



Assessment of energy sustainability, CO₂ neutrality, ecological impact and technical viability of the commercially available bio fuels

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1. INTRODUCTION

The World economy has witnessed an unprecedented call to extend the implementation and consumer uptake of bio fuels in the recent years. There are many reasons that initiated the interest in replacement of petroleum-derived fuels with alternatives, among them:

- (i) growing fear of depletion of the World non-renewable natural resources;
- (ii) uneven distribution of the crude oil reserves, leaving to scarcity of supply in the main consumption areas;
- (iii) search for less polluting fuels;
- (iv) and, prevention of rapid climate changes that might be caused by anthropogenic factors, incl. these caused by the usage of crude-oil derivatives for transport fuels.

Then, it is extremely important, to identify whether bio fuels present a factual alternative to the petroleum-derived fuels. The viability of bio fuels is usually assessed in three general categories of interest [1]:

- (i) reducing dependence on fossil fuels through a positive energy balance;
- (ii) reducing emissions of greenhouse gases (CO₂ and CH₄) to the atmosphere throughout the life cycle of the bio fuels;
- (iii) reducing health and environmental impacts throughout the life cycle of the bio fuels.

This *Discussion Paper* examines the capability of selected list of bio fuels to satisfy conditions that are related to:

- (i) **diversification of the feedstock for manufacturing bio fuels:** There is a tension between food production and the production of bio fuels. A range of raw materials suitable for the

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manufacturing of bio fuels should be considered. An assessment should be made on the impact that bio fuel production may have on the costs of food;

- (ii) **energy sustainability along the life cycle of the bio fuels:** The introduction of carbon trading schemes and other proposed taxation on pollution emitters will have an impact on the development of a domestic bio fuels industry. The “carbon footprint” a domestic bio fuels industry needs to be assessed. Consequently, the research should be directed towards the most environmentally viable process. In short, the environmental benefits of introducing bio fuels can not be negated by an industry contributing more emissions than the benefits bio fuels present for cleaner transport emissions. In addition the production of bio fuels should not negatively impact on the existing ecosystems;
- (iii) **fuel quality standards:** At present consumers tend to be hesitant about using bio fuels such as ethanol. Reducing the costs of ethanol fuel will not necessarily mean an uptake of the product. The consumer needs assurances that the fuel is completely safe to use in their vehicle and is of the highest quality. The current regulatory issues surrounding fuel quality standards needs to be examined;
- (iv) **consumer education:** Essential to consumer uptake of viable bio fuels is an effective education campaign of its benefits and safety. Such a campaign will require a process of consensus building amongst bio fuels industry, vehicle manufactures and motoring organisations;
- (v) **economic viability of the bio fuels:** It is imperative the production of bio fuels is not only economically viable for producers but attractive enough to encourage existing fuel producers to expand operations. It needs to be examined what tax incentives could be employed to encourage the industry to widen its production of viable bio fuels. It is also imperative that bio fuels would allow their use in the existing engines with no major investments in retrofitting, since the enormous extra cost of retrofitting will impede the application of the bio fuels;
- (vi) **security of supply:** Australia’s economic and national security is directly linked to our nation’s ability to ensure a steady supply of transport and stationary fuels. To date, Australia unlike, other industries countries does not have a security of supply plan. The introduction of a bio fuels industry provides policy makers with the opportunity to develop safeguards and strategies to ensure Australia have access to bio fuels in the event of natural disaster or act of aggression;
- (vii) **imports and a domestic industry:** Australia relies on fuel imports and this dependency on imports should be reduced through the development of a viable bio fuel domestic industry;
- (viii) **manufacturers warranty targets and ethanol mandates:** The Page Research Centre will undertake consultation and assessment of the effectiveness of mandates and how they effect manufactures and associated warranty issues. The Centre has already identified this issue as complex and fraught with difficulties. Research will investigate the possibility of any other alternatives to mandating ethanol at a state level and seek a broader more national approach.

The aim of The Page Research Centre is to develop a policy and regulatory model to extend the implementation and consumer uptake of these fuels that have passed the viability test.

