Compelling Case for Integrated Biorefineries

B. A. Thorp, Benjamin A. Thorp IV
And L. Diane Murdock-Thorp
May 2008

Abstract

Biofuels are liquids or gases made from renewable sources. Petroleum-based liquid transportation fuels represent the largest segment of imported energy in the United States. The technology is here for liquid biofuels to supplement petroleum-based transportation fuels. Activity is increasing on this needed 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. The U.S. has established renewable fuel standards that go well beyond the capability of corn-based ethanol. Many analysts forecast the need for "second generation" biofuels to meet demands. Commercial activities show that renewable fuels can be cost-effectively produced on a commercial scale.

Presented in the article are:

- Current process pathways to produce "second generation" biofuels.
- A comprehensive summary of commercial North American activities in "second generation" biofuels and the biorefinery.
- A comparison of the 2007 U.S. Department of Energy (DOE) funded projects with "Section 932" grants.
- An understanding of technical and commercial activities used to predict both short-term and long-term winning approaches.
- A compelling case for an integrated forest biorefinery.

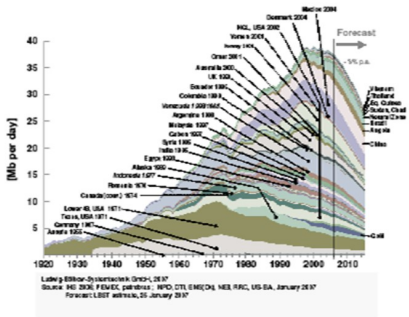
Looming National Priority

The material, which follows, is focused on North America and "second generation" biofuels. Biofuels are liquids or gases that are made from renewable sources. Some broaden this definition to include the power made from biomass or reclaimed heat because most hybrid cars use power. In the U.S., the most predominate "first generation" biofuel is ethanol derived from corn. Other "first generation" fuels include ethanol derived from hemicellulose at sulfite pulp mills and biodiesel derived from vegetable oil or animal fat using transesterification or trasesterification. It is important to note that "first generation" biodiesel has cloud point issues and cannot be used for jet fuel or other cold temperature applications. "Second generation" fuels include renewable diesel, renewable gasoline, cellulosic ethanol and fuel feedstock made from catalytic reactions like the Fischer-Tropsch. These fuels typically meet all ASTM standards. Petroleum-based liquid transportation fuels represent the largest U.S. segment of imported energy[1]. Liquid biofuels can supplement 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.**

Compelling Need

Many notable forecasters use historical trends to predict use and price 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 U.S. 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 about 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]. It also calls for the development of alternative fuels including biofuels like ethanol and biomass 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 be inadequate. This is illustrated in Figure 1, which shows that production has peaked in most major oil fields.

Figure 1 - EWG Peak Oil Analysis



A combination of events will bring supply and demand into balance. 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.

Others are starting to publish glimpses of the future. Examples include major Wall Street Journal articles, "Where Has All the Oil Gone"[3], "Oil Officials See Limit Looming on Production"[4], and "Biofuel Costs Hurt Effort to Curb Oil Price"[5]. Finally there is a new report from Packaged Facts that anticipated investments in renewable energy projects could skyrocket to $50 billion by 2011.

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 the 20-10 goal is not yet law. The Energy Independence and Security Act of 2007 is law and has a goal of 36 billion gallons of renewable fuel in 2022. Of this 36 billion, only 15 billion gallons are corn-based ethanol while the other 21 billion gallons are "advanced biofuels". Now, rules will be adopted to monitor compliance and ensure that the goals in the EISA will be met.

Good News

There is good news that emanates from forecasted oil shortages. There will be a demand for renewable fuels from all industrialized and industrializing nations. Renewable fuels will become a national priority for most. The Forest Products Industry has commercial skills and resources that are critical to this emerging industry and is on the cusp of awakening to the opportunities. What remains for all is to develop the knowledge to sort out real opportunity from volumes of information, which contain far too much hope and hype.

