What Now and What Next for global Biofuel Technologies?

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Paper prepared for presentation at the "Biofuels, Energy and Agriculture: Powering Towards or Away From Food Security?" conference conducted by the Crawford Fund for International Agricultural Research, Parliament House, Canberra, Australia, August 15, 2007

KEYNOTE ADDRESS

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This paper provides an overview of first- and second-generation biofuels. First-generation biofuels are ethanol-derived from food crops such as grains and sugar cane, and biodiesel, which use feedstocks of vegetable oils and animal fats. The technologies for manufacturing first-generation biofuels are generally mature and are commercially available. It is also noted that biogas is gaining favour in countries such as Sweden, where it currently accounts for about half the vehicle gas use. The focus of the paper then shifts to consider alternative processing paths under development, using non-food crops and agricultural and forestry residues. The two major pathways are: Biochemical — conversion of cellulose and hemicellulose to sugars and their fermentation to alcohol fuels and; Thermochemical — gasification of biomass to a syngas rich in carbon monoxide and hydrogen, and synthesis to fuels. The paper also considers the production and use of pyrolysis bio-oil as a fuel and as an intermediate product for conversion to transportation fuels. The land areas required for the production of various biofuels are considered, together with their greenhouse gas reduction potentials. Work related to the global potential of biofuels for meeting future energy needs is briefly discussed.

DR STEPHEN SCHUCK has worked for over 32 years in the energy sector. In 1997 he started his own consultancy, Stephen Schuck and Associates Pty Ltd, which consults in sustainable energy sources and technologies and through which he manages Bioenergy Australia, a government-industry group of some 56 organisations fostering the development of bioenergy. He was the co-author of a report *Wood to Alcohol Fuels* and also provided an independent expert report for the prospectus for a large biodiesel project for Geelong, Victoria. Steve is Australia's representative on the Executive Committee of the International Energy Agency's Bioenergy program and has represented the alternative and renewable fuels industry on the Australian Government's statutory Fuel Standards Consultative Committee. Stephen's academic qualifications include a PhD, an MSc (Engineering) and an MBA (Technology Management).

Introduction

Bioenergy Australia is a government-industry forum set up to foster the development of biomass for energy and energy-related products. It is also the vehicle for Australian participation in the IEA Bioenergy Program. One of the tasks Bioenergy Australia is involved in is called *Commercialising First- and Second-Generation Biofuels*.

Bioenergy covers the broad spectrum of heat and power, transportation fuels and chemical production (Fig. 1). Biomass can take many and varied forms — from fairly dry (15% moisture content) to fairly wet (over 90% moisture content), including agricultural and forestry residues and food wastes.

The focus of this presentation is shaded grey in Figure 1.

Processing options

Anaerobic digestion

Biogas from anaerobic digestion is less known and not well recognised as a transport fuel. Anaerobic digestion is a biochemical process that uses microbes to convert wet wastes into 'biogas' rich in methane and carbon dioxide. Anaerobic means it operates in the absence of air to produce fuels and chemicals. In countries such as Sweden there are some 15 000 vehicles running on biogas. The carbon dioxide and other contaminants in the gas are stripped off. There is an anaerobic digester near Parramatta.

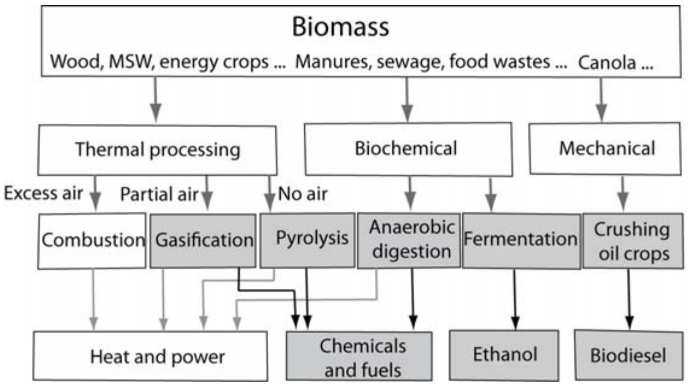

Figure 1. The sources of biomass, various processing options and outputs

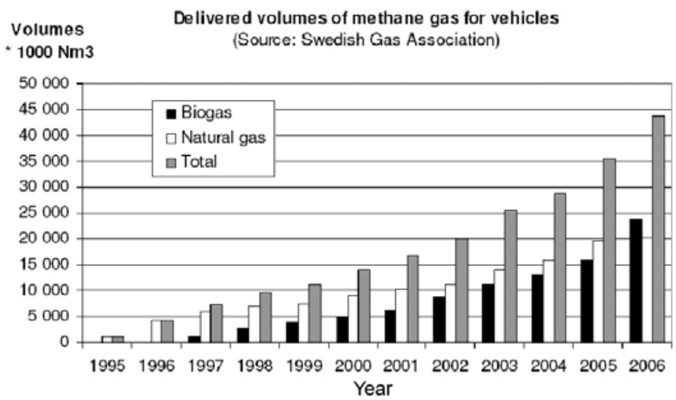

Figure 2. In Sweden during 2006, 54% of the gas delivered to vehicles was biogas. In 2006 both Germany and Austria set up national targets of 20% biogas in the gas sold for vehicles.

