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Plants MATTER

Multinational energy corporations and the academic community are taking biofuels and biorefining seriously

By Nick Sutcliffe and Alan Mencin
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If you heat wood to approximately 500 degrees Celsius in the absence of oxygen you get pyrolysis oil—a flammable liquid that can be used to make liquid fuels or a variety of chemicals. If you heat wood to greater than 700 degrees and include a small amount of oxygen and steam, you get synthesis gas, or syngas, which, among other things, will run a combustion engine, generate electricity, or yield a variety of liquid fuels. All this from wood—or switchgrass, or straw, or just about any dried cellulosic biomass.

While the promise of these and other renewable energy technologies is great, much of the science is poorly understood and technologies for industrial-scale production are immature. To help advance understanding, Colorado School of Mines has entered into a partnership with three Front Range research institutions and several private corporations to form the Colorado Center for Biorefining and Biofuels, known by the acronym C2B2. The collaboration includes the University of Colorado at Boulder (CU); Colorado State University (CSU); the National Renewable Energy Laboratory (NREL); Mines; and more than 10 private corporations including Chevron, ConocoPhillips, Dow Chemical and Shell Global Solutions.

To explore how much energy America could generate from domestically produced biomass, the U.S. Department of Energy and the Department of Agriculture completed a joint research project in 2005 known as the "Billion Ton Study." Their conclusions were that the U.S. could sustainably provide sufficient biomass for one-third of its transportation fuel needs without undermining current food crop production. And these conclusions assumed the use of current conversion technologies and only small changes to agricultural and forestry practices.

While the potential is evident on paper, if the U.S. is going to get anywhere near such a lofty goal, the science must be better understood and complex new systems engineered. Therein lies the mission of C2B2, which is the first major initiative of the recently established Colorado Renewable Energy Collaboratory created in February 2007.

Materials from Biomass

While energy from biomass is the main focus of C2B2, materials shouldn’t be ignored. John Dorgan, professor of chemical engineering, points out that bioengineering and biorefining can yield many of the materials traditionally produced from petroleum. Illustrating the point, he explains how switchgrass can be genetically modified to synthesize and store polyester. When harvested, cellulose from the plant can be used as feedstock for ethanol production and the polymer extracted to provide a valuable co-product.

Chemical Engineering Professor John Dorgan, who is the C2B2 site director for the Mines campus, points out there are three primary pathways for converting biomass into electrical power or useable fuels: biochemical, chemical and thermochemical.

The biochemical platform, currently the most widespread, involves breaking biomass down into simple sugars that can be fermented into ethanol. An example of chemical conversion is converting plant oils into biodiesel. This process typically involves growing crops rich in triglycerides (such as soybeans), extracting their oils and chemically converting them into liquid fuel. There are also a variety of thermochemical conversion methods, most of which involve heating biomass to produce either syngas or pyrolysis oil.

Biochemical Conversion

By far the most popular biofuel in the U.S. is ethanol, and production has skyrocketed in recent years. The U.S. produced in excess of 5 billion gallons during 2007, up from 3.7 billion gallons in 2005. And almost all of this was produced using corn as the primary feedstock. The starch in corn is a relatively simple carbohydrate, easily broken down (hydrolyzed) into glucose. Put into solution, it is then biochemically converted to ethanol by microbes commonly referred to as yeast, which ultimately poison themselves when they elevate ethanol concentrations to around 11-14 percent. Industrial ethanol is then derived by simply distilling this “beer.”

Although this approach is successfully yielding large quantities of ethanol, it is expensive and the industry is propped up by a 51-cents-per-gallon subsidy. The use of corn grain as the feedstock inflates the price of conversion considerably, and switching to a production process that utilizes cellulosic feedstocks (for example, wood, grasses and corn stover) is viewed as the key to lower costs. In addition, by using non-edible cellulose (for example the corn stalk) industrial ethanol production would put less inflationary pressure on food supplies.

Cellulose, probably the most abundant organic compound on Earth, is a complex polysaccharide composed entirely of glucose. However, unlike starch, it is hard to break down. A triumph of evolutionary design, it is the biological equivalent of armor plate and has become the fundamental building block of the plant kingdom. In their search for a chink in the armor that would allow cellulose to be easily and inexpensively hydrolyzed into simple sugars, researchers have explored the use of heat, sulphuric acid and a family of enzymes called cellulases. The combination of heat and sulphuric acid is effective, but energy intensive. Cellulases—enzymes found in a variety of organisms that break cellulose down into simple sugars—are expensive and industrial scale use is impractical at present. However, they are being intensively studied by C2B2 researchers and may one day offer an efficient pathway for converting cellulose into a sustainable fuel source.

Chemical Conversion

Ethanol is only one of several biofuels the energy industry is taking seriously—another is biodiesel. Made from vegetable oil, this organic liquid fuel can be manufactured at room temperature using a rather simple chemical conversion process. In the presence of a catalyst and an alcohol, the triglyceride (fat) molecule is converted into fatty acid esters and the byproduct, glycerin.