2. ASSESSMENT OF THE VIABILITY OF BIO FUELS

2.1 Diversification of the feedstock for manufacturing bio fuels

Alternative fuels, as defined by the American Energy Policy Act from 1992 [2], include:

- (i) **alcohols** – methanol and ethanol;
- (ii) **natural gas** (containing mainly methane and presented in the market in a form of Liquefied Natural Gas – LNG);
- (iii) **propane** (coming to the market mainly in form of mixtures with butane that is known as Liquefied Petroleum Gas – LPG);
- (iv) **hydrogen**;
- (v) **biodiesel** (this is a renewable fuel that is manufactured from vegetable oils and animal fats or greases).
- (vi) **P-series fuels** (this group of fuels, which are blends of natural gas liquids, ethanol, and methyltetrahydrofuran were added to the list of alternative fuels in 1999).

Although not included in the Energy Policy Act from 1992, there are two more groups of alternative transport fuels that can be added to the list:

- (vii) **pyrolysis oils** or bio-oils (these are viscous, slightly acidic fuels of relatively low calorific value, which are products of pyrolysis conversion of the biomass) and their derivatives;
- (viii) **biomethane** (methane that comes as a bi-product of the anaerobic decomposition of biomass);
- (ix) **biohydrogen** (this is hydrogen produced from organic waste materials via fermentation);
- (x) **biological hydrogen** (should be distinguished from the biohydrogen, here the hydrogen is produced in photobioreactors by algae);
- (xi) **other alcohols** – propanol and butanol.

In a strict sense, only alcohols that are derived from biomass (e.g. bioethanol, biobutanol), biodiesel, pyrolysis oils, biomethane, biohydrogen and biological hydrogen can be considered as bio fuels. Out of these, only two types of bio fuels (bioethanol and biodiesel) are produced in significant commercial quantities and have research data gathered from sufficient number of diverse resources to make general conclusions on their viability. The wide distribution of these bio fuels is related to the abundance of the feedstock, the relative simplicity of the manufacturing process and the low toxicity of the final products. The worldwide production of the bioethanol and biodiesel is estimated in [3] to be 33 and 3.9 billion litres (for the 2005), respectively.

Although ethanol can be produced as a petrochemical by hydration of ethylene, only biologically produced ethanol is of interest to the bio fuel industry. The main production method of ethanol is by anaerobic fermentation of sugars with yeast. The dominant feedstock for ethanol production is sugarcane in the tropical and subtropical regions, while sugar beet, grain (mainly corn and wheat), potatoes and cassava and other starch containing feedstock dominate in the temperate climate zone. Although at higher cost, ethanol can also be produced from ligno-cellulose using enzymes capable

of hydrolysing the feedstock. USA and China produce 19.5 and 5 billion litres of bioethanol from corn and other starch containing crops. The data for Australia is about 150 million litres per annum of bioethanol, which is manufactured in 3 facilities, all of them located on the East Coast. CSR's Sarina and the Rocky Point distillery produce ethanol from molasses feedstock. There is a facility near Nowra owned by the Manildra Group, New South Wales that produces bioethanol from waste starch and grain.

Biodiesel is produced via trans-esterification of vegetable oils or animal fats through the addition of alcohols and a catalyst, giving glycerol as a by-product. In a strict sense, the alcohols used in the process of trans-esterification should also be produced from biomass, for example, methanol of fossil origin should be replaced by bioethanol to produce ethyl- instead of methyl-ester of the fatty acids. The feedstock base of the biodiesel is substantially smaller than the feedstock base of the alcohols. It includes tallow and virgin oils extracted from rapeseeds, sunflower seeds, soy beans and oil palm. International Energy Agency estimates the world yearly output of biodiesel to be about 4 billion litres in 2005 [3]. For comparison, current estimate for the world consumption of oil is about 31.1 billion barrels (4944.5 billion litres) per year, and Australian own production of oils is approximately 32.6 billion litres per year [after 4]. It is yet to be proven that synthetic bio fuel production via biomass gasification and subsequent catalytic conversion to liquid using Fischer-Tropsch process is energy and economically sustainable.

