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Industrial Biotechnology is Revolutionizing the Production of Ethanol Transportation Fuel:

The President's Advanced Energy Initiative Announced in the State of the Union Calls for Rapid Development of Cellulosic Ethanol; Biotechnology Will Play a Key Role

In his Jan. 31, 2006, State of the Union Address, President Bush announced the Advanced Energy Initiative. Stating "America is addicted to oil, which is often imported from unstable parts of the world," the President proposed a 22 percent increase in clean-energy research at the Department of Energy, including funding for research in cellulosic ethanol. The President continued:

> "We must also change how we power our automobiles. We will increase our research in better batteries for hybrid and electric cars, and in pollution-free cars that run on hydrogen. We'll also fund additional research in cutting-edge methods of producing ethanol, not just from corn, but from wood chips and stalks, or switch grass. Our goal is to make this new kind of ethanol practical and competitive within six years.
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> "Breakthroughs on this and other new technologies will help us reach another great goal: to replace more than 75 percent of our oil imports from the Middle East by 2025. By applying the talent and technology of America, this country can dramatically improve our environment, move beyond a

> petroleum-based economy, and make our dependence on Middle Eastern oil a thing of the past."

Jim Greenwood, president and CEO of the Biotechnology Industry Organization (BIO), applauded the President for the initiatives outlined in his State of the Union Address:

> "The Advanced Energy Initiative will increase America's competitiveness by providing clean, affordable energy sources that will enable us to lessen our dependence on foreign oil through biotechnology. Using crop wastes, we can produce tens of billions of gallons of ethanol. We could produce 25 percent of our transportation fuel need by 2015 if we dramatically ramp up biorefinery development."

The President continued to advance his energy initiative at a Feb. 2 visit to 3M in Maplewood, Minn., saying:

> "I'm excited about ethanol. Now, we've been making ethanol out of corn, mainly. But now we got a chance, with breakthroughs in research and development, new technologies to make ethanol out of switch grass or wood products or weeds. And we're close. And I said the other night in the State of the Union, within six years, this kind of fuel ought to be competitive with gasoline.
>
> Now, people say, that's fine, how about the automobiles? Well, I had an interesting experience. I went down to Brazil and I saw President Lula down there. I don't know if you know this, but the vast majority of fuel to fuel the cars in Brazil is made from sugar. And guess who makes the cars that run on sugar? General Motors. So the technology is available for flex-fuel automobiles. As a matter of fact, I am told there's over four million flex-fuel automobiles operating in the United States today. And so the hope is, and the belief is, is that, with a breakthrough with these cellulosic technologies -- big word for a history major -- (laughter and applause) -- I don't want to try to spell it. (Laughter.) The car industry has got the capacity to manufacture automobiles that can burn that stuff.

What Is Cellulosic Ethanol?

Cellulosic ethanol is fuel ethanol made from cellulosic biomass – plant matter composed primarily of inedible cellulose fibers that form the stems and branches of most plants. Crop residues (such as corn stalks, wheat straw and rice straw), wood waste, and even municipal solid waste are potential sources of cellulosic biomass. High-biomass dedicated energy crops, such as switchgrass, are also promising cellulose sources that can be sustainably produced in many regions of the U.S.

Cellulosic biomass is a highly undervalued and underutilized energy asset in the United States and around the world. Many forms of cellulosic biomass can contribute to energy solutions, including grain crops and switch grass, or crop residues like corn stalks, wheat straw, rice straw, grass clippings, and wood residues. These cellulose-containing natural waste products are widely abundant and can be sustainably produced: indeed, cellulose has been estimated to make up half of all the organic carbon on the planet. A recent analysis by the Natural Resources Defense Council found that cellulosic ethanol could supply half of U.S. transportation fuel needs by 2050, without decreasing production of food and animal feed.

Currently, ethanol is made primarily from the sugar that makes up the starch in grain. Corn is the chief source of starch for ethanol production in the United States. The sugar is fermented with yeast, just as in making beer or distilled spirits. Overseas, countries such as Brazil, India and Malaysia use other dedicated crops as feedstocks, including sugarcane and palm oil.

Cellulosic biomass has been a challenge for scientists to convert to ethanol. In the past, scientists have used harsh acids and high temperatures to try and break the cellulose matrix into its individual sugar components. However, an economical process has never been developed using traditional chemistry.

Recently advances in the relatively new field of industrial biotechnology – using techniques in genomics, proteomics, and bioinformatics – are making it possible to convert cellulosic biomass to fermentable sugars that can be used as feedstocks for a new type of “carbohydrate crude oil.” This technology breakthrough is creating a paradigm shift in the way we make transportation fuel because enzymes can economically convert plant matter to fermentable sugars.