Key Terms

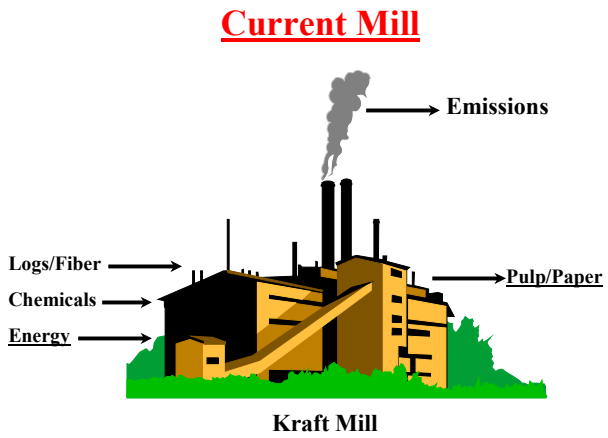
In the material, which follows there, will be several key terms that will be used repeatedly. Definitions for these terms are:

- **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.
- The current DOE strategy defines two technology platforms:
  - Thermo-chemical Platform
  - Sugar Platform
- There is a third:
  - Chemical Platform

Exactly what is a biorefinery?

Let us begin by looking at a starting and ending point for a forest-based biorefinery. Examples from other industries are also possible. Figure 2 shows the major inputs and outputs for a modern pulp and paper mill.

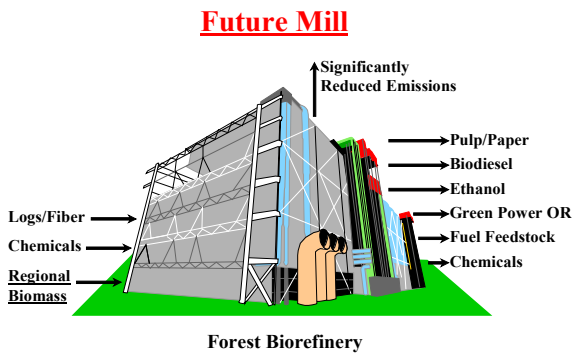
Figure 2



Note that one of the major inputs is energy. The average U.S. integrated pulp and paper mill has a thermal demand of ~40% fossil fuel and ~60% biomass, which is largely met from combustion of black liquor.

Figure 3 shows the inputs and outputs for an integrated forest biorefinery.

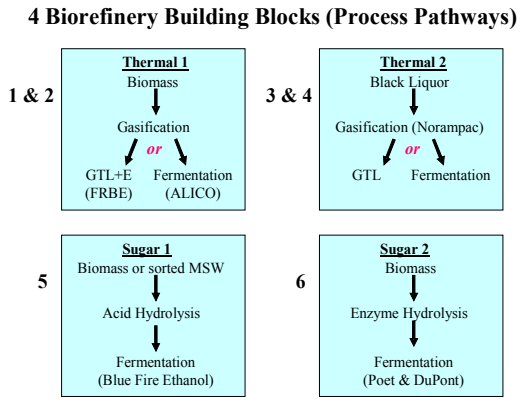
Figure 3



Note that there is no longer an input for fossil fuel based energy. The pulp and paper facilities should now run on heat recovered from the biorefinery. As will be discussed later, this "heat sink" aspect of integration is critical because it represents a critical revenue stream for the biorefinery. It also reduces capital and improves the environmental footprint by reducing the need for cooling towers. More importantly it drastically cuts CO_2 emissions from the "steam host". The outputs include pulp and paper plus one or more "green" fuels or "green" chemicals. Power input will be an option determined by its cost versus the value of other output streams.

Figure 4 shows 6 biorefinery process pathways for integrated biorefineries.

