Bioenergy Update

Second Generation Biofuels & Biorefinery Development Report Card

Introduction

Based on a review of bioenergy research and emerging technologies, we reported in March 2006[1] that a great deal of new technology was in various stages of development that had the potential to dramatically transform rural economies within the relatively near future. We also indicated that biomass energy offered considerable opportunity for owners and managers of Minnesota's farms and forests, with production of liquid transportation fuels offering the greatest potential. In August 2007, after a more extensive look at bioenergy research and development globally, we again described bioenergy as a substantial opportunity for Minnesota, and particularly for production of both liquid biofuels and biochemicals.[2] We also discussed the biorefinery concept – a vision of a network of integrated manufacturing plants, capable of producing a variety of energy, chemical, and fiber products from wood and other forms of biomass; this is an idea that has been pursued by scientists for at least 90 years, aggressively pursued by commercial interests in northern Europe since the mid-1980s, and more recently promoted and financed by governments worldwide.

Despite the reality that biodiesel was made from pulping liquor in Germany as long ago as 1920, wood-derived ethanol was extensively produced in Europe in the 1940s, and a wide range of chemicals and energy have been produced from woody biomass by pulp and paper mills worldwide for the better part of a century, commercialization of technologies needed for present-day biorefinery viability remains elusive. Is it all just a dream that will never be realized? When might technical and economic feasibility of second generation fuels occur? What products are likely to go into large-scale commercial production first? These are a few of the questions that people are asking regarding the likely future of biochemicals and second generation biofuels production.

This report examines the current status of second generation biofuels and biorefinery development globally, and in North America and the Upper Midwest in particular. We begin by looking at current uses of biomass-derived energy in various parts of the world, regional trends, and national and regional priorities for development of transportation biofuels vs. other forms of bioenergy. We then focus on progress toward second generation fuels and biochemicals and near-term prospects for biorefinery commercialization. Our review reveals considerable technological progress, current production of a number of biofuel and biochemical products on pilot and limited commercial scales, and optimism that large-scale commercialization of at least portions of the biorefinery concept is not far away.

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1 Bowyer, J., J. Howe, and K. Fernholz. 2006. Biomass Energy – From Farms to Forests an Emerging Opportunity for Rural America. Dovetail Partners, March 23. (http://www.dovetailinc.org/documents/DovetailBioenergy0306b.pdf)

2 Bowyer, J., and Ramaswamy, S. 2007. An Assessment of the Potential for Bioenergy and Biochemicals Production from Forest-Derived Biomass in Minnesota. Dovetail Partners, Inc., August 29. (http://www.dovetailinc.org/reports/pdf/BlandinIRRBioenergyPaper082907yf.pdf)

Biofuels Within the Context of Bioenergy Development Globally

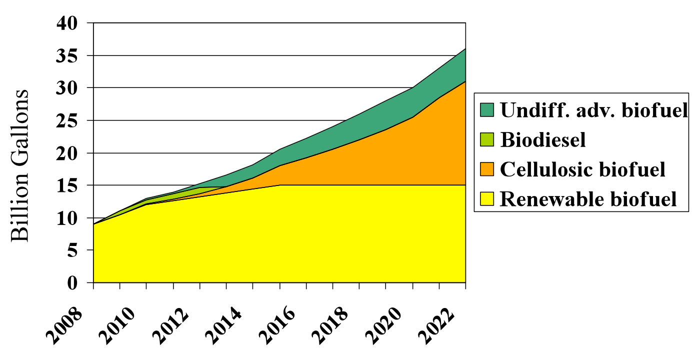
Biofuels and biochemicals technology development and production continue to be driven by government funding of research and development and by a range of incentives and mandates. These tools are being used by governments worldwide in an attempt to reduce reliance on fossil fuels and chemicals derived from petroleum, while also reducing carbon emissions.

Currently, first-generation biofuels production is generally rewarded through investment and production credits, at the same time that a portfolio of research and development support, incentives, mandates, and investment credits are being used to bring about progress toward production of second-generation biofuels and biochemicals. The greatest public sector support for biofuels and biochemicals development exists in the more economically developed countries, with greater emphasis on other forms of bioenergy in the lesser developed countries.

United States

The Federal Renewable Fuel Standard (USEPA 2009a,b) drives much of the activity within the U.S. relative to biofuels development. Under requirements of the standard, the volume of renewable fuel to be blended into gasoline rises from 9 billion gallons in 2008 to 36 billion gallons by 2022. Targets call for the production of conventional ethanol to increase to 15 billion gallons per year by the year 2016, with advanced biofuels production about 7.25 billion gallons in that year. The federal standard also requires further increases in the production of advanced biofuels, such as cellulosic ethanol and biomass-based diesel, to reach 20 billion gallons annually by 2022 (Figure 1). These goals are tempered by a recent Department of Energy assessment that concluded that the U.S is unlikely to attain the 36 billion gallon target.

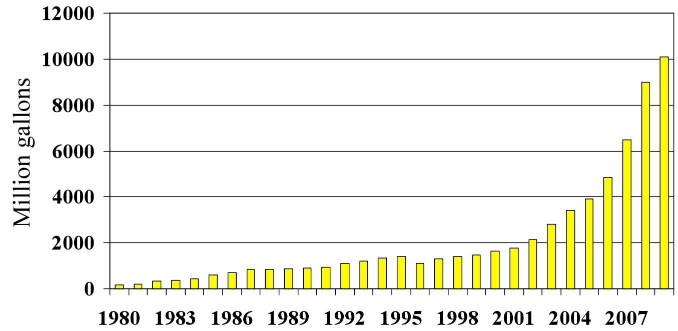
Figure 1
Biofuel Targets Under the U.S. Renewable Fuels Standard



Source: U.S. Energy Independence and Security Act of 2007 (H.R. 6)

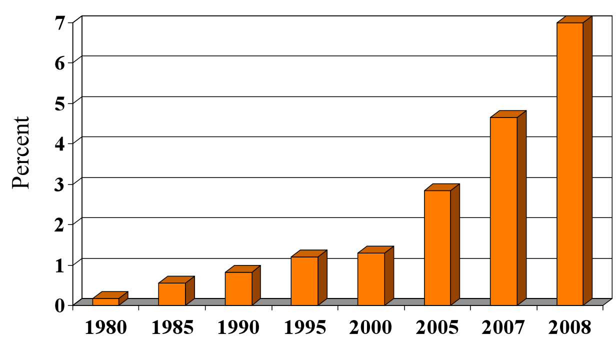
Sharp increases in U.S. production of first-generation ethanol since 2004, almost all from corn starch, resulted in production levels by the end of 2008 that were on target, approximating 9 billion gallons from 170 production facilities (Figure 2); domestic production plus net imports brought ethanol consumption as a percent of gasoline consumption to an estimated 7 percent in 2008, up sharply since 2000 (Figure 3). The United States is now the world's leading producer of ethanol, having recently surpassed Brazil in this regard. Interestingly, the United States, Brazil and Germany together now account for over half of biodiesel and more than ninety percent of bioethanol production globally.

