Nexant Chem Systems

PERP Program - Ethanol

New Report Alert

February 2006

Nexant's *ChemSystems* Process Evaluation/Research Planning program has published a new report, ***Ethanol (04/05-8)***. To view the table of contents or order this report, please click on the link below:
http://www.nexant.com/products/csreports/index.asp?body=http://www.chemsystems.com/reports/show_cat.cfm?catID=2

Background

In 2004, the total global ethanol production was at a historical high of 40.9 billion liters (10.8 billion gallons), contributed mainly by Brazil and the United States (and Canada) at 37 percent and 33 percent share of world production, respectively. Given the strong interest in fuel ethanol production worldwide, this fuel ethanol market can be expected to grow even larger.

Ethanol has been the subject of previous PERP reports. PERP Report, 93-5, Ethanol, reviewed fermentation ethanol technologies for fuel applications. PERP Report, 99/00-8, Ethanol, further reviewed industrial ethanol via ethylene hydration and fermentation ethanol via corn-based and biomass-based processes. Another recent report, PERP Report 00/01S6, Plants as Plants, reviewed genetically engineered bacteria and plants for making specialty and commodity chemicals and other basic materials. The objectives of the present report are to update the current commercial technologies for ethanol production via ethylene hydration and via corn and biomass fermentation processes.

Technology

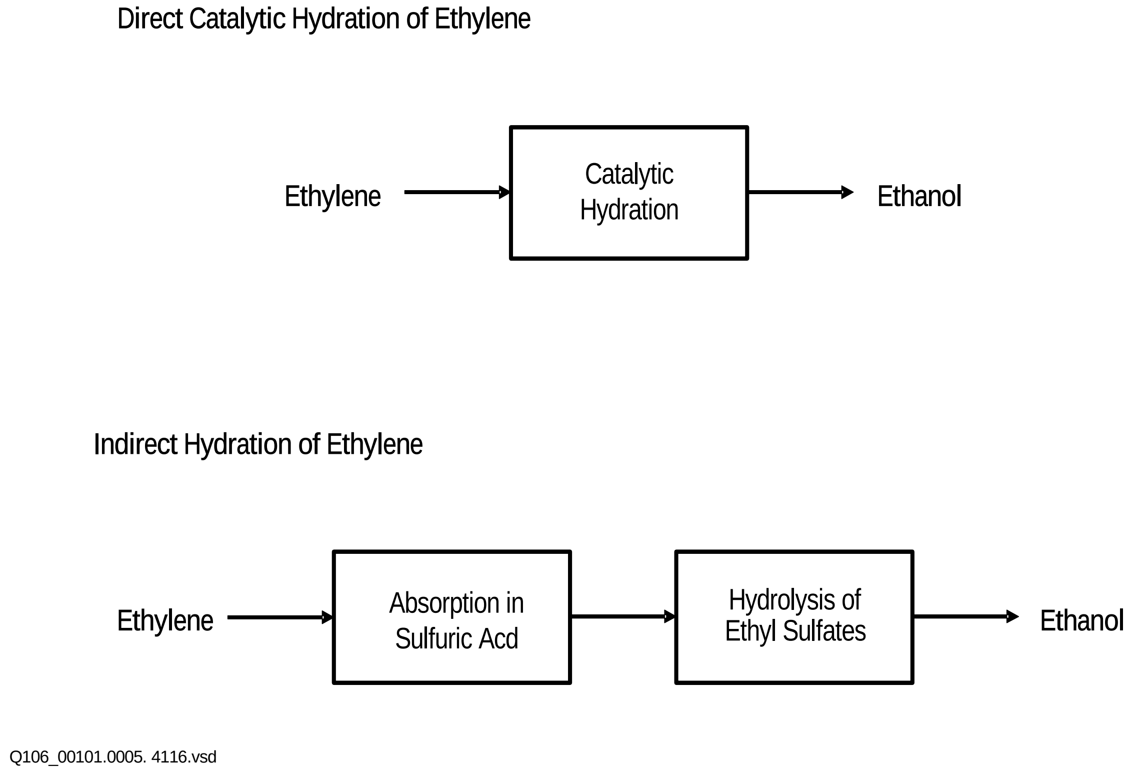
The report presents the detailed chemistry and process descriptions for the current commercial and developing ethanol production technologies for the following:

- Direct hydration of ethylene
- Indirect hydration of ethylene
- Sugar crop fermentation
- Corn dry milling fermentation
- Corn wet milling fermentation
- Lignocellulose fermentation

Recent trends and developments in ethanol technologies and processes are discussed, including gasification of biomass to syngas to ethanol, conversion of distiller's dried grains to ethanol via dilute acid hydrolysis, and pretreatment technologies for lignocellulosic biomass.