Figure 4



The Pathways 1 and 2 start with biomass as the raw material. The biomass is gasified by placing it in a receptacle with controlled and limited oxygen and applying heat. The result is that the organic portions volatilize into a gas composed of hydrogen, carbon monoxide and carbon dioxide. This is called syngas. After gas cleanup (not shown), 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. Gasification converts the organic material including lignin to syngas. Certain gasification units can better tolerate and process mixes of biomass. This is critical when comparing feedstock costs of the various pathways. There are two choices for the subsequent treatment of syngas and the cost of equipment dictates that each facility will have to choose Pathway 1 (left fork) or Pathway 2 (right fork), but not both. The left pathway uses a gas to liquid process (GTL) like a Fischer-Tropsch catalytic reactor. This produces a clear, sulfur-free, multi-molecular fluid that is chemically superior to low sulfur crude. It can be further refined to biogasoline, biodiesel or a variety of other bioproducts. South African Synthetic Oil Ltd (SASOL) has been doing this for 50 years with syngas from coal. The "Thermal 1" pathway has been proposed for New Page, Wisconsin Rapids, Wisconsin and Flambeau River Biofuels adjacent to Flambeau River Papers in Park Falls, Wisconsin. The "Thermal 1" pathway has also been selected by the Stora-Neste JV and the UPM-Carbona JV in Europe. When the "Thermal 1" pathway is adjacent to a steam host, this pathway has two significant revenue streams: recovered heat (shown as an "E") and biofuels (shown as "GTL").

The second pathway (right fork) will ferment the syngas making a variety of products, which are listed, in a previous article[6]. This pathway was chosen by ALICO in Labelle, Florida.

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. More importantly, there is a higher requirement for carbon conversion because of pulping chemical recovery. Norampac in Trenton, Ontario, Canada is successfully gasifying all of their carbonate black liquor in a TRI low temperature "Steam Reformer" and burning the syngas in existing gas boilers since 2003.

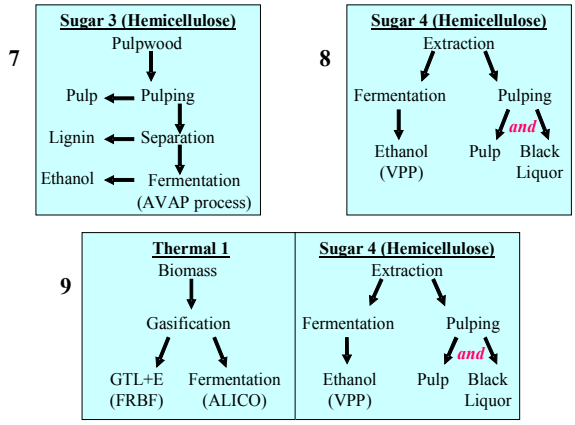
For several years, Weyerhaeuser in New Bern, North Carolina has been gasifying approximately 15% of their Kraft black liquor in an atmospheric, high temperature gasifier supplied by Kvaerner-Chemrec. This unit restarted with a new vessel and refractory lining about the same time that Norampac started.

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 be used. The acid converts compounds like cellulose to sugars, which are 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 with partial DOE funding is planned for southern California. Pathway 6 typically takes a selected, uniform raw material like corn stover or wheat straw and converts the cellulose material to sugars by enzymatic hydrolysis. Subsequently, the sugars are 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. Neither Pathway 5 or 6 utilizes any lignin present in the raw material, so they are primarily being customized for low lignin feedstocks like MSW or energy crops like wheat straw. To date, enzyme hydrolysis has been very sensitive to the uniformity of raw material input, even water quality.

Figure 5 shows 3 more pathways.

Figure 5

3 Biorefinery Building Blocks (Process Pathways)



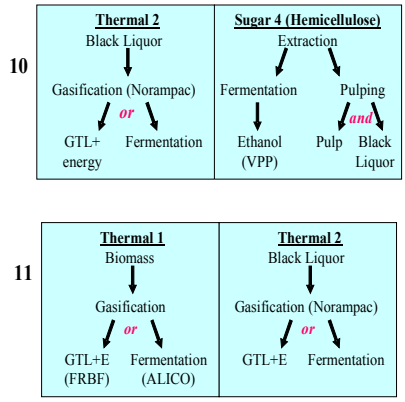
Pathway 7 starts with debarked pulpwood chips, which are pulped with a unique AVAP™ process. The cellulose is bleached and sold as chemical grade dissolving cellulose or market pulp, both of which have a higher selling price per pound than ethanol. Next, the lignin is removed from the pulping liquor and used to fuel the entire process. Finally, pulping chemicals are removed and the resulting broth is rich in monomer hemicelluloses, which are subsequently fermented to ethanol or other chemicals. This process pathway has two revenue streams and an energy cost reduction stream.