Figure 2
Ethanol Production in the United States,
1980-2009



Source: Renewable Fuels Association (November 2009). (2009 est.)

Figure 3
Ethanol Consumption in the United States as a
Percent of Gasoline Consumption, 1980-2008



Source: Renewable Fuels Association (2008) and Energy Information Administration (2009).

Domestic biodiesel production, which has been running ahead of targets as established in the Renewable Fuel Standard, reached an estimated 700 million gallons in 2008 from 173 production facilities. However, a sharp decline is projected for 2009, the result of a loss of European export markets due to anti-dumping actions on the part of the E.U. and dropping diesel prices (Figure 4).

A number of separate governmental initiatives are intended to attainment of goals as established in the Renewable Fuel Standard such as the Biomass Research and Development Initiative of the US Departments of Energy and Agriculture (January 2009). Such measures, when combined with numerous other federal measures and separate initiatives in a number of states aimed at biofuels and biochemicals technological advancement and private investment, are likely to provide powerful incentives for continued development leading toward establishment of a network of biorefineries.[3]

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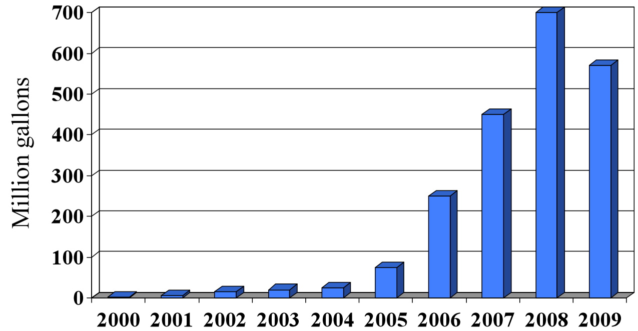
[3] Unfortunately, it is also likely that prices in established biomass markets will increase, and especially for woody biomass products such as pulpwood and hog fuels with potentially substantial negative impacts on established wood products manufacturers.

Figure 4
Biodiesel Production in the United States,
2000-2009



Source: National Biodiesel Board (November 2009); Davis (May 2009).

A new wrinkle in the national biofuels effort developed in May 2009 when the Environmental Protection Agency issued a draft rule reaffirming government support for increased use of advanced biofuels. Following the lead of the E.U., the EPA also indicated intent, for the first time, to measure carbon dioxide emissions from alternative motor fuels. Under the draft rules, manufacturers of corn-based ethanol will have to demonstrate that their products deliver full lifecycle greenhouse gas emission savings of 20 per cent compared to the fossil fuel it replaces. Other biomass-based fuels and cellulosic biofuels will have to save 50% and 60%, respectively. Whether such rules will serve to limit future development remains to be seen.

One factor that *is* likely to inhibit biofuels development is use of substantial quantities of biomass for production of energy products other than biofuels – products such as biomass-derived electricity and fuel pellets. While volumes at this point are relatively modest, growth is rapid. For example, about 1.8 million tons of fuel pellets, mostly from wood and mostly for export markets, were produced in 2008, a quantity more than 2.5 times greater than just four years earlier (Table 1).

Energy products such as biomass-derived electricity and fuel pellets also benefit from a variety of incentives. Biomass to electricity, for instance, is encouraged through direct subsidies of as much as 2.1 cents per kilowatt hour, while production of both biomass electricity and fuel pellets are supported by measures such as the 2008 Biomass Crop Assistance Program (BCAP) under which payments are made to those delivering biomass to qualifying biomass energy products producers.

Canada

As in the United States, Canada has adopted a biofuels mandate. The Canadian measure specifies 5% and 2% renewable content in gasoline and diesel fuel, respectively, by 2010. Several provinces have adopted higher targets. Manitoba recently became the first province to mandate biodiesel blends, requiring a minimum 2 percent blend beginning Novermber 1, 2009. National renewable fuels targets are supported by what is known as the ecoENERGY for Biofuels program. The initiative is funded by up to CDN$1.5 billion over 9 years. Additional funding is available to support production of liquid biofuels by farmers and large-scale demonstration facilities for second-generation biofuels production.

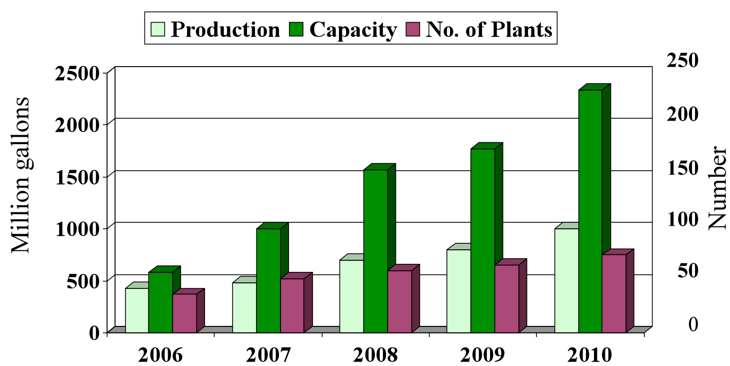
The ecoENERGY initiative provides operating incentives to producers of renewable alternatives to gasoline and diesel and makes investment in production facilities more attractive by partially offsetting the risks associated with fluctuating feedstock and fuel prices. As in the U.S., continued development activity is likely.

Rapid growth of production of other forms of biomass energy, including biomass-derived electricity and fuel pellets, complicates the biofuels picture. Various incentives provided by government entities at the federal and provincial level are helping to drive this development.

