THE NEW ZEALAND BIOFUEL SALES OBLIGATION requires all petrol and diesel sales in this country to include a 0.53 per cent biofuel component. This equates to roughly 35 million litres of biofuel, or one petajoule of energy per year. The original obligation was to rise to 3.4 per cent by 2012, committing the country to roughly 220 million litres, or seven petajoules of energy per year.

When it was announced by Prime Minister Helen Clark in 2006, the figure of 3.4 per cent was widely criticised as unrealistic and unachievable, and with the passing of the Biofuel Bill, which came into effect on 1 October 2008, the target figure for 2012 was knocked back to 2.5 per cent. But is this any more realistic or achievable?

Establishing a profitable biofuel enterprise within New Zealand is fraught with problems. At present biofuels are manufactured from oilseed rape, tallow, waste cooking oil, algae, whey and wood. Growing maize or any other crop-based feedstock for ethanol production is unlikely to be a realistic option in New Zealand – any land suitable for growing feedstock will most likely also suit the more profitable venture of dairying. Even if was realistic, it costs a great deal to transport raw materials scattered all over the country to the large-scale processing plants that would be required to produce biofuels economically.

Energy is another important consideration – manufacturers must ensure that the energy used to produce a biofuel does not exceed the potential energy contained within the biofuel. Some conventional processes used to make biofuels use a lot of energy, such as drying sewage pond algae, and are uneconomical on a small scale.

George Hooper, Executive Director of the New Zealand Centre for Advanced Engineering, says that a major factor that is often overlooked in the rush to produce biofuels, is that biofuels, and in particular ethanol, are chemicals that require quite separate transport and handling systems from other transport fuels.

"Blending and distribution are actually expensive processes," he says. "Our existing infrastructure deals with crude coming into the refinery where fuels are blended to specification. One third of New Zealand's total petrol and diesel goes by pipeline to Auckland and the rest is distributed by coastal tankers. Unless ethanol is produced and blended in the same area, it will need to be transported to the refinery by chemical tankers with stainless steel tanks. At the refinery, it will also need to be stored in new tanks. These considerations will greatly increase costs and make it hard for us to compete with imported biofuels."

As of 2008, only very small quantities of biofuel are produced in this country, forcing local transport fuel suppliers to import the bulk of their biofuels to meet the 0.53 per cent legal obligation. BP, for example, uses some locally made tallow-based biodiesel and imported ethanol from Brazil, and Mobil, Shell and Caltex import similar quantities to achieve the obligation target.

However, Gull Petroleum, which controls its entire supply chain, is able to incorporate locally produced ethanol manufactured from whey into its two 10 per cent ethanol-petrol mixes. Gull New Zealand's General Manager, Dave Bodger, reports that in late 2008, approximately 60,000 cars filled-up with the new fuel every month in service stations from Masterton to Whangarei. Gull sells the mixture slightly cheaper than its usual brands and is competitive with petrol supplied by other companies.

Gull buys ethanol produced by Fonterra's Reporoa milk processing plant. Whey is fermented by yeast into a four per cent ethanol solution, which is concentrated by steam distillation and trucked to Gull's Mount Maunganui terminal about 90 minutes away. At the terminal, the ethanol is immediately denatured with one per cent

petrol and stored. Mixing to a vehicle-ready blend of 10 per cent ethanol and 90 per cent petrol does not occur until it is pumped into tankers for delivery.

"We decided to produce a 10 per cent blend because the end product is better able to cope with unwanted water in the car's engine, tank or other infrastructure that it passes through on the way," says Mr Bodger. "A 10 per cent blend stops the ethanol from separating from the petrol and causing the car to grind to a halt."

The right cocktail

Fonterra produces more than 20 million litres of ethanol each year in its three manufacturing plants, but ethanol is a valuable product and the company exports 60 per cent of its production, leaving a serious shortfall for any company wanting to use it as a biofuel.

