

Impact of feedstock quality and variation on biochemical and thermochemical conversion

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ABSTRACT

The production of biofuels from lignocellulosic feedstock is attracting considerable attention in the United States and globally as a strategy to diversify energy resources, spur regional economic development and reduce greenhouse gas emissions. Because of the wide variation in feedstock types, compositions and content of convertible organics, there is a growing need to better understand correlations among feedstock quality attributes and conversion performance. Knowledge of the feedstock impact on conversion is essential to supply quality controlled, uniform and on-spec feedstocks to biorefineries. This review paper informs the development of meaningful feedstock quality specifications for different conversion processes. Discussions are focused on how compositional properties of feedstocks affect various unit operations in biochemical conversion processes, fast pyrolysis and hydrothermal liquefaction. In addition, future perspectives are discussed that focus on the challenges and prospects of addressing compositionally intrinsic inhibitors through feedstock preprocessing at regionally distributed depots. Such preprocessing depots may allow for the commoditization of lignocellulosic feedstock and realization of stable, cost-effective and quality controlled biomass supply systems.

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1. Introduction

1.1. Background

Renewable biomass represents an abundant source of carbon

neutral domestic energy, and its use for biofuels is attracting considerable attentions in the US and worldwide as a strategy to mitigate climate change, secure a constant energy supply, and improve rural economies [1]. The Billion-Ton Study update released by the US Departments of Energy (DOE), Agriculture (USDA) and DOE's National Laboratories in August 2011 predicts that there will be more than one billion dry tons of biomass sustainably available annually in the US for conversion to 85 billion gallons.

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With the continued development of biorefinery capacity and technologies, this amount of fuel may potentially displace approximately 30% of the nation's petroleum consumption by 2030 [1–4].

The success of biofuel and biochemical industries depends on a reliable supply of high-quality biomass, available at a cost that enables meeting the cellulosic biofuel and business profitability targets [5,6]. The current technical focus is on the development of cellulosic feedstocks, e.g., non-grain, non-food-based feedstocks and on economically viable technologies to convert cellulosic material into transportation fuels and other products. The cellulosic feedstock types being considered include: 1) agricultural residues that are non-food based by-products (e.g., corn stover); 2) energy crops including woody (e.g., hybrid poplar, willow) and herbaceous (e.g., switchgrass, miscanthus, sorghum, energy cane); 3) forest resources such as existing and re-purposed pulp and paper products, logging residues, and forest thinnings; and 4) industrial and other wastes which are from waste processing (e.g., municipal solid wastes, yard wastes, urban renewal wood waste) [2].

While the broad-scale use of these feedstocks is still emerging, existing biomass supply systems have been developed for mature agriculture, logging, food, and pulp and paper industries. This has fostered assumptions that the biomass quality specifications for the original applications are also appropriate for conversion to bioenergy. Although progress has been made in biomass harvesting, collection, and storage to improve operational efficiency, reduce material loss and drive down logistics costs, an emphasis on feedstock quality and its impacts on conversion are lacking [5,6].

To further the economic growth of the biofuels industry, it is critical to understand that not all biomass is suitable for conversion into biofuels, biochemicals or biopower because biomass resources are inherently heterogeneous, have variable compositions and conversion properties, and can contain introduced soil and other endogenous contaminants that are detrimental to handling and downstream processing [6–8]. The viability of conversion facilities depends highly on supply systems that ensure low-cost, high-volume, and quality controlled feedstock supplies. A variety of conversion pathways can be used to convert renewable feedstocks into fuels and chemicals. However, these conversion technologies will necessarily have different requirements for feedstock quality.