The rest of the bio fuels are produced in even smaller (often laboratory scale) quantities and it is too premature to draw any firm conclusions on their overall feasibility. There are mixed unsolved environmental and technological problems that prevent wider application of these fuels:

(i) environmental problems – alcohols;

The group of alcohols include methanol, ethanol, propanol and butanol. Out of these, only ethanol is produced in large scales as bio fuel, despite the fact that, for instance, butanol shows superior performance in internal combustion engines [5]. Methanol, propanol and butanol can be manufactured from the same feedstock as the bioethanol, however they are rarely used as bio fuels mainly because of their toxicity and concerns of polluting the environment in a case of accidental spilling.

(ii) technological problems –pyrolysis oils, biomethane, biohydrogen and biological hydrogen;

Manufacturing of both fast and slow pyrolysis oils can be integrated in bio-oil [6] and bio-char [7, 8] refineries to minimise the production cost and to allow complete utilisation of the feedstock. The potential reserves of the feedstock (forest and agricultural cellulose residues) are enormous [7, 8]. There are studies that demonstrate the ability of the pyrolysis oils to be used in diesel engines [9, 10, 11, 12]. Despite these benefits, pyrolysis oils are not widely used as transport bio fuel because of number of unsolved technical issues related to their physical and chemical properties: high viscosity, acidity and electrical conductivity, presence of water and various oxygenated compounds, ash and other solid impurities. While low in sulphur, these oils contain nitrogen, which results in increased emission of nitrogen oxides (NO_x) compared to NO_x emission from standard diesel fuel flames [13]. Aging of pyrolysis oils leads to further viscosity increase, a phase separation on fractions and later carbonisation. The presence of ash and other solid impurities can lead to filters or nozzles blocking and lubricity problems.

Biomethane is an important bio fuel, which is used in many areas around the World for power generation. Biohydrogen and biological hydrogen have the potential to become important bio fuels too, providing that technological issues related to the low efficiency of the production facilities are

solved. However, the potential of these fuels to be mass used as transport fuels in the near future is highly doubtful, mainly because of the gaseous state of the substances, which require storing the fuels in pressurised vessels and major retrofitting of the engines.

It should be noted that any estimate of the viability of a bio fuel reflects on the contemporary level of knowledge, and it could rapidly change if new evidence is found. For example, manufacturing of biological hydrogen in photobioreactors by algae is intensively studied, and although there are no evidences that this process is able to satisfy all of the listed factors now, it may happen in the future.

The Page Research Centre supports further scientific research that will lead to diversification of the number of commercially available bio fuels through governmentally funded research centres, universities and industrial enterprises. The application for government grants should be assessed in terms of satisfaction of several preliminary criteria that provide an estimate of the bio fuels viability:

- (i) energy sustainability along the life cycle of a bio fuel. It would be an apparent nonsense to spend more energy that comes from fossil fuels in upstream processing steps like agriculture, transportation, manufacturing and storage than it is produced during combustion of bio fuel. Hence, an energy sustainability criterion could be satisfied only if a unit mass of the bio fuel produces more energy when combusted than the energy coming from fossil fuels that is consumed in entire production track of the same amount of bio fuel;**
- (ii) reduction of greenhouse gases emissions and CO₂ neutrality along the entire production track and utilisation of a bio fuel. Satisfaction of this criterion is directly related to the expectations that using bio fuels would reduce greenhouse gas emissions to the atmosphere;**
- (iii) minimal negative environmental impact. There are number of factors that must be taken into account such as toxicity of the fuels and their bi-products, soil health, contamination of the atmosphere and waterways, and others;**
- (iv) potential for complex utilisation of the raw materials into a number of useful products (energy and material cost of manufacturing bio fuels could be substantially reduced if they are produced in bio refineries);**
- (v) technical viability of a bio fuel as a replacement of petroleum-derived fuels. The commercially available bio fuels are rarely used as clear substances in the existing internal combustion engines (ICE)². An ideal replacement of the petroleum-derived fuels would not require major investments in retrofitting the existing engine park if used as clear substances;**
- (vi) abundance of domestic resources. National energy security would not be improved if importing crude oil for energy needs is replaced by importing raw materials for bio fuel**

