The Verdict Is In: Biofuels Boom
by
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Abstract

Biofuels are liquids, gases or that are made from renewable sources. Petroleum-based liquid transportation fuels represent the largest segment of imported energy. The technology is here for liquid biofuels to replace petroleum-based transportation fuels and we are now seeing attention to this needed and promising energy source.

The consensus forecast on world oil availability is changing because, for the first time, the annual increase in oil demand exceeds the annual discovery rate of new oil. In the U.S. both the President and Congress have established renewable fuel standards that go well beyond the capability of corn-based ethanol. The need for "advanced biofuels" is being quantitatively forecasted by many. Past commercial activities show that cellulosic ethanol can be cost effectively produced on a commercial scale.

Numerous studies and data has been collected and reviewed. Current process pathways to produce "advanced biofuels" are presented. A comprehensive summary of commercial North American activities in biofuels, bioenergy production, and the biorefinery is presented. A comparison of the 2007 U.S. Department of Energy (DOE) funded projects with "Section 932" grants is presented. An understanding of technical and commercial activities is used to predict both short-term and long-term winning approaches.

Looming National Priority

Biofuels are liquids, gases or that are made from renewable sources. Some also want to consider the power made from reclaimed heat as a fuel for hybrid cars. In the U.S. the most predominate biofuel is ethanol derived from corn. Other sources include ethanol derived from cellulose and biodiesel derived from vegetable oils or animal fat. Still other sources include biodiesel, biogasoline and fuel feedstock made from a catalytic reaction like the Fischer-Tropsch process. Petroleum-based liquid transportation fuels represent the largest segment of imported energy[1] but liquid biofuels can replace these transportation fuels and they are beginning to receive attention and emphasis. Liquid biofuels are becoming one of our best options for energy independence and they need to become a national priority.

Key Drivers In Energy Forecasting

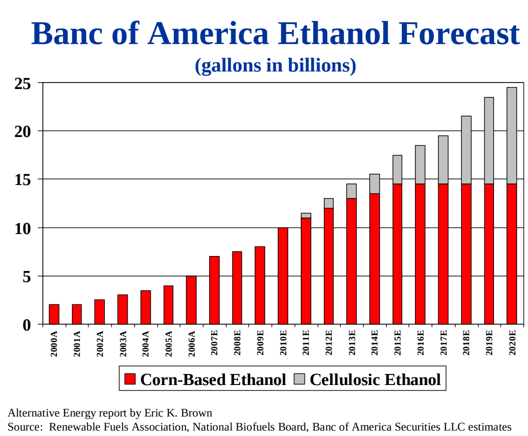
Many notable forecasters use historical data because the information is solid and reliable. Recently these forecasts have not predicted market behavior. These forecasts came under renewed criticism in October of 2005 when Samuel Bodman, the Energy Secretary, asked Lee Raymond, then Chairman of Exxon Mobil, some fundamental questions about the future of the US oil and gas supply. Lee Raymond, who was also head of the Federal Energy Council (a federal advisory group representing the oil industry), was determined to provide better and more comprehensive answers to our energy future. His work, took nearly two years and involved 350 participants and suggestions from over 1,000 people and submissions by 19 foreign governments. This research resulted in a colossal 476 page report entitled "Facing the Hard

Truths About Energy". Important fact based conclusions include the determination that world annual increase in oil and gas demand NOW exceeds world annual discovery rate[2]. When fundamentals as basic as this change statisticians knew that the forecasts based on old data could no longer be used alone. This fundamental change had to be analyzed and taken into consideration when new forecasts were developed. The council's report calls for expanding and diversifying traditional supplies of oil, natural gas, coal and nuclear power. It also calls for the development of alternative fuels including biofuels like ethanol and gas to liquid fuel feedstock (e.g., Fischer-Tropsch liquids). Simply stated, if the world continues to increase its use of oil and natural gas at just the current rate, oil and gas supplies will become inadequate in the next few years. There will be a combination of events that will bring supply and demand into balance. One is that prices will rise until demand equals supply. As oil prices increase, alternative fuels will be developed and commercially produced to help meet demand. Obviously, these and other events will occur simultaneously. This will make forecasting more difficult going forward.

Each country has and will address its situation differently. In the U.S., the President has publicly promoted a 20-10 goal. That goal is for America to reduce gasoline use by 20% in 10 years. This will require 35 billion gallons of renewable fuel by 2017. However, this is not yet law. The Senate version of the 2007 energy bill has a goal of 36 billion gallons of renewable fuel by 2023. Of this 36 billion, only 15 billion gallons are corn-based ethanol while the other 21 billion gallons are "advanced biofuels" [3]. These goals are very similar and most predict they will become law by the end of 2007 or early 2008. Once law, rules will be adopted to monitor compliance and ensure that the goals will be met.

