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NATIONAL CENTRE FOR ENGINEERING IN AGRICULTURE

The Feasibility and Development of Alternative Energy Sources for Cotton

NEC1201 Final Report

"How to save energy, save money and reduce your carbon footprint."

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Published in September 2014 by the National Centre for Engineering in Agriculture, Toowoomba. Material from this publication may not be used unless prior written approval has been obtained from the National Centre for Engineering in Agriculture and the CRDC.

This document should be cited as follows:

Sandell G.R., Hopf J., Chen G., Yusaf T., (2014). 'The Feasibility and Development of Alternative Energy Sources for Cotton.' National Centre for Engineering in Agriculture, Publication 1004527/1, USQ, Toowoomba.

Australian Government
Cotton Research and Development Corporation

FINAL REPORT 2014

Part 1 - Summary Details

Please use your TAB key to complete Parts 1 & 2.

CRDC Project Number: **NEC1201**

Project Title: The Feasibility and Development of Alternative Energy Sources for Cotton

Project Commencement Date: 1/07/2011 **Project Completion Date:** 30/06/2014

CRDC Program: 4. Farming Systems

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Preface

This report, commissioned by the Cotton Research and Development Corporation, is the outcome of an exploratory research designed to shed light on possible solutions or new ideas in the alternative energy space as applied to the Australian cotton industry.

The report splits the discussion of energy and alternative energy into three main types of energy sources: liquid, electrical and solid sources for the following reason. Simply, they are different forms of energy. They have different performance characteristics, are taxed differently and have different applicability. Therefore it is sensible to discuss the various sources in these groups. For example, all cotton farms have a heavy reliance on liquid fuels for transport and field work. Most cotton farms also use liquid fuels for pumping. Accordingly significant investigation made into liquid fuels, such as biofuels and biofuel blends. Electrical energy, while important in cotton production has different applicability and completely different tariff structures. Finally, solid fuels offer potential, are generally less well developed as an energy source for cotton production and have different constraints relative to other fuels.

Acknowledgements

The National Centre for Engineering in Agriculture (NCEA) would like to acknowledge the support of the Cotton Research and Development Corporation in funding this project. The NCEA recognises the significant contribution made by Australian cotton growers in paying levies and the Federal Government in matching these levies, which in turn, fund research to better the industry.

In addition to the researchers who authored this work, the NCEA would like to acknowledge the work of the following people: Kim and Andrew Bremner, Dalby, for their generous support in conducting field testing. Dr Ihsan Hamawand, Dr Bernadette McCabe and Dr Les Bowtell for their contribution to the discussion on cotton gin trash utilisation. Students Soma Rasul and Adnan Khalid for their contribution to the PTO and field testing carried out at USQ. Dr Paul Baker and Dr Sadam Al-Iwayzy for their contribution to the testing and performance of fuels. Dr Joseph Foley and Mr Phillip Szabo for their advice on water pumping.

Executive Summary

This report, commissioned by the Cotton Research and Development Corporation, is exploratory research designed to shed light on possible solutions or new ideas in the alternative energy space as applied to the Australian cotton industry.

The broad aim of this project is to develop farmer-friendly resources to assist the Australian cotton industry evaluate alternate energy sources that can be integrated into normal farming operations to save energy, save money and reduce cotton's carbon footprint.

Principal findings

- A survey of 165 growers show that price, availability and ease of use are the most import decision factors when choosing an alternative energy source. Environmental concerns are of important, but to a lesser degree (figure 120, pp. 85).
- Diesel, LPG injection (for electronic engines) and electricity are similar in cost when expressed per GJ of energy output at the flywheel. Of these, LPG injection has the lowest emissions, followed by diesel. Electricity has the highest emissions of any energy source. Each of these options could be viable given different values for engine efficiency, electrical tariff and so on. Growers will need to evaluate their own specific circumstances in light of these results.
- Conversely, B100 biofuels (100% biofuel) have negligible contribution to global warming, however their costs are much higher than traditional alternatives. Straight biofuels are hampered by the fact that there is no fuel rebate available.
- B20 blends from waste feedstock, such as tallow, are close to being economic because fuel blends up to 20% still attract the full fuel rebate. These blends may be economical at different times depending on the relative pricing of B20 and diesel. Growers need to be aware that due to differences in calorific value and viscosity, biofuels have a slightly lower combustion efficiency than diesel. These fuels would need to be around 2% cheaper than diesel for price parity.
- It is recommended that options for utilising the significant cotton gin trash (CGT) biomass resource be investigated and quantified. While there are several options to utilise this resource to generate electrical and/or thermal energy, such as those listed in section 6.3, there is little evidence as to the relative merit of each system. In particular, major parameters such as CGT production, CGT calorific value, process efficiencies and capital and operating costs need to be identified for each system. A brief scoping review into the viability of collecting in-field plant residue should be conducted in conjunction with such an investigation. Utilisation of cotton biomass presents a large potential energy source that is essentially carbon neutral.
- Coal Seam Gas (CSG) had the highest level of resistance to adoption. There is no current use and only 2% of respondents plan to use CSG. It was rated as 'Not an option' by 57% of respondents to this question with a further 4% selecting *Potential but would not use it*. This is consistent with the environmental concerns over CSG.
- Solar PV is an option to offset workshop and domestic electricity and is less feasible for pumping water.
- The reliability of wind in cotton growing areas is too low, and the generation costs too high, for wind power to be viable.
- Similarly, the reliability of water makes the economics of hydroelectric energy generation less attractive.

