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An Overview of Biofuels Process Development in South Carolina

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Abstract

The South Carolina Bio-Energy Research Collaborative is working together on the development and demonstration of technology options for the production of bio-fuels using renewable non-food crops and biomass resources that are available or could be made available in abundance in the southeastern United States. This collaboration consists of Arborgen LLC, Clemson University, Savannah River National Laboratory, and South Carolina State University, with support from Dyadic, Fagen Engineering, Renewed World Energies, and Spinx. Thus far, most work has centered on development of a fermentation-based process to convert switchgrass into ethanol, with the concomitant generation of a purified lignin stream. The process is not feed-specific, and the work scope has recently expanded to include sweet sorghum and wood. In parallel, the Collaborative is also working on developing an economical path to produce oils and fuels from algae. The Collaborative envisions an integrated bio-fuels process that can accept multiple feedstocks, shares common equipment, and that produces multiple product streams. The Collaborative is not the only group working on bio-energy in South Carolina, and other companies are involved in producing biomass derived energy products at an industrial scale.

Introduction

The State of South Carolina, though abundant in natural resources above the ground (e.g., sunshine, wind, biomass, and water) has no indigenous coal, oil, natural gas, or uranium deposits of any significant size, and imports nearly all of its energy sources from other areas. In addition, the State is suffering high unemployment (12.6%) and routine shortfalls in State revenues.

One possible answer in the longer term to these concerns is to encourage the creation of a robust, local bioenergy and biomaterials industry, one that uses energy resources from local farmers, foresters, and suppliers; keeps the money spent on energy sources within the State; and employs thousands in higher paying manufacturing and support jobs. To avoid unintended consequences with the food supply, the new bioenergy and biomaterials industry must be built upon a foundation of abundant non-food biomass.

To assist in this endeavor, a South Carolina Bio-Energy Research Collaborative (SC BERC) has been formed consisting of Arborgen LLC, Clemson University, Savannah River National Laboratory, and South Carolina State

University. The mission of the Collaborative is to develop bioprocess technologies and processes; understand their implications in the context of the larger energy, economic, and regulatory environment; and to learn how best to utilize locally-grown or regionally-grown non-food crops for the production of biofuels and biomaterials. The Collaborative is funded through a combination of funding internal to each partner and DOE funding, and is supported in the form of services and information exchange by Dyadic (enzyme producer), Fagen Engineering LLC (engineering design firm), the Spinx Company (largest ethanol and biodiesel marketer in the Southeast), and the South Carolina Biomass Council (SC BIO). The Collaborative is an open arrangement, and additional partners are welcome.

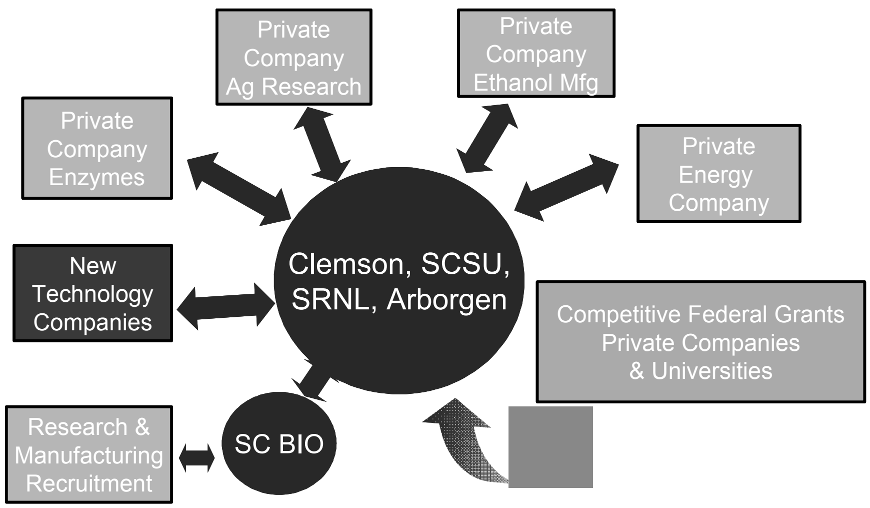

Figure 1. SC BERC Collaboration Model

Thus far, most work has centered on development of a fermentation-based process to convert switchgrass into ethanol, with the concomitant generation of a purified lignin stream. The process is not feed-specific, and the work scope has recently expanded to include sweet sorghum and trees. In parallel, the Collaborative is developing an economical path to produce oils and fuels from microalgae. The Collaborative envisions an integrated bio-fuels production facility that can accept multiple feedstocks, shares common equipment, and that produces multiple product streams.

