstock, the volume of enzymes needed in the production process, and waste treatment (Jing 2008; also, Sanchez and Junyang 2008, 8, and author, pers. comm., September 16, 2008). Despite the projected increases in capacity, however, industry sources have stated that it is possible that future supply may not meet domestic demand. Demand for fuel ethanol in 2010 is expected to amount to 5.4 billion gallons and ethanol blends are expected to account for one-half of China's consumption of gasoline.[18]

Chinese imports of ethanol, mainly undenatured, spiked in 2005 at almost 5 million gallons before declining substantially to almost 185,000 gallons in 2007, reportedly because Chinese feedstock advantages reduced the price competitiveness of imported ethanol versus domestically-produced ethanol Sanchez and Junyang 2008, 11). China emerged as a major net exporter of ethanol in 2006. Traditionally an exporter of undenatured ethanol, mainly to Japan and Korea for use in making alcohol, Chinese exports of fuel

[16] The construction and operation of pilot plants and demonstration-scale plants precede scale-up to commercial production facilities. According to one industry source, pilot plants have production capacities of about a few thousand gallons of ethanol per year (gpy); demonstration-scale plants, about 1 million gpy; and commercial-scale, upwards of about 100 million gpy (author, pers. comm., April 8 and 9, 2008).

[17] See, GreenCar Congress 2006b and 2006h; Burke 2007; Lauridsen and Peckous 2008, 24; and author, pers. comm., September 16, 2008. State-owned COFCO Limited is working with Novozymes to build a cellulosic ethanol plant in Heilongjiang Province in 2009 with a capacity of 3 million gallons per year. (Lauridsen and Peckous 2008, 24).

[18] See, GreenCar Congress 2006b and 2006h; Burke 2007; Lauridsen and Peckous 2008, 24; and author, pers. comm., September 16, 2008.

ethanol (denatured) increased significantly in 2006 to 12 million gallons from about 950,000 gallons in 2005. During the same period, total Chinese exports of ethanol increased from 42 million gallons to 264 million gallons, reportedly "in reaction to higher world petroleum prices" (Latner, Wagner, and Junyang 2007, 8-9). The United States was the third largest market for China's ethanol exports in 2006, accounting for 16 percent (Latner, Wagner, and Junyang 2007, 8-9; Benjamin 2006).

In 2007, however, reportedly as a result of the elimination of the refund of the 13 percent value-added tax (VAT) on exports, ethanol exports declined by 88 percent to less than 53 million gallons (roughly 2005 levels). The elimination of the rebate, reportedly implemented in an effort "to discourage the expansion of [the] grain-processing sector," is said to have substantially reduced ethanol export profits (Sanchez and Junyang 2008, 10).

Biodiesel

Expansion of China's biodiesel industry has reportedly been limited because much of the progress to date on the national biofuels program has focused on ethanol, even though diesel consumption in China is double that of gasoline because of the increased use of trucks and farm machinery. A lack of standards and regulations has also reportedly hampered the industry's development. A voluntary national biodiesel standard was announced in July 2007 (Sanchez and Junyang 2008, 8).

As with ethanol, food security is a major concern. Vegetable oils are one feedstock for biodiesel. Whereas China is the world's second largest producer of rapeseed after Canada, it uses it mainly to produce edible oils for food use. China supplements such production with imports; it is the largest importer in the world of major edible vegetable oils. Land use is also limited; only 14 percent of land in China is arable. Given the lack of availability of virgin vegetable oils, biodiesel feedstocks are largely waste grease and oils. In July 2008, the NDRC approved three biodiesel pilot projects using jatropha oil, a nongrain feedstock.[19] Three state-owned entities–PetroChina Company Limited, Sinopec, and the China National Offshore Oil Corporation (CNOOC)–will develop the projects, bringing onstream about 51 million gallons of capacity (Zang 2008).

[19] Jatropha does not compete for acreage with crops as it can be grown on marginal acreage.

Also as with ethanol, in addition to working with domestic research organizations, China is collaborating with foreign entities to develop its biodiesel industry (CORDIS News 2006; *Dow Jones Energy Service* 2006; and BP 2007). For example, D1 Oils PLC (UK), in a joint venture with China's Ministry of Agriculture, is developing *Jatropha curcas* farms with the eventual expectation to build a biodiesel production facility using jatropha as a feedstock. D1 Oils has also entered into a 50-50 joint venture with BP to cultivate jatropha in South East Asia, Southern Africa, Central and South America, and India.

In regard to international trade, official statistics are not available but much of the biodiesel produced is said to be exported to Europe; very little, if any, is said to be imported. Biodiesel exports in 2006 were estimated to amount to about 3 million gallons (Latner, Wagner, and Junyang 2007, 7; Wen 2005; and Li, Jiao 2007). In 2007, one firm was reportedly planning to focus new production capacity towards exports to expand revenues and profit margins to offset an 18 percent increase in the price of waste oil, the company's feedstock (*BiofuelsMarketplace.com* 2007).

Government programs

A draft version of the 11th Five-Year Plan, introduced in 2006 by the NDRC addressed biofuels development in the 2006-10 period and was expected to be implemented in December 2006. At the same time, however, concerns about food security for the country's population of 1.4 billion escalated in combination with increased commodity prices, including grain prices. Given these concerns, the State Council did not approve the initial draft plan; however it did approve a revised version at a later date. The NDRC subsequently published the "Mid- and Long-Term Renewable Energy Development Plan" (Renewable Energy Plan) on September 4, 2007, to guide the development of the biofuels sector through 2020. According to the plan, 670 million gallons of nongrain fuel ethanol and 60 million gallons of biodiesel would be produced by 2010, increasing to 3,349 million gallons of ethanol (from all feedstocks) and 600 million gallons of biodiesel by 2020. The NDRC also sought proposals from private and State-owned entities as of June 2007 for the development of 10-15 pilot plants utilizing nongrain feedstocks (e.g., sweet potato, cassava, sweet sorghum, and oilseeds) with resulting funding tied to meeting specific technology and productivity objectives. One ethanol plant, based in Guangxi Province and using cassava as the feedstock, was approved and started commercial production in April 2008.[20] Another proposal, if accepted by the NDRC, would start construction in 2008 on a 30 million gallon ethanol plant using sweet potato as the feedstock.[21]

China regulates the prices of ethanol, gasoline, and diesel and has reportedly maintained energy prices at levels below those on international markets, providing monetary incentives to domestic petroleum companies to offset the difference between the regulated price in China and increasing world market prices. As noted by Sanchez and Junyang (2008, 4),

> "The government evaluates international oil prices periodically to determine a benchmark price for gasoline and diesel for domestic distribution. The fuel ethanol price is linked to the set government fuel price and then marketed by state designated retailers."