Europe

In 2003 the European Union adopted a goal of 5.75% biofuels in road transport fuel by 2010. While this goal and accompanying incentives have served to stimulate biofuels production (Figures 5 and 6) and consumption it appears that the EU will fall short of the 2010 goal (Figure 7).

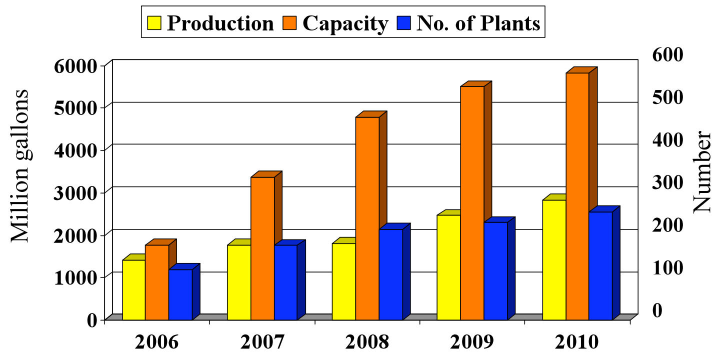
Figure 5
EU Ethanol Production, Production Capacity, and Number of Plants, 2006-2010



Source: U.S.D.A. Gain Report NL9014 (2009).

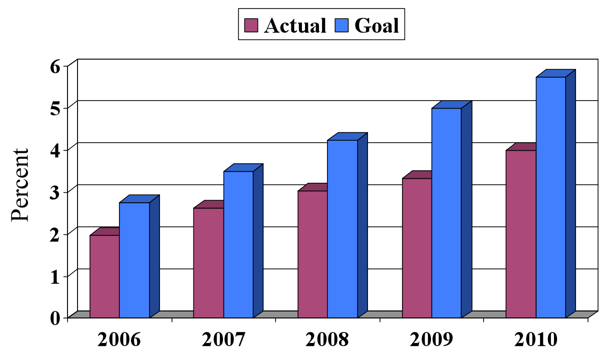
New goals for renewable fuels production have been established as part of 2009 EU Climate Change legislation. The newest measure calls for an overall 20 percent share for renewable energy in the EU energy mix, with part of this 20 percent share to be realized in the form of at least 10 percent renewable energy in transport. Biofuels per se are not specified (meaning that biomass-electricity powered vehicles would count toward the goal), but given present momentum in biofuels development, a significant portion of the renewable target is likely to be satisfied in this way. A recent stipulation to biofuels targets is that GHG emissions associated with production and use of such fuels must be at least 35% lower than for fossil fuels, and by 2017 50% lower (and 60% for new installations). Moreover, biofuels may not be made from raw materials obtained from land with high biodiversity value, including forests or other wooded land. Continuously forested areas are also excluded as a source of raw materials for biofuels production. An interesting caveat is that second generation fuels meeting the above guidelines will count double toward renewable energy goals, while renewable energy used to power transport vehicles will be counted by a factor of 2.5.

Figure 6
EU Biodiesel Production, Production Capacity, and Number of Plants, 2006-2010



Source: U.S.D.A. Gain Report NL9014 (2009).

Figure 7
EU - Total Biofuels as a Percent of Transportation Fuels, 2006-2010



Source: U.S.D.A. Gain Report NL9014 (2009).

Although both the U.S. and EU are pursuing biofuels development, such development looks quite different on the two sides of the Atlantic. In Europe, where diesel has long been the preferred automotive fuel, biodiesel is the dominant focus; in 2009 the EU is expected to produce four times the volume of biodiesel as the U.S. On the other hand, production of ethanol within the EU in 2009 will be only about 8 percent of that in the U.S. (Table 1).

As noted earlier, one factor that is likely to inhibit biofuels development in the U.S. is use of biomass for production of other forms of energy. The same is true in Europe. In EU-27 countries production of pelletized fuels from biomass will reach an estimated 8 million metric tons in 2009, about four times U.S. production. Some of those pellets and other forms of biomass are likely to eventually provide direct competition to the developing biofuels industry, not only through consumption of a portion of the same raw material pool, but also through production of electricity that will be used to power vehicles.

Table 1
Production of Biodiesel, Ethanol, and Wood Pellets in EU and US

	E.U. 2009	U.S. 2009
Biodiesel (bill. gal)	2.5	0.6
Ethanol (bill. gal)	0.8	10.1
Wood pellets (mill. mt)	8.0	1.8*

* This figure is for 2008; production in 2009 is projected to be substantially greater. Much of U.S. wood pellet production is currently exported to EU countries.

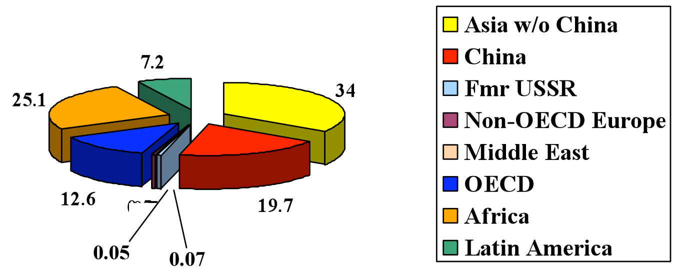
Research and development aimed at new and improved biofuel technologies (including woody biomass to biofuels), pilot scale research, technology adoption and biofuel systems implementation is being aggressively financed in the EU centrally and by a number of individual countries. The highest priorities are being pursued in a coordinated fashion. The EU, for instance, is currently pursuing identification/ establishment of ten Pan-European Research Infrastructures and Centers of Excellence that will focus on renewable energy and chemicals development. Research priorities for the new centers include biofuels, sustainable chemistry, biorefineries, and novel technologies for carbon dioxide capture and storage. Specific to biorefineries, a key objective is immediate support and coordination of ongoing biorefinery research projects with high potential in terms of industrial exploitation of results (FTP-Update, 2008).

Asia

In view of the fact that some 1 billion in Asia, including over one-half of the rural populations in China and India, currently still do not have access to electricity (Schaefer-Preuss 2008), there is great interest in finding ways to expand energy availability across Asia. Moreover, 70 percent of Asia's energy needs are currently provided by fossil fuels. These two factors, combined with the fact that over one-half of potential bioenergy supplies globally are reportedly located in Asia (Figure 8), are driving interest in bioenergy development in the Asian countries.