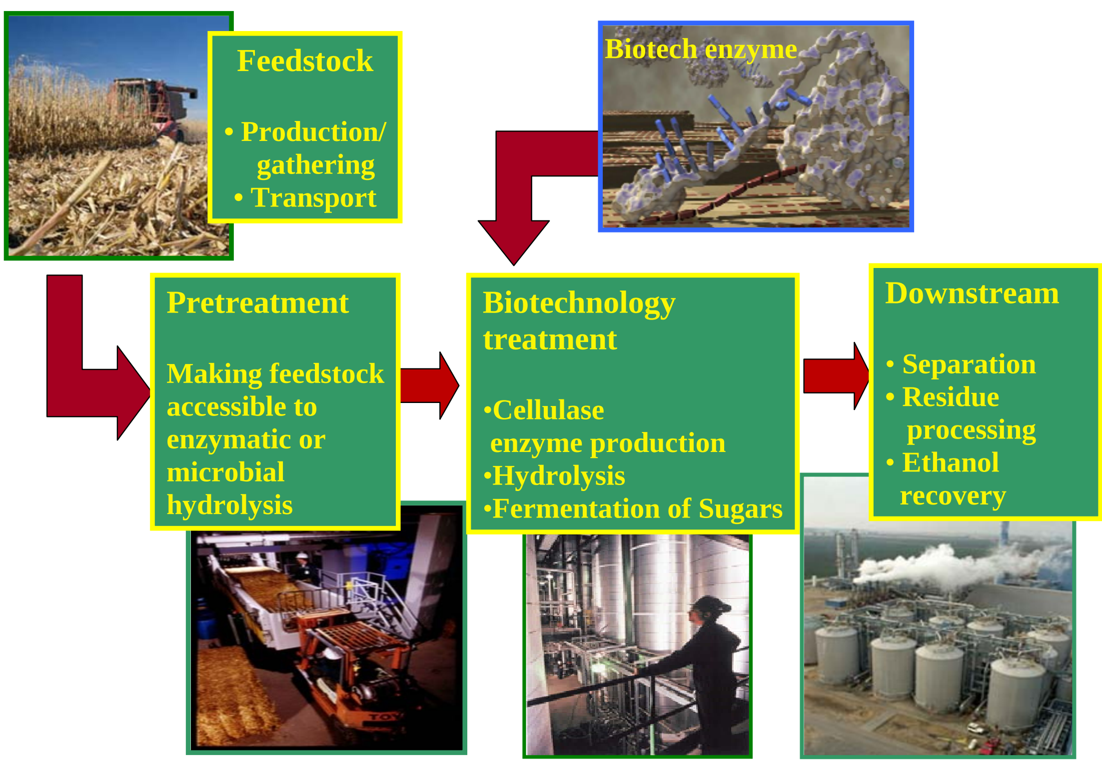
Enzymes that break down cellulose are called cellulases and are found in nature in fungi as well as in microbes that are in the guts of termites. Biotech tools are necessary to identify or produce the most efficient cellulases on a scale useful for ethanol production.

Cellulosic ethanol can substitute for petroleum in many manufacturing processes – such as plastics – and could contribute in a major way to reducing America's "addiction to oil," while at the same time helping to address the climate change issue, by reducing our need to burn fossil fuels.

What Is Industrial Biotechnology and How Is It Enabling Ethanol Production?

Industrial biotechnology companies develop biocatalysts, such as enzymes, to be used in industrial manufacturing involving chemical synthesis. Enzymes are proteins that are present in all living organisms. Enzymes trigger or speed up chemical processes that would otherwise run very slowly, but they are not consumed in the process of changing other molecules. They are unique due to their catalytic activity and their ability to break down compounds such as cellulose. As catalysts, they can also put broken protein fragments back together.

The Path to Ethanol from Cellulose



Over the past 35 years scientists have learned how to convert these biological systems and enzymes into very useful industrial tools that replace less efficient and possibly toxic chemical processes. Natural enzyme-based processes operate at lower temperatures; produce less toxic waste and fewer emissions than conventional chemical processes. They may also use less purified raw materials because they have precise chemical selectivity.

Industrial biotech companies conduct genomic studies on microbes to capitalize on the wealth of genetic diversity in microbial populations. Researchers then use DNA probes to look for genes that express enzymes with specific biocatalytic capabilities. Once snared, enzymes can be identified and characterized for their ability to function in specific industrial processes and, if necessary, they can be improved with advanced biotechnology techniques. This is exactly what scientists have been doing to improve enzymes for ethanol production.

Once the needed enzyme is discovered and improved, it may be produced in commercial quantities using fermentation or systems similar to those that produce human therapeutic proteins or bulk yeast for the brewing industry.

To improve the productivity of enzymes, scientists are using not only genomics, but also proteomics and bioinformatics to increase enzyme output rates. Biotechnology enables scientists to maximize the effectiveness and efficiency of enzymes and to custom tailor the specificity of enzymes, improve catalytic properties or broaden the conditions under which enzymes can function so that they are more compatible with existing industrial processes.