However, whey is not the only ethanol feedstock. Ethanol can also be produced from forest wastes or purpose-grown plantations using enzyme cocktails and fermentation organisms. New Zealand has 1.8 million hectares of plantation forests growing mostly radiata pine and Douglas fir. Unfortunately, wastes from these softwood trees are more difficult to break down than other biomass sources because they require harsher pre-treatment processing.

Scion has developed processes to overcome this tractability, using a combination of mechanical and chemical means, and has optimised it sufficiently to produce feedstocks for ethanol production. Scion and United States-based Verenium Corporation have created a research programme (the Lignocellulosic Ethanol Initiative) with New Zealand industry partners to fast-track the development of the process by splitting the research and development between New Zealand and the United States.

Scion will use its own pilot-scale facilities to prepare pretreated wood samples and send these to Verenium's ethanol facility in Louisiana for processing by their sophisticated microbial and enzymatic systems. The product will be sent back to New Zealand for quality assurance and performance analysis.

Trevor Stuthridge, Scion's Group Manager Sustainable Design, says it makes a lot more sense to produce the fuel offshore. "Verenium has a 50,000-litre-per-year plant in Louisiana and huge experience in developing bioconversion processes for these kinds of projects. It would cost us $38 million to produce a pilot plant here and using the proposed 'virtual plant' will be much more cost and time effective."

Scion estimates that the cost of producing ethanol from waste wood could be $1.37 per litre, although that's a worst-case scenario, according to Dr Stuthridge, who believes it could be less when sales of valuable co-products such as lignin are considered. The group estimates there are sites in the middle of the North Island with enough waste wood to fuel a large plant capable of producing 100 million litres per year, more if purpose-grown tree crops complement forest-waste feedstocks in the next few years.

One-hundred million litres represents a fair chunk of the country's yearly biofuel requirements, but at this stage, production using this technology is still theoretical – experimental at best – and Scion says it does not plan to build a demonstration plant until at least 2015, so even if everything goes to plan, full commercial quantities are probably at least a decade away.

Another chemical promoted as a biofuel is butanol. Ken Morison, from the Chemical and Process Engineering Department at the University of Canterbury, was astounded when he read that

DuPont and BP were setting up a partnership to develop and commercialise butanol as a biofuel in the United States. Maize, the primary feedstock, produces extremely poor butanol yields and the experimental processes involved are extraordinarily difficult to ramp-up to viable commercial scales.

"It is second-nature for chemical engineers to do these calculations, but no one else does," says Dr Morison. "The more I listened to what people were saying about biofuel production, the more I realised that the rest of the world does not understand basic chemical engineering mass and heat balance."

He says to make biofuels work in New Zealand we need one very large plant with very large bioreactors processing crops grown nearby.

Back to basics

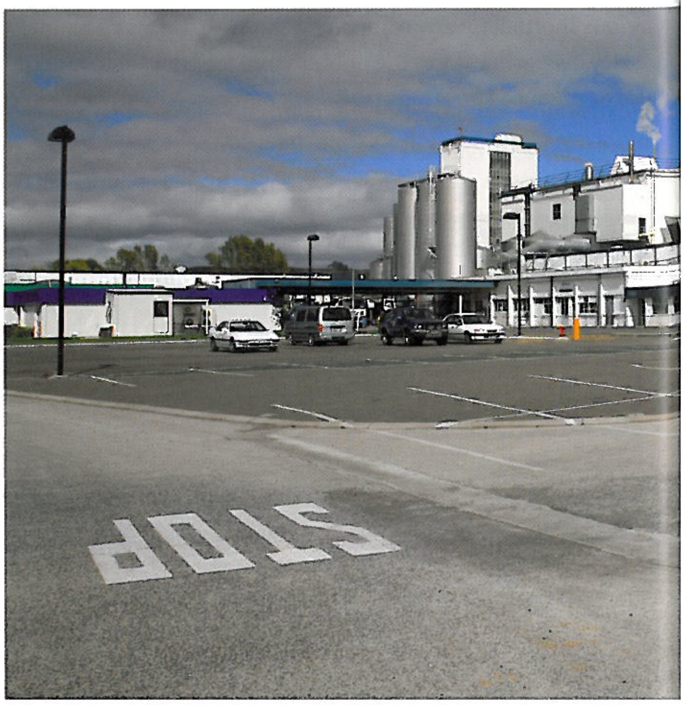
In order to prove his theory, he set a group of final-year chemical engineering students the task of designing a butanol plant in the Waikato. Using a feedstock grown in close proximity to the plant, the group postulated that 86,000 hectares of maize (3.4 per cent of the Waikato and twice the currently planted area in the entire country) would be required to produce 175,000 tonnes of butanol per year, or 5.25 per cent of the current volume of transport fuel used in New Zealand.

