INEEL Bioenergy Initiative

INEEL External Web site Document

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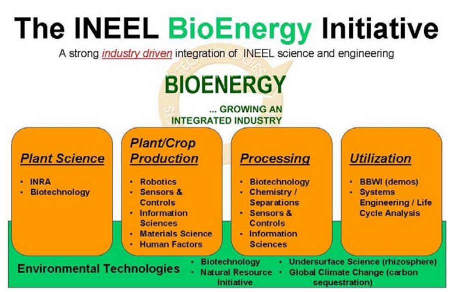
Summary

The United States Department of Energy (DOE) and Department of Agriculture (USDA) recently began a national effort to develop a range of renewable energy sources with bioenergy as the centerpiece, to lessen our dependence on fossil fuels. DOE released two vision documents outlining bioenergy research and technology development needs. These included the BioEnergy Vision: Achieving integrated development and use of our nation's biologically derived renewable resources (2000), and the Technology Roadmap for Plant/Crop-Based Renewable Resources 2020 (1999).

In partnership with Inland Northwest Research Alliance (INRA) universities and with industry partners, the INEEL is investigating and developing methods to overcome key barriers to cost-effective utilization of crop residuals and forestry wastes for energy, fuels, and chemicals production. These technologies are well suited for use in the current model for utilization of agriculture and forestry residues, the centralized Biorefinery. In addition, the new technologies are well suited for use in smaller distributed systems that are modeled after agricultural systems such as dairies and systems for perishable food items. In this way, value is captured at each stage of processing, and shipping costs are minimized.



The INEEL Bioenergy Initiative leverages key multidisciplinary INEEL capabilities to address the major science and technology needs associated with the cost-effective utilization of waste biomass.

The INEEL Bioenergy Initiative embraces the vision of "**Whole Crop Utilization**," and leverages key multidisciplinary INEEL capabilities to address the major science and technology needs associated with the cost-effective utilization of waste biomass. Whole Crop Utilization means the use of the entire crop, including both the grain and traditionally discarded plant biomass, to produce food, feed, fiber, energy, and value-added products. Besides promoting use of agricultural biomass to produce energy, fuels, chemicals and durable goods, the Whole Crop Utilization concept has the added advantage of revitalizing rural economies by providing an additional revenue source to growers.

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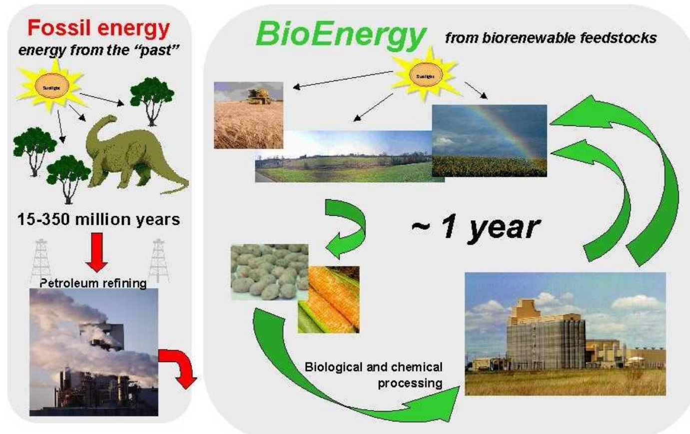
Background

Lignocellulosic biomass is a renewable energy resource. Renewable energy sources are replenished in one to a few years. This definition thus includes both solar- (hydroelectric, solar, wind, biomass) and terrestrial-derived (geothermal) energy sources. While hydroelectric power is currently the principal source of renewable energy in the U.S., there is considerable potential for significant energy generation from the other sources as well. DOE projections suggest that much of the growth in renewable energy use for electricity generation will be from municipal solid waste (MSW), wind, and biomass.



Carbon fixed today into renewable bioenergy sources is renewed about once every year. Conversely, fossil energy is the product of carbon fixation many millions of years ago.

More than 86 million metric tons (95 million tons) of agricultural residues are produced in the U.S. each year, including residues such as wheat straw, corn stover, orchard trimmings, etc . These and other agricultural residues, including sawdust, wood and yard trimmings / thinnings, and manure, are the most economical biomass fuels for generating electricity. Additional feedstocks could be drawn from non-hazardous landfill debris and from new, fast growing tree and fiber crops. However, most agricultural residues have yet to be widely used for power generation. They could offer a sizeable biomass resource if the technologies and supply infrastructures are developed to economically deliver them to power plants in a form that is readily usable as fuel.

In addition to being a source of electrical power generation, renewable biomass can be used as a source of fermentable carbohydrates for the production of fuels and chemicals. In the U.S., more than 400 million acres are used to produce corn, soybeans, wheat, and other crops, while pastures and range lands occupy about 800 million acres, and forests cover more than 650 million acres. The globalization of these markets continues to pressure growers with lower prices even as they strive to improve yields, harvesting techniques, and efficiency. Creating a dual crop – food and energy from biomass – contributes to local economies and promotes the production of excess agriculture and forestry residues as bioenergy feedstocks.

