Detoxing Our

MAES chemical engineering scientist Bruce Dale has been studying how to convert cellulose into ethanol for 30 years. As petroleum prices rise and concerns flare over dependence on imported oil, biofuels may be the antidote to the country's incessant craving for crude oil.

Oil Addiction

Bruce Dale believes that the time has never been more right for biofuel refining to come into its own. "I want to help design the processes so they're environmentally sound," he says.

"The United States has a serious problem."

Bruce Dale, MAES chemical engineering and materials science researcher and associate director of the MSU Office of Bio-based Technologies, is speaking calmly but strongly, and the standing-room-only crowd that has spilled out into the hallway at the 2006 BIO International Convention is hanging on every word. Dale cites the statistics: "In the words of President Bush, we're 'addicted to oil.' Our national and state economies are absolutely dependent on liquid fuels. The United States currently uses more than 140 billion gallons of gasoline and almost 40 billion gallons of diesel fuel annually. More than 60 percent of the petroleum we use is imported, and the percentage is rising."

There's more to the bioeconomy than fuels. But the promise and potential of biofuels for the economy and the environment have captured the attention of politicians, the public and the media like no other bioproduct.

"We really can't do without liquid fuels," said Dale, who has spent his entire career studying ways to turn plant leaves and stems — biomass — into ethanol. He also leads the MSU Biomass Conversion Research Lab at MSU. "Liquid fuels underpin our economy."

Aside from sustaining the country's transportation needs, liquid fuels are the basis of the food supply and the manufacturing, processing and recreation industries. Everything we touch depends on liquid fuels in some way — whether it's getting us to the store to buy it or allowing it to be grown, made or operated.

Compared with petroleum, biomass raw materials are inexpensive. Much of the raw materials are now considered waste — stems and stalks left over after plants are harvested. But the processing costs for turning plant materials into ethanol, biodiesel and other biochemicals traditionally have been much higher than the costs for turning crude oil into gasoline and diesel fuel. This has been a longstanding roadblock for widespread acceptance of biofuels. When gasoline was cheap and plentiful, not many people wanted to pay more for ethanol, despite its many environmental benefits. But as the cost of crude oil jumped and hurricanes Rita and Katrina caused gasoline shortages and spiking prices, ethanol began to look more and more attractive.

"At $20 per barrel, oil is still cheaper to refine than biofuels are," Dale explained. "But when oil costs $40 a barrel, biofuels are very competitive."

Now that oil prices are hovering around $60 per barrel, Dale believes the time has never been more right for biofuel refining to come into its own.

"I strongly believe that bio-based fuels and chemicals will become a reality," he said. "I want to help design the processes so they're environmentally sound."

If the interest in Dale's presentation at BIO 2006 — or interest in the whole of BIO 2006 — is any indication, his prediction may come true sooner rather than later. The annual international convention and exhibition is sponsored by the Biotechnology Industry Organization and is the largest biotechnology event in the world. Countries, universities, private companies, entrepreneurs, venture capitalists and others attend to learn about new technology, business development, and licensing and partnership opportunities.

"Former President Bill Clinton spoke at BIO 2006," said Steven Pueppke, director of both the Michigan Agricultural Experiment Station and the Office of Bio-based Technologies, who also attended the conference. "He noted how one of the primary challenges of this current century will be to reduce our dependence on fossil fuels and grow our own. That's why all of us were at BIO 2006 — to talk to one another, to figure out where we are and where we need to go, and to kick the effort into high gear."

Breaking Down Cellulose More Efficiently

Much of Dale's research focuses on technology to convert biomass from plant materials into ethanol.

Plants are a huge potential source of energy — each year plant biomass captures an amount of energy equivalent to about eight times the total energy used by people from oil, coal, natural gas, wind, water, etc. But about 90 percent of this biomass energy is unavailable for use because it's in the form of cellulose and hemicellulose, the complex sugars that make plant stems and leaves and tree trunks rigid. Cellulose and hemicellulose don't dissolve in water. This is good for plants but not so good for making biofuels. Before the complex sugars can be fermented into ethanol, they have to be broken down into simple sugars, such as glucose, by enzymes. Microorganisms are then used to ferment the glucose into ethanol.

Breaking down cellulose and hemicellulose into fermentable sugars cost effectively has been the main issue slowing ethanol production. It's difficult to do efficiently and can significantly raise production costs, and that makes ethanol more expensive to refine than gasoline.