These and other serious events have caused many organizations to study the biofuels area to determine their course of action. Independent groups like financial institutions are studying biofuels to determine investment opportunities. Figure 1 below is a graph from the executive summary of a Banc of America Study showing their forecast for corn-based ethanol and cellulosic-based ethanol[4].

Figure 1



The implications of forecasts like this imply that the rapidly growing corn-based ethanol market will stabilize and the next growth market will be based on cellulosic ethanol. This is not a blanket financial endorsement and there are financial concerns that are unique to each market segment.

What Is A Biorefinery And What Are The Product Pathways?

In the material which follows there will be several key phrases that will be used repeatedly. Figures 2 and 3 below will define key concepts and will add clarity for that which follows.

Figure 2

Key Definitions

- **Bioenergy is the production of steam and power from biomass.**

  Conventional Bioenergy is typically done with solid fuel boilers and produces steam (and some power from that steam).

  Modern Bioenergy projects use technology like gasification which allows displacement of the most expensive fuels, like natural gas.

- **Biorefinery is a biomass facility that uses distillation, cracking or chemical separation to export energy from the facility.**

Figure 3

Key Definitions

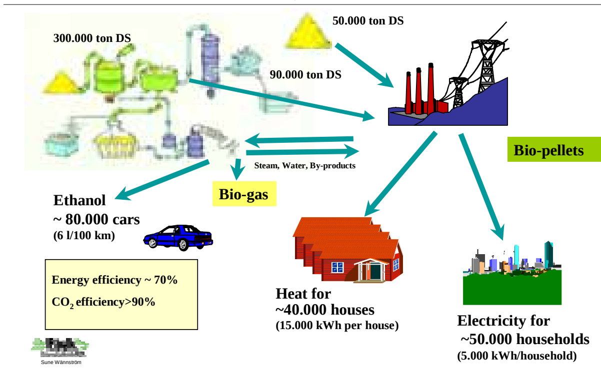
- **The current DOE strategy defines two technology platforms:**
  1. **Thermal Platform**
  2. **Sugar Platform**
- **There is a third:**

  3: Chemical Platform

Cartoon-like drawings such as Figure 4 below are used to give the public a conceptual view of things like a biorefinery.

Figure 4

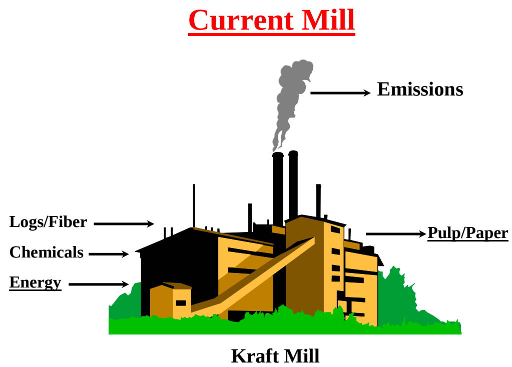
Integrated Bioenergy Plant for Ethanol, Electricity and Heat Production



We are familiar with them because they work their way into the media. Biorefineries will be quite different. They will each use specific raw materials, have specific processes and will make specific products. There are at least 12 pathways for which there is hardware on the ground or at least proposed commercial facilities where money has been appropriated or identified.

Let's begin by looking at a starting and ending point for a forest-based biorefinery. Examples from other industries are also possible. Figure 5 shows the major inputs and outputs for a modern pulp and paper mill.

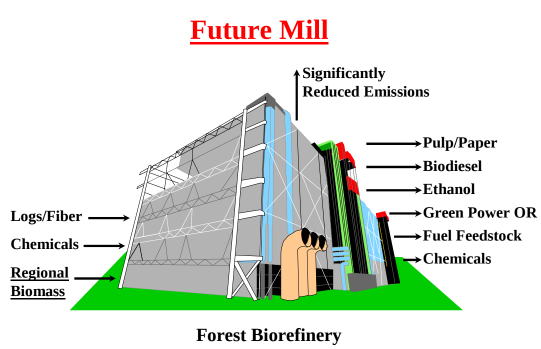
Figure 5



Note that one of the major inputs is energy. An integrated pulp and paper mill's thermal demand is typically 40% fossil fuel and 60% biomass, which is largely from combustion of black liquor.

Figure 6 shows the inputs and outputs for an integrated forest biorefinery.

Figure 6

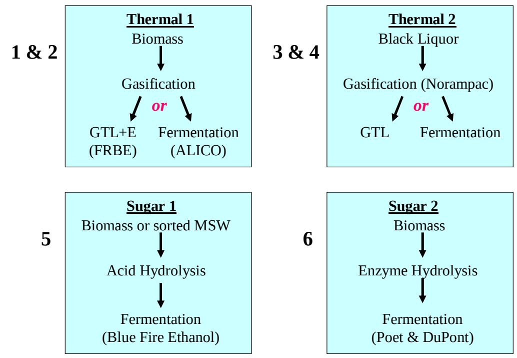


Note that there is no longer an input for fossil-based energy. The pulp and paper facilities will now run on recovered heat from the biorefinery. As will be discussed later, this aspect of integration is critical because it represents an important revenue stream for the biorefinery. The outputs include one or more "green" fuels or "green" chemicals which are being increasingly valued as an energy source.

