Accelerating Innovation: Building on the Past to Expand Biorefining and Sustainable Manufacturing in Wisconsin

Preston Schutt, Wisconsin Department of Administration, Energy Division
Sean Weitner, Energy Center of Wisconsin
Kevin Grabner, Energy Center of Wisconsin

ABSTRACT

The concept and practice of biorefining and sustainable manufacturing are neither new nor revolutionary. Biorefineries were common in Pennsylvania until oil was discovered. Nature is the ultimate sustainable manufacturer, and nothing is wasted. Today's new technologies are making it increasingly possible for biorefineries to compete with oil refiners and help industries move toward sustainable manufacturing.

The Wisconsin Industries of the Future Biobased Products program's goal is to reduce energy intensity and production waste while increasing value-added production. It focuses on using traditional business models and management techniques to accelerate adoption of biorefinery technologies. This paper will describe the results of our approach to generate sustainable industrial economic development through expansion of industrial biorefining in our existing core industries.

Background

The most critical component of the emerging bioeconomy is, obviously, the development of technologies that find new and innovative uses for biofeedstocks – uses such as energy, fuel, plastics, manufactured goods, construction materials, pharmaceuticals and nutraceuticals. Only slightly less important, however, is the development of a model for the adoption of these technologies, a theoretical framework with which to identify needs and prepare markets. Without this, the maturation of the bioeconomy may be impeded – after all, only when research is valued and readily commercialized will biobased technologies attract and retain the innovators and investors needed to ensure lasting economic change. To facilitate such change, we have developed a biorefinery model that we believe will become an invaluable tool for communicating the potential of the bioeconomy.

Perhaps the most important idea behind the biorefinery model as we use it is that, rather than considering biobased industry as the exclusive province of green-field business start-ups, a biorefinery can be created as an integrated component of an existing facility that uses organic raw materials. The modern biorefinery:

- uses sustainable feedstocks;
- minimizes waste;
- emphasizes developing multiple products from traditional input and waste streams; and
- facilitates modular enhancements intended to be easily replaceable as technology progresses.

This approach can quickly create bona fide biorefineries out of existing manufacturing operations, as opposed to the risky and laborious process of trying to acquire financing and build a production floor around a new technology that must sink or swim on its own. We believe that leading by example and working with established manufacturers to incorporate process-altering biotechnologies will result in the fastest market transformation and cause existing industries to reevaluate just what a manufacturing facility can be. The biorefinery model redefines manufacturing, changing it from a linear process in which everything that is not "the end product" is waste to a potential refinery in which every aspect of a feedstock can be a value stream. If successfully communicated, such a fundamental change in understanding may speed the adoption of biobased technologies that can be modularly added to existing processes.

Biorefineries are nothing new. For instance, Pennsylvania had a number of biorefineries operating in the 19th and early 20th century that used wood pyrolysis to produce charcoal, methanol, industrial acids and other chemicals out of smaller wood rejected by the timber industries. Taking an even longer view of biorefineries, we can see that natural processes are the ultimate sustainable manufacturers – there is no waste in nature, just a wealth of value-added products. The challenge is finding ways to make sustainable processes work on a manufacturer's time scale and in a way that is competitive enough to wrest market share away from the very mature petrochemical industry.

The genius of the petrochemical industry is just how much can be made from crude oil and, specifically, the byproducts of fuel production. Like many manufacturing processes today, oil refineries once considered their byproducts to be waste streams that could, at best, be co-fired to produce additional energy or illumination. In time, however, it became clear that there were many more valuable potential uses for these hydrocarbons. For example, MTBE was for many years a valueless waste stream in oil refining. Refiners discovered its fuel oxygenate properties and quickly sought regulatory approval for its inclusion in gasoline blends designed to reduce air pollution. As we all now know, MTBE was subsequently found to have significant environmental problems. Its replacement is a biorefined product: ethanol.

Perhaps the most remarkable aspect of the mature petrochemical industry is that many of these uses found their own price point – that is, that the individual margins and demands for plastics, textiles, fertilizers, explosives and many other products are such that each is low-cost and profitable, but not so profitable as to monopolize the hydrocarbons at the expense of the other products.