Dale has developed a process, ammonia fiber expansion (AFEX), to pretreat biomass with ammonia. The AFEX process, for which MSU has received a patent, makes the breakdown of cellulose and hemicellulose more efficient. Using enzymes alone, about 15 percent of cellulose and hemicellulose are broken down into simple sugars; when AFEX is used before adding the enzymes, more than 90 percent of the cellulose and hemicellulose are broken down into fermentable sugars. After treatment, the plant material comes out looking a bit like popcorn — slightly puffed up and dry.

In July 2006, Dale received a $790,000 Strategic Partnership Grant from the MSU Foundation. This research will refine and enhance the AFEX process, integrating it with both commercially available enzymes and new enzymes being developed on campus. The sugars produced will be fermented into ethanol using microorganisms developed by top research groups. In September 2006, U.S. Rep. Mike Rogers, who has made several visits to Dale's campus lab, announced that MSU was to receive almost $400,000 from the Biomass Research and Development Initiative, a joint project of the U.S. departments of Agriculture and Energy. This grant money will be used to better understand and improve the environmental performance of ethanol and other biofuels.

"The ultimate success of biofuels will be determined largely by the ability to manipulate plants at the genetic, seed and field level. MSU is the premier place for this work to be done." —Bruce Dale

Dale firmly believes in ethanol as an alternative to gasoline — as opposed to hydrogen fuel cells or solar-powered cars — because of both its quality and its form.

"The quality of the energy is important," he said. "Ethanol is a good quality fuel. We have about $10 trillion invested in the infrastructure for liquid fuels, so that's what we have to work with — we're not going to change that infrastructure anytime soon. Any fuel alternatives are going to have to be in liquid form."

The Supply Chain of Biomass

Most experts agree that ethanol isn't a niche fuel anymore. The 2005 Energy Act made ethanol a permanent part of the country's fuel mixture, and production is expected to rise from a current 4 billion gallons per year to about 7.5 billion gallons per year by 2012, according to Dale. Most of this will be made from corn grain.

"But construction of new ethanol plants is moving so quickly that we'll achieve the 7.5 billion gallon target much earlier than 2012," Dale said. "The Energy Act of 2005 also mandated that 250 million gallons of ethanol be produced from cellulose materials by 2012."

Ethanol continues to raise some questions, however. Some critics contend that corn grain, the primary crop currently used to make ethanol, needs more fertilizers and pesticides than other crops that could potentially be used. But because the corn lobby is so strong, the critics say, other crops aren't being studied as intensively as raw materials for ethanol. There are also concerns about potential air pollution coming out of ethanol refineries.

According to statistics from Dale, about 400 gallons of ethanol can be produced from an acre of corn grain. The technology for making ethanol from switchgrass isn't well developed yet, but he estimates that improvements will allow about 1,000 gallons to be made from an acre of switchgrass, more than doubling production from corn grain.

"Increasing interest in ethanol will encourage the United States to grow more perennial grasses, such as switchgrass," Dale said. “Grasses are a good source of protein for animals and can also provide more ethanol per acre than corn.

“That’s why I believe MSU is the premier place for this work to be done,” he continued. “We have one of the top three plant science programs in the world. MSU is the foremost university worldwide in the field of plant metabolism and biochemistry. The ultimate success of biofuels will be determined largely by the ability to manipulate plants at the genetic, seed and field levels. MSU researchers such as Christoph Benning, John Ohlrogge, Dean Della Penna, Yair Shachar-Hill and Ken Keegstra are manipulating non-food plants — woody plants and grasses — so the conversion process from biomass to biofuel is more efficient. This research is going to fundamentally change biofuel production.”

Coupled with Dale’s work on pretreating biomass, all this MSU research on making cellulosic ethanol — ethanol from cellulose and hemicellulose from grasses, wood and other biodegradable material rather than grain — holds much promise. Bill Knudson, product marketing economist in the MSU Product Center for Agriculture and Natural Resources, said cellulosic ethanol would unhitch ethanol production from corn-producing areas and allow biorefineries to exist in a variety of areas.

“The potential with cellulosic ethanol is enormous,” Knudson said.

Cellulosic ethanol also may be better than corn-based ethanol for the environment. An article in the January 2006 issue of *Science* reports that production and use of cellulosic ethanol gives off about 90 percent less greenhouse gases than gasoline. The authors report that corn-based ethanol results in about 13 percent lower emissions than gasoline.

