

Implementation of switchgrass as feedstock for a industrial biofuels process in a nuclear complex

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Abstract

The use of switchgrass (*panicum virgatum*) as the feedstock for a biofuels complex requires a procedure that coordinates harvesting, drying, storage, and densification techniques with the perpetual availability of process heat from a nuclear reactor and gas from a hydrogen facility. Preparation of feedstock involves assuring a 20% moisture content and compacting the biomass into pellets that can be easily implemented in a 3500 ton-per-day complex. Among the issues that must be considered for on-site switchgrass production are economic viability and logistic feasibility, as well as the introduction of CO_2 emissions from transportation that cannot be sequestered.

Nomenclature

FT Fischer-Tropsch

SG Switchgrass

1 Introduction

Switchgrass (*panicum virgatum*) is an optimal bioenergy crop due to its ability to grow in dry climates, its reproducibility on poor land, and its exclusion from use as a food crop [1]. Among other alternatives for biomass feedstock, it has a more water-efficient C4 Carbon Fixation cycle and higher energy density of lignocellulose [2]. Employing this bioenergy crop into an industrial process requires systematized preparation and the use of established transportation networks. The amounts that are needed at any time are determined by the limitations of the refining processes used and the amount of heat that is available, which requires coordination with engineers overlooking the core and process heat.

2 Process Overview

A feedstock flow rate was chosen by the biofuels group based on the correlation of the power supplied by the process heat to drive Fischer-Tropsch (FT) reactions. Using power from a ~450 MWe reactor, the process heat will supply 12.5 MW of H_2O to the SILVA[®] gasifier (which includes bringing the air intake to the operating temperature of 354 °C) and more power to the distillation procedure further on in the process. Due to the excess reaction heat of syngas formation, the biofuels process will supply heat back to the main process by cooling the syngas with water. This will allow the syngas to undergo an acid-gas removal at the low temperatures needed (see Figure 1). The hydrogen group will supply the input H_2 to the FT process, upon which reactions will take place between the hydrogen and the syngas (now free of H_2S and CO_2). The liquid produced from the reactions will then be passed onto a distillation and refining procedure (which also employs H_2). Light gases, biodiesel, and biogasoline will be separated, and all refining will be conducted on-site to meet the targets of the overall design of the complex.

It was calculated that to fuel this process, there would need to be input 41 kg/s of feedstock at 20% moisture content. The amount of moisture was made higher than the previously assumed 12% to correlate

