Synchronization of Biofeedstocks and Conversion Technologies: Current Status and Future Prospects

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As the biobased industry emerges, synchronization of biofeedstocks and conversion technologies is necessary to maximize economic competitiveness. The objectives of this paper are to

- address this issue primarily with respect to conversion technologies for production of bioenergy,
- highlight important logistical issues,
- address some needs of cellulosic energy systems, and
- speculate on future prospects for the industry.

Conversion Technologies

Cellulose and hemicellulose comprise more than 50% of fibrous plant biomass such as that contained in grasses, legumes, crop residues and wood. In the context of cellulosic biomass discussed in this paper, conversion technologies are methods for converting this material to energy in the form of heat, electricity or liquid fuels. These conversion technologies vary with respect to the ideal composition of the biomass raw material or feedstock to be processed. Therefore, in order to develop useful cellulosic energy crops, it is important to have a basic understanding of available conversion technologies and their needs in relation to feedstocks. However, certain desirable characteristics are common to almost all conversion technologies, including:

- high energy efficiency (useful energy produced as a percent of the energy contained in the feedstock),
- flexibility with respect to feedstock composition,
- low capital cost,
- low production cost,

- flexibility with respect to size of processing plant,
- ability to control undesirable emissions,
- market-ready products,
- high-value co-products,
- low volume of residue that requires disposal,
- low consumption of fossil fuels,
- low water requirement, and
- small environmental footprint.

HEAT AND ELECTRICITY

Production of heat is one of the most efficient processes for generating useful energy from biomass: typically it is possible to recover 80% or more of the energy contained in the feedstock. Both small and large systems are available for producing heat from cellulosic biomass. Pellet stoves are used for home-heating systems, and small furnaces or gasifiers are used for applications such as heating industrial buildings or broiler houses. Combustion occurs with limited or no restriction of air (or, therefore, of oxygen) to the furnace, and relatively high temperatures (> 2,500°F) are involved. If combustion is complete, the products are mainly water vapor, CO_2 and ash. However, depending on feedstock composition, combustion may also result in release of gases such as oxides of N and S, which are harmful to the environment.

Electricity can also be generated from biomass in both small and large systems. An example of a small biomass power system would be use of a gasifier to produce synthesis gas, or syngas (mainly CO and H, but also small amounts of CH_4 and CO_2), which then powers an internal combustion engine to drive an electric generator. However, syngas typically contains no more than 400 Btu/ft^3 compared to about 1,000 Btu/ft^3 for natural gas. On a larger scale, biomass can be used in a furnace or gasifier to generate steam, which then drives a turbine. This fundamental process is used in most pulp mills to generate power from mill residues and is also the basic method used to generate about half the electrical power in the United States from burning coal.

In typical coal-fired power plants, co-injecting the coal and biomass (a process known as co-firing) offers immediate opportunities to use biomass for production of electricity, with very little capital investment. Trials for co-firing up to 10% switchgrass with coal in existing power plants have been conducted in Alabama and Iowa. Co-firing higher proportions of switchgrass with coal is difficult because of its relatively low bulk density: 10% switchgrass by weight amounts to about 50% by volume. Low bulk density also necessitates separate handling of the two feedstocks. Coal is fed by gravity feeding systems to a pulverizer, and the resultant powder is delivered pneumatically to boilers. However, chopped biomass tends to “bridge” in gravity-feeding systems, causing blockages, and thus needs to be injected into the boiler separately from the coal. Co-firing biomass with coal typically results in a reduction in undesirable emissions but is more expensive than burning only coal on an energy-equivalent basis.