Using enzymes in industrial processes has several benefits. Use of enzymes can reduce the amount of harsh chemicals in industrial processes that contaminate the environment. In addition to creating cleaner process outputs, enzymes help conserve energy and raw materials by reducing the amount of inputs in industrial processes. These enzymes are the key to ensuring that older industrial manufacturing processes evolve into cleaner, more sustainable industrial ones.

Biotech companies are producing improved enzymes for converting starch to ethanol production and have been perfecting enzymes for cellulosic ethanol production. Modern biorefineries will be constructed in Idaho, by Iogen, the

Midwest, by Cargill, and overseas. These refineries will that take cellulosic biomass, convert the cellulose to sugars, and then fermented the sugar into ethanol. See figure below.

Biotech Breakthroughs and Promising Developments in the Production of Cellulosic Ethanol

Dramatic Cost Reductions
In 2001, the cost of cellulase enzymes to convert cellulose to sugars was the greatest technical barrier to cost-effective production of cellulosic ethanol. Enzyme producers Genencor International and Novozymes A/S partnered with the U.S. Department of Energy to increase enzyme activity and reduce the cost of production. Both have achieved dramatic results.

Novozymes identified a range of new enzymes, and enhanced their activity to dramatically boost sugar yields, reducing the cost of enzymes for making ethanol from corn stover 30-fold from $5 per gallon in 2001 to a mere 10¢ to 18¢ in 2005. Genencor also achieved a 30-fold reduction in cost by developing a team of genetically enhanced enzymes that act in synergy to convert cellulose to sugar. DOE has determined that enzymatic processing is no longer an obstacle to commercialization

Other Enzyme Breakthroughs
Diversa Corporation has partnered with a consortium that includes DuPont, Deere & Co., the National Renewable Energy Laboratory and Michigan State University to develop a biorefinery that can produce ethanol and other products from the entire corn plant, integrating traditional grain-based ethanol production with cellulosic ethanol production from stalks and husks.

In 2005, Diversa successfully developed a suite of enzymes that has enabled the consortium to begin developing a demonstration facility for this "Integrated Corn-Based Biorefinery" concept. DuPont will also utilize the enzymes to produce a biobased plastic, "bio-PDO" at a facility in Loudon, Tennessee.

Dyadic International has developed an integrated technology platform (C1) which will enable researchers to identify, select and analyze novel enzymes best suited to convert biomass materials into biofuels. Dyadic has also developed enzymes for the textiles, pulp and paper, food and feed, and chemicals industries that greatly reduce waste while offering new and enhanced products to a variety of markets.

The First Commercial Production

In 2004, Iogen Corporation became the first company to begin commercial production of cellulosic ethanol. Using biotech enzymes that convert wheat straw to clean burning ethanol, Iogen's pilot plant in Ottawa, Canada, has an annual capacity of 260,000 gallons. Ethanol from the plant is sold at a nearby Shell gas station. In January 2006, Iogen and Shell announced plans to explore cellulosic ethanol production in Germany, and Iogen is seeking government assistance to construct the first commercial-scale cellulosic biorefinery in the US.

More Biorefineries

In August, 2005, Abengoa Bioenergy began construction of the world's first commercial scale cellulosic ethanol plant. Upon completion in 2006, the plant is expected to process 70 tonnes of agricultural residues, such as wheat straw, each day, producing over 1 million gallons of cellulosic ethanol annually. Advances in cellulose enzymatic hydrolysis and fermentation were key to enabling Abengoa to take their technology to market.

Abengoa has also received a $10 million DOE grant to develop a next-generation dry mill corn ethanol plant. This next-generation plant will be capable of producing ethanol from the entire corn kernel – both starch (the only portion currently utilized for ethanol) and the residual fiber (also known as dry distillers grains, or DDGs), which would require processing with cellulase enzymes. The application of cellulosic technology could dramatically increase the ethanol yield of the nation's over 100 existing ethanol facilities.

In 2005, Cargill announced plans for two 110-million-gallon bioethanol plants that use traditional feedstocks, in Nebraska and Minnesota, and began construction of a biodiesel plant in Mainz, Germany. Cargill is exploring incorporating cellulosic feedstocks into its existing refineries.

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- Glenn Nedwin, president, Novozymes -- (530) 757-4976 (enzymes)

Enzyme, Bioethanol and Biobased Products Companies

Abengoa Bioenergy Corporation -- www.abengoa.com
BC International Corporation -- www.bcintlcorp.com
Codexis, Inc -- www.codexis.com
Diversa Corporation -- www.diversa.com
Dyadic International, Inc -- www.dyadic-group.com
Genencor International -- www.genencor.com
Iogen Corporation -- www.iogen.ca
NatureWorks, LLC -- www.natureworksllc.com
Tate & Lyle -- www.tate-lyle.co.uk

What Policies Will Help Cellulosic Ethanol Meet the Challenge of the Advanced Energy Initiative?

