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# Comparison of combined ethanol and biogas polygeneration facilities using exergy analysis

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ABSTRACT

Polygeneration processes for production of ethanol (2500 t/y, anhydrous), electrical power, and district heat from wheat (grain + straw) were evaluated via exergy analysis and compared with a standard ethanol process that yields DDG as a supplementary product. A tool was developed to account for exergy in processes utilizing biological matter based on major classes of biomolecules (carbohydrates, lignin, lipids and protein) and ash. This allows for an estimation of the exergy of complex streams that occur throughout the conversion process. Standard ethanol production from wheat grain yielded an exergy efficiency of 37.9% for ethanol and 60.9% for products (ethanol and DDG). The interim case (wheat grain + straw) was found to be more efficient producing ethanol (47.4%), since the stillage was used to supply utilities. Wheat straw only facilities have limited ethanol efficiency since only part of the raw material was converted into ethanol. As was shown with the lignocelluloses only scenario using the stillage to produce valuable products can raise the overall performance of the process potentially to 68.7%.



## 1. Introduction

The industry can rely on a proven and robust process using starch-rich source materials that can be stored and processed conveniently to produce ethanol. Or, industry can advance beyond these First Generation processes. Lignocellulosic materials are the essence of Second Generation biofuels. Some of these source materials (e.g. straw from grain production and corn stover) are agricultural residues, others such as hardwoods, softwoods and grasses are grown dedicated for use in energy production.

These Second Generation biofuels have (in general) a lower hexose content than for example maize or wheat grain. However, in addition to hexoses these raw materials contain significant amounts of pentose-sugars and lignin.

The heterogeneous structure of lignocellulose requires additional process steps to realize the full potential. A polygeneration process that yields fuel, heat, and electricity can be more effective in minimizing wasted heat and unwanted by-products. This polygeneration process productively uses what would otherwise be underutilized side streams as a fuel, to increase the total energy output of the process and increase exergy efficiencies. This can be exergy in a chemical form (ethanol and methane) or a physical form (electricity, steam and hot water). In recent times, several scenarios have been proposed to more fully utilize lignocellulosic source material for the production of ethanol [1,2]. They have in common that the production facility is optimized for ethanol production in conjunction with the maximum utilization of the side streams that occur during the processing. Side streams may include: low temperature heat, organic matter or carbon dioxide formed during fermentation [3]. Recently Bösch et al. [4] studied dual temperature single-step dilute acid hydrolysis method compared with two-step single-temperature dilute acid hydrolysis of biomass for ethanol production.

The agricultural residue of feedstock growth is often used to provide the utility steam of the process via incineration as with bagasse. A good example of this process is ethanol production from sugar cane. By combusting the residue in its native form a considerable amount of exergy is irrecoverably lost that could be saved if processed differently.

Another drawback of incineration alone is that elements such as nitrogen or phosphor in a bioavailable form are lost for later recirculation to the soil and therefore have to be substituted by mineral fertilizers that have a negative impact on the life cycle analysis [5].

The main goal of these facilities is the conversion of low-value source materials to high value energy forms.

It is in the nature of polygeneration concepts to yield a broad spectrum of products. To have a common ground for the comparison

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