TECHNOLOGY OPTIONS

Diverse technologies aim to make the leap from lab to market

The challenge of conversion of biomass – particularly lignocellulosic biomass and agricultural waste – into chemicals, materials and fuels is being approached in multiple directions and a slew of technologies are now being developed, tested and deployed in semi-commercial or pilot stage. The range includes gasification, pyrolysis and fermentation, amongst others, and many involve tinkering with genes of bacteria, yeast and fungi, to produce metabolic pathways that can then go about turning cellulosc sugars and starches into chemicals or fuels.

Not all of these technologies – and not all of the companies – will make it to the finish line, failing at the vulnerable stage of scale-up from a bright idea in a laboratory or a pilot plant, to a commercial project with the right techno-economics. Many will not find the traction required to convert an idea in a garage to a sound business model that can sustain ups and downs.

But, as the following sections show, a host of ideas are emerging – many from Universities and research institutes – and have managed to attract the first few tranches of investments to prove concepts.

Bringing back the old

HCL Cleantech (USA), a California-based company founded just four years ago, is investing in reinventing a 70-year old idea, first developed in Germany around the Second World War for treating cellulosic biomass with hydrochloric acid (HCl). The process, as it then stood, was costly due to the extensive use of water to recover and dispose the acid.

According to Mr. Philippe Lavielle, CEO, HCL Cleantech, the company has pioneered a low temperature version that uses HCl to hydrolyse the pre-treated cellulosic biomass, with full recycle of acid. “The process is energy