As shown in Figure 1, industrial synthesis processes, employing ethylene as a feedstock, involve direct catalytic hydration of ethylene or indirect hydration of ethylene.

Figure 1
Industrial Synthesis Processes for Ethanol Production

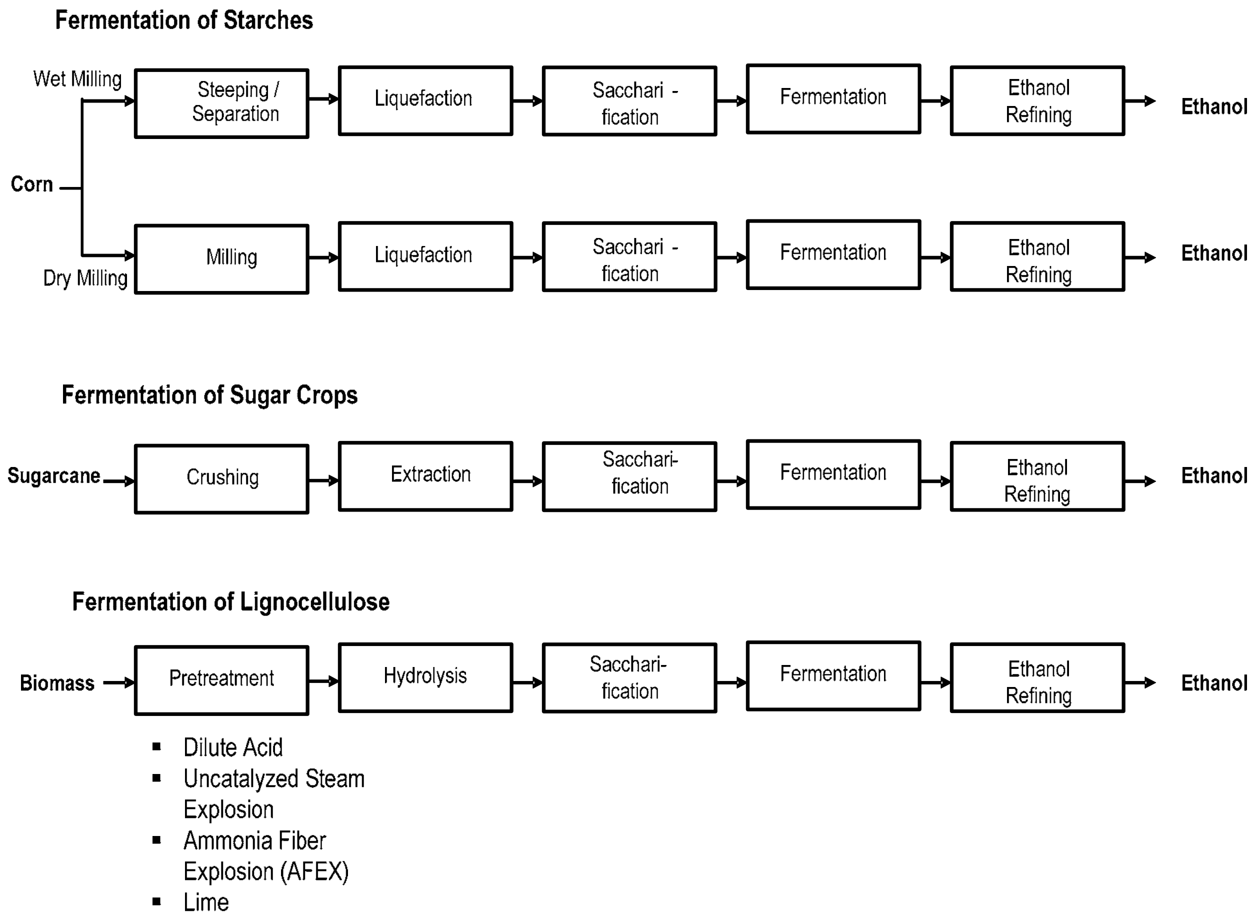


Industrial fermentation processes, employing starches (e.g. corn), sugar crops (e.g. sugarcane), or lignocellulose (e.g. biomass) as feedstock, are shown in Figure 2.

