

semi-simultaneous saccharification fermentation is still a study objective; however, the process proposed in the next paragraph is satisfactory. In our practice, saccharification at 45 °C combined with fermentation at 37 °C has permitted saccharification to continue at an acceptable rate during fermentation. In Ref. 3, fermentation was carried out at 40 °C combined with stripping of the ethanol as produced. This procedure merits further exploration. Fed batch of paper, and perhaps of enzyme, are better than when these are added all at once, in part because paper solids above 10% are difficult to keep in suspension but are necessary for high ethanol concentration, however after partial saccharification the mix becomes very fluid and more paper can be added. Saccharification is more efficient at low solids, which combined with a fed batch mode of operation can produce high ethanol concentration.

2. A 'best' process for bioconversion of waste paper can be specified as follows: a saccharification medium containing enzymes plus additives (Vitamin B₁₂, trace elements, Triton X100) is prepared. The enzymes are a mixture of cellulase and cellobiase in the ratio of 70:30 (or 80:20⁸), the amount being about 34 IU/g of the initial paper addition. The pH is adjusted to 4.8 with lime, and waste paper divided into reasonably small pieces, about 1–2 cm², is added to a density of 8–10%. This is incubated with agitation at 45 °C for 6 h. The temperature is then reduced to 37 °C and yeast and YMP added, the yeast at 10–20 g/litre, the YMP at 3, 3 and 5 g/litre. Agitation is continued for 24 h when a second batch of paper and enzyme is added. Incubation and agitation are continued for 24–48 h. The ethanol so produced should be at the rate of 350+ litres/t waste paper at a concentration of 6% by volume or more.

3. A new, inexpensive benchtop fermenter suitable for waste paper processing or for cellulase production is described.

4. Cellobiase is added to saccharification to hydrolyse cellobiose, a product of cellulose hydrolysis and an inhibitor of it. The use of cellobiose-fermenting yeasts¹¹ should remove the need for cellobiase addition. Some of these yeasts also ferment xylose, an added advantage when hardwood-containing papers are being processed.

5. The potential for ethanol production from MSW is about 200 litres/t. The amount of MSW in North America is about 260 million t each year, sufficient for bioconversion to 52000 million litres annually (13000 million US gallons each year). This

amounts to 16% of all motor fuel used in North America. The USA now imports nearly half of its crude oil, total oil consumption being about 1 million million litres/year (17 million barrels/day; 1 barrel equals 160 litres), compared to domestic annual production of 540000 million litres, leaving a gap of 460000 million litres of crude oil to be filled by imports. Upon refining, the amount of motor fuel produced is less than half the crude oil volume, such that 1 litre of motor fuel comes from 2.2 litres of crude oil. Thus 1 litre of fuel ethanol replaces 2.2 litres of crude oil. The potential production of ethanol from MSW can therefore displace 114000 million litres of crude oil, about 25% of imports, the amount normally imported from the Middle East. The potential production of ethanol from MSW is large enough to have significant political impact. Similar calculations can be made for Europe.

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