**Commercial-scale cellulosic biofuels projects in the United States**

**Summary Report**

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Although no commercial-scale cellulosic biofuels facilities are operating in the United States at present, at least ten projects exceeding 20 million gallons per year are expected to begin operations by 2014. These projects employ six distinctive thermochemical and biochemical processing pathways: catalytic pyrolysis and hydrotreating to hydrocarbons; gasification and Fischer-Tropsch synthesis to hydrocarbons; gasification and methanol-to-gasoline synthesis; dilute acid hydrolysis, fermentation to acetic acid, and chemical synthesis to ethanol; enzymatic hydrolysis to ethanol; and consolidated bioprocessing to ethanol. This report summarizes the progress on these projects. Further details can be found in Brown and Brown (2013) (1).

**Hydrocarbon-based biofuels via catalytic pyrolysis and hydrotreating of bio-oil**, shown in Figure 1, thermally depolymerizes polysaccharides and lignin in lignocellulosic biomass to intermediate compounds that are subsequently converted to hydrocarbons suitable as transportation fuels, including gasoline, diesel, and jet fuel (2, 3). The process involves the direct liquefaction of solid molecules by processes variously referred to as fast pyrolysis, catalytic pyrolysis, hydropyrolysis, and solvent liquefaction. The resulting liquid is catalytically upgraded to hydrocarbons suitable for transportation fuels. KiOR plans to construction a 41 MGY catalytic pyrolysis facility in Natchez, MS starting in the first quarter of 2013, with operations commencing by late 2014. The Natchez facility is estimated to cost $350 million. While the Natchez facility was originally expected to have a capacity of 34 MGY, the company announced in August 2012 that it was employing a new catalyst that decreased coke yields and increased facility capacity by 20%.

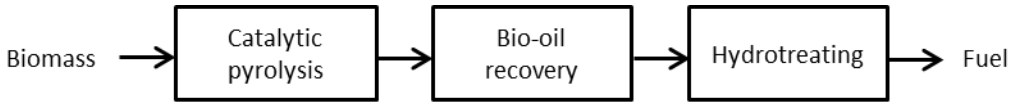


Figure 1. Catalytic pyrolysis and hydrotreating to hydrocarbons

The **gasification and Fischer-Tropsch (FT) pathway** to hydrocarbons, shown in Figure 2, thermally decomposes solid carbonaceous feedstock into a gaseous mixture of predominately carbon monoxide and hydrogen that is catalytically synthesized into alkanes (4). The technology has been commercially demonstrated with coal feedstock in South Africa and, during World War II, in Germany. Rentech plans to construct a $200 million facility using lignocellulosic biomass in Collinwood, TN with a fuel capacity of 20 MGY (5). The original plans called for groundbreaking in 2011 and operations starting in early 2014. In November 2011 Rentech

announced that construction of the Collinwood facility was on hold. Rentech also stated that a final decision on the Collinwood facility would not be made until a demonstration-scale facility being built by Rentech in Commerce City, CO was completed.

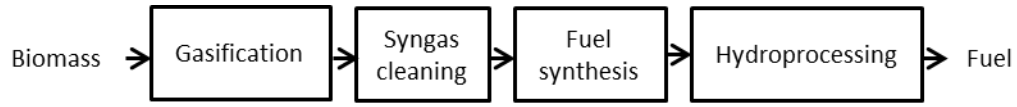


Figure 2. Gasification and Fischer-Tropsch synthesis to hydrocarbons.

The **methanol-to-gasoline (MTG) pathway**, shown in Figure 3, was developed by ExxonMobil in the 1970s and first operated on a commercial-scale in New Zealand using natural gas feedstock (6). More recently biomass has been proposed as feedstock for this pathway. Sundrop Fuels is building a $500 million facility in Alexandria, LA to produce 50 MGY of hydrocarbon-based fuels (7). Commercial operation is expected to begin in early 2014. The Alexandria facility is the first of several facilities planned by Sundrop Fuels to produce 1000 MGY of biofuels by 2020. While Sundrop Fuels initially planned to use solar energy to heat the gasifier, the Alexandria facility will employ natural gas for this purpose.