At minimum, the lignin side stream may be burned to generate process steam, but it would be worth more as a raw material for making chemicals, fuels, or materials. In the near future, work will be performed to determine whether switchgrass lignin is a suitable starting material for making carbon fibers. Also, samples of lignin from this process may also be tested as a feed material for Envergent's Rapid Thermal Processing (RTP) system for the production of pyrolysis oils.

The Collaborative is not the only group working on bioenergy in South Carolina, and other companies are involved in producing biomass-derived energy products at an industrial scale.

Lignocellulosic Ethanol

The centerpiece of research for the Collaborative has been a process that is capable of converting switchgrass and sorghum into ethanol with the concomitant production of a purified lignin side stream. The process consists of the following steps: harvesting, size reduction, pre-treatment, hydrolysis (saccharification), fermentation, and product purification

The distinguishing characteristics of this process in comparison to other fermentation-based processes are the following. Aqueous ammonia is used as a pre-treatment fluid[1]. The lignocellulosic matrix is hydrolyzed into sugars using Dyadic enzymes. C-5 and C-6 sugars are both fermented to make ethanol using a single non-engineered organism. Relatively pure lignin is recovered as a distinct side product.

To date, all of the process steps except for purification of the ethanol have been performed using switchgrass as the starting material. The size reduction step, pre-treatment step and lignin purification step have also been demonstrated with sweet sorghum. In addition, an Aspen flow sheet of the process as applied to switchgrass has been created, and capital and operating costs have been estimated for a 1 metric ton/day (feed rate) pilot plant.

Unlike switchgrass, sweet sorghum is rich in soluble sugars, and a substantial amount of sap may be squeezed from the stalks prior to size reduction. The sap may be fermented directly upon harvesting with little preparation, thus boosting the overall ethanol yield from the feedstock, and fermentation tests of sorghum sap have been performed to confirm this assertion.

Experimental work is ongoing in order to learn more about the operational boundaries of the process steps and to optimize the process conditions. Also, initial testing of the pre-treatment and lignin recovery steps with yellow and loblolly pine as a feedstock are underway.

Algae-based Fuels

The Collaborative is also very interested in algae-derived biofuels and has begun working with RWE in Georgetown, SC, to identify microalgae species and operating conditions, and to identify and/or develop the hardware needed to harvest the oil produced by the algae. RWE employs a closed algae growth system (see Figure 2) that is modular, scaleable, and automated.

Figure 2. RWE Photo-bioreactor module for microalgae.

At a larger scale, the modular systems under investigation may be tied to fossil-fueled power plants or landfill off-gases in order to utilize CO_2 emissions as a raw material for algae growth.

Integrated Biofuels/Bioproducts Facility

The Collaborative envisions an integrated biofuels/bioproducts process that can accommodate multiple lignocellulosic feedstocks and that can ferment multiple sugar types (C-5 sugars, C-6 sugars, C-12 sugars) into ethanol (or other fermentation products), with the recovery of lignin as a useful side product. In a parallel process, oils may be produced using algae fed with CO_2 vented from fossil-fueled electrical power plants or landfills. Instead of disposing of biomass waste materials from these processes, the waste materials may be gasified to make syn-gas, or pyrolyzed to make pyrolysis oil. The integrated process flows are shown in Figure 3.

The processes do not have to be co-located except as a matter of convenience. The lignocellulosic facility and the algae processing line operate independently and there is no overlap in their operations. The gasifier or pyrolysis unit may also be placed independently as long as it is economically accessible to both process lines. As a practical matter, it may be advantageous to locate the gasification or pyrolysis unit closer to the algae processing facility in order to take advantage of existing environmental permits associated with either a fossil-fueled power plant or landfill. Within the lignocellulosic process, growth and harvesting of feedstock crops are necessarily distributed across a wide area, and storage of a size-reduced product may be performed at regional centers around a central lignocellulosic processing facility as long as the size-reduced feedstock is stable and does not spoil when stored.