From the perspective of converting biomass to heat and electricity, ash and moisture are two important feedstock constituents. Moisture should be as low as possible to minimize the energy required to eliminate it in the conversion process. Ash is the inorganic material that remains after combustion or gasification. It has little or no value, and may be a liability if it has to be disposed of in a landfill. Therefore, ash concentration in cellulosic feedstocks intended for conversion to heat and electricity should also be as low as possible. Corrosion and slagging (solid deposits developing on the inside of reactors) can be a problem when biomass is processed in a furnace or gasifier. This depends largely on the ash-fusion temperature for the feedstock, which, preferably, should be as high as possible. Since ash-fusion temperature generally decreases with increased concentrations of Cl, K and, especially, Si in the feedstock, concentration of these elements should be as low as possible. In general, grasses typically have a lower ash-fusion temperature and are more prone to slagging than legumes or wood, mainly due to higher concentrations of Si. Finally, when feedstocks are processed by combustion or gasification it is desirable to minimize production of undesirable emissions, especially oxides of S and N. It is, therefore, desirable for the concentration of these elements in feedstocks to be low.

Liquid Fuels

At present, ethanol from corn starch or sucrose from sugar cane, and biodiesel from vegetable oils such as those derived from soybean, canola and oil palm, are the primary or "first generation" biofuels that are being produced commercially. Ethanol production from sugar cane is the cheapest process, because it simply involves fermentation of the sucrose in the juice of the cane to ethanol, and subsequent separation of the ethanol from the resultant "beer" by distillation. The residual solid material (bagasse) is used to generate heat and power needed to run the plant. Consequently, the fossil-energy ratio (FER: energy contained in the final product as a ratio of the fossil-energy input) for ethanol produced from sugarcane is well over 10.

A number of liquid fuels can be produced from cellulosic biomass. Even though ethanol is perhaps the most widely recognized and promoted, it has a considerable number of limitations. First, it contains only two thirds of the energy content of gasoline, thus providing only two thirds of the mileage in currently available engines. Although it can be blended with gasoline as an octane enhancer at a concentration of 10%, if used as a primary fuel it is typically made available in a blend of 85% ethanol and 15% gasoline, or E85. Use of this fuel requires flex-fuel vehicles and separate E85 storage tanks and pumps at filling stations. Furthermore, ethanol cannot be transmitted by existing pipelines, thus necessitating transport by road or rail. Even though it is possible to produce liquid fuels from biomass that are similar to those produced from oil, ethanol has accumulated considerable momentum as a transportation fuel due to the corn-to-ethanol industry.

Cellulosic biofuels can be produced by either of two primary pathways: biochemical or thermochemical (Pu *et al.*, 2008). The biochemical pathway for producing cellulosic ethanol (as well as other alcohols such as methanol and butanol) has received more research attention than the thermochemical pathway, possibly because it strongly resembles the corn-ethanol process. It involves enzymatic or acid hydrolysis of the cellulose and hemicellulose into component sugars, fermentation of the sugars into ethanol, and separation of the ethanol from the resulting beer by distillation. Typically, a pretreatment step is required to reduce feedstock recalcitrance (masking or binding of the cellulose and hemicellulose by lignin) to conversion. Most current pretreatment processes involve steam explosion or application of ammonia to break apart the feedstock fibers. Cellulose is more difficult to hydrolyze than hemicellulose, but the five-C sugars derived from hemicellulose are more difficult to ferment. Expected yields from biochemical processes are 60 to 80 gal ethanol/dry ton of biomass. Due to lower lignin and higher cellulose and hemicellulose contents in grasses and herbaceous legumes, ethanol yields from this process are expected to be higher than for wood. Lignin is a residue that remains after fermentation and can be used to generate heat and/or power to run the plant.

Thermochemical conversion involves gasification of the biomass into syngas and conversion of the syngas to liquid fuel by catalysts under high pressure and high temperature in catalytic reactors (Pu *et al.*, 2008). These fuels can be ethanol, methanol, and/or diesel, depending on the catalyst used. Thermochemical technology is more flexible with respect to feedstock, and expected yields are above 100 gal/ton of biomass.