The price of ethanol sold to Sinopec and CNPC is set at 91 percent of the price of unleaded gasoline. China also pegged the retail price of E10 to the price of gasoline (Bilin 2007; Sanchez and Junyang 2008, 4; and Wang et al 2007). After increasing gasoline and diesel prices by almost 10 percent in November 2007 as prices rose on international markets, China announced in January 2008 that it was freezing energy prices in an effort to offset inflation concerns (Yardley 2008, C3; and *Xinhua* 2008a, 2007b, and 2007c). However, in June 2008, China increased fuel prices yet again, boosting gasoline prices to $3.83 per gallon (up 16 percent) and diesel to $3.58 per gallon (up 18 percent) (Benjamin 2006; Bradsher 2008a and 2008b).

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[20] Questions have been raised, however, as to whether the supply of cassava is sufficient to supply such projects. Although Guangxi Province is the source of about 60 percent of China's domestic production of cassava, the Guangxi ethanol project is said to have imported cassava chips from Thailand and Vietnam to meet supply needs. However, as the price of imported cassava doubled in 2007 and early 2008 to around $200 per ton because of speculation that the facility would have to import two-thirds of its annual input, industry sources indicated that the profitability of the project has decreased. The Guangxi Provincial Government is said to be promoting domestic cassava production. Moreover, after peaking at 5.4 million tons in 2006, China's imports of cassava have declined through 2008; imports in the first quarter of 2008 amounted to about 660,000 tons, a decline of about 70 percent compared with the like period in 2007, leading to a projected total for 2008 of about 830,000 tons. (Sanchez and Junyang 2008, 7; and Shuping and Nakanishi 2008).

[21] The information in this paragraph was obtained from various sources, including Sanchez and Junyang 2008, 3, 5, and 7, and Latner, Wagner, and Junyang 2007, 4; author, pers. comm., January 29, 2008; Shuping and Nakanishi 2008; Shuping 2007; and Dehua Liu n.d.

The United Nations (UN; 2008) announced in March 2008 the formation of the International Biofuels Forum, calling it "a joint project" of Brazil, China, India, South Africa, the United States, and the European Commission. The forum, initially expected to meet regularly for 1 year, was intended to increase the production, distribution, and consumption of biofuels by promoting increased interaction between producers and consumers, in turn creating a world market for biofuels. The National Institute of Standards and Technology (2008) announced that a February 2008 report on standards commissioned by three Forum parties–the United States, Brazil, and the EU–concluded that existing standards developed by the parties' national standards organizations "share much common ground and, therefore, impose few impediments to biofuel trade."

As with many other countries, government support plays an important role in promoting China's development of a bio-based economy, particularly in regard to biofuels.[22] Long-term support of industrial biotechnology and related strategic planning are reflected in the country's 11th Five-Year Plan. The Chinese government's approach has been expansive in scope, addressing research and development (R&D) as well as measures supporting supply and demand. The policies are summarized below.

R&D Support

During the mid-1980s, China initiated several R&D programs related to ethanol. R&D on biofuels is continuing today in many of China's research institutes, often funded by the government and increasingly focused on biodiesel. For example, China has initiated and is funding several government research programs related to biodiesel that have, to date, identified technological improvements allowing for feedstock diversification and lower feedstock costs (e.g., the breeding of a rapeseed plant with an oil content that is nearly 2 percent higher than the current highest strain) (Worldwatch Institute 2006 and *Xinhua News Agency* 2006a). The resulting technologies are often adopted by the industry (Cao and Liu 2006 and Chervenak 2006, 175).

Government-sponsored research funding for small enterprises in China and national R&D and commercialization funding for high-technology projects, including liquid biofuels or bio-based projects, is also available (Cao and

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[22] In its report on industrial biotechnology, the Commission (USITC 2008, 4-1) noted that Brazil, Canada, China, the EU, Japan, and the United States have "extensive policies to support industrial biotechnology." Much of the support is focused on liquid biofuels.

Liu 2006). Three such programs are the National High-tech R&D Program, or the "863 program," launched in 1986; the National Program on Key Basic Research Projects, or the "973 program," launched in 1997; and the National Innovation Fund of China. Examples of specific R&D programs related to biofuels that are classified under the 863 or 973 programs include five focusing on feedstock processing, enzymatic modification, and technological processes.[23] It is not clear, however, what percentage of total such R&D spending under these programs is accounted for by projects related to liquid biofuels and bio-based chemicals (Jiayang Li 2007, and author, pers. comm., January 7, 2008). China is also entering into numerous alliances and policy agreements with other countries to increase its supply of biofuels (box 1).

Supply-side policies

China has implemented numerous measures intended to promote the supply of biofuels, including agricultural feedstock support, monetary support to ethanol producers, loan assistance, tax and VAT exemptions, and interest support for loans. China also recently announced it would invest $5.0 billion over the next 10 years in expanding ethanol production capacity, particularly cellulosic ethanol.[24]

Agricultural feedstock policies

China capped the volume of corn that can be used for industrial applications in late 2006, largely limiting the amount available for use by fuel ethanol producers to what is currently used by the existing plants and significantly tightening the conditions firms must meet before being able to start-up production (e.g., approving no new plants using grain feedstocks). Moreover, citing inflation concerns amid rapid increases in food prices and concerns about food security, China moved to decrease grain exports in late 2007 by rescinding the 13-percent VAT rebate on such exports (*People's Daily Online* 2007; author, pers. comm., January 29, 2008; and Eyre 2007).

The Ministry of Agriculture has announced plans for growing sugarcane, sweet sorghum, cassava, and rapeseed for use in the production of ethanol

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[23] The Chinese Academy of Sciences also funds several research projects, including R&D in biobutanol, micro-organisms, and energy crops.

[24] Chervenak 2006, 175; ABARE 2005, 68; Bilin 2007; Kojima, Mitchell, and Ward 2007, 94; and GreenCar Congress 2006h.