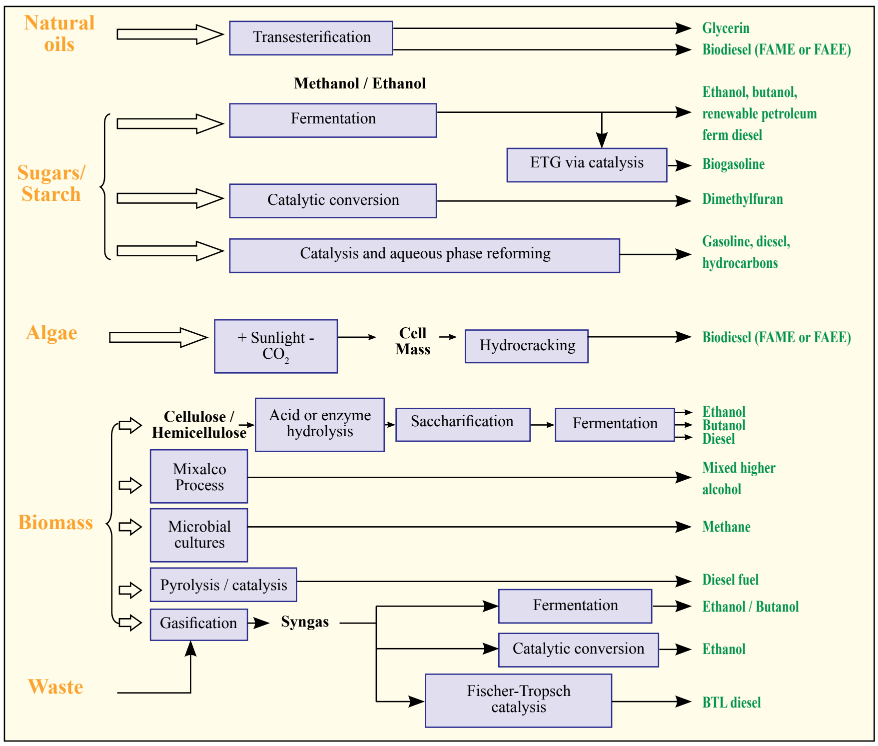


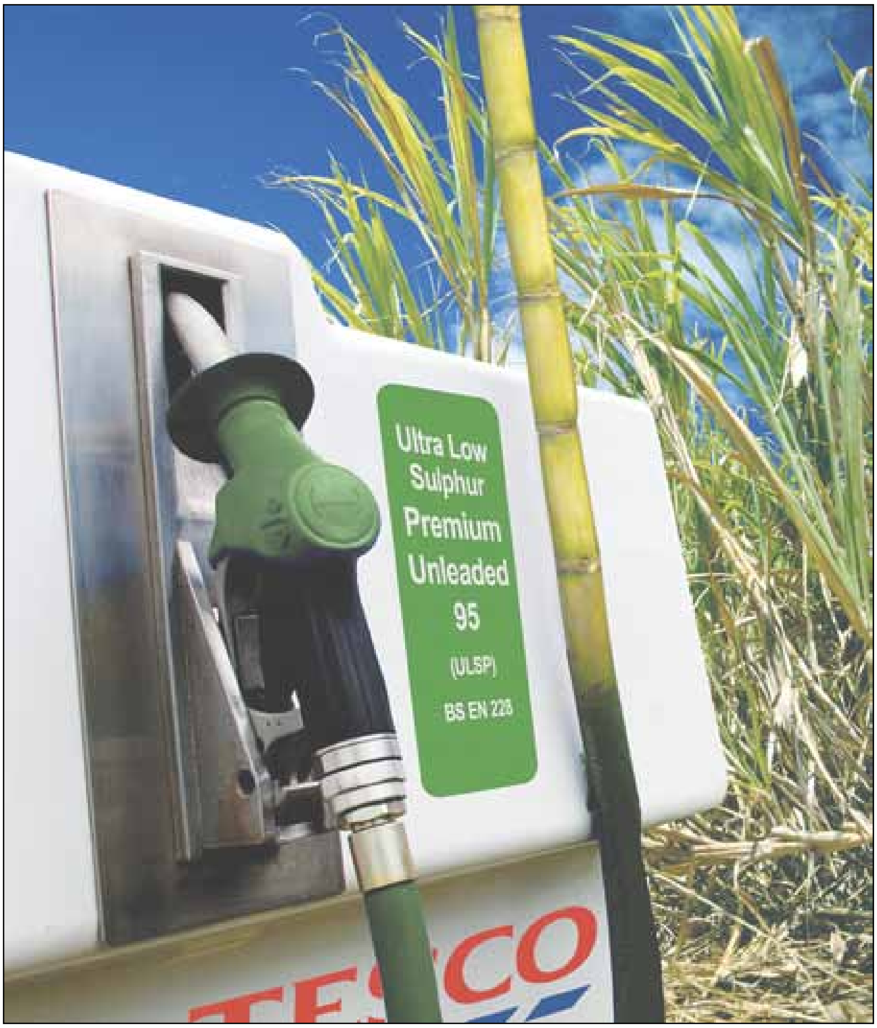
Fig. 2: Biological pathways to chemicals and fuels

positive and extracts the economically important tall oils from the biomass and yields sugars in high yield. We get two clear and refined streams of lignin and sugars."

At a biomass price of US$60 per dry tonne, Mr. Lavielle claims the process can compete with alternate processes that produce sugars from corn at a price of US$4 per bushel.

The sugars can then be subjected to biochemical transformations to produce plastics, fibres, surfactant raw materials, fuel additives and amino acids; or can under catalytic chemical processes to give a variety of plastics or fuels (such as jet fuel or diesel). The lignin can be used for power generation.

While the technology has only been demonstrated at a scale of a few tonnes per day, Mr. Lavielle is optimistic it can leverage "serious economies of scale." The first commercial unit is planned for end-2013, somewhere in Southeast USA.



Isobutanol as feedstock

Gevo, headquartered in Englewood (Colorado, USA), is developing bio-based alternatives to petroleum-based products using a combination of synthetic biology and chemistry. The company plans to produce isobutanol, a versatile platform chemical for liquid fuels and petrochemicals, using a novel technology that coaxes proprietary yeasts to produce the alcohol from sugars.

Isobutanol has broad market applications as a solvent and a gasoline blend-stock that can help refiners to meet their renewable fuel and clean air obligations. It can also be further processed using well-known chemical processes into jet fuel and for raw materials for synthetic rubber, plastics and polyesters.

According to Mr. Jack Huttner, Executive Vice-President of Commercial and Public Affairs, Gevo's technology can be retrofitted to existing ethanol plants of all kinds, at a capital cost of about US$60 per gallon, and two such installations are now on the cards in the US, which has a significant corn-based ethanol industry.

While the isobutanol produced in the process does inhibit the activity of the yeast, it is removed as soon as it is formed, allowing the conversion to go to completion. While the process currently uses corn and sugarcane as the source of sugars, Gevo's technologists are confident it can work on cellulosic biomass, just as well.

