Wood-Based Bio-Fuels and Bio-Products:
A Maine Status Report

Prepared for the

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Office of Innovation

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Executive Summary

Maine has an opportunity to position itself as a leader in the emerging industry of conversion of wood to bio-fuels and bio-products. With a long history of forest industry, and significant and varied forest resources, the State of Maine has the resources, industrial infrastructure and intellectual institutions to capitalize on this research.

This analysis provides:

- A preliminary review of the major technologies that are emerging in the marketplace for conversion of wood to fuels and chemicals, including fermentation, gasification, pyrolysis and fractionation;
- A brief description of the challenges each technology group faces in achieving commercial maturity and acceptance,
- A listing of some of the companies active in each technology category, and
- A set of recommendations for the State of Maine to consider as it pursues recruitment of these firms.

Recommendations, developed through interviews with industry experts and developers, include:

1. Take a "technology neutral" approach to the development of bio-fuels and bio-products in Maine;
2. Develop a state role for the financial support of capital investment in new projects;
3. Provide Funding of Feasibility Analysis;
4. Support research, development and deployment of new technologies;
5. Place bio-fuel and bio-product development on par with existing industries;
6. Develop production-based tax incentives to support facility operations;
7. Provide a better understanding of the resource base available;
8. Serve as matchmaker between developers, opportunities, feedstocks, infrastructure and financing;
9. Help develop a forward market for biomass;
10. Develop permitting rules for bio-product facilities that are clear and reasonable;
11. Address the Cost of Electricity;
12. Develop Regional Support for Cellulosic Fuels.

This analysis is intended to provide Maine leaders, businesses, organizations and citizens with an introduction to the opportunities that wood based bio-fuel production presents the state, as well as careful consideration of the challenges this sector faces. This is not meant to be an exhaustive review of the technologies or companies active in this area.

Purpose

Maine has an opportunity to position itself as a leader in the emerging industry of conversion of wood to bio-fuels and bio-products. With a long history of forest industry, and significant and varied forest resources, the State of Maine has the resources, industrial infrastructure and intellectual institutions to capitalize on this research.

Interest in this field is growing. In 2005, the Maine Technology Initiative made several awards to companies for the development of bio-fuel and bio-product facilities (see Appendix A). In January 2006, the Rumford-based Fractionation Development Center issued a report on the opportunities for bio-fuel development in Maine, and presented a "roadmap" to have nearly 60 bio-fuel and bio-product facilities in 15 years.

In March, the University of Maine announced $10.35 million in funding, including $6.9 million from the National Science Foundation, to establish a Forest Bioproducts Research Institute. This funding will help develop the base of understanding upon which the bio-fuel and bio-product industry is built, and "will enable Maine's private sector to build an integrated forest biorefinery -- one that allows mills to create new, high-margin revenue streams while maintaining their traditional production."[1]

The conversion of wood to bio-fuels and bio-products has long been a goal of the forest products industry. Speaking at his company's 50th Anniversary Dinner in 1948, International Paper's president John Hinman noted:

> *…once wood is reduced to a pure and stable chemical it provides the base on which the chemist can build a hundred different products…More and more the wood pulp and paper industry is joining forces with the chemical industry….It is conceivable that the forests of the United States and Canada within the next half century will supply us not only paper for many varied purposes…but also quantities of foodstuffs, alcohol, and chemical raw materials from parts of the wood which we are only beginning to use today.*

While the second half of the twentieth century was not characterized by significant advances in the commercial development of wood-based bio-fuels and bio-products, the next half-century may be. Rising demand for oil, concerns regarding the stability and price of supplying that demand, increasing investment in research and development, and growing public concern regarding climate change all provide reasons to think that wood-based bio-fuel and bio-product production can grow exponentially in the coming years, and Maine should use every advantage to capture this growth and anchor the economic and environmental benefits here.

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[1] University of Maine press release, "$6.9 Million Federal Grant Will Build Bioproducts Research at UMaine, Will Help Industry Create Forest Biorefinery." March 28, 2006.

Introduction

This analysis provides:

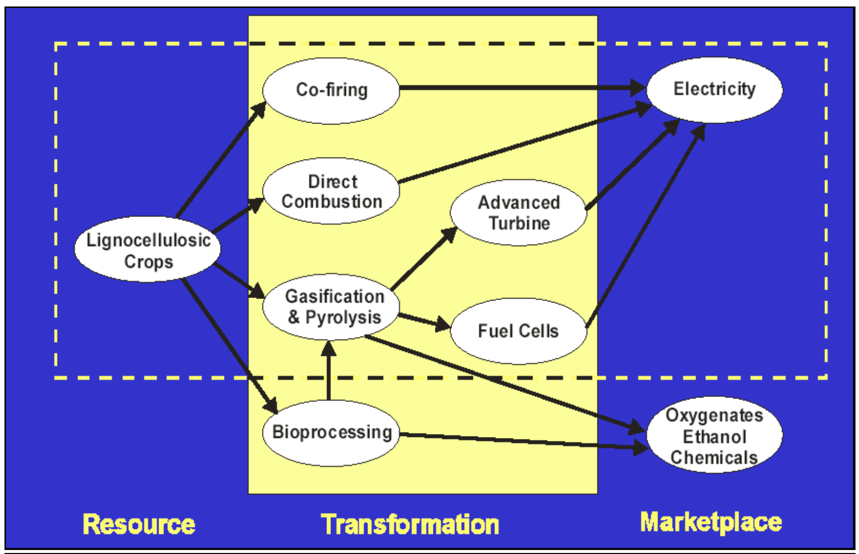
- A preliminary review of the technologies that are emerging in the marketplace for conversion of wood to fuels and chemicals,
- A brief description of the challenges each technology faces in achieving commercial maturity and acceptance,
- A listing of some of the companies active in each technology category, and
- A set of recommendations for the State of Maine to consider as it pursues recruitment of these firms.

