Issue Brief:
Converting Cellulose into Ethanol and Other Biofuels

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Fuel from Cellulose: The Holy Grail. The Brass Ring. The Pot of Gold at the End of the Rainbow. Or is it? Maybe. Probably. Let's see.

Developing technologies that can convert cellulosic materials into motor fuels has been a goal of government and private industry for three decades. Researchers have been predicting that commercialization is only 5 years away, but they have been making that prediction since 1985. It is a fair question for anyone concerned about government spending, energy security, the economy, and the environment to ask when we can expect to see the conversion of cellulose into renewable transportation fuels as a commercial reality. Despite the 30 years of predicting we are only 5 years away, as this Issue Brief will illustrate, we really are on the verge of some dramatic and game changing developments. But are we there yet?

Not yet, but we are fast approaching warp speed and meeting the cellulosic ethanol targets in the nation's Renewable Fuel Standard (RFS) appears to be reachable. Technology has reached a tipping point. Limited quantities of cellulosic ethanol are being produced in Wyoming, Louisiana, Arizona, Alabama, Canada, China, Spain, and the United Kingdom. These are not typical ethanol producing regions. The race towards second generation ethanol has become very exciting. Shell Oil is putting cellulosic ethanol in Le Mans race cars, Alabama is fueling their FlexFuel Vehicle (FFV) police cars with ethanol produced from wood waste, and making renewable diesel fuel from cellulose is a marketplace reality.

This Issue Brief is an overview of the status of cellulose conversion technologies (CCTs). It is a holistic overview of what could be termed as the "Biofuels Program Development Life Cycle" in the context of the different components that impact CCT development (see Figure 1). The life cycle starts with the creation of public policies that encourage CCTs and concludes with the end-uses of ethanol and other biofuels. The ample reference materials cited in this brief will provide readers with the opportunity for additional research and the ability to make their own assessment. Should the U.S. continue to invest in the development of CCTs?

Cellulose: a True Game Changer

Cellulose is the most common organic compound on Earth. About 33 percent of all plant matter is cellulose (e.g., the cellulose content of cotton is 90 percent and that of wood is 50 percent). Cellulose is an organic compound with the formula $(C_6H_{10}O_5)_n$, a polysaccharide consisting of a linear chain of several hundred to over ten thousand linked D-glucose units.[1] Cellulose is the structural component of the primary cell wall of green plants, many forms of algae, and oomycetes.

The higher potential yield of cellulose is due to the fact that it is an easier path to sugar because of the high glucose content. While first generation ethanol technology effectively converts the starch portion of grain to sugar and then the sugar to ethanol, cellulose is a more direct route and also contains both 5- and 6-carbon sugars. Cellulosic feedstocks meet the requirement of being renewable since they originate from plant matter which

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Inside

Dear Friends,

Policies affecting energy and biofuels touch on a range of issues such as job creation, economic stimulation, environmental protection, energy independence, and national security. The commercialization of cellulosic ethanol conversion technologies is a very important component of the policies we are crafting in Congress as we try to develop programs to reduce our use of petroleum. To some that may be a quest for a cleaner environment, to others the argument is one of energy security, and yet to others it is all about economic development and stemming the flow of U.S. dollars to foreign countries. In 2008 the U.S. spent $453 billion on imported oil.[2] Whichever of those compelling arguments one chooses, or in many cases it is all of them together, we recognize the need to expand biofuel production beyond the use of feed grains to a wider range of cellulosic feedstocks.

The nation's Renewable Fuel Standard (RFS) was written to ensure that the government studies and continually monitors the environmental, economic, and energy security benefits of the program. So far, the RFS has allowed our nation to protect and expand our feed grain production and displace the equivalent amount of crude oil we import from Venezuela or Iraq.

But we can do more. As the world's largest oil user, and as the requirements of the RFS increase in the coming years, we must take some responsibility to become the recognized leader in developing technologies that will help us and our allies lessen their dependence on one of the most turbulent regions in the world for oil. In addition, the growing threat of climate change can certainly be addressed by reducing the use of fossil fuels. The Department of Energy estimates that ethanol from woody biomass can reduce CO_2 emissions up to 120 percent compared to gasoline! And, as we have seen with the corn ethanol and biodiesel industries, these domestic "energy factories" are in themselves stimulus packages, creating jobs and keeping dollars at home.

The path to commercialization of cellulosic ethanol technologies will not be easy, cheap, or immediate. We still need to create and manage policies to attract private funding and encourage the end-use markets for these strategically important biofuels. We need to stay the course so we can realize a return on our investment from these emerging technologies. Giving up now would be the equivalent of ending progress on telephone research with the discovery of the rotary dial and the non-assisted call.

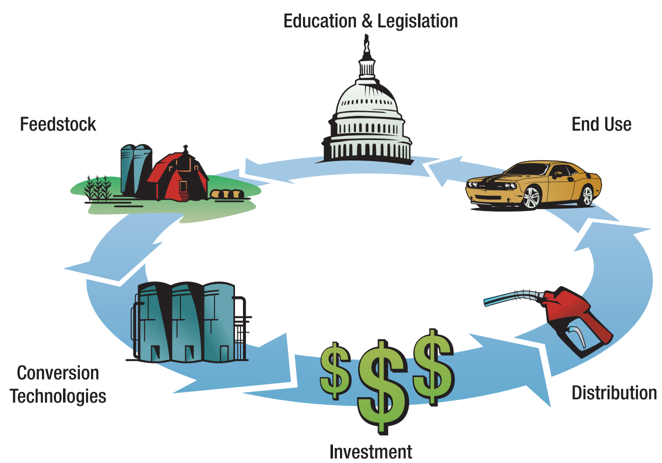
The Ethanol Across America education campaign will continue to provide concise and factual information through the Issue Brief series. Thank you for taking the time to learn more about the opportunities for our nation to produce more ethanol and biofuels from America's abundant and renewable cellulosic resources.

Sincerely, Ethanol Across America
U.S. Senate Advisory Committee:

Sen. E. Benjamin Nelson **Nebraska**	Sen. Richard Lugar **Indiana**	Sen. Tim Johnson **South Dakota**

is grown and produced on a recurring basis. From a public policy standpoint, it is very important to specifically define cellulose feedstocks to determine the eligibility of the biofuel produced for federal tax credits. Generally, cellulosic ethanol is a biofuel produced from wood, grasses, or the non-edible parts of plants. Corn stover, switchgrass, miscanthus, woodchips, and the byproducts of lawn and tree maintenance are some of the more popular materials for potential cellulosic ethanol production.[3] Billions of dollars are being invested into the commercialization of CCTs that will produce clean burning domestic renewable fuels to replace fossil fuel-based gasoline and diesel.