Considerable environment benefits can also be realized from the production of

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energy, fuels, and chemicals from biomass. This is in part because open field burning, which injects pollutants such as particulates, carbon monoxide, polycyclic aromatic hydrocarbons (PAH), NO_X and SO_X into the atmosphere, is minimized or eliminated. Also reduced are net increases in CO_2 emissions to the atmosphere, since biomass production sequesters / recycles this important greenhouse gas from the atmosphere. Finally, used together with coal to co-fire utility plants, biomass reduces sulfur and nitrogen emissions.

In the U.S., more than 86 million metric tons of agricultural residues are annually available for utilization.

A robust bioenergy and bioproducts industry will require developing both dedicated energy crops and waste biomass to their potential. Although these feedstocks hold considerable promise, significant technical challenges exist that must be addressed before they can be utilized for economical production of fuels and commodity chemicals.

Thus, cost effective utilization of agricultural residues for production of energy, fuels, chemicals, and materials presents unique technical challenges. The DOE BioEnergy Vision and the Technology Roadmap for Plant/Crop-Based Renewable Resources 2020 address this need with specific areas of emphasis. These include effective public/private partnerships that can integrate technologies, applications, markets, and policies, as well as basic and applied research, development and education in the areas of plant science, production, processing and bioproduct utilization.

Barriers to Utilization of Agricultural Residues for Bioenergy

For more than a century, researchers have sought economical methods for production of fuels and chemicals from lignocellulosic biomass such as wood, agricultural residues, and the like. Excellent yields of fermentable glucose can be obtained, and molecular biology and genetic engineering have produced microbes that can ferment xylose and arabinose (C-5 carbohydrates) to ethanol as well. Considerable work has been done to harvest value from each part of the lignocellulose, in order to improve the economics of the process.

Much of the need for these advances arises from the economic need for centralized processing. Economies of scale determine plant capacity and location for lignocellulose conversion technologies, as for most industrial processes. Market size and location set annual production of the fuel or chemical, dictating the maximum plant size. The cost of required capital equipment and the associated energy requirements dictate minimum plant size and the land area necessary to maintain feedstock supplies. The economics of the currently favored technologies for production of fermentable sugars from renewable lignocellulose suffer from high capital equipment costs and high energy costs associated with acid hydrolysis and acid recovery, enzymatic hydrolysis rates, yield losses, toxic thermal decomposition products, sugar purification costs, and product recovery costs. These are the principal factors that make centralized processing facilities a necessity. To help make these centralized processes economical, value must be then harvested from each fraction of the lignocellulose, e.g. cellulose, hemicellulose, lignin, and ash.

This requirement for large centralized processing plants increases the land area required to supply feedstock for a single plant, and the feedstock must then be shipped great distances. For example, feedstock and transportation costs for lignocellulosic biomass can account for a substantial portion of the cost of producing ethanol, even with specialized in-field feedstock densification equipment. Reductions in capital equipment and energy requirements could improve centralized process economics and potentially allow distributed processing, reducing transportation costs.


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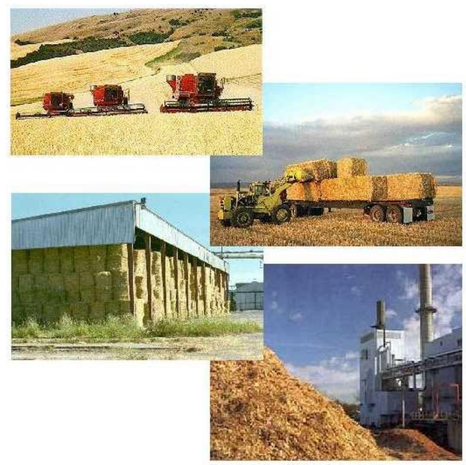
The INEEL Bioenergy Initiative

Utilization of agricultural and forestry residuals is currently uneconomical in part because the historically favored approach has been patterned after petroleum and grain processing systems. In these systems, the feedstock is harvested and then shipped, often great distances, to centralized processing plants that produce the end products, which are then shipped to distribution centers and then to the end users. While the centralized Biorefinery concept can work well for many renewable biomass sources, lignocellulosics such as agricultural residues have very low bulk densities, placing an added constraint on the economics. The economics of distributed systems may or may not be able to compete with centralized processing plants, depending on the economies of scale associated with the necessary processing steps (e.g. pretreatments, fermentation, product separation).

Many agricultural commodity markets operate successfully in a distributed manner. Examples important to Idaho and the Pacific Northwest include dairies, potatoes, and sugar beets. In each case, the feedstock is perishable and has a high water content, which places constraints on shipping. The solution in these markets is to perform part of the processing near the site where the feedstock is produced, and the remainder in centralized facilities. This is the core of the INEEL approach. By performing preliminary processing steps at or near the feedstock source, value can be captured for the feedstock producer and a higher value product that needs less processing can be delivered in a more efficient manner to the centralized processing plant. The INEEL Bioenergy Initiative is working to develop a suite of key technologies that enable Whole Crop Utilization in both centralized and distributed systems, thus allowing processing to be economically tailored to the available feedstock.