Once the glycerin has been removed, the resulting fatty acid esters provide an adequate substitute for petroleum-based diesel in almost every application. The drawback is cost: vegetable oil production is expensive and the industry’s growth is currently supported with subsidies ranging from 50 cents to one dollar per gallon. A potentially promising alternative is oil from algae, which can be produced much more intensively than traditional crops. While soybeans typically yield about 48 gallons of oil per acre annually, algae grown in carefully monitored shallow, open ponds or clear plastic tubes have the longer term potential of producing yields upwards of 10,000 gallons of oil per acre. The process is capital intensive and requires large quantities of water and nutrients, but its potential has captured the interest of capital investment markets and the energy industry.

A synthetic diesel fuel can also be made by introducing heated animal or vegetable oils into a hydrogen-rich environment in the presence of a catalyst. Called renewable or “green” diesel, it is nearly indistinguishable from the petroleum-based product and is the focus of a recently announced joint venture between ConocoPhillips and Tyson Foods.

Thermochemical Conversion

Turning biomass into useable fuel via thermochemical conversion processes can involve a variety of different paths, all of which involve heating biomass in either low- or no-oxygen environments.

When cellulosic biomass is heated in the absence of oxygen (a process known as fast pyrolysis), the main product is bio-oil, which can be burned as a substitute for petroleum-based fuel oil in boilers. When cellulosic biomass is heated with a limited amount of oxygen and steam (a process known as gasification), the main product is synthesis gas, or syngas. Among other uses, this flammable combination of carbon monoxide and hydrogen can be burned in a turbine, fed into a solid oxide fuel cell to produce electricity, or converted into a variety of liquid fuels.

Before these processes can be applied on a commercial scale, however, numerous problems must be solved and the chemistry better understood. Syngas made from biomass contains ash and tars, which can damage turbines and degrade catalysts in fuel cells. Understanding how to engineer solid oxide fuel cells that tolerate supply-streams of un-scrubbed syngas is a research focus of William Coors Chaired Professor of Chemical Engineering, Tony Dean. Understanding how to deliver a clean supply-stream of biomass-produced syngas has researchers busy around the world, including Mines Professor of Chemical Engineering, Andy Herring.

The C2B2 Partnership

C2B2 brings together four diverse research institutions that encompass the full spectrum of biofuel- and biorefining-relevant expertise: CSU has world-class capabilities in the agricultural sciences, as well as the internationally recognized Engines and Energy Conversions Laboratory; CU-Boulder is well known for its expertise in biological and chemical engineering, molecular and cellular biology, and biochemistry; NREL has highly specialized laboratory facilities and decades of experience researching biomass energy conversion technologies; and Mines brings a wealth of knowledge in refining, chemical engineering, materials engineering and fuel cell technologies.

The goal of C2B2 is to develop new technologies and advance them into the private sector as quickly as possible. Companies participate in C2B2 with payment of a membership fee that funds shared research initiatives. In so doing, they gain access to this rich pool of expertise, as well as the research and development resources of sponsoring industrial partners.

The C2B2 partnership has received strong political support at the state level. The formation of the Renewable Energy Collaboratory can be traced back to the 2006 Renewable Energy Summit sponsored by Senator Ken Salazar’s office. His staff have remained actively involved by facilitating negotiations and helping to frame the final C2B2 agreement. After campaigning on a strong renewable energy platform, Governor Bill Ritter has embraced C2B2. And on the Mines campus, President Bill Scoggins is enthusiastic, seeing it as “substantive and timely progress toward finding solutions to [our energy] challenges.” On the front lines of C2B2 research, Dean is particularly upbeat about the School’s role: “We are a key player on a big-league team. We’ve got a lot to offer and we have a lot to gain in terms of sharing knowledge and sharing facilities. Having NREL so close is a major advantage.”

With the partnership just begining, it’s impossible to predict where C2B2 will lead, but with four multinational corporations on board, exceptional research capacity at hand and worldwide interest in biofuels at an all-time high, the future looks bright.

Believing in Bioplastic

Birgit Braun (left), a member of John Dorgan’s research group, won the 2007 Arthur B. Sacks Award for Excellence in Sustainability.

“The main inspirations for me during my graduate work were the challenges humanity is facing in the near-to-medium-term future; namely, meeting energy demands for a growing worldwide population in a sustainable fashion while working towards a more environmentally friendly society without sacrificing our living standards,” said Braun, who successfully defended her Ph.D. thesis in November 2007.

Plastics play an important role in the energy balance, and the bioplastic research conducted by Braun and other researchers in this field will eventually lead to a decrease in the amount of petroleum-based plastics.

Braun’s research is focused on a bioplastic called polylactide (PLA). PLA is a polyester derived from renewable resources that is economically competitive and can be used for packaging and single-use applications. Given that the packaging sector accounts for approximately one-third of the total plastics market, this is an important area of research.