MAJOR CELLULOSIC BIOFUELS/BIOCHEMICAL ACTIVITIES IN THE U.S.

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The U.S. Federal policies are outlined. The programs of the Department of Energy (DOE) and Department of Agriculture (USDA) are drivers for a large number of projects. The impact of the anticipated budget cuts is uncertain. The RFS2 implementation of 2007 Energy Security and Independence Act (EISA) is helpful, but it is not currently a driver of future commercial facilities. The authors used their extensive data base, tours of many facilities, and DOE public information to provide an overview of 55 projects including 62 individual pilot, demonstration and proposed commercial facilities. They are grouped into biological and thermal technologies. Only information that could be validated was used. Key metrics are provided for demonstration and commercial facilities that are proposed for sugar and thermochemical platforms. Included are 11 commercial activities in bioproducts resulting from "natural platforms", such as tall oil and turpentine. This accomplishment offers an insight into the development of "by-product" businesses.

Keywords: US biochemical projects, US biofuel projects, key metrics and US Federal policies

INTRODUCTION

The purpose of the article is to provide a list of validated cellulosic biofuel and biochemical projects in the United States. Corn ethanol, vegetable and animal diesel and algae projects are not covered. Corn ethanol is commercial, and algae technology is emerging and needs to be added in the future.

The key metrics of selected cellulosic biofuel projects are listed and discussed. It is both difficult and unwise to make technical, economic and market evaluations based on key metrics alone. Evaluations can be made for projects, groups of like or dissimilar projects, ownership of inexpensive raw materials, or technologies. Evaluation and definitive conclusions represent a complex process done by experts in technology, finance and marketing.

Status of Federal Policy

One factor that dominates the fledgling biofuels/biochemicals industry is the U.S. Federal policy. The major U.S. policy is the "TARGET" of 36 billion gallons per year (Bgpy) of renewable biofuels, by 2022 articulated in the 2007 Energy Independence and Security Act (EISA). The critical items are listed below:

- 15 billion gpy corn-ethanol and 21 billion gpy of "advanced" biofuel. Included in the 21 billion gpy of advanced biofuel is the 16 billion gpy of cellulosic biofuels;
- None of the preceding targets are mandates;
- The controlling rules are primarily in the Renewable Fuel Standards 2 (RFS2) documents issued in the fall of each year by the Environmental Protection Agency (EPA);
- There is no requirement that involved Federal departments and agencies coordinate their activities;
- Therefore, the various U.S. regulations and incentives are presently a "patchwork".

In the U.S., the Department of Energy (DOE) has been the dominant Federal agency with 3 rounds of solicitations, individual awards and a loan guarantee program. In addition, the United States Department of Agriculture (USDA) is adopting its long standing rural development loan guarantee program to biorefineries. Through January 2011, there have been over 25 substantial grants and 4 loan guarantees to biorefinery projects and numerous research grants. USDA has also initiated a biomass crop assistance program (BCAP). It is unclear how anticipated budget cuts will impact these programs.

The U.S. Congress has passed a number of biofuel incentives. The ones for ethanol are typically in the Farm Bills and the cellulosic biofuel producer credits are typically in the Energy Bills. These are typically tax incentives from $0.35 per gallon to $1.01 per gallon. They are only paid for certified shipments and the incentives are valid for a few years. Therefore, these incentives are generally not of much help in raising investor funding for projects. If continued for longer periods of time, they will be of significant value in helping biorefineries meet or exceed their financial expectations.

EPA was empowered by Congress to track and enforce the goals in EISA. This program is called RFS2 (RFS1 was created for the 2005 Energy Policy Act). Each November, EPA mandates goals for the following year. Each gallon of biofuel is given a Renewable Identification Number (RIN) and the responsible parties (refineries and importers) must achieve their prorated RINs or fulfill their mandate by buying RIN credits. The RFS2 system is complicated and involved. EPA is given latitude in assigning mandates for the following year, so there is no certainty for the biofuel industry. Table 1 uses the 2011 mandate as an example, where units are in millions of gallons per year (Mgpy) or billions of gallons per year (Bgpy).

Cellulosic biofuels are derived from cellulose, while biomass-based diesel is derived from vegetable oil or animal fat. Advanced biofuels include all renewable materials, except corn ethanol. Consequently, cellulosic biofuels as well as biomass-based diesel and sugar cane ethanol, etc. are here included. Corn ethanol makes therefore the difference between advanced biofuels and total renewables. In the 2011 RFS2, the corn ethanol mandate is of 12.6 Bgpy (13.95-1.35).

