EDITORIAL

SPECIAL FOCUS: ADVANCED FEEDSTOCKS FOR ADVANCED BIOFUELS

An overview of lignocellulosic biomass feedstock harvest, processing and supply for biofuel production

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> “The questions here are whether the existing grain-producing infrastructure is capable of handling these huge volumes of biomass, and what potential barriers must be addressed through research to accomplish the goal as stated.”

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The US Biomass R&D Technical Advisory Committee has envisioned a 30% replacement of the current US petroleum consumption with biofuels by 2030 [1–3]. This goal implies that the demand for cellulosic feedstock will increase to 1 billion dry tons annually, more than three-times the US corn production in 2011 [1,2]. Nearly 3 million tons of lignocellulosic feedstock must be harvested, processed, stored and transported each day. The questions here are whether the existing grain-producing infrastructure is capable of handling these huge volumes of biomass, and what potential barriers must be addressed through research to accomplish the goal as stated. It should be noted that the primary goal of feedstock processing and supply is to provide materials in a form that, given a certain method of pretreatment, allows optimization of the conversion efficiency. This article summarizes the state-of-the-art in biomass provision and logistics, as well as addressing future needs.

Challenges in cellulosic feedstock supply for commercial-scale bioenergy production

The success and sustainability of the biofuel industry is highly dependent upon an efficient feedstock supply system [3–7]. Based on the current supply infrastructure, the cost of feedstock production, processing and supply accounts for 40–60% of the cost of biofuel production for a medium or large biofuel plant [3]. Accounting for the US Department of Transportation’s legal weight limit of 21.8 tons per truck, to transport 3 million tons of biomass feedstock from harvest sites to bioconversion plant gates by 2030, approximately 150,000 road trips would be required per day. The preprocessing, storage and transportation of green energy crops is even more challenging than that of dry herbaceous feedstock [8].

The efficiency of the existing biomass preprocessing and supply systems needs to be improved to sustain biofuel production, especially for grassy biomass crops and agricultural residues [9,10]. The bulk densities of loose agricultural residue or prairie energy crops range from 50 to 100 kg dry matter m^{-3}, while the bulk densities of corn and bituminous coal are approximately 721 and 830 kg m^{-3}, respectively [11]. As the biomass energy density is similar to or slightly lower than that of corn and coal, the low bulk densities of herbaceous and agricultural residue feedstock pose major barriers to an efficient feedstock supply.

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Advanced feedstock preprocessing & supply

An advanced feedstock processing and supply system must take into account both feedstock properties and biorefinery requirements. Some pretreatment methods render the material form less important, by incorporating a mechanical means of exposing cellulose to enzymatic engagement. A trade-off is present between the conversion efficiency, which favors small particles, and the energy required to grind materials to these smaller particle sizes, which is substantial. In fact, the energy requirement for size reduction can be 100-times higher than that of harvesting or compression, and research is needed to develop improved millers, cutters, shredders and choppers [9,12,13]. Determining which currently available technology is most suitable for size reduction depends on feedstock types. For instance, a shredder or chopper is more suitable for coarse size reduction of green energy crops than a hammer mill, but they do not allow size reduction to finer particle sizes. While rotary veneer processing may be more efficient for forest wood logs, the chopper or shredder is a preferred option for forest residues and short-rotation woody coppice [12].

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An advanced feedstock preprocessing and supply system should provide an efficient supply facility and infrastructure in terms of energy use and costs. The system needs to be tailored to the biofuel plant size and its choice of pretreatment and conversion technology, as well as the feedstock type, geography and climate. These parameters dictate the optimal preprocessing methods, storage facilities and transportation needs. For instance, a small biofuel plant size can have on-site storage and delivery of material by on-road trucks [5]. In contrast, local depots or centralized storage and processing centers together with road and railway transportation will be required for a large biofuel plant. For rail transportation, ideally, compressed biomass in pellet form should reach the bulk density of coal, which would allow using the existing infrastructure as well as co-combustion with coal.