1.2. What is feedstock quality?

At the highest level, the physical characteristics and chemical composition of the biomass are the most important indicators of a biomass source's potential for conversion into biofuels. The requirements are markedly different among conversion processes for these quality indicators. For example, biochemical conversion of biomass to ethanol is typically much more dependent on cellulose and hemicellulose content and less susceptible to ash content, and thus high ash herbaceous feedstocks such as corn stover are commonly used for biochemical pathways [9–11]. In contrast, low ash woody biomass with high lignin content is typically more favored in thermochemical conversion processes such as pyrolysis and gasification, because they produce high yields of products and have decreased catalytic poisoning, slagging, and equipment fouling/corrosion problems as compared to herbaceous feedstocks [5,8,12,13]. If the full potential of the billion tons of biomass is to be achieved while ensuring year-round feedstock supply and taking advantage of conversion economies of scale, it will be necessary to devise ways to improve the quality attributes of locally available biomass sources for use in conversion processes that they may not be perfectly suited for. Hence, a deeper understanding of the meaning of feedstock “quality” and its cost and yield impacts on specific conversion technologies is critical.

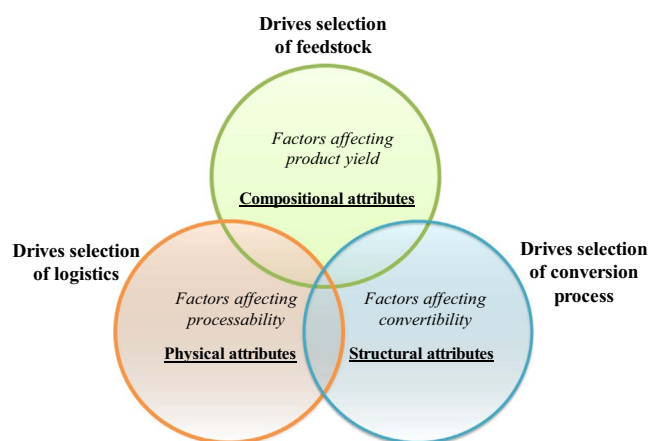


Fig. 1. Feedstock quality drives selection of supply, logistics and conversion process.

Feedstock quality attributes that impact conversion performance and process economics can be divided into three categories: physical attributes, structural attributes and compositional attributes (Fig. 1). Dividing feedstock quality attributes into these categories considers feedstock quality at three different scales: physical attributes are generally at the macroscale, structural attributes are generally at the microscale, and compositional attributes are at the molecular scale. Physical attributes primarily affect feedstock processability and drive the logistics, structural attributes primarily affect convertibility and thus drive selection of the conversion process, while compositional attributes primarily affect product yield and drive the selection of feedstock. However, the impacts of these attributes are not always independent but can overlap. For example, a compositional attribute such as the presence of inhibitors can affect both yield and convertibility depending on the conversion process.

Table 1 summarizes the primary impacts of some key feedstock quality attributes on feedstock selection, logistics and conversion. At the macroscale, feedstock type, particle size and shape, moisture content, energy density, bulk density, hygroscopicity, and flowability, can affect feedstock handling, storability, reactivity, product yield, and transportation cost. At the microscale, cell wall structure, cellulose crystallinity, degree of polymerization (DP), porosity, and surface area, can affect the biomass recalcitrance and reactivity. Finally, at the molecular scale, the feedstock's compositional properties including ash content and species (alkali metals, alkaline earth metals, heavy metals, silica, chlorine, sulfur, etc.), extractives, structural carbohydrate contents, C5 and C6 sugars present, lignin content and its monomer composition, elemental content (carbon, hydrogen, oxygen and nitrogen), etc., can directly impact product yield, equipment wear, conversion cost and the need for wastewater treatment. In addition at this scale, various inhibitors generated during conversion (sugar and lignin degradation products) can also pose direct or potential inhibitory effects on the conversion pathway, product yield and process cost.

There are inherent advantages of choosing a single feedstock for use in both biochemical and thermochemical processes, and process designs must always factor in anticipated variations in their chosen feedstock [14]. The best case is when there is a guaranteed year-round supply of a single type of biomass in a local area. Unfortunately for much of the billion tons of biomass, this is the exception rather than the rule. Thus, as noted earlier it will be necessary to devise ways to improve the quality attributes of locally available but less-preferred biomass sources so that they can also be utilized. Developing robust processes that can handle these

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