It is important to note that this analysis was prepared with limited time and budget, and should not be considered an exhaustive or comprehensive listing of technologies, opportunities, challenges, or companies in this emerging industry. Rather, it is written to provide a general overview and understanding of the opportunities and challenges for the industry, and identify actions that can be taken to best position the State of Maine for the future.

"Bio-fuel" and "bio-product" are terms that are just now coming into common usage. For purposes of this analysis, these terms refer to wood-derived processed fuels and chemicals, generated through conversion of the chemicals found in wood into other forms, and generally serving as replacements for petroleum-derived products currently in the marketplace. This analysis does not cover the production of solid fuels for use in conventional combustion as a thermal energy source (e.g., firewood or the production of wood pellets) or the production of electricity from the combustion of wood at wood-fired power plants. While these are important existing and potential markets for wood, and represent tangible ways that wood can be used to meet our energy needs, they are not part of this analysis, which focuses on the wood conversion technologies that are moving from the research and development stage toward commercial scale deployment.

Wood, or other cellulosic material, can be used in a number of ways to provide useful energy. Traditionally, wood has been combusted to generate heat, either for direct thermal applications (heating houses, providing steam for manufacturing uses, etc.) or harnessed to generate electricity. A number of new technologies – grouped into fermentation, pyrolysis, gasification and fractionation – are now approaching commercial maturity. Figure 1 shows how lignocellulosic crops (including but not limited to wood) can be transformed into bio-energy. This analysis concentrates on the pathways that lead to "oxygenates, ethanol and chemicals".

Figure 1. Bio-energy Pathways[2]



[2] Grabowski, Paul. *Biomass Thermochemical Conversion OBP Efforts* (Presentation). US DOE Office of the Biomass Program. March 11, 2004.

Challenges for Development of Wood-Based Bio-Fuel or Bio-Product Facilities

As part of its research, Innovative Natural Resource Solutions LLC (INRS) identified challenges to development of wood-based bio-fuel facilities, both specific to Maine and universal. It is important to note that the challenges identified here are not necessarily common to all potential projects and technologies.

1. **Process Economics.** Each technology discussed above has process economics that are, at best, not proven for Maine at the commercial scale. Some technologies have pilot facilities that provide important data and scale-up information; others have little more than lab tests and mechanical drawings. The economics of these technologies have not been fully demonstrated, and initial commercial facilities are almost certain to run into unanticipated (and unbudgeted) challenges. The fact that the economics have not been proven is *not* a reason to view the industry with skepticism, but it is important to understand that these technologies are at a financially immature state and represent both risk and opportunity to developers.

2. **High Capital Cost.** Some of the projects being considered for Maine are best described as pilot, demonstration, or first application of technologies. Often these facilities are built to learn about the technology, demonstrate its commercial viability, and provide customers with product samples. However, once a technology moves beyond this stage it generally needs to be large in order to achieve economies of scale; it could cost hundreds of millions of dollars to construct a facility. Securing this level of financing is often a long and frustrating process, and relies upon excellent planning on the part of a developer and a stable regulatory and business environment on the part of the hosting state and community.

3. **Cost and Availability of Feedstock.** Cost of feedstock is a significant variable in the economics of many bio-fuel and bio-product processes, and generally represents the largest operating expense for a facility. While Maine has an abundance of wood, it also has significant existing demand for this wood from pulp mills, wood-fired power plants and engineered wood manufacturers. Some wood-fired power plants are reportedly paying over $30 per green ton for wood (biomass chips), or almost $60 per dry ton[3]. This is higher than some other parts of the U.S., and notably higher than some other parts of the world.

    - In addition to cost, developers also seek assurances that they can buy consistent volumes of wood over a long period of time. Given the existing markets for low-grade wood, combined with concerns about the state's logging infrastructure, it is not clear that volumes of wood will consistently be available at a reasonable price.

[3] Unless otherwise noted, all volumes in tons are bone-dry short tons.

- The forest industry generally operates on spot pricing, not long-term contracts and futures markets, and this can give project developers and their financial backers discomfort. Some developers are suggesting they require 10 year fixed (or known) price contracts for feedstock in order to invest in facilities. This would be a challenge.
- As a result, there may be opportunities in Maine where geography, land ownership and transportation patterns, or mill residue disposal problems provide a unique opportunity to develop niche bio-fuel or bio-product manufacturing facilities.

4. **Perspective.** When partnering with oil or chemical companies, it is critical to understand that what the forest industry thinks of as a very large facility would appear tiny when compared to a typical refinery. For example, a good size Maine pulp mill may use 1 million green tons of wood a year, or about 550,000 dry tons (assumes 45% moisture content). If this is converted to ethanol with the generous yield of 100 gallons per dry ton, this is 55 million gallons of ethanol each year. This volume is roughly equivalent to the volume of gasoline U.S. refineries currently produce in one day[4]. In the past, this has made it difficult to get large oil and chemical companies to focus on bio-fuel opportunities. However, in the last year a number of major firms have announced plans to develop bio-fuel or bio-product capacity, including British Petroleum, Chevron, Royal Dutch Shell, DuPont and Cargill.

[4] http://tonto.eia.doe.gov/dnav/pet/pet_pnp_wiup_dcu_nus_w.htm

Fermentation

State of Technology

Fermentation is a long-understood process of converting naturally occurring plant sugars into alcohol. Fermentation is a biological process in which enzymes produced by microorganisms catalyze chemical reactions that convert simple sugars into alcohol.

