

## A NEW PROCESS FOR THE CONVERSION OF SPENT GRAIN TO ETHANOL

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### ABSTRACT

TMO renewables Ltd, a UK based technology company, has developed a thermophilic bacterium (TM242) to convert the diversity of biomass-derived sugars efficiently into ethanol at high yields and high temperatures. A Process Demonstration Unit (PDU) has been built in the UK and is designed to handle a wide range of Lignocellulosic feedstocks, including Distillers' Dried Grains and Solubles (DDGS). It has been configured to work in batch and full continuous mode with utmost flexibility utilising TMO's bespoke Pre-treatment, Enzyme Hydrolysis and Fermentation processes and has been testing feedstocks with potential clients from summer 2008.

This paper describes the process design and development, the project implementation and the results achieved over the last six months.

**Keywords:** *lignocellulose, bioethanol, thermophilic*

### INTRODUCTION

The biofuel industry has developed rapidly over the last few years and the key driver for increased activity is government mandates and primarily, in USA and Europe, based on environmental, security, economic and social development. In the UK, the government is targeting 5% of all road transport fuels from renewable sources by 2010 and the EU vision is 25% by 2030. In the USA the Energy Independence Act of 2007 requires the annual use of 36 billion gallons of renewable biofuels by 2022 but the traditional conventional biofuels (e.g. corn ethanol) was capped at 15 billion gallons.

Security policy has resulted from the desire for local sourcing and production and to reduce or eliminate dependence on highly politicised crude-oil producers. Additionally it is seen as beneficial for rural communities in developed and developing countries, to couple energy and agricultural policies with the possibility to raise farm incomes and bring land, which was becoming uneconomical, into productive use.

Most important of all are the environmental considerations, as biofuel is intrinsically carbon neutral and is cleaner burning with fewer hydrocarbon emissions.

There is a range of possibilities for biofuels but currently 90% of the total production is bioethanol, at 16.2m tonnes of oil equivalent per annum and 92% of the production is in Brazil and USA.

Bioethanol as a fuel is an old concept with the first Ford motorcar, the Tin Lizzie, being designed to run on it. Ethanol was also used as a fuel in the Russian battle tank of World War Two. It is now used in spark-ignition engines and is interchangeable with ordinary gasoline blended at up to 10% ethanol, without any retuning of the engine.

With engines specifically tuned, blends of up to 85% ethanol (E85) can be utilised and technology has been developed in Brazil for engines automatically to self-adjust at blends between 20% (E20) and 100% (E100).

Nearly all current production is first generation technology, either by direct fermentation of sugars from sugar cane or sugar beet, or by saccharification of starch followed by fermentation of sugars. **Table I** shows the crops that are most suitable together with their typical yields per hectare of land and unsurprisingly, most production is from sugar cane, sugar beet and maize. Bioethanol from maize grain (as widely adopted in USA) produces substantial quantities of spent grain as a byproduct, typically one third of the original crop by mass and the sale of this as animal feed is essential for the economics of the process. In 2007 this amounted to 10 million tonnes, 90% of which was used domestically. It is predicted that by 2010, output will reach 13 million tonnes and the market will be saturated. By 2030 output will be 50 million tonnes, a vast oversupply for which new technologies will need to be developed in order to add value.

<b>TABLE I</b>	
<b>Crops used for ethanol</b>	
	<b>Ethanol Yield (l/ha)</b>
Sugar Cane	5000 - 10000
Sugar Beet	4000 - 5000
Maize	3000 - 5000
Sorghum	2000 - 4000
Cassava	2000 - 4000
Rice	1500 - 2500
Barley	1500 - 2000
Wheat	1000 - 1500
Potatoes	2000 - 4000