A hybrid thermochemical-biochemical system can also be used in which the syngas from the gasifier is converted to ethanol by microorganisms, or biocatalysts, instead of chemical catalysts. Another version of the thermochemical process involves catalytic degradation or depolymerization of polymers, followed by catalytic synthesis into renewable alkanes or hydrocarbons that resemble the diesel, gasoline, and aviation fuel that are currently generated from oil.

While no economically successful commercial plants that produce transportation fuels from cellulosic feedstocks are in production yet, the US Department of Energy (DOE) is in the process of assisting with funding for six projects that involve building commercial-scale cellulosic-ethanol plants. In addition, private companies are proceeding with similar efforts without government assistance. Therefore, it is likely that the first plants of this kind will be in operation within the next 3 to 5 years, and substantial expansion of the industry can be expected in 5 to 10 years.

Biomass Crops

Although the ideal traits needed in a biomass-energy crop depend partly on the conversion technology that will be used, many desirable traits are not strongly dependent on the nature of the conversion technology. In this regard, desirable traits for biomass crops include:

- high yield,
- low input requirements,
- cheap, easy and quick to establish, preferably from seed instead of vegetative material,
- perennial, with good longevity,
- native and not invasive,

- good wildlife habitat,
- easy and cheap to harvest, dry, process and store,
- low in Cl, K and Si, and
- low in ash.

In a study that led to publication of a document by the US DOE and Department of Agriculture, commonly known as the "billion-ton report" (Perlack *et al.*, 2005), the aim was to determine if a billion tons of biomass could be produced annually in the United States. The report concluded that 1.36 billion tons of biomass could be produced per year, including 368 million tons of forest materials, and 998 million tons of agricultural materials. The agricultural materials included 428 million tons of annual crop residues (mainly corn stover, but also wheat straw and soybean residue), 377 million tons from perennial crops such as switchgrass, 87 million tons of grain, and 106 million tons of animal manure and other materials. Surprisingly, the report did not consider the potential contribution of cover crops. While corn and wheat are clearly grasses that could contribute substantially to the biomass resources needed to produce energy through use of their residues following harvest of grain, the main focus of this chapter is on crops that can be grown specifically for biomass production.

Because switchgrass has most of the desirable traits listed above, in 1992 it was chosen by the DOE as the model herbaceous energy crop for further development in the United States, and much of the ensuing discussion in this chapter focuses on this species. However, other important perennial candidates are *Miscanthus* × *giganteus*, which has been extensively developed for energy production in Europe and more recently evaluated in the United States, and sugar cane or a related hybrid known as energy cane. Finally, there is also considerable opportunity to use annuals in rotation with traditional crops: in particular, high-yielding sorghums can be grown in rotation with winter wheat, and winter annuals like rye and triticale can be grown in rotation with crops like corn, soybean and cotton. Not surprisingly, high-yielding C4 grasses are likely to play the biggest role in this developing industry. On the other hand, legumes have received relatively little research attention, probably due mainly to their failure to provide yields above the generally recognized break-even levels of 3.5 to 4.5 tons per acre. Use of polycultures, or species mixtures that resemble rangelands, have also been suggested for energy production (Tilman *et al.*, 2006). However, research so far has failed to demonstrate that this approach can achieve the yields required for growers to make a profit.

As is the case for forage that will be fed to livestock, the composition of biomass feedstocks for production of energy is important, and needs to be optimized for the conversion technology in question. Major constituents in herbaceous biomass include ash, cellulose, hemicellulose, lignin, and moisture. Herbaceous biomass typically contains 3 to 6% ash, 30 to 34% cellulose, 24 to 27% hemicellulose, 16 to 19% Klasson lignin, and about 8,000 Btu of energy per pound on a dry basis. Variation in these major components is remarkably low among species. In contrast, woody biomass such as that from hybrid poplar, is generally lower in ash (1–2%) and hemicellulose (16–19%) but higher in cellulose (40–43%), lignin (22–25%), energy (~8,400 Btu/lb), and moisture

(40–45%) than herbaceous crops. Both herbaceous crops and wood generally contain low levels of N and S, resulting in low emission of oxides of N and S, which can have negative impacts on human and environmental health.