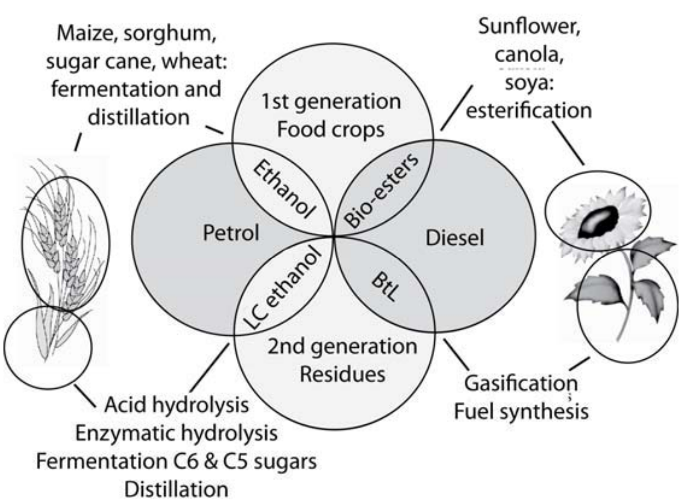

Figure 3. Options for biofuel production (after Shell)

Examples of use of biogas in transport include a bus in Switzerland and a train in Sweden.

Biogas may be obtained from landfills as a result of anaerobic processes. The biogas naturally migrates out of the decaying landfill, is captured and purified and can be liquefied, and used for transport fuel.

Sweden has fairly aggressive renewable energy targets; biogas is providing more than half the gas that is used in vehicles (Fig. 2). Biogas can be thought of as a renewable form of natural gas.

Figure 3 provides an overview of both first- and second-generation biofuels. First-generation biofuels are essentially derived from food crops.

Ethanol, produced by fermentation technologies, mainly blends into petrol but with suitable emulsifiers can also blend into petroleum diesel. Vegetable oils can be converted into bio-esters; a substance we call biodiesel that blends extremely well into diesel and can meet at low blend levels the Australian Diesel Standards.

These first-generation technologies are essentially using only a small fraction of the standing biomass, for instance oil seeds from crops such as canola and soya; or for ethanol, maize, sorghum grain and molasses. There are huge benefits in moving towards the whole-of-biomass approach because of the larger scales and more complete utilisation attainable. Much current development is focused on conversion of all of the biomass to biofuels. One of the main routes being followed is the production of lignocellulosic ethanol via the fermentation of some exotic sugars.

The first-generation ethanol processes may be categorized by the so-called six-carbon sugars, such as glucose, whereas the more exotic sugars like arabinose and xylose are C-5 sugars and are associated with the hemicellulose fraction of the biomass and require alternative processing.

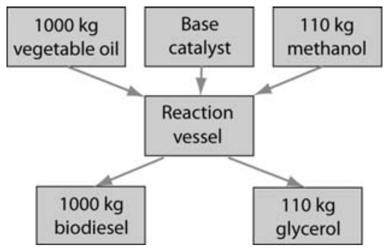

Figure 4. The production process for biodiesel (methyl ester)

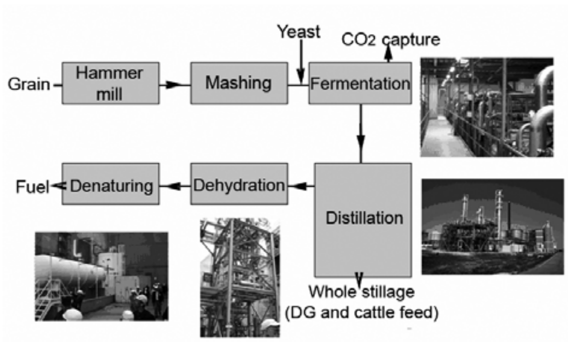

Figure 5. The production process for first-generation ethanol

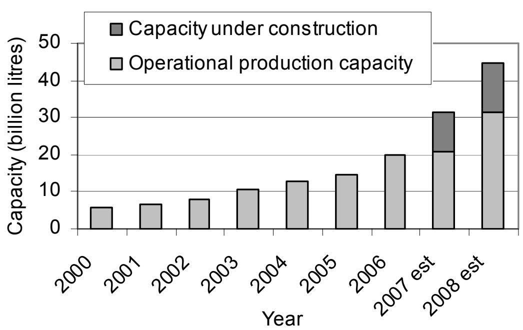

Figure 6. US ethanol production capacity (RFA/DoE 7 February 2007)

