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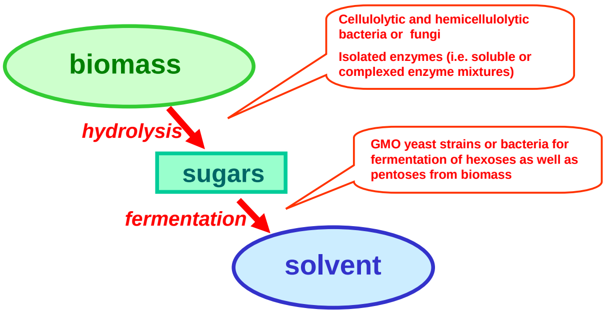
Bacteria for our future biofuels

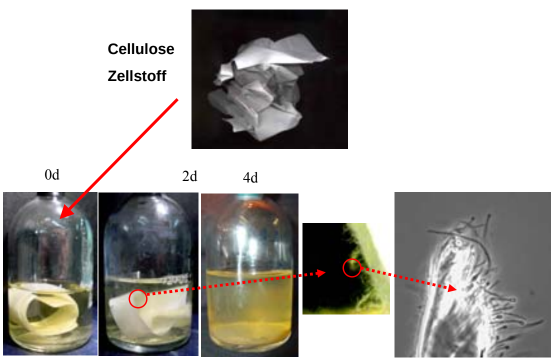
Introduction

Bacteria are involved in at least two areas of biofuel production processes from renewable biomass (lignocellulosic biomass, LCB): (1) production of enzymes and abd hydrolysis of polysaccharides, and (2) fermentation of the sugar syrups to short chain fatty acids or alcohols. An example is butanol through the Weizmann process with *Clostridium acetobutylicum*. A crucial advantage of bacterial fermentations is the usage of pentoses (in addition to the hexoses) which are produced from hydrolysis of hemicellulose. Examples of such processes and new developments are shown here.



C. thermocellum has a highly efficient cellulase system

Filter paper is degraded by a growing culture of *C. thermocellum* within 2 days at 55 to 68 °C. Fermentation products are ethanol, acetate, CO_2 and hydrogen. The bacterial cells adsorb tightly to the substrate surface and take up the hydrolysis products directly (Fig. 2). *C. thermocellum* forms small colonies on anaerobically prepared agar plates. Colonies hydrolyze crystalline cellulose arond the colonies on the plate surface (Fig. 3).



David Ramey: "*Butanol is an alternative power grade alcohol that replaces gasoline in your car today without having to be highly modified*."

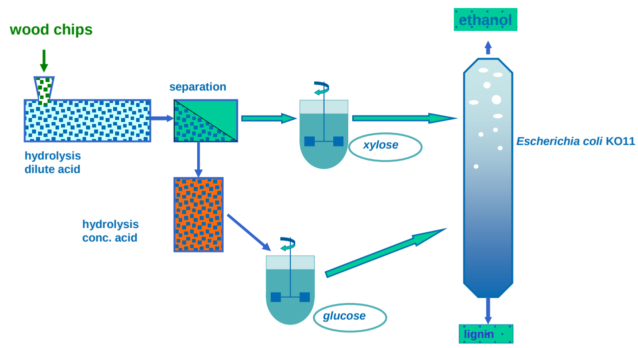
Table 1: Comparison of fuel characteristics: End products of the AB process and some basic data, including combustion energy, for the products. Ethanol from yeast fermentation of corn starch (industrial average) and some data on gasoline and diesel are shown for comparison.

product	kg[a)]	kJ/g	MJ/t substrate[b)]
butanol	207 ± 10	33.1	6852
aceton	100 ± 8	28.5	2850
ethanol	56 ± 15	26.7	1495
CO_2	≈ 600	-	-
H_2	≈ 19	119.8	2276
Total AB			**13273**
ethanol (yeast)	≈ 380	26.7	10146
CO_2 (yeast)	≈ 330	-	-
gasoline	-	43.4	-
Diesel fuel	-	42.7	-
Total ethanol			**10146**

a) kg product per ton of starch equivalent; b) kJ combustion energy (net calorific value) in end product per ton of starch equivalent.

Bioethanol production from wood-chips

The bioethanol plant of BC Intl. Corp., Dedham (MA) hydrolyses wood-chips in a two step-acid hydrolysis producing a pentose syrup fromhemicellulose (step 1) and glucose syrup from cellulose (step 2). The sugar syrups are fermented with the recombinant *E. coli* strain KO11 (the "Florida-strain") to ethanol and CO_2.



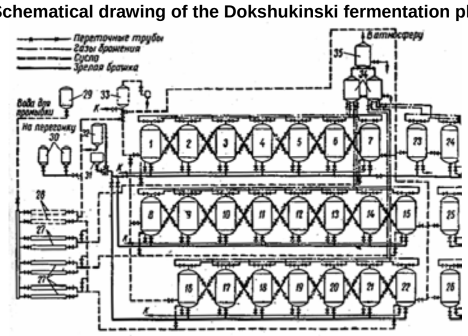
An example butanol plant for LCB usage

Schematical presentation of the acetone-butanol production line: the substrate passes 3 parallel lines of 7or more 250m³ fermenters each (#1-26). The preculture fermenter is #33, the feeding fermenter is #30. #27/28 are substrate coolers. CO_2 is collected in #34/35. At the time of description in 1975 this plant has been run successfully for 10 years and produced 70.000 to/a solvents (ABE 4:6:1) and 28.000 to/a gases (CO_2, H_2 1,5:1). Eight such plants are known.

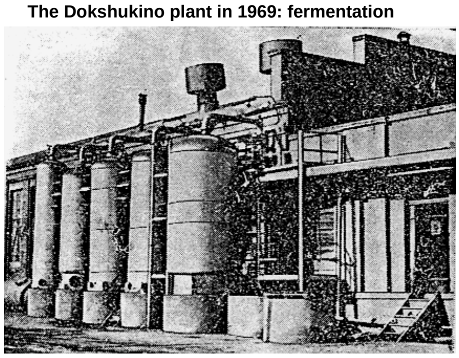
It was reported that the ***Dokshukinski*** plant was run with a mixture of flour (heat treated) and molasses (30:70). About 7,5 % of an acid hydrolysate from corn stubbers and other agricultural waste was used (sulfuric and phosphoric acid 3:1 or 4:1).

__Efficiency__: 50 % of the substrate sugars were converted to CO_2, and 33-39 % to solvents (60 % of that was butanol), leading to a yield of 9 tons solvents per 100 tons grain. By-products were CO_2, vitamin B_{12} and yeast protein for feed. The production of methane gas provided the energy for running the process.

Schematical drawing of the Dokshukinski fermentation plant



The Dokshukino plant in 1969: fermentation



Substrate storage and hydrolysis at Dokshukino plant (1963): corn stubs