Figure 7 shows 4 biorefinery building blocks (process pathways) for integrated biorefineries.

Figure 7

4 Biorefinery Building Blocks (Process Pathways)



The first pathway starts with biomass as the raw material. The biomass is gasified by placing it in a receptacle with controlled and limited oxygen and applying external heat. The result is that the organic portions decompose into a gas composed of hydrogen, carbon monoxide and carbon dioxide which is called syngas. After gas cleanup, it is chemically the same as syngas that is derived from the gasification of coal which has been done for 50 years in South Africa. There are two choices for the treatment of syngas and the cost of equipment dictates that each facility will have to choose one pathway or the other, but not both. The left pathway is to use a gas to liquid process (GTL) like a Fischer-Tropsch catalytic reactor. This produces a sulfur-free, multi-molecular fluid that is chemically superior to “Texas light sweet crude”. It can be further processed to biogasoline, biodiesel or a variety of other bioproducts. South African Synthetic Oil Ltd (SASOL) has been doing this for 50 years. This is also the process that has been proposed for Flambeau River Biofuels adjacent to Flambeau River Papers in Park Falls Wisconsin. This “Thermal 1” pathway has also been selected by the Stora-Neste JV and the UPM-Carbona JV in Europe.

The second pathway (right fork) will ferment the syngas making a variety of products that will be illustrated in Figure 15.

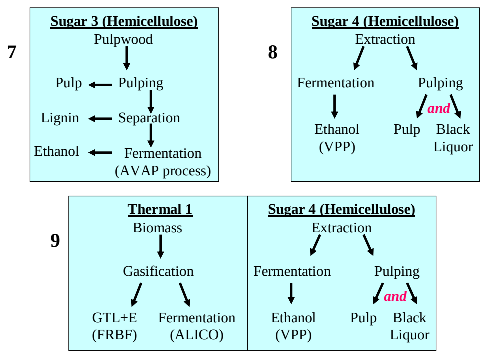
Pathways 3 and 4 are similar to pathways 1 and 2 except that black liquor is used as the raw material. This is a tougher application for gasifiers because black liquor is much more corrosive than biomass. Norampac in Trenton, Ontario, Canada is now gasifying all of their carbonate black liquor in a TRI low temperature “Steam Reformer” and burning the syngas in existing gas boilers. For about 10 years, Weyerhaeuser in New Bern, North Carolina has been gasifying approximately 15% of their Kraft black liquor in an atmospheric, high temperature gasifier produced by Kaverner-Chemrec.

Pathway 5 is based on a sugar technology platform. This starts with biomass as the raw material. The acid hydrolysis is so powerful that sorted municipal waste can also be used. The acid converts compounds like cellulose to sugars which can be subsequently fermented to ethanol or other chemicals. This process has been developed by Blue Fire Ethanol and demonstrated at a pilot plant in Japan. A full scale plant is planned for southern California. Pathway 6 typically takes a different raw material like corn stover or wheat straw and converts the compounds like cellulose into sugars by enzymatic hydrolysis. Subsequently they can be fermented into ethanol or other chemicals. This will be done by Poet (formerly Broin Industries) and DuPont. For all process pathways, yield may be fractionally lower when both 5 and 6 carbon sugars are fermented.

Figure 8 shows 3 pathways based on isolating just the hemicelluloses and fermenting them to ethanol or other chemicals. This hemicellulose pathway has not been recently developed but older versions are commercial.

Figure 8

3 Biorefinery Building Blocks (Process Pathways)

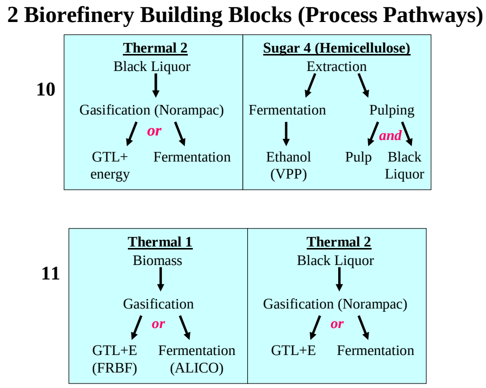


Pathway 7 starts with debarked pulpwood chips which are pulped with a unique AVAP^{TM} process. The cellulose is bleached and sold as chemical grade dissolving cellulose or market pulp both of which have a higher selling price per pound then ethanol. Next, the lignin is removed from the pulping liquor and used to fuel the entire process. Next, pulping chemicals are removed and the resulting broth is rich in monomer hemicelluloses which are subsequently fermented to ethanol or other chemicals.