Gevo is taking the partnership route for the downstream development of the isobutanol produced. It has entered into an agreement with Sasol (South Africa) to address the opportunities in the significant solvents market; and with synthetic rubber producer (Lanxess) to produce isobutylene – a key raw material for butyl rubber – which is expected to start yielding revenues from 2013.

The alcohol to jet fuel technology is expected to get a leg-up following its certification by the ASTM – a currently ongoing process. As a drop-in replacement for gasoline, isobutanol has a lower octane rating than ethanol but is Reid Vapour Pressure (RVP) is also lower.

Also under development is a process to make p-xylene (PX), the key raw material for purified terephthalic acid (PTA), required for polyester resin and fibre, through an intermediate product (isooctane). "Toray has successfully made renewable fibre and sheets from Gevo's isobutanol," says Mr. Huttner.

Leveraging the glut of glycerol

Glycos Biotechnologies Inc. (Houston, TX, USA) is planning to take advantage of the glut of glycerine that is expected as biodiesel capacity expands. The company has developed technologies that first emerged from the laboratories at Rice University, to produce platform chemicals using proprietary strains of *E. Coli*. The first facility to deploy this technology on a commercial scale is being built in the Bio-Xcell Park in the southern part of Malaysia. The location is strategic, particularly from a feedstock standpoint: Malaysia is the hub of palm oil production and the biodiesel industry, and significant quantities of glycerine are expected to be available in the region.

The first product planned is isoprene – the monomer for a synthetic version of natural rubber. The *E. Coli* bacteria – produced using standard tools of metabolic engineering, and by turning off competing pathways – will turn the glycerine into ethanol, and then isoprene. Variations on this theme will allow the production of a broad range of organic chemicals, including organic acids and 1,2-propanediol, using a variety of feedstock besides glycerine, such as glucose and fatty acids.

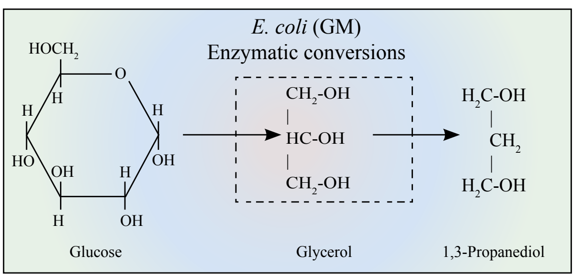
According to Mr. Paul Cambell, CEO, the engineering plans for the Malaysian project are being finalised and start-up is planned for Q1 2013. The timing will be opportune – at least 14 new synthetic rubber plants are likely to be built between now and 2015.

Designer chemicals from algae

Solazyme, a biotech start-up from Palo Alto (California, USA), is pioneering development of algal strains that can produce oils that have tailored fatty acid compositions, with controlled chain lengths and unsaturation levels.

Algae are amongst the most prolific producers of oils and genetic engineering has allowed creation of special strains that grow in the dark to produce oils at a scale that allows for industrial scale operation.

The petroleum-type oils that are produced can be refined and processed to be 'drop-in' replacements into the existing hydrocarbon industry infrastructure. The technology is feedstock flexible – it can use a variety of sugars including sugarcane-based sucrose, corn-based dextrose and other biomass sources such as cellulosics.



Mr. Harrison Dillon, President & Chief Technology Officer, Solazyme, says the economics of production of these oils was brought down to below US$1000 per tonne one year ago, and "have gone down lower since."

Stacking of traits allows production of oils equivalent to palm oil, palm kernel oil or even lard. Again, these oils are drop-in replacements to their natural products in terms of functionality. The PKO equivalent, for example, can be used for manufacture of surfactants.

French efforts

MEtabolic Explorer, headquartered in France, has developed technologies that facilitates the production of chemical compounds used in a wide range of everyday goods (textile fibres, paints, solvents, plastics and animal feed), by optimizing the metabolic yield of non-pathogenic bacteria in a contained, controlled environment.

METabolic is currently focusing on production of five compounds, of which three – Methionine (an amino acid); 1,3-Propanediol (PDO) and 1,2-Propanediol (MPG) – are at an advanced pilot or industrial stage. Two others – glycolic acid and butanol – are at a more basic stage of technology development. The company claims to be the first to produce methionine by fermentation and has an exclusive licensing arrangement for the technology with French company, Roquette.