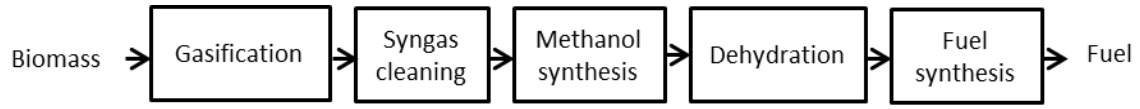


Figure 3. Gasification and methanol-to-gasoline synthesis.

The **dilute acid hydrolysis, fermentation to acetic acid, and chemical synthesis route** to ethanol qualifies as a hybrid processing pathway, incorporating both biological and thermochemical steps in the production of transportation fuels. The sugars liberated from cellulosic biomass are fermented to acetic acid, which is chemically converted to ethyl acetate and in a final step is reacted with hydrogen to produce ethanol. ZeaChem is constructing a 25 MGY facility in Boardman, OR based on this pathway with an expected completion date of 2014 (8). Facility output will be evenly split between ethanol, and biobased chemicals such as acetic acid and ethyl acetate. The Boardman facility will cost $391 million and will employ a combination of agricultural residue and hybrid poplar as feedstock (9).


Figure 4. Cellulosic ethanol via dilute acid hydrolysis, fermentation, and chemical synthesis.

**Cellulosic ethanol via enzymatic hydrolysis** uses enzymes to release sugars from polysaccharides in biomass, which are then fermented to ethanol (10). Several companies are commercializing this pathway. Abengoa Bioenergy is a European ethanol producer that is building a commercial-scale cellulosic ethanol facility in Hugoton, KS. This facility will produce 25 million gallons of ethanol and 20 MW of electricity annually from corn stover via enzymatic

hydrolysis (11). Beta Renewables is a joint venture between Chemtex, TPG, and TPG Biotech that is constructing a 20 MGY cellulosic ethanol via enzymatic hydrolysis facility in Sampson County, NC named Project Alpha (12). DuPont Biofuel Solutions, a subsidiary of DuPont, is constructing a commercial-scale cellulosic ethanol via enzymatic hydrolysis facility near Nevada, IA. The facility will be built for an estimated $276 million and utilize corn stover as feedstock to produce 25 MGY of ethanol (13). POET and DSM are jointly constructing a 20 MGY facility in Emmetsburg, IA called "Project Liberty", which will produce cellulosic ethanol from corn stover and cobs via enzymatic hydrolysis.

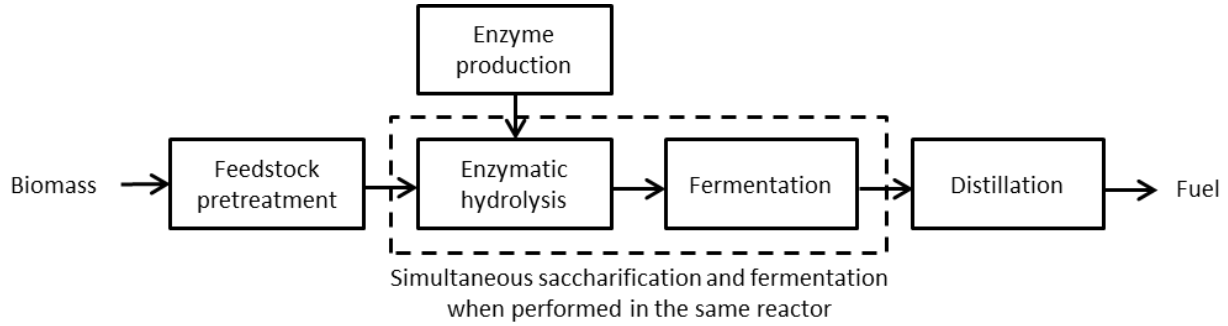


Figure 5. Cellulosic ethanol via enzymatic hydrolysis.