Direct Catalytic Hydration of Ethylene

Ethanol is synthetically produced from the catalytic hydration of ethylene. The common catalyst used today is phosphoric acid impregnated on an inert support, such as Celite® diatomite. The reaction is carried out at high pressures and temperatures, typically 1,000 psig and 300°C.

Figure 2
Industrial Fermentation Processes for Ethanol Production



The reaction is near quantitative, with relatively minor side reactions producing ethers, aldehydes, ketones, and higher hydrocarbons (the last from unwanted polymerization of ethylene). The major by-product is diethyl ether, which is usually recycled back to the reactor to form ethanol.

Indirect Hydration of Ethylene

The preparation of ethanol from ethylene by the use of sulfuric acid is a three-step process:

- Absorption of ethylene in concentrated sulfuric acid to form monoethyl sulfate (ethyl hydrogen sulfate) and diethyl sulfate
- Hydrolysis of ethyl sulfates to ethanol
- Reconcentration of the dilute sulfuric acid

No producers in the world have employed the indirect hydration of ethylene to manufacture ethanol since the mid-1980s. The shift away from the indirect route to the direct route has been due to better yields, less by-products, and reduced quantity of pollutants.

Fermentation of Sugar Crops

Sugar crops include sugarcane, sugar and fodder beets, fruit crops, etc. The following discussion pertains to fermentation of sugarcane for ethanol production.

Although sugarcane is grown primarily for sucrose and molasses production, it is also used as a raw material for ethanol production. It has a desirable composition for high ethanol yield. The fermentable carbohydrates from sugarcane may be directly utilized in the form of cane juice or in conjunction with a sugar factory from black strap molasses.

Cane juice extract is a green, sticky fluid, slightly more viscous than water, with an average sucrose content of 12 to 13 percent. It may then be evaporated to the desired concentration and used directly in the fermentation. A major disadvantage in the utilization of sugarcane juice is its lack of stability over an extended period of storage.

Black strap molasses is the non-crystallizable residue remaining after the sucrose has been crystallized from cane juice. This heavy viscous material is composed of sucrose, glucose, and fructose at a total carbohydrate concentration of 50 to 60 percent. Molasses may be easily stored for a long period of time and diluted to the required concentration prior to use.

Fermentation of Corn

Corn can be processed into ethanol using two main routes: dry milling and wet milling. The major differences in unit operations are the initial treatment of corn (milling vs. steeping) and the production of by-products (distiller's dried grains vs. high fructose corn syrup and corn gluten feed). Each process has inherent advantages and disadvantages.

The whole-kernel dry milling process is the simplest of the processes considered, and is generally the one recommended for new entrants into the market. Dry milling has certain advantages over wet milling:

- The process is simpler to operate than wet milling.
- Dry milling has lower capital and operating costs than wet milling.

While dry milling produces a slate of by-products, including distiller's dried grains (DDGs), that are overall less valuable than the wet milling process, it avoids the need for swing production and syrup integration, hence avoiding the need of the entrant to compete in the corn syrup and sweetener market.

Wet milling of corn is the conversion technology used when high-fructose corn syrup (HFCS) is desired as the main by-product of ethanol formation. HFCS is often used in conjunction with or as a substitute for sugar and other sweeteners in many food products, specifically soft drinks and baked goods. The system is highly integrated to disassemble the corn into as many valuable products as possible.

The corn is not milled. Rather, it is first steeped in a solution of water and sulfur dioxide for 24 to 48 hours. This loosens the germ and hull fibers. The germ is then removed from the kernel, and corn oil is extracted from the removed germ. The crude corn oil can be further processed in an edible oil plant.

The remaining germ meal from the corn oil extraction is combined with the hulls and fiber to produce corn gluten feed. The corn gluten feed is combined with the heavy stillage from the beer still and dried, forming the corn gluten feed. The high protein fraction of the corn kernel is later separated out to produce corn gluten meal, a high-value animal feed made up of about 60 percent protein.

The remaining starch fraction is liquefied and fermented in a process similar to dry milling. In wet milling, often the clear, liquefied starch is split into two fractions: one fraction diverted to ethanol production, and the other fraction used for the production of HFCS or other sweeteners. Typically, HFCS enjoys a higher margin, and more starch is diverted to HFCS production than to ethanol.

Hydrolyzed corn starch is converted to dextrose (D-glucose), which is then partially isomerized to convert a portion to fructose. This mixture is further refined and concentrated for sale as HFCS.

The primary capital cost associated with the wet milling plant is the front end, where the corn oil, gluten feed, and gluten meal are separated out.

Comparative Economics

The comparison of total capital employed and the comparison of cost of production are presented in Figure 3 and Figure 4, respectively.

