SWEET SORGHUM ETHANOL: THE NEXT CROWNING BIOFUEL

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Mitigating climate change and greenhouse gas (GHG) emissions makes the development of renewable energies imperative around the world, even as oil prices continue to plunge. Many countries have devoted tremendous efforts to developing biofuels and solar power in order to shake off their dependence on fossil fuels. The efforts have sparked many exciting discussions about a sustainable future.

Biofuels—mainly the fuel ethanol—are the only available large-scale substitute for petrol and diesel in transport. Brazil's ethanol production using sugarcane is recognised as the most successful biofuel economy in the world so far, due to its high-energy balance and GHG emissions; however, the sugarcane-ethanol model is not suitable for every region or country because of the requirement of strict agronomic conditions for sugarcane cultivation.

Sweet sorghum, a fast-growing, non-food energy crop with high sugar, has a wide potential cropping area from tropical to temperate regions, which makes it one of the top energy crops. Sweet sorghum ethanol could benefit from the conventional sugarcane ethanol industry, including its fermentation technology, feedstock processing equipment and mechanical harvesting system; however, there are some unavoidable handicaps in adopting the sugarcane ethanol process that prevent sweet sorghum ethanol from real commercialisation. Consequently, sweet sorghum is still an untapped energy crop that requires some novel technology and processes for a significant breakthrough.

Sweet sorghum: an energy crop with unmatched versatility for bioenergy applications

Sweet sorghum has received worldwide attention because of its unmatched versatility in bioenergy applications; it is the only energy crop that can provide starch, sugar and lignocelluloses. As a sugarcane-like energy crop, sweet sorghum can accumulate high levels of fermentable sugars in its stalk—up to 18 per cent—which could be directly fermented into ethanol by yeast. Moreover, grain from sweet sorghum can be food, feed and a source of starch for ethanol production; several commercial ethanol plants in the United States rely on sorghum as their primary starch source. Sweet sorghum bagasse has the potential to be cellulosic feedstock, as well, and exhibits strong tolerance to drought, waterlogging, salinity and alkalinity, while sugarcane can only survive between 30 and 34 degrees Celsius. As a result, the Brazilian Government is starting to encourage growers to adopt sweet sorghum.

Advanced solid-state fermentation (ASSF) industrialises sweet sorghum ethanol

The conventional sugarcane ethanol process is based on traditional liquid-state fermentation, which requires an energy-intensive juice-squeezing process, resulting in the significant issues of wastewater disposal and tremendous energy input. Unlike sugarcane, the stalk of sweet sorghum contains sponge-like pith, requiring higher energy consumption during juice-squeezing, and meaning that sweet sorghum ethanol cannot benefit greatly from the traditional sugarcane ethanol industry.

Compared with liquid-state fermentation, solid-state fermentation has the advantage of converting fermentable sugars directly into the target products without the juice-squeezing process.

A large portion of energy and water is saved, wastewater is reduced and sugar utilisation is increased. During the solid-state fermentation process, however, the absence of free water leads to poor heat removal, and it is not easy to mix solid particles. The control of mass and heat transfer is a major challenge in the design and operation of large-scale solid-state fermenters. Due to a lack of engineering data and knowledge about the design and scale-up of solid-state fermenters, solid-state fermentation has not yet been proven feasible in large-scale production.

To address these challenges, we developed the ASSF process using non-food and high-potential sugar-based sweet sorghum for fuel ethanol production, which largely circumvents the fundamental constraints of solid-state fermentation, with a redesigned rotary drum fermenter and a proprietary yeast strain. Our process was the first in the world to corroborate the feasibility of the application of solid-state fermentation and the economically viable utilisation of sweet sorghum at industrial scale, making ASSF-driven sweet sorghum ethanol a promising biofuel model worldwide.

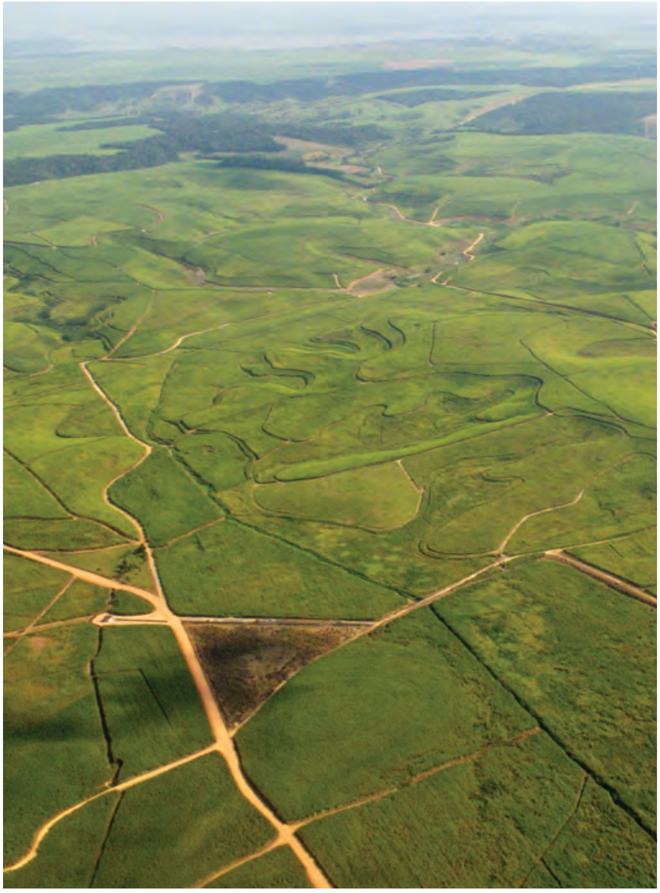
Over the past 10 years, the technology has been scaled up to industry scale. A 10,000-metric ton (MT)-scale sweet sorghum ethanol plant equipped with 550-cubic-metre advanced rotary drum fermenters (the largest solid-state fermenter used in fuel ethanol production in the world so far) was constructed in China in 2015, and is run continuously.