Box 1. Examples of China's international agreements and investments related to biofuels

Brazil:	In 2006, China signed a memorandum of understanding (MoU) with Brazil to share information on policies and projects in the mining and energy sectors and to promote joint ventures related to energy, including renewable resources and biofuels.
Indonesia:	China has also been investing in Indonesia. State-owned CNOOC announced in early 2007 that it, in a joint venture with PT Smart Tbk (a producer of palm oil) and Hong Kong Energy Ltd., will invest $5.5 billion over eight years in biodiesel production from palm oil and ethanol production from sugarcane and cassava. Sinopec will invest $5 billion in the cultivation of palm and jatropha and in biodiesel production in Indonesia in a project that will begin in 2008. Many such projects in Indonesia, however, including the CNOOC project, are being re-evaluated because of the high price of palm oil. As of early 2008, the price of palm oil had doubled from the previous year.
Malaysia:	In 2006, China entered into an R&D alliance with Malaysia focusing on technology to manufacture biofuels from biomass, including palm-based biomass. Malaysia, the world's largest producer of palm oil, creates a significant supply of palm-based biomass annually.
The Philippines:	In early 2007, China signed memoranda of agreement (MoA) with the Philippines to not only invest in hybrid rice, hybrid corn, and, eventually, hybrid sorghum (intended for use in ethanol production), but to also increase Philippine ethanol production to be imported by China. About three ethanol production facilities–using sugarcane and cassava as feedstocks– were expected to be established under the MoA.
United States:	In late 2007, the U.S. Department of Agriculture, the U.S. Department of Energy, and the NDRC signed an MoU on biofuels cooperation that addresses biofuel development, production, technical issues, and policy.

Sources: Ali and Suhartono 2007; *BiofuelsDigest.com* 2008; *Checkbiotech.org* 2008; Lane 2008; Soeriaatmadja 2008; Wood and Aglionby 2008; GreenCar Congress 2006a; *Checkbiotech.org* 2007; *BiofuelsBusiness.com* 2007; and USDA 2008, 8.

and biodiesel. China also announced the initiation of large-scale cultivation of bioenergy forests with trees yielding nuts or fruit with high concentrations of oil for use in producing biodiesel. China ultimately intends to cultivate 13 million hectares of bioenergy forests by 2020, much of it in mountainous areas, enough to yield an estimated 1.8 billion gallons of biodiesel (Bloomberg News 2007, Liang 2008, and Jiao 2007).[25]

Tax and investment incentives

Initial government-sponsored financial support provided to companies in the ethanol industry, tendered during the industry's initial years to promote production, has been described as being very generous (Xinhua News Agency 2006b). China appropriated $188 million annually from 2004 to 2006 to support companies producing fuel ethanol. Annual monetary support levels, set at $0.85 per gallon in 2005, $0.72 in 2006, and $0.59 in 2007, have been declining as the companies' profitability has improved. In 2008, however, the government switched to a flexible support program, which is based on performance evaluations for each plant as of November of each year (Latner, O'Kray, and Jiang 2006a and Sanchez and Junyang 2008, 5).

China also recently promulgated new laws (the creation of risk reserves, changes in financial incentives, availability of venture capital,[26] etc.) that are reportedly intended to help the fuel ethanol industry become more economically self-sufficient.[27] For example, in regard to risk reserves, companies are expected to establish internal funds that would cover losses should crude petroleum prices decline significantly; if crude prices remain low, then government compensation would be implemented. Investment sources are also becoming available and more diversified. As of 2006, Cathay Industrial Biotech (Shanghai) began developing bio-based products, including biobutanol, another liquid biofuel, using $78 million invested by companies such as Goldman Sachs (OECD 2008).

[25] Liang (2008) notes three benefits of use of mountainous areas: (1) farmland is not diverted to biofuel crops; (2) mountains have a great deal of unused acreage; and (3) local incomes are likely to be enhanced.

[26] The availability of private equity and venture capital has increased in recent years. Examples cited include investments by Biolux (Austria), Directions-Based Investments (USA), and venture capital raised by Gushan Group (Chervenak 2006, 176).

[27] China maintains an import duty of 30 percent on ethanol imports.

National economic incentives related to biodiesel production include tax benefits;[28] preferential loans, depending on the project; and, as with ethanol, monetary assistance to farmers producing nonfood feedstocks and to companies developing demonstration-scale production of biofuels using nonfood feedstocks (e.g., producing biodiesel from forest products and ethanol from cellulosic sources, sweet sorghum, and cassava) (Dow Jones Energy Service 2006; Jia 2007; *Xinhua* 2007a; and Kojima, Mitchell, and Ward 2007, 94). The projected publication of a national biodiesel standard in 2007 was expected to further spur industry growth. The voluntary standard introduced in July 2007 is for 100 percent biodiesel (Cao and Liu 2006; Chervenak 2006; Graham-Harrison 2007; and Sanchez and Junyang 2008, 8).

Demand-side policies

China has implemented a mandatory use program for ethanol, stimulating demand. In the 2000-2002 timeframe, China started a trial ethanol program in several provinces, expanding the program in 2004 when it proved successful. The provinces, primarily on the eastern coast, are concentrated geographically around the five approved ethanol production sites. Of the ten provinces currently participating in the program, six are using E10 almost exclusively, and four are still expanding E10 consumption (Sanchez and Junyang 2008, 5, and Latner, Wagner, and Junyang 2007, 4; Ke 2006; Kojima, Mitchell, and Ward 2007, 93; and Wang et al. 2007). In 2005, China mandated that ethanol blends would replace conventional gasoline for all vehicles. The share of gasoline consumption accounted for by such blends is expected to increase from 20 percent in 2006 to 50 percent in 2010. According to the NDRC's Renewable Energy Plan, the E10 plan is expected to be implemented on a national basis by 2020 (Speckman 2008).

China also implemented a Renewable Energy Law on January 1, 2006. The law, intended to complement the national biofuels initiative and to promote production and use of liquid biofuels, calls for renewable energy to account for 10 percent of total energy consumption by 2020 versus about 3 percent in 2003. Moreover, the law requires entities selling gas to include liquid biofuels in the gasoline mix; any economic losses to biofuels producers resulting from failure to comply must be compensated by the marketing entity (Mohan, Phillippe, and Shiju 2006, 68; EIA 2006; and ABARE 2005, 68).

[28] For example, as of December 2006, biodiesel derived from animal fat or vegetable oil is not subject to consumption taxes.

Outlook for the Liquid Biofuels Industry?