METabolic is also investing in an 8,000-tpa plant for PDO in Malaysia, using glycerine as a starting material, and if all goes well, the plans are to ramp up capacity to 50,000-tpa, mainly for application in the manufacture of polytrimethylene terephthalate (PTT), a speciality polyester.

MPG, which is an isomer of PDO, is a chemical that finds use in manufacture of polyester resins, besides other speciality applications. The technology for this product is at a pilot stage.

Waste to plastics ....

Micromidas, another California-based start-up, has developed a technology that can magically transform municipal sewage to polyhydroxybutylvalerate (PHBV), a biologically-derived and biodegradable plastic, using carefully constructed microorganisms.

Mr. John Bissell, CEO, Micromidas justifies the choice of sewage as raw material: "The price of most carbohydrates is high as compared to the price of the target and all the more so if one looks at just the carbon price, as these products are highly oxygenated."

The technology, which has been developed by the company, can use a variety of organic waste materials, including palm oil mill effluent (POME), and through a process of anaerobic digestion produce bio-plastics. "The global production of POME can support 6.5-mtpa PHBV production," he says.

Micromidas is now building a demo-scale facility with a capacity of 1-tpd (tonne per day) in California.

.... and to fuels

Another company, Terrabon (Houston, TX, USA), is leveraging disposed organic waste and biomass to create chemicals and drop-in transportation fuels such as gasoline and jet fuel. Founded in 1995, based on research work carried out at Texas A&M University, Terrabon has invested in a 150,000-tpa demonstration unit in Bryan (TX, USA).

The technology enables the company to convert any biodegradable feedstock into acids, which are then chemically converted stepwise into ketones, alcohols and drop-in fuels, through a combination of biological and chemical conversions. The first biological step is akin to the natural fermentation in the rumen of cattle and produces carboxylic acids (such as acetic acid, propionic acid and butyric acid), which in a conventional aneraobic fermentation system would go further to methane.

According to Mr. Cesar Granda, Chief Technology Officer, the process uses no enzymes, does not need sterile/aspetic conditions and does not employ any genetically modified organisms. "The technology is ultra-feedstock-agnostic, i.e. it can process cellulose, proteins, chitins etc. and has been tested on a variety of these."

While Mr. Granda claims more than 100 chemicals can be made using the technology, the current focus is on the production of acetone (a ketone) for isopropanol. This is intended for dehydration to propylene and then converted to bio-gasoline.

Levulinic acid as a platform chemical

Segetis, a Minnesota (USA) based technology-driven company, is developing platform technologies based on levulinic acid (LA) that the company believes can address a US$80-bn market now.

LA is widely seen as a platform chemical that can be sustainably produced from biomass via thermochemical processes. Although it is not yet commercially available in large quantities, sporadic production has emerged from China.

The core of the Segetis' technology development efforts is on the conversion of LA to ketals and subsequently to a host of other chemicals, using proprietary technologies. But the focus is currently on two key markets to validate the technology and these include a non-phthalate plasticiser for PVC and a cleaning agent that has already found its way into commercial products now marketed by *Target,* a retail chain.

"We have a 120-tpa plant making ketals in a consistent manner since 2009," says Mr. Atul Thakrar, President & CEO, Segetis. The next step in the evolution is a toll manufacturing facility, with a capacity of 3-mn lbs/year, which is expected to go on-stream in January 2012. "By 2014, we are planning on a 50-100 mn lbs/year facility, but this requires assured LA supplies," he says.

This is where Malaysia comes in. The empty fruit bunches of the palm tree – the part left behind after the palm fruit has been taken out for oil extraction – can be used to make LA, as can wood or even organic municipal waste. "This can be a bolt-on facility to a palm oil plant and will also produce formic acid and furfural as co-products," adds Mr. Thakrar.

In China, some enterprising companies are producing LA on a small scale using corn cobs. "The technology is inefficient and production is sporadic," he adds.

Ten year horizon

Over the next five years, it is very likely large plants for lactic acid and succinic acid will be built. But it will probably take another five to ten years for some – not all – of the other technologies to come into play.