Fuel-grade ethanol, a gasoline additive and substitute made from corn and grains in this country, is made through an existing and well-understood fermentation process. The promise that other plant feedstocks, including wood, can be converted into ethanol ("cellulosic" ethanol) holds great promise.

Ethanol can be produced through fermentation from any plant-based substance, and was produced using wood as a feedstock during both World War I and World War II. However, the process to do so is not as straightforward as converting high-sugar crops such as corn or sugar cane into ethanol, and cellulosic ethanol production through fermentation has not yet proven to be economical at the commercial scale.

Spurred by the rising cost of gasoline, historically high prices for ethanol on the spot market, and public policy incentives, a number of firms are seeking to develop fermentation-based cellulosic ethanol facilities. Some firms currently have demonstration or pilot facilities and are seeking to move this technology to commercial scale. While wood is one potential feedstock for cellulosic ethanol and perhaps a very good feedstock, extensive research has also been conducted on corn stover, bagasse, switchgrass, and a number of other agricultural crops and residues.

Most fermentation for ethanol production practiced today converts six-carbon sugars, such as glucose. While wood is high in these sugars (39% - 50% for hardwoods, 41% to 57% for softwoods), it also has high concentrations of five-carbon sugars, such as xylose (18% - 28% for hardwoods, 8% to 12% for softwoods). Recent advances have improved yields from five-carbon sugars, but these require additional enzymes, and add complexity to feedstock processing.

Potential also exists for the extraction of hemicellulose, a component of wood, leaving behind the cellulose and lignin to still produce forest products – for example pulp and oriented strand board. The hemicellulose can then be fermented to produce ethanol. This extraction process, aqueous extraction, is the subject of research at the University of Maine and other universities, and may provide commercial opportunities for integration into the state's existing forest industry.

Products and Applications

Ethanol is the primary product of fermentation, though the process can be tailored to produce various quantities of other alcohols. Ethanol is attractive because it has an existing and known market, transparent pricing, and increasing demand (much of which results from government price support mechanisms). Yields vary significantly by technology and feedstock, but cellulosic ethanol technologies appear to yield between 75 and 115 gallons per bone dry ton of input.

Products in addition to ethanol currently produced at the commercial scale through fermentation of corn include: antibiotics, lysine, monosodium glutamate, gluconic acid, lactic acid, acetic acid and malic acid. Once a facility was operational, it is possible that side-streams could be used to produce high-value products.

Issues with Commercialization

A US DOE estimate of capital costs for a commercial scale cellulosic ethanol facility, constructed on a stand-alone basis to utilize agricultural residues is $250 - $300 million. Due to the complexity of cellulosic fermentation, the capital costs for this process are higher than for a comparably sized corn-to-ethanol facility. A number of technology experts indicated that, for stand-alone facilities at least, this will always be the case due to the relative complexity of converting cellulosic material to ethanol.

However, this also means that existing infrastructure, such as can be found at Maine pulp mills and biomass energy facilities, may be valuable assets for firms looking to construct cellulosic ethanol operations. To date, the high cost of capital has reportedly served as a deterrent to commercialization of this technology.

Significant advances have recently been made in enzymes tailored to breaking down cellulosic material. The National Renewable Energy Laboratory, in partnership with enzyme companies, was recently recognized for significant reductions in the cost of enzymes designed for cellulosic ethanol production. However, even with these advances, cellulosic ethanol enzymes have not been proven in a process-relevant way, including how the microorganisms that create the enzymes survive over time in a commercial environment.

Wood is highly recalcitrant, or difficult to break down, when compared to other potential cellulosic feedstocks such as agricultural residues. For that reason cellulosic ethanol may be produced through fermentation from feedstocks other than wood initially, or “pre-treated” woody feedstocks such as pulp and paper mill residue or aqueous extractions may gain favor.

Active Companies

Bioengineering Resources, Inc. (commonly known in the U.S. as BRI Energy LLC, http://www.brienergy.com/index.html) claims a breakthrough that uses cellulosic waste, including a wide variety of feedstocks including wood, to produce ethanol and electricity. BRI's website indicate that they expect to have a facility in commercial operations by 2007.

William Bruce, President
BRI Energy LLC
1650 East Emmaus Road
Fayetteville, AR 72701
479/521-2745

Celunol Corporation, www.celunol.com, formerly BC International Corp., claims a patented process for turning a range of cellulosic feedstocks, including wood, into ethanol. The company is constructing a pilot facility near Jennings, Louisiana, and has plans to build a commercial facility at this site as well. Initial efforts are focused on ethanol production from cellulosic agricultural feedstocks (bagasse, grains), but the company claims wood is an acceptable feedstock for their process.

Michael Dennis, President & CEO
Celunol Corporation
980 Washington Street
Dedham, Massachusetts 02026
Phone 781/461-5700

Iogen (www.iogen.ca), with a large-scale demonstration facility currently operating in Ontario, has focused on use of switchgrass as an ethanol feedstock. Iogen asserts that its process can also use hardwood feedstocks, and may look to wood as a feedstock once the technology is commercialized.

Brian Foody, President
300 Hunt Club Rd. East
Ottawa, Ontario
Canada K1V 1C1
Phone 613-733-9830

Mascoma Corporation, www.mascoma.com, is a cellulosic ethanol company. According to their web site, Mascoma expects to have its first facility constructed in 2007, with paper mill sludge as a feedstock.