China is currently transitioning from grain-based fuel ethanol to ethanol based on nonfood crops, such as cassava, sweet sorghum, and sweet potato, and lignocellulosic feedstocks. Annual growth levels appear likely to level off for the short-term, perhaps remaining in single-digits, as supplies of grain for existing production facilities remain capped; lignocellulosic technology becomes technically and economically viable on a commercial basis; and as alternative feedstocks are cultivated and the logistical infrastructure for such crops and other biomass (e.g., agricultural residue) is enhanced. New projects using alternative feedstocks are under development. Questions have arisen, however, as to whether the supply of alternative feedstocks such as cassava is sufficient to supply some of these projects (Shuping and Nakanishi 2008). As shown in box 2, state-owned entities within China are investing significant amounts in renewable energy, liquid biofuels (including cellulosic ethanol), and the production of bio-based chemicals; they have also been acquiring shares in existing state-owned ethanol producers.

Box 2. Examples of Expanding Investment by State-Owned Entities in China's Biofuels Industry

- COFCO Limited announced it would spend renminbi (RMB) 10 billion ($1.3 billion) by about 2010-12 to expand its fuel ethanol production capacity to 104 billion gallons from its current level of 335 million gallons. COFCO purchased CRAC in 2005 and acquired 20-percent stakes in ethanol producers Anhui BBCA Biochemical Co. and Jilin Fuel Ethanol Co., and has since been expanding its production of ethanol and bio-based chemicals.
- CNPC announced in 2007 it would invest RMB 10 billion ($1.34 billion) in renewable energy by 2020; the company also bought a 55 percent stake in Henan ethanol producer Tianguan Group.
- As mentioned earlier in this article, CRAC, COFCO, and Tianguan Group are planning and/or operating demonstration-scale cellulosic plants. PetroChina, Sinopec, and CNOOC will develop three jatropha-based biodiesel projects, bringing onstream about 51 million gallons of capacity.
- Sinopec is said to be the majority investor in an ethanol plant that will use sweet potatoes as its feedstock. PetroChina is also investing in nongrain ethanol.

Sources: Zang 2008; Commission of the State Council n.d.; *EnergyCurrent* 2007; *Chinamining.org*

New laws recently implemented are reportedly intended to help the fuel ethanol industry become more economically self-sufficient (Wang et al. 2006, 80). Investment sources are becoming available and more diversified. Monetary support for ethanol producers is still available from the government but the payments will now be flexible based on annual evaluations. Whereas some believe that such monetary support will eventually be phased out, others suggest that it is likely to remain in place as long as the price of fuel in China remains significantly lower than world prices (Xinhua News Agency 2006b; *Farms.com* 2006; Sanchez and Junyang 2008 and 2006a, 9).

The value of fuel ethanol exports continued to decline in January-July 2008 to $2.4 million versus $11.6 million and $8 million in the like periods in 2006 and 2007, respectively. The continued elimination of the VAT rebate through 2008 will probably continue to temper ethanol exports. More information on the elimination of VAT rebates, as well as other economic changes such as the new labor regulations, is provided later in this article in the section on bio-based chemicals. At the time this article was prepared, it was not clear yet what impact the changes would have on the biofuels industry, given the high level of state ownership combined with an official projection in June 2008 of a probable gradual slowing in economic growth in China, the decline in energy prices in the latter part of 2008, and the volatile effects of the economic slowdown that cascaded globally during the latter part of 2008 (Sanchez and Junyang 2008, 10; and Hong'e 2008).

Opinions about the outlook for biodiesel are mixed. The NDRC's Renewable Energy Plan calls for biodiesel production to reach about 600 million gallons by 2020. Whereas some expect biodiesel capacity to increase in coming years as a result of possible national consumption mandates, the likelihood of blending ratios of 5-20 percent, and expected export potential (Latner, O'Kray, and Jiang 2006a, 21; Wen 2005; and Wang et al. 2006,44), others suggest that the lack of feedstocks will delay the initiation of production incentives for biodiesel (Sanchez and Junyang 2008, 9). Concurrent with the increasing government focus on biodiesel, new companies, domestic and foreign, private and state-owned, are entering the industry and several large-scale plants are expected to be brought onstream in the next 3-5 years. Exports are likely to remain limited in the near future.

Bio-based chemical products

Use of industrial biotechnology in the Chinese chemical industry is also rapidly growing, particularly in emerging areas such as biopolymers. As with biofuels, the growth builds upon the country's longstanding use of fermentation. The information presented below largely addresses biopolymers and bio-based chemicals derived from fermentation processes.

Industry Profile

China's production of chemicals increased steadily in value during 1994 to 2004 to $190 billion, registering an increase of almost 300 percent, before climbing to $223 billion in 2005, $310 billion in 2006, and almost $390 billion in 2007. The industry's ranking increased steadily from the world's fourth largest chemical producer in 2004 (after the United States, Japan, and Germany), to third largest in 2005, and second largest in 2006 and 2007 (after the United States).[29] This increase was largely attributed to dynamic growth in consuming industries (e.g., the automotive, construction, textile, and consumer products industries) resulting from the country's increasing economic prosperity. Domestic consumption of petrochemicals and polymers is expected to increase by 6 to 8 percent annually, or by about 50 percent by 2010. Commodity and specialty chemicals are expected to be strong growth sectors with continued increases in production capacity to meet the growing demand (Mergent 2007, 2).

The chemical industry's expanded use of industrial biotechnology to manufacture many chemicals, including enzymes, starches and sweeteners, citric acid, lactic acid, xanthan gum, vitamin C, and bioplastics, with much of the output exported, has created "relatively mature" sectors (Chervenak 2006, 175; also OECD 2008). China's production of enzymes, many critical to industrial biotechnology and themselves fermentation products,[30] increased by almost a quarter during the past decade, reaching about 440,000 tons in 2005 according to Chervenak. About 50 domestic companies are said to produce enzymes; two major multinational enzyme companies–Novozymes and Genencor®, a Danisco Division (both of Denmark)–maintain a significant share of the Chinese market (Chervenak

[29] See, ACC 2005, 53 and 55; 2006; 2007, 43 and 45; and 2008, 43 and 45. These data are likely to include ethanol, particularly food-grade ethanol.
[30] Enzymes are generated from the fermentation of micro-organisms.

2006, 174-175). Royal DSM N.V. (DSM; the Netherlands) is participating in a joint venture to produce lignocellulosic enzymes (Jiang 2008, 17).

Production of bio-based chemicals is expanding beyond traditional fermentation products. Cathay Industrial Biotech (Shanghai) began developing bio-based products such as dibasic fatty acids, biobutanol, biopolymers, and specialty chemicals in 2006 (OECD 2008, 13). Research is also underway in China on the use of biocatalysis, according to a sampling of papers published in recent years; one focus of this research is the production of pharmaceuticals (H. Li, 2006; Zheng 2007; and Yan 2007).[31] Ethanol producers, particularly those focusing on cellulosic inputs, are developing production of value-added bio-based chemicals as co-products (Lauridsen 2008, 25).