The latitude given by EPA is illustrated by examining the 2007 EISA target for cellulosic biofuels – 250 Mgpy *versus* the 6.0 Mgpy target in RFS2 for 2011. This is a 98% miss of mandated *versus* target in 2011 for cellulosic biofuels. EPA said they were hopeful that the cellulosic biofuel industry would evolve. EPA has kept the EISA total for now by mandating higher volumes in other categories. EPA may also have the authority to waive certain targets. So, RFS2 and 2007 EISA are helpful but not drivers of future commercial facilities, because of the uncertainty of each year's mandates.

Definitions and limitations

In this article, pilot scale is defined as the liquid biofuels production up to 350000 gallons per year (gpy), while demonstration scale is the production from 0.5 to 5.0 million gpy (Mgpy), and commercial scale is the production over 8 Mgpy. These definitions have gaps, but all facilities discussed below fit these ranges. Tables 2 and 5 include the status and size of projects. Table 2 is for the sugar pathway and Table 5 is for the thermal pathway. Projects will be grouped by sugar and thermochemical platforms, with hybrid projects included in each according to major capital. A "Natural Platform" has been added for reference, not to lose sight of progress before the emphasis on biofuels and biochemicals.

Sugar platform

Unless otherwise noted, the sugar platform includes raw material acquisition, raw material preparation, raw material conversion to sugars, and sugar conversion to biofuels and/or biochemicals. Variations from this definition will be noted. Many of the sugar projects discuss the use of lignin for generating process heat and/or power. Lignin is included in several commercial projects, but typically not in pilot projects. No one has reported the development of a higher value commercial use for lignin.

The status of U.S. sugar platform facilities whose public information could be verified is shown in Table 2. The location is for the largest facility listed. "R" indicates running and "IP" indicates in progress (which includes a financing stage), while "SU" stands for startup. Capacity is given in gallons of ethanol, unless otherwise stated. Each project is tracked by BDC and additional data, like Operational Expense (OpEx) and Capital Expense (CapEx), are available for many demo or commercial projects. Their inclusion makes most charts unreadable.

Thermal and mass conversion efficiencies are typically not public information and are not included. DOE National Renewable Energy Laboratory (NREL) studies have calculated thermal efficiencies for standalone sugar biorefineries in the 30 to 35% range.[1] Mass efficiencies (usable mass divided by dry raw material mass times 100 percent) can be calculated from yields. Typically, they are between 25 and 35%, with higher mass efficiency obtained from lower lignin content raw materials. The use of lignin as fuel or a product will increase these numbers.

Table 2 shows significant and varied activities. For example, the Abengoa project involves the production of electricity.

Table 1
RFS2 mandates for 2011

Cellulosic biofuels, Mgpy	Biomass-based Diesel, Bgpy	Advanced biofuels, Bgpy	TOTAL renewable, Bgpy
6.0	1.2	1.35	13.95

Table 2
Status of 32 sugar platform projects[2,3]

Company	Location	Pilot capacity (XX Mgpy)	Demonstration capacity (XX Mgpy)	Commercial capacity (XX Mgpy)	Grant and/or loan guarantee
Abengoa	York, NE	R		IP (25.0+18 MW power)	G+LG
ADM	Decatur, IL	IP (1ptd feedstock)			G
AE Biofuels	Butte, MT	R (0.15)			
American Process	Alpena, MI		IP (0.76+0.8 potassium acetate)		G
Auburn Univ.	Auburn, AL	IP (0.035)			
Blue Fire Renewables	Fulton, MS	R-Japan	IP	IP (19.0)	G+LG
BP Biofuels	Highland Co., FL	R	R (1.5)	IP (36.0)	
Cobalt Tech.	Golden, Co	R (0.001 n butanol+other)			
Colusa BioEnergy	Stuttgart, AR			IP (12.5 Mgpy)	
HCL-Cleantech	Durham, NC	R (0.004)			
Iogen	Ottawa, Can.		R (0.5)		G
DuPont-Danisco	Vonore,TN	R (0.25)			
Edeni Q	Visalia, CA	PI (0.005)			
Fiberight	Blairstown, IA	R	IP (5)		State G
ICM	St Joseph, MO	IP (0.26)			G
Iowa State Un.	Boone, IA	R (0.05 lube oils)			State G
KL Energy	Upton, WY	R	R (1.5)	IP (Brazil)	
Lignol	Burnaby, Canada		R (2.0+lignin)		G
Logos	Visalia, CA	R (0.05)			
Mascoma	Kinross, MI	R		IP (40.0)	G
Myrant	Lake Provident, LA	R		IP (30M # succinic acid)	G
Old Town Fuel and Fiber	Old Town, ME	R	IP (5 acetic acid+n butanol+other)		G
Osage Energy	Hopewell, VA			SU (65.0)	
Pacific Ethanol	Boardman, OR		IP (2.7)		G
Poet	Emmetsburg, IA		R	IP (25.0)	LG
Qteros	Chicopee, MA	Small			
Segetis	Golden Valley, MN	R (0.013 luvulinic acid)			
Terrabon	Bryan, TX	R9 (O.09)			