The specific objectives of this work include:

- Review commercially available alternative (renewable) energy and fuel options.
- Assess the feasibility of commercially available alternative (renewable) energy and fuel options.
- Examine performance / characteristics of non-commercial alternative fuel sources and mixtures.
- Reduce operating costs and emissions of non-commercial alternative fuel sources and mixtures.
- Inform the cotton industry on opportunities, costs and greenhouse gas implications of alternative (renewable) energy and fuels.

Background

Energy use and efficiency has become increasing important globally due to the increasing cost and scarcity of energy sources (particularly crude oil) and the associated production of greenhouse gasses causing global warming. The rising costs of energy and associated energy-intensive products such as fertilizers and chemicals are now one of the major challenges facing modern mechanised agriculture. This problem is particularly acute in Australian cotton farming systems which are often expansive and require high inputs of all of these commodities.

Continuously increasing energy prices and the needs for significant reductions in greenhouse gas emissions make the improvement of farming energy efficiency essential. Exploration of new alternative and renewable energy sources is also vital.

Energy Costs

The rising cost of energy is driven by two main factors: decreasing supply and increasing demand.

Individual oil fields universally see a production peak followed by persistent decline. This phenomena is known as 'peak oil'. Analysis of the BP Statistical Review of World Energy, 63rd Edn., June 2014 shows that, when weighted by production, 61% of the world's oil fields have passed peak production. This report also states that 'Global oil consumption grew by 1.4 million barrels per day (b/d), or 1.4% [per annum]' and 'global oil production did not keep pace with the growth in global consumption, rising by just 560,000 b/d or 0.6% [per annum]'. This has seen more expensive oil sources like tight oil (fracking), deep-water oil, and oil sands come into use.

Demand is being driven by a growing world population and also improved living standard in many counties such as China. The United Nations, Department of Economic and Social Affairs, Population Division (2014) notes that "the current world population of 7.2 billion is projected to increase by 1 billion over the next 12 years and reach 9.6 billion by 2050".

Climate change

The National Research Council (2010) states that "Climate change is a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. It may be a change in average weather conditions, or in the distribution of weather around the average conditions (i.e., more or fewer extreme weather events)." This work also states that "(p1) ... there is a strong, credible body of evidence, based on multiple lines of research, documenting that climate is changing and that these changes are in large part caused by human activities.

Note that figure and table numbers used in this section correspond with the same figure and table numbers used in the body of this report.