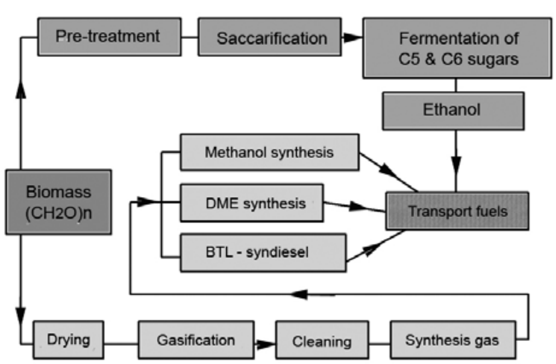

Figure 7. Production processes for second-generation biofuels

The first-generation fuel — biodiesel (methyl ester) is essentially produced from vegetable oils and animal fats (Fig. 4).

To produce biodiesel, vegetable oils and methanol (or ethanol) are combined in the presence of a base catalyst such as sodium hydroxide in a reaction vessel to produce the same amount of biodiesel as the vegetable oil feedstock; basically a thousand kilograms to a thousand kilograms, and with a by-product of glycerol.

An example of this well established technology is in Western Australia — the Australian and Renewal Fuels Picton Plant, using Energea technology. Gull Petroleum, one of the Bioenergy Australia members, has been very involved in the retailing and the marketing, which is extremely important for consumer acceptance.

First-generation ethanol production is very well established, with the technology being used for several decades, particularly in the USA and Brazil (Fig. 5).

Ethanol production from a grain feedstock entails milling, mashing, fermenting, distillation to increase the content of the ethanol in the product, dehydration to get to anhydrous ethanol — basically 100% ethanol — and denaturing with petroleum petrol so that you can't drink it. Denaturing overcomes some of the excise issues. In the USA ethanol production has increased rapidly (Fig. 6).

Some of this increase has been driven by the requirement to get rid of MTBE, methyl tertiary butyl ether, which is associated with water contamination and is carcinogenic. Capacity has doubled in quite a short time, and this has led to the discussion about competition for food supplies.

Second-generation biofuels

Production of second-generation biofuels is illustrated in Fig. 7.

Interest in these fuels has been driven by the requirement to find a broader range of feedstock and to allow production at a much greater scale to provide a greater proportion of our future energy needs. The two main avenues for second-generation biofuels are bio-chemical — using microbes to convert cellulose and hemicellulose in the bio-mass to sugars for fermentation, and thermo-chemical — applying heat to gasify the biomass into a chemical feedstock that can be re-synthesised into fuels.

For second-generation ethanol, the biomass goes through the steps of pre-treatment; saccarification — to liberate the sugars for fermentation to ethanol — and then fermentation to produce the ethanol.

For the thermo-chemical pathway, the steps are: drying — fresh biomass tends to be about 50% moisture — followed by gasification and then conditioning the gas and then various synthesis processes. DME is di-methyl ether; and BTL is biomass-to-liquid, essentially synthetic diesel. The latter steps are not essential; there are enthusiasts who put gasifiers directly onto their vehicles — particularly in Europe. Australia had about 45 000 charcoal gasifiers on board vehicles during the Second World War. As such, this technology is not totally new, but it is now being taken to new levels.

European developments

What's going on, particularly in Europe, in the thermo-chemical process? An example is the work of a company called CHOREN. The name stands for carbon, hydrogen, oxygen (the main constituents of biomass) and renewables. The company is linked with Shell and Daimler Chrysler. At a pilot plant in Freiberg in south-eastern Germany they are building a commercial-scale demonstration plant to gasify biomass into its component — mainly carbon oxide and hydrogen — and then to make a synthetic diesel. This is what South Africa has been doing for the past 50 years in Sasol — gasifying coal and then using a very similar synthesis process. The goal is to build an operational plant at the million tonnes of biomass per annum level, using woody biomass.

An alternative is being tackled in the pulp and paper industry. Instead of burning the black liquor, a by-product of the kraft pulping process, it can be gasified — to recover the energy content —to produce exactly the same feedstock of carbon monoxide and hydrogen.