Univ. FL /Buckeye	Foley, FL	R (0.14 undefined)		
US Environmental Fuels	Highlands Co., FL		IP (20)	
Virent Energy	Madison, WI	R (0.010)		
ZeaChem	Boardman, OR	IP (0.25)		G

The sugar pathway approaches are well covered, as there are at least 20 significantly different techno-economic procedures. Significant learning and key metrics will evolve. The technology to achieve commercial success also continues to evolve. In February 2011, DOE Peer Review of funded integrated biorefinery projects, the largest barrier to progress for sugar platform projects, was achieving financing, not solving technical issues. Key metrics will help explain why this happens.

Some key differences among projects are worth highlighting. In Alpena, the host collects and transfers raw material to American Process, who then prepares sugars and converts them to ethanol and biochemicals. KL Energy economically produces premium pellets from one of their commercial designs. This co-product potential gives this approach an exceptionally high mass and energy (BTU) yield. The Myrant project is targeted to produce 30 million pounds per year of succinic acid, for 3 months, to fill the DOE requirements, and will presumably produce higher value-added chemicals.

For US Environmental Fuels, the raw materials used are sugar cane and sorghum, and the processes are commercial in other countries.

The Segetis project will produce luvulinic acid. The Virent Energy development starts with sugars purchased or produced in another process.

There are some unique projects included in Table 2. Cobalt Technology begins with sugars and uses unique technology to convert them to chemicals including n-butanol. The selling price of these products is different from that of ethanol and will be an exception to the ranges used in Table 4. EdeniQ is developing a low CapEx approach to adding corn fiber to the ethanol process in corn ethanol plants. Old Town Fuel and Fiber will extract hemicellulose from pulp wood chips prior to digesting. They will also convert the hemicellulose to chemicals including n-butanol, which will have a higher selling price shown in Table 4. One can look at yield as the part removed from the existing pulpwood, or as part of a small volume of additional wood required. The latter gives high benchmark numbers. Osage Energy (now shut down) worked with farmers to produce a second crop of winter barley, so that the land can continue to be used for its original purpose. The resulting ethanol qualifies as an advanced biofuel. Qteros, while still at an early stage, has developed a microbe that converts any cellulose to ethanol. Environmental Fuels also produces ethanol, which qualifies as an advanced biofuel because they use sorghum. Virent begins with sugars and uses a catalytic reduction to ethanol, gasoline or other chemicals. ZeaChem is actually a hybrid technology as there is a gasifier on internal streams and the hydrogen is used to enhance yield and products. In the pilot line, hydrogen will be in bottled form. Isolation of lignin and the development of markets for it offer an upside to all processes that use cellulosic biomass feedstock. The lignin content is lower for grasses and the highest for wood. A session in the Third Nordic Wood Biorefinery Conference covered lignin for those who had an interest in the sugar pathway.

Table 3
Summary of validated sugar platform facilities in the U.S.

18	Pilot plants running
4	Pilot plants in progress
4	Demonstration facilities running
5	Demonstration facilities in progress
0	Commercial plants running
6	Commercial plants in progress

Table 4
Range of key metrics for demonstration and commercial projects[2,3]

Conversion pathway	CapEx ($/annual gallon)	OpEx ($/gallon)	Liquid yield (g/dry short ton)	Additional products	Product selling price (% gasoline)
Acid hydrolysis then fermentation	17	0.90-1.00	70-74	Possible, not planned	70-80
Enzyme hydrolysis then fermentation	10-15	1.50-2.50	50-82	Possible, and proposed	70-80

Table 4 shows the range of 4 key metrics for the above demonstration and commercial projects/facilities, as they are now being proposed.

The above data and the planned developments indicate that the DOE OpEx goal of $1.12 per gallon will be achieved.