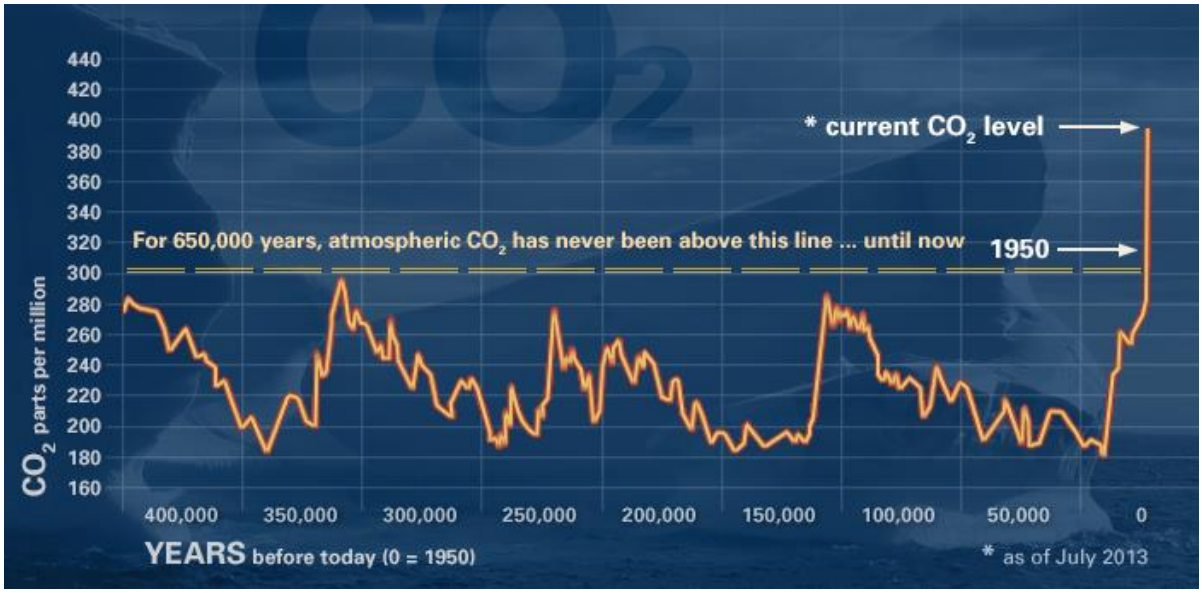


Figure 5. NASA's Jet Propulsion Laboratory, Earth Science Communications Team. Evidence of CO2.

Figure 5 shows that atmospheric carbon dioxide have remained increased dramatic since the industrial revolution. The rise in CO2 concentrations in the atmosphere correlates with temperature rises as seen in figure 6.

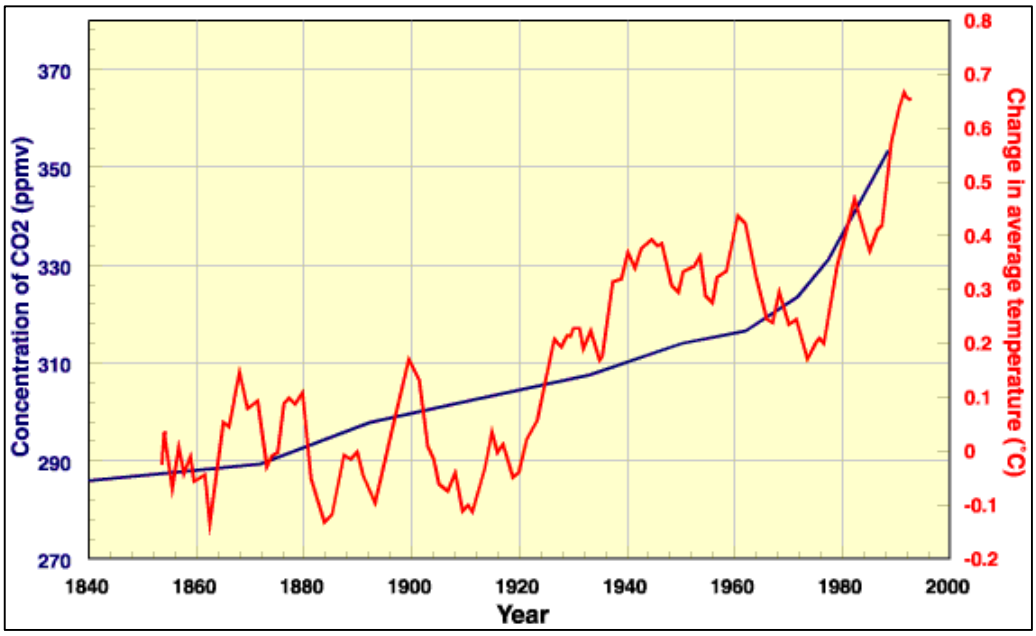


Figure 6. Correlation of the rise in atmospheric carbon dioxide concentration (blue line) with the rise in average global temperature (Honsberg and Bowden, 2014).

Le Quéré et al. (2012) state that coal burning was responsible for 43% of the total emissions, oil 34%, gas 18%, cement 4.9% and gas flaring 0.7%.

Global warming projections incorporate economic, sociological and atmospheric assumptions. There will always be uncertainty when modelling something as complex as the world's climate. Results from these models will vary based on the assumptions and complexity of the model. However, all significant models confirm that surface temperature will rise between 2 ^{o}C and 5 ^{o}C by 2100 with good match between the various models. It is widely believed that to avoid the most radical impacts of climate change, average temperature should not be allowed to rise to any higher than 2°C above pre-industrial levels.

Climate change and cotton production

Climate change and agriculture are interrelated processes that occur on a global scale. Agriculture affects climate change through the release of greenhouse gasses primarily created through the manufacture and infield volatilisation of fertilizers and chemicals and through the combustion of fossil fuels. Subsequent global warming affect plant growth and yield and access to resources such as water and energy. For more details refer to section *1.4 Global Warming and cotton production* on page 11.

Consumer awareness

Consumers are increasingly aware of global warming and use their purchasing power to source sustainably produced goods and services. Big brands are making public comments on their long-term intent to support responsible cotton. Any possible reductions in emissions ensures that Australian cotton will remain in this preferred 'responsible production' market.

Energy use in cotton production

Chen et al. (2013) show that energy directly consumed on-farm contributes around only 10% to 15% of total cotton life cycle energy consumption from field to processed fibre (lint). However, this sector is important for the following reasons:

- To control production costs.
- To better understanding energy use and thus where to target savings.
- For environmental sustainability and responsibility.
- To promote Australia's 'clean and green' image.