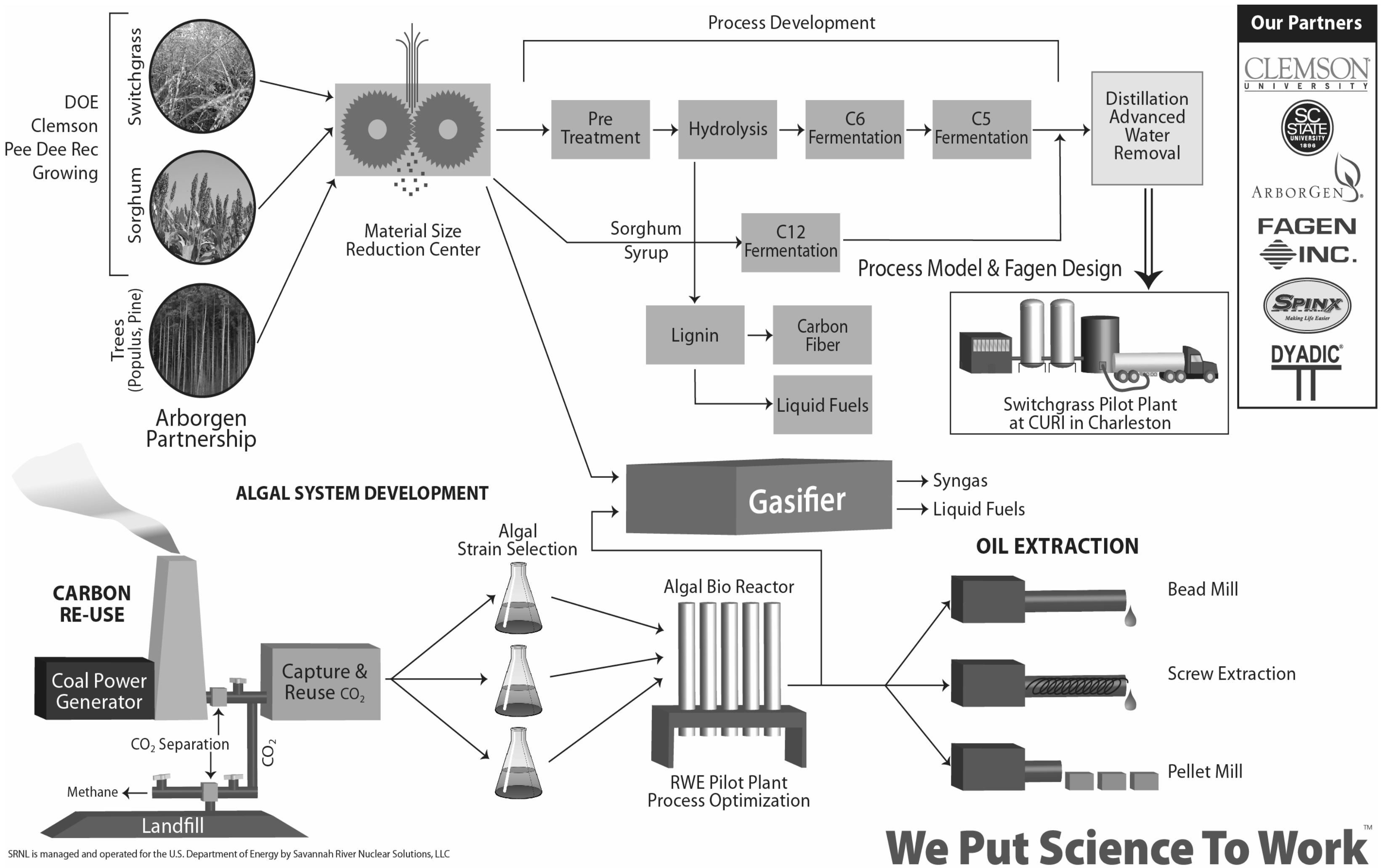

Figure 3. Vision of integrated bioenergy production facility.

Efforts by Other South Carolina Companies

The work performed by the South Carolina Bio-Energy Collaborative is not the only biofuels effort in South Carolina, and other organizations are also working on developing and marketing alternative energy solutions based on South Carolina's biomass resources. Carolina Pacific is currently operating four pellet lines in Georgetown, SC, that convert switchgrass into compressed blocks that can be burned as boiler fuel (see Figure 4). At the present time, Carolina Pacific supports the agriculture of more than 16,000 hectares of switchgrass, and sends the compressed product to Great Britain, where it is used to displace the burning of coal in order to take advantage of generous carbon credits.

Figure 4. Combustible compressed cylinder made from switchgrass.

The University of South Carolina and the Savannah River Site each have small biomass-fired power plants, and the Savannah River Site is constructing a larger 30 MW cogeneration plant near the Savannah River National Laboratory that will be able to use wood and other materials to make steam and electricity. Four other biomass burners are also under contract or consideration in South Carolina. In addition, there are multiple biodiesel plants located in South Carolina who are producing biodiesel from soybeans and seed crops, and current production capacity exceeds 270 million liters/year.

Summary

At a grass-roots level, the South Carolina Bioenergy Research Collaborative is working towards the development of a bioenergy industry that can take advantage of the abundant sunlight and biomass that is available in the southeastern United States for the economic benefit of the region and the nation. Lignocellulosic and algae-based processes are under investigation. Increased economic benefits may be realized by utilizing multiple processes in parallel in order to generate multiple energy-related products.

Reference

1. Kim, T.H.; Taylor, F., and H.B. Hicks (2008), “Bioethanol production from barley hull using SAA (soaking in aqueous ammonia) pretreatment,” *Bioresource Technology*, 97, 5694-5702.