Volkswagen has been producing a product called SunDiesel on a trial basis in conjunction with CHOREN.

In Sweden, Volvo has linked up with CHEMREC to produce a fuel called di-methyl ether, DME. It is an interesting fuel — there are no carbon-to-carbon bonds in the molecule, and thus it is an extremely clean-burning fuel — without soot. It is very similar to LPG, although it suffers from what some other biofuels also suffer from — low energy density. It has only about 57% of the energy density of diesel, so tank range is significantly reduced.

A lot of research is in progress on thermo-chemical processes in Europe. An example is a combined heat and power project close to the Austrian boarder, that uses a slipstream of the gas from a small gasification plant to produce a fuel termed BioFit — from the words Biomass Fischer Tropsch. Fischer Tropsch is the catalytic process for producing the synthetic diesel. Some parameters of the product are shown in Table 1.

The calorific value is better than that of synthetic diesel; it has a slightly slower density than petroleum diesel and it is totally blendable in all ratios with petroleum diesel. It has a satisfactory cetane number — this, for diesel, is analogous to an octane rating for petrol.

The European Union has the CHRISGAS project in Sweden at Varnamo, where a range of alternative transport fuels is being studied.

Some of this work is being driven by a desire to reduce greenhouse gas emissions; Figure 8 compares alternatives with petrol.

Because of the high compression ratio of diesel engines, diesel is a moderately better fuel than petrol in regard to greenhouse gases (Fig. 8, top). The data shown here are from the European Union's Joint Research Centre in The Netherlands and it reflects a range of studies on life cycle emissions of fuels. The assumptions made in life cycles analyses are important. Some studies of ethanol from grains (including corn) have shown that it is mildly negative in terms of greenhouse gas performance, but most show it is fairly positive.

Table 1. Parameters of Güssing-Tropsch diesel

Parameter	Unit	Diesel EN 590	BioFit Güssing
Water content	mg/kg	max. 200	200
Density 15°C	kg/m^3	820–45	780
Viscosity at 40°C	mm^2/s	2.0–4.5	2.4
Sulphur content	mg/kg	max. 10	8.25
Calorific value	MJ/kg	min. 42.8	43.5
Cetane number	-	min. 51	79.7

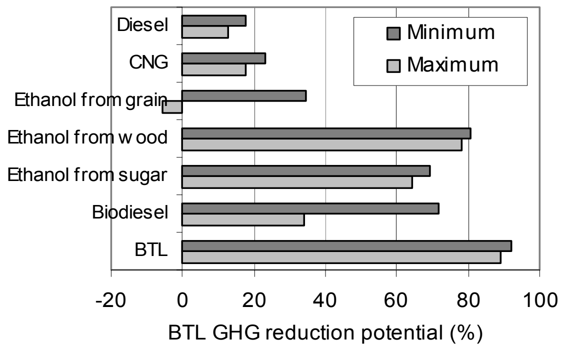

Figure 8. Greenhouse gas reduction potentials with regard to petrol. BTL = 'biomass to liquid'. (JRC/EURCAR/CONAWE Well-to-Wheels Report Jan 2004)

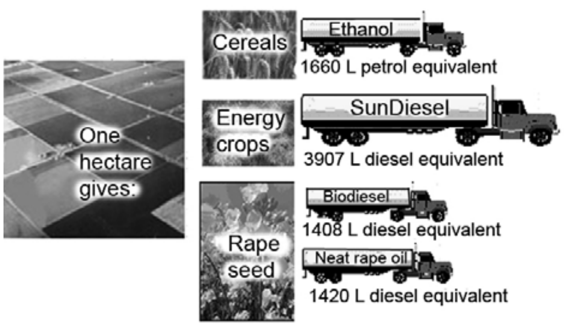

Figure 9. Liquid biofuel yield, litres per hectare per year (FNR(Fachagentur Nachwachsende Rohstoffe) 2006)

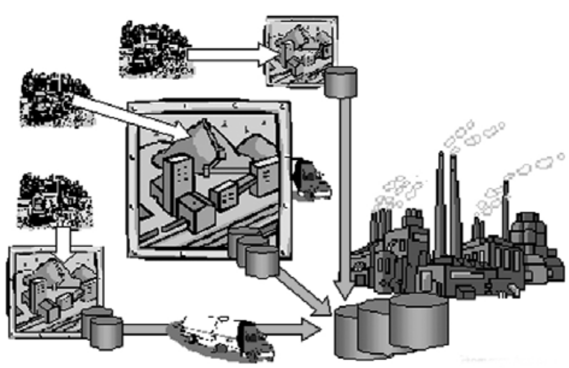

Figure 10. Distributed pyrolysis plants

But of particularly interest is that 'biomass to liquid', BTL, can achieve about 90% greenhouse gas reduction, similar to ethanol from wood. Sugar is quite a good performer as well as biodiesel. The benefit of the latter is quite variable, depending on where the feedstock has come from, distances travelled, and so on.