There is a widespread belief that the lowest CapEx for biofuels occurs *via* the sugar platform. However, the data in Table 4 do not support this. The above data and the stated expectations indicate that the CapEx for lignocellulose-based biorefineries will not approach those of $2.0 to $3.0 per annual gallon for corn ethanol this decade. Advanced thought leaders are now focusing on integrating the cellulosic biorefinery with another facility, which runs 24 h per day and 7 days per week (24x7), mostly ethanol plants. In this integration, the use of Combined Heat and Power (CHP) would be greater. The CHP concept is included in several of the demonstrations and commercial plants listed above.

The key metric range for the N^{th} plant requires significant assumptions beyond the scope of this article. Assumptions for N^{th} plant metrics are best made by individuals involved in detailed analysis. The product selling price does not include any state and federal incentives.

Thermochemical platform

Unless otherwise stated, the thermochemical platform includes material acquisition, raw material preparation, raw material conversion to gases, gas cleanup and gas to liquid conversion (GTL). Because the raw material is almost immediately oxidized and the subsequent processes can be exothermic, high thermal efficiencies contribute to overall economics. Thermochemical biorefineries co-located with steam hosts, which operate 24x7, have shown that thermal efficiencies of 70+% can be reached even in small scale facilities. Fuels produced *via* the thermochemical process are Fischer-Tropsch (F-T) liquids, primarily diesel and premium wax.

Table 5 also shows significant and varied activities with fewer projects than the sugar platform.

With significant coal gasification experience and subsequent F-T, more is known about some of the thermochemical technologies. Also, demonstration scale and commercial scale plants gasifying black liquor (a very caustic solution of biomass) are operating at Smurfit Kappa in Pietà (Sweden) and at Norampac, in Trenton (Ontario, Canada).

The GTI project is a small research-like event, where a new process converting biomass to gasoline products will be evaluated. If successful, a demo project will be proposed. The Ensyn project produces pyrolysis oil or bio-oil whose low pH has been mitigated. This product can be burned in commercial boilers or developed into gasoline, diesel or refinery oil. The KiOR project uses catalytic cracking to go directly to the refinery oil.

Even though integration with a steam host offers significant economic advantages to pure thermochemical projects, only Flambeau River Biofuels, New Page and Powers Energy have announced integration plans.

Hybrid projects use gasification to produce a syngas that only needs a mild cleanup to go into the rapid fermentation process. Hybrid projects have reported that only a few seconds are necessary for the molecules of biomass to be gasified and transformed into ethanol. Replacement of chemical conversion with a biological process reduces the CapEx. However, the production of ethanol can potentially result in a lower selling price than diesel. There is some indication that RFS2 mandates will put cellulosic ethanol at a premium price.

Table 7 shows the range of 4 key metrics for the above demonstration and commercial projects/facilities, as they are now being proposed. The selling price does not include any state or federal incentives. There were fewer projects and fewer data points, so that the information in Table 7 may not be rigorously representative. However, the indications are that the DOE OpEx goal of $1.12 per equivalent ethanol gallon will be achieved.

For thermochemical projects, CapEx is in the same range as those in the sugar platform, and both are significantly higher than corn ethanol. The yield for projects recovering heat and power for sale must be adjusted, as not all input BTUs are converted to a liquid product, which will be very project specific. BTU yields can exceed 70%. Lignin is not an issue in the thermochemical platform, because it is converted into syngas.

Table 5
Status of 20 thermal platform projects[2,3]

Company	Location	Pilot capacity (XX Mgpy)	Demo capacity (XX Mgpy)	Commercial capacity (XX Mgpy)	Grant or loan guarantee
Assured Aerospace	Wright AFB, OH	IP (0.01 diesel)			
Coskata	Madison, PA		R (0.04 Ethanol)	IP	
Enerkem	Ponatoc, MS	R	IP	IP (10 ethanol)	G+LG
Gulf Coast Energy	Livingston, AL	R (0.2 ethanol)			
GTI	Des Plaines, IL	IP (small-gasoline)			G
Ensyn	Renfew, Canada	R (0.017 bio-oil)			
Flambeau River Biofuels	Park Falls, WI	R-TRI		IP (17.5F-T liquid+1.3T BTU+8 MW power)	G seeking LG
Fulcrum	Story Co, NV	R		IP (10.5 ethanol)	
KiOR	Mississippi	R		IP (TBD refinery oil)	State LG+ Fed. LG
New Page	Wi. Rapids, WI	R-TRI		IP (8.5 F-T liquid+steam+power)	G
Range Fuels	Soperton, GA	R	R (3.3 methanol+ ethanol)		G+LG
REII	Sacramento, CA	IP (0.5 diesel)			G
Rentech – ClearFuels	Commerce City, CO	IP (0.35 jet fuel, etc.)			G
Rentech	Rialto, CA		IP (1.7 F-T Liquids)		
Topsoe	Des Planes, IL	IP (0.34 gasoline)			G
ThermoChem Recovery Int.	Durham, NC	R (0.01 FT liquids)		FRB and NP Projects	
UOP/Ensyn	Kapolei, HI	IP (small-refinery oil)			G
West biofuels	San Diego, CA	IP (0.18 FT Liquids)			
Hybrid – gasification followed by fermentation					
Coskata	Madison, PA		R (1.5 ethanol)	Announcing	
INEOS	Vero Beach, FL	R		IP (8.0 ethanol)	G
Powers Energy	Lake Co, IN			IP (32.0 ethanol)	