Rapid commercialization of cellulosic ethanol will require government support in three key areas: biorefinery construction, R&D, and market creation/expansion.

Biorefinery Construction

The single greatest hurdle to commercialization of cellulosic ethanol is construction of the first integrated biorefineries. Potential refiners are unable to secure private financing for construction of the first plants without some government assurance/participation.

The Energy Policy Act of 2005 established a suite of programs to provide the necessary government assurance. These programs must be funded at a level sufficient to mobilize private financing:

- **Biorefinery Loan Guarantee Program:** For the construction of up to 4 demonstration cellulosic ethanol facilities (Sec. 1511).
- **Biorefinery Grants Program:** Authorizes $750 million in grants over 3 years for the commercial production of cellulosic ethanol (Sec. 1512)

R&D

The cost of cellulosic ethanol production has declined dramatically over the past five years with breakthroughs in industrial biotechnology. However, production at prices competitive with the mature petroleum industry still depends on advances in new crop varieties, harvesting, storage, transportation and processing. This will require an intensive, focused R&D and demonstration program.

The Energy Policy Act of 2005 provided for strong programs at both the Department of Energy and USDA. These R&D and demonstration programs should be funded at least at the level authorized in the Act:

- **DOE Bioenergy Program** – $738 million authorized over 3 years for R&D and integrated biorefinery demonstrations. The program received $91 million in FY06 appropriations. The President has proposed increasing funding to $150 million for FY07. This is still just over half the authorized level.
- **Joint USDA/DOE Biomass R&D Program** – $2 Billion authorized over 10 years for enhanced USDA/DOE Biomass Research Program. The program is funded at just $14 million in FY06. The President has given no indication that this will be increased in FY07.
- **DOE Office of Science** – $196 million over 3 years for programs, projects and activities through DOE office of Science for additional integrated bioenergy research and development. This program has not yet been funded.

Market Creation/Expansion

Even with cellulosic ethanol production underway, federal policy is needed to ensure penetration into the petroleum-dominated market for transportation fuels.

The Energy Policy Act of 2005 established several programs to create and expand the market for cellulosic ethanol. These programs should be fully implemented:

Renewable Fuels Standard -- Beginning in 2013, a minimum of 250 million gallons a year of cellulosic ethanol must be blended into the nation's fuel supply.

Federal Offtake Agreement – Federal government will award cellulosic ethanol producers a per gallon incentive until U.S. production reaches 1 billion gallons per year. Awards are offered through production auctions, with awards given to the lowest bidders, thereby reducing the per gallon subsidy over time. Program is authorized at $250 million.

Federal Procurement – Requires the use of renewable fuels in all government fleet vehicles capable of their use.

Flex Fuel Pumps – Fueling stations will receive a tax credit for 30 percent of the cost of installing pumps dispensing ethanol blends of at least 85%, up to $30,000 per station through 2010.

*Glossary**

Terms used frequently in this and other discussions of bioenergy are defined below. The definitions given here are in some cases specific to the context of energy supply from biomass, and may not be complete or fully accurate in other contexts.

Bioenergy -- Useful energy (fuel, electricity, heat) produced from biomass.

Biomass -- Plant matter of recent (non geologic) origin or materials derived there from.

Biorefinery -- A processing facility in which multiple products are produced from biomass feedstocks.

Cellulosic biomass -- Biomass composed primarily of inedible plant fibers having cellulose as a prominent component. These fibers may be hydrolyzed to yield a variety of sugars that can subsequently be fermented by microorganisms. Examples of cellulosic biomass include grass, wood, and cellulose-rich residues resulting from agriculture or the forest products industry.

Co-utilized crops – Crops that are used for both energy and non-energy uses each of which are of comparable importance.

Dedicated energy crops – Crops grown for the primary purpose of energy production. Examples of such dedicated crops include corn used for production of ethanol in a dry mill, as well as switchgrass and short rotation trees used for production of fuels and/or power.

Feedstock – The source of carbon for production of organic fuels and chemicals via industrial processes.

Lignin – A component of cellulosic biomass that is rich in energy but not fermentable.

Residues – Biomass feedstocks available as a result of activities or processes undertaken for some purpose other than energy production. Examples of such residues include corn stalks and other non-edible parts of plants used to produce food, waste sludge produced at paper mills, and animal manure.

Sustainability - Having the capacity to be utilized for an indefinite period of time without degradation. Thus a sustainable resource can be used by present generations without compromising opportunities for use by future generations. Similarly, a sustainable activity can be undertaken by present generations without compromising opportunities for future generations to undertake that activity.

* From Dr. Lee Lynd, Dartmouth university