Switchgrass

Switchgrass has been widely evaluated for biomass production in the United States, and several comprehensive reviews on this work have been published (McLaughlin and Kszos, 2005; Parrish and Fike, 2005; Parrish *et al.*, 2008). The species can be divided into two basic morphologic forms: tall, lowland types like 'Alamo' and 'Kanlow,' that are adapted mainly to southern regions, and shorter upland types like 'Cave-in-Rock,' 'Blackwell' and others, that are adapted to colder northern regions. Lowland types typically provide slightly higher yields (6–8 tons/acre/yr) than upland types (4–6 tons/acre/yr). Switchgrass is established from seed that is small, but varies considerably in size among cultivars. Recommended seeding rates are usually 5 to 10 lb seed/acre. When seeding switchgrass, great care is needed to avoid deep placement, to ensure good compaction of soil following sowing, and to implement effective weed control. It takes 2 to 3 years to reach full yield.

Following establishment, switchgrass is typically harvested once per year for production of biomass to produce energy. Harvesting after the aboveground biomass has senesced can improve persistence, facilitate harvest operations, conserve N, and improve feedstock quality for certain conversion technologies. However, anecdotal information from Alabama suggests that harvesting in late August or early September in the southeast results in the highest yields, and a small amount of regrowth before winter reduces establishment of winter weeds with less damage from spring frosts and provision of an attractive habitat for wildlife over winter. Fertilizer requirements should be no more than 50 lb N/acre/yr, with P and K applied according to soil-test results. Switchgrass has an enormous root system, and if established on land that was previously in annual row crops it will usually sequester a considerable amount of carbon in the soil. The crop can be harvested with conventional forage-harvesting equipment. General procedures for harvesting are outlined in the next section.

Miscanthus

Miscanthus × *giganteus* is a rhizomatous perennial that has provided biomass yields approximately double those recorded for switchgrass (Heaton *et al.*, 2004). This suggests considerably higher potential profitability for miscanthus than for switchgrass. However, miscanthus is a sterile hybrid that needs to be planted with vegetative material, such as rhizomes or plantlets, generated from tissue culture. Consequently, establishment costs will likely be higher, and ramp-up of acreage slower than for switchgrass. The crop is more cold tolerant than is switchgrass, also requiring only low levels of fertilization while providing similar soil and environmental benefits. It is already in commercial production as a feedstock for electric power plants in Europe, and is presently under evaluation and commercial development in the United States. Miscanthus is typically harvested once per year in late winter with currently available equipment.

Sugar Cane and Energy Cane

Sugar cane (*Saccharum officinarum*) is the feedstock of the renowned ethanol industry in Brazil. Although it is typically recognized as a tropical and subtropical crop, and is grown in only very small portions of south Texas, Louisiana and Florida, cold-tolerant varieties could be grown across a large region of the southeast. In addition, *Saccharum* hybrids known as energy cane are being developed with greater dry-matter yields and lower sucrose contents. Both sugar cane and energy cane offer opportunities to produce ethanol from the sucrose contained in the stems, as well as heat, electrical power or cellulosic biofuels from the bagasse that remains following extraction of the juice. As for miscanthus, dry-matter yields are typically about double those provided by switchgrass. Due to sterility, vegetative propagation is necessary, by means of stem material. Not a true perennial, it requires replanting approximately every 5 years. Sugar cane planting and harvesting equipment is available commercially, but will involve a major capital outlay if crop acreage is expanded substantially for production of energy.

