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BIOREFINERY AND BIOGAS TOUR

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Report Highlights:
Denmark is making strong advances in the commercial availability of biofuels while addressing the problem of agricultural waste. A newly-opened commercial biorefinery converts wheat straw into ethanol and by-products, and demonstrates the commercial feasibility of second-generation biofuels technology. A lower-tech operation, a farmer-owned cooperative, used established technology to convert manure and agricultural waste into biogas for heat and electrical production.

Executive Summary:
On February 5, 2010, US Ambassador Laurie S. Fulton accompanied by Embassy Officers visited the DONG Energy/Inbicon biorefinery in Kalundborg to learn about their process for turning wheat straw into ethanol. Representatives of Novozymes also participated, to explain the crucial role their

enzymes perform in economically breaking up cellulose molecules into simpler sugars. Embassy Officers later visited the Hashøj Biogas facility, which converts manure and agricultural waste into biogas for heat and electrical production.

General Information:
During the COP-15 in December 2009, Ag Counselor and Embassy Economics Officer accompanied US Secretary of Agriculture Tom Vilsack to a meeting with Danish Minister of Agriculture Eva Hansen, in which Minister Hansen described Danish progress in renewable agricultural-based fuels. Ministry of Agriculture staff offered to arrange visits to facilities for Embassy officers, which visits took place on February 5, 2010.

BIOREFINERY
The first stop for the Ambassador and Embassy Officers was the newly-opened biorefinery in Kalundborg owned and operated by DONG Energy and Inbicon. DONG Energy is one of the leading energy groups in northern Europe with headquarters in Denmark. Inbicon is a fully-owned subsidiary of DONG. It develops sustainable biomass refineries based on new and/or optimized technologies for treating agricultural waste and energy-integration systems. Its core business is not producing ethanol but selling technology. Its website is www.inbicon.com.

The purpose of the Kalundborg plant is to show that DONG Energy's second-generation technology can be applied on a large scale. Ethanol from corn or sugarcane is "first-generation" ethanol. Second-generation ethanol is derived from cellulose. The difficulty is that cellulose is a long-chain polysaccharide that is very difficult to convert to a fermentable form. Conversion requires pretreatment (often heat and pressure) and enzymes. Inbicon has proprietary pre-treatment technology for optimizing the cellulose breakdown and recycling enzymes. In combination with Novozymes' products, Inbicon claims great efficiencies in ethanol production.

The Kalundborg plant has the capacity to process 30,000 MT of wheat straw annually, with expected output of 5.4 million liters of ethanol, 13,100 MT of lignin pellets, and 11,250 MT of C5 molasses. Lignin pellets can replace coal as a fuel. The molasses can either be fed to livestock, or could be further processed into biofuel. Inbicon uses wheat straw as a feedstock because it is plentiful, and Denmark already has the infrastructure to collect and transport it economically. Their process can be adapted to other agricultural wastes, such as corn stover, bagasse, sorghum waste, etc.

The Process:
1. Wheat straw is delivered. The plant has storage for about week's worth.
2. Biomass is mechanically conditioned using a proprietary process.
3. It undergoes hydro-thermal pre-treatment, also proprietary, in which lignin structures are opened making cellulose available to enzymes. Molasses is extracted at this point, and prepared for storage and delivery.
4. The biomass undergoes enzymatic hydrolysis, in which cellulose is broken up into simpler sugars. The end product is liquefied and can be moved with normal pumps. NB: Steps 2-4 involve proprietary core technology which Inbicon claims is the basis for their efficiency.

Subsequent steps involve well established, commercially available technology from sugar and starch fermentation.

5. The mash undergoes fermentation for 50-60 hours, and carbon dioxide is siphoned off and stored.
6. Fermentation product undergoes distillation through a molecular sieve.
7. The ethanol is denatured and stored.

Inbicon representatives cited several advantages of their process:

- Simple, based on water, enzymes and yeast.
- Uses high dry matter content throughout the process, saving water and energy.
- Low enzyme consumption.
- High degree of internal integration and with collocated power plant.
- Integrated contamination control.
- End product reduces CO2 production compared to gasoline.
- The plant is 70 percent efficient, compared to 35 percent efficiency if the straw is burned.

In 2003 Inbicon built a pilot plant capable of handling 2.4 MT of straw a day. In 2005 it built another pilot plant with a daily capacity of 24 MT per day. These two plants are technology and process test beds. The Kalundborg plant, completed in 2009, has a daily capacity of 100 MT of straw a day, and is intended to prove that the technology is robust and sound. Inbicon hopes to eventually build a plant with a daily capacity of 1200 MT; since Denmark currently uses 1.5 MMT of wheat straw annually for heat and power generation, the country could manage only 3 such plants. Inbicon representatives referred to studies that showed that there are areas within the US suitable for a plant that large. (Inbicon determined that transportation of the raw material is the major variable cost consideration, and that it is not economical to transport inputs more than 25 miles.)

