INL/CON-09-15568
PREPRINT

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2009 AIChE Spring National Meeting

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April 2009

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Abstract

The U.S. Department of Energy (DOE) aims to displace 30% of the 2004 gasoline use (60 billion gal/yr) with biofuels by 2030 as outlined in the Energy Independence and Security Act of 2007, which will require 700 million tons of biomass to be sustainably delivered to biorefineries annually. Lignocellulosic biomass will make an important contribution towards meeting DOE's ethanol production goals. For the biofuels industry to be an economically viable enterprise, the feedstock supply system (i.e., moving the biomass from the field to the refinery) cannot contribute more than 30% of the total cost of the biofuel production. The Idaho National Laboratory in collaboration with Oak Ridge National Laboratory, University of California, Davis and Kansas State University are developing a set of tools for identifying economical, sustainable feedstocks on a regional basis based on biorefinery siting.

Keywords : Sustainability, biomass, Logistics, lignocellulosic

Introduction

The U.S. Department of Energy Office of Energy Efficiency and Renewable Energy's Biomass Program has implemented the Biofuels Initiative, with the goal of reducing U.S. dependence on foreign oil. The Biomass Program has established the following programmatic targets in support of these policy goals:

- Make cellulosic ethanol (or ethanol from non-grain biomass resources) cost competitive with gasoline by 2012[1].
- Replace 30% of current levels of gasoline consumption with biofuels by 2030 (30x30), which equals 60 billion gallons of ethanol production[2,3].

The terms "sustainable" and "sustainability" embody efforts to balance today's resource requirements with future demands. For example, agriculture is considered sustainable when agricultural inputs – such as natural resources, energy, chemicals, labor– meet current demand for food, fuel, and fiber without environmental consequences that impair future production. In terms of meeting the DOE 30x30 goals, the sustainability concern is whether or not the U.S. agricultural system can produce sufficient feedstocks for biofuel production while continuing to meet the food price expectations of

American consumers without causing environmental degradation that would threaten to curtail the production of food, feed, fiber and fuel.

From a feedstock supply system design perspective, the concern is to develop a means of assessing the sustainability of a national commoditized feedstock supply system. This paper will discuss the current research efforts at the Idaho National Laboratory (INL) in collaboration with Oak Ridge National Laboratory (ORNL), the University of California, Davis and Kansas State University that help design and analyze biomass supply system logistics and biorefinery siting. The goal is to improve conventional feedstock supply systems and establish performance criteria required to make the system functional, aid in siting biorefineries to ensure adequate sustainable feedstock supply, and allow biorefinery sizing to reduce unit production cost

The authors believe that there are two main barriers for meeting biomass quantity demands: first, providing a sustainable, diverse biomass supply that doesn't adversely impact food supply, and second, developing a feedstock supply system that is able to access the supply in a cost-effective manner. In addition to transportation issues, densification, material stability, and storage, and queuing are also supply system considerations. This paper will outline current status, developing trends, and future vision for biofuel production.

Biorefinery Siting

A common perspective on dealing with feedstock supply system challenges is that minimizing the biomass collection areas is necessary for reducing total production costs. This perspective leads down two primary pathways: (1) build smaller, more distributed biorefineries and (2) increase the unit area energy density of the lignocellulosic feedstock. As with most processing facilities, biorefineries find significant reductions in unit production cost with increasing biorefinery scale. Scaling down conversion facilities to accommodate feedstock supply system constraints puts added economic pressure on an already challenged system.

Increasing the energy provided per unit area of feedstock is a highly desirable outcome from multiple perspectives. For example, if a feedstock genome is developed that results in a two-fold increase in biomass yield, the biomass collection radius necessary could be reduced by over 30%. Supply system economics and revenue for producers/landowners are positively impacted by this dynamic. High-yielding bioenergy feedstock will provide a profitable crop for producers/landowners and a consistent resource base within a tight logistical radius for conversion facilities. Unfortunately, this dynamic also has the potentially crippling effect of creating unsustainable monoculture cropping systems unless biorefineries can economically receive and use a mix of crop species.

As demonstrated by recent increases in the value of corn grain, profit margins quickly drive agricultural decisions on land use. The acreage committed to growing corn for grain has increased by approximately 29% over the last 20 years[4]. The upper Midwest of the United States is generally a corn grain monoculture. It is well understood and accepted within the agronomy community that monoculture cropping systems create wide-ranging problems and are generally not sustainable over the long-term[5,6]. This includes the suite of perennial crops[7] along with standard annual cropping systems.