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. In Pathways 1 to 4, the heat should be recovered from all processes and sold to an adjacent steam host. This is a valuable co-product.

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 6

2 Biorefinery Building Blocks (Process Pathways)

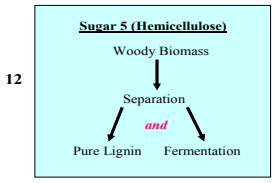


Pathways 9, 10 and 11 in Figures 5 and 6 are combinations of Pathways 1 to 8, which can be combined economically and technically. Even these simple block flow diagrams (which do not show all of the necessary steps like gas cleanup or reuse of water) demonstrate that biorefineries will be quite different from each other and far more complex than can be shown in conceptual diagrams.

Figure 7 shows the last of the 12 processes.

Figure 7

1 Biorefinery Building Block



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.

Predictions

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 us look at basic economics. The most common yield reported is about 80 gallons of biofuel per bone dry ton (BDT) of biomass. The most frequently used selling price for biofuel is about $2.00 per gallon. This gives a revenue stream of about $160 per BDT 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 BDT leaves little or no profit margin.**

Therefore, the profit can only be made when there is a unique situation of very low cost 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, 2, 3, 4, 7, and 12 have co-products. Pathway 8 does as well, but may have raw material limitations (hardwood only). It appears that the short-term winners will use pathways 1, 2, 7 and 12 or have unique raw material situations. There is far more commercial experience with the unit operations of Pathway 1. Short-term means those biorefineries, which are being built now, or construction will start this decade.

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 BDT 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, new winners will be based on one or more of these chemical technology platforms. It appears that there will be other long-term winners, but they are likely to be based on "niche" situations.

Key Projects With DOE Funding

2006/2007 DOE 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[16]. Details of each DOE project are located in a previous article[6].

Comparison of Projects

Figure 8 shows some critical technical information for the DOE funded projects and a typical dry, mill corn, ethanol plant. Other projects can be added for comparison. Critical techno-economic data includes process technology, capital costs, product yields, and capital effectiveness which is capital per gallon per year

Figure 8: 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	92	About 5.8
Corn[17]	50 Million GPY "dry mill"	~ 100	80	new about 2.0

The comparison data in Figure 8 is taken from published information (a lot of background data is still not 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.

Key Projects With DOE Funding

DOE has selected four biorefinery demonstration projects, with three more scheduled for selection. Negotiations between the selected companies and DOE will begin immediately to determine final project plans and funding levels. Funding is subject to Congress appropriations. The following four projects were selected:

<u>ICM Incorporated of Colwich, Kansas; DOE will provide up to $30 million</u> - The proposed plant will be located in St. Joseph, Missouri, and will utilize diverse and relevant feedstocks including agricultural residues, such as corn fiber, corn stover, switchgrass and sorghum. ICM, Inc. will integrate biochemical and thermo chemical processing and demonstrate energy recycling within the same facility. This project stands to broaden the company's focus from corn-based to energy crop-based ethanol production. ICM, Inc is a privately held company with the mission of sustaining agriculture through innovation, primarily through the engineering and construction of ethanol biorefinery.

<u>Lignol Innovations Inc., of Berwyn, Pennsylvania; DOE will provide up to $30 million</u> - The proposed plant, co-located with a petroleum refinery, will be located in Commerce City, Colorado, and using biochem-organisolve, will convert hard and soft wood residues into ethanol and commercial products, co-located with a petroleum refinery. Lignol Innovations is a U.S.-based company with a publicly traded Canadian parent based in Vancouver, British Columbia. Lignol has acquired and since modified a solvent-based pre-treatment technology that was originally developed by a subsidiary of General Electric (pathway 12)

Pacific Ethanol Inc., of Sacramento, California; DOE will provide up to $24.3 million - The proposed plant will be located in Boardman, Oregon, and will convert agricultural and forest product residues to ethanol using BioGasol's proprietary conversion process. Pacific Ethanol is a leading producer of low-carbon renewable fuels in the Western United States. The company is headquartered in Sacramento, California, and planning to add cellulosic conversion capability to their corn-based ethanol facility in Oregon (pathway 6).