While there is considerable interest in bioenergy, the lack of electricity availability in rural areas is driving Asian bioenergy development toward electric generation, charcoal, and biogas. In these countries concerted research and development focused on biorefinery development is unlikely in the near to mid-term.

Figure 8
Estimated Regional Shares (Percent) of Biomass
Supply Globally, 2004



Source: Renewables Information 2006 @ OECD/IEA 2006, [Figure Number 4], p. [4]

China

As reported by the United Nations in 2003, and based on 1996 data, 61 percent of rural household energy in China came from traditional uses of biomass (i.e. heating and cooking and small-scale biogas). Based on projections of growing energy demand, near-term energy shortages in rural areas have been forecast.

Given the growing need for both traditional uses and for expansion of electricity to households that do not now have it, combined with recognition that current uses of biomass are inefficient, China has set ambitious goals for renewable energy development. The Renewable Energy Law of the People's Republic of China (National People's Congress 2005) which went into effect on January 1, 2005 addresses a wide array of renewable energy pathways, including wind, solar, hydro, biomass energy, geothermal, ocean waves and others. The direct burning of straw, firewood, and dung is specifically not covered by the law, as the government is seeking to displace these forms of energy production by more efficient technologies. Targets are aggressive. In 2003 it was envisioned that renewable energy would provide 10 percent of total energy demand in 2010 and 16 percent by 2020. With 2010 at hand, the reality is much different. As reported in China Climate Change Info-Net (2009) bioenergy will account for only 1 percent of *renewable* energy consumption in 2010 and an estimated four percent by 2020.

Although the percentages are small, the numbers are impressive. According to statistics from China's Ministry of Agriculture, by the end of 2005 more than 18 million peasant households were using methane gas for fuel. The ministry also reports rapid bio-energy electricity development; China's installed generating capacity will reportedly reach 5.5 million kilowatts by 2010, and 30 million kW by 2020.

Despite the fact that biofuels are mentioned prominently in China's current renewable fuels planning documents, numerical targets show clearly that the emphasis in bioenergy development is biomass power, biogas, and briquettes (Table 2). Based on biomass availability, crop residues are expected to play the greatest role in bioenergy production (Figure 9).

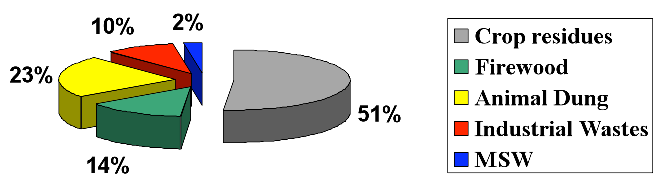
Table 2
Biomass Energy Development Targets – China

Form of Energy/ Year	Development Target 2005	2010	2020	Actual 2007
Biomass power (GW)	2.0	5.5	30.0	2.2
Biogas (billion m^3)	8.0	19.0	44.0	
Biomass ethanol (million metric tons)*	1.0	1.8	10.0	1.6
Biodiesel (million metric tons)*	0.1	0.2	2.0	
Briquettes (million metric tons)	0.0	1.0	50.0	

* Plans call for production of ethanol from cassava, sugar cane, sweet sorghum, and cellulose (with about 1/3 from cellulose) and production of biodiesel from waste food oil, jatropha, and other oil plants suitable for cropping in mountainous regions.

Source: Targets, Chuangzhi (2003); Actual 2007, Research and Markets (2008).

Figure 9
Composition of the Biomass Resource in China



Source: Chuangzhi (2003).

Production of ethanol in China reached 1.6 million tons (about 536,000 gallons) in 2007 and based on current investment is expected to reach 5 million tons in 2010. Biodiesel capacity is also increasing, although slowly. Recent reports indicate that most biodiesel production to this point has made use of waste cooking oil. Near-term plans, however, are to greatly increase biodiesel production, and to target oil-producing plants such as rapeseed and oil-bearing woody plants. A current pilot initiative, involving the United Nations Development Program and China's Ministry of Science and Technology, is encouraging farmers in several southern provinces to grow Jatropha curcas trees as raw materials for biodiesel. In addition, the groundwork is being laid for large-scale planting of shrubs and trees that yield oil (Li 2007).

India

Little progress in bioenergy development has occurred within India, although the potential for such development is high. Rajvanshi (2007) reported that about 60 percent of the rural population, or 400 million people, do not have access to electricity, relying instead on primitive biomass-fueled cooking stoves and kerosene lanterns. Even in urban areas blackouts and brownouts are reported as common, sometimes resulting in unavailability of power for 12 to 15 hours a day.

Beyond biomass-fueled cooking stoves, biogas is produced by a number of communities and family units for a variety of uses. As long ago as 1997 it was estimated that there were as many as 2.5 million biogas plants in operation across the country (Lawbuary 1999). Despite this reality, there has been only limited progress in recent years in expanding renewable energy development. However, perhaps as a sign of things to come the central government created a Ministry of New and Renewable Energy that began operations on May 29, 2009. In the newest five-year plan the Ministry has set a goal of 10 percent of domestic generating capacity to be provided by renewables, translating to 4-5 percent of total electricity use within the country.

The situation with biomass energy is similar. In 1998 biomass was estimated to supply 57 percent of India's energy demand, mostly in the form of fuel used in cooking stoves. Recent progress in developing a more modern biomass energy industry is summarized in Table 3; as yet achievements relative to estimated potential are modest.

Table 3
Biomass Energy Development Progress in India, 2002-2007

		Year			Estimated production potential
Method of Production	Units	2002-03	2004-05	2006-07	
Electricity/Cogeneration	MW	102.6	136.1	228.0	80,000
Biomass gasification	MW	2.1	8.3	--	
Waste to energy	MW	3.8	8.0	17.4	
Ethanol	litres	--	--	300 million (79 mill. gal.)	156 billion
Pyrolysis oil	kg	--	--	--	400 billion

Source: India Ministry of New and Renewable Energy (2009); Est. production potential, Rajvanshi (2007)

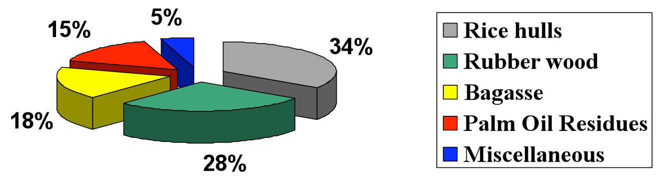
Virtually all biomass derived fuels are expected to be derived from agricultural residues (an estimated 600 million tons annually). Projected biomass electricity production potential is about 50 percent of current installed capacity while the ethanol potential is 42 percent of projected oil demand within India in 2012. Thus, the potential impact of biomass energy development on India is quite significant.