Figure 1 **Biofuel Program Development Life Cycle**



"According to our April 2009 industry assessment, 11 plants are currently at advanced stages of planning and likely to go online in the near future. Along with those plants currently operational or under construction, we believe that these facilities will enable the U.S. to meet the 100 million gallon cellulosic biofuel standard in 2010."
Source: EPA, Federal Register / Vol. 74, No. 99 / Tuesday, May 26, 2009

The RFS is Charting the Course for Cellulose

Landmark legislation in 2005 created the first Renewable Fuel Standard (RFS) which requires a certain percentage of all motor fuels used in the United States to be renewably derived. The tremendous success of that program led to an expansion of the program via the Energy Independence and Security Act of 2007 (EISA). This legislation substantially increased not only the volume requirement for renewable fuels like ethanol, but established new specifications for the RFS which included advanced biofuels and cellulosic biofuels. The RFS established a usage requirement that, along with incentives and funding opportunities, should spur wide scale investment in the development of ethanol production from feedstocks other than grain. This was clearly an intent of Congress in terms of both limiting the amount of grain used in the biofuel program and more importantly, driving technology by requiring these advanced and cellulosic biofuels[4] (see Figure 2).

Advanced biofuel is renewable fuel, other than ethanol derived from corn starch, that is derived from renewable biomass and achieves a 50 percent greenhouse gas (GHG) emissions reduction. The emissions reduction requirement for advanced biofuels may be adjusted to a lower percentage (but not less than 40 percent) by the Administrator of the U.S. Environmental Protection Agency (EPA), if it is determined the requirement is not feasible. The definition – and the schedule – of advanced biofuels include two subcategories: cellulose and biomass-based diesel.

Cellulosic biofuel is renewable fuel produced from any cellulose, hemicellulose, or lignin that is derived from renewable biomass and achieves a 60 percent GHG emission reduction requirement. (Cellulosic biofuels that do not meet the 60 percent threshold, but do meet the 50 percent threshold, may qualify as an advanced biofuel.) The 60 percent GHG emissions reduction requirement for cellulosic biofuels may be adjusted to a lower percentage (but not less than 50 percent) by the EPA Administrator if it is determined the requirement is not feasible for cellulosic biofuels.[5]

Figure 2 **U.S. /Biofuel/Cellulosic Ethanol Requirements**

The Nation Needs 16 Billion Gallons Per Year of Cellulosic Ethanol

Year	Total Volume of Renewable Fuels	Advanced Biofuel Requirement	Cellulosic Requirement	(Resulting Cap on Corn Ethanol)
2008	9.000			
2009	11.100	.600		10.5
2010	12.950	.950	.100	12.0
2011	13.950	1.350	.250	12.6
2012	15.200	2.000	.500	13.2
2013	16.550	2.750	1.000	13.8
2014	18.150	3.750	1.750	14.4
2015	20.500	5.500	3.000	15.0
2016	22.250	7.250	4.250	15.0
2017	24.000	9.000	5.500	15.0
2018	26.000	11.000	7.000	15.0
2019	28.000	13.000	8.500	15.0
2020	30.000	15.000	10.500	15.0
2021	33.000	18.000	13.500	15.0
2022	36.000	21.000	16.000	15.0

Feedstocks for Cellulosic Ethanol

One reason people are so excited about the potential of cellulosic biofuels is the nearly unlimited supply of feedstocks that could be utilized. There is little doubt the nation has sufficient quantities of cellulosic biomass to make a significant impact on U.S fuel supply and price.

The terms "biomass" and "cellulose" are often used interchangeably. Cellulose/biomass is particularly attractive because it is currently available and has no geographical limitations. Virtually every part of the U.S. has cellulosic resources, ranging from specialty crops like switchgrass to urban wastes, to forest and agricultural wastes. The potential volumes that could be converted to liquid transportation fuel makes it invaluable in reducing crude oil imports — one of the most pressing energy needs that comes with geopolitical and national security implications. The most peer reviewed assessment of cellulose available for converting into ethanol and other biofuels is the *"1 Billion Ton Study."*[6] This report was work conducted on behalf of the Biomass R&D

Technical Advisory Committee. This committee was established by the Congress to guide the future direction of federally funded biomass R&D with the objective of replacing 30 percent of U.S. petroleum consumption with biofuels by 2030. The report recognized the 30 percent goal would require approximately 1 billion dry tons of biomass feedstock per year. Looking at just forest and agricultural land, the two largest potential biomass sources, the study found over 1.3 billion dry tons per year of biomass potential available — enough to produce biofuels to meet more than one-third of the current demand for transportation fuels, and the 30 percent target.

From just agricultural lands alone the United States can produce nearly 1 billion dry tons of biomass annually and still meet food, feed, and export demands. About 368 million dry tons of sustainable removable biomass could be produced on forestlands. This projection includes 52 million dry tons of fuel wood harvested from forests, 145 million dry tons of residues from wood processing mills and pulp and paper mills, 47 million dry tons of urban wood residues including construction and demolition debris, 64 million dry tons of residues from logging and site clearing operations, and 60 million dry tons of biomass from fuel treatment operations to reduce fire hazards. All of these forest resources are sustainably available on an annual basis. This annual potential is based on a more than seven-fold increase in production from the amount of biomass currently consumed for bioenergy and biobased products (see Figure 3).

Do we have enough feedstocks?