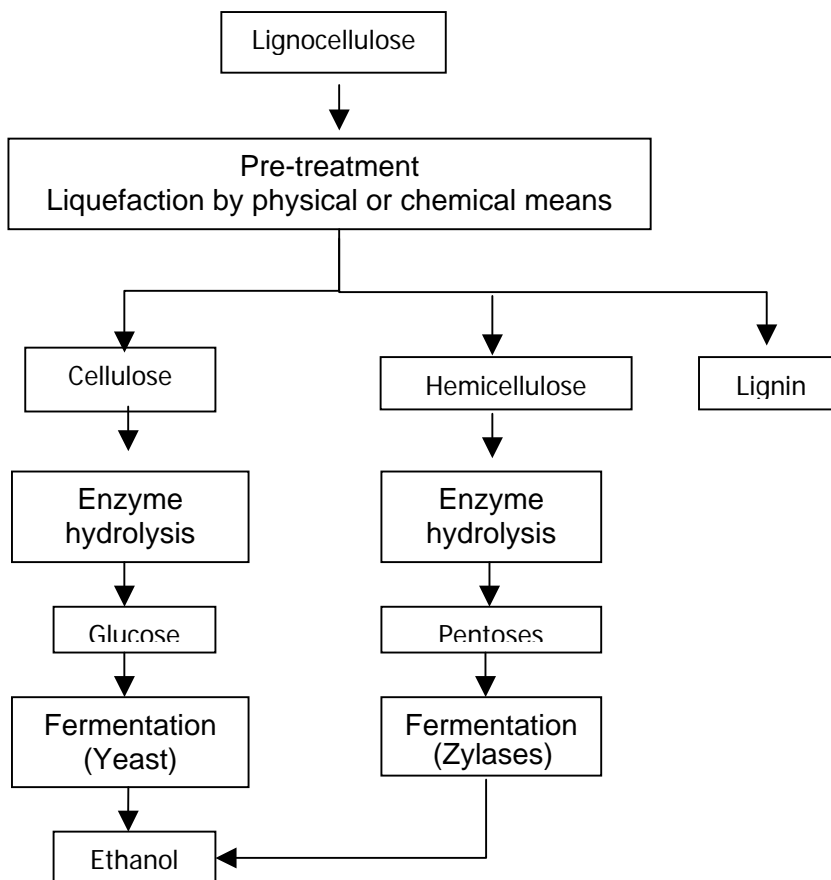
<b>TABLE II</b>	
<b>Lignocellulosic non-food sources</b>	
Crop residues	(corn stover, basasse, straw)
Grasses	(Switch grass, Miscanthus)
Trees	(Willow, poplar, etc)
Municipal Solid Waste	
Distillers Dried Grain with Solids (DDGS)	
Brewers' Spent Grain	

Second generation technology is being developed to convert lignocellulosic non-food crops and waste (**Table II**). This is not a new idea, but the challenge has been to find a commercially viable solution. The economic problems of the traditional acid hydrolysis process are shown in **Table III**.

TABLE III Economic issues of lignocellulosic conversion	
Capital cost, particularly in pre-treatment	
Expensive materials of construction	
Cost and availability of suitable enzymes	
Conversion of C5 and C6 sugars separately	

TABLE IV Lignocellulose constituents	
	%
Cellulose	30 - 50
Hemi cellulose	30 - 50
Lignin	15 - 25
'Other'	5 - 35

Lignocellulose is a complex raw material as show in **Table IV** and it is this that has, up to now, made its conversion to ethanol basically uneconomical. **Fig. 1** shows the traditional pathways.