The maize would be wet-milled to release starch, which would then be fermented using a hyper-butanol producing bacterium. This organism is capable of breaking down starch and fermenting it simultaneously to produce acetone, butanol and ethanol in the ratio 22:44:1, a much higher proportion than was previously achievable.

However, the bacterium is very sensitive to product inhibition and the process must keep the broths in a very dilute state – approximately two per cent. The bacteria need to be fed slowly with a concentrated glucose solution via a batch system and gas stripping is necessary to continuously remove the product. Another complication is that butanol can be difficult to separate from water in the final distillation step because it forms a heteroazeotrope (where the vapour phase coexists with two liquid phases) and requires a more complex distillation step than ethanol. Both are major barriers to commercial butanol production.

If we ignore these drawbacks though, a plant capable of producing 175,000 tonnes of butanol per year would provide 5.8 petajoules of fuel energy per year, a figure that exceeds the government's target of two petajoules (for petrol blends and excluding diesels) per year by 2012.

Maize production makes up 63 per cent of the cost of the operation, and at the time of the project, maize cost $310 per tonne. To be economic, the plant would need to run continuously, so feedstock would need to be stored on-site, although maize does have a long storage life outside its nine-month growing season. The processing plant would use clean and dry maize kernels removed from the cobs. Before fermentation, the kernels would be steeped in mildly acidic water for 22 hours at 50 degrees Celsius in ten 500-cubic-metre stainless steel tanks. The maize



would then undergo a two-step wet milling process – coarsely at first and then more finely – and the resulting slurry would be screened to allow the starch and gluten to pass into another tank. There it would be injected with steam at 88 degrees Celsius and hydrolysed by the enzyme amylase. The semi-processed starch would need yet further enzymatic degradation and this would take place in another eleven 100-cubic-metre stainless steel tanks at 60 degrees Celsius.

Operating a biological system with sensitive micro-organisms requires completely sterile equipment and fluids, which adds another energy-intensive step as the liquor to be used as a fermentation medium and glucose substrate would need to be sterilised at 110 degrees Celsius. Finally, the broth, bacteria and glucose would be mixed in fermenters where carbon dioxide and hydrogen would be pumped through to help maintain the anaerobic environment necessary for the bacteria to produce butanol.

Within the fermenters, the bacterium would break down the starch and produce 0.303 grams of butanol per gram of glucose. Other products include acetone and ethanol, and small amounts of acetic acid and butyric acid, as well as large amounts of hydrogen and carbon dioxide (0.502 grams). The solvents would leave the fermenters in a gas stream and pass through a condenser and two distillation columns (to cater for the azeotropic process required for butanol) as a final step.