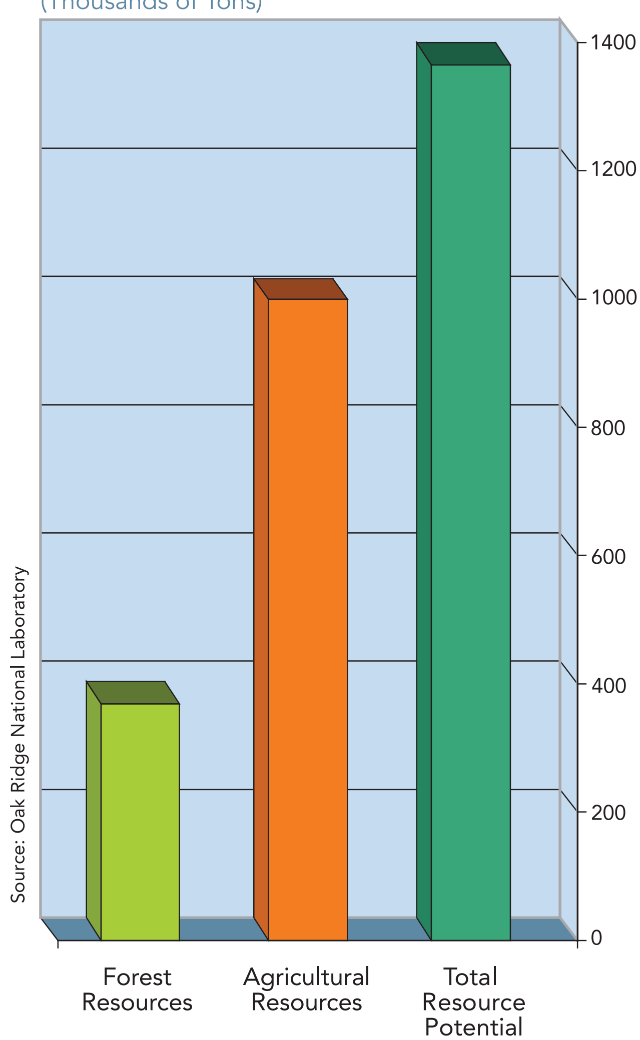
According to a 2009 "*90 billion gallon study*" by Sandia National Laboratories and General Motors, biofuels can provide a viable, sustainable solution to reducing petroleum dependence. Using a newly developed tool known as the Biofuels Deployment Model, or BDM, Sandia researchers determined that 21 billion gallons of cellulosic ethanol could be produced per year by 2022 without displacing current crops. The speed at which cellulosic ethanol becomes cost-competitive with gasoline is a function of conversion yield, capital cost, crude oil price, and feedstock cost. The study assessed the feasibility, implications, limitations, and enablers of producing 90 billion gallons of ethanol per year by 2030 and found no theoretical barriers to achieving the stated goal. However, the difficulty of predicting oil prices and fully quantifying the economic consequences from oil price spikes would continue to make investment difficult, and the report identified the need to protect and manage investment. While the study did identify a number of practical obstacles that need to be addressed such as developing large scale production of energy crops, these challenges could also be seen as economic development opportunities for rural and urban areas rich in renewable resources. The probability to advance cellulosic ethanol technology needs to be seen in the same light as other great breakthroughs in technology. Vaccines, biotechnology, agriculture productivity, or the utility of cell phones and availability of cell phone towers should all provide great examples of the future of cellulosic ethanol. The nation has yet to achieve economic, environmental, and energy/national security based solely on the market price of crude oil. Are you willing to bet on the technological advancement of cellulosic biofuels or bet your 401K on the long-term reliance of sustainable sources and prices of foreign oil?

Looking Ahead

One of the critical links in the CCT Biofuels Program Development Life Cycle will be the feedstock owner/producer. Hurdles such as feedstock eligibility restrictions in the RFS, and the cost and logistics of transporting biomass to CCTs need to be addressed before full-scale implementation of a program. DOE currently has 38 field tests underway[7] in cooperation with various universities and another five regional partnerships with universities to help improve and understand new energy crops.[8] Private companies like Ceres[9] and Mendel Biotechnology[10] are also partnering with farmers to build business models that will allow for the long-term investment, planning, and harvesting of specialty energy crops and to define and quantify how much cellulose can be produced by when and for how much. The DOE/EERE Office of the Biomass Program, USDA, EPA and several other federal agencies continue to work through the Biomass R&D Technical Advisory Committee towards this goal and deploying the *2008 National Biofuels Action Plan*.[11]

Figure 3 **Over 1 Billion Tons of Forest and Agricultural Resources are Available Each Year***

**Does not include Corn*



CCT Snapshots

As noted earlier, the maturation of the cellulose industry includes the recognition that this is not a one size fits all approach and a variety of technologies are going to be successful. Examination of recent DOE awards illustrates this range as they are pursuing multiple paths. The following "CCT Snapshots" are examples of the different approaches companies are taking towards commercialization of their technologies.

BlueFire Ethanol

Perhaps no one has been focused on a single pathway longer than BlueFire Ethanol. Having evaluated numerous technologies that might be paired with the power plants the company was building in the early 1990s, BlueFire elected to further develop the acid hydrolysis technology originally developed by the Department of Energy at the Tennessee Valley Authority labs. Nearly 20 years later, BlueFire is on the verge of spinning straw into gold, or in their case, garbage into high value biofuel.

A key to the BlueFire approach is to utilize low cost, abundant cellulosic wastes such as those from municipal and other urban sources. Through their years of development and testing, BlueFire has found that acid was particularly well suited to breaking down cellulose which can be as much as 80 percent of typical urban trash sent to landfills. This pathway also offers a solution to the growing problem of waste disposal by creating more beneficial uses of the waste. Urban waste is a prime example of the unlimited application of a CCT—urban areas in literally any part of the country deal with trash. Areas where there are significant volumes of trash generated from its population base are also likely to be within significant markets for transportation fuels. Hence the technology could be deployed to use a region's waste materials to supply its market transportation fuels.

The BlueFire technology is a brute force transformation of virtually any cellulosic material into fermentable sugars using acid to break the linkages that join the sugar monomers together. Once separated, the sugars are fermented into ethanol using conventional yeasts. The lignin that held the sugars together is extracted and used as fuel to provide the thermal needs of the production process. The BlueFire process has minimum feedstock requirements, namely less than one inch in size and preferably a moisture content of 10 percent or less. Because the acid can get to the chemical bonds quite easily no pretreatment to expose the linkages is necessary as is the case for some hydrolysis processes.

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CCT Pilot, Demonstration, Commercial, and R&D Projects

Both DOE and the USDA have committed significant resources to the research, development, and demonstration of new biofuels technologies. DOE has announced more than $1billion in awards since 2007 and USDA has invested almost $600 million. Numerous states are also offering grants, tax incentives, and loan guarantees to help encourage biofuel production. The majority of efforts are centered on expanding ethanol production, and more recently, cellulosic ethanol production.