Sandell et al. (2013) note that Australian irrigated cotton production consumes 10.9 GJ/Ha (1.2 GJ/bale) and 88% of this energy is supplied by diesel with the remaining 12% largely supplied by electricity.

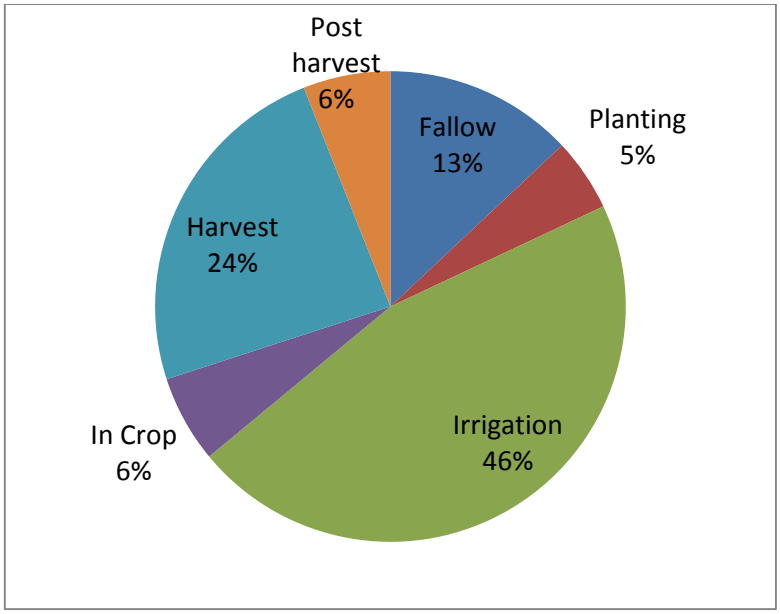


Figure 14. Average distribution of on-farm direct energy consumption for irrigated cotton. Sandell et al. (2013).

Classification of energy sources

Energy can be broadly defined as the capacity to do work. Energy sources can be broadly classified as renewable and non-renewable, as set out in table 1, below.

Table 1. Classification of energy sources.

Non-renewable (Limited)	Renewable (Unlimited)	Biological Renewables (can be reproduced)
Oil	Solar	Wood
Coal	Wind	Energy crops
Natural gas	Hydropower	Biomass fermentation (ethanol)
Liquefied petroleum gas (LPG)	Tidal and wave energy	Bio-diesel
CSG (LNG, CNG)	Geothermal	Biogas (Anaerobic digestion)
Nuclear power (Uranium)		Animal and human power

Global warming potential of various energy sources

Different energy sources have different calorific values[1] and a different Global Warming Potential[2] (GWP). The Australian Government Department of the Environment provide *The National Greenhouse and Energy Reporting (Measurement) Technical Guidelines* (NGER Technical Guidelines).

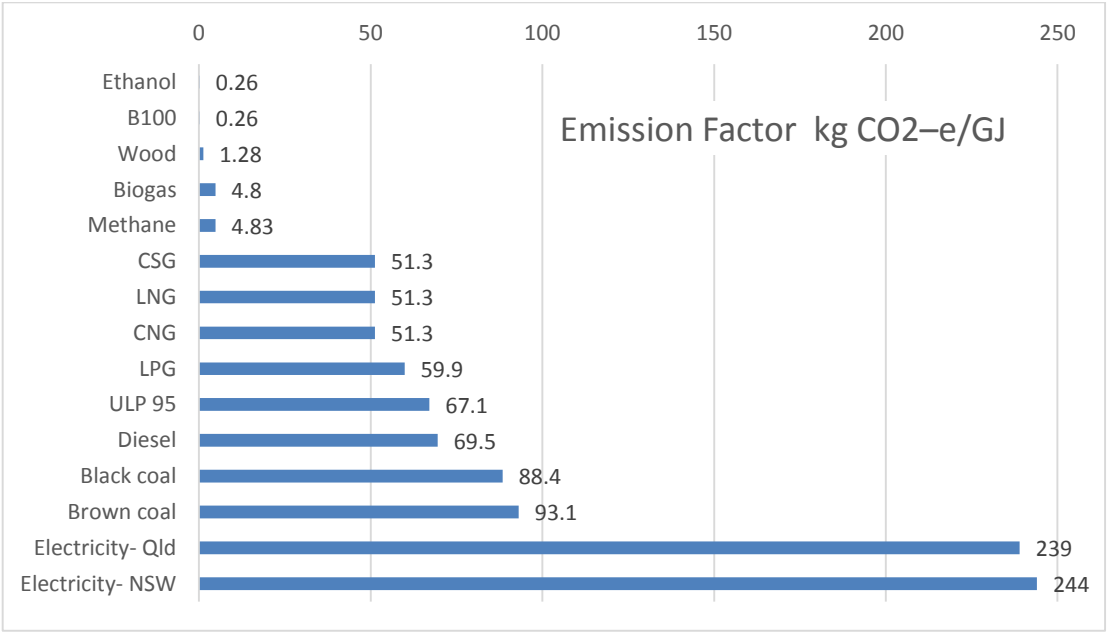
[1] Calorific Value refers to the amount of the heat that can be released during the combustion process of the fuel. Also referred to as the heating content, heating value (HV), or heat of combustion.