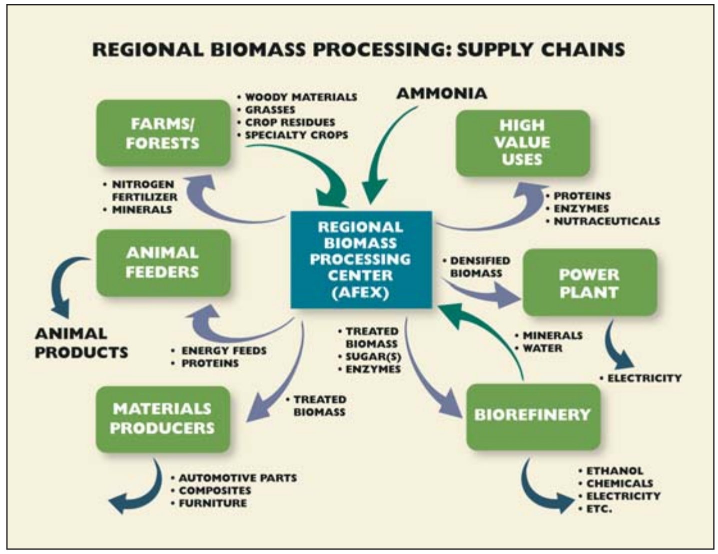
Creating Biorefineries

As new technologies are developed, the logistics of ethanol become more complex. Dale and other experts agree that when crude oil prices are $40 per barrel and higher, the cost of ethanol becomes very competitive for consumers. But a gallon of ethanol provides only about 75 percent of the mileage that a gallon of gasoline does in current engines. Satish Udpa, dean of the MSU College of Engineering, said that MSU engineering researchers are developing new engine technology that will reduce or eliminate this discrepancy. So exactly how much ethanol does the United States need to refine to meet current fuel needs? And do we have the land available to grow all this biomass?

“Those seem like simple questions, but the answers aren’t simple,” Dale explained. “The United States uses about 140 billion gallons of gasoline each year and about 40 billion gallons of diesel. If we had 140 billion gallons of ethanol at some time in the future, we could probably replace all of our gasoline because we’d be building cars with engines designed for ethanol. If we did it today, with current engine technology, we would need about 200 billion gallons of ethanol to replace all our gasoline.”

If only corn were used to make ethanol, this would translate into 460 million acres of the crop at 160 bushels per acre.

“That’s more than all of the cropland in the United States,” Dale said.



Bruce Dale’s concept of a regional biomass processing center supply chain shows how renewable materials such as crops, grasses and woody plant material will be turned into a range of products, from fuels to electricity, enzymes, composites and furniture, some of which will be used to power the processing center.

One ton of switchgrass produces about 70 gallons of ethanol, and researchers are aiming for an ultimate target of 100 gallons per ton. Right now, an annual yield of 5 tons of biomass per acre of switchgrass is the production standard. In the near future, Dale believes that it would be possible to produce 15 tons of biomass per acre of switchgrass. This is a significant increase that would mean about 130 million acres would be needed.

The supply chain particulars of providing biomass for ethanol production are as important to the biofuel’s future as the technology to refine it. To couple the two, Dale has developed a supply chain for biomass.

The hub of the operation, a regional biomass processing center, would contract with approximately 100 farmers to use the AFEX process to pretreat locally grown grass or residue for animal feed.

“The same physical and chemical barriers that slow down bioconversion of cellulose to sugars in a biorefinery also interfere with bioconversion in ruminant animals, such as cattle, and these barriers are broken down by AFEX,” Dale explained. “Preparing animal feed at a regional center will create the supply chain, logistics and economies of scale required to supply pretreated, densified biomass to a biorefinery, and perhaps higher value products and solid materials for other uses. Densified biomass might also be provided to an electric power plant for direct burning.”

The biorefinery would process about 5,000 tons of cellulosic biomass per day supplied by more than 1,000 farmers, Dale said. This would require about 500 farmers each growing 500 acres of switchgrass.

“The designs we’re developing assume that the scales are small enough so farmers can invest in them, just like a corn dry mill or cooperative,” Dale said. “This would be an economic boost for the farmers as well as the state. They wouldn’t just be the raw material providers — they would be part of the value-added process and would capture more of the economic benefits.”

::: Jamie DePolo