NewPage, Wisconsin Rapids, Wisconsin; DOE will provide up to $30 million - The proposed plant will be located in Wisconsin Rapids, Wisconsin, and proposes to take wood wastes and convert it to Fischer-Tropsch liquid then converted into renewable diesel and renewable gasoline (pathway 1). NewPage Corporation of Miamisburg, Ohio, recently acquired Stora Enso North America, the original applicant for this funding opportunity announcement.

RSE Pulp And Chemical, Old Town, ME; DOE will provide up to $30 million - The facility will have a capacity of 2.2 million gallons per year of cellulosic ethanol from 80 tons per day via wood extract.

Mascoma, Vonroe, TN; DOE will provide up to $26 million - The facility will produce 2 million gallons per year of cellulosic ethanol from switchgrass and hardwood chips via enzymatic hydrolysis.

Ecofin, LLC Washington County, KY: DOE will provide up to $30 million- The facility will produce 1 million gallons per year of cellulosic ethanol from a variety of feedstocks via enzymatic hydrolysis followed by fermentation.

By using a variety of regional feedstocks, advanced biofuels can be produced in nearly every region of the country. Moreover, because these fuels rely on non-edible portions of crops, and agricultural residues and forest wastes, they have the added advantage of not competing with food crops. Though it requires a more complex refining process, they typically contain more net energy than traditional corn-based ethanol, and have the potential to reduce greenhouse gas emissions by more than 85 percent relative to gasoline.

Key Projects Without DOE Funding (excludes pilot lines[7])

One modern bioenergy project has been announced in the pulp and paper industry. Intrinergy has announced the installation of a biomass gasifier at Costal Paper in Wiggins, Mississippi. Weyerhaeuser, Kamloops, British Columbia, Canada is in a syngas development program to fuel their lime kiln. Parsons and Whittemore have constructed a vegetable oil esterification based biodiesel plant co-located with their pulp mill in Claiborne, Alabama[8]. The synergy is shared utilities and increased thermal efficiency of both facilities. There is the KL Process Design plant in Upton, Wyoming, which has constructed a 1.5 million gallon per year cellulosic ethanol plant where the raw material is Ponderosa pine biomass[9]. Finally, there are some exciting developments for modular design gasifiers and GTL units from Community Power who have one BioMax unit running and another being installed.

Key Projects Proposed

Flambeau River Biofuels has proposed a demonstration plant to DOE[10]. This is a "Thermal 1" process pathway. The raw material is about 580 tpd of unmerchantable biomass and the output is about 5.8 million gallons of renewable fuel feedstock, superior to low sulfur crude and about 4 million BTU's of thermal energy per day for the nearby Flambeau River Papers. This integration helps make the per barrel cost of the renewable fuel 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[11]. 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 utility grid and steam to a local facility. Biomass gasification has recently been added to the project.

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 is a "Sugar 2" process pathway[12].
Potlatch Corporation, with financial help from Winrock International, developed a comprehensive biorefinery project for their mill in McGhee, Arkansas[13]. The biomass feed was specified to be <u>about</u> 2,000 BDT 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 of steam for the mill and <u>about</u> 14 million BTU/hr of tail gas for the lime kiln. Because of integration, thermal efficiency was expected to be as high as or higher than others have achieved with larger gas to liquids processes[14].

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[15]. 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. Energy Quest and Willow industries have announced a JV to construct a 6 MV facility powered by the Quest downdraft gasifier. The Louisiana Economic Development Corp has approved a grant for the Tyson Food-Syntroleum JV called Dynamic Fuels. The facility will use technology to convert animal fat to biofuel. Verenium is in the process of starting up a 1.4 million gallon per year pilot plant producing cellulosic ethanol and has announced a 30 million gallon per year cellulosic ethanol facility also in Jennings, LA. Coskata will build a 40 thousand gallon per year cellulosic ethanol plant at the Westinghouse Plasma Center in Madison, PA where the pilot gasifier is located.