The INEEL Bioenergy Initiative is building capabilities that directly address the U.S. Department of Energy (DOE) Biobased Products and BioEnergy Initiative, which has the lofty goals of tripling domestic use of biobased products and bioenergy by 2010, and increasing use 30-fold by 2050. The technology roadmap for the initiative targets a range of bioenergy technologies, including dedicated energy crops and the utilization of crop residuals and forestry wastes for production of fuels and chemicals. Although both of these approaches show considerable promise for the long term, utilization of crop residuals and forestry wastes has the most promise for near term application. Still, several major technology barriers must be addressed before these biomass resources can economically be utilized for the production of energy, fuels, and chemicals.



Whole Crop Utilization promotes the use of the entire crop.

Supporting the DOE Bioenergy Vision

In a recent National Research Council (NRC) report (2000), priorities for research and commercialization on biobased industrial products were outlined. Key committee findings indicated a need to take advantage of the present national emphasis on biotechnology to develop long-term, focused, and fundamental bioenergy / bioproducts related research based on the biorefinery model. Technical prerequisites for practical biorefineries included inexpensive processing systems and utilization of all anatomical (stems, leaves, seeds, etc.) and molecular (carbohydrates, lignins, proteins, etc.) biomass components. The INEEL Bioenergy Initiative builds on this approach by improving systems that improve the overall economics of centralized biorefineries, with the added benefit of being suitable for use in smaller, distributed systems.

Both the DOE BioEnergy Vision and the Vision 2020 Technology Roadmap for Plant/Crop-Based Renewable Resources emphasize the need for collaboration among national laboratories, universities, and industry to achieve their ambitious goals. In the Roadmap, research and technology development needs were categorized into four areas:

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- Plant Science
- Plant/Crop Production
- Processing
- Utilization

The INEEL Bioenergy Initiative and its Vision are built around these four research areas. The INEEL Bioenergy R&D program focuses on agricultural and forestry crops and their direct and indirect uses as energy and as sources of fuels, chemicals, and materials. Example INEEL Initiative focus topics in each of these areas are:

- <u>Plant Science:</u> The use of recombinant DNA technology to exploit plant genomics, including selection and characterization of key genes that influence the quality, quantity, and performance of bioenergy products. Genetic engineering to develop improved crop/tree varieties with optimized feedstock characteristics or that produce genetically introduced value-added products.

- <u>Plant/Crop Production:</u> Development of new processes and equipment for efficient distributed harvest and fractionation of crop residues. Development of improved control methods for on-site optimization of crop production from initial tillage through harvest. Selective breeding of crop strains to improve their characteristics for harvest of both grain and biomass.

- <u>Processing:</u> Bioprocessing of biomass for optimized direct combustion or production of bioproducts. Development of distributed and low-cost biological pretreatment methods for production of fermentable carbohydrates from biomass. Development of improved separation methods for reducing feedstock and product purification costs. Development of extremophilic biocatalysts for bioprocessing at high temperature and low pH.

- <u>Utilization:</u> Development of improved equipment engineering designs for direct feedstock use for electricity production. Development of scaling strategies for distributed production and processing of bioenergy/bioproducts. Identification of biomass characteristics for efficient energy production, conversion to fermentable carbohydrates, and production of added-value chemicals and materials.

Significance to National and Regional Needs

Utilization of residual forest and agricultural biomass to produce bioenergy and bioproducts will help to grow the U.S. economy. In addition, it will strengthen U.S. energy security, protect the environment, reduce greenhouse gas emissions, and revitalize rural America. Many of these are particularly important to the Inland Northwest. Agricultural crop residues and forest products industry wastes are plentiful in the Inland Northwest. However, both of these industries are undergoing difficult times due to low product prices and increased operating costs due to rising energy prices and environmental requirements. The long-term viability of these industries is presently in jeopardy in this region. Development of a robust and vibrant biofuels and bioproducts industry in the Inland Northwest could revitalize these industries by making use of biomass residues, providing a significant boost to regional rural economies.

Implementing the INEEL Bioenergy Initiative greatly enhances the potential for successfully implementing the DOE's Technology Roadmap for Plant/Crop-Based Renewable Resources 2020.

Implementing the INEEL Bioenergy Initiative and the Whole Crop Utilization Vision greatly enhances the prospect of successfully implementing the DOE's Technology Roadmap for Plant/Crop-Based Renewable Resources 2020, and can positively impact our nation's present and future energy needs. The Initiative practically and effectively addresses all four of the research and development areas targeted in the Renewables Resources Vision 2020. The INEEL and its partners will leverage extensive in-house expertise in the production of crops, pretreatment of biomass, microbial fermentations and molecular biology, and utilization of forestry wastes and pulp and paper effluents. This expertise includes computational simulation and modeling, development of site specific technologies for crop production, development of chemical and biological methods for producing fermentable carbohydrates from biomass, production of chemicals via microbial conversion of carbohydrates, and genetic modification of microbes to enhance production of fuels and chemicals. This approach thus integrates the efforts of multiple research facilities and supports a critical mass of scientists and engineers with the essential expertise in the areas of the plant sciences, production, processing and utilization of renewable biomass.

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