[2] Some atmospheric gasses will retain more heat in the atmosphere than others. GWP is a measure of how much heat a particular gas will trap in the atmosphere. It is relative to the GWP of carbon-dioxide. For example, one kilogram of methane traps 310 times more heat than one kilogram of carbon-dioxide. Thus, methane has a GWP of 310.

The NGER Technical Guidelines provide the caloric value and GWP for various fuel sources. The calorific values are presented for energy sources relevant to the cotton industry in the following table. Because GWP has a common unit – $kgCO_2e$[3], these values are presented graphically below.

Table 2. Department of Climate Change and Energy Efficiency (2013) emission factors.

Fuel Type	Energy Content		Fuel Type	Energy Content	
Ethanol	23.4	GJ/m^3	LPG	25.7	GJ/m^3
B100	34.6	GJ/m^3	ULP 95	34.2	GJ/m^3
Wood	16.2	GJ/t	Diesel	38.6	GJ/m^3
Biogas	0.0377	GJ/m^3	Black coal	27.0	GJ/t
Methane	0.0377	GJ/m^3	Brown coal	10.2	GJ/t
CSG	0.0377	GJ/m^3	Electricity- Qld	3.6	GJ/kWhr
LNG	25.3	GJ/m^3	Electricity- NSW	3.6	GJ/kWhr
CNG	0.0393	GJ/m^3			



Graphical representation from Table 2. Department of Climate Change and Energy Efficiency (2013) emission factors.

Liquid fuels

Liquid fuels are important globally because of the need for a portable energy source for transport. This is particularly an issue in agriculture, which relies on mobile plant and the transport of inputs and final product. Most liquid fuels in widespread use are derived from fossil fuels, such as diesel, petrol and LPG. There are several types of renewable liquid fuels, such as ethanol, biodiesel and biogas. Currently, fossil fuels are generally cheaper than biofuels. However, as noted in section 1.3, they cause significant environmental damage.

[3] Equivalent kilograms of carbon-dioxide.

Because of the heavy reliance of the cotton industry on diesel (Sandell et al., 2013, figure 12) it is important to closely examine the performance characteristics of commercial and non-commercial alternative diesel sources and mixtures.

Because of sometimes conflicting research concerning biofuel emission and performance results and variations in biofuel properties a controlled testing program was conducted at the fuel laboratory at the University of Southern Queensland. This laboratory provides the high precision equipment to measure the performance and emission characteristics of liquid fuels. Performance and emissions were analysed simultaneously in each test. The fuel testing included diesel, cotton seed biodiesel, tallow biodiesel, low purity ethanol, algae biodiesel and LPG in combination with diesel and biodiesel. These fuels were selected because of their potential in the cotton industry and their selection was informed by an industry survey (section 7). A summary of fuel testing is presented in section 3.3, page 27 and complete results are presented in Appendix A. Performance characteristics of liquid fuels.

An industry survey into grower perceptions of alternative energy sources (section 7.4) shows that price, availability and ease of use are the most import decision factors when choosing an alternative energy source. Environmental concerns are also of importance.

An economic analysis was conducted (*6.1 Economic and environmental feasibility of alternative liquid fuels*, page 56) using fuel testing results and other information to ascertain the economic viability of various fuels.

Different energy sources have different energy densities and different efficiencies when converted to mechanical energy, which is required by the cotton industry. Figure 41 shows that diesel, LPG/diesel (when used in an electronically injected engine), LPG/biodiesel and electricity are similar in cost when expressed per GJ of energy mechanical output at the drive shaft of the engine. Of these, LPG/biodiesel has the lowest emissions and electricity has the highest emissions.

These analyses use broad assumptions, each of these options could be viable given different values for engine efficiency and so on. Growers will need to evaluate their own specific circumstances in light of these results.

Conversely, B100 biofuels (100% biofuel) have negligible contribution to global warming, however their costs are much higher than traditional alternatives. Straight biofuels are hampered by the fact that there is no fuel rebate available because there was, effectively, no rebate paid on the fuel. Cotton seed oil is the most expensive energy option due to the low extraction rate of the oil. However, it is possible for the industry to be self-sufficient with cotton seed oil. Canola, which has a higher extraction rate is the next cheapest option. Australian canola production would generally meet the energy demands for cotton, however this would require most of the canola crop. B100 tallow is closer to being economic due to the low cost of the feedstock. Obviously, such high demands on any of these feed stocks would increase the cost of the feed stock and therefore the cost of the fuel.