**Cellulosic ethanol via consolidated bioprocessing** combines enzyme production, enzymatic hydrolysis, and fermentation of the resulting sugars in a single step by genetically-engineering micro-organisms to produce enzymes that accomplishes both hydrolysis and fermentation to produce ethanol from lignocellulosic biomass (14). Mascoma is constructing a 40 MGY cellulosic ethanol facility based on this pathway in Kinross, MI as part of a joint venture with refiner Valero (15). The Kinross facility, expected to be completed at the end of 2013, will cost $232 million. The project will convert hardwood pulpwood feedstock into ethanol.

Based on the commercial-scale cellulosic biofuel facilities that are currently expected to begin operations by 2014, total U.S. cellulosic biofuel capacity in 2014 will be 266 MGY on a volumetric basis, or 215 million gallons on a gasoline-equivalent basis (see Table 1). This capacity will be roughly split between ethanol-based fuels and hydrocarbon-based fuels, with 111 million gallons of hydrocarbon-based fuels per year (52% of total) and 104 MGY of ethanol-based fuels on a gasoline-equivalent basis (48% of total). The success or failure of these cellulosic biofuels facilities will determine the direction of the advanced biofuels industry and influence future U.S. energy policy.

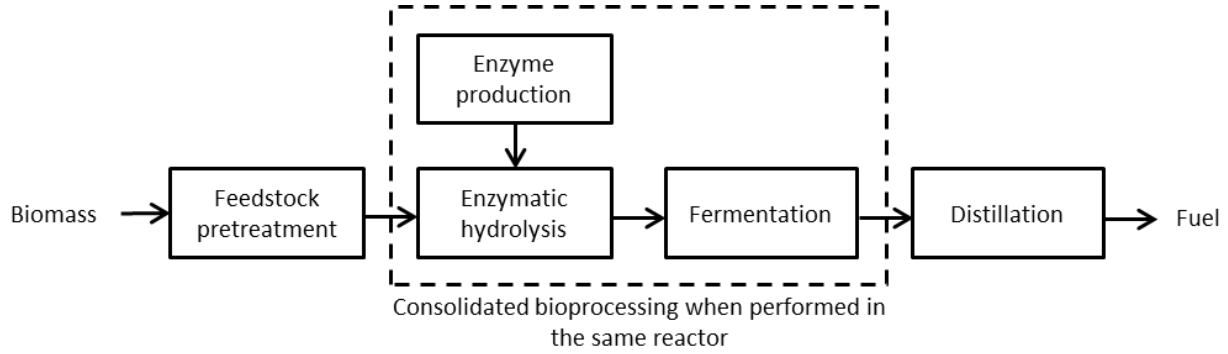


Figure 6. Cellulosic ethanol via consolidated bioprocessing.

Table 1. Details of commercial-scale cellulosic biofuel projects expected to be in operation by 2014.

| Company | Pathway | Location | Capacity (MGY) | Feedstock | Capital cost (million) |
|---|---|---|---|---|---|
| KiOR | Catalytic pyrolysis & hydrotreating to hydrocarbons | Natchez, MS | 41 | Yellow pine | $350 |
| ClearFuels | Gasification & F-T synthesis to hydrocarbons | Collinwood, TN | 20 | Woody biomass | $200 |
| Sundrop Fuels | Gasification & MTG synthesis | Alexandria, LA | 50 | Mixed biomass, natural gas | $500 |
| ZeaChem | Dilute acid hydrolysis & acetic acid synthesis to ethanol | Boardman, OR | 25 | Agricultural residue, hybrid poplar | $391 |
| Abengoa | Enzymatic hydrolysis to ethanol | Hugoton, KS | 25 | Corn stover | $350 |
| Beta Renewables | Enzymatic hydrolysis to ethanol | Sampson County, NC | 20 | Arundo, switchgrass | $170 |
| DuPont Biofuel Solutions | Enzymatic hydrolysis to ethanol | Nevada, IA | 25 | Corn stover | $276 |
| POET | Enzymatic hydrolysis to ethanol | Emmetsburg, IA | 20 | Corn stover, corn cobs | $250 |
| Mascoma | Consolidated bio-processing to ethanol | Kinross, MI | 40 | Hardwood pulpwood | $232 |

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