Chinese production of bioplastics is also increasing.[32] Pilot-plant production of two biopolymers—polyhydroxyalkenoate (PHA) and polylactic acid (PLA)—currently accounts for the majority of Chinese production of all bioplastics. In June 2006, a representative of the Degradable Plastics Committee of the China Plastics Processing Industry Association stated that 3 companies each produced PLA and PHA, with a combined production capacity of about 1,100 tons for each biopolymer. In late 2007, state-owned COFCO Limited announced it was investing RMB 200 million (about $26 million) in an 11,000 ton per year demonstration facility to produce PLA and plans to construct other PLA facilities. It is projected that there will be at least eight Chinese manufacturers of PLA by 2010. DSM Venturing, a unit of DSM, announced it had invested $20 million in March 2008 in Tianjin Green Bio-Science Co., Ltd., (China) to build an 11,000 ton per year production facility for PHA that was expected to be operational in early 2009 (DSM 2008). Other companies are also starting up R&D and/or production efforts for biopolymers (*BiopackNews* 2007, 7).

Annual sales of bulk fermentation products in China were valued at approximately $2.5 billion in 2003. In 2007, the value of products manufactured utilizing industrial biotechnology was said to exceed $60.5 billion with sales expected to increase by about 10 percent annually. Large, state-owned enterprises account for a significant share of chemical

[31] Several papers address the use of biocatalysis in the manufacture of pharmaceuticals. Moreover, the 973 program covers "Basic Research on Critical Problems in Biocatalysis and Biotransformation." (National Basic Research Program of China.)

[32] The information in this section was obtained from various sources including Chervenak 2006, 175; *Bioplastics World* 2006a; Weng 2006; G. G.-Q. Chen 2007; and *China Chemical Reporter* 2007.

production in China. The expanding presence of domestic companies utilizing industrial biotechnology, however, is complemented by the growing activity of foreign companies (Cao and Liu 2006; *People's Daily Online* 2008; and Chervenak 2006, 175-176).[33]

China's trade flows also increased during 1995-2007. China's chemical imports increased during the period from about $18 billion to about $120 billion, or by over 550 percent. Export growth, however, outpaced that of imports in 2007, reducing the sector deficit (*Chemical & Engineering News* 2008). China's chemical exports increased in value from $9 billion in 1995 to $36 billion in 2005, or by 300 percent, before increasing to almost $61 billion in 2007. The two largest categories, bulk organic chemicals and plastics–Harmonized System (HS) Chapters 29 and 39, respectively–together accounted for more than 50 percent of the total value of chemical exports in 2006 and 2007. Plastics accounted for almost 18 percent of the total, versus 10 percent or less in the years prior to 2003. These chapters also include many of the bio-based chemicals currently produced commercially.[34]

Examples of major bio-based organic chemicals exported from China and their approximate annual export volumes in 2005 include citric acid (about 704,000 tons, or about 80 percent of domestic production); vitamin C (about 52,800 tons, or about 80 percent of production); and glutamic acid (about 110,000 tons, or 8 percent of production) (Chervenak 2006, 175, and Cao and Liu, 2006).[35] Industry sources note that most of the biopolymers produced in China are currently exported, given a limited domestic market, the relatively high prices of products made from the biopolymers, a limited recycling and composting infrastructure in China, and a lack of national standards for biodegradable plastic products (Embassy of the United States

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[33] Values were converted from RMB using IMF exchange rates.

[34] Trade data were obtained from the World Trade Atlas based on the 2007 HS-Standard International Trade Classification (SITC), rev. 4, concordance for Section 5, "Chemicals and Related Products, n.e.s." Miscellaneous plastics products are excluded from the totals shown for Chapter 39. The chemicals classified in Chapter 29 range from commodity chemicals (low-value, high-volume products) to specialty and end-product bulk chemicals such as pharmaceuticals and their intermediates (high-value, low-volume products). The HS classifications do not differentiate by production process. Individual chemicals are classified together whether produced using conventional chemical processes or new technologies such as biotechnology or nanotechnology.

[35] The two-step fermentation process developed in China in the 1908s to produce Vitamin C is said to have allowed it to become the leading world producer of Vitamin C (Jiang 2008, 12).

of America, Beijing, China, 2006; author, pers. comms., December 7, 2007, and January 3 and 10 and February 6, 2008).

HS 3907, the heading under which biopolymers such as PLA and PHA and certain other plastics are exported, accounted for almost 30 percent by value annually of China's total exports of plastics (excluding miscellaneous plastics products) during 2005-07 (versus 10 percent in 1996). According to data from the World Trade Atlas, the value of exports classified in this heading doubled during this period, climbing from $1.5 billion to $3 billion.

Business strategies

As with biofuels, much of the technology used in the production of bio-based chemicals has been obtained either from Chinese research institutes or imported from overseas. Much of the Chinese production and marketing of bio-based chemical products is open to foreign firms, and significant levels of sector-specific foreign investment are entering the country. Total investment by the U.S. chemical industry in China increased from $329 million in 1998 to $2.6 billion in 2006, or by 690 percent (ACC 2008, 83). Several new facilities are located at industrial parks established by the government. Companies that have made large investments in R&D and/or production facilities in China include Archer Daniels Midland Company (United States), BASF SE (Germany), Cargill, Incorporated (United States), The Dow Chemical Company (Dow; United States), DSM, E. I. du Pont de Nemours and Company (DuPont; United States), Genencor, NatureWorks LLC (United States), and Novozymes (Chervenak 2006, 176; *Plastics News* 2006; and Mergent 2007, 2).

Several projects address bio-based chemicals. For example, Dow Epoxy, a Dow business group, is building two plants at the Shanghai Chemical Industry Park that are expected to start-up in 2010-11. One will produce 165,000 tons per year of bio-based epichlorohydrin (it will be the first commercial-scale facility to utilize Dow's proprietary technology using glycerin from biodiesel production as the feedstock) and the second will produce 110,000 tons per year of liquid epoxy resins (LER). Epichlorohydrin is a key input for LER; about 40 percent of the epichlorohydrin produced at the site will be used as an input for the neighboring LER plant (Dow 2007 and n.d.; and author, pers. comm., July 17, 2008). Dow announced on September 2, 2008, that China's Ministry of Environmental Protection had approved the project's environmental impact assessments, a step said to be required of all chemical plants in China before initiating construction. The company stated that its use of its proprietary technology to produce epichlorohydrin will reduce chlorine consumption by 50 percent and will “produce 10 times less waste water, while also improving process efficiency and product quality” (Dow 2008).