Indonesia

Indonesia is estimated to produce 146.7 million metric tons of biomass per year, equivalent to about 470 gigajoules per year (Duryea 2007). Primary forms of biomass and their potential contribution to energy production are shown in Figure 10. Note that Figure 10 does not include palm oil or the oil of any other plant species; Indonesia is a leading producer of palm oil (with Malaysia and Indonesia ranked #1 and #2 globally in palm oil production).

Duryea reported that several kinds of biomass to energy-production technologies have been empirically tested in Indonesia including 1) production of biogas from organic vegetable waste for use as a fuel and for generating electricity, 2) gasification of charcoal and wood sawdust for electricity generation, and 3) carbonization of small-diameter logs, sawdust, wood slabs and coconut shells into charcoal. All of these pathways are being pursued, though the latter is viewed as perhaps having the greatest promise for the near term. At this point it appears that guidelines for harvesting and removing biomass in the form of small-diameter trees and logging residues have not yet been developed.

Figure 10
Composition of the Biomass Resource in Indonesia



Miscellaneous includes plywood and veneer residues, logging residues, sawmill residues, coconut residues, and agricultural wastes.

Source: Duryea (2007)

In addition to the three technologies identified above, development of biofuels is also being pursued, with these efforts focused almost entirely on palm oil.

In January 2006 a national energy policy calling for 5 percent biofuels in the energy mix by 2025 was issued as a Presidential Regulation. In July of that same year the Energy Ministry announced aggressive plans to invest US$22 billion over the following five years to develop alternative fuels from such crops as oil palm, cassava, jatropha, and sugar cane (Rademakers2006). Ethanol production in Indonesia was about 140 million liters in 2007, with most produced from sugar cane, while biodiesel was about 1,550 million litres – virtually all from palm oil. Despite aggressive targets for growth in both areas, falling petroleum prices in 2008 had a severe impact on the fledgling industries.

Given the extensive palm oil estates across Indonesia and the large biomass production potential, Indonesia is likely to emerge as a major player in the global biofuels market. Many observers note that the country does not currently require the blending of biofuels with traditional transportation fuels, denying domestic biofuels producers stable markets.

Africa

As reported by the Energy Information Administration (EIA 1999), Africa is the world's largest consumer of biomass energy (firewood, agricultural residues, animal wastes, and charcoal), calculated as a percentage of overall energy consumption. Biomass in 1999 accounted for as much as two-thirds of total African final energy consumption.

EIA further reported that about two-thirds of biomass use was in the form of firewood in 1999, with biomass energy use accounting for 5% of North African, 15% of South African, and 86% of sub-Saharan (minus South Africa) consumption in that year. Africa-wide, some 70-90 percent of households use biomass energy (Fehse 2006), with 91 percent of wood produced in Africa consumed as fuel. This use is projected to grow significantly in the near term (Table 4).

Table 4
Wood Fuel Use in Africa
(million m^3)

2000	2010	2020
635	741	850

Source: Fehse (2006)

Despite and partially because of dependence on biomass energy, deforestation is one of the most pressing environmental problems faced by most African nations, and one of the primary causes of deforestation is wood utilization for fuel. So, as the developed countries move decisively to create a new biomass energy industry, the world leader in biomass energy production is experiencing major problems related to reliance on biomass for energy production. The reality serves as a caution to aggressive biomass energy development.

In the face of such daunting problems, recent high-level conferences within Africa have begun to address renewable energy and biofuels development possibilities across the continent. A meeting in Ethiopia in mid-2007 resulted in an "Action Plan for Biofuels Development in Africa" and the "Addis Ababa Declaration on Sustainable Biofuels Development in Africa. Another meeting in Senegal in early 2008 examined renewable energy more broadly and resulted in further declarations to scale up renewable energy. In both meetings it was noted that among the many benefits of renewable energy development in Africa would be greatly enhanced prospects of food self-sufficiency. Nonetheless, potential impacts on forests of southern Africa loom large, and guidelines for how, when, and how much biomass to remove in energy harvests are among the pressing needs in this region.

Despite the problems, several players are actively engaged in biofuels development in Africa. One player is Energem, an energy and biofuels company that currently produces ethanol from molasses in Kenya. The company is also focusing on production of biodiesel from jatropha in Mozambique.

South America

Brazil is by far the leading producer of bioenergy in South America and a major player globally. In 2008, ethanol production in Brazil approximated 6.5 billion gallons, second only to the United States (9 billion gallons).

A report, now more than a decade old (de Andrade 1998) noted that Brazil accounted for 49 percent of all biomass energy consumed in Latin America and that 21 percent of Brazil's total energy consumption was bioenergy – mainly sugar cane ethanol for transportation, fuelwood for the industrial, commercial, and residential sectors, and charcoal for industrial use. At that point just under one-half of Brazil's biomass energy came from fuelwood – an estimated 71.7 million tons in 1996 - gleaned both from primary and secondary forests. This volume was down from a peak of about 106 million tons of woody biomass use for the period 1983-1989, with the decline mainly attributable to a decline in conversion of wood to charcoal for use by the metals and minerals industries. Subsequently, charcoal production continued to decline through 1999, but since then has begun to increase again, increasing about 50 percent over the past seven years.

Currently there are a number of multi-country renewable energy initiatives underway across South America, with many led by or involving Brazil. Thus far, negative impacts of bioenergy production on the Amazon forests have not been realized. Charcoal production is mostly concentrated in the subtropical regions south of the Amazon basin and mostly in secondary planted forests. The remoteness of most of these forests, for now at least, makes them an unlikely candidate in the near term as a source of raw materials for liquid fuels production.

One South American country in which biofuels development may impact natural forests is Chile. Here, wood supplies much of the energy for much of the country's state-of-the-art forest products manufacturing facilities. Wood-fired commercial electrical generation on a significant scale is being pursued. The government, amid controversy, has also announced a renewable energy target of 15 percent by 2010, with biofuel a significant part of such development. Initial discussions are focused on rapeseed, sunflower, and wheat as potential raw materials for biodiesel and ethanol; forest biomass is currently not being actively discussed as a biofuel raw material, though commercialization of cellulosic ethanol technologies could change this situation.