Figure 4 **Projected U.S. Cellulosic Ethanol Production Capacity***

Operational	**Location**	**Feedstock**	**Size (Gal./Yr.)**
Abengoa Bioenergy (York)	York, NE	Wheat Straw	11,600,000
BRI Energy	Fayetteville, AR	MSW, Wood waste, coal	40,000
AE Biofuels	Butte, MT	Crop Residue	150,000
BPI/Universal Entech	Phoenix, AZ	Paper waste, sorted MSW	10,000
Gulf Coast Energy	Livingston, AL	Wood waste, sorted MSW	200,000
Mascoma Corp. (NY)	Rome, NY	Wood chips	200,000
POET (Project Bell)	Scotland, SD	Corn cobs, fiber	20,000,000
Verenium (Celunol/Diversa/BP)	Jennings, LA	Sugar Cane/Bagasse	500,000
Verenium (Celunol/Diversa/BP)	Jennings, LA	Sugar Cane/Bagasse	1,500,000
Western Biomass Energy (KL Process Design)	Upton, WY	Wood	1,500,000
Abengoa Bioenergy	Babilafuente, Spain	Ag Waste	1,500,000
Greenfield Ethanol	Edmonton, AB, Canada	Municipal Solid Waste (MSW)	36,000,000
TMO Renewables	Surrey, UK	Municipal Solid Waste (MSW)	TBD
Iogen	Canada	Wheat/Barley Straw	TBD
Under Construction	**Location**		**Size (Gal/.Yr.)**
Abengoa Bioenergy (Hugoton 1)	Hugoton, KS	Wheat Straw	15,000,000
ClearFuels Technology, Inc.	Kauai, HI	Bagasse	1,500,000
Coskata Energy	Madison, PA	Crop Residue	10,000,000
Dupont Danisco Cellulosic Ethanol, LLC	Vonore, TN	Energy Crops/Switch Grass	250,000
Ecofin/Alltech	Springfield, KY	Crop Residue	10,000,000
Fulcrum Bioenergy	Storey County, NV	TBD	10,500,000
ICM, Inc.	St. Joseph, MO	Ag Waste	1,500,000
Range Fuels	Soperton, GA	Wood	20,000,000
RSE Pulp & Chemical	Old Town, ME	Wood waste	2,200,000
Southeast Renewable Fuels	Clewiston, FL	Citrus Waste	20,000,000
ZeaChem	Bordman, OR	Poplar Trees, Wood, Sugar	1,500,000
Vercipia (Verenium)	Highlands County, Florida	Sugar Cane/Bagasse	36,000,000
Gulf Alternative Energy Corp.	Blairstown, IA	Ag Waste	
Capacity			**201,650,000**

*Capacity estimates are based on conversations with project managers, press releases, trade press articles, and other sources of information in the public domain. Information is often proprietary and/or not available. This information is provided for illustrative purposes as data sets can vary based upon project funding, ownership, government funding and appropriations, legislation, and project schedules.

Thirty-three states currently offer some form of ethanol production incentive (a complete list can be found on the DOE's Energy Efficiency and Renewable Energy (EERE) web site). The incentives range from support for ethanol producers to support for research and development companies to support for feedstock suppliers. Kansas, Maryland, and South Carolina each offer specific cellulosic feedstock incentives. The result of this investment and efforts to spur research and development may astound you. Figures 4-7 identify CCT projects that are operational, under construction, in various stages of development, and R&D projects.

As alluded to previously, the quest for practical and profitable conversion of cellulose to ethanol has been the objective of government and industry alike for decades. By establishing requirements through the Renewable Fuel Standard, one of the key questions of assuring market demand is answered. Consequently, this has unleashed even more interest in converting cellulose into biofuels and few people are aware of the extraordinary depth of this effort.

The fast closing reality of using abundant cellulose to produce clean burning, domestic, renewable, and low carbon fuels has the attention of venture capitalists, Fortune 500 companies, international oil companies, automobile producers, numerous countries, universities, NGOs, and federal agencies encouraged by Congress. Our research identified a very impressive array of nearly 100 CCT projects that are in the operational, construction, planning, and/or other stages of

Figure 5 **U.S. Cellulosic Ethanol Plants in the Project Development Stage**

Project Development	Location	Feedstock	Size (Gal./Yr.)
Agresti Biofuels	Pike County, KY	Municipal Solid Waste (MSW)	20,000,000
BlueFire Ethanol I	Fulton, MS	Wood Chips	20,000,000
BlueFire Ethanol II	Lancaster, CA	Municipal Solid Waste	3,900,000
Catalyst Renewables Corporation	Lyonsdale, NY	Wood Waste	300,000
Coskata Energy	TBD, FL	Sugar Cane	10,000,000
Flambeau River Biorefinery, LLC	Park Falls, WI	Spent Pulping Liquor	6,000,000
Gulf Coast Energy	Mossy Head, FL	Wood Waste	70,000,000
KAAPA Cooperative	Central Nebraska	Ag Waste	20,000,000
Lignol Innovations Inc..	Commerce City, CO	Wood Chips, Corn Stover	2,000,000
Mascoma Corp. (MI)	Lansing, MI	Wood	40,000,000
NewPage Corp.	Wisconsin Rapids, WI	Wood Waste, Mill Residue	5,500,000
Ineos	LaBelle, FL	MSW, Citrus/Ag Waste	13,900,000
Pacific Ethanol, Inc.	Port of Morrow, OR	Ag and Wood Residues	2,700,000
Pan Gen Global	Stuttgart, AR	Rice Hulls	2,700,000
POET (IA)	Emmetsburg, IA	Corn Stover	30,000,000
Pure Vision Technology	Fort Lupton, CO	Corn Stover, Switchgrass	2,000,000
Qteros	TBD	TBD	TBD
SunOpta Inc. Bioprocess (Central MN Ethanol Coop)	Little Falls, MN	Wood Waste	10,000,000
West Biofuels	San Rafael, CA	Municipal Solid Waste	1,500,000
Xethanol (VA Tech)	Auburndale, FL	Urban Waste	8,000,000
Total Capacity			**268,200,300**

Figure 6 **Cellulosic Ethanol/Biofuels Research & Development Projects**

Corporate Projects

Ceres, Inc. Contact
AFSE Enzyme, LLC.
Agrigy Inc.
American Energy Enterprises
American Ethanol
American Recycled Energy
Amyris Biotechnologies
Archer Daniels Midland
Atlantic Biomass Conversions, Inc.
Aurora Biofuels (FL Ins. Of Tech)
BAE Systems/Lignol
Biomass Gas & Electric (FERCO/Future Energy/Silva Gas)
Boeing
BP Biofuels
C5-6 Technologies (Lucigen Corporation)
Cauffiel Industries
Cello Energy
Ceres, Inc.
Chevron/Univ. California Davis
CHROEN Industries
Cilion, Inc./Virgin FuelsCleanTech Biofuels (Merrick & Company/Coors)
Codexis
ConocoPhillips
Dyadic International, Inc.
Edenspace
Ethanol Technologies Limited (Ethtec)
Genahol
Genencor International
General Motors
Honda Motors/RITE
Mossi & Ghisolfi (M&G)
NatureWorks, LLC (Cargill/Dow)
Nova Fuels
Novozymes
Pearson Technologies
Pioneer
Renewable Agricultural Energy, Inc.
Rohm and Haas Company
Southridge Enterprises Inc. (Celuhol Inc.)
Tyson Foods, Inc.
UOP, LLC