DuPont, in partnership with Zhangjiagang Glory Chemical Industry Co., Ltd., is initiating commercial production and distribution of its renewably-sourced Sorona® biopolymer in China “so that the entire supply chain–from polymer to fabric–will be in Asia” (DuPont 2008.). DuPont will ship the feedstock, bio-based 1,3-propanediol, derived from corn sugar via its proprietary process, from the DuPont Tate & Lyle Bio Products LLC production site in Loudon, TN (DuPont 2006).[36] Licensees are reportedly testing material made at the 33,000 ton per year plant and commercial production is expected to start in late 2008 (Patton 2008). DuPont also produces Sorona® in the United States in Kinston, NC.

Government Programs

As with biofuels, long-term support of industrial biotechnology and related strategic planning are reflected in the country’s 11th Five-Year Plan. Such measures address R&D as well as supply and demand. Although many of the policies enacted to date are focused on biofuels, numerous policies also address bio-based chemicals. For example, in addition to providing incentives to profitable companies displaying production efficiency, China also provides tax and investment incentives for emerging industries in “bio-chemistry” that show promise (author, pers. comm., December 18, 2006).

R&D Support

R&D programs related to bio-based chemicals, many funded by the government, are underway in many of China’s research institutes, generating technology often adopted by the industry (Cao and Liu 2006; and Chervenak 2006, 175). Industrial parks focusing on chemicals have also been established, reportedly to increase investment by domestic and foreign firms and to provide economic stimulus (Mergent 2007, 2).

Government-sponsored research funding programs mentioned earlier (e.g., the 863 program, the 973 program, and the National Innovation Fund of China) also apply to bio-based chemicals (Cao and Liu 2006). For example,

[36] DuPont Tate & Lyle Bio Products LLC is a joint venture formed between DuPont and Tate & Lyle plc to manufacture and distribute the bio-based 1,3-propanediol.

Tianan Biologic Material Co. Ltd., a developer of bioplastics, receives funding from both the 863 program and the National Innovation Fund. It is not clear, however, what percentage of total such R&D spending under these programs is accounted for by projects related to liquid biofuels and bio-based chemicals (MOST 2007b; Grace 2007; and Lunt 2007). Morever, in line with its increasing focus on innovation and, according to Adams (2008), on "high-value-added production," the Chinese government announced on September 27, 2007, that it would expand financial support to high-technology capacity building in its 11th Five-Year Plan period and would encourage investment in high-technology industries by organizations such as banks and investment firms (Sanger 2008, 4, and Linton 2008).

Policies Addressing Supply and Demand

Bioplastics are one area of focus within bio-based chemicals. Several government organizations are responsible for policies, regulations, and funding of bioplastics, including the Ministry of Science and Technology, the State Environmental Protection Administration, the Standardization Administration, and the NDRC. To offset China's growing consumption of plastic, estimated to amount to 25 to 30 million tons in 2005, the government is implementing several measures. In January 2008, the Chinese government announced that, as of June 1, 2008, it would ban the production and use of ultra-thin plastic bags and prohibit stores from giving free plastic bags to customers. The government also is said to have established a program in 2005 to promote the production and consumption of PLA with a goal of boosting demand to 9-11 million tons by 2020. The 11th Five-Year Plan is said to call for annual production of 330,000 tons of bioplastics, equivalent to1 percent of the Chinese plastics market, by 2010. Under the Plan, a partnership is reportedly being developed between a unit of the Chinese Academy of Sciences and private sector companies to develop R&D and production facilities for polybutylene succinate polyester, funded by an initial RMB 100 million (about $13 million) (*BiopackNews* 2007, 7; *Bioplastics World* 2006a, 3; *Xinhua* 2008b; DECHEMA e.V. 2007, 4; and Jiang 2008, 8).

Moreover, production and consumption of bioplastics in China was expected to be spurred by the decision by the Beijing Olympics Organization Committee, as noted in the Olympic Science and Technology (2008) Action Plan, to use "environmentally friendly products," including those made from bioplastics (e.g., utensils, food containers, packaging, beverage bottles, home furnishings, and apparel), during the 2008

Olympics as part of its commitment to host a "Green Olympics" (Cargill 2006; *Bioplastics World* 2006b; 3, *Plastics News* 2006; and H.S. Chen 2007). The use of bioplastics in the 2008 Olympics was also promoted by the United Nations' International Center for Science and High Technology as part of the organization's program related to biodegradable plastics. In cooperation with the UN, the organizing committee sought to promote widespread use of biopolymers during the games, as well as promoting the development of "green" products within China, such as those derived from biopolymers (*Bioplastics World* 2006c, 3, and H.S. Chen 2007). The use of such products is also expected to be a focus of the 2010 Shanghai World Expo (Guangming 2007).

Outlook for the Chemical Industry?

The market conditions facing many ongoing and prospective ventures in the chemical industry, however, including projects relating to bio-based chemicals, are changing as a result of the combined impact of factors, including the strength of the Chinese currency, new labor regulations, tax changes, and volatile energy prices. These factors are expected to affect manufacturing and transportation costs, as well as export levels and prices. Many bio-based chemicals produced in China, including biopolymers, are exported. Although China is a net importer of chemicals, mainly to satisfy growing domestic demand, China is a major world supplier of many commodity chemicals, including those produced using industrial biotechnology. Exports have been characterized by Scimo and Bjacek (2008) as "the ultimate demand drivers" for the Chinese chemical industry.

The strength of the renminbi against the U.S. dollar, however, eroded export growth in major sectors, including chemicals, in the first seven months of 2008[37] (World Trade Atlas[38] and *C&E News* 2008). Moreover, in mid-2007, China reduced or eliminated the VAT refund to Chinese exporters of certain chemicals and other products, reportedly focusing on chemicals and products that have a negative environmental impact (i.e., whose manufacture consumes significant amounts of energy, products that are highly polluting, and products that use scarce natural resources) and goods deemed likely to cause international trade disputes. The refund on plastics resins and products, for example, was reduced to 5 percent from

[37] According to IMF data, after the RMB strengthened versus the U.S. dollar over the past few years and during the first half of 2008, the relative positions of the two currencies stabilized as of mid-2008.