Table 6
Summary of validated thermal platform facilities in the U.S.

7	Pilot plants running
7	Pilot plants in process
2	Demonstration facilities running
2	Demonstration facilities in progress
0	Commercial facilities running
7	Commercial facilities in progress

Natural platform

A frequently overlooked aspect of the commercial biochemical activities in North America includes the traditional businesses born from the by-products of pulping and papermaking. These businesses have a long and sustainable history of market value and commercial significance, supplying critical chemical intermediates and products. They represent true examples of potential, when ingenuity is coupled with the need to develop a technology meeting the environmental and market demands. Also, these businesses support a multibillion dollar industry in the U.S., built on biomass and biochemical processes.

The historical significance of these businesses can be borne from the fact that rosin was declared a critical raw material in WWII, due to the need for the production of paper sizing. Today, activated carbon produced from sawdust prevents 1 billion gallons of gasoline from evaporating into the air each year, by capturing vapors from automobiles, followed by their combustion, due to the unique release capabilities of carbon.

Table 7
Range of key metrics for demonstration and commercial projects[2,3]

Conversion pathway	CapEx ($/annual gallon)	OpEx ($/gallon)	Liquid yield (g/dry short ton)	Additional products	Product selling price (% gasoline)
Conventional thermochemical	11.4-17	1.00-2.00	38-54	Included	130-150
Hybrid thermochemical	10-16	1.70	80-90	Possible, not proposed	70-80

Table 8
Status of 11 natural platform facilities

Process	Company	Location	Raw material	Published capacity (TPY)	Markets
Biorefining	MWV	Charleston, SC	Tall oil	105000	Lubricants, Paper Sizing, Adhesives, Inks, Rubber, Detergents, Oil Field, Asphalt
	MWV	Charleston, SC	Lignin		Dispersants, Textiles, Agriculture, Masonry, Asphalt
	Arizona	Savannah, GA	Tall oil	200000	Coatings, Fuel Additives, Oil Field, Surfactants, Lubricants, Ink Solvents, Adhesives, Roadmarking, Neutraceuticals
	MWV	DeRidder, LA	Tall oil	127000	Coatings, Oil Field, Paper Sizing, Detergents, Roadmarking, Adhesives, Inks, Lubricants
	Renessenz	Brunswick, GA	Turpentine		Flavors, Fragrance, Resins
	Arizona	Panama City, FL	Tall oil	82000	Coatings, Oil Field, Adhesives, Alkyds, Polyamides, Lubricants, Roadmarking
	Arizona	Panama City, FL	Turpentine		Flavors, Fragrances, Ink Binders, Adhesives
	Georgia	Crossett, AR	Tall oil	118000	Mining, Oil Field, Rubber,

	Pacific				Adhesives, Paper Sizing, Coatings, Lubricants
	IFF	Jacksonville, FL	Turpentine		Flavors, Fragrances
Bioconversion	MWV	Covington, VA	Sawdust		Activated Carbon for Automotive and Environmental Control, Air Purification for Control Rooms
	MWV	Wickliffe, KY	Sawdust		Activated Carbon for Automotive and Environmental Control, Air Purification for Control Rooms

CONCLUSIONS

- There are a large number of varied projects in all pathways.
- It is likely that the DOE OpEx goal of $1.12 per ethanol equivalent gallon will be met.
- A CapEx goal is needed with equal emphasis, as it may prove that capital costs to refine the necessary molecules will always be cheaper than growing the unnecessary molecules and transforming them.
- Biorefineries will always incur a penalty for scale, as economic harvest radius makes them small compared to petrochemical refineries.
- The quantity of projects in the U.S. is due to federal grants and loan guarantees.
- Information from federally funded projects will generally be available, which is expected to facilitate additional projects.
- There is a lot of information and unsupported claims in biorefining. Organizations, such as the Bioenergy Deployment Consortium, provide value by screening reports, validating claims and organizing tours of operating facilities.

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