Another aspect of this, and one that is of particular interest in the food / fuel debate, is how much land is required require per unit of equivalent fuel. The product that CHOREN is developing with Volkswagen in Germany comes out at about 3907 litres per hectare of equivalent diesel (Fig. 9).

European work has concentrated on the thermo-chemical direction, whereas the US has been emphasising the bio-chemical route. President Bush, in a recent State of the Union address, gave a major impetus to the development of lignocellulosic ethanol and biofuels in an attempt to lessen the USA's oil addiction. This has led to quite a lot of money going in to developing and getting a number of pilot plants going to permit a technological 'shoot-out' between the different proponents. Six different, fairly large (commercial) scale, biofuels projects have been announced. Most of them are on cellulose ethanol, but some, such as Range Fuel, is taking the thermal route, which includes methanol production as well. Iogen has been running a pilot cellulosic ethanol plant with funding from Shell, in Ottawa. Iogen, a recipient of US funding, is now proceeding to scale up their technology.

One of the greatest limitations of biomass and biofuels is the fairly low energy density, particularly if you are transporting it as wood chips. One way of overcoming this, in a decentralised manner, is to apply technology known as pyrolysis (Fig. 10).

This is basically a thermal process which operates in the absence of air; one can thermally fractionate the biomass into much the same chemical constituents as the original biomass, but in a liquid form. Up to 75% of the dry biomass can be converted to this liquid fuel. It is quite different from diesel, of very high density, acidic, has a pungent odour, and has an energy density of about 60% on a volume-for-volume basis as petroleum diesel. There has been a lot of research work in the last twenty years on pyrolysis bio-oil. Although the process offers opportunities to produce various value-added products, its great attraction is in densifying the biomass so that existing infrastructure (fuel tankers etc.) can be used. There is also work in progress on gasifying the pyrolysis bio-oil to produce other fuels, although the oil itself could be used as a fuel.

There is a plant at West Lorne in Ontario, Canada, where a pyrolysis bio-oil plant has been set up adjacent to a floorboard manufacturing company. An Australian company, Renewable Oil Corporation, has obtained the licence and is trying to develop a project in Darwin.

Can the world produce enough biomass?

A vexing question is how much of the planet's energy needs can be provided by biomass? Some relevant work in this area has been done for the International Energy Agency by the likes of Ecofys from The Netherlands and by Utrecht University.

Some interesting scenarios have been done, for instance by Monique Hoogwijk and others — a lot does depend on the scenarios and the way the world moves on.

Under a scenario of high population growth and people moving to meat-intensive diets (something like 3.7 kg of vegetable protein is required to produce 1 kg of animal protein) there is little potential to produce substantially more biomass for fuel. In another scenario, moving from subsistence farming to industrial agriculture and without great competition for other things such as pure carbon sequestration in plantations and so on, you can get a very high potential, of 1100 exajoules. The world's total primary energy use at the moment is only about 470 exajoules. This is over two-and-a-half times current global energy requirements. A lot of work now needs to be done to refine the quantum between these two scenario extremes.

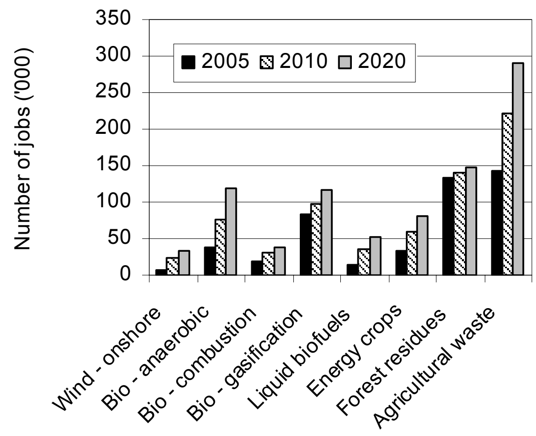

Figure 11. Projected employment in the EU for biomass technologies. Wind is included for comparison (EU Altener Report: *Impact of RES on Employment*, 2000)

Lastly Figure 11 indicates the job opportunities likely to arise from various alternative sources of energy. These projections are from a study for the European Union Altener program, exploring a range of bioenergy and biofuel related activities. There is no doubt that considerations of employment and regional development underpin some of the current interest in bio-energy and biofuels.