Among the three ethanol technologies compared, the dilute acid and enzymatic hydrolysis process of corn stover has the highest capital requirement, while the corn dry milling process has the lowest capital employed.

Figure 3
Comparison of Capital Investment of Ethanol Processes

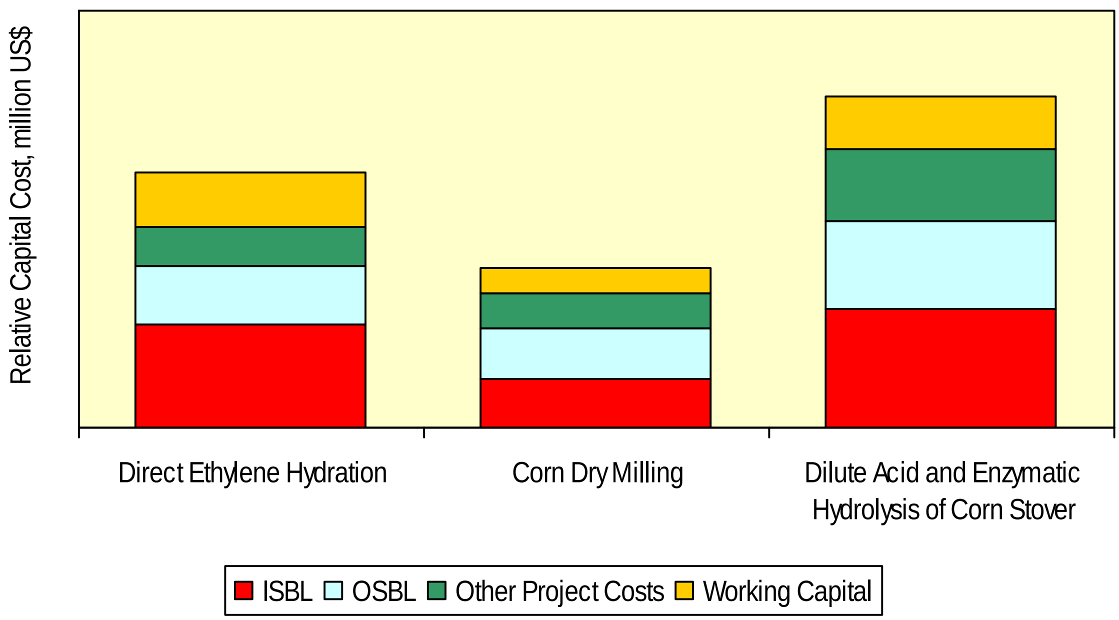


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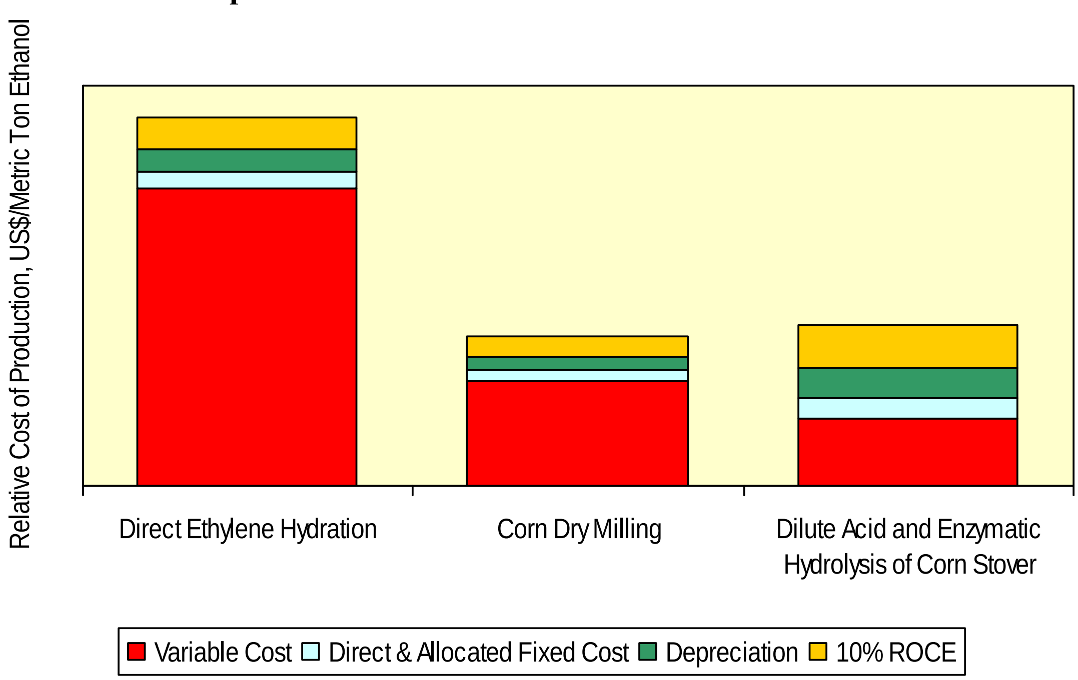
Figure 4
Comparison of Cost of Production of Ethanol Processes