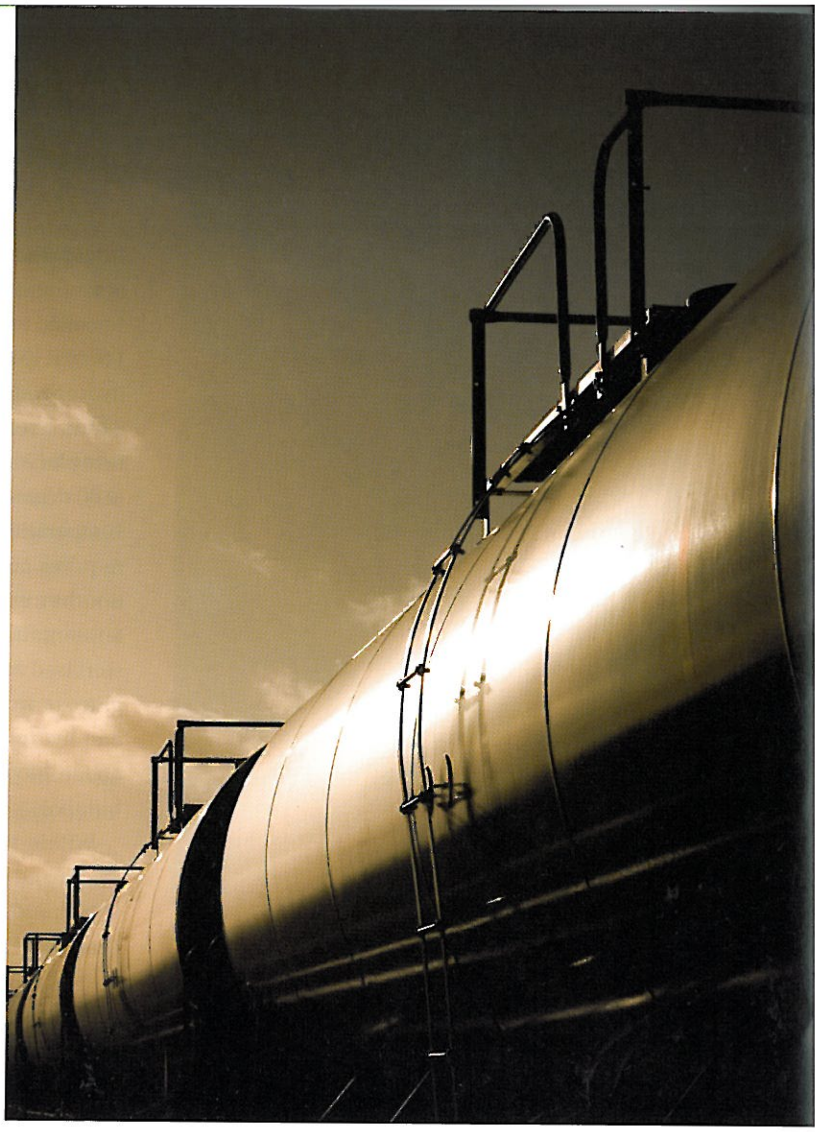
It would take approximately 22 hours for a full batch to ferment, which is quite rapid, but the butanol is very dilute, so the fermenters, like the rest of the plant, would need to be large to achieve efficient production output.

"If you want to produce so many kilograms per year, then you need to work out how many you should produce each second to get that production rate," says Dr Morison. "We know that this bacterium can withstand only a certain concentration of butanol and this reduces the production."

The biggest surprise to Dr Morison was the sheer size and number of the fermenters required. Using the largest available milk silo as a guide, the process would need 65 stainless steel fermenters, each measuring 500 cubic metres. At 78 per cent of the installation cost, these fermenters would be the most expensive item in the entire processing facility. On-site storage for five days production would need a 1,000-cubic-metre acetone tank and a 5,000-cubic-metre butanol storage tank located some distance from the main plant for safety reasons.

The most damning results came from the plant's estimated energy balance. Even using the most economical processes available and energy recovery systems throughout the plant, the process used more energy to produce the butanol than was available in the fuel.