This is a good place to note a fundamental difference between some of the processes. Pathway 7 separates the biomass which in this case is wood into its 3 naturally occurring chemicals namely lignin, cellulose and hemicellulose. Each can be sold into markets for their maximum value illustrating the powerful concept of co-production. Gasification also uses all of the incoming raw material and chemically manipulates the output into products of increased value.

Pathway 8 is called value prior to pulping and is under development by a consortium of paper companies, universities, DOE and USDA being led by Clean Tech Partners in Middleton, WI. In this pathway wood chips are exposed to a water-based extraction phase prior to pulping in order to remove a portion of the hemicelluloses. This process must preserve both pulp yield and strength which has only been demonstrated for hardwoods. The hemicelluloses are taken to a separate process and are fermented to ethanol or other chemicals. The chips are taken to the Kraft process which can be operated with lower energy consumption and less load on the recovery boiler.

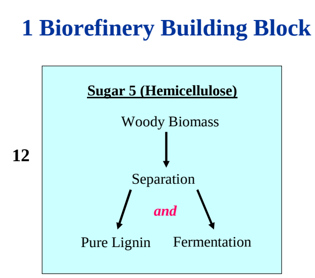
Figure 9



Pathways 9, 10 and 11 in Figures 8 and 9 are combinations of pathways 1 to 8, which can be economically and technically combined. Even these simple block flow diagrams (which do not show all of the steps like gas cleanup or reuse of the water after fermentation) demonstrate that biorefineries will be quite different from each other and far more complex than can be shown in conceptual diagrams.

Figure 10 shows the last of the 12 processes.

Figure 10



This process starts with woody biomass which is treated with a patented separation process. The lignin is separated without being exposed to sulfur or severe oxidation conditions. This pure lignin is sold at a higher price than ethanol into markets which require purity. The remaining cellulose and hemicellulose is fermented to ethanol or other chemicals. This is another example of a process with co-products.

Based on raw material costs, reported yields and operating cost estimates, it is possible to predict at least SOME of the short-term winners. Let's look at basic economics. The most common yield reported is about 80 gallons of biofuel per bone dry ton of biomass. The most frequently used selling price for ethanol is about $2.00 per gallon. This gives a revenue stream of $160 per bone dry ton of raw material. This revenue must pay for raw material procurement, utilities, labor, marketing, debt payment, etc. Just a few calculations will illustrate that **a revenue stream of $160 per bone dry ton leaves little or no profit margin.**

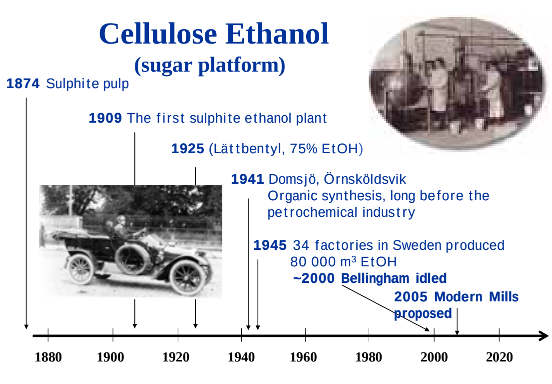
Therefore, the profit can only come when there is a unique situation of free raw material (like the Blue Fire business model) or when the chosen process produces another high value product like cellulose, lignin, or salable recovered heat that offsets expensive fossil fuel. Pathways 1, 7, and 12 have one of these co products. Pathway 8 does as well, but may have raw material limitations. It appears that the short-term winners will use these pathways 1, 7 and 12 or have unique raw material situations. Short-term means those biorefineries which are being built now or will be built in the next few years.

Long-term means those facilities whose construction will start in approximately 5 years and will begin production in approximately 7 years. Currently there are processes being developed based on the chemical technology platform. Most are emerging and typically proprietary so we do not hear much about them. One of the more promising features of the longer term chemical processes are yields exceeding 120 gallons per bone dry ton of raw material. An example of an older chemical technology is BioOil. An example of a newer emerging technology can be seen at www.Virent.com. Long-term, perhaps 7 to 10 years from now, the winners will be based on one or more of these chemical technology platforms **plus cleverly integrated short-term winners**. It appears that there will be other long-term winners, but they are likely to be based on "niche" situations.

Brief Historical Perspective

Corn, potato, juniper and other biobased alcohols have been produced for centuries. The price for "adult beverages" has supported their costly process. What has not been properly understood is available technology like scale-up. Even cellulosic ethanol has been available in commercial quantities since 1909 as depicted in Figure 11 which was "borrowed" from the Swedes.

Figure 11



Ethanol was made in traditional softwood sulfite pulp mills which sold their lignin and fermented the 6 carbon sugars in the residual liquor to ethanol. The 5 carbon sugars went with the effluent. Current mills with a biorefinery capability are shown in Figure 12.