Compelling Technology, Compelling Economics

Data in a previous article documents that commercial biomass gasification has been practiced in the U.S. for over 20 years[18]. Earlier gasifiers produced low quality syngas primarily used for heating applications. Currently, there is a commercial gasifier that has produced medium value syngas for several years. Clearly, this technology is advancing and ready for additional applications. Fischer-Tropsch liquids were produced in the 1940's in Germany and since the 1950's in South Africa. They used cleaned syngas from coal.

Clean syngas from biomass is chemically the same. One new driving force is that it has been demonstrated that high thermal efficiency can be achieved with a "single pass" Fischer-Tropsch unit by integrating it with a facility that can take and pay reasonable rates for recovered heat of modest BTU value (e.g., 850 PSI steam, hot water and tail gas). Pulp and paper mills represent one excellent "host" facility. Escalating energy cost has increased attention to combining these technologies at a host site.

Announced examples of increased attention to biomass gasification followed by Fischer-Tropsch include, but certainly not limited to:

- Choren-Shell joint venture in Freiberg, Germany
- Stora-Neste JV with demo unit for the P&P mill at Varkaus, Finland
- UPM-Choren JV with a semi-works plant at another P&P mill in Finland
- Norske Skog Follum will build a demo plant at their Honefoss facility
- New Page, Wisconsin Rapids, Wisconsin
- Flambeau River Biofuels at Park Falls, Wisconsin
- Potlatch developed project at McGhee, Arkansas
- Volkswagen investment in Choren for another proposed plant
- Daimler investment in Choren
- Chippewa Valley Ethanol JV with Front Line Bioenergy

Further, these projects can eventually follow the traditional power project investment model recommended at the October 2007 Cellulosic Ethanol Conference in Washington, D.C. (which included other biofuels). The traditional model has 3 major elements. First, the owner/developer obtains a feedstock supply contract; second, the owner obtains a facility guarantee from an EPC contractor; and, finally, the owner secures a power purchase agreement. The EPC contractor is able to provide a guarantee because in turn he obtains a guarantee from the boiler manufacturer and the turbine manufacturer. After several of the gasification/gas-to-liquid facilities are built, the same model can be applied. Here, the EPC contractor would get guarantees from the gasifier and gas-to-liquid manufacturers. This model gets more difficult when enzymatic and biological reactions are involved.

Integrated Forest Biorefinery

Figure 9 shows the scope and benefits of a modest size integrated facility.

Figure 9

Flambeau River Integrated Forest Biorefinery Overview

- **Objective:** Commercial-scale production of clean, renewable liquid transportation fuels; secondary energy streams such as electricity, steam and hot water sold to integrated host mill facility
- **Scope:** State-of-the-art, commercially-proven steam-reforming gasifier producing high-quality syngas, converted to renewable transportation fuels via proven Fischer-Tropsch process
- **Cost:** $210 - $250 million
- **Benefit:** Investment-grade opportunity for renewable fuels at a solid profit; Biorefinery converts local wood waste and other available biomass streams into clean, renewable, high-value liquid transportation fuels, transforming regional economy; industrial host controls energy costs at less than fossil fuel prices, reduces carbon footprint and opens new revenue streams

TRI — *Advanced Systems for Biomass-to-Green Energy Solutions*

With any facility there are certain assumptions made concerning the cost, inputs and outputs. Major assumptions are shown in Figure 10.