Colin South, Chief Executive Officer
Mascoma Corporation
161 First Street
Second Floor East
Cambridge, Massachusetts 02142
Phone: 617/234-0099

Xethanol Corporation, http://www.xethanol.com/, is a company seeking to commercialize cellulosic ethanol production. The company has announced plans to explore ethanol production in New England using cellulosic feedstocks (including but not limited to wood), and recently indicated its intention to purchase a major manufacturing facility in Georgia from the pharmaceutical company Pfizer, presumably to use for ethanol production.

Christopher d'Arnaud-Taylor, Chairman & CEO
Xethanol Corporation
1185 Avenue of the Americas, 20th Floor,
New York, NY 10036
Phone: (646) 723 4000

C2 Biofuels has announced plans to build a wood to ethanol facility in Georgia. This company is partnering with Georgia Tech and the University of Georgia on developing the process and designing the plant. The company has indicated an intention to build a pilot facility in Georgia in 2007.

Roger Reisert
C2 Biofuels
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Gasification

State of Technology

When biomass is rapidly heated in a reduced oxygen environment, the plant matter does not combust but rather becomes a synthetic gas (syngas), a combination of hydrogen (H_2) and carbon monoxide (CO). Because gaseous fuels such as syngas mix more easily with oxygen than either liquid or solid fuels, combustion of syngas is more efficient and cleaner than direct combustion of the fuel (e.g. wood chips) from which it was made. Because of this, most gasification projects to date have concentrated on supplying thermal heat, and in some cases electricity generation.

However, significant promise exists for the use of gasification as an intermediate process in the production of fuels and chemicals from biomass feedstocks. Just as syngas mixes easily with oxygen for combustion purposes, it also interacts better with chemical catalysts. This provides the opportunity to use syngas to create, through catalytic conversion, a range of value-added fuels and chemicals. To date, production of liquid fuels and chemicals at the commercial scale has not been proven for biomass gasification, but many experts believe this area holds great promise.

Gasification is an incredibly flexible conversion technology, and can accommodate a wide range of feedstocks. In addition to a full range of wood (chips, sawdust, bark, etc.), gasification feedstocks can include paper mill waste, agricultural residues, animal waste, and other carbon-based feedstocks. Some gasification technologies can use coal or crude oil as well. An extensive listing of gasification projects installed and operational around the world can be found at the Gasifier Inventory website, www.gasifiers.org.

Products and Applications

Gasification creates syngas, which is essentially hydrogen (H2) and carbon monoxide (CO). Syngas can be combusted directly in a boiler or used in a gas turbine to generate electricity. The hydrogen from syngas can be isolated and used to power fuel cells.

In terms of value added fuels and chemicals, syngas has the potential to produce a wide range of commercial fuels and chemicals, including:

- Synthetic diesel,
- Acetic acid (used in the chemical processing industry and as a food additive),
- Methanol (CH_3OH), or “wood alcohol”, used to produce formaldehyde, other chemicals, as a fuel additive, or in other applications,
- Dimethyl Ether (CH_3-O-CH_3), propane substitute, and
- Mixed alcohols (ethanol, propanol, butanol, etc.), to be further processed into saleable fuel and chemical alcohol products.

Issues with Commercialization

Gasification describes a wide range of technologies, and each technology has its strengths, limitations and unique applications. In general, the use of biomass gasification to produce liquid fuels or other biofuels (i.e., not thermal and electricity generation applications) has found a number of challenges, including the following:

- The pre-treatment of feedstocks has been a challenge for a number of technologies. Many gasification technologies require very dry and uniformly sized feedstock, necessitating pre-treatment that can add expense and energy consumption to the process.
- Syngas produced from biomass feedstock has the tendency to be high in tars, which require cleanup prior to conversion into liquid fuels or other value-added products. The clean up of this tar, or production of syngas without tars, has proven a challenge for the industry. Some technologies are now claiming to have processes that address this issue; none have demonstrated their technology in a commercial setting for an extended period of time.
- The utilization of biomass-derived syngas to produce the range of products it is capable of has not been demonstrated at the commercial scale for extended periods of time. Significant questions remain regarding how catalysts perform over time, if tars foul the syngas to liquid fuel process, and if the products produced can consistently and economically meet commercial standards.

Active Companies

The following companies are active or seek to become active in biomass gasification, and claim the ability to convert biomass-derived syngas into a wide range of products including process heat and steam, electricity and liquid fuels. It should be noted that a number of companies produce gasifiers that are designed exclusively around thermal and electric applications; these companies are not included in this listing.

Biomass Energy Concepts
www.becllcusa.com
850 Washington Road
St. Mary's, PA 15857
Phone 814/834-4470
areinc@alltel.net

Carbona Corporation
Jim Patel, President
2611 Marshfield Road
Vallejo, CA 94591
Phone 707/553-9800
carbona@carbona.us

Choren Industries GmbH
www.choren.com
Tom Blades, Managing Director and CEO
Frauensteiner Strasse Sq.
09599 Freiburg, Germany
Phone +49 (0) 3731 26 62 0

Enerkem Technologies Inc.
www.enerkem.com
615 Boul. Rene-Levesque Ouest
Suite 1220
Montreal, Quebec H3B 1P5 Canada
Phone 514/875-0284

EnerWaste International Corp.
www.enerwaste.com
Tom Dutcher, President
PO Box 1194
Bellingham, WA 98227
Phone 360/738-1254

Alfred Dozier
Global Concepts Inc.
1712 Pedregoso Place, SE
Albuquerque, NM 87123
Phone 505/294-5068
globalc@peoplepc.com

Grand Teton Enterprises
www.grandtetonenterprises.com
5721 S. Mt. Vernon
Spokanee, WA 99223
Phone 509/939-6044