Progress Toward Commercialization of Second Generation Fuels

Although progress continues to be made in bringing second-generation lignocellulosic biofuels into commercial production, there is currently no commercial production anywhere in the world outside of small pilot and demonstration facilities. That this is the case in the United States is not surprising given targets established in the Renewable Fuel Standard that call for production of only very small volumes of advanced biofuels starting in 2010, with marked increases in production beginning about 2015 (Figure 1). This timetable meshes with current projected start-up dates for a number of facilities that have been announced or that are now under construction (Dovetail Partners 2009a,b; IEA 2009).

A key to when commercialization will occur is the point in time at which biofuels become cost competitive with established fossil fuel products. As this is a moving target depending upon global petroleum prices, biofuel commercialization depends upon a combination of factors. These include 1) the success of scientific and technological efforts to reduce operating costs in biofuel production, 2) the rate of scientific and technological advancement relative to solving remaining technical problems and developing new technologies, 3) unwavering government support for biofuels development, and 4) government policies that define subsidy levels for biofuels vs. fossil fuels. Changes in policy that would either remove subsidies from fossil fuels, or that would shift subsidies away from fossil fuels and toward biofuels could have a significant impact on how rapidly the biofuels industry in the U.S. and elsewhere develops.

In contemplating when commercial production of biofuels such as cellulosic ethanol and biodiesel might become reality, it is worth reflecting on the past. The technology of producing ethanol from lignocellulosics is not new. At least 17 pulp mills in Finland have been periodically in the business of producing ethanol on a commercial scale from by-product black liquor (i.e. from lignocellulosics) over the past 90 years. Much of this production is directly linked to World War II, and thus production periods for these plants during the period 1940-45 are common; however, in many cases production continued through the 1950s, and in one case up to 1990 (Niemelä 2008). Tembec (a Canadian manufacturer of pulp and paper) has been producing lignosulfonates and resins since the mid-1980s, ethanol since 1991, and biogas since 2006.

Successes in research and development combined with the financial support of governments worldwide are beginning to attract considerable interest and investment in second-generation biofuels development on the part of the private sector. For instance, a European biomass-to-liquids project, termed OPTFUEL, has been initiated by a group of 10 industrial firms.

Volkswagen AG has taken the leadership in the initiative that includes automobile manufacturers Ford Motor Co. and Renault SA., among others. The goal is to develop over the next three to four years a commercial-scale, second-generation bio-diesel plant with 200,000 tons (60 million gallons) per year output. In the U.S., the Dow Chemical Company announced in late June 2009 that it plans to work with Algenol Biofuels, Inc. to build and operate a pilot-scale algae-based integrated biorefinery that will convert industrially derived CO_2 into ethanol and industrial chemicals. In Asia, Nippon Oil, Toyota Motor and others announced in March 2009 that they will jointly establish a bioethanol research association, to be named the Research Association of Innovative Bioethanol Technology, to research and develop full-scale production technologies for cellulosic bioethanol.

For now a trickle of lignocellulosic biofuels is coming from pilot and demonstration biofuels facilities across North America, Europe, and from several facilities in Brazil and Asia. When large-scale production of second-generation lignocellulosic biofuels will become reality is anyone's guess at this point, but commercial-scale plants now under construction around the world combined with those recently announced point to the period 2012 to 2016 as one in which a breakthrough is likely.

Biofuels to Biorefineries – Prospects for Integrated Biorefinery Development

The Biorefinery Concept

In discussing future prospects for technical and economic viability of "integrated biorefineries" it is important to define what is meant by this term. The Biomass Program of the U.S. Department of Energy defines integrated biorefineries as follows:

> *Biorefineries are similar to petroleum refineries in concept; however, biorefineries use biological matter (as opposed to petroleum or other fossil sources) to produce transportation fuels, chemicals, and heat and power.*
>
> *Integrated biorefineries employ various combinations of feedstocks and conversion technologies to produce a variety of products, with the main focus on producing biofuels. Side products can include chemicals (or other materials) and heat and power. The renewable feedstocks utilized in integrated biorefineries include, but are not limited to: grain such as corn, wheat sorghum, and barley; energy crops such as switchgrass, miscanthus, willow and poplar; and agricultural, forest, and industrial residues such as bagasse, stover, straws, forest thinnings, sawdust and paper mill waste. The benefits of an integrated biorefinery are numerous because of the diversification in feedstocks and products.*

Included under this definition are existing commercial facilities that produce ethanol from corn starch and biodiesel from soy oil, one reason perhaps why both the Renewable Fuels Association and National Biodiesel Board have begun referring to current ethanol and biodiesel plants as biorefineries. With ethanol and biodiesel plants already spread across much of United States, and with evidence in the historical record of an operating "biorefinery" in Germany that produced several chemicals and biogas from pulp mill black liquor as early as 1920 (Niemelä 2008), one might wonder why there is still discussion about when commercial biorefineries might become reality.

The key here is the word "integrated." What is being sought through current initiatives around the world that seek to bring about integrated biorefinery development are new technologies (second generation technologies) for integrating the production of biomass-derived fuels and other products in a single facility.

There are many forms of renewable bio-materials that can be used as biorefinery feedstocks. The form of raw material has a major impact on technologies employed and thus the type of refinery. European energy researchers Reith and Steinmetz (2009) described four different types of biorefineries:

1) whole crop/cereal biorefineries that use dry cereal grain residues or sugar crops as raw materials.
2) oilseed biorefineries that use raw materials such as rapeseed, sunflowers, or soybeans as raw material.
3) green biorefineries that can use we biomass such as green grass, potatoes, sugar beets, seaweed, or algae.
4) lignocellulosic biorefineries that can use various forms of wood and bark, pulping and paper residues, crop residues, and energy crops as raw material.

Research and Development

<u>EU-27</u>

Research and development efforts relative to integrated biorefineries are occurring on all four of these fronts. In the EU-27 alone there are at least 60 pilot and demonstration facilities focused on integrated production of second-generation biofuels and other products (with most depicted on a new interactive web-based map and associated database (IEA 2009). Table 5 shows the number of EU pilot and demonstration facilities by area of focus.