A profitability analysis revealed the project would make an after-tax return of -40 per cent, hardly a winning prospect. But Dr Morison anticipated a loss, as it is well known that the profitability of acetone, butanol and ethanol fermentation is adversely affected by the cost of the substrate and the high energy cost of product recovery. A butanol price of $2.40 per kilogram would be required



to yield a positive net present value, a price the team believe it is unlikely to achieve. They estimated a loss to investors of $1.45 billion over the expected 15-year lifespan of the plant.

So could this project be a winner in New Zealand? Dr Morison thinks probably not.

"If we were to make 100 per cent of our transport biofuels from this process, which is not particularly sensible, we would need 1.6 million hectares of farmland," says Dr Morison. "I am not sure there is enough land available in the Waikato for such a process. I think we need to have much more discussion on alternative land use because that is what it comes down to. If you have land that is good enough for growing crops, then it is good enough for growing other things – cows for example. We are not competing with petrol, we are competing with other things that we can grow on our land. But most importantly the energy consumption must be reduced so that it releases more energy than it consumes."

Diesel alternatives

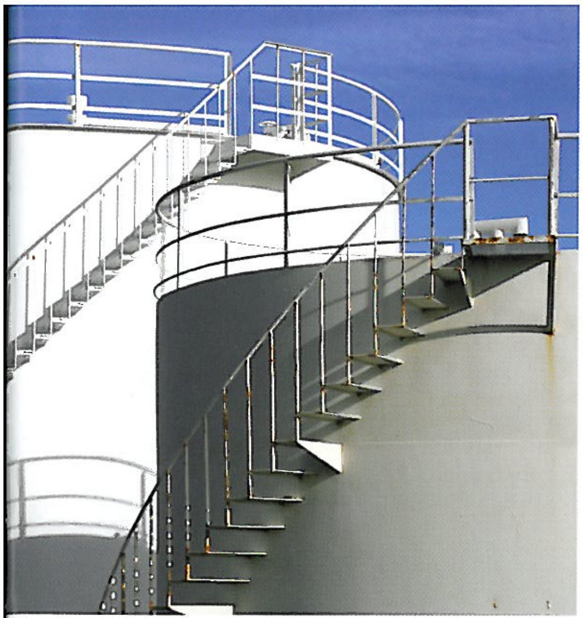
Biodiesel production from vegetable oils is also being investigated in New Zealand. The product sells at about the same price as diesel and gives almost the same mileage, maybe down one to two per cent. In late 2008, Christchurch-based Biodiesel New Zealand, for example, was producing one million litres of biodiesel per year from used cooking oil sourced from throughout New Zealand. It has also contracted South Island farmers to grow oilseed rape to help increase production to eight million litres in 2009. Solid Energy, the company's owner, is building a seed press and storage facility in Rolleston to process the increasing volumes of seed harvested by its contracted growers.

"The proportion of business that is about cooking oil will decrease when we get to our target of 70 million litres per year," says Biodiesel New Zealand's General Manager, Andrew Simcock. "We don't know if one large plant will be enough. We might build a plant capable of processing 15 million litres, with the ability to expand in the future." Nevertheless, the company reports that this is still some time away and that, for the moment, it has far more potential customers than it can supply.

There are several groups investigating the manufacture of biodiesel from algae, and in particular those that grow on sewage ponds. Owner of Solvent Rescue, Christchurch engineer Chris Bathurst MIPENZ, plans to produce and harvest algae from an oxidation pond at Christchurch City Council's Wastewater Treatment Plant in Bromley, then extract crude oil from the algae using a supercritical water extraction process.

One of the treatment plant's existing ponds is being reconfigured into four separate ponds, each with a paddle to agitate the wastewater, and transport the gases and nutrients that the algae needs to grow. To increase the growth further, the system will bubble carbon dioxide collected from the exhaust of the council's diesel generators at Bromley through the water. Once the wastewater reaches the end of the pond it is clean, having given up all its nutrients to the algae.

