The Good Oil

Stephanie Williams and Peter Gresshoff explain why legumes promise to improve the efficiency of biodiesel production, making them an even better prospect as a green alternative to liquid fossil fuels.

A *Pongamia* seedling featuring its seed cotyledons, the source of the vegetable oil used for making biodiesel. Photo: Q. Jiang, CILR

It seems hard to imagine that tomorrow's cars could be full of beans, but it's a fact that geological reserves of petrol are dwindling.

The world uses 3.8 trillion litres of oil each year. Known reserves can provide 162 trillion litres per year, which means we have 43 years left.

There's no choice but to find "sustainable" alternatives as petrol prices continue to soar. Enter biodiesel: a masked hero promising a renewable, cleaner and safer source of energy for the future.

Biodiesel is made predominantly from fresh or recycled vegetable oils and animal fats. It is non-toxic and biodegradable, and produces significantly lower emissions compared with petrol-based diesel.

Currently, Australia's transport sector is responsible for approximately 15% of total carbon dioxide emissions, and this figure is on the rise. Notably, biodiesel is carbon dioxide-neutral, a concept that links greenhouse gas emissions with greenhouse gas absorption. This means biodiesel's carbon footprint is minimal and does not contribute to increased atmospheric concentrations of carbon dioxide.

Plants convert solar energy into chemical energy using photosynthesis, and it is this chemical energy that biodiesel releases when burned. Unlike other emerging alternatives such as nuclear power, biodiesel is a storable form of energy.

Diesel blends containing up to 20% biodiesel (B20) can be used in most diesel-powered equipment. Higher level blends and pure biodiesel (B100) can be used in many diesel engines with minimal modifications to seals and piping.

Biofuels made from renewable organic sources are not a new concept. Rudolph Diesel's first internal combustion engine was powered by peanut oil. However, in the 1920s diesel engine manufacturers altered their engines to use the fossil fuel petroleum because it was cheaper to produce. Along came the rise of the petroleum oil cartels.

In Australia, the main focus on biofuels has been on ethanol blends made from sugar and petrol. This is fuelled by an abundance of sugarcane and the associated low average price being paid for sugar.

While ethanol production has been heavily subsidised by the government, the jury is still out as to whether the subsidy money may be better spent elsewhere. Since ethanol will only replace a very small fraction of Australia's petrol consumption, its impact on fuel security will be fairly small. Environmental benefits are at best marginal, as sugarcane requires nitrogen fertiliser, which is itself manufactured with the aid of fossil fuel.

Biodiesel's revival began with farm cooperatives in Austria in the 1980s. Now more than 20 European Union (EU) countries are producing biodiesel on an industrial scale. Diesel engines, after all, are much more accepted in Europe than in Australia.

However, recent technical advances in engine design have eliminated the smell and the characteristic "gluck-gluck" noise, and heightened the performance component. Outstanding passenger vehicles marketed by Audi, Volkswagen, Mercedes, BMW and Peugeot, among others, use attractive diesel engines. Such engines develop great torque, have less moving parts and, more importantly provide excellent mileage: 800–900 km/tank is quite common.

The EU has slowly but surely become the production stronghold for biodiesel, producing nearly 3.2 million tonnes in 2005. Germany is by far the leading biodiesel producer with a production capacity of 2.35 million tonnes and, encouraged by tax breaks, used a reported 1.98 million tonnes last year.

While most European biodiesel is made from canola oil, the main source of biodiesel in the United States is soybean oil. The US is the world's fourth largest biodiesel producer behind Germany, France and Italy, making 250,000 tonnes in 2005.

In Australia, commercial biodiesel production is in its infancy. Notably, all public transport trains and most public transport buses in Adelaide have been

operating on a B5 blend (5% biodiesel) made from mustard seed and canola oil since March 2005.

While diesel in Australia attracts a federal government excise of 38 ¢/L, biodiesel is excise-exempt until July 2011. This creates a cost advantage in marketing and an attractive profit margin for the industry.

Unfortunately, an excise equivalent ramping to 19 ¢/L is legislated to phase in for 2011–16. It would appear to be logical for governments of all persuasions to continue to support the broader public acceptance of biodiesel through continued exemption status into the future.

Biodiesel is undoubtedly a good alternative to fossil fuels. The success of biodiesel sourced mainly from canola in Europe is a testimony to its numerous benefits.