The key to developing sustainable cropping systems, and ultimately maintaining the long-term viability of the agricultural landscape, is providing producers/landowners access to a diverse set of markets. An emerging cellulosic bioenergy industry has potential to provide these new markets capable of supporting progression towards agronomic sustainable integrated cropping systems. The essential hurdle in providing market access to growers is the design and implementation of a uniform-format, commodity-scale lignocellulosic biomass supply system.

Supply System Designs

The feedstock supply system consists of five basic operations: harvest and collection, storage, handling and queuing and preprocessing. The current research is focused on three feedstock system designs (Figure 1). The Conventional-Bale and Pioneer-Uniform designs represent systems that use current technologies, while the Advanced-Uniform, represents a supply system that can achieve the 2017 and 2030 feedstock cost and quantity targets established by Department of Energy Office of Biomass Program (DOE-OBP)[8]. The Conventional-Bale system is what is the current design being used to collect feedstock supplies, such as corn stover and wheat straw. While the Conventional-Bale works for the current demand, cost and performance restrictions cannot accommodate future supply needs. A transformation of the supply system must occur to support the increased demand for cost effective biomass supply, and the transformation is outlined in Figure 1.

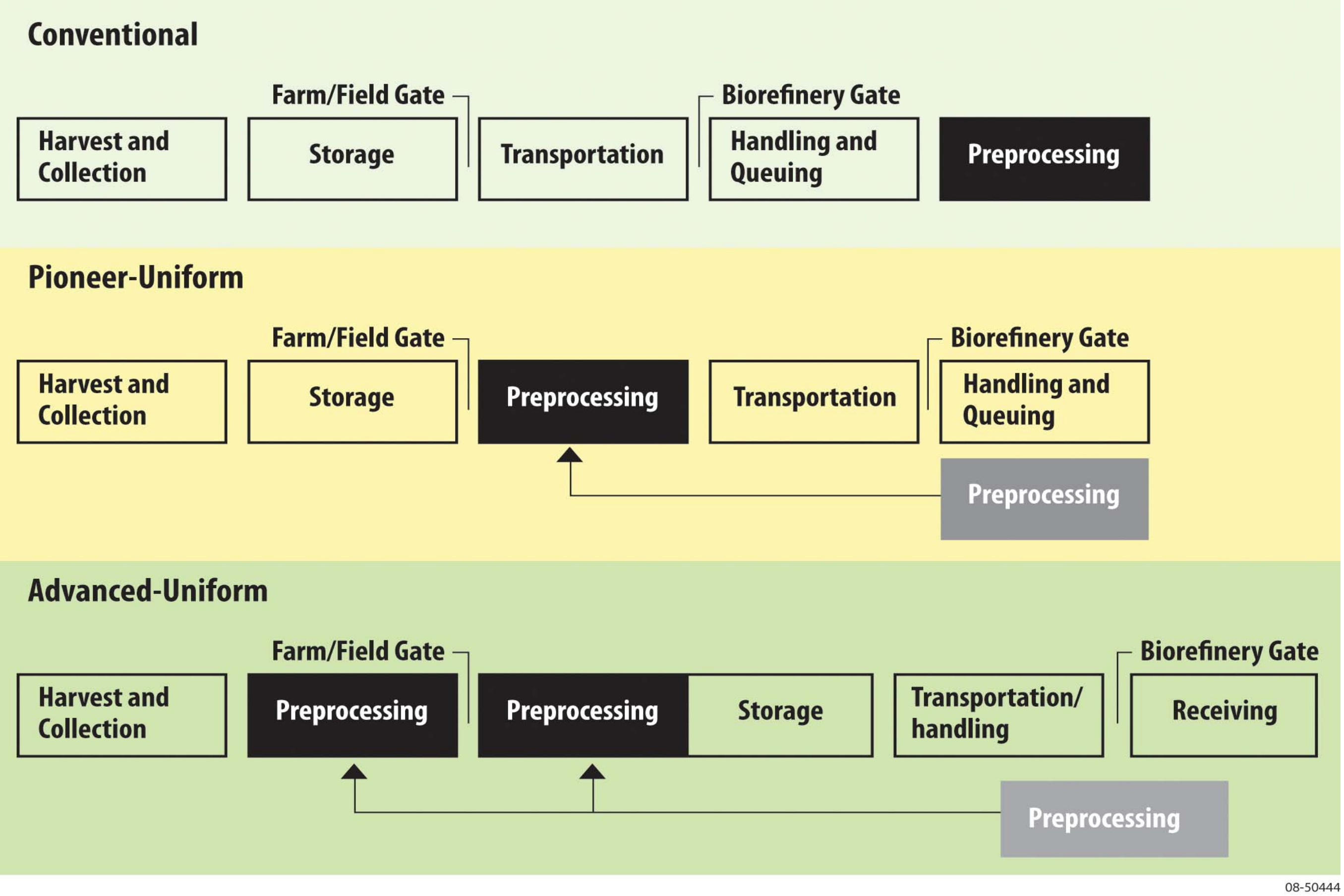

Figure 1. Three feedstock supply systems are currently being analyzed. The first two systems are assumed to use current technology and equipment. The third supply system concept requires new equipment yet to be developed.

For any supply system design to be truly functional, the design must be flexible enough to couple accommodate resources that can be quite site-specific due to such issues as yields, landscape characteristics and accessibility. This is a fundamental design feature of the Advanced-Uniform design, envisioned under the premise that the upstream modular nature of the supply system is much better suited to effectively conform to feedstock supply diversity than downstream, larger capital supply and conversion systems.

Additionally, harvesting systems will have variable-rate harvesters that can selectively collect biomass based on localized conditions. Access to U.S Geographical Survey and U.S. Department of Agriculture soil, slope and climate data will provide real-time analysis of removable biomass.

When connecting supply systems to the biorefinery, the vision is clear; develop a supply system infrastructure that can connect diverse biomass resources to a uniform format biorefinery receiving and conversion system. At the resource end of the supply system, the objective is to accommodate the diversity of biomass resources without unique equipment for each respective resource. The design concept is to invest in a minimum number of technologies that, with adjustments or attachments, are able to adapt to handle diverse feedstock resources, production systems, and landscapes.