University Projects

Cornell
Iowa State University
Louisiana Tech University
Michigan State University
Mississippi State University
New Mexico State University
Penn State
Princeton University
Purdue University
University of Arkansas
University of California/Berkeley
University of Central Florida
University of Florida
University of Georgia
University of Hawaii at Manoa
University of Nebraska
University of New York
University of Northern Iowa
University of Wisconsin
Virginia Tech
Washington State University
West Virginia University

Government/NGO Projects

Australia
Brazil
Brookhaven National Laboratory
Canada
China
Danish Energy Agency
Egypt
France
Japan
Los Alamos National Laboratory
National Renewable Energy Laboratory
National Science Foundation
Natural Resources Defense Council
New Zealand
Oklahoma Bioenergy Center and Noble Foundation
Philippines
South Korea
U.S. DOD/DARPA Research Program
U.S. EPA/DOE/USDA
UK

Figure 7 **U.S. Cellulosic Ethanol Projects in the Planning Stage**

Project	Location
Alternative Energy Sources	TBD
American Energy Holdings	New Milford, CT
BioEnergy International Corn	Clearfield, PA
California Ethanol and Power	Imperial Valley, CA
EcoSystem Corp.	TBD
Colusa Biomass Energy Corp.	Colusa, CA
Consus Ethanol, LLC of Pittsburgh	TBD
Diversified Ethanol (contact)	TBD
Flex Fuels USA, Inc.	TBD
Florida Crystals/Univ. of Florida	Gainsville, FL
FuelFrontiers	TBD
FutureFuel Chemical Company	TBD
Genesee Regional Bio-Fuels	Rochester, NY
GEVCO	TBD
Greenfuels Technology Corporation	TBD
Gulf Ethanol (Meridian Biorefining)	TBD
Ibicon	TBD
Imperium Renewables	TBD
Indian Oil Corp.	TBD
Inventure	Seattle, WA
Liberty Industries (FL AG)	Hosford, FL
Louisiana Green Fuels	TBD
Pencore-Masada (Auburn, AL)	Alabama
Pencore-Masada (NY)	New York
Raven Biofuels International Corp.	Maryland
Pure Energy	Saline County, MO
Syntec Biofuel Inc.	Washington
Terrabon	TBD
United States EnviroFuels LLC	Venus, FL
Valero Renewable Fuels	Multiple Sites
Virent Energy Systems	California
Zymetis, Inc.	TBD

CCT Snapshots

BlueFire *(cont. from pg. 5)*

Among other things, the patents protecting the technology are associated with the improvements made to make acid hydrolysis competitive in today's marketplace. These include a more effective process to separate the acid from sugars, re-concentration of the acid to minimize make-up requirements, and higher yields of sugar conversion from the cellulose for optimum production of final products.

With several years of successful demonstration at pilot facilities in the U.S. and Japan, BlueFire has permits in hand for its first commercial plant adjacent to an existing landfill in Lancaster, California that will produce nearly 4 million gallons of ethanol annually. The project will rely on reclaimed water for cooling, avoiding groundwater impacts. It will convert abundant cellulosic trash using a process with nearly zero discharge to the environment.

Verenium

Verenium is pursuing a number of different ways to convert cellulose to ethanol. The company's integrated, proprietary process, under development since the early 1990s, makes full use of the sugars found in biomass. These include both the crystalline (six-carbon) sugars in cell walls, as well as the amorphous (five-carbon) sugars in jelly-like hemicellulose.

In Verenium's process, biomass is subjected to mildly acidic conditions that break the lignin bonds and free up two streams of sugars. The syrupy hemicellulose sugars are drawn off into a vessel and fermented using a proprietary, engineered bacterium. Meanwhile the cellulose sugars, the consistency of kraft paper, are broken down and fermented in a separate vessel by a mix of proprietary enzymes and other bugs working in concert. The resulting "beer" is distilled to fuel-grade ethanol. Finally, the glue-like, highly combustible lignin contained in the residue is dewatered and used as a boiler fuel, making the process nearly closed-loop and highly energy-efficient.

Verenium is at the forefront of efforts to prove the commercial viability of cellulosic ethanol. It is using its 1.4 million gallon per year demonstration-scale facility in Jennings, Louisiana to optimize its process, learn about feedstock handling, and confirm its economic projections for commercial production of ethanol. Recently, Verenium joined with petroleum giant BP to

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development. Our research also identified another 100 research and development projects designed to advance CCTs. The lists of CCT projects and research are compiled based on interviews, trade press articles, press releases, and other information in the public domain. The lists are intended to illustrate the depth, breadth, and billions of dollars currently being invested into commercializing CCTs.

The Evolution of Technologies

Because cellulose is the most abundant molecule on Earth and comes in so many different forms, it stands to reason there will be numerous paths to convert cellulose to biofuels. In fact, the notion that a single technological breakthrough would take place that would produce a clear winner in the race to the Holy Grail, and make others obsolete, has been completely turned on its ear. It is likely that a range of technologies using a range of feedstocks will be successful. The recent trend of technology awards from the Department of Energy and the Department of Agriculture reflect this realization. Acid hydrolosis, enzymatic technologies, thermal, and microbial technologies are all being supported by the federal government and all are showing great promise.

Pathways: Cellulose Conversion Technologies (CCTs) Being Developed Today

Although the RFS has been called an "ethanol mandate," there is no explicit requirement to use ethanol. The law was written to accelerate the development of many CCTs and cellulose feedstocks to diversify the feedstock base of biofuel production. As previously noted, the approach for developing CCT projects is also evolving with the RFS. The "one-cellulose-conversion-technology-fits-all" R&D path of the 1980's has been replaced with a fast evolving 21st century approach using hybrids of conventional and emerging technologies. R&D projects are showing a new importance of finding the right fit between feedstocks and technology paths.[12] Currently there are two primary CCT paths being developed that generally fall under the classifications of thermal or biochemical. There are advantages, disadvantages, combinations, and many variables to all CCT processes.