Figure 10

Major Project Assumptions

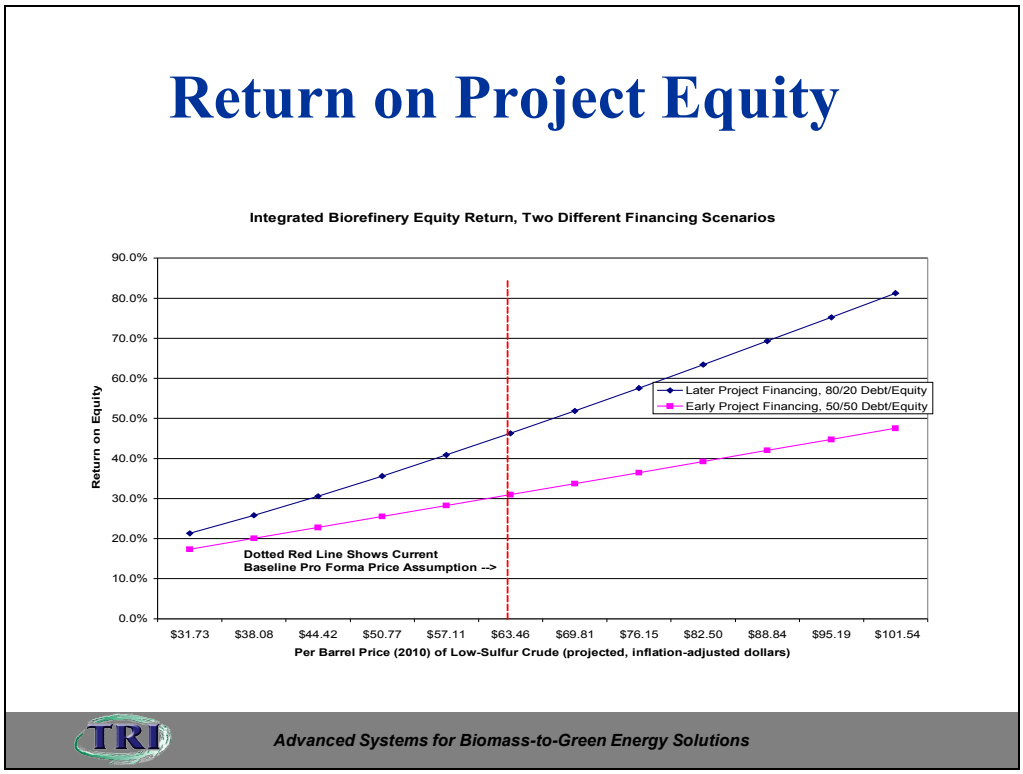
- **Overall project cost:** $210 - 250 MM
  Cost estimates include engineering, construction, commissioning and turnkey premiums. *Pro forma* economics include development and financing costs, interest reserve and interest during construction requirements
- **Raw material/biomass volume:** 1,900 dry tons per day
  Existing literature and related studies estimate a "typical" commercial biorefinery to convert between 2,000 – 3,000 dry tons per day of biomass; to tilt to the more conservative low-end for an early project, we have chosen 1,900 dry tons per day as our target; project biomass will be a combination of various locally-available woody biomass
- **Biomass cost:** $50/dry ton
  Biomass cost estimates are derived from local market analyses, existing local contracts and industry/academic/government estimates
- **Output**
  Liquid Transportation Fuel: 2,691 bbl/d (40 million gpy, 70 million ethanol equivalent gpy)
  Steam: 150 Kpph, sold to host
  Hot water: 14MMBtu/hr, sold to host
- **Future Energy Prices**
  Product pricing forecasts are pegged primarily to the Energy Information Agency's (EIA) most-recently released petroleum estimates (Feb. 2007), i.e. Low-Sulfur crude projected to be ~$63.50/barrel in 2010
- **Permitting**
  Permitting period will range from 9-18 months and will begin prior to the anticipated 18-21 month construction period; will be faster and less costly than for a commensurate greenfield site, as biorefinery will benefit from host facility's existing permitting umbrella and infrastructure
- **Financing**
  50/50 D/E split, with (tax-exempt) industrial development revenue bond & loans rates ranging from 6-7.5%

TRI — *Advanced Systems for Biomass-to-Green Energy Solutions*

It is important to note that the biomass cost is conservatively higher than recommended by DOE in a recent solicitation[10]. The availability of the quantity and quality of biomass was rigorously studied and validated by a state peer review. The facility was sized so that the waste heat recovered would meet the demands of a host pulp and paper mill. Such integration requires unique skill and proprietary knowledge.

Figure 11 shows a breakeven analysis for the integrated facility. The vertical axis shows return on project equity. The horizontal axis shows the price per barrel of low sulfur crude. The red line shows project returns with 50% debt and 50% equity, which might be typical for some early projects. The blue line shows 80% debt and 20% equity, which might be typical for some mature projects. There is sufficient maintenance in the direct operation cost to maintain the facility. The variable costs are fully loaded with catalyst replacement. Any improvement projects would be justified with their ROI.