The groundbreaking technology demonstrates that ASSF:

- can be used for mass production of fuel ethanol
- makes sweet sorghum much more competitive as a supreme energy crop
- makes a significant contribution to the world's transition away from fossil fuels to biofuels.

Economic analysis of ASSF-driven sweet sorghum ethanol

Full utilisation of the products of sweet sorghum can make sweet sorghum ethanol more cost-effective. To further reduce production costs and meet different demands, we devised two models for sweet sorghum ethanol production using the ASSF technology. For areas where power is not in urgent demand, Model 1



Aerial view of sugarcane plantations in Brazil

should be adopted, in which the vinasse would be processed for animal feeding—combined fuel and feed (CFF). Model 2 is for areas that lack fuel or power; the vinasse would be processed for power and heat generation using a biomass boiler—combined fuel and power (CFP). It should be noted that the following investment and financial data based on one crop per year is based on the Chinese market and its labour costs.

In the models, 2000 hectares of sweet sorghum can produce 10,000 million tonnes of ethanol and 138,000 MT of vinasse. For the CFF model, the vinasse can be processed into animal feed for 6000 cattle; their manure can be used to produce 2.8 million normal cubic metres (Nm^3) of biogas and 60,000 MT of organic fertiliser.

The minimum ethanol sell price (MESP) of the CFF model is estimated at US$635/MT ethanol (US$1.90/gallon) at a sorghum stalk cost of US$25/MT. The capital cost is around US$14–16 million.

For the CFP model, the vinasse can be used to generate 15 million kilowatt hours of power, and 10 million kilowatt hours would be sold to the national grid. The MESP of the CFP model is estimated at US$652/MT ethanol (US$1.98/gallon) at the sorghum stalk cost of US$25/MT. The power generation cost is six cents per kilowatt hour, and the capital cost is around US$22–24 million for the ethanol plant.

On the other hand, due to the short crop duration of only 90–110 days, sweet sorghum can grow in three seasons each year in tropical areas, ensuring year-round ethanol production, and a stable feedstock supply. Taking into account the high productivity of sweet sorghum, its low water requirement and tolerance to drought, sweet sorghum has great potential to be the principal energy crop worldwide.

The potential of sweet sorghum ethanol in Australia

Sweet sorghum is capable of growing in Queensland, the Northern Territory, Western Australia, New South Wales, Victoria and Western Australia. The sweet sorghum industry may be beneficial in producing higher-value products to large agro-industrial complexes built around broad-acre cropping areas, particularly for integration with the sugarcane industry for higher sugar production in Queensland.

To our best knowledge, however, all studies involved in assessing the feasibility of the application of sweet sorghum ethanol in Australia only focused on liquid-state fermentation. Consequently, the cost-competitiveness of sweet sorghum ethanol is always underestimated.

Australia currently has more than 50,000 abandoned mines. Reclamation of these abandoned mines is imperative for restoration of the contaminated soil. Revegetation is the most widely used method of reducing erosion and protecting soils from degradation.

The fibrous roots of sweet sorghum branch profusely into soil, slowing erosion and competing with weedy species. Sweet sorghum is also capable of taking up a spectrum of heavy metals from contaminated soil. Therefore, we proposed a novel model that includes sweet sorghum ethanol in bioremediation of soil contaminated by heavy metals or mining.

Meanwhile, our primary study indicated that amendment with vinasse from ASSF sweet sorghum ethanol to saline-alkali soil for one crop season exhibited a significant increase in soil fertility, resulting in normal growth of corn, while the control grew nothing. Our preliminary study suggested that vinasse could stimulate microbial activity, which provides the nutrients and organic carbon to soil.

Given the supreme agronomic characteristics and versatility, the sweet sorghum ethanol industry has great potential in Australia.

Lei Zhang will be speaking at the 17th International Biotechnology Symposium (IBS 2016).