This is the brass ring that the biorefinery should hope to achieve as it matures — a diverse portfolio of many staple products, competitively priced — but it is the relative cheapness of petrochemical products that poses the greatest challenge to the biorefinery: Costs are already so small that there would seem to be little economic incentive to fund research. While certainly not true in a macro sense — in addition to being a non-renewable resource, petrochemicals come bundled with considerable environmental and geopolitical costs — it is still the expectation against which biotechnologies must compete.

Impressively, however, bioproducts are proving competitive. Though this is visible in a mostly scattered set of products – biodiesel vs. petrodiesel, cornstarch vs. polyethylene sandwich bags – these nevertheless represent a first wave of products that show how biomass can supplant petrochemicals. Although bioproducts do not yet have the economy-of-scale or infrastructure advantages that petroproducts enjoy, one area in which biorefineries can capture value is by using feedstocks that manufacturers are, in many cases, currently paying to landfill. The Oak Ridge National Laboratory estimates that there is in excess of 500 million dry tons of biomass available every year, much of which is process waste that requires disposal and disposal costs. The prospect of turning that expense into value-added products could be critical to having biotechnologies adopted, and is at the heart of our biorefinery concept.

A Biorefinery Model for Wisconsin

This biorefinery model was arrived at after several years of work on the Wisconsin Industries of the Future program, which is committed to making the state's major manufacturing sectors more competitive through cost- and energy-saving measures. WI IOF has invested significant effort in working with industry and research players to capture the state-of-the-art in each sector, to prioritize industry needs and to foster linkages between stakeholders. One major effort in this area has been the development of Industry Roadmaps for each sector: pulp & paper, printing, metalcasting, food processing, plastics, biobased products and water/wastewater. These Roadmaps are designed to communicate the needs of industry and research to all stakeholders and, additionally, each Roadmap also links these needs with potential solutions discovered in the course of its research. As an example, a page from the pulp & paper roadmap follows, showing the top 10 process needs cited by the industry and pairing these with research findings where appropriate.

It was in considering these connections that we arrived at our first working premise for the adoption of biotechnologies: Innovative bioprocessing technologies will be more quickly adopted by established industries that manufacture products from biobased feedstocks. Unlike biotech startups, established manufacturing facilities have systems for purchasing, transportation, handling and sales of biobased feedstocks, waste streams and final products. In most cases, these established industries are producing a commodity product under low profit margins and are looking to add value to their production systems.

By trying to determine the manner in which these companies would adopt these technologies, we arrived at our second premise: The commercialization of new bioprocessing technologies will mimic computer hardware and software in that most new technologies will serve as add-ons or improvements to existing systems. This can already be seen in related industry sectors: In the burgeoning microturbine industry, for instance, the solution for a client who wants to generate more power is not to receive a bigger turbine; she instead receives an additional microturbine. Should a microturbine fail, the manufacturer's solution is not to perform in-line maintenance; the turbine is simply replaced. This modular approach will be critical to successful adoption of biotechnology. Established bioprocessing industries will purchase technology rights or licenses from the innovators, add the new technology to their existing system, and get on with the business of creating value. This also allows for easy upgrades when technology improves.

Figure 1. Excerpt from the Wisconsin Industries of the Future Roadmap of the Pulp and Paper Industry