DONG Energy first started burning straw in its coal-fired power plants because the government of Denmark mandated it -- partly in an effort to enhance energy security, partly to create another revenue source for local farmers. Inbicon grew largely out of DONG's efforts to find a way to still use straw but remove the corrosive components. Later the government provided incentives for energy from non-fossil fuels. Inbicon still relies on the government premium because coal is very cheap; it could not compete otherwise. The principal reason that the process cost is relatively high is the enzymes; they are confident that once the price of enzymes decreases, they will not need the premium.

Inbicon is interested in supplying their technology to customers in the US. They asked for information on access to US Department of Energy projects, and were pleased to learn that USDA has available funds.

ENZYMES

Embassy visitors were also briefed by representatives of Novozymes, a Danish leader in global production and sales of enzymes. Novozymes has locations in 8 countries, including 4 sites in the US (North Carolina and California). It has a particular interest in producing enzymes for the

production of cellulosic ethanol.

The representatives pointed out how industrial enzymes can reduce CO2 emissions. While it costs 1 to 10 kilograms of CO2 to produce 1 kg of enzymes, 1 kg of enzymes can reduce CO2 emissions by 30 to 3,800 kg. They said that the World Wildlife Federation calculated that industrial biotechnology could save the world up to 2.5 billion MT of CO2 per year by 2030.

Novozymes actively collaborates with global leaders in cellulosic ethanol. In the US it collaborates with POET, ICM, and KL Process Design.

On February 16, 2010, Novozymes launched a new line of enzymes that will enable commercial biorefineries to produce cellulosic ethanol at a price commercially competitive with gasoline and conventional ethanol. (See report DK0002)

Our interlocutors opined that it is technically feasible for Denmark to eliminate the use of fossil fuels by 2050, and said that the government of Denmark will soon release a plan to achieve that goal.

BIOGAS

While cellulosic ethanol is cutting edge and glamorous, biogas is well-established and anything but glamorous. The basic premise is simple – gather the methane produced by the decomposition of manure and barnyard waste and use it for fuel. However, the site Embassy officials visited shows how a mixture of sound business practices and progressive technical improvements can turn porcine effluent into black gold.

Hashøj Biogas is a farmer-owned cooperative in Dalmose. It operates jointly with Hashøj Kraftvarmeforsyning, its sole customer for its biogas, to provide heat and electricity to local consumers.

Hashøj Biogas accepts roughly 50 MT per day of input, mostly raw liquid pig manure from cooperative farmers, but also slaughterhouse waste, food-processing waste, and other. The waste is pasteurized at 70 degrees C to kill salmonella and other unwanted bacteria, weed seeds, etc. The liquid slurry is pumped to a biodigester and inoculated with mesophilic bacteria which digest the slurry and produce methane and CO2. The processed manure is returned to the farmers for use as liquid fertilizer. This degassed, digested liquid manure is superior to raw liquid manure because it often has higher fertilizer values, it is more easily absorbed by the soil, and its nutrients are more easily taken up by plants.

The biogas is pumped to a storage tank, then cleaned, cooled, and pressurized to 600 millibar and either pumped to a storage tank or moved directly to the combined heat and power (CHP) unit of Hashøj Kraftvarmeforsyning. Hashøj Biogas produces 13,000 to 15,000 cubic meters of biogas a day. The CHP unit has a flexible boiler and is able to use biogas, natural gas, wood pellets and other biofuels. The gas engines can run on biogas or natural gas. The company selects fuels based on market prices.

COMMENT

Committed to reducing its dependence on imported fossil fuels, Denmark is making great advances in developing alternative sources of energy. Since plants are nature's solar cells, and given Denmark's extensive crop and livestock agriculture, deriving energy from agricultural waste is a natural step forward for the Danes. Their experiences in cellulosic ethanol production and in commercializing biogas energy are good examples of strategies the US could adopt to promote energy independence, create jobs, and address environmental problems caused by livestock waste.

The Inbicon biorefinery is commercially-ready technology for second-generation biofuels. The previous US Administration supported first-generation ethanol as a stepping stone to establish the infrastructure for more sustainable second-generation ethanol. With Novozymes' announcement of more efficient and economical enzymes for breaking down cellulose, cellulosic ethanol looks poised to meet USG mandates for renewable fuels. The US' extensive agricultural economy can provide ample inputs, and Inbicon is anxious to do business.

Denmark's experience with biogas provides an alternative model for dealing with livestock waste. The US has long experience with farmer cooperatives, so the business model Hashøj Biogas uses should be familiar to rural areas across America. Many regions have intensive livestock operations and have to deal with the massive amounts of manure produced; Denmark's experience shows how a costly waste can be converted into a useful resource.

There is no single solution to the challenges of developing alternative energy sources and dealing with agricultural waste; rather, there are a variety of technologies that offer solutions to various situations. Denmark shows that these solutions can be found and can be effective and economical.