The CCT path can also be driven by the economics of the feedstock source selected. For example, most CCT projects that have announced construction plans have a strategy to bridge the very narrow gap between existing feed grain (corn)-based ethanol plants and cellulose-ethanol plants (e.g., ag/feed grain residues) by utilizing advances in biochemical (i.e., enzymatic-based) processes. They have chosen the biochemical process because the process and new feedstocks are very similar in nature to feed grain-based ethanol production facilities. The ag residue (e.g., corn or wheat stover) feedstocks are very uniform. Because of the uniform nature of these feedstocks the cost and logistical hurdles of collecting the feedstocks are low, the cost to manufacture the enzymes to convert the cellulose are getting continually lower, the success of those enzymes breaking down the cellulose successfully and consistently are high, and the fermentation part of the facility already exists. Much of the research and advances with biochemical or enzymatic hydrolysis have been accomplished by the DOE working in cooperation with industry and academia. As a result of DOE and CCT stakeholders working together, enzyme costs have been reduced dramatically in existing corn-based ethanol plants. The next likely advancements in biochemical-based technologies will be in CCT facilities.

In comparison, current enzyme-based technologies have a difficult time breaking down the cellulose or biomass in wood residues, the complex and inconsistent mixes of municipal solid wastes, or industrial waste streams such as used tires. It appears that thermochemical conversion technologies are better suited to make these feedstocks uniform with high heat temperatures or other related technologies such as the plasma arc. Once these varied feedstock sources have been converted to a syngas or biogas platform, complementing technologies such as catalytic conversion can take these streams and convert them into higher value end-use products such as ethanol and other alcohols. As the various CCT Snapshots illustrate, the paths to commercializing CCTs are changing and evolving at a rapid pace.

It's a long and winding road …

No, the Beatles were not singing about cellulose in their famous song, but they may as well have been. As is the challenge with any alternative fuel, what is economic today may not be tomorrow and it all comes down to cost. The cost of producing cellulosic ethanol is higher compared to its competition — feed grain/corn-based ethanol or gasoline from imported oil. Determining the exact cost of converting cellulosic materials into ethanol is the function of hundreds of variables such as public policy, feedstock costs, processing costs, debt servicing, equipment and construction costs, CCT path, supply contract terms, and world commodity markets. As a result, new technologies such as CCTs have a difficult time attracting conventional financing. The cost of producing cellulosic-ethanol has dropped dramatically in the past 30 years. New technology developments have lowered the cost from over $7 per gallon to under $2.20 per gallon today. Similar to petroleum and chemical refining industries in the early 1900's, new biotechnologies will make CCTs more efficient. Enzymes that break down plant cell wall tissue cost 30 to 50 cents per gallon of cellulosic-ethanol compared to 3 cents per gallon for feed grain ethanol. DOE hopes to reduce the cost of producing cellulosic-ethanol to $1.07 per gallon by 2012.

The role of market development in driving technology

While it would seem to be an easy task for new cellulosic-ethanol to enter the market and reduce more oil imports, it's not. The U.S. ethanol/biofuels program has been a remarkable success. Today, ethanol is

CCT Snapshots

Verenium *(cont. from pg. 9)*

announce plans for one of the world's first truly commercial-scale cellulosic ethanol facilities, to be located in Highlands County, Florida.

Novozymes

Novo, as they are often referred to in the industry, is focusing on the development of enzymes for cost competitive production of lignocellulosic ethanol.

The R&D effort within Novozymes to engineer and produce cost effective enzymes for the conversion of lignocellulose based substrates into biofuels is the largest such effort in company history.

They are currently working with industry leaders on numerous lignocellulose to biofuel pilot and demonstration plants worldwide. These collaborations include: Poet, ICM, Mascoma and KL Energy (USA), Sinopec and COFCO (China), CTC (Brazil), Abengoa (Spain) and Inbicon (Denmark). The work includes optimizing enzymes and integration of key process steps on substrates such as corn stover and corn cobs, wheat straw, sugarcane bagasse, hard wood, softwood, urban waste, and dedicated energy crops such as sorghum and switch grass. Novozymes' enzymes for lignocellulosic based biofuels are helping to bring overall processing costs down to cost competitiveness with starch based biofuels:

- In February 2009 Novozymes reached an R & D milestone by offering the industry new enzymes that cut the cost of the enzymes for lignocellulose conversion by 50 percent.
- Novozymes believes these enzyme costs can be reduced by another 50 percent in 2010. This will be done through a combination of new enzymes and by working with industry leaders to integrate and optimize the overall conversion process. This combination of new enzymes and more efficient processing will bring the total cost of lignocellulosic bioethanol to competitive levels with starch based ethanol by 2011.
- Novozymes estimates that by 2015, lignocellulose based biofuels will directly compete with fossil fuel derived transportation fuels in the US.

Range Fuels

Range Fuels is currently constructing a commercial scale facility in Georgia converting biomass to gas and then gas to liquids.

continued on pg. 13

replacing about 10 percent of our nation's gasoline consumption, mostly used as an additive at a volume of 10 percent (10%). Moving forward, the challenge will be to encourage consumers to use ethanol blends at levels above 10% – when 10% is the current legal limit for conventional vehicles. The success of CCTs may be directly tied to growing the end use market for ethanol. Drivers may be able to use higher than 10 percent blends in the nation's 223 million legacy vehicles depending on regulatory decisions being made at the EPA. Many ethanol proponents are hopeful EPA will make the determination that blends between 10 and 20 percent can be used in conventional vehicles without any degradation of emissions equipment or have any impact on performance. The next step in creating a truly significant market is to get owners of the nearly 8 million flexible fuel vehicles (i.e., FFVs, or vehicles capable of operating on any combination of ethanol, up to 85 percent, or E85) to use higher than 10 percent blends of ethanol in their vehicles. This may be the easiest and quickest way to avoid the negative policy implications of hitting the E10 blend wall. There is a national FFV awareness campaign being conducted by the Ethanol Across America education campaign in cooperation with the FlexFuel Vehicle Club of America www.flexiblefuelvehicleclub.org that will help increase the utilization of E85 in FFVs.

There are currently over 2,000 gasoline stations offering E85 in the United States. The American Recovery and Reinvestment Act of 2009, through the Department of Energy's Clean Cities Program, recently provided over $300 million in funding to help stimulate the installation of more E85 refueling infrastructure[13] (www.eere.doe.gov).