Figure 12

Sulfite Mills with Biorefinery Capability
(sugar platform)

- **GP, Bellingham, USA (1945 to ~2000)**
- **Tembec, Temiscaming, Canada**
- **Borregard, Lingo-Tech, Norway**
- **Borregard, Ligno-Tech, South Africa**
- **Domsjo, Sweden**
- **Nippon Specialty Chemical, Japan**
- **Flambeau River, Hardwood Line, USA**

Flambeau River Papers, Park Falls, WI has a traditional hardwood sulfite pulp mill. The wood is rich in 5 carbon sugars. Xylose (a 5 carbon sugar) and saleable lignin are extracted from the red liquor off-site. The xylose is then converted to xylitol. Traditional sulfite pulp mills are high cost and are decreasing in number. Because they are regarded as "passé industry", additional research in this area has not been easily approved for funding. Therefore, improvements have been minimal. Recent activity suggests that hemicellulose sugars can be more efficiently extracted from both the sulfite and Kraft liquor cycles more efficiently than previously thought.

The commercial thermal conversion experience in pulp and paper is largely in North America. Weyerhaeuser at New Bern, NC has a high temperature, atmospheric pressure Kraft black liquor gasifier running to boost capacity for several years. There is a recent installation of a low temperature gasifier supporting the entire mill at Norampac in Trenton, Ontario, Canada.

There are 3 conventional BioEnergy projects which are noteworthy because these non-integrated mills have become fossil fuel free. They are Jackson Paper, Sylva, NC, Gray's Harbor Paper, Hoquiam, WA, and Catalyst Paper, Port Alberni, British Columbia[5]. The technology is biomass acquisition and level use of steam during sudden machine outages. Also note that these are small and mostly independently-owned mills. The technology development and implementation pathway of small, independent mills verses large corporations has been markedly different.

While biomass gasification may be relatively new to pulp and paper, it has been used by other industries in North America for 25 years. Figure 10 shows there are at least 18 biomass gasifiers in commercial operation in North America in industrial applications[6].

Figure 13: **Partial List of Commercial Biomass[a] Gasifiers in North America (Plus 4 Interesting European Installations)**

Technology Provider	Start Year	No. Units	Amount & Type Biomass	Owner	Location	Use of Syngas
1. TRI	1980's	1	~1 tpd-any	Pilot Line	Baltimore MD	Analysis & trials. 1st unit in CA, 2nd in MD
2. PRM Energy	1982/3	2	125tpd-rice hulls	Pro.Rice Mills	Stuttgart, AR	Exhaust dries rice and steam boils rice
3. EnvirOcycler	1982/3	2	135 tpd wood waste	Norboard	Solway, MN	Heats MEC rotary dryers
4. Homemade[b]	1993	1	900 tpd biomass	GB Packaging	Morrilton, AR	Steam turbine, then 270,000 #/hr to the mill
5. PRM Energy[c]	1995	1	570tpd rice hulls	Pro.Rice Mills	Greenville, MS	7.5 MW power + steam boils rice
6. PRM Energy	1996	1	30 tpd-any	Pilot Line	Tulsa, OK	Analysis & trials-uses PRM technology
7. PRM Energy	1996	3	550 tpd-rice hulls	Riceland	Stuttgart, AR	15 MW steam turbine + 100,000 #/hr steam for the soybean processing plant
8. PRM Energy	1997	1	175 tpd-rice hulls	Riceland	Jonesboro, AR	Exhaust dries rice, steam boils rice
9. Ethopower[d]	1997	1	~20tpd-wd.shavings	Canfor Wood	Smithers, BC	Space heating for remanufacturing plant
10. EPI-modified	1998	2	150 tpd msc biowaste	BFC G&E	Ankeny, IO	Steam used to make salable power
11. Ethopower[d]	2001	1	~15-wd.shavings	Princeton Wd	Princeton, BC	Exhaust from combustor to lumber kiln
12. Nexterra	2004	1	15 tpd-any	Pilot Line	Kamloops, BC	Analysis & trials
13. ChipTec (with modifications)	2004	1	240 tpd 60% wet wood waste & bark	Marion Plywood	Marion, WI	Close-coupled gasifier, the syngas fuels a conventional 900 HP triple pass boiler
14. PRM Energy	2005	1	67 tpd sewage sludge	City	Philadelphia, PA	Dries bio-solids from 90% moisture to 10%
15. PRM Energy	2005	1	66 tpd carpet waste	Shaw Carpet	Dalton, GA	50,000 #/hr steam for manufacturing
16. PRM Energy	2006	1	240 tpd wd waste[e]	Minn. Ethanol	Little Falls, MN	1 MW steam turbine + drying DDG
17. Nexterra	2006	2	40 tpd wd. waste	Tolko Ind.	Kamloops, BC	Exhaust from oxidizer to vainer drying, steam to log conditioning
18. GEM (UK)	2007	1	66 tpd crum rubber	Intrinergy	Coshocton, OH	Syngas to Clow Pipe for gas boilers
19. Nexterra/JCI	2007	3	312 tpd wood waste	U of S.C.	Columbia, SC	Steam for campus heating+1.38 MW to grid
Black Liquor Units						
20. Chemrec[f]	1996	1	~300-tpd bl solids	Weyerhaeuser	New Bern, NC	Syngas goes to multi fuel boiler
21. TRI	2003	1	126 tpd bl solids	NorAm Pac	Trenton, ON	Syngas to gas boilers
Notable European Units						
E1. KavernerCFB	1986	1	75 tpd bark	Sodra Cell	Vario, Sweden	Fuel for lime kiln+20% to rotary dryers
E2. PRM Energy	2002	1	144 tpd olive waste	Guascor	Rossano, Italy	Gas engine driven 4 MW turbine[g]
E3. Choren	2007/8	TBD	TBD	TBD	Freiberg, Germany	Worlds first commercial gas to liquid plant on biomass feedstock
E4. PRM Energy	2006	1	30 tpd wood/dist res	Eneria	Moissannes, France	IC Engine 1.0MWe to grid[g]