Table 3.4 Energy Needs in the Wisconsin Paper Industry

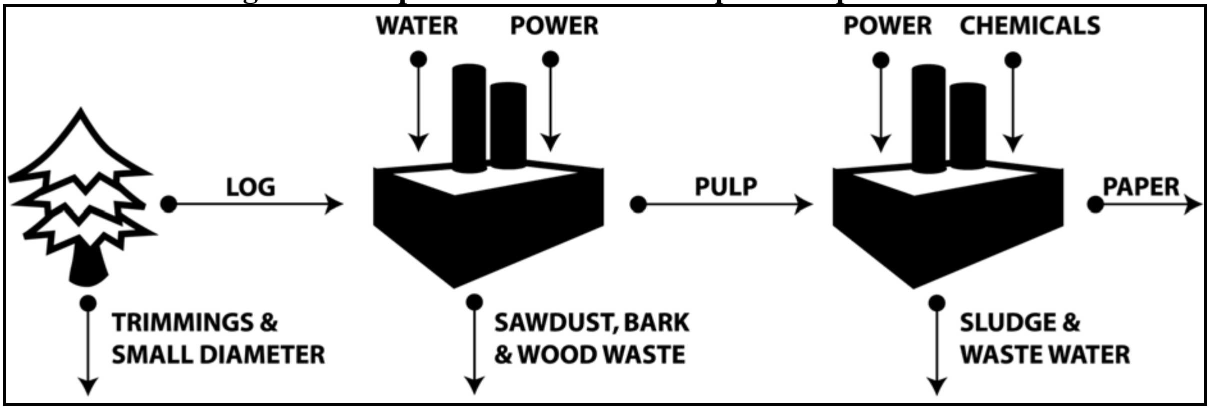
	Needs	Responsive Activity	Status
1.1 Process			
1.1.1	Improvements in water removal technology (priority)	Beck, VoithF: Proprietary Feasibility Study of a Continuous Process for Displacement Dewatering	
1.1.2	More efficient paper drying (priority)		
1.1.3	Pulping chemistries that work at temperatures below 100C.		
1.1.4	Need new pulping and bleaching technology, alternatives to Kraft process: higher yield (keep hemi's), faster process, no sulfur	Atalla, University of Wisconsin: Polyoxometalate Bleaching Sarkanen, University of Minnesota: Producing a True Lignin Depolymerase for Biobleaching Softwood Kraft Pulp Ragauskas, IPST: Mill Designed Biobleaching Technologies	
1.1.5	Improved and energy efficient process for mechanical pulping.	Biopulping	
1.1.6	Efficient energy utilization in refining of chemical pulps.		
1.1.7	Develop waterless, non-solvent paper coating (e.g. powder coating technology).		
1.1.8	Develop waterless paper forming.		
1.1.9	Standardized benchmark database to review energy efficiency of process.		
1.1.10	In-system energy and raw material recovery.		

The alternative to the microturbine approach is the anaerobic digester approach. Currently, there is no modular anaerobic digester technology, and while there exists a healthy body of shared knowledge, installing an anaerobic digester is a little bit like reinventing the wheel each time. This, combined with economy-of-scale issues, has hindered the implementation of a technology that so easily creates value from a common waste stream. If emerging biotechnologies were to follow this approach – big, dedicated, unique installations that permanently alter a facility's geography and complicate the later adoption of better technology – they could easily face the same roadblock.

Having established these premises, the next step is to apply them to the sectors targeted by the Wisconsin IOF plan. Many of them – pulp and paper, solid wood, food processing (dairy, beverages, meat, and agriculture), as well as municipal wastewater – are centered on biological feedstocks, and therefore provide a large potential market for modular biorefinery technologies.

By modeling a typical workflow for each industry, it becomes easier to identify where and how the process can be modified to accommodate a biorefinery component. For instance, a simple model of the pulp & paper process might look like this:

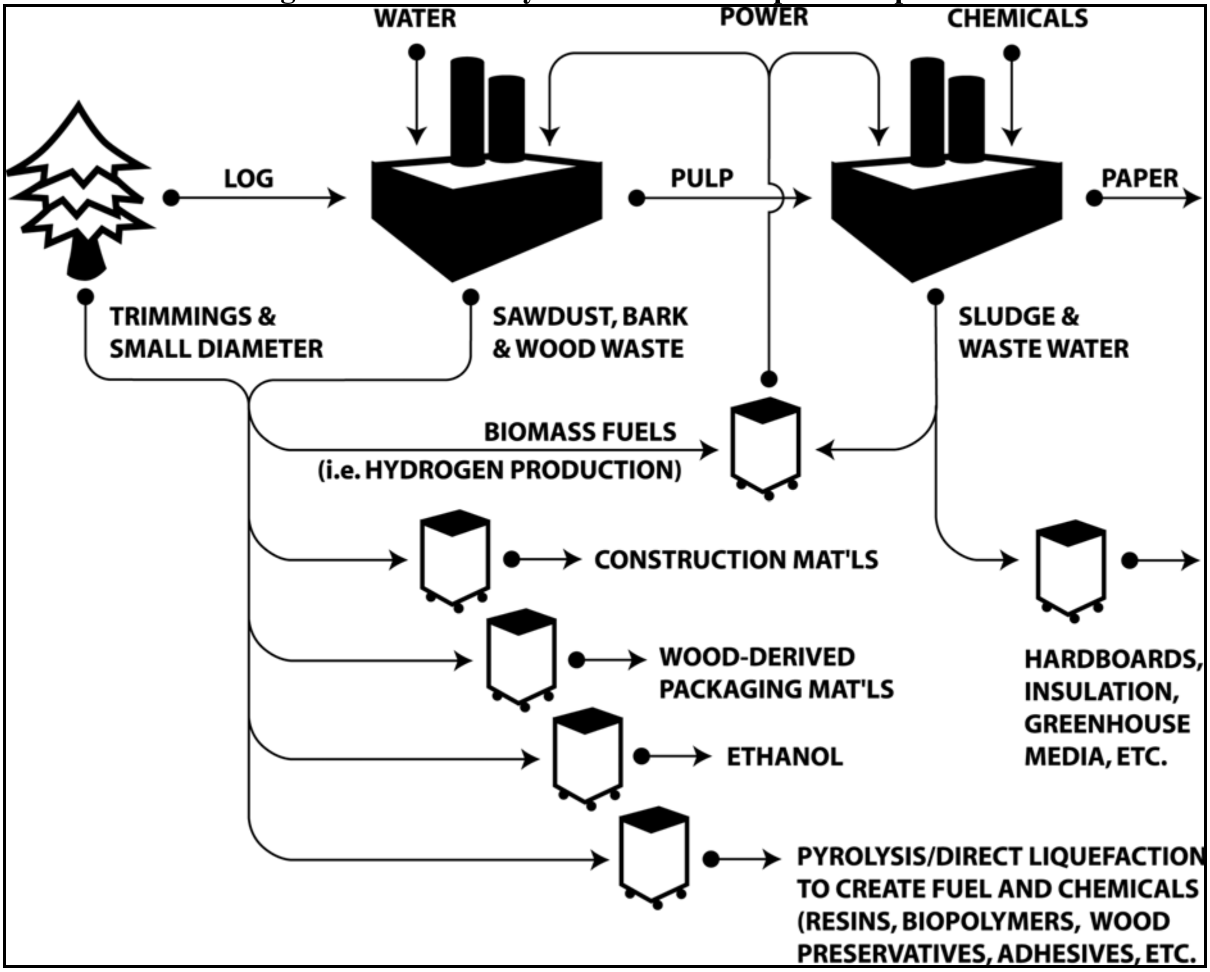
Figure 2. Simplified Flow for the Pulp and Paper Process



Typically, the waste streams shown above – trimmings, bark, sawdust, wood waste, ash and sludge – are either landfilled or, like hydrocarbons in early petrochemical refineries, used as combustible biomass to produce energy. Emerging technologies suggest that there are more valuable uses for the wood resources than simple incineration, however.

This can be seen in an expanded diagram of the process flow. Having identified industry needs and emerging technologies through the roundtable process, we can change the basic pulp and paper workflow to reflect the biorefinery concept.

Figure 3. Biorefinery Model of the Pulp and Paper Process



Note in particular how waste streams have been captured to add new value to the process. This is, of course, at the heart of our biorefinery concept – capturing or enhancing the value of existing resources, many of which are removing value from the operation by requiring disposal.

It is worth nothing that simply incorporating biotechnology into a manufacturing facility does not create a biorefinery. To continue with the example of paper mills: Biotechnologies such as energy-saving biopulping techniques or new biobleaching agents are coming into prominence and will no doubt prove valuable to improving the performance of the mills, but they do not alter the existing process flow (aside from potentially reducing waste volume) or change a mill's product mix.