The type of algae is not important to Dr Bathurst. "We don't worry about whether the algae make lipid oil or not. We break



> "Crude oil is the Holy Grail of manufacturing. We don't just want diesel for trucks, we want all the products you get from oil."

everything down and that is the beauty of our supercritical process. All we are really interested in is the maximum growth." He reports that the system could potentially produce over 100 tonnes of algal biomass per hectare per year.

The supercritical water extraction process replicates what nature took many millennia to do – produce crude oil by applying extreme heat and pressure to algal biomass. Algae collected at the ponds are fed into a reactor capable of heating to supercritical conditions. Once it cools and the gases are separated, the remaining grey-green sludge is fed into a large, counter-current high-pressure solvent extraction column. This column produces a familiar-looking black liquor, which, when distilled, produces all the common components of crude oil, including LPGs, napthas, diesel, heavy oils and bitumen.

"The crude oil it forms is the Holy Grail of manufacture. We don't just want diesel for trucks, we want all the other products you get from oil. We can get just about everything from algae using this process," says Dr Bathurst.

He has recently set up a new plant that is an order of magnitude larger than the pilot plant. Once this proves successful, he may build a third version, an order of magnitude larger again. Such a plant would use the entire capacity of the Bromley Treatment Plant, and according to Dr Bathurst, would yield several thousand tonnes of crude oil per annum. To put this in perspective, New Zealand imported 4.4 million tonnes of crude oil in 2007.

A team of University of Canterbury final-year mechanical engineering students are less optimistic about algal biomass. In 2008, they designed a system to pump carbon dioxide through specially designed ponds to enhance algae growth and produce biomass for conversion into biofuel. The team produced a feasibility plan to use 65 hectares of land to install 650 100-metre open-style raceway ponds complete with motorised paddle wheels to circulate the water and encourage algal growth.

The students' calculations estimate that the scheme would run at a loss of $1.3 million per year, due largely to the price of the biomass. For the scheme to pay for itself over 10 years the price of algal biomass would have to be at least $1.10 per kilogram with all other costs remaining the same. They forecast the chances of these events happening would be slim.

Another raw material for biodiesel production is tallow collected from meat processing. There was a lot of work done to produce biodiesel from tallow during the 1980s and the process might well have proven profitable because of the high prices paid for glycerol, its main by-product, but the estimated capital expenditure was thought to be too high. Today, the price of glycerol has dropped from the highs of $2,000 to $3,000 per tonne, largely due to new supplies from biofuel operations overseas.

New Zealand has even contributed to the decline – seventy per cent of the 150,000 tonnes of tallow produced in this country heads overseas, usually on short-term contracts at spot prices, which can fluctuate wildly between $600 and $1,100 per tonne.

However, proponents of tallow-based biodiesel argue that it has an advantage over any crop-based biofuel because it does not require agricultural land that could be used for food-producing purposes. This is a fallacy, though, because production depends on the price and availability of tallow feedstock, which ultimately depends on agriculture to produce the livestock from which the tallow is derived.

Flo-Dry Engineering's Albany-based demonstration plant uses a simple and efficient process to create biodiesel from tallow. The process pumps methanol containing a small amount of sodium hydroxide (less than 0.1 per cent) and melted tallow into a four-metre reactive distillation column. After a reaction time of three to ten minutes, biodiesel and glycerol leave the reaction column. The biodiesel is washed with dilute sulphuric acid to neutralise the hydroxide and remove any residual glycerol and methanol, and is dried by passing counter-current to air in a second column. For every 100 kilograms of tallow and 10 kilograms of methanol, the process produces approximately 100 kilograms of biodiesel and 10 kilograms of glycerol.

Brian Earl FIPENZ, a chemical engineer contracted to Flo-Dry Engineering, designed the plant to produce 100 litres of biodiesel per hour, but he says it has produced up to 400 litres per hour, with limitations imposed by the pumps and heating ability. Flo-Dry plans to scale-up to a larger facility in 2009, and when complete it will produce 2,000 to 3,000 litres per hour and require only two operators to run.