Interstate Waste Technologies
http://www.interstatewastetechnologies.com/
17 Mystic Lane
Malvern, PA 19355
Phone (610) 644-1665

Thermogenics, Inc.
http://www.thermogenics.com/
Tom Taylor, President Thermogenics, Inc.
7100-F Second Street NW
Albuquerque, New Mexico 87107 USA
Phone 505-463-8422

Pyrolysis

State of Technology

Pyrolysis (fast pyrolysis or flash pyrolysis) is a thermal process that rapidly heats biomass in an oxygen-free environment[5] to a controlled temperature (generally around 500°C, then quickly cools the volatile products formed during the reaction. This process creates three distinct products – pyrolysis oil, char, and gasses. Pyrolysis oils (also referred to as bio-oil), the primary product of pyrolysis, can be used as a fuel, and researchers believe holds great promise as a "platform intermediate" for the production of high-value chemicals and materials.

Fast pyrolysis is a technology with a significant history, primarily in Europe and Canada. Several reactors have shown yields of liquid product as high as 75% (based on starting weight of the biomass), and companies are pursuing new applications for the product.

Pyrolysis companies have developed operating facilities, with one in the U.S. and several operating in Canada. Ensyn has constructed six pyrolysis reactors, including an 80-ton per day facility in Renfrew, Ontario, and is reportedly pursuing a number of new opportunities in North America. Dynamotive has an operating commercial facility in West Lorne, Ontario, and is reportedly constructing a 200-ton per day facility. Renewable Oil International has taken a different approach; instead of seeking to build large pyrolysis oil facilities, this firm has developed units that can be constructed remotely, transported in container-size pieces, and quickly installed on-site. Renewable Oil International is currently constructing a 15-ton per day demonstration facility in Massachusetts.

[5] This differs from gasification, which uses a reduced oxygen environment.

Products and Applications

Fast pyrolysis provides a mechanism to convert solid biomass, such as wood, into a liquid fuel that can be stored and transported. Pyrolysis oil, with roughly half the heating value of oil on a volume basis, can be used in thermal energy applications with modest changes to existing equipment designed for oil. Pyrolysis oil can be used in direct combustion applications, and has been successfully tested or demonstrated in engines, turbines and boilers for the production of heat or electricity.

However, many observers believe that the potential for pyrolysis oil lies not in combustion applications but in upgrading to transportation fuels and chemicals. Much of this is already occurring, in both the lab and at the commercial scale. One company, partnering with the National Renewable Energy Laboratory, has developed a process to convert pyrolysis oil to transportation grade fuels, to be used in place of or as additives to gasoline and diesel. Another firm has developed a substitute for phenolic resin, used as an adhesive in engineered wood products (Oriented Strand Board, for example). A food flavoring, liquid smoke, is extracted from pyrolysis oil at a facility in Wisconsin.

Pyrolysis oil can also be used in some gasification and fractionation processes, essentially serving as a way to turn bulky, high moisture biomass into a product that can be handled and transported for further processing at a centralized site.

Issues with Commercialization

While bio-oil has established conversion sites and processes, this technology has not yet gained widespread adoption. Issues that need to be addressed for this technology to gain increased market acceptance include:

- The handling of pyrolysis oil once produced, including ways to address concerns regarding separation;
- The consistency of the properties of bio-oil over a range of feedstocks, and the variation in pyrolysis oil over a variety of feedstocks;
- Refinement and continued development of extraction processes to allow highest value-added use of the product

Active Companies

The following companies are involved in development of pyrolysis facilities.

Ensyn Corporation
www.ensyn.com
David Boulard
400 W 9th Street
Wilmington , Delaware
Phone: 302/425-3740

DynaMotive Energy Systems Corporation
www.dynamotive.com
Andrew Kingston, President & CEO
Angus Corporate Centre
1700 West 75th Avenue, Suite 230
Vancouver BC
Canada V6P 6G2
Phone: (604) 267-6000

Renewable Oil International
www.renewableoil.com
Phillip C. Badger, President & Chief Manager
3115 Northington Court
P.O. Box 26
Florence, AL 35630
Phone: 256/740-5636

JND Group Ltd (HQ)
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Nottinghamshire
DN22 7AN, England
Phone +44 (0) 1777 706 777

Fractionation

State of Technology

Fractionation refers to the conversion of wood (or other biomass) into its constituent components – cellulose, hemicellulose and lignin. The critical element of successful fractionation is the reduction of degradation and cross contamination among the fractions. Processes for this include steam explosion, aqueous separation and hot water systems.

Fractionation, through any of its forms, is a process that holds enormous potential for conversion of biomass to biofuels and other products but has seen very limited commercial activity to date.

One firm active in this area, BioFine, piloted their technology for over a decade in South Glens Falls, NY. This company has licensed its technology to a 50 ton per day facility in Italy that is currently undergoing commissioning, and may be scaled up to 150 tons per day.

Products and Applications

Fractionation can theoretically produce a myriad of chemicals, with a number of commercial applications. Chemicals often cited as likely commercial products of biomass fractionation include levulinic acid, xylitol and alcohols (most notably ethanol).

Levulininic acid is a platform chemical, and there are dozens of patented uses for this product. Its earliest applications likely include use as a diesel fuel additive, but it also has potential for the production of synthetic fibers, pharmaceuticals, pesticides, plastics and rubber, and other applications currently met using petroleum-based products.

Issues with Commercialization

Fractionation and refinement of the constituent components of biomass – cellulose, hemicellulose and lignin – has long been the goal of biomass researchers. There is a limited amount of information on fractionation technologies in the public domain, and is not as generally well understood as fermentation, gasification and pyrolysis.