22.033 BIOFUELS PROCESS

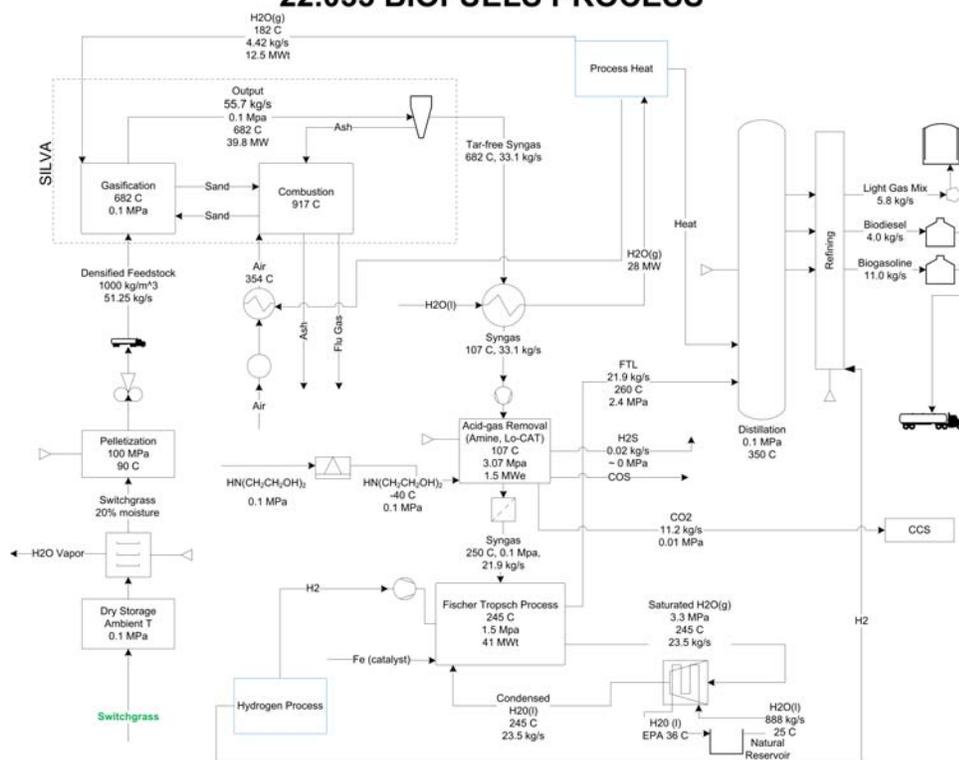


Figure 1: The simplified process that will be employed by the biofuels team. Notice the outlining of Process Heat and Hydrogen Processing in blue; these will be determined by other groups in the 22.033 design team.

with known gasification characteristics, which are more difficult to modify overall. The water comprising this percentage of the biomass was calculated into the mass balances for the gasification reactions.

The plant expects to operate at 20 hours a day and cannot go without operation for more than three days due to storage limitations from the hydrogen process. It must ensure that proper heat dumps are managed when the process stops and must coordinate with reactor shutdowns such that process heat is available.

3 Densification

In order for the feedstock to be properly introduced into a streamlined process, it must first be compressed into a dense material. The actual volume of the raw material is too great relative to its actual energy density for practical application; when switchgrass is formed into bales, it typically has a bulk density of around 150 kg/m^3 [5]. The transportation of these volumes are not economical, which necessitates a briquetting or pelletizing to take place beforehand.

The structure of switchgrass (SG) is porous on a microscopic scale. When large amounts of pressure are applied to small surface areas of biomass, the particles become compressed and fill in these spaces, and then further interact with intermolecular bonding. The moisture content serves as a binding agent for the lignin and cellulose, activating the bonding mechanisms of the macromolecules at high pressure. It also doubles as a lubricant, but at 20% the process is bordering on the optimal content, considering that water allows cell walls to maintain their shape and for their lignin to be contained. At high pressure, friction causes heating up to $90 \text{ }^\circ\text{C}$, which allows the bonds to consolidate upon cooling [4].

A pelletizer at 137 MPa with a screen size of 3.2 mm can produce pellets at 12% moisture with a density of 1000 kg/m^3 [5], which is an order of magnitude higher than the raw material. The molecular bonding and the secondary structure resulting from that bonding during the application of force maintains the pellets in cohesive units such that loss of material due to disintegration is negligible. Switchgrass compression requires

a more prolonged application of force compared to other energy crops, and although it may have a greater bulk density than barley straw, wheat straw, and corn stover, its pelletized density is the lowest [5] amongst those alternatives. The advantage of using SG lies in its greater composition of useable macromolecules per unit volume.

Bales taken directly from a switchgrass farm will need to be stored in a climate-controlled, dry location. When moisture content is achieved, they will then be hoisted by machine from the holding facility into a large hopper, which will feed directly into a grinder. This will allow for smoother pressing, as the grounded material will then proceed to the pneumatic pelletizer (see Figure 2). The pellets will then be arranged into a transportable medium.

4 Transportation

The key economic factor in the biofuels task force decision to outsource switchgrass production and preparation to farmers and their facilities was rooted in taking advantage of an extant external network to remove the logistical burden of maintaining on-site facilities and to improve the transportation condition of the biomass itself. In densified form, the bulk feedstock takes up less volume and allows for trucks of limited size to haul more per trip on a consistent basis. With fewer trips, the overall CO_2 emissions are reduced and deduct from the amount of greenhouse gases produced in our process that cannot be sequestered.