[38] Trade data from the World Trade Atlas based on the 2007 HS-SITC, rev. 4, concordance for Section 5, "Chemicals and Related Products, n.e.s."

11 percent, reportedly resulting in tighter profit margins (PriceWaterhouseCoopers 2007; Ho and Gong 2007; Hautekeete 2008; and Sung 2007). As of late 2008, however, the refunds for some chemicals were reportedly increased to stimulate economic growth (China Briefing 2008).

The increase in energy costs through the first half of 2008 compounded the impact on companies. Despite inflation concerns, the Chinese government raised fuel prices in June 2008, increasing gasoline prices to about $3.83 per gallon (up 16 percent) and diesel to about $3.58 per gallon (up 18 percent), after having frozen them in January 2008 (Benjamin 2006; Bradsher 2008a and 2008b). Higher international energy costs increased transportation costs for companies worldwide, including those exporting product from China, resulting in many companies "tightening" their global supply chains–in some cases reducing the geographical reach of portions of their supply chains–to reduce fuel and energy consumption and emissions (Rohter 2008).[39] The higher energy costs were also expected to prompt companies to increasingly implement "green" policies, potentially including utilizing bioprocesses common to industrial biotechnology, particularly if energy costs increase over the long term. Energy costs declined significantly in the latter part of 2008 but potentially remain volatile.

Companies are also contending with increasing labor costs, largely because of new labor regulations implemented as of January 1, 2008, that, according to Batson and Fong (2007), provide "the most significant overhaul of China's workplace rules in a decade."[40] The regulations provide increased protection for employees by calling for, among other things, written employee contracts that are signed; more ways for employees to seek redress; higher hourly rates for overtime and holiday work; limits on overtime; and for companies to pay a higher share of social costs (Adams 2008 and Sung 2008). According to official Chinese statistics, the average annual wage of staff and workers for all manufacturing increased from RMB 12,496 ($1,510) in 2003 to RMB 17,966 ($2,253) in 2006, or by about 12-14 percent annually; the average annual wage of staff and workers in the

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[39] Rohter (2008) cites a May 2008 study published by CIBC World Markets (Canada) that found that the increased shipping costs were, on average, equal to the imposition of a 9 percent rate of duty. He notes, though, that transportation costs "are only one factor" of many considered when companies make investment and sourcing decisions.

[40] Batson and Fong (2007) note that the Chinese Government, in an effort perceived at increasing transparency in the formulation of legislation, sought public comments on the draft version of the law (first presented in December 2005) and received almost 200,000 comments, resulting in "substantial changes" to the legislation.

chemical industry increased by 17 percent from RMB 15,585 ($1,902) in 2005 to RMB 18,212 ($2,284) in 2006 (*China Statistical Yearbook* (2004-06 editions)). Kim and Kuijs (2007,12) state that annual increases in nominal wages within the chemical industry fluctuated between 12 and 14 percent during 2002-05. Although Scimo and Bjacek (2008) note that labor costs were still considered "the primary advantage" for the Chinese chemical industry as of early 2008,[41] labor costs are reportedly expected to increase by as much as 25 percent annually; given the strength of the renminbi at the time, the impact was expected to be exacerbated when considered in terms of dollars. Inflation rates of 7-8 percent per year were also expected to intensify such increases (Benjamin 2006; and Bradsher 2008a and 2008b). Companies are also facing an expected gradual slowing in China's economic growth, as projected by the Deputy Director of the National Bureau of Statistics in June 2008 citing a "cyclical adjustment" (Hong'e 2008),[42] as well as the progressive effects of the global economic slowdown that began in the latter part of 2008.

These factors pushed Chinese manufacturing costs and export prices for chemicals closer to those of the United States (Sung 2008; and Kim and Kuijs 2007, 12). The combination of the strengthening currency and the reductions in the VAT refunds alone, for example, was expected by industry sources to temper China's competitive pricing for exported chemicals, including bio-based products such as xanthan gum (Chervenak 2006, 174-175; and *BakeryandSnacks.com* 2005).

Profit margins within the industry are also narrowing.[43] The Chinese chemical industry's profit margins grew annually during 1999-2004, increasing by about 2 percent in 1999 to over 5 percent in 2004; the increases tapered off, however, during 2005-06 to an increase of slightly over 3 percent in 2006 (Kim and Kuijs 2007, 12). Profit margins for Vitamin C, a bio-based fermentation product derived from corn starch, are said to have declined significantly because of inflation and concomittant increases in production costs. At the same time, the product's export price increased as a result of short supplies (purportedly attributed to production shutdowns resulting from factors such as tightened environmental

[41] Another source states that despite the increases, manufacturing costs of Chinese chemicals in mid-2008, including bio-based products, were still considered to be lower than those in the United States (author, pers. comm., 2008).

[42] According to Hong'e (2008), a report published a week earlier by the People's Bank of China attributed the slowing growth to "the U.S. credit crunch, a spate of tightening measures ad natural disasters."

[43] See, Sung 2008; and Kim and Kuijs 2007, 12.

standards) and the currency situation (A. Liu 2008).[44] Citric acid, a product produced by Chinese companies via fermentation since the 1980s, has reportedly been the subject of numerous unfair import investigations in various countries over the years, most recently in 2008 in the EU and the United States. EchinaChem Trading Marketplace (2008) states that "According to experts, the worldwide antidumping actions against citric acid producers, the increasing prices of raw materials and the appreciation of Renminbi with respect to U.S. dollars, will all cause the exports of citric acid to fall in 2008, with export growth slowing."

The cumulative impact of the changing market environment is still unfolding, particularly given the volatile economic situation resulting from the global economic slowdown. Anecdotal reports mention higher Chinese manufacturing costs and export prices, citing larger increases in feedstock prices and energy costs in the first half of 2008 than in previous years, coupled with higher labor costs and the strength of the renminbi versus the U.S. dollar (author, pers. comm., July 2 and September 5, 2008). One preliminary indicator of future trends could be shifts in export levels and unit values during the first seven months of 2008, although such shifts could also be attributed to factors other than those listed above (e.g., changes in the product mix).

