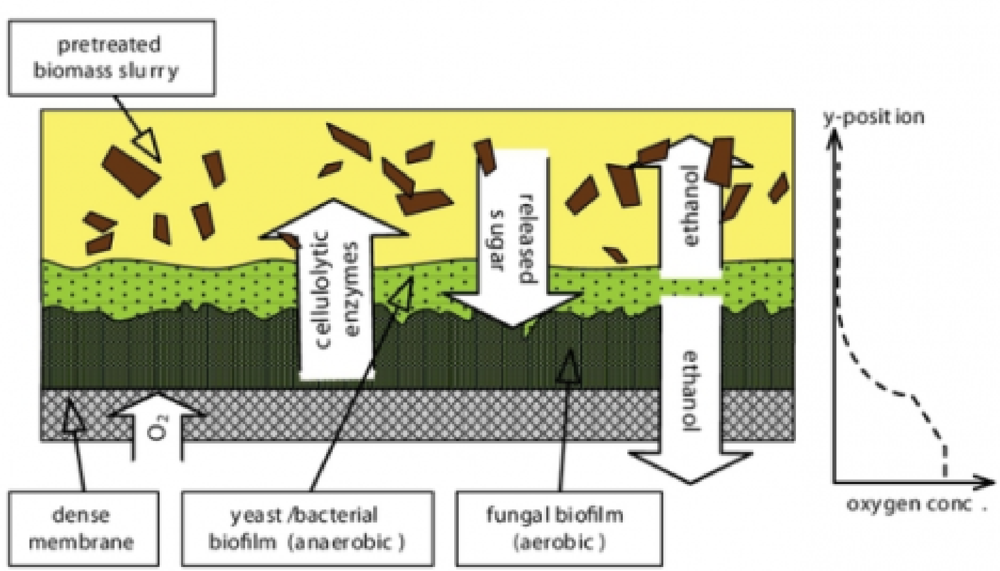
New technique could help to lower cost of next-generation biofuels

July 21 2014, by Harry O'neill



According to the UN's Intergovernmental Panel on Climate Change, world temperatures could rise to threatening levels within 30 years if fossil fuels continue to be incinerated at current rates. Alternative fuels can be derived from sustainable organic sources using intensive refinement methods, known as bioprocessing. To encourage this technology's proliferation, Swiss scientists have developed a method for streamlining biofuel production using chemical engineering to consolidate fundamental stages in the production chain

"It's imperative that we find alternatives to fossil based combustibles," says Dr Michael Studer of Bern University of Applied Sciences (BFH-HAFL) in Zollikofen. "Second generation biofuels are a viable solution to this dilemma, which could be provided at sufficient scale to address these problems immediately." In contrast to first generation biofuels made from edible crops like sugarcane or corn, the resource for such advanced biofuels is lignocellulosic biomass, the most ubiquitous organic material on earth. Unfortunately, the processing techniques for refining lignocellulose are much more elaborate and expensive compared to first generation feedstocks. "Consequently," says Studer, "economic conversion of biomass into chemicals and fuels is an important scientific challenge."

Currently, biochemically refining biomass such as wood or agricultural residues to the desired end-product requires several steps. First, the material is pre-treated at elevated temperatures necessary to achieve high yields in the following enzymatic hydrolysis step. Here, the polymeric carbohydrates – the hemicellulose and the cellulose – are cleaved by the action of enzymes into monosaccharides, e.g. glucose and xylose, which can then be fermented by selected microorganisms into the desired product. The enzymes necessary for the hydrolysis step are either produced onsite in a separate reaction tank or are purchased from an external vendor, with both versions contributing significantly to the conversion costs. The three main steps are often accompanied by additional separating, washing and detoxification steps in order to maximise yields.

One way to make the process more cost effective is the integration of several process steps into one step (called consolidated bioprocessing), ideally combined with the elimination of washing and detoxification steps. This molecular biology approach involves the engineering of one superior genetically modified microorganism that is able to produce the hydrolytic enzymes as well as ferment the derived sugars into ethanol. Though undoubtedly a highly attractive approach, it is still an open question whether such a highly engineered organism could withstand the rigours of a large-scale industrial process. Furthermore, the use of such biocatalysts might lead to considerable disposal costs.

As an alternative, Dr Studer and his team at the Swiss Federal Institute of Technology (ETH) in Zurich are developing a novel consolidated bioprocessing technique using a mixture of robust industrial microbial strains growing in one reactor. The main challenge was that the oxygen requirements of the involved organisms are different: fungal cellulolytic enzyme production requires oxygen rich (aerobic) conditions, whereas the conversion of sugars to ethanol by yeast takes place under anaerobic conditions. A special membrane reactor was developed to counter this problem, where the researchers layered the involved groups of microorganisms in a biofilm atop each other, creating a reactor in which both catalysts function simultaneously.

Oxygen necessary for the growth of the aerobic fungi is delivered via a dense oxygen-permeable membrane, whereas the upper layer of the biofilm and the fermentation broth are purposely deprived of it, creating different growth environments for the varied types of microorganisms needed. Enzymes secreted in the aerobic part of the biofilm are released into the slurry of pre-treated biomass, hydrolysing the cellulosic material to release monomeric sugars. Rapid fermentation of the sugars ensues due to the intervention of the faster growing yeast cells, which grow in the anaerobic regions of the reactor. As these complete their work, ethanol is released. "Our process definitely functions effectively," says Studer. "Yields are around 80 per cent if we're converting pure cellulose into ethanol. Using pre-treated, non-detoxified wheat straw as a raw material, the yield is only slightly lower - around 70 per cent."

The team is now seeking to diversify its outputs. To date, ethanol as product has been the focus of the work. "But, in fact, we can produce any chemical which can be derived from sugar fermentation in an anaerobic environment," says Studer. Alternative outputs have included lactic and succinic acid, and the scientists also intend to generate butanol. Generally, a significant challenge when switching to a new product is to establish an environment that nurtures all the different but cohabitant strains of microorganism. "Because of the varying pH and temperature conditions such entities may require, this isn't easy. We must, therefore, ensure our system is sufficiently adaptable," says Studer.

Funded by the Swiss National Science Foundation, Studer's latest ongoing research project aims to reduce the necessary pre-treatment severity and thereby save energy by enhancing the microbial consortium with a different type of fungi when using wood as feedstock. "These fungi modify or degrade the lignin, which otherwise is done thermochemically by high temperatures in order to render the hydrolytic enzymes effective," explains Studer. Furthermore, the team is working on a larger and continuous version of the process. "We're using equipment analogous to that found in industry, such as a set of stirred tank reactors connected in series. The membrane is integrated in the conventional reactors, just as it might be done in a commercial installation," says Studer. The researchers anticipate that the new process will be compatible with existing facilities, and could be realised using new modules that conveniently function within current infrastructures. Within three to five years, the team aims to establish an industrial pilot to assess its practical merits.

"Instead of using genetic engineering to create superior microorganisms that enhance fermentation, we've managed to achieve analogous results purely through chemical engineering," says Studer. "This is a unique alternative, which we consider unprecedented. It's also largely unheralded, but, we hope, could ultimately be recognised as making a significant contribution towards realising popular, economically competitive biofuels."

More information: The complete report is available online: viewer.zmags.com/publication/fdbffeae#/fdbffeae/16

Provided by Insight Publishers