Future prospects

Equipment & supply system standardization

To streamline the supply logistics for a medium or large commercial biofuel plant, the biomass form and production equipment and procedure should be standardized [5,14]. For smaller biofuel plants, it seems logical to utilize existing agricultural equipment and facilities for preprocessing, storage and transportation. For a medium or large biofuel plant, however, standardized feedstock forms, preprocessing and supply equipment and procedures have to be developed. For example, the US Department of Energy's biomass program developed self-propelled bale loading/unloading equipment [15]. In the case of baling, standard sizes and weights are needed to facilitate efficient handling. Ultimately, a standard size biomass 'particle' or 'kernel' would allow handling, storing, transporting, blending and trading bioenergy feedstock as a commodity such as corn and soybean. Similarly, a formal definition and standard methods to measure the biomass 'quality' would be indispensable. These ideas have been articulated in the advanced uniform biomass form [4].

Logistic simplification & optimization

Systems approaches are required to optimize equipment configurations, as well as simplifying and streamlining the supply logistics. For instance, concepts exist that include integration of biomass pretreatment with storage at the farm site or local processing centers and, subsequently, transforming the pretreated biomass into pellets as a deliverable form to the refinery [16,17]. However, such ideas need to be approached with care, since chemical pretreatment is more complicated and potentially harmful compared with classical mechanical preprocessing. Another potentially simplifying concept is to directly compress bales into briquette (or pellet) bulk density at a local processing centre for subsequent storage, transportation and size reduction.

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Interface among feedstock production, preprocessing & supply logistics

To optimize the efficiency of the entire biofuel production chain it is essential to use a systems approach, rather than attempt optimization of individual components. To study the system as a whole, modeling is essential. The outcomes of model predictions, however, are predicated upon model structure, assumptions and data reliability; therefore, models should be thoroughly validated before any predictive power can be claimed.

Another aspect of biomass is that it needs to be characterized by determining physical and chemical properties. Physical properties include mass and energy density, particle size and shape, but also mechanical properties such as flowability, storability and grindability. Chemical composition determines the convertibility, but the latter parameter is highly correlated with, for example, the particle size and shape. This shows that optimal pretreatment and conversion methods should be developed in combination with mechanical preprocessing technologies that allow producing materials with properties that have been generated by optimization of the complete biofuel production chain [16,17].

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Evaluation of the complete biofuel production chain needs to be conducted by rigorous evaluation of energy requirement and machinery costs with a uniform unit. For size reduction, for example, specific energy consumption per unit of resulting particle area (MJ m^{-2} particle area) should be used for efficiency evaluation rather than specific energy consumption per unit of mass (MJ kg^{-1}). For unit operations in the supply chain, it seems logical to express the energy used relative to the energy content of the crop, or in the percentage of the inherent heating value. The costs of feedstock production and processing should not be reported in currencies such as US dollars or euros, but rather in purchase power parity.

▪ Feedstock precision mechanical preprocessing & supply

Along the same lines as the proliferation of precision agriculture technologies, it seems logical to apply similar concepts to the field of bioenergy. The main pillars of precision agriculture are data acquisition and systems analysis through remote sensing, GPS, GIS, automatic control and sensor technologies. The latter pillar has been the bottleneck for decades, but there are new opportunities in the bioenergy field to develop efficient control algorithms and real-time sensors allowing measuring crop parameters such as yield, machine parameters such as instantaneous throughput, as well as process parameters such as moisture content and temperature. In addition, there is a need to develop sensors that can rapidly evaluate biomass quality, which in itself lacks a proper definition but is evidently dominated by the conversion efficiency potential.

Automatic control and sensor technology can be applied to feedstock harvest and processing. For instance, the speed of a harvester can be controlled to reach the throughput potential of the machine using a real-time yield sensor as the measuring element. A control mechanism could be applied to control the speed of a size reduction machine to ensure it is running at a speed that minimizes the energy use within the target throughput range. A map-based decision-support system in combination with real-time weather and traffic information could be helpful for feedstock supply management at the operational level.

Summary

The main future challenge in biomass logistics comprises transportation of huge volumes of low value/low energy density materials in an effective and efficient manner. The overall aim is to produce materials in a form that allows optimization of the conversion efficiency, while minimizing energy input and costs. Although feedstock production is a variation on a known theme, the sheer scale of the material flow requires innovative approaches and technologies. A systems approach that includes properly validated models is imperative to optimize the complete bioenergy production chain. Finally, sensors and control algorithms need to be developed for optimization of machinery.

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