² In most cases, bio fuels come to the market in form of blends with standard petroleum-derived fuels, e.g. gasohol, which in Australia contains 10% ethanol and 90% gasoline (E10 blend) or 5% blend of biodiesel with standard diesel fuel (B5). This adversely affects the potential benefits of manufacturing and utilising bio fuels.

production. At the same time, exporting bio fuels or feedstock could be beneficial for the national economy, providing that previously mentioned conditions are satisfied.

2.2 Energy sustainability along the life cycle of the bio fuels

All literature sources indicate the superiority of producing ethanol from sugar crops in tropical countries compared with ethanol production from starch containing feedstock. The International Energy Agency states that the fossil energy input could be as low as 10-12% if all of these conditions are satisfied [3]. An example of a country that could possibly achieve this low level of fossil energy input is Brazil. We were not able to find reliable data on the fossil fuel input requirements in Australia. It can be assumed that they follow a general trend mentioned in [1] that production of sugar cane bioethanol is much more energy efficient than the sugar beet bioethanol, which requires about 50% fossil energy input, after [1]. In turns, sugar beet bioethanol is more efficient than the starch based bioethanol production. The most optimistic scenario for the latest is 60-80% required fossil fuel input [1, 3]. In fact, there are studies [14, 15, 16, 17, 18] questioning the energy sustainability of the corn ethanol at all. The general consensus though is that the energy balance of the starch based bioethanol is slightly positive [1, 3]. Bioethanol from molasses require up to 91% fossil fuels input [1]. At present, the total fossil energy input needed for the production process of ligno-cellulosic bioethanol may be even higher as compared to bioethanol from corn [3], however this energy might be replaced by energy that comes from the combustion of the biomass (which, at the other end, will reduce the feedstock base).

The energy input for biodiesel production also depends on the feedstock and the process. Different approaches in the estimate of the life cycle impact for biodiesel result in different estimates. Typically, the fossil fuel inputs for biodiesel manufactured from vegetable oils are between 30 and 40% [3].

The emissions levels of greenhouse gases from biofuel production are sensitive to process and feedstock, to fossil energy input and to local conditions. Estimates on the potential of the bioethanol and biodiesel to reduce greenhouse gases emissions are mostly favourable. If bagasse is used to provide the heat and power for the process, and bioethanol and biodiesel are used for crop production and transport, the emissions can be as low 0.2-0.3 kgCO₂/litre bioethanol compared with 2.8 kgCO₂/litre for conventional gasoline (90% reduction) [3]. Bioethanol from sugar beet provides 50-60% emission reduction compared with gasoline, while the emissions reduction of bioethanol production from cereals and corn may be as low as 15%-25% compared with gasoline [3]. In accordance with the same literature source, net CO₂ emissions reduction from ligno-cellulosic bioethanol can be close to 70% versus gasoline, and could even approach 100% if electricity co-generation displaces natural gas or coal-fired electricity. The estimates are also favourable for the biodiesel, with typical values of CO₂ emission reductions of 40-60% versus diesel [3, 19].

The benefits of bioethanol are not fully realised when they are used in blends with gasoline. A CSIRO study [20] shows that the greenhouse gas emissions of the E10 blend is only marginally lower than that of the gasoline: from -5.1% for E10 from C-molasses using co-generation, to -1.7% for E10 from wheat. The same study shows the following greenhouse gas emissions for biodiesel as compared to diesel:

- waste vegetable oil ranges from 89.5% lower for B100 to 4.2% lower for B5;
- tallow ranges from 29% less for B100 to 1.5% less for B5;

- canola ranges from 15 % less for B100 to 1.5 % less for B5.