Uniform-format supply system design strategies are based on the following assumptions:

- A highly efficient, large capacity, dependable feedstock supply system for biomass already exists with the nation's commodity-scale grain handling and storage infrastructure.
- No alternate supply system design for lignocellulosic biomass is capable of handling large quantities at the same or greater efficiencies and reliability than existing grain handling infrastructure.
- The national goal of annually supplying in excess of 700 million dry matter tons of biomass to a bioenergy industry can only be effectively accomplished through development of harvesting and preprocessing systems that reformat lignocellulosic biomass resources into a "uniform-format bulk solid" that can be stored and handled in an expanded grain commodity infrastructure. A grain system has standardized equipment for handling; the format is dense and flowable and is aerobically stable.

Biorefinery Sizing

One of the benefits of moving to a commodity-based feedstock supply system is the ability to scale biorefineries to minimize unit output cost, versus constraining plant size based on local resource availability. A second factor impacting the economics of biorefineries is the delivered cost of biomass; as plant size increases, assuming a contiguous biomass resource, the cost to bring biomass to the plant increases. The competition between the delivered cost of biomass and the plant capital cost leads to an optimum plant size (Figure 2), and has been described by many sources[9 - 15].

From Figure 2, a more dispersed biomass resource will move the cost of delivered feedstock up, shifting the optimum size lower, while a higher processing cost, i.e., a more expensive plant, will shift the optimum size higher. Therefore more expensive conversion technologies have more of an economic disadvantage by being built at smaller scales. If the cost of biomass at the field (grower payment) is independent of location, meaning all farmers are willing to sell straw or corn stover for a similar price regardless of their distance from a processing plant, then the field cost of biomass at its point of origin has no impact on optimum size of a processing plant. Only feedstock costs that vary with distance, which would be the incremental per mile trucking cost, impact optimum plant size. For example, Searcy and Flynn[9] found the optimum plant size to be in the range of 2,000 dry t/d from very low biomass availability and relatively low capital intensity facilities (in this case, direct combustion) to 19,500 dry t/d for higher biomass availabilities for capital-intensive biorefineries (in this case, Fischer-Tropsch synthesis).