That noted, issues in commercialization of fractionation technologies include scale-up of existing technologies, establishment of a continuous system with high operating efficiency, and establishment of known and secure markets for products.

Active Companies The following U.S. companies are seeking to commercialize fractionation technologies and establish the economic basis for their processes.

Steve Fitzpatrick, President
Biofine Renewables LLC
300 Bear Hill Road
Waltham, MA 02541
781-684-8331

Purevision Technologies, Inc.
511 McKinley Avenue
Ft. Lupton, CO 80621
Phone 303-857-4530
Ed Lehrburger, President & CEO
ed@purevisiontechnology.com

Case Study: Potlatch Bio-refinery Proposal[6]

In January 2006, Potlatch announced an effort to study the feasibility of a biorefinery at its pulp and paperboard mill in Cypress Bend, Arkansas. This announcement was in anticipation of a significant competitive funding announcement from the U.S. Department of Energy. This effort, while still in the feasibility stage, has the potential to reduce Potlatch's energy costs, reduce emissions of atmospheric greenhouse gasses, and demonstrate the commercial production of forest-based bio-fuels.

Potlatch plans to integrate biomass gasification and gas-to-liquid technologies into its existing operations. The plan is to phase in bio-product development.

- Phase 1 is to install a gasifier and a gas-to-liquid processing plant. This would use up to 1,500 tons of feedstock per day, and produce 2,000 barrels of ethanol and bio-diesel.
- Phase 2 would concentrate on the gasification of black liquor, a by-product of the pulping process, producing a synthetic gas for use in a boiler.
- Phase 3 would integrate the aqueous extraction of hemicellulose into the pre-treatment of the pulp chips, with ethanol produced from the hemicellulose.

When and if complete, Potlatch anticipates the biorefinery will utilize 8,000 tons of biomass per day (over 2.5 million tons per year) and 1,300 tons of black liquor solids per day, producing approximately 10,000 barrels of transportation grade fuel per day.

Potlatch chose its facility at Cypress Bend for this effort because of the facility's access to a variety transportation networks (the Mississippi River, rail and truck routes), the economic development potential and likelihood the project will be easily permitted, and the proximity of 11,000 tons per day of low-cost biomass (wood and agricultural residue).

Potlatch intends to pursue this effort with a number of partners, including Winrock International, the University of Arkansas at Monticello and the Arkansas Department of Economic Development. Taking steps to develop the biorefinery is contingent upon partial funding from the U.S. Department of Energy.

[6] DiGiuseppe, Gary. "Biomassive Ventures." *Ethanol Producer Magazine.* July 2006.

Steps Maine Can Take to Encourage Bio-Product Development

As part of this research, Innovative Natural Resource Solutions LLC (INRS) interviewed a number of professional in the bio-fuel and bio-product field, reviewed literature in the area, and drew upon its own professional experience and judgment to compile the following recommendations for ways that Maine might seek to become a leader in the development of wood-based bio-fuels and bio-products. These recommendations are presented as received, and are presented without comment for consideration by the state of Maine. It is important to note that INRS did not confirm the validity or appropriateness of each claim or suggestion.

1. **Take a "technology neutral" approach to the development of bio-fuels and bio-products in Maine.** While understanding specific technologies and the feedstock – processing – product opportunities each provides is important, many developers and others believe that Maine would be well-served to view each project as a stand-alone effort, and evaluate it on its unique merits. At this time, developers are taking two approaches – some are looking to develop large-scale facilities; others are looking for small-scale solutions to unique circumstances. While this report contains information on technologies and the challenges each faces, a critical part of the entrepreneurial culture that will bring wood-derived bio-products and bio-fuels to commercial production is the belief by individual developers that they have solved a challenge – either technical or business – in a unique manner that gives them an advantage in the marketplace. Unless the State of Maine is participating financially in the development of a project or impacts matters of public interest (e.g. emissions), it is not necessarily important for the state to understand how a particular developer will uniquely address bringing a technology to market.

2. **Develop a state role for the financial support of capital investment in new projects.** Bio-fuel production is a new industry, and the financial community has some reservations about financing the first large ventures. Developers and others active in this area noted that state loan guarantees or direct state funding could be tailored to provide developers with the ability to either attract additional outside capital or to lower the cost of borrowing money.
    - In the event that such an approach was taken, it would obviously need to a significant amount of money ($5 to $10 million per project was suggested) to make a meaningful difference in the ability to finance a project;
    - If becoming a financial partner in a project -- either through loan guarantees, direct grants or equity involvement -- the State of Maine would need to fully understand the technology and the business, and conduct thorough due diligence on both the technology and the developers;
    - The most cost effective way for the State to do this may be to offer state-backed loan guarantees, which would lower the cost of borrowing money for a developer while exposing the state to limited risk;
    - Developers and others urged that any such effort, if funded, be conducted in the most apolitical manner possible, and cited the Maine Technology Institute

as an example of the type of entity that addresses economic development with a minimum of political influence.

- It is important to note that Maine is not alone in looking to develop bio-fuel and bio-product facilities, and other states are using money to lure development. For example, the State of New York recently announced "up to $20 million available to as many as four (4) proposers or teams of proposers that successfully demonstrate the technical, financial, business, and organizational capability to construct a pilot-scale lignocellulose-to-ethanol facility and use the information derived from its operation to develop a commercial-scale production facility."[7]

3. **Provide Funding of Feasibility Analysis.** Given the availability of feedstock and the high cost of power in the region, Maine and the Northeast may provide some ideal circumstances for small, niche facility development. One expert interviewed strongly believed that there are unique circumstances and niches where bio-fuel and bio-product investment will make economic sense, and that every effort should be taken to identify those opportunities and move toward capturing these opportunities. By having state funding for feasibility and early analysis of opportunities, such as has been provided by the Maine Technology Institute to some efforts, private entities will be more likely to explore and find options that make sense for their particular set of circumstances.