Figure 11



At a modern price for oil Figure 11 shows returns on equity from 40 to 60 %. This exceeds any returns projected for the U.S. stock market, and perhaps with about equal risk. There are and will be compelling opportunities for those who supply, host, invest or operate. These opportunities are apparent to those who conduct detailed studies and will become more apparent as these plant, demo and commercial sites become operational.

The returns for non-integrated projects are not shown in Figure 11 but run about 8 to 12 percentage points below the red and blue lines respectively. The non-integrated early case has had returns, which have been lower than needed for commercial financing.

At this point it is typical for questions about what can go wrong. There are 3 major areas and they will be briefly covered. The first area is raw material supply and price. In this instance, there is a validated raw material supply study and the price used is more conservative than that recommended by DOE. The second area is equipment reliability and availability. The gasifier selected is a "steam reformer" with no moving parts. One design has been running several years with normal outages. A second generation design is now available. Fischer-Tropsch units have been running for 50 years. The third issue is the economic stability of the host facility. Should that facility fail, steam could be used to generate power for the grid from existing steam turbines and some new generating capacity with modest capital. Another area is the price of the output but that sensitivity is displayed in Figure 11. The base case economics do not include upside opportunities like alternative forms of biomass, which could be cheaper or higher value added co-products. There are also upsides from higher oil prices.

The dotted vertical line is simply a reference price used by some lending institutions. The returns are more than adequate for a mature, lower risk project. **When oil gets to a sustainable price of something like $83 per barrel, the returns are adequate for early, moderate risk projects**.

Conclusion

The Federal Energy Council report documents that worldwide petroleum consumption is growing faster than new petroleum capacity can be added. The U.S. has renewable fuel standards that are beyond the capability of the corn ethanol industry. Technology development dictates that biomass gasification followed by GTL and/or cellulosic ethanol will be the next "boom" segments of our energy fuel market.

The need for renewable fuels, especially those with chemical characteristics equal to or better than those made from petroleum is a current and future driver. Biomass gasification followed by Fischer-Tropsch technology is well understood and adequately developed. The current price of oil gives attractive economics when the biorefinery is integrated. There are compelling economics, which will be shared by suppliers, hosts, investors and operators.

This type of facility is receiving increased commercial attention and is sufficiently promising to receive support by DOE, DOD and non-profit organizations looking to help solve national priorities.

Final thought --- this appears to be a business with an incredibility long life cycle.

References:

[1] DOE Publication," Energy Consumption". Use refinery output not gross allocation, which contains gas and power.

[2] "Oil Report's Conclusion…" International Herald Tribune, 18 July 2007

[3] "Where Has All the Oil and Gas Gone" WSJ 6/7 October 2007. page 1

[4] "Oil Officials See Limit Looming on Production", WSJ 19 November, 2007

[5] "Biofuel Costs Hurt Effort to Curb Oil Prices", WSJ 5 November, 2007

[6] Ben Thorp and W J Frederick, Jr "Standing at a Fork in the Road", Paper 360 June/July 2007, pages 6-9

[7] Pilot lines like Abengoa at York Nebraska, Verenium (formerly Celunol) at Jennings Louisiana, Range Fuels at Broomfield Colorado and Mascoma/UT in Monroe County Tennessee are critically important but not the focus of this article.

[8] Press Release, Independence Renewable Energy Corporation, September 27, 2006.

[9] See **www.klprocess.com**

[10] Demonstration Plant-Biomass Fuels to Liquids submitted to DOE Funding Opportunity DE-PS36-07G097003

[11] DOE Press Release, New York Governor Announces 25 Million to Develop Cellulosic Ethanol Facilities,

[12] Private communication with Tom Bowers

[13] Tom Belin, "Demonstration of the Forest BioRefinery at the Potlatch, Cypress Bend Mill", 2006 Forum on Energy-May 15-17 2006, Appleton WI.

[14] Private communication with Dan Burciaga, President TRI

[15] University of Florida press release 23 August 2007

[16] DOE press release February 28, 2007, S. W. McLean.

[17] 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

[18] Ben Thorp, "Paper Industry Must Protect Its Status in Cellulosic Innovation", Pulp and Paper, May 2007, pages 30-34