Sorghum

Sweet sorghum offers opportunities similar to those provided by sugar cane: to produce ethanol from the juice, as well as other forms of energy from the bagasse. Other high-yielding sorghums can be used simply as cellulosic biomass crops. Because sorghum is an annual, it can be grown a lot further north than is sugarcane. The greatest potential for sorghum may lie in crop rotations with winter wheat, which was planted on 44 million acres in the United States in 2007. Yields of the best sorghum varieties are also double those recorded for switchgrass. However, due to thicker stems, it may be more difficult to dry before baling or field-chopping prior to storage.

Others

Winter cover crops, such as triticale and rye, offer considerable opportunity for biomass production in rotation with traditional summer row crops. Although yields of these crops on their own may be insufficient to be profitable, integration into crop rotations could facilitate economic viability. Legumes such as alfalfa may also offer potential as sources of energy, particularly in light of sharply increasing prices of N fertilizer. For example, alfalfa leaves and stems might be separated and the leaves used for animal feed while the stems are processed for energy. Legumes are typically better than grasses for combustion because they have lower levels of Si and an associated higher ash-fusion temperature, which indicates that they are less prone to slagging in boilers and gasifiers.

LOGISTICS: HARVESTING, HANDLING, STORAGE AND TRANSPORT

Logistical procedures outlined in this section apply directly to switchgrass, but have similar implications for other crops such as miscanthus and sorghum. Green switchgrass is best cut with a mower-conditioner to ensure rapid drying. Once mown, raking switchgrass into windrows can accelerate drying, but in fields with high yields, this can create difficulty for subsequent chopping or baling operations: windrows may be too large for proper handling with existing hay-making equipment that is designed for lower yields, and in such cases it might be best to simply let the material dry in the mown swath instead of raking, even if drying takes longer. The biomass may be baled with a big-round or big-square baler. As an alternative to baling, mown switchgrass can be directly chopped in the field with either pull-behind or self-propelled silage choppers with pick-up heads attached. Ideally, the objective is to achieve a particle size of about half an inch. Chopping might be slower than round baling in the field, but chopped material can be loaded and unloaded in less time than it takes to load round bales, and in-field chopping eliminates the need for tub grinding prior to feeding the material into a processing plant.

Principles related to storing bales of biomass for production of energy are the same as for storing bales of hay: moisture causes damage and loss of dry matter. Uniformly dry material needs to be put into storage to reduce these risks and the likelihood of fire. It is best to store material under a roof or with a perforated tarp that limits condensation of moisture on the underside of the cover, particularly for large square bales. If this is not possible, bales can be stored outside, preferably on well-drained gravel to prevent contact with soil, and well spaced to allow adequate air movement among bales for drying following rain. Chopped switchgrass is also best preserved if under cover, but the material will stay remarkably well preserved if stored in a pile that is exposed to the weather. If such piles are compressed (by riding on them with a tractor) and care is taken to ensure the sides of the pile are smooth and relatively steep, the surface particles can form a thatch that sheds moisture. Cotton-module builders represent another handling option currently being considered for chopped feedstock. Chopped biomass can also be pelletized or cubed, but the spongy nature of grasses compared to material like alfalfa can make them more difficult to process, depending on equipment. In such cases, adding a "binder" might be effective.

The efficient transportation of biomass will depend on the hauling distance and the local road regulations. For longer-distance hauling, high-density 3×4×8 bales will provide the greatest load. For example using a 53-ft single-drop deck trailer, fifty bales can be transported. Using normal-density switchgrass bales, this results in a 22- to 24-ton load. Bulk density of switchgrass chopped to a particle size of half an inch is 8 to 9 lb/ft^3. This results in a load of 12 to 13.5 tons on a 42-ft walking floor trailer. Some newer forage harvesters are successfully achieving finer chops from the field, resulting in loads of up to 20 tons.