[a] Any mass that has a biological origin except turkey/chicken parts/waste as most of those were environmentally not energy driven
[b] An old recovery was equipped with a vibrating grate and auger feeders to make a "section 29" gasifier. There could be others.
[c] Some of these units were installed by Prime Energy who used to be a licensee of PRM Energy
[d] This is a predecessor of Nexterra.
[e] The fuel may include corn Stover at a later date. DDG = dry distillers grain (an animal feed)
[f] This is an atmospheric pressure designed for capacity gain and is a net consumer of energy
[g] This includes a patented gas cleanup technology

A biomass gasifier is coming on line at the University of South Carolina in Columbia, SC where the thermal output will be used for "district heating". The project developer was Johnson Controls who have to meet the performance criteria and Nexterra provided the gasifier.

Key Projects Without DOE Funding

There is one modern bioenergy project that has been announced in pulp and paper. Intrinergy has announced the installation of a biomass gasifier at Costal Paper in Wiggins, MS. Weyerhaeuser, Kamploops, BC is in a syngas development program to fuel their lime kiln. Parsons and Whittemore has constructed a vegetable oil based biodiesel plant co-located with their pulp mill in Claiborne, AL[7]. The synergy is shared utilities and increased thermal efficiency of both facilities. Finally, there is KL Process Design plant in Upton Wyoming who have constructed a 1.5 million gallon per year cellulosic ethanol plant where the raw material is Ponderosa pine biomass[8].

Key Projects Proposed

Flambeau River Biofuels has proposed a demonstration plant to DOE [9]. This is a "Thermal 1" process pathway. The raw material is about 600 tpd of unmerchantable biomass and the output would be 6 million gallons of renewable fuel feedstock, superior to "Texas light sweet crude" and 4.5 MW's of energy for the nearby Flambeau River Papers. This integration makes the cost of the feed stock cheaper than the cost of oil.

New York State has given a 10.3 million dollar grant to Catalyst Renewables Corporation to help fund a 130,000 gallon per year cellulosic ethanol pilot plant line in upstate New York[10]. This is a "Sugar 4" process pathway. The project is aimed at extracting hemicellulose from woody portions of biomass going to an existing solid fuel boiler that produces power for sale to the electric utility grid and steam is sold to a local facility.

Colusa Biomass is proposing a plant in California. They propose to produce 12.5 million gpy of cellulosic ethanol from rice straw using enzymatic hydrolysis followed by fermentation which id a "Sugar 2" process pathway[11].

Potlatch Corporation, with financial help from Winrock International, developed a comprehensive biorefinery project for their mill in McGhee, AR[12]. The biomass feed was specified to be <u>about</u> 2,000 bone dry (BD) tons per day and the output was <u>about</u> 2,300 barrels per day of renewable refinery feedstock, plus <u>about</u> 150,000 pph steam for the mill and <u>about</u> 14 million BTU/hr tail gas for the lime kiln. Because of integration, thermal efficiency was expected to be as high as others have achieved with larger gas to liquids processes[13].

The University of Florida has announced that Florida Crystals is their recipient of a 20 million dollar state grant to build a 1 to 2 million gpy cellulosic ethanol plant to be used simultaneously as a commercial facility and a development plant[14]. Florida Crystals harvests 10 million tons of sugarcane annually, refines 4 million tons of sugar and operates a 75 megawatt renewable power plant at Okeelanta, Florida.

Finally, DOE has just closed another solicitation for "demonstration plants" that meet their selected criteria. About 7 awards are expected from the ESTIMATED 70 projects submitted.

Most of these activities are being led by smaller or privately owned companies. All of this shows significant activity and that progress is being made. However until mid 2007, the typical response from technical and commercial leaders in LARGE, PUBLIC, U.S. pulp and paper companies has been that there is no proven technology available to justify even a pilot line forest biorefinery. Fortunately both Stora and UPM have commissioned pilot lines in Europe.