4. **Support research, development and deployment of new technologies.** While many technologies are approaching commercial maturity, none are clearly at that stage. At this time, research into how to best produce bio-fuels and bio-products in a way that makes sense for Maine is critical. The University of Maine, with recent funding from the National Science Foundation, is beginning to undertake some of this important work now. Once operational, facilities producing bio-fuels and bio-products will need research support to better understand process improvement and full utilization of products and co-products. Efforts in this area have been funded by the Maine Technology Institute in combination with the U.S. Department of Energy; continued funding of this at both the University and commercial level would provide important incentives to develop and refine technologies in Maine.

5. **Place bio-fuel and bio-product development on par with existing industries**. A number of bio-fuel and bio-product developers expressed frustration that Maine appears to view their efforts solely in the context of a way to revitalize the state's pulp & paper industry. While some facilities may co-locate and share synergies with Maine's existing forest industries, others may set up as stand-alone facilities and operate as competitors. Maine should understand that bio-fuel and bio-product facilities may work with or without infrastructure and synergies provided by existing industries, and provide support to efforts that seek to turn wood into value-added products, regardless of the interaction with existing industries.

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[7] http://www.agmkt.state.ny.us/rfps/cellulosic_ethanol/Cellulosic%20Ethanol%20RFP%203.pdf

6. **Develop production-based tax incentives to support facility operations.** Because of the significant public benefits that can arise through the production of bio-fuels, a number of individuals suggested that production-based incentives would provide meaningful support to development of these projects. A production-based incentive, modeled after the federal Production Tax Credit for qualifying renewable electricity production, would provide modest tax credits or other state financial incentives on a per-gallon or per-ton production basis, and help new projects address concerns about product market volatility and uncertainty.
   - Maine currently has a tax credit of $0.05 per gallon for "biofuels commercial production and commercial use", applicable to bio-fuels derived from biomass, including but not limited to forest-derived fuels. The details of this tax credit can be found in the Maine statutes at Title 36, §5219-X. The fact that this credit is little known to developers may highlight a need for more outreach and publication of its availability.

7. **Provide a better understanding of the resource base available.** While Maine has the largest percentage of forested land in the nation, the economic availability of wood is not uniform throughout the state. This is because existing markets for low-grade wood, such as pulp mills and wood-fired power plants, produce significant demand in some areas. Providing high-level analysis of wood availability, type (e.g. hardwoods / softwoods, chips/bark/sawdust, etc.) and pricing would give developers an understanding of what locations to consider when evaluating opportunities in Maine. Massachusetts is currently undertaking a process similar to this to help potential developers of biomass power facilities understand the opportunities by geographic location.

8. **Serve as matchmaker between developers, opportunities, feedstocks, infrastructure and financing.** Many developers may approach Maine as a location to site a bio-product facility because of its significant wood resource. Feedstock analysis is an important and necessary part of facility siting, but alone is insufficient. Maine should be prepared to quickly help developers to identify locations where feedstocks can be reliably and affordably procured, where necessary processing infrastructure exists, and where private sector partners may have interest. This can be done at the state level; it can also be done by identifying a number of organizations, firms and individuals that potential developers can be directed toward.

9. **Help develop a forward market for biomass.** For many other fuel sources, such as oil or natural gas, developers are able to understand and secure future pricing for the commodity. This transparent market in future purchases, common for fossil fuels and many agricultural products, does not exist for biomass fuel. Developers in Maine and elsewhere have noted this as a significant challenge for project financing. The fact that the feedstock – wood -- has an unknown future price is a concern for both developers and the lenders that finance them. Developing a mechanism that allowed new *and* existing facilities to purchase wood on a forward basis would remove much of the uncertainty that developers face, and would help remove a hurdle for development of new facilities. Wisconsin is pursuing an initiative to address this

issue by attempting to develop a *Timber Products Commodity Exchange*, and Maine may be able to learn from that state's efforts.

- As an alternative, developers could seek to enter into long-term known price[8] supply contracts for wood. To date, these have proven to be difficult for large biomass facilities. Recent experience in New England has shown that producers are reluctant to enter into contracts longer than a single year, and are unwilling to enter into contracts for durations that last as long as facility financing. When suppliers are found that are willing to enter into such contracts, they tend to lack the financial backing necessary to secure such contracts, and providing surety through bonding or other mechanisms raises the cost of fuel to an unacceptable level.

10. **Develop permitting rules for bio-product facilities that are clear and reasonable.** Some developers indicated that they have concerns about the standards and timeliness of permitting a bio-fuel or bio-processing facility in Maine. Because this is a developing industry, some claim it is not clear what standards for water, air emissions and solid waste handling will apply (for example, will a facility using pulp mill sludge as a feedstock be treated as a solid waste handling facility?). The Maine Department of Environmental Protection could help address this concern by having clear and reasonable standard to both provide certainty to developers and to adequately protect the public interest.

11. **Address the Cost of Electricity.** Developers noted that Maine, and New England in general, has notably high prices for electricity. For facilities that need to use significant volumes of electricity, this either means high operating costs or additional capital costs to allow self-generation of electricity. Most recognize that this is a complicated issue with many stakeholders, but urged that it be identified as a concern.
    - INRS would note that this is an issue with both cost and benefit for bio-product developers; for those technologies that can have heat, steam or electricity as co-products, the high price of electricity in the region presents developers with additional revenue opportunities. Additionally, the region's renewable energy market, supported in particular by Renewable Portfolio Standards in other states, may provide additional financial opportunity for technologies that can produce not only bio-fuels but electricity as well.