Table 5
Biorefinery Pilot and Demonstration Projects in the EU-27
as of December 2008 by Area of Focus

Focus of Biorefinery	Number of Facilities
Whole crop/cereal	10
Oilseed	8
Green	13
Lignocellulosic	23
Other	6
Total	60

* Source: Reith and Steinmetz (2009), Dovetail Partners (2009), IEA (2009)

Details regarding EU lignocellulosic biorefinery pilot and demonstration projects are shown in Table 6. In the area of lignocellulosics, as in all other areas of focus, the greatest number of projects is located in western and northern Europe. There are few projects in southern Europe and none to date in eastern European countries.

Table 6
Details Regarding EU Lignocellulosic Biorefinery Pilot and Demonstration Projects

Objective/raw material	Principal/Location
Syngas, FT-diesel from forest residues, recycled wood waste, wood from short rotation woody crops	StoraEnso, Finland Choren, Germany
Syngas from black liquor: FT-diesel, DME	Chemrec, Sweden
Bioethanol from wood chips, sugarcane bagasse, wheat and corn stover, grass, recycled waste	SEKAB, Sweden
Biodiesel from tall oil	Sunpine, Sweden
Ethanol from wheat straw	Abengoa, Spain Dong Energy, Denmark
FT-diesel from straw	FCZ, Germany
Cellulose pulp from straw	CIMV, France
Wood-based chemicals: specialty cellulose, lignin, vanillin, ethanol, yeast	Borregaard, Norway
Lignin removal from black liquor; lignin to fuel, phenols, carbon fibers, metal ion sequestering	Lignoboost, Sweden
Biodiesel from straw pellets, other lignocellulosics	BFT Bionic Fuel Technologies, Denmark Forschungszentrum, Germany
Ethanol, biogas, lignin, hydrogen from various grasses, garden waste, straw	BioGasol, Denmark
Syngas from lignocellulosics	CTU, Austria Vienna Univ. of Tech., Austria
FT liquids from straw, wood, dried silage, organic residues	Cutec, Germany
Ethanol from agricultural and forestry wastes	Mossi & Ghisolfi-Chemtex, Italy
Ethanol from lignocellulosics	Procethol, France TMO Renewables, UK
Ethanol, biogas, lignin from wheat straw, corn fiber	Tech. Univ. of Denmark
Sugars, concentrated acid from coniferous wood sawdust	Weyland, Norway
Ethanol from cereal straw, grasses, or wood	Süd-Chemie, Germany

Source: Fagernäs and Solantausta (2009); Johnson et al. (2009), Dovetail (2009a), IEA (2009).

None of the European projects have yet reached commercial scale. According to the European Commission, Community Research and Development Information Service (CORDIS) deployment of integrated biorefineries is not expected before 2020.

Under the European Commission 7th Framework Program, a program that sets priorities and provides funding for research and development in the EU, €57 million (about USD$85 million) is provided for collaborative biorefinery projects. Some believe that this is insufficient. A recent article (Milmo 2009) reported that "In the worldwide push to develop technology and infrastructure for biorefineries, Europe is losing ground internationally because of the fragmented nature of its R&D activities and the lack of funds and resources for large demonstration facilities. It was noted that funding for the development of biorefineries is "tiny" in the EU region, compared with funding provided for development in the US and China. In the article the director for industrial biotechnology policy at the European Association of

BioIndustries (EuropaBio) is quoted as saying that while the EU is spending considerable sums on research in general it doesn't have a budget for development schemes, like demonstration plants. It was noted that demonstration units are important for the development of biorefineries because they are required to test technologies for making co-products, since biorefineries will need to gain financially from the better margins of higher-value products to be economically viable.

U.S.

There are currently at least 35 pilot and demonstration facilities in operation in North America, with about a quarter of them focused on woody biomass (Table 7). A number of others are in the conceptual stage. Figure 11 illustrates where activities are located throughout the country. Details are provided for lignocellulose oriented projects in Table 8; the number of projects listed is 27 – a number greater than the 22 indicated in Table 7 – due to the fact that some projects fall into more than one category.

Figure 11. U.S. Cellulosic Ethanol Biorefineries

Developed by Dovetail Partners, available at:
http://maps.google.com/maps/ms?ie=UTF8&msa=0&msid=102871790831467386457.00046943d4c666e3cefe8&z=4

Blue markers display operational biorefineries.
Yellow markers display biorefineries in development.
Red markers display biorefinery projects that have been suspended.

Table 7
Biorefinery Pilot and Demonstration Projects in the United States
by Area of Focus

Focus of Biorefinery	Number of Facilities
Whole crop/cereal	5
Oilseed	0
Green	5
Lignocellulosic	22
Other	3
Total	35

Table 8
Details Regarding Biorefinery Pilot and Demonstration Projects in the United States

Objective/raw material	Principal/Location
Ethanol from corn stover, wheat straw, milo stubble, switchgrass	Abengoa, Kansas Abengoa, Nebraska
Ethanol from switchgrass, grass seed straw, small grain wheat straw, corn stalks	AE Biofuels, Montana
Ethanol from lignocelluosic feedstocks that require little or no pretreatment	BBI BioVentures, Colorado
Biodiesel, syngas from forest residues, stumps, and bark in pellet and chip form	Gas Technology Institute, Illinois
Ethanol from softwood, waste wood, cardboard, paper	KL Energy, Wyoming KL Energy, S. Dakota
Mixed alcohols from Georgia pine and Colorado beetle killed pine	Range Fuels, Colorado
Ethanol, methanol from hardwood and softwood residues.	Range Fuels, Georgia
FT liquids, mixed alcohols from lignocellulosics, municipal wastes via syngas	Southern Research Institute, North Carolina
Objective/raw material	Principal/Location
Ethanol, mixed alcohols, various chemicals from municipal solid waste, sewage sludge, manure, agricultural residues, energy crops	Terrabon, Texas
Ethanol from green waste, wood waste, and other cellulosic urban wood waste	BlueFire, California
Ethanol from plant biomass, municipal solid waste, bagasse, and agricultural waste via syngas	Coskata, Pennsylvania
Ethanol from lignocellulosics	Coskata, Florida Coskata, Illinois
Ethanol from corn cobs	Ecofin, Kentucky
Ethanol from wood chips, grasses, corn stover, and sugar cane bagasse.	Mascoma, New York
Ethanol from corn fiber, corn cobs, corn stalks	POET, South Dakota POET, Iowa Dupont Danisco Cellulosic Ethanol Gulf Alternative Energy, Iowa
Ethanol, biogas, lignin from wheat straw, corn stover, poplar	Pacific Ethanol, Oregon
Ethanol and intermediate chemicals from poplar wood chips, sugar	ZeaChem, Oregon
Ethanol from plant biomass and wood waste	American Energy Enterprises, Connecticut
Biodiesel and waxes from softwood chips, non-merchantable wood and forest residues	Flambeau River Biofuel, Wisconsin
Ethanol from municipal solid waste	Fulcrum Bioenergy, Nevada
Biofuels from hemicellulose extracts from wood chips	Old Town Fuel and Fiber, Maine

Source: Fagernäs and Solantausta (2009); Johnson et al. (2009), Dovetail (2009b), IEA (2009).