B20 blends, especially tallow, are close to being economic because fuel blends B5 and B20 still attract the full fuel rebate. These blends may be economical at different times depending on the relative pricing of B20 and diesel. Growers need to be aware that due to differences in calorific

value and viscosity, biofuels have a slightly lower combustion efficiency than diesel. Results from the B20 tallow biofuel tests show that this has a combustion efficiency around 2% lower than that of diesel. Thus this fuel would need to be 1.8% cheaper than diesel for price parity.

A sensitivity analysis of the key variable was conducted by keeping all variables constant other than the variable in question. All variables linearly increase the cost of energy at the flywheel except for increases in engine combustion efficiency and increases in pump efficiency.

Improving engine efficiency reduces the cost of energy at the flywheel significantly. This can be achieved by changing to electronically injected, turbo charged engines.

Improvements in pump efficiency will similarly achieve the same results by reducing the total energy required.

Similarly, improvements in water application efficiency will result in less water being pumped for the same result. Imporvements in water application efficiency will result in a larger crop area availe for a given quantity of water.

Energy benchmarking is a useful tool for growers as it allows individuals to identify high cost areas and to compare their operation with industry benchmarks.

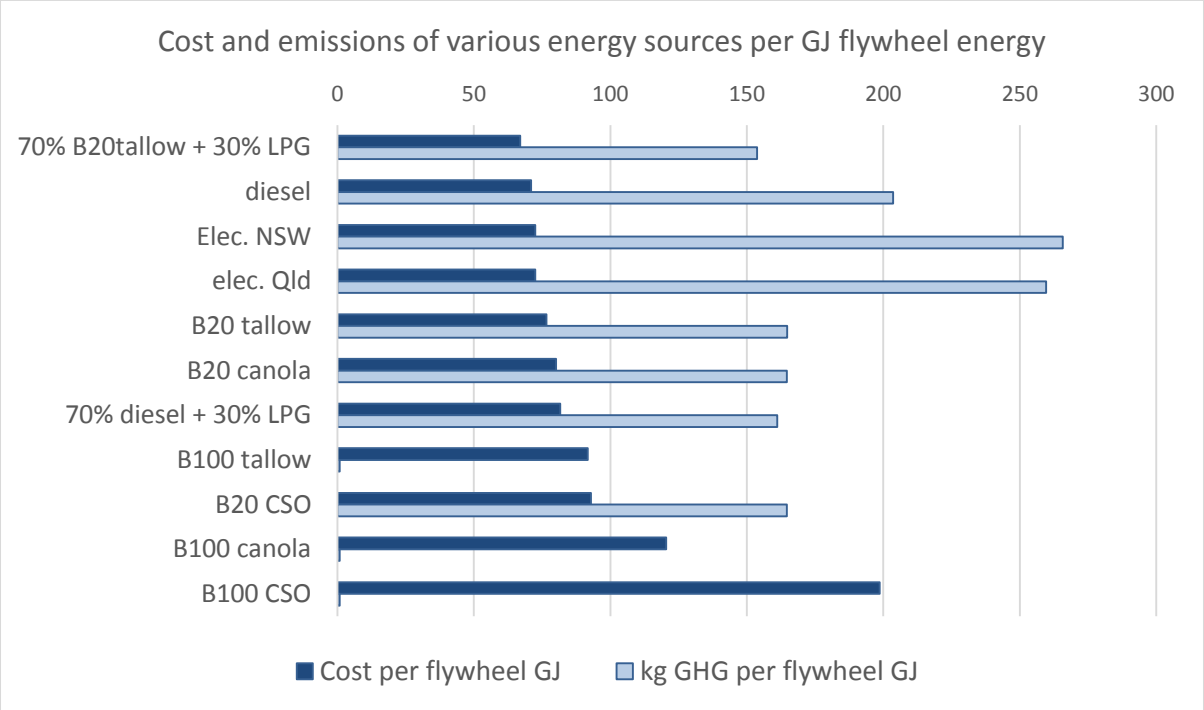


Figure 41. Cost and emissions of various fuels per GJ of flywheel energy.

Electrical energy

Tariff and policy issues

Historically the Australian Government has strong electrical energy policies including the Mandatory Renewable Energy Target (MRET) and Feed-in-tariffs (FiT). The Mandatory Renewable Energy Target (MRET) which was introduced in 2001 aims to ensure that renewable energy obtains a 20% share of

total electricity supply in Australia by 2020. Feed-in-tariffs (FiT) are rebates paid to those who generate renewable energy and feed it inot the grid. There are large and small scale FiTs.