Reality cheque

Despite Kiwi innovators producing several experimental successes and workable biofuel solutions, New Zealand's current commercial biofuel production falls well short of even the first step in the

COMPANY	FUEL	FEEDSTOCK	TECHNOLOGY	VOLUMES
Anchor Ethanol (Fonterra) (Reporoa plant)	Ethanol	Whey	Fermentation using yeast	Commercial (greater than 20 million litres per year)
Scion (Rotorua)	Ethanol	Waste wood Coppice wood	Fermentation using enzymes and microbes	Experimental
Flo-Dry Engineering (Auckland)	Biodiesel	Tallow	Chemical transesterification	Demonstration (up to 500 litres per hour)
Biodiesel Oils (Auckland)	Biodiesel	Tallow	Undisclosed	Undisclosed
Biodiesel New Zealand (Solid Energy New Zealand) (Christchurch)	Biodiesel	Used cooking oil	Chemical transesterification	Commercial (one million litres per year)
		Oilseed rape	Chemical transesterification	(included in the figure above
Solvent Rescue (Christchurch)	Crude oil	Sewage pond algae	Supercritical water extraction and distillation	Demonstration
Aquaflow Bionomic (Nelson)	Biodiesel	Sewage pond algae	Undisclosed	Experimental

Biofuel Sales Obligation, and it looks unlikely that the industry will meet the knocked back target of 2.5 per cent by 2012. Oil companies are forced to buy offshore and leave New Zealand, at least in the near future, still dependent on foreign imports for the bulk of its growing energy requirements – we have simply swapped Saudi Arabia for Brazil.

Clearly, there is nothing wrong with our biofuel science, so what is the problem, why are we in this situation?

"You can't make a profit on a very small scale," says Dr Earl. "Even with an efficient process you need to have a properly designed, automated plant at a reasonable scale."

As Dr Earl says, the whole biofuels issue boils down to one problem – scale. The sheer quantity of raw materials required to capture petajoules of fuel energy is staggering. Vast land areas must be committed to feedstocks, and enormous capital investment must be pumped into collection, production and distribution infrastructure. And the entire enterprise must be achieved economically. By comparison, exploiting crude oil was easy – once located and extracted, petroleum oil offers an enormous supply of virtually ready-made fuel in one location. Even so, the infrastructure to support the oil industry took decades and big money to mature.

Some overseas investors have withdrawn from New Zealand because of lack of financial assistance. London-based Argent Energy, which operates a large biodiesel plant in the United Kingdom, recently abandoned its plans to build a multimillion-dollar plant here because of a lack of funding and support.

In mid-2007, LanzaFuels put its proposed maize-to-methanc plant in the Waikato on hold indefinitely.

The price fluctuations of a barrel of oil have also confused th biofuel scene lately. The change of government hasn't helpe either, because of uncertainties in the provision of subsidie and in funding of research and development. Then there is th widespread confusion over the Emission Trading Scheme.