Federal Programs Investing in CCTs

The goal for developing CCTs intersects with many major pieces of energy, tax, economic, and environmental protection legislation. These include goals in The Clean Air Act Amendments of 1990; the Energy Independence and Security Act of 2007 (RFS); the Food, Conservation, and Energy Act of 2008; and the American Recovery and Reinvestment Act of 2009 – to name a few. There are biofuel related programs in the Departments of Defense, Energy, Agriculture, Commerce, Transportation, and the Environmental Protection Agency. In 2008 DOE announced solicitation for $30.5 billion in loan guarantees[14] and grant programs that include potential funding for CCT projects.[15] The Department of Treasury is also being considered the site for a Clean Energy Bank to help accelerate the financing of new clean energy related projects. Several state governments are considering adopting low carbon fuel legislation to accelerate CCT projects in their state in order to lower greenhouse gas emissions and stimulate local economies. All things considered there are few government programs that have a positive impact on so many levels.

EISA authorizes $500 million annually for FY08-FY15 for the production of advanced biofuels that have at least an 80 percent reduction in lifecycle GHG emissions relative to current fuels. The law authorizes $25 million annually for FY08-FY10 for R&D and commercial application of biofuels production in states with low rates of ethanol and cellulosic ethanol production. DOE issued a Funding Opportunity Announcement (FOA) for up to $200 million over six years (FY 2009 - FY 2014), subject to annual appropriations. The funding is designed to support the development of pilot and demonstration-scale biorefineries, including the use of feedstocks and production of advanced biofuels (such as bio-butanol, green gasoline and other innovative biofuels). The funding announcement number is DE-PS36-09GO99038 and can be viewed at www.grants.gov. Projects are expected to begin in Fiscal Year 2009 and continue through Fiscal Year 2014.

USDA's Rural Development office has announced funds available for its Advanced Biorefinery Loan Guarantee Program. This program is designed to assist lenders in financing new biorefineries or retrofitting existing biorefineries that utilize non-corn or cornstarch feedstocks. These include but are not limited to cellulose, sugar, starch, crop residue, animal waste material, food waste, yard waste, biomass, vegetable oil, animal fat, biogas from landfill or sewage plant gas, and others.

The 2008 Farm Bill

The Food, Conservation and Energy Act of 2008, H.R. 2419,[16] includes a new income tax credit for the producers of cellulosic alcohol and other cellulosic biofuels. The credit is 56 cents per gallon, bringing the total credit available to cellulosic biofuel to $1.01 per gallon. The credit will apply to fuel produced after 2008 and before 2013. Section 9005, the Bioenergy Program for Advanced Biofuels establishes the Bioenergy Program for Advanced Biofuels that provides payments to producers to support and expand production for advanced biofuels. The Biomass Crop Assistance Program (section 9011) encourages biomass production or biomass conversion facility construction with contracts that will enable producers to receive financial assistance for crop establishment costs and annual payments for biomass production. Producers must be within economically practicable distance from a biomass facility. It also provides payments to eligible entities to assist with costs for collection, harvest, storage and transportation to a biomass conversion facility.

Will History Repeat Itself?

Many hope so. While keeping one eye on the future, one should not lose sight of the present. Billions of dollars have been invested in harvesting and transporting feedstocks, developing refueling infrastructure, and advancing production efficiencies used in the 226 plants currently producing ethanol from feed grains. The similarities, successes, inventors, and investors of these production facilities will likely play a critical role in the advancement of and transition to CCTs in the future. The ethanol industry has already reached the goals of the RFS with 15 billion gallons of ethanol from feed grains. The transition to CCTs has a solid foundation for continued growth and consumer acceptance. Are we going to hit our RFS target for cellulosic ethanol? EPA says yes.[17]

CCT Snapshots *continued*

Range Fuels *(cont. from pg. 11)*

Under the Range process, biomass such as wood, grasses, and corn stover is fed into a converter. Using heat, pressure, and steam the feedstock is converted into synthesis gas (syngas), which is cleaned before entering the second step. The cleaned syngas is passed over a proprietary catalyst and transformed into cellulosic biofuels. These cellulosic biofuels can then be separated and processed to yield a variety of low carbon biofuels, such as cellulosic ethanol and methanol, which can be used to displace gasoline or diesel transportation fuels, generate clean renewable energy or be used as low carbon chemical building blocks. In addition, clean renewable power is produced from energy recovered in the conversion process.

Because Range Fuels' process utilizes a thermochemical process, it relies on the chemical reactions and conversions between forms that naturally occur when certain materials are mixed under specific combinations of temperature and pressure. Other conversion processes use enzymes, yeasts, and other biological means to convert between forms. The Range Fuels process accommodates a wide range of organic feedstocks of various types, sizes, and moisture contents, which they believe will greatly increase their chances of success.

ClearFuels

ClearFuels, established in 1998, is developing advanced sustainable biorefineries that convert multiple mixed cellulosic biomass feedstocks into sustainable, high-value energy products. These include Fischer-Tropsch ("FT") diesel and jet fuel, ethanol, hydrogen, and power at industry-leading yields. The ClearFuels proprietary thermochemical conversion process is based on its advanced High Efficiency Hydrothermal Reformation (HEHTR) technology for biomass-to-syngas conversion (BTG). This modular flexible BTG technology platform is combined with various ClearFuels' strategic partners' synthetic gas-to-liquid (GTL) technologies, such as Rentech's proven technology for converting syngas to renewable diesel and jet fuel. They believe it will result in versatile, flexible biomass to biofuels biorefineries that can be co-located and integrated at wood processing and sugarmill facilities. This results in reduced risk, lower overall production costs and biorefineries that can be successful when faced with changes in the biofuels market over the long term.