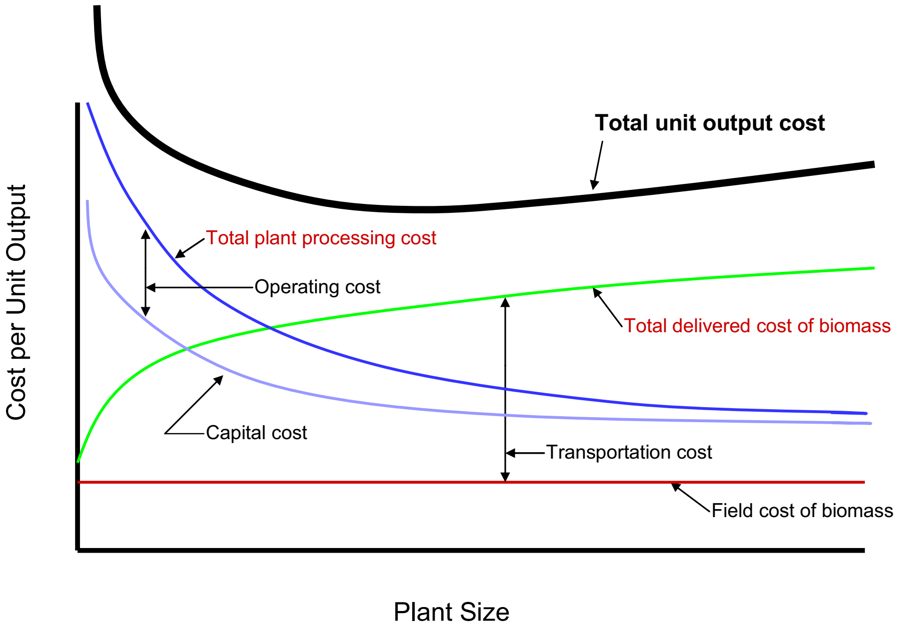

Figure 2. Impact of plant size on biomass conversion cost per unit output. Processing cost includes maintenance and operating costs in addition to capital cost. Plant size could be a power output (for example, megawatts production from a direct combustion facility), or fuel production (for example, million gallons annual production).

Limiting the biomass draw area to 80 km (50 mile) radius as is the typical rule for biorefinery siting (for example, Aden *et al.*[16]) which limits the plant size to around 2000 t/d, which, depending on the biomass yields, may be well below a plant size where economies of scale are realized.

Sustainability

While perhaps not immediately clear, the issue of sustainable cropping systems is crucial to biorefinery siting. Conversion facilities built based on access to unsustainable resources will quickly become unsustainable themselves. Through the development of a commodity-scale lignocellulosic biomass supply system, diverse markets will become available to the agricultural community. These markets will facilitate, and even encourage, a shift towards sustainable integrated cropping systems producing a multitude of bioenergy feedstocks which will be processed and blended to biorefinery feedstock specifications. Through this commodity distribution system, material will be delivered within tight quality specifications to conversion facilities that are sited based more on utility and transportation access and upstream distribution constraints, rather than downstream resource access constraints.

The overall objective of this ongoing research focus is to identify adequate sustainable resources on a regional basis and cost-effectively couple those resources to biorefineries, while identifying bottlenecks and restrictions for different supply system designs. Potential biorefinery sites that will ensure adequate, sustainable biomass supply will be indentified.

Conclusions

Sustainable agriculture provides food, fiber, and fuel while protecting environmental or enhancing systems in an economic framework that is profitable for farmers. Experience to date with ethanol production and how it distorts agricultural markets underscores the potential of energy, agronomic/environmental, and economic sustainability concerns to undermine the DOE 30x30 goals: Can the U.S. agricultural system produce sufficient feedstocks for biofuel production and meet the food, feed, and fiber price expectations without causing environmental degradation?

Achieving national biofuel goals can only be accomplished through development of a uniform-format feedstock supply system consisting of modularized harvesting and preprocessing systems adapted to the diversity of feedstocks and yet connect to uniform-format receiving systems of standardized and highly replicable biorefinery designs.

The feedstock supply systems employed today are not capable of meeting the biomass supply required to achieve national biofuel production goals.

The Advanced Uniform design vastly increases the availability of biomass resources and enables DOE biomass supply targets to be met. The commodity-based system produces a stable, storable, flowable product early in the supply chain. This system promotes diversity in cropping systems and prevents the stranding of biomass resources. Securing a sustainable biomass feedstock supply to biorefineries allows scaling based on capital economy rather than resource availability.

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