Cellulosic Bioenergy Systems

Wide adoption of biomass to produce energy will depend largely on developing economically competitive supply and conversion systems. Cellulosic energy crops will need to compete with traditional crops for land on farms and with other forms of biomass that can be used for the desired conversion process, such as woody biomass and crop residues like corn stover and wheat straw. Another economic hurdle for some perennial energy crops can be relatively low biomass yields in the seeding and second years. On the product end, cellulosic biofuel systems need to be competitive with other biofuels, such as ethanol from corn, and with competing fossil-fuel products including gasoline, diesel, heating oil, propane, natural gas and coal.

Because many traditional crops enjoy government price-support programs, it may be difficult for energy crops to compete for farmland without such incentives. One way to mitigate this disadvantage would be to provide bridging payments in the first two years following seeding. Alternatively, Conservation Reserve Program (CRP) land could be used to grow and harvest biomass crops for energy without growers forfeiting CRP payments, but this latter option will require cultural-management strategies that are compatible with concerns from the environmental and wildlife advocacy communities. Recently approved legislation that should facilitate use of biomass for energy in the United States is the Energy Independence and Security Act of 2007, which mandates at least 44% of alternative fuels be produced from cellulosic feedstocks by 2022. In addition, carbon credit markets are developing, and because perennial energy crops are effective in sequestering carbon, these should also facilitate commercial production.

At current input costs, the delivered price of switchgrass is between \$50 and \$60 per dry ton over a fairly wide range of conditions. If a \$10/ton profit for the grower is added, this would amount to an average delivered price to the processing plant of \$60–70/ton. Areas with low land rents will likely be in the lower end of this range and areas with higher land rents could be well above it. Successful projects will need to evolve in areas where energy crops can compete with alternative feedstocks. In some areas, woody biomass and crop residues are currently available at considerably lower prices than this.

Assuming an energy content of 16 million Btu/dry ton of switchgrass, a delivered price of \$65/ton amounts to a cost of \$4.06/million Btu. In comparison, oil (which contains 5.8 million Btu/barrel) at a price of \$90/barrel amounts to an energy cost of \$15.5/million Btu. Therefore, on a cost/million Btu basis, switchgrass is extremely competitive with oil as a raw material, and this could partially explain the rapidly increasing interest in cellulosic biofuels among oil companies. However, technology that can convert biomass to liquid fuel as efficiently as for oil has still not been developed. The current cost of natural gas is between \$5 and \$6/million Btu with higher prices in the peak winter heating period of January through March, and that of coal is mostly between \$2 and \$3/million Btu. The low price of coal explains why utilities are reluctant to co-fire switchgrass with it without significant government incentives or premium prices for the "green power" produced.

As energy cropping matures as an agricultural enterprise, new machinery for harvesting and processing biomass will likely be developed; but in the near term, it is likely that there would be an advantage to using existing forage-handling equipment. Bransby *et al.* (2005) developed an interactive budget model to evaluate four systems that could be used immediately in the southeastern United States:

- traditional mowing and round baling, then hauling bales to the plant where they are ground prior to processing,
- field chopping following mowing, and transporting chopped material to the processing plant in a walking floor trailer,
- field chopping and creating a compacted module with a cotton module builder, thereafter transporting the modules to the processing plant in a cotton module truck, and
- field chopping followed by pelletizing and transporting pellets to the plant.

The model was then used to examine the effect of switchgrass yield, transport distance, truck capacity, and stand life on delivered cost of biomass to the plant using each of the four systems.

The results indicated that field chopping and hauling chopped material in a walking-floor trailer or after it had been compacted with a cotton-module builder resulted in lower delivered cost to a large bioenergy conversion facility than round baling or pelletizing. The high cost of baling was related to more individual operations needed in the baling option, whereas the high cost of the pelletizing system resulted from producing the pellets. As suggested above, chopped switchgrass can be stored in piles that tend to thatch and shed water, resulting in relatively low losses. Switchgrass yield and hauling distance to the plant had greater impacts on delivered cost than stand life and truck capacity. Delivered cost decreased as yield increased, but this effect was not linear, and the response was relatively small above 8 tons/acre. In contrast, delivered cost increased linearly with distance from the processing plant. Delivered cost decreased as truck capacity and stand life increased, but effects were relatively small above a truck capacity of 20 tons and a stand life of 10 years. Breakeven yield was about 4.5 tons/acre.