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On a cash cost basis, i.e. based only on variable cost and fixed cost combined, the corn stover dilute acid and enzymatic hydrolysis has the lowest cost. The cash cost for the ethylene hydration is more than three and half times of that of the corn stover process.

Based on the cost of production plus 10 percent ROCE, both the dilute acid and enzymatic hydrolysis process of corn stover and the dry milling process of corn are equally competitive. However, capital requirement for the biomass-based process is about twice as high as that for the corn-based process. Reducing the capital requirement for the biomass-based process has been the major R&D and engineering thrust of the biotechnology companies and research institutes.

Ethanol production via direct ethylene dehydration has recently become less competitive due to high ethylene price, resulting in many shut-downs of ethylene hydration facilities. Ethylene price has to come down to $100/metric ton ($0.048/lb) or lower in order for the process to be competitive in the current fuel ethanol market.

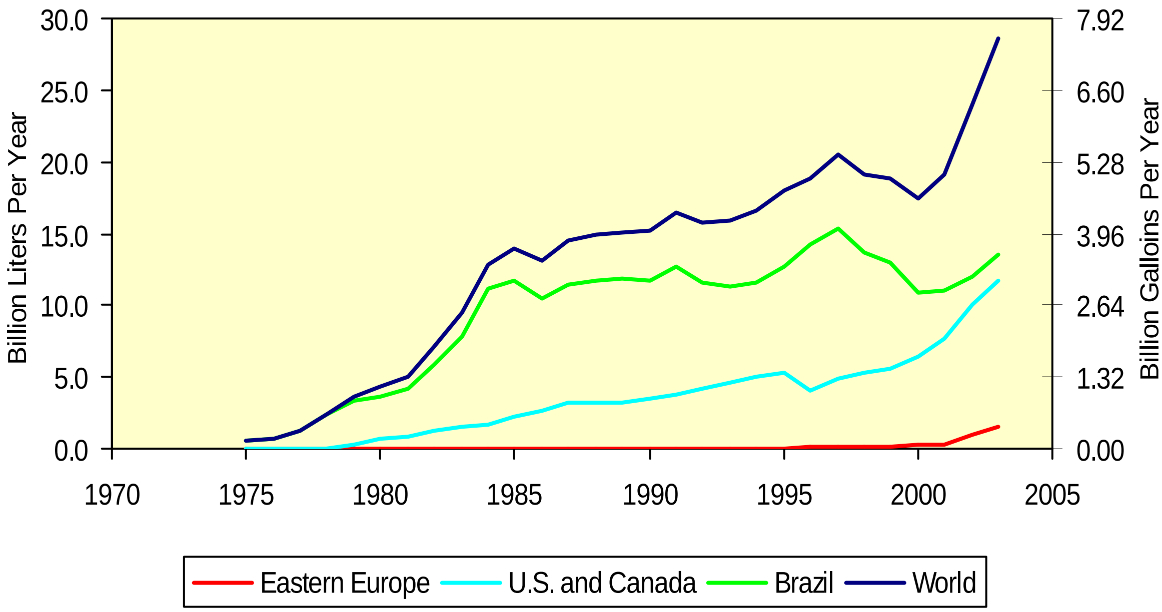
Overview of Global Ethanol Demand

On a global scale, synthetic ethanol plays a minor role, with less than 5 percent of overall ethanol output in 2003. More than 95 percent of ethanol came from agricultural crops and, given the strong interest in fuel ethanol production world-wide, this share can be expected to grow even higher.

As shown in Figure 5, Brazil (37%) and the United States (33%) are the two leading producers of ethanol in the world. Next come China, India, France, and Russia. All other countries individually represent less and 1% of production. In 2003, the total global fuel ethanol production was 28.6 billion liters (7.55 billion gallons).

Report sections provide an overview of several major ethanol producing and/or consuming entities: United States, Brazil, Canada, and the European Union.

Figure 5
Ethanol Production



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