12. Develop Regional Support for Cellulosic Fuels. The agricultural trade organizations and states have done an excellent job of positioning their products – notably ethanol and bio-diesel – for research dollars, price supports, and other incentives that make otherwise risky projects viable. Maine should recognize that it is not alone in seeking ways to support the development of wood-based and cellulosic bio-fuel production, and work with other states to form the political momentum necessary for public policies that place wood-based fuels on par with agriculturally-based fuels.

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[8] In this use, "known price" includes fixed prices, prices that escalate at a predictable rate (e.g., inflation adjusted), and prices that are indexed to another commodity, such as diesel fuel.

Appendix A
Maine Technology Institute Awards to Support Forest Bio-products and Bio-fuels

The following companies have received funding from the Maine Technology Institute to research or develop forest-based liquid bio-fuels and bio-products[9].

Cyr Lumber Company, Aroostook County

Seed Grant: To evaluate the feasibility of extracting pharmaceutical and other high value chemical compounds from Maine wood biomass. The proposed work will involve preliminary investigation of markets, extraction technology, and intellectual property.

Maine Biodiesel LP, Oxford County

Development Award: Maine Biodiesel will fractionate crude tall oil using vacuum distillation and esterification, yielding biodiesels and sterols. MTI funding will help overcome process hurdles while designing and characterizing the material thermal balances and yields of an integrated and optimized process. Biodiesel LP is a partnership of the River Valley Technology Center, Enerkem Inc. and Frontier Energy.

Maine BioFuels, Cumberland County

Seed Grant: To conduct a feasibility survey of gasification process economics and viable product options for gasifiers under 10 megawatts in size.

Maine Bioproducts, Oxford County

Development Award: Maine Bioproducts will develop a high volume biorefinery to convert forest biomass into value-added fuel additives and chemicals. MTI funding will support the manufacturing process and development planning necessary to qualify a high volume levulinic acid biorefinery for financing and construction.

River Valley Growth Council

Seed Grant: This study will evaluate additional product opportunities for the River Valley Biorefinery and will allow for the optimization of product mix and process control, resulting in a more attractive commercial model and allowing for appropriate facility design. The work will result in substantive changes to DOE proposals and industrial partner contracts.

River Valley Technology Center (RVTC) Oxford County

Approved for a **Cluster Enhancement Award** of up to $78,000, matched by over $105,000, to plan, organize and develop preliminary designs for a Fractionation Development Center for forest biomass conversion in Rumford. Tasks will include: evaluation and selection of technologies, development of commercialization priorities, development of a facility plan, identification of necessary equipment, development of an organizational strategy, identification of academic links, development of a business plan for sustainability and a network throughout the state that will use the FDC.

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[9] Information provided by Tucker Kimball, Maine Technology Institute, June 26, 2006.

Safe Handling Inc.[10], Oxford County

Development Award: Safe Handling will research and plan for a commercially viable biorefinery using emerging technologies to be tailored to biomass feedstock, predominantly forest bioproducts, producing energy, chemicals and high value derivative chemicals.

Tethys Research LLC, Peonobscot County

Development Award: Tethys is developing an enzyme-assisted pretreatment step for oxygen delignification to improve the yield and quality of cellulose from wood pulp while reducing the use of harsh chemicals. Tethys will work in cooperation with the Pulp and Paper Process Development Center at the University of Maine in Orono. The effect of the developed enzyme on the physical and chemical characteristics and on the subsequent oxygen delignification of wood pulp will be determined.

> **Seed Grant:** Environmentally friendly, enzyme-assisted pulping processes are greatly needed by Maine's Advanced Technologies for Forest and Agriculture sector. Until recently, no suitable enzymes were available. Tethys and the University of Maine will synthesize a model compound to develop a process based on a newly discovered enzyme and to discoer additional enzymes.
>
> **Seed Grant:** Tethys Research LLC will use/test chemicals designed in a previous Seed Grant project, to search for useful enzymes in microorganisms to assist in the pulping process.

[10] *Disclosure:* Innovative Natural Resource Solutions LLC serves as a consultant to Safe Handling Inc. on this project.

Appendix B
Experts Providing Information

Individual	Organization
Badger, Phil	Renewable Oil International
Bowyer, Jim	Dovetail Partners
Boyce, Gordon	Massachusetts Forest Service
Bregger, Dwayne	Massachusetts Division of Energy Resources
Christiansen, Scott	Fractionation Development Center
Cleaves, Robert	Cleaves & Company
Dell'Orfano, Brian	XGenesys Development Corporation
Dozier, Alfred	Global Concepts Inc.
Evans, Robert	MicroChem Technologies Inc.
Grabowski, Paul	US DOE Office of the Biomass Program
Handley, Rick	Northeast Regional Biomass Program
Brandon Fowler	Honeywell Corporation
Ibsen, Kelly	National Renewable Energy Laboratory
Jarnefeld, Judy	NY State Energy Research & Development Authority
Lefcort, Malcolm	Heuristic Engineering Inc.
Mason, Tad	TSS Consultants
McGaha, Theresa	Potlatch Corporation
Miranda, Amy	US DOE Office of the Biomass Program
Nace, Paul	Maine BioProducts LLC
Polanowicz, Todd	Fractionation Development Center
Reiche, Ford	Safe Handling Inc.
Ruderman, Jack	NH Office of Energy & Planning
Turner, Ralph	rturner.com
Wichert, Don	Focus on Energy (Wisconsin)

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