Development of a viable commercial enterprise that uses biomass as a feedstock to produce energy requires consideration of a wide range of issues. These include the amount of biomass and land area needed, average hauling distance and business structure. The challenges related to developing a feedstock supply system are often underestimated, so a specific example of how these issues might be addressed should be useful. The capacity of most corn-ethanol plants ranges from 50 to 100 million gal/yr. If a 50-million-gal/yr capacity and an efficiency of 80 gal/ton are assumed for a cellulosic processing facility, the plant would need 625,000 tons of biomass per year. For 350 days of operation each year, this would amount to 1,786 tons (or eighty-nine truck loads of 20 tons each) per day. At a crop yield of 5 tons/acre, 125,000 acres would be needed, and if a 10-day supply of biomass is needed on site at the conversion plant, storage space is required for 17,860 tons. Assuming the plant is in the center of a circular production area, and assuming the average hauling distance is 20% farther than a direct line from the grower to the plant (to account for curvature of roads) average hauling distance would be 29.9, 21.2, and 15.0 miles if 5, 10, or 20% of the land surrounding the plant was established to the biomass crop.

Finally, the issue of energy balance (energy output as a proportion of energy inputs) is often raised in relation to production of biofuels. For corn to ethanol, this statistic is about 1.3 and, surprisingly, for gasoline produced from oil it is negative: 0.81. In contrast, a recent study from the Great Plains (Schmer *et al.*, 2008) indicated that, for ethanol produced from switchgrass, this figure is 5.4, or alternatively, that 440% more energy was contained in the ethanol produced, than was used in growing the switchgrass and converting it to liquid fuel. Because the emerging bioenergy industry is at a very early stage, it is likely that this figure can be improved substantially by improving crop yields and conversion technology.

THE FUTURE

Development of the bioenergy industry offers multiple benefits, including reduced risk of global climate change through reduced production of greenhouse gases, increased national security, and improved national and local economies. Grasses in particular, but possibly legumes as well, will play a vital role as feedstocks for this emerging industry. Production of heat and electricity from biomass is already commercial on a relatively small scale. Commercial cellulosic biofuel plants can be expected to be in production within the next 3 to 5 years, and initial expansion of the industry will begin in 5 to 10 years. On a per-unit-energy basis, the cost of biomass from cellulosic energy crops is higher than for wood and coal, but only 26% of that for crude oil at $90/barrel. Therefore, wood is likely to be the most favored feedstocks for the first plants. Commercialization of cellulosic energy crops for production of energy will require development and optimization of not only agronomic practices, but also harvesting, storage, transport and conversion systems. Procedures and equipment used for these purposes in commercial forage production can be adapted for this purpose, including baling, field-chopping and pelletizing. Due to economic growth in countries like China and India, the price of oil will probably continue to rise and this will ultimately lead to competition between food and energy crops for limited land resources: an issue that will need to be anticipated well in advance, and properly managed to avoid a crisis.

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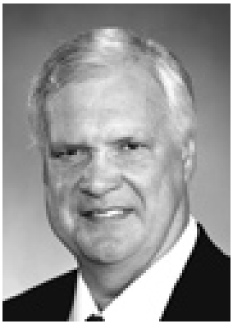

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In September of 2006, Dr. Bransby briefed Governor Riley of Alabama and President Bush on the status of the emerging biofuels industry. In February 2007, he was invited to the White House to advise President Bush, Secretary of Energy Samuel Bodman and senior White House officials on the feasibility of large-scale cellulosic biofuel production in the United States over the next 10 years.

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