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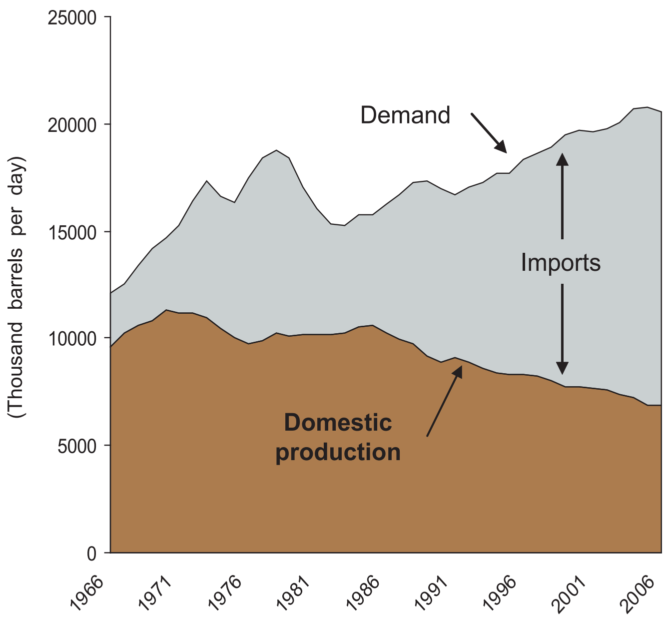
The U.S. oil production/demand/reserve/import scenario does not paint a pretty picture (See Figure 8). Now consider the value of avoiding our head on collision course with the energy security challenges from increasing oil imports (See Figure 9). Figures 8 & 9 present the business case to keep investing in energy security by lowering the current $2.20 per gallon cost for CCTs and developing a bigger market for their end use. Today, the price consumers pay at the pump does not reflect the value of the economic, environmental, energy, and national security benefits from ethanol nor does it reflect the real price of oil and gasoline. What is the value of CCTs and the RFS? You decide.

"Advanced biofuels hold the potential to transform America's fuel supply, enhance our national security and energy security, reduce our carbon footprint, and foster economic growth in rural America. This is an enormous opportunity, and it will require the best efforts of many parties in many sectors — the federal government, national and university labs, state and local governments, and the private sector — to ensure that these multiple potentials are realized."

Dallas Tonsager, Under Secretary for Rural Development, USDA, Before the Subcommittee on Conservation, Credit, Energy, and Research, U.S. House Committee on Agriculture, October 29, 2009

Figure 8 **U.S. Petroleum Production Capacity and Demand**

The U.S. Has Growing Oil Demand and Only 3% of World's Oil Reserves.



Source: EIA Top World Oil Producers & Consumers. Available at http://www.eia.doe.gov/emeu/cabs/topworldtables1_2.htm; BP Statistical Review of World Energy, 2007

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DOE, USDA, EPA, Industry, POET, Abengoa, Range, BlueFire, CFDC, NGOs, Ethanol Across America, ACE, EPIC, RFA, Growth Energy, Stakeholder Organizations.

Endnotes: Electronic copies and links to reference materials used to produce this Issue Brief can be found on the Ethanol Across America Website at www.ethanolacrossamerica.net/cellulosicissuebrief

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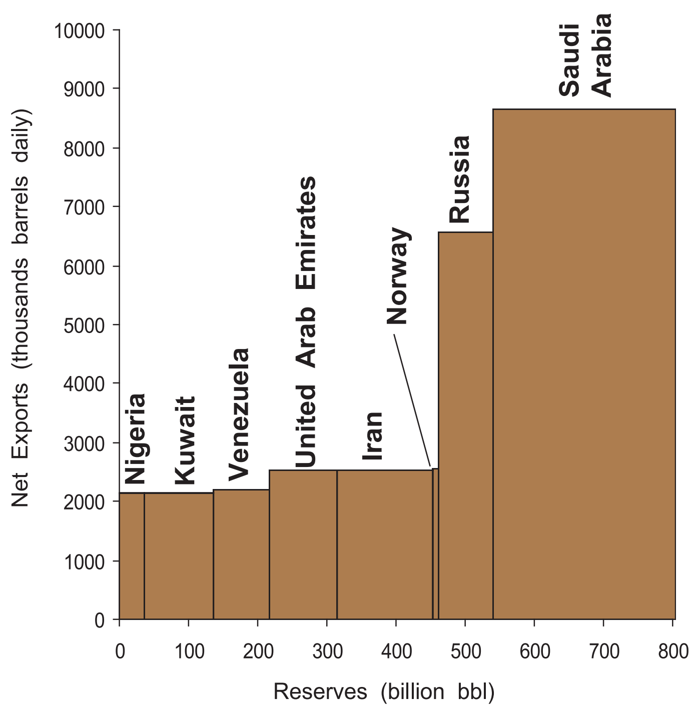
[11] The 2008 National Biofuels Action Plan developed by the interagency Biomass Research and Development Board http://www1.eere.energy.gov/biomass/ to get a PDF The Biomass Research and Development Initiative (BRDi) website provides information about the Board, the Technical Advisory Committee

Figure 9 **Top Eight World-Wide Countries for Petroleum Reserves and Net Exports**

From an Energy/National Security Perspective, The World's Oil Reserves Are Not Favorably Located.



Source: Department of Energy, EIA

(TAC), and the Initiative. The BRDi website is located at http://www.brdisolutions.com

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CCT Snapshots *continued*

ClearFuels *(cont. from pg. 13)*

The ClearFuels biomass-to-syngas thermochemical conversion technology is based on a one-step rapid indirect reformation process that uses steam instead of oxygen or air that is commonly used with most gasifiers. Company officials believe this approach holds capital and operating cost advantages as well as providing the flexibility to "dial in" the syngas composition that is desired for the production of diesel, jet fuel, ethanol, hydrogen, power, and other products.

ClearFuels, in combination with its technology partner Rentech, Inc., has the potential to produce significant volumes of direct substitute renewable jet fuels and diesel at competitive prices. The ClearFuels and Rentech technologies have both been proven in various demonstrations over the past 15 years. The next step is validation of the combined technologies of converting bagasse and wood waste to diesel and jet fuel at the Rentech Process Demonstration Facility in Colorado in 2010. This integrated biorefinery system can be employed across multiple regions of the United States and with a wide range of feedstocks. This investment will help improve the nation's renewable energy portfolio, and provide new jobs in rural communities.

Coskata

Coskata opened its semi-commercial cellulosic ethanol facility near Madison, Pennsylvania in October 2009. Coskata is uniquely partnered with General Motors Corporation and a plasma gasification technology company Alter NRG Corp., although it uses a hybrid of technologies. The "hybrid approach" to cellulosic ethanol is a combination of biochemical and thermo-chemical technologies—and the significance of being truly feedstock flexible.

Coskata employs a three-step technological process that is capable of converting multiple feedstocks including woody biomass, agricultural waste, energy crops, and construction/industrial wastes into synthesis gas. The syngas undergoes bacterial fermentation using Coskata's proprietary microorganisms, and is converted into ethanol without using enzymes. The entire process reduces greenhouse gases by about 96 percent compared with gasoline, and uses half the amount of water. The plant is co-located with a pilot-plant gasifier owned and operated by a unit of Calgary, Alberta's Alter NRG.

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