Overall, solar energy is:

- Very competitive for remote, rural locations where connection to the grid is difficult or expensive
- With the new technologies currently under development, prices will further reduce in the near future.

However, all current renewable electrical energy rebates are currently under review and may be changed or removed.

As with other energy sources, the long term trend of electricity prices is up.

Reducing the cost of electrical energy

On average, electrical energy is a lesser cost of cotton production. However, some growers use electrically driven pumps and for these growers electricity is a much more significant cost. Importantly, there is large variations in the unit cost of electricity between individual consumers. Therefore, individual cotton growers should investigate their current electricity tariff and how other tariffs would work in their situation.

There are some efficiency measures specific to electric motors. In particular, Variable Speed Drives (VSD) will reduce total energy demand where the load on the motor changes, such as when a river of tail water level varies between upper and lower limits. Soft start switching reduces the peak demand that a motor requires on start up. Often, electricity retailers will invoice an additional charge based on peak current draw over a billing cycle. Soft start switching systems reduce this peak load and associated charge. It is recommended that these strategies be part of an awareness campaign for the cotton industry.

As with other energy sources, the following is equally true for electrical energy used in pumping:

- Improving engine efficiency reduces the cost of energy at the flywheel significantly. This can be achieved by changing to electronically injected, turbo charged engines.
- Improvements in pump efficiency will similarly achieve the same results by reducing the total energy required.
- Similarly, improvements in water application efficiency will result in less water being pumped for the same result. Imporvements in water application efficiency will result in a larger crop area availe for a given quantity of water.

Energy benchmarking is a useful tool for growers as it allows individuals to identify high cost areas and to compare their operation with industry benchmarks.

An online renewable energy calculator (Chen et al, 2011) has been developed at the National Centre for Engineering in Agriculture (NCEA), University of Southern Queensland (USQ), to provide an indication of potential for solar or wind systems to replace purchased electricity and feed electricity into the grid. The calculator can select the appropriate size of solar or wind turbine system and provide a simple cost benefit analysis based on available information of expected energy demand, renewable energy to be generated, electricity costs and system capital and operating costs.

Solid fuels

It is recommended that options for utilising the significant cotton gin trash (CGT) biomass resource be further investigated and quantified. While there are several options to utilise this resource to generate electrical and/or thermal energy, such as those listed in section 6.2, there is little evidence as to the relative merit of each system. In particular, major parameters such as CGT production, CGT calorific value, process efficiencies and capital and operating costs would need to be identified for each system.

Annual industry production of Cotton Gin Trash (CGT), based on 330,000 hectares of production, is in the order of 230,000 to 330,000 tonnes of biomass. With a calorific value of around 15.5 GJ/t this is a total of 3.6 to 5.1 million GJ of energy. CGT is currently a waste stream accumulating in large disposal sites, which present environmental, fire and pest and disease issues for cotton ginners.

The cotton plant itself, which is left in the field after picking, represents a much larger source of biomass, adding another 25 to 27 million GJ of energy for the same production area of 330,000 Ha. However, added complexity and costs of collecting and processing in-field biomass exist.

Options for capitalising on the CGT resource to replace thermal demands at the cotton gin (currently supplied largely by LPG) or to generate electricity summarised in table 32, below. These are 'broad brush' estimates of gross income only and do not include capital or operating costs. These figures are based on 330,000 Ha of cotton and the total industry value of lint and seed are also presented in table 32 to provide scale.

Table 32. Summary of Cotton Gin Trash options based on 330,000 Ha of production.

	Gross revenue, $millions	Thousand tonnes CO2e avoided	Notes
any method to replace LPG	10	23	CGT resource oversupplies LPG need. Value is therefore limited to LPG cost.
ethanol	30	51	Questions as to economic viability of process.
Bio-digester to generate electricity	7	40	Low capital and low to moderate complexity
pyrolysis for electricity generation	28	160	moderate capital and moderate complexity
high pressure boiler for electricity generation	40	227	high capital and complexity
lint	1,280		
cotton seed	304		

Survey

A survey was designed to assess existing use of alternative energy options and to identify particular industry interests in alternative energy options and technologies. The survey was conducted in late winter 2013, focusing on the 2012-13 cotton crop.

165 survey responses were received which cover approximately 23% of the irrigated cotton area grown industry wide in 2012-13 and 27% of the dryland cotton area. The survey is therefore representative of the cotton industry. Responses were the same between region, age and farm size.

Cotton growers were generally receptive of the concept of alternative energies other than CSG (figure 59). An alternative energy is currently used by 35% of growers and a further 39% are planning to use some form of alternative energy. However, not all growers are convinced as there was also a significant level of resistance to alternative energies.