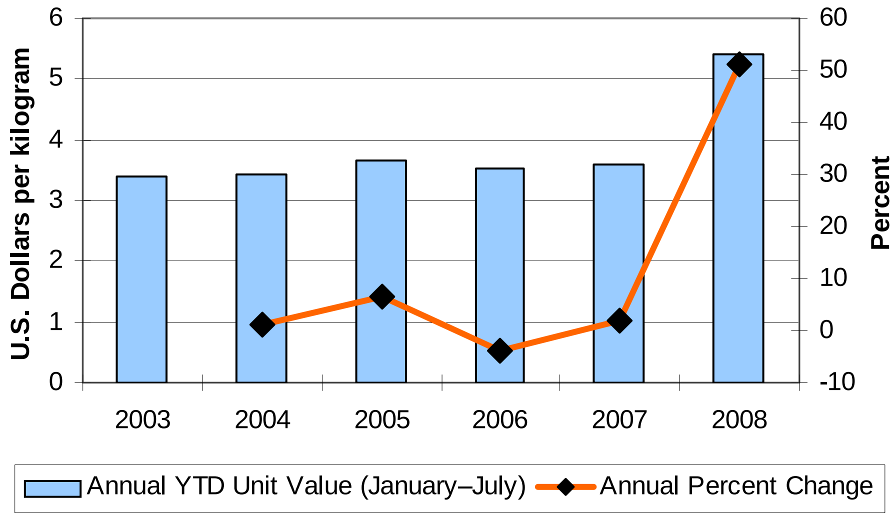
During January-July 2008, the value of Chinese chemical exports totaled $48 billion, an increase of 47 percent over the like period in 2007. Quantity data are not readily comparable for total exports given the mix of units in the products considered. For HS Chapter 29 alone (organic chemicals in bulk form), however, the value of exports increased by 59 percent to $18 billion during the seven-month period versus the same period in 2007, while growth in the quantity of exports slowed, increasing by only 10 percent. The average unit value increased significantly during the first seven months of 2008, climbing to $3.71 per kilogram (up by 43 percent) from $2.59 per kilogram and $2.67 per kilogram for the like periods in 2007 and 2006, respectively.[45]

The unit value of such exports to most markets increased substantially during January-July 2008. For example, as shown in Figure 1, the unit value

[44] Liu cites increased costs associated with feedstocks, energy, labor, and transportation. Inflation is also said to have played a role (A. Liu 2008).

[45] Trade data from the World Trade Atlas based on the 2007 HS-SITC concordance for Section 5, "Chemicals and Related Products, n.e.s." In comparison, the year-on-year increases in the value and quantity of exports of Chapter 29 during January-July 2007 increased by 34 percent and 38 percent, respectively, versus the like period in 2006.

Figure 1 Chinese Exports under HS Chapter 29 to the United States, January–July 2003-08



of exports to the United States increased by 50 percent to $5.42 per kilogram after remaining relatively constant between $3.40 and $3.70 per kilogram during the like periods in 2003-07. Of about 150 export markets worldwide for which unit values increased, almost half increased by as much as 50-400 percent. Another third increased by between 20 to 50 percent.[46]

Exports classified in HS 3907 (plastics) were valued at $2 billion in January-July 2008, an increase of 22 percent versus the like period in 2007; the quantity of such exports, however, increased by only 11 percent. The unit values also increased, but at a more measured pace than those for HS Chapter 29, increasing steadily from $1.21 per kilogram in January-July 2003 to $1.87 per kilogram in the like period in 2008.[47]

Industry sources indicated in mid-2008 that whereas companies still considered the Chinese chemical industry/market attractive given its size, breadth, and potential, some companies were also adding new capacity

[46] Trade data from the World Trade Atlas based on the 2007 HS-SITC concordance for Section 5, "Chemicals and Related Products, n.e.s." The unit values of exports to about 20 countries decreased by up to 100 percent during the 2008 period.
[47] Trade data from the World Trade Atlas. In comparison, the year-on-year increases in the value and quantity of exports of this product grouping for January-July 2007 were 47 percent and 43 percent, respectively, versus the like period in 2006.

and/or expanding existing operations within other Asian countries, including Vietnam, to offset some of the changes (Bradsher 2008a and Sung 2007). Within China, continued productivity gains, such as those enabled by industrial biotechnology, have been suggested as one way to potentially mitigate some portion of the impact (Benjamin 2006). Kim and Kuijs (2007, 13-14) note that despite increased prices for raw materials and higher labor costs, the Chinese chemical industry maintained annual productivity gains in every year during 2002-06 except 2005; the industry's gains of 35-36 percent in 2002-03 declined to a low of -2 percent in 2005 before increasing again to 15 percent in 2006, short of the 2004 level of 20 percent. As Kim and Kuijs concluded in late 2007 (2007, 17), " . . . the ability of China's industry to offset rising raw material prices by increasing efficiency has so far remained undiminished."

Conclusion

China's use of industrial biotechnology in its biofuels and chemical industries has enhanced its positioning as the world's third-largest producer of ethanol and second-largest producer of chemicals and has corresponded with concurrent export growth in chemicals. The country's continued use of bioprocesses and renewable resources is reflected in both its rigorous efforts to develop nongrain biofuels, including cellulosic ethanol, and its ongoing research into biocatalytic processes, particularly for use in the chemical industry. The strength of these industries has encouraged expanded domestic and foreign investment, including investment in bio-based projects and generated related gains in exports, particularly in the chemical industry. However, the market conditions facing many of the ongoing and prospective ventures in the two industries are in flux because of changes such as China's implementation of new labor laws, the reduction or elimination of VAT refunds to Chinese exporters in many industry segments, the strength of the Chinese renminbi versus the U.S. dollar, and higher domestic energy prices through the first half of 2008. Moreover, the June 2008 projection of slowing domestic economic growth has been exacerbated by the impact of the global economic slowdown that cascaded globally during the latter part of 2008. Although the magnitude of the impact is likely to vary by sector and the economic situation remained volatile as of the end of 2008 (e.g., energy prices declined significantly in the latter part of the year), the changing market conditions appear to have tempered export gains and related profits in the liquid biofuels and chemical industries in the first seven months of 2008.[48] Within the chemical industry, industry sources cited higher increases in manufacturing costs (e.g., higher feedstock and energy prices) and lower profit margins in the first half of 2008 than in previous years. Continued productivity gains, such as those enabled by industrial biotechnology, have been suggested as one way to potentially mitigate some portion of the impact of the abovementioned factors.

[48] The November 2008 decline in China's exports was the largest since 1999 (Jacobs and Barboza 2008). Several sources state that the sectors experiencing the largest impact–furniture, toys, and apparel–are those with lower infrastructure investments and narrower price margins. In comparison, the chemical industry incurs significant capital investment and many of its products (e.g., specialty chemicals and end products such as pharmaceuticals) have higher profit margins and significant value-added components.

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