However, biodiesel faces a number of drawbacks. Worldwide production of vegetable oil and animal fat is not sufficient to replace liquid fossil fuel use. With current yields, huge amounts of land and fresh water would be needed to completely replace fossil fuel usage. Thus, ongoing research is looking for more suitable crops with high oil content. Enter legumes.

Legumes are plants with a seed pod that splits in two. There are about 18,000 species worldwide. Some have edible seeds and include peas, beans, soybeans, lentils, peanuts and chickpeas.

It is the ability to fix nitrogen that makes this family of flowering plants remarkable, and good candidates for biodiesel production. "Fixing nitrogen" means that a plant can take an unlimited supply of nitrogen gas in the atmosphere to produce ammonia, which is the building block of proteins and other essential components of any organism.

Thus legumes can grow on rather poor soils and generate good crops and sources of biodiesel. Perhaps it is no coincidence that the first biofuel was indeed peanut oil.

Legumes can fix nitrogen due to a symbiotic relationship with soil bacteria known as rhizobia. These bacteria live harmoniously in tiny nodules on legume roots. In return for food and shelter, the soil bacteria convert atmospheric nitrogen to ammonia, which the plant can then use to make proteins and nucleic acids such as DNA. Consequently, legumes do not need nitrogen fertiliser, and in fact are used as a natural fertiliser during crop rotations.

Legumes are an important food source for both humans and animals since their seeds are high in protein and contain various nutriceuticals, such as phytoestrogens. The value of legume crop production worldwide and associated inputs in nitrogen fertiliser equivalents exceeds A$200 billion each year.

Thus legumes have an advantage over other biodiesel sources such as canola or oil palm because they make their own nitrogen fertiliser. Non-leguminous crops, on the other hand, require nitrogen fertiliser, which is made by an intensive industrial process using fossil fuel energy (the Haber-Bosch process) and produces greenhouse emissions.

It is this ironic turn of events that reduces the cost–benefit of most biodiesel and puts the mighty pea and bean family forward as a serious contender for biodiesel production in the future.

Soybean has been the major source of biodiesel in the United States and Brazil because it is commonly grown. However,, its oil yields per hectare are 37% that of canola. Even though soybean does not require nitrogen fertiliser input, it is not a truly economically viable alternative to fossil fuels.

It would seem that the perfect biodiesel feedstock crop would be a legume with high oil content and high yields per hectare. Enter a little-known legume called *Pongamia pinnata*.

Pongamia is a tree that is native to Asia. It can grow up to 25 metres in size, producing large legume seeds that contain about 27–34% vegetable oil consisting mainly of oleic acid (C18:1). However, several flavones make the oil distasteful and unfit for human consumption.

Nevertheless the oil has good thermal properties and is used in India to fuel stoves and lanterns. Oil yields of 2 tonnes/ha/year are possible. In contrast canola, which requires nitrogen fertiliser, yields about 0.9 tonnes/ha/year.

Most importantly *Pongamia* is fast-growing, has no known diseases and is tolerant to salt and drought condi-

tions. How perfect for our dry continent.

Research is now needed to optimise our potential legume crops to feed supplies into the expanding biodiesel production facilities in Australasia. We need to find technologies to detect superior plants (both in terms of yield and oil content), propagate them clonally *en masse* without major genetic instabilities, and then attempt to use modern genetics to optimise the oil product for its industrial applications. Such research capabilities exist within the ARC Centre of Excellence for Integrative Legume Research (see www.cilr.uq.edu.au).

The Australian biodiesel industry is poised for rapid expansion over the next 2 years. Three biodiesel manufacturing plants are in production in New South Wales and South Australia, several are under construction in Queensland and the Northern Territory,

A nitrogen-fixing nodule of the legume *Lotus japonicus*. The inside is filled with bacteria that convert nitrogen gas into ammonia, which is used for protein biosynthesis. A normal legume plant develops about 50 nodules on its root system. Photo: Diana Buzas, CILR

and a number of Australian companies are looking at constructing biodiesel plants overseas. Australian biodiesel production capacity is expected to increase more than sevenfold to 750 million litres by 2008; more than double the federal government's target of 350 million litres of biofuel use by 2010.

It is estimated that Australian biodiesel will replace about 5% of our total diesel market in the next few years. The stage is thus set for a major cultural shift in transport fuel usage in Australia.

In the meantime, the research focus is on improving the efficiency of biodiesel production using legumes with high yields and oil content. This is a valuable opportunity to decrease national dependence on foreign petroleum, increase efficient and sustainable production of domestically grown crops and significantly boost agricultural revenue for Australia.

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