An analysis [1] based on 47 independent Life Cycle Impact assessments on bioethanol production show that impacts on acidification, human and ecological toxicity, occurring mainly during the growing and processing of biomass, are more often unfavourable than favourable. The transport of large amount of biomass required for bioethanol production is a logistics barrier that limits the size of the production plants and put extra pressure on the transport infrastructure.

There are sustainability issues rising with the increased production of bio fuels such as conflicts with conservation of biodiversity and increasing amounts of required water, pesticides and fertilisers. In scenarios having 25% of transport fuels derived from biomass, the use of fertilisers increases by about 40% [3]. Therefore, increased usage of nitrogenous fertilisers for bio fuel production could offset the benefits of reduced NO_x emissions.

The aforementioned CSIRO study [20] shows that all criteria air pollutants except oxides of nitrogen (NO_x) are significantly reduced when replacing low sulphur diesel with biodiesel. Particulate matter emissions are significantly lower for pure biodiesel (B100) from tallow, canola and waste oil than for diesel and these benefits are greatest for pure biodiesel, and lowest in B5 blends where the benefits are swamped by the diesel. The same study states that the benefits of bioethanol are less clear: there may be benefits from reductions in particulate emissions from the tailpipe, however there are increased evaporative emissions of aldehydes and other smog-forming volatile organic compounds. In addition, N₂O and NO_x emissions could be higher [21].

Based on this assessment, The Page Research Centre encourages further expansion of the production of bioethanol from sugar cane, providing that:

- (i) the crop grows in agricultural areas that can ensure high yield of the crop per hectare;**
- (ii) the sugar is easy to extract;**
- (iii) expanding of sugar cane plantations does not cause environmental damage, soil deterioration and water shortage;**
- (iv) bagasse is used to provide heat and power for the process; and,**
- (v) bioethanol and biodiesel are used for crop production and transport.**

The Page Research Centre recommends extreme caution in estimating the viability of proposals for expanding production of starch-derived bioethanol, since the positive margin seems to be very volatile.

The Page Research Centre supports biodiesel production in small scale, decentralised privately or community owned bio refineries that are built in the locality of the crop growing plantations. This is the only way of minimising the energy cost of transportation of bulk amount of feedstock to the bio refineries. The following preconditions apply:

- (i) crops must grow in agricultural areas that can ensure high yield of the crop per hectare;**
- (ii) expanding of the plantations should not cause environmental damage, soil deterioration and water shortage; and,**
- (iii) bioethanol and biodiesel are used for crop production and transport.**

2.3 Fuel quality standards and consumer education

Bio fuels have unique physical and chemical properties, which differs from the properties of standard petroleum-derived fuels. Very often the quality of the bio fuels depends on the quality of the feedstock and the manufacturing method used. The fundamental differences between the bio fuels and the petroleum-derived fuels must be properly addressed in the bio fuel quality standards and safety regulations.

Bioethanol drawbacks include miscibility with water and compatibility issues with some plastics and metals, including aluminium alloys, brass, zinc and lead. High latent vapourisation heat of the ethanol lead to cold start issues. For these reasons bioethanol is used only in form of blends with gasoline. The gasoline strongly dominates in these blends (85-90%), which substantially diminish the positive effects of bioethanol usage. Bioethanol use in diesel engines needs additives due to the low cetane number and is impractical [4].

Biodiesel is a partially oxygenated substance, which means that it has the lower relative energy density than the standard diesel fuel (90-92%). Biodiesel has less than 0.05% vol water at the moment of manufacturing; however, it may contain hydrophilic components that are able to absorb moisture from the atmosphere. The presence of water in the biodiesel adversely affects the exploitation time and the overall performance of the diesel engines, causing corrosion, phase separation of the fuel blends and freezing at sub-zero temperatures. The water in the fuel also provides media for bacterial and algal grow, which besides being a health risk, can also lead to sedimentation of sludge and blockage of the fuel delivery system of the diesel engines [8]. Biodiesel is a good rubber solvent, and forming of wax crystals at low temperatures could also be an issue.