Current "Other" Biorefinery Activities

In 2006, the President began to speak about cellulosic ethanol and DOE issued their "Section 932 proposal" to fund up to 40% of a limited number of cellulosic ethanol plants that met 4 quantifiable criteria. On Wednesday, February 28, 2007 DOE announced up to $385 million in matching funds for 6 cellulosic ethanol plants that would have an installed cost exceeding 1.2 billion dollars[15]. Let's look at each of those in a more detail.

Figure 14

Company	Abengoa Bioenergy, St Louis, MO
Plant site	Hugoton, Kansas
Project	Ethanol via biochemical routes, syngas for energy via thermochemical conversion routes, with the long term strategy of using the syngas for ethanol and chemicals production.
Technology	Co-processing of agricultural residue at a corn dry grind facility via biochemical and thermochemical conversion routes.
Feedstock	700 tpd corn stover, wheat straw, switchgrass, and other lignocellulosic biomass (400 tpd into ethanol plant, 300 tpd into syngas plant).
Energy products	Initially 15 million gal/yr of fuel ethanol based on 400 tons lignocellulosic biomass feedstock
Yield	79 gallons ethanol per BD ton biomass
Projected investment	Total cost $190 million or greater, DOE match $76 million,
Previous experience	Lignocellulosic biomass: 1.2 tpd pilot facility in York, NE (previous DOE award, 2003,) and 70 tpd integrated process in Spain to startup in 2007. Corn: Portales, NM (1985) - 30 million gallons of fuel ethanol; York, NE (1994) - 50 million gallons of fuel ethanol; Ravenna, NE (2007) - 88 million gallons of fuel ethanol
References	16,17,18

Figure 15

Company	Alico, Inc., Labelle, Florida
Plant Site	Labelle, Florida
Project	Ethanol via bioconversion of syngas generated from biomass.
Technology	To produce fuel in the Bioengineering Resources Incorporated process, raw material is first gasified in a two-stage process that reaches temperatures as high as 2350^o F (1290^{o}C), producing a mixture of CO, H_2 CO_2, and water vapor. The hot gases are scrubbed, cooled to 100^{o}F (38^{o}C), passed through activated carbon filtration and fermented in a bioreactor where ethanol is produced.
Feedstock	770 tpd Agricultural residues (citrus peel), wood and later energycane
Energy products	20.9 million gallons ethanol per year, 6,255 KW power, 8.8 tpd hydrogen; also produces 50 tpd ammonia used by ALICO for fertilizer
Yield	75 gallons ethanol per BD ton biomass PLUS energy values of power, hydrogen and ammonia
Participants	Bioengineering Resources, Inc. Fayetteville, AR; Washington Group International Boise, ID; GeoSyntec Consultants, Boca Raton, FL; BG Katz Companies/JAKS,LLC, Parkland, FL; Emmaus Foundation, Inc., AR
Projected investment	Total cost $190 million or greater, DOE match $76 million.
Previous experience	Bioengineering Resources Incorporated has demonstrated process at pilot scale for 6 years
References	16, 17, 19

Figure 16

Company	BlueFire Ethanol Inc., Irvine, CA
Plant Site	Southern California
Project	Ethanol via strong acid hydrolysis of biomass waste and biochemical conversion of the sugars produced.
Technology	Arkenol Process: concentrated acid hydrolysis of sorted green waste and wood waste to liberate sugars that are then converted to ethanol using a fermentation technology developed by NREL to ferment both 5- and 6-carbon sugars.
Feedstock	700 tpd of sorted green waste and wood waste from landfill sites
Energy products	19 million gallons ethanol per year
Yield	68 gallons ethanol per BD ton biomass
Participants	Waste Management, Inc., Houston, TX; JGC Corp., Yokohama, Japan; MECS, Chesterfield, MO; NAES, Issaquah, WA, and Petro-Diamond Inc., Irvine, CA
Projected investment	Total cost $100 million or greater, DOE match $40 million,
Previous experience	Demonstrated in a wood chip-fed pilot plant in Izumi, Japan since 2002, producing 21,500 gal ethanol per year
References	16, 17, 20

Figure 17

Company	Broin Companies (now POET), Sioux Falls, SD
Plant Site	Emmetsburg, IA
Project	Enzymatic hydrolysis biomass waste and biochemical conversion of the sugars produced.
Technology	Advanced corn fractionation and ligniocellulosic conversion technologies that include enzymatic hydrolysis followed by fermentation
Feedstock	842 tpd corn fiber, corn stover, and corn cobs
Energy products	Approximately 30 million gallons ethanol per year from lignocellulosic biomass and (adjacent dry mill plant will make 100 million gpy ethanol)
Yield	83 gallons ethanol per BD ton biomass
Participants	E. I. DuPont, Wilmington, DE; Novozymes, Bagsvaerd, DK; NREL, Golden, CO
Projected investment	Total cost $200 million or greater, DOE match $80 million,
Previous experience	Pilot line being built by POET, a company with considerable experience with corn ethanol. DuPont reported to have a small laboratory line
References	16, 17, 21