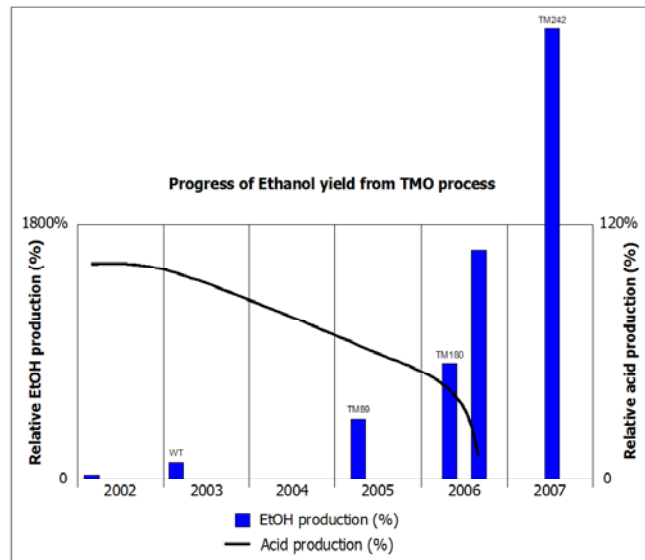


**Fig 1. Traditional Lignocellulose conversion**

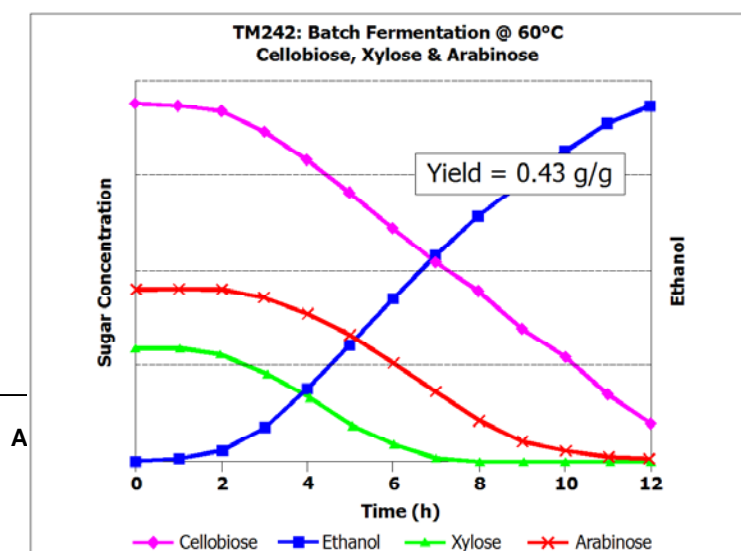
## TMO Technology

TMO Renewables Ltd, a UK based company, was set up in 2002 to develop new technologies in biofuel production and particularly in bioethanol. Their approach has been to find an organism which ferments C5 and C6 sugars, including polymeric forms and which is amenable to modification. They have developed a strain (TM242) that can provide a number of process advantages including rapid conversion of feedstock, use of low cost commercially available enzymes for hydrolysis, low microbial contamination and lower capital cost.

TM242 is a thermophilic bacterium able to operate at above 60°C and convert C5 and C6 monomers and polymers at high yields, utilising feedstock at high dry solids. The evolution of the organism is shown in **Fig. 2** and its ability to convert mixed sugars simultaneously is shown in **Figs 3 & 4**. Further laboratory trials were carried out on a variety of feedstocks. In particular, Distillers' Dry Grain and Solubles (DDGS) was shown to be a very promising prospect.

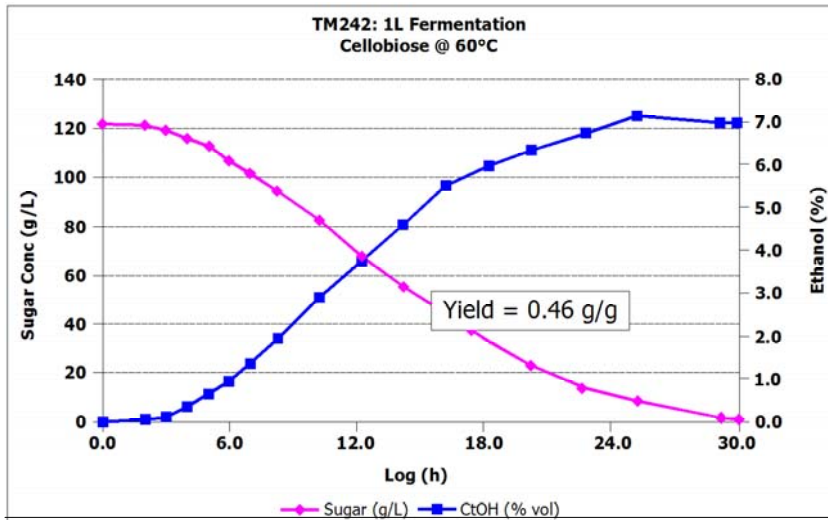


**Fig. 2 Evolution of TM242 organism**



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**Fig. 3 Conversion of mixed sugars simultaneously**