The Page Research Centre supports Consumer Education Campaigns that aim providing objective information to the final users of bio fuels. The final users should be made aware of the potential benefits and risks of bio fuel usage. Manufacturers should be encouraged to develop new models of engines that are capable of flexible utilisation of various blends of bio fuels with petroleum-derived fuels, tolerating 0÷100% pure bio fuels in the blends. Development of unified bio fuel standards is an absolute necessity for the successful communication and integration of the efforts of the bio fuel manufacturers, transporting and storage companies and the motor building industry.

2.4 Economic viability of the bio fuels

None of the bio fuels is presently able to compete with the price of petroleum-derived fuels [22]. A bio-char refinery can provide one of the very few, cost effective schemes for liquid fuel production from biomass.

A bio refinery is an industrial enterprise that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals. Similarly to the oil refineries that convert petroleum and natural gas into numerous products, a bio refinery can benefit from the diversity of the products of biomass conversion [6]. A bio-refinery can, for example, produce one or several low-volume, but high-value, chemical products and a low-value, but high-volume liquid transportation fuel, while generating electricity and process heat for its own use and for sale. The products of the bio-refinery can provide significant volumes of substitutes for petroleum-derived fuels and chemicals, reducing in part the huge volumes of petroleum and other fossil fuels currently

in use. Production of bioethanol and biodiesel can be incorporated in two of the existing bio refinery proposals:

- (i) **Sugar-lignin bio refinery**, in which cellulose and hemicellulose are broken down to sugars for fermentation. In addition to the alcohol, the sugars or the intermediate breakdown products can be processed into a number of products. Lignin, which is the third main component of plant biomass, can be used as fuel or to produce variety of chemicals [6]. Although not included in the sugar-lignin bio refinery concept as it was defined by [6], it must be stated that the production of bioethanol from sugarcane, sugar beet and starch also shows the features of bio refinery manufacturing. There is an almost full utilisation of the raw materials into useful products: fuel, animal food and chemicals;
- (ii) **Carbon-rich chains (biodiesel) bio refinery**, in which plant oils and animal fats with long hydrocarbon chains undergo trans-esterification with methanol or ethanol to produce biodiesel. The main co-products are glycerine and fatty acids, which can be used to make a wide assortment of products, including explosives and detergents [6].

The Page Research Centre believes that reduction of the production cost of the bio fuel is the only way of making them competitive on the market. Any forced introduction of the bio fuels on the market via:

- (i) **increased excises on petroleum derived fuels; or,**
- (ii) **subsidising of the bio fuel production on regular base,**

would result in higher inflation burden to the national economy.

2.5 Prognosis on the security of supply, the trade pattern and the future development of a domestic industry

Bioethanol and biodiesel supply is constrained by the availability of water and arable land and compete with food production for water and land use. CSIRO prognosis for bioethanol production [20] is that:

“Conversion of export fractions of wheat and coarse grains could theoretically have supplied upper limits of 11–22 % of Australia’s current petrol usage (taking lower energy value of ethanol into account)”.

However, the same study indicates that:

“If all of the ethanol capacity that is currently proposed was to be fulfilled by existing crops (principally wheat and sugar), or if a national E10 target were to be met (eg. by 5.5 Mt of wheat as the feedstock), it could force the import of wheat in drought years. There are biosecurity issues restricting the import of grain from overseas markets”.

The estimate on biodiesel production [20] is that conversion of domestic waste oil, tallow exports and oilseed exports could have theoretically provided upper limits of 4-8%.

At the current level of technological development, any significant expansion of the amount of bio fuels manufactured in Australia may come with the cost of liquidation of the strategic

advance that Australia has on the world food market. The Page Research Centre believes that this is a risk that should not be taken. Politically motivated decisions should not be put ahead of realistic estimates of the bio fuels viability. The production of bio fuels like sugar cane bioethanol and biodiesel has some potential to grow, but this potential is severely restricted by natural and technological factors. Manufacturing bio fuels from non food feedstock is one of the ways to go and The Page Research Centre supports further investigations in this direction.

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