CSG had the highest level of resistance. There is no current use, 57% of farmers rate it as *not an option* and a further 4% state that it has *potential, but I would not use it* (figure 59). This is consistent with the environmental concerns over CSG.

Importantly, figure 64 shows that the survey identified that any alternative energy must be economically sound. It must also be available and easy to use. Environmental risks and benefits had some importance.

Solar energy has the highest level of adoption (17% currently using and 21% planning to). Most of these respondents felt that solar was useful to offset the cost of domestic and workshop electricity. Some growers were supportive of the idea of using solar energy for water pumping.

Biodiesel is currently used by 9% of growers (a further 5% are planning to and another 2% have used it in the past). There was some experience in using biodiesel and low levels of resistance.

Current use of ethanol and LPG is 5% and 4% of growers respectively. There was little interest in wind, biogas, micro-hydro or biomass.

Energy initiatives were common in the field sector with 96% of growers using auto-steer on most operations and 42% using traction control.

Irrigation energy is typically half to three-quarters of total on-farm direct energy consumption yet only 19% of growers have had a pump efficiency investigation in the last five years.

Most farmers did not benchmark energy use with 11% having a level one benchmark and 16% had a level two benchmark.

Table of Contents

1. Background

Agricultural producers are currently aware of increasing energy costs associated with diesel, electricity and other inputs requiring high levels of energy input, such as fertilizers and chemicals and in the production of machinery. Like most sectors of the global economy, the Australian agricultural sector is very dependent on fossil fuels, in various forms, to meet energy needs associated with production demands. These trends are shown below in figures 1 to 4, below.

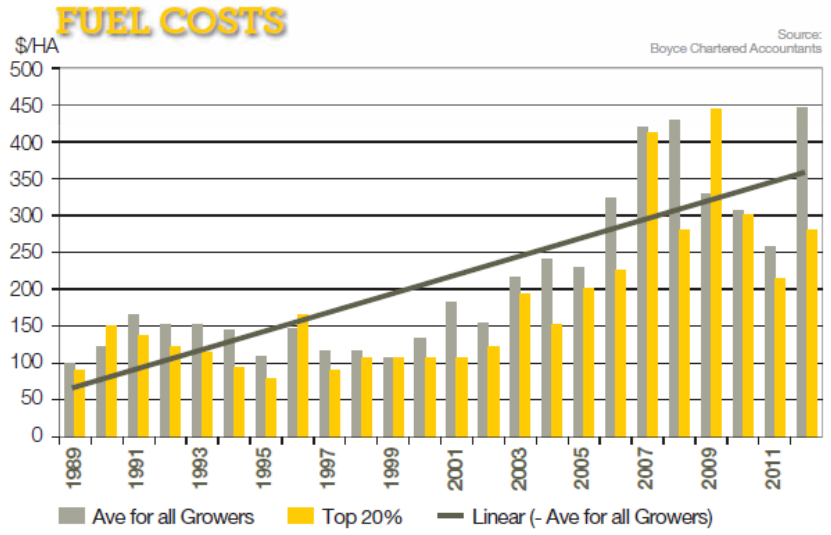


Figure 1. Fuel cost trends in cotton production, 1989 to 2012. Cotton Australia, (2014a).

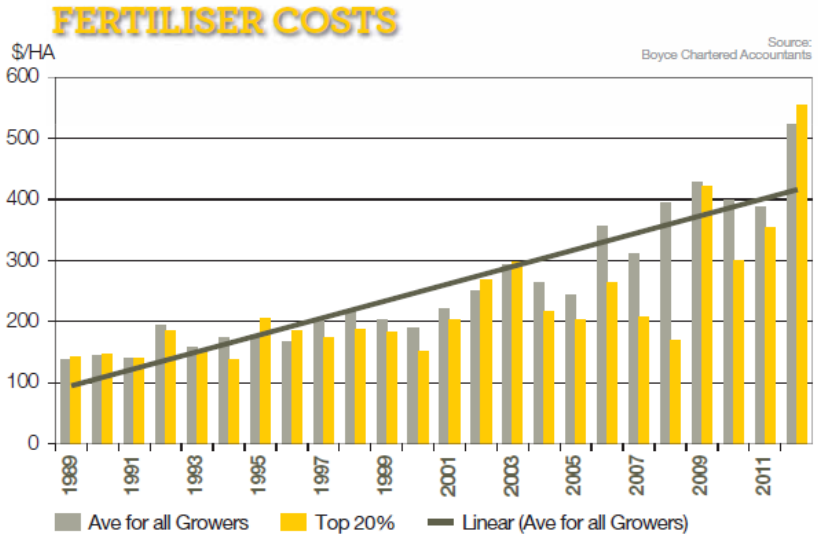


Figure 2. Fertilizer cost trends in cotton production, 1989 to 2012. Cotton Australia, (2014a).