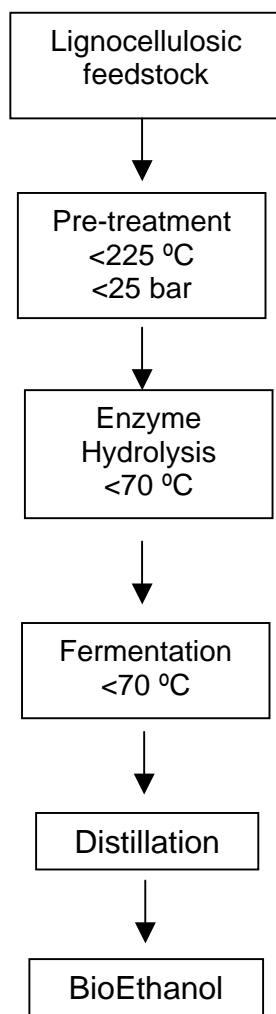
**Fig. 4 Conversion of cellobiose**

The major advantages of TM242 compared with other lignocellulosic technologies are set out in **Table V**.

<b>TABLE V TM242 advantages</b>
Thermophilic bacterium >60°C
Utilises C5 and C6 sugars together
Normal austenitic stainless steel (ph ~ 7.0)
Fast fermentation
High yield > 80% of theoretical
Tolerates > 10% ethanol
Low contamination (no antibiotics)

## The Process

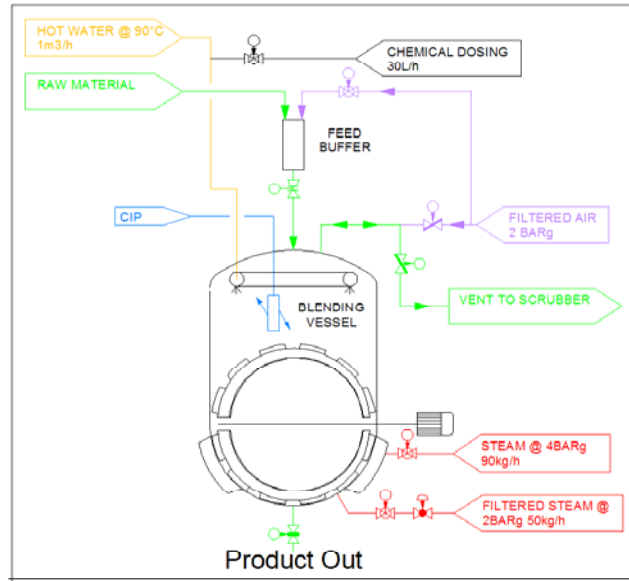
The Process Demonstration Unit (PDU) is designed to handle a wide variety of feedstocks including wheat straw, corn stover, corn fibre, bagasse, woodchips, switchgrass, distillers spent grain, etc. The principal steps are shown in **Fig 5** and the plant is designed to process nominally up to 750kg/hr at 50% dry solids, with a potential ethanol output of 200 litres per dry tonne of DDGS.