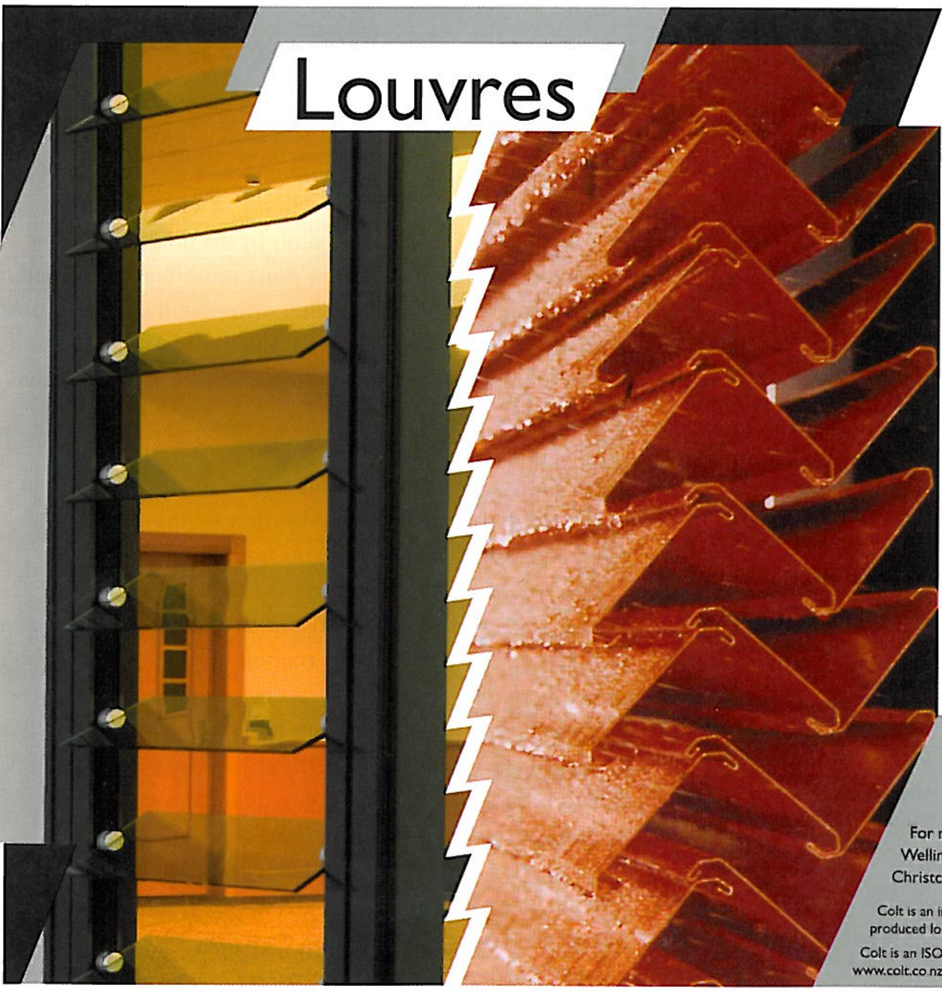
Dr Hooper from the New Zealand Centre for Advance Engineering believes New Zealand should not try to reinvent th biofuel industry from scratch. Instead, we should take advantage o proven overseas technologies, where successful biofuel industrie have endured for some time.

Engineers generally agree that a strong dose of reality is neede when considering how, or even if, to scale up laboratory successe to commercial-scale biofuel production. A stable local biofue industry must carefully consider how to source a large-scale economic and long-term supply of suitable raw materials. A best, we have only niche opportunities to produce biofuels i New Zealand and widespread commercial production still seem a while away.

So for now, our emerging biofuel industry simply canno compete with imported alternatives.

CLAIRE LE COUTEUR *is a Christchurch-based freelance writer.*

COMMENT
Gull incorporates ethanol made in the Reporoa plant into its 10 per cent fuels.
Some years away from production but experiments are ongoing with associates AgResearch, Carter Holt Harvey and US-based Verenium.
The market price of tallow is limiting for New Zealand manufacturers of biodiesel. It is also in short supply because of competition from other countries for soap manufacture.
The company has provided ECan with biodiesel for a successful bus trial. The product stood up well to cold winter temperatures in blends of five and 20 per cent. BP has also used the company's biodiesel blended with petro-diesel in Auckland.
Cooking oil is collected and recycled to make different grades of biodiesel depending on the quality of the raw material.
Oilseed rape must be grown in rotation with other crops away from other contamination-sensitive seed crops. If grown on marginal land it will require more labour, fertiliser and possibly irrigation to grow. Growers may also choose to sell their crop for edible oil use to gain higher returns.
The company has produced a crude oil from algae in Christchurch's Bromley oxidation ponds. The supercritical water extraction process also processes wood chips to yield oil and lignin.
Aquaflow Bionomic declined to provide any information, other than to confirm it had produced an algal sludge and that it had filed six patents around its technology.



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