Building Biorefineries in Wisconsin

Many of the linkages in the Figure 3 are dependent on uncommercialized technology, but it is the intent of this effort to aid commercialization by making every actor aware of the degree to which the integrated biorefinery model rewards all stakeholders. Each of the identified technologies came out of the WI IOF biobased products roadmapping process, and each has been cited as being "in development" by a research organization or technology company. This biorefinery diagram, and others like it, is intended to encourage industry interaction by showing what is being done, who is doing it, and how the manufacturing facility can be changed, conceptually and practically, from a mostly linear process to an integrated system with many value streams. WI IOF uses tools like these diagrams and the roadmaps to help create an active network of buyers and sellers of biobased innovations and to actively assist with demonstrations and commercialization activities.

WI IOF has already taken an active hand in working with technology companies to start building biorefineries. For instance, the University of Minnesota-Duluth National Resources Research Initiative is developing a process that would use paper mill waste residue as a furnish to create particleboard cores for use in interior doors, replacing the virgin roundwood that is commonly used for this product. We have assisted NRRI by finding both a paper mill and door manufacturer to collaborate with us on demonstration, and we are working to secure funding for both the demonstration and commercialization phases of the project. Because each door core needs about 25 lbs. of wood fiber, it is clear to see how quickly the amount of roundwood that will be saved for other uses and the amount of mill waste that will be diverted from landfills will add up. With paper mills producing hundreds of tons of residue a day, this technology has the possibility of significantly transforming its market and strengthening one of the state's primary industries.

Another group that is working with WI IOF, and whose impact on industry promises to be even more significant, is Virent Energy Systems. Virent has developed a unique biomass-to-hydrogen process, Aqueous-Phase Carbohydrate Reforming™, which can be used to create liquefied propane or hydrogen, depending on the market need. Among their endeavors is an attempt to tap into the state's cheese industry by developing a modular unit that would accept as input cheesemaking's whey waste stream and then output fuel. The alternative to such beneficial whey reuse is the more than \$100,000/year that the average plant pays for land spreading, or the almost \$200,000/year that the average plant pays for wastewater treatment. Of course, the deferred fuel and energy costs might be the real windfall for facilities that adopt Virent's technology. Whey is only one of many potential input streams, and WI IOF is working with Virent to develop its business and find potential adopters.

The stakeholder-discovery process has shown us that other Wisconsin biotechnology companies have long ago embraced the same idea of the biorefinery and achieved success. Ensyn Group has developed a patented pyrolysis technology, Rapid Thermal Processing™, which produces fuel and chemicals from biomass or hydrocarbons. Ensyn licensed the first generation of this technology to Red Arrow Food Products Company, which has been using the technology to produce "Liquid Smoke," bio-oil and fuel for more than a decade. Ensyn technologies are currently being used to create these products at five plants, and a sixth plant refines the bio-oil into natural resin products. The newest RTP plant has a capacity of 80 green tons per day, and the resin plant produces 4 million lbs. of products annually.

Another WI IOF effort to aid in the development and commercialization of biotechnologies was its part in the formation of the Center for Technology Transfer, a non-profit, non-stock corporation devoted to encouraging the adoption of resource-saving technologies by helping innovators find venture capital and demonstration sites. Formed in 2002, the CTT has already begun facilitating and investing in start-up bio-businesses. The fruits of these endeavors will include greater interaction between market actors and quicker commercialization of important technologies, as well as increased credence for the work of

WI IOF. Clearly, the CTT's client base is the target audience for the modular biorefinery idea.

Conclusions

Biobased technologies run a much greater risk of floundering if the market for those technologies fails to understand the potential for business transformation. The modular biorefinery model is a tool that can get stakeholders thinking about emerging technologies in the same way that some market actors have demonstrated they are thinking. Combined with other alliance-building efforts, the Wisconsin Industries of the Future program feels that evangelizing about modular biorefineries to all market actors will encourage adoption of these measures and help make Wisconsin a leader in the demonstration and commercialization of these potentially economy-changing technologies.

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