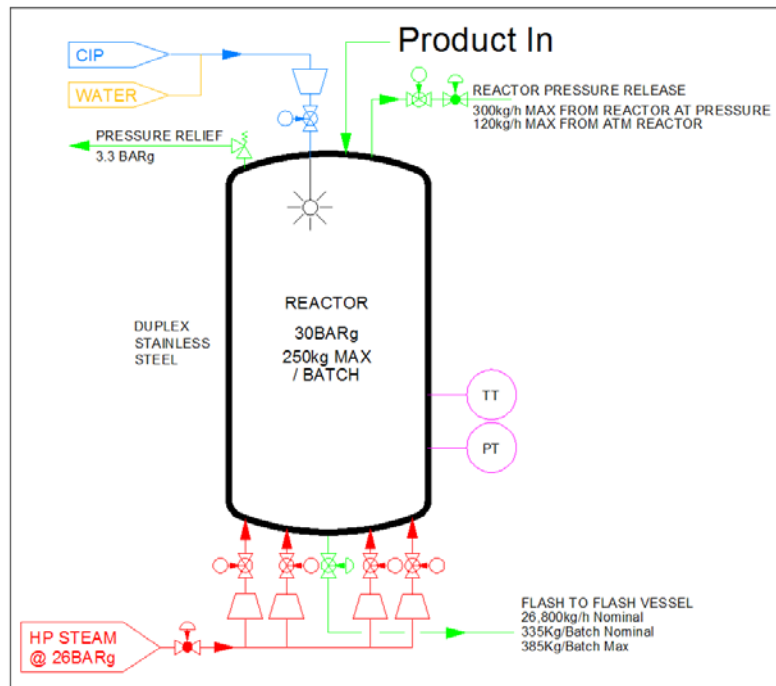
**Fig. 5 The TMO process**

### (1) Pre-treatment

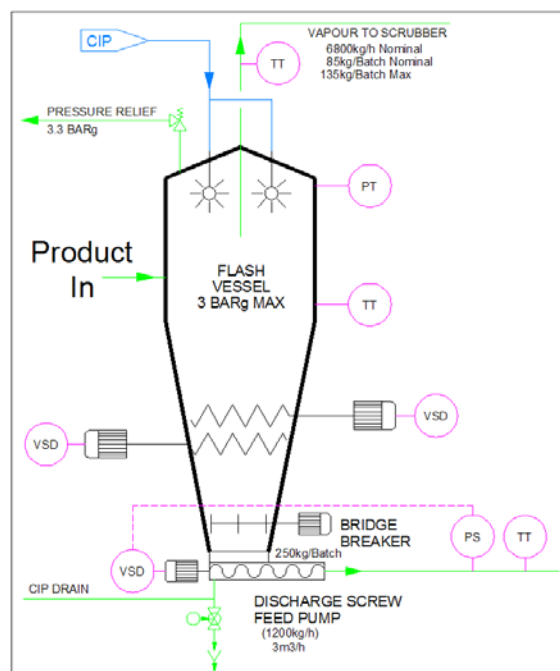
The pre-treatment process is the most novel and technically demanding part of the plant, from an engineering perspective and the key elements are identified in **Figs. 6, 7 & 8**. The viscosity at the outlet of the flash tank, before enzyme hydrolysis, is up to 300 000 Cp.



**Fig. 6 Premix vessel**



**Fig. 7 Reactor vessel**



**Fig. 8 Flash vessel**

**(2) Enzyme Hydrolysis**

The Enzyme Hydrolysis system can utilise high solids concentration in excess of 35% DS, which is important in downstream ethanol processing to avoid sending a dilute ethanol stream to distillation and ethanol dehydration. The system can operate as a batch and continuous process.

**(3) Fermentation**

This is a high temperature fermentation process. A geobacillus bacterium operates at temperatures in excess of 60°C. The organism can also utilise longer chain sugars with data indicating that it can break down cellulosic material with a high degree of polymerisation of greater than 30 and that it is not necessary to completely hydrolyse biomass feedstocks into individual monomeric sugars. Yeast, for example, can use monomeric sugars like glucose, however these are ineffective in breaking down sugars like cellobiose (two glucose monomers) and cannot utilise any C5 or hemicellulosic sugars. This concept has been demonstrated in lab and pilot scale operations.

**(4) Distillation or Membrane Separation**

The final step in the overall process can be by traditional distillation or more interestingly, by membrane separation, with potentially a 50% reduction in energy usage. The process demonstration plant does not include this step as TMO consider that the required distillation technology is well developed and well understood.

CLOSE

## SUMMARY

Briggs of Burton plc has constructed a Process Demonstration Unit to convert lignocellulosic feedstock to bioethanol utilising TMO Renewables Ltd proprietary technology, in particular the thermophilic micro-organism they have developed for rapid conversion of C5 and C6 monomers and oligomers to ethanol.

The specific advantages of the TMO technology over all others are:

1. Thermophilic bacterium operating at 60-70°C, which has multiple positive impacts in the production of Lignocellulosic ethanol:
  - a. high metabolic conversion of carbon sources to ethanol thereby operating significantly faster than yeast which can reduce capital and operational costs;
  - b. minimises contamination and therefore the use of antibiotics.
2. TMO's Pre-treatment system operates at higher pH than the alternative acid hydrolysis process therefore eliminating the use of expensive materials of construction and potentially reducing the costs of the pre-treatment system by 50%.
3. Energy usage may be improved by ~25%.
4. Water usage may be improved by ~25%.

## ACKNOWLEDGEMENTS

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