Figure 18

Company	Iogen, Arlington, VA
Plant Site	Shelley, ID
Project	Ethanol via biochemical conversion of agricultural residues.
Technology	Enzymatic hydrolysis followed by fermentation of the sugars produced.
Feedstock	700 tpd of wheat, barley, and rice straw, switchgrass and corn stover
Energy products	18 million gallons ethanol per year in first plant; 250 million gal/yr in future plants
Yield	71 gallons ethanol per BD ton biomass
Participants	Goldman Sachs, New York, NY; Royal Dutch Shell, The Hague, The Netherlands
Projected investment	Total cost $200 million or greater, DOE match $80 million,
Previous experience	Their technology was demonstrated in a pilot plant near Ottawa, Canada
References	16, 17, 22

Figure 19

Company	Range Fuels, Inc., Broomfield, CO
Plant Site	Soperton, GA
Project	Ethanol and methanol from southern pine
Technology	Thermo-chemical conversion of wood and forest residues to syngas; catalytic conversion of syngas to alcohols.
Feedstock	1200 tpd of unmerchantable pine wood and forest residues
Energy products	10 million gal/yr from first unit; 40 million gallons of ethanol and 9 million gallons of methanol per year from commercial unit
Yield	113 gallons of alcohols per BD ton biomass
Participants	Khosla Ventures, Yeomans Timber, Ga. Forestry Commission, Western Research Institute, Merrick and Company, PRAJ Industries, CH2MHill, and Gillis Ag & Timber
Projected investment	Total cost $225 million or greater, DOE match $76 million,
Previous experience	Their technology was demonstrated in a 5 tpd pilot line in Colorado
References	16, 17, 23

Comparison Of Projects

Figure 20 shows some critical technical information for: 1) the DOE funded projects, 2) a typical dry mill corn ethanol plant, and 3) the proposed project at Potlatch. Other projects can be added as key data become known. Critical techno-economic data includes process technology, capital costs, product yields, and capital effectiveness which is capital per gallon per year.

Figure 20: Project Comparison (yield does not account for all BTUs)

Project	Technology	Capital Cost ($ millions)	Yield (gal/ton)	Capital Effectiveness ($/gal/yr)
Announced Projects				
Abengoa	Gasification & GTL	190 or more	79	more than 16.7
Alico	Gasification & fermentation	83 or more	75+ power, etc.	less than 4.0
BlueFire	Hydrolysis & fermentation	100 or more	68	about 5.3
Broin	Enzyme & fermentation	200 or more	83	cannot break out
Iogen	Enzyme & fermentation	200 or more	~71	about 11.1
Range	Gasification + GTL	~225	113	about 4.6
Corn[24]	50 Million GPY "dry mill"	~ 75	80	new about 1.6
Proposed Projects				
Potlatch	Gasification & GTL	~150	50+steam +gas	less than 4.3

The comparison data in Table 2 is taken from published information and a lot of background data is not yet available. For example, reclaimed heat is not known for all projects and must be included in the calculations. Cost of raw material, operating cost per gallon, and energy ratio information is not yet available and needs to be added for a more complete evaluation. The historical cost of corn ethanol was estimated at $0.96 per gallon[24]. The same article predicted a cost of $3.35 per gallon for cellulosic ethanol in 2007 dropping to $2.43 per gallon in 2020. It will be interesting to track the performance of the DOE funded projects against this prediction. When looking at the Potlatch project, it compares well with available metrics.

Conclusion - Macro

The Federal Energy Council report documents that worldwide petroleum consumption is growing faster than new petroleum capacity can be added. The U.S. has proposed renewable fuel standards that are beyond the capability of the corn ethanol industry. Technology development dictates that cellulosic ethanol will be the next "boom" segment of our energy fuel market. Even cellulosic ethanol is not predicted to fill the need for renewable fuels and cannot impact the diesel market which is likely to grow. Vegetable oil and animal fat based biodiesel cannot meet cold weather specifications and is not suitable for the largest military need, jet fuel.

Conclusion - Micro

Current technology and economic conditions strongly point to the short-term winners as those who cost-effectively produce multiple products and/or sell their recoverable heat to "steam hosts". There will be niche exceptions.

Economic analysis strongly suggests that the long-term winners will be those who use higher yield processes which allow direct conversion of biomass to biofuels. Currently the only known high yield processes use the emerging chemical technology platform. Long-term winners will also include short-term winners who have economically and technically integrated their processes with the "right" host facilities

Final thought: "Wherever you see a success in business, someone made a courageous decision."

Author unknown

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[24] Jerry Taylor and Peter Van Doren, "The Ethanol Boondoggle", The Milken Institute Review-First Quarter 2007. Newer plants have greater energy efficiency and higher production costs as energy and corn prices have increased.