Johnson et al. (2009) report that although none of these facilities have reached commercialization, two – the POET South Dakota facility and the Range Fuels Georgia facility – have reached Stage 4 (validation) in the U.S. Department of Energy five stage development process. The POET South Dakota effort is expected to lead to commercial production of ethanol from corn cobs in 2011.

The Range Fuels Georgia plant, that uses wood residues to produce ethanol and methanol, is close to commercialization. Construction of the first phase of what will eventually be a 300 million liter (79 million gallon) per annum plant is reportedly scheduled for completion by early 2010, with a production rate of 38 million liters (10 million gallons) by the middle of the year; the effort is supported by USDA with an $80 million loan guarantee (Johnson et al. 2009). Full commercialization will obviously take longer.

Whereas integrated biorefinery pilot and demonstration projects in the European community are reported to be severely limited by unavailability of funding, the situation is significantly different in the U.S. In January 2009 the US Department of Energy announced the availability of up to US$200 million over six years (2009-2014) to support the development of pilot and demonstration-scale biorefineries, focused on pilot-scale, (minimum throughput of one dry metric ton of feedstock per day) and demonstration-scale (minimum throughput of 50 dry metric tons of feedstock per day) facilities. This funding comes on top of $585 million in federal funding provided to establishment of such facilities since 2005; various states are providing funding and development incentives as well. This level of funding has attracted interest from scientists and entrepreneurs from around the world, bring considerable off-shore expertise to the U.S. biorefinery development effort.

<u>Canada</u>

Canadian lignocellulosic pilot and demonstration biorefinery facilities are listed in Table 9. These facilities are all focused on production of ethanol.

Table 9
Details Regarding Lignocellulosic Biorefinery Pilot and Demonstration Projects in Canada

Objective/raw material	Principal/Location
Ethanol from treated wood waste	Enerkem, Alberta Enerkem, Quebec Enerkem, Quebec
Ethanol from agricultural residues, wheat, barley, and oat straw	Iogen, Ontario
Ethanol, lignin from hardwood and softwood residues	Lignol Innovations, British Columbia
Ethanol from wood chips, forest and agricultural residues	Woodland Biofuels, Ontario
Ethanol from wheat straw	Birch Hills, Saskatchewan
Ethanol from lignocellulosics, spent sulfite liquor	Tembec, Quebec

As in other parts of the world commercialization is not imminent in any of these projects.

In that Canada has abundant oil and natual gas reserves, biofuels development is generally viewed as less urgent than in the United States. Nonetheless, as noted earlier Canada has dedicated up to $1.5 billion during the period 2008 through 2017 to boost production of biofuels.

Support for biorefinery development is being handled strategically, with grants provided as opportunities arise. Recent investments include CDN$10 million by the BC provincial government for biorefinery development, and CDN$15.5 million from Canada's Agricultural Bioproducts Innovation Program to the Canadian Triticale Biorefinery Network in Alberta.

Outside North America and Europe

Lignocellulosic pilot and demonstration facilities outside of North America and the EU-27 are listed in Table 10. There is relatively little work in biorefinery development occurring outside of North America and Europe. It should be noted, however, that China inagurated its first bioenergy research center in June-2009, preceded by several days by the release of a Chinese Academy of Sciences report that outlined a plan to achieve commercial production of bioenergy on a massive scale in China, replacing 30 percent of oil imports by 2050.

Table 10
Details Regarding Lignocellulosic Biorefinery Pilot and Demonstration Projects Outside North America and the EU

Objective/raw material	Principal/Location
Ethanol from wheat and barley straw	Abengoa Bioenergy, Spain
Ethanol from wood construction waste	Bioethanol, Japan CRAC, China
Ethanol from sugarcane bagasse	Dedini, Brazil Marubeni, Thailand Queensland Univ. of Tech., Australia
Ethanol from wood residues, bagasse and other lignocellulosics	Ethec, Australia
Ethanol, various sugars, electricity from agricultural residues	Mission New Energy, India
Ethanol from various lignocellulosics	Venenium Biofuels, Japan

There is no information available that indicates that any of the facilties indicated above are near commercialization.

Paper Mills as a Primary Focus for Biorefinery Development

Within the forest sector, chemical pulp and paper mills have long been viewed as a logical first point of lignocellulosic biorefinery development. Such mills have long been in the business of procuring and handling large volumes of woody biomass, reducing wood to constituent chemicals, and profitably producing an array of useful products, including industrial chemicals, and energy in the process.

While it can be argued that many paper mills around the world are currently operating as biorefineries, at the present time it is not obvious that second generation biofuels and biorefinery development will, in fact, be centered in the pulp and paper sector. Examination of current pilot and demonstration projects shows that while the pulp and paper industry is a principal player in some initiatives, this is not the case in a great many others. This may change as biofuels technologies are perfected and investors begin looking for profitable by-product opportunities to improve overall profitability.

The Bottom Line

Biofuels and biorefinery technology is developing steadily, with the most concerted effort to date centered in the United States. The U.S. is the current leader in production of first generation ethanol and a major player in first generation biodiesel. Now it appears that the first commercial scale production of second-generation biofuels may occur in the United States as well, albeit with the considerable involvement of scientists and entrepreneurs from the EU, Canada, and elsewhere. Nonetheless, full-scale commercial production of lignocellulosic biofuels still appears to be several years to a decade away.

Whether the pulp and paper industry will play a major role in the biofuels/biochemicals industry of the future remains to be seen. Developments over the next few years should bring more clarity to how this is likely to play out.

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