The capital costs of transportation include \$0.028/ton/km for rail \$0.137/ton/km for trucks, with the latter having a greater rate of change per distance traveled but a low initial fixed cost [6]. Considering that we idealize the plant being located in a growing region (such as Minnesota or Texas [3]) near the necessary natural reservoirs needed for the process, shipping of feedstock by truck should be under 200 km and meet optimal pricing. Although there would be a clearer advantage to railway for both long-distance transport and insertion of materials into an continuous process, it poses negative implications for the plant's reaction time to reactor shutdown periods. Land vehicles can be dispatched most efficiently in the event of feedstock shortage and can be readily halted if necessary. They also do not require large changes to existing infrastructure [7].

5 Process Input

To accommodate for moisture content in the pellets, the additional hydrogen and oxygen contributed by the water molecules were factored into the reaction. Basing the dry feedstock flow on the needs of the gasification reactions, and accounting for 20% moisture, it was calculated that 55.7 kg/s of pellets were needed as an input, which account for ~ 41 kg/s (3500 t/d) of useable biomass.

The input process will rely on an unloading mechanism and a temporary storage system, which cannot be fully automatic and will require some degree of manual labor. The unloading dock will need to consist of several bays and have direct access to an area of low traffic congestion. Pellets from the temporary storage area will be fed to a conveyor belt that leads to a weighing hopper, which will then feed directly into the gasification chamber in fixed amounts for particular durations of the process (see Figure 2).

Considering that gasification proceeds at a temperature of 682 °C, there must be considerable distance between the gasification chamber and the holding area, and the conveyors and hoists will need to consist of fireproof material. In the event of a reactor shutdown, the holding area will need direct access to short-term storage. The engineers will need to schedule the reshipment of feedstock with the refueling of the core such that downtime between start-up of the reactor and that of the biofuels facility will be very short. Furthermore, it is possible that shipments may fluctuate with the perennial growing cycle of switchgrass, such that it may be necessary to arrange for backup suppliers in case of emergency shortage. All possible locations of suppliers must be evaluated for typical weather conditions that may prove troublesome to providing a consistent source of feedstock. If this is a decisive factor, then the complex must take footing based on that locality.

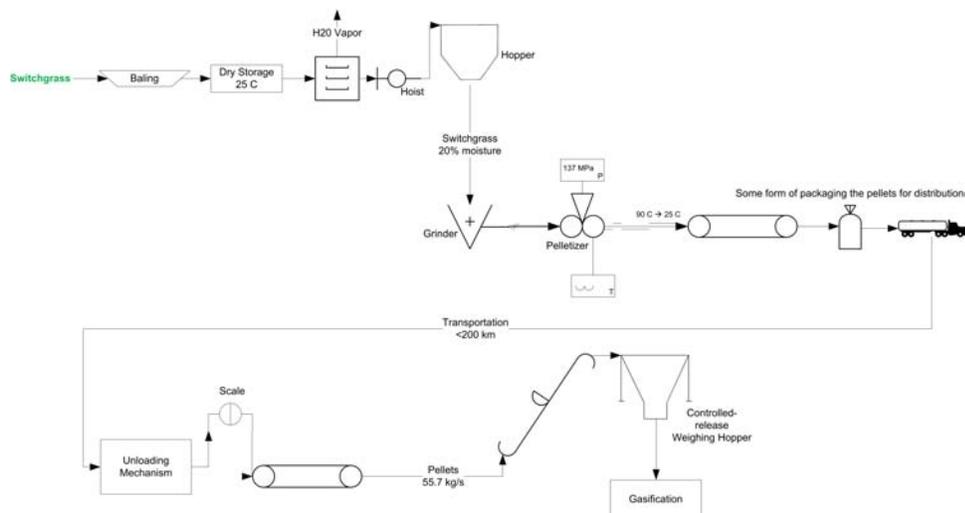


Figure 2: Overview of switchgrass processing layout from field to gasifier.

6 Conclusions

Before the biofuels facility can operate, ground transportation must be established between the reactor complex and the energy crop source such that feedstock can be delivered in a controlled and consistent manner. Processing SG into a dense form allows for a more economical transportation option and a very controlled injection into gasification processes, which allows the overall process to be more streamlined and manageable. However, as opposed to the other sectors of the reactor complex, there are external variables that weigh into the availability of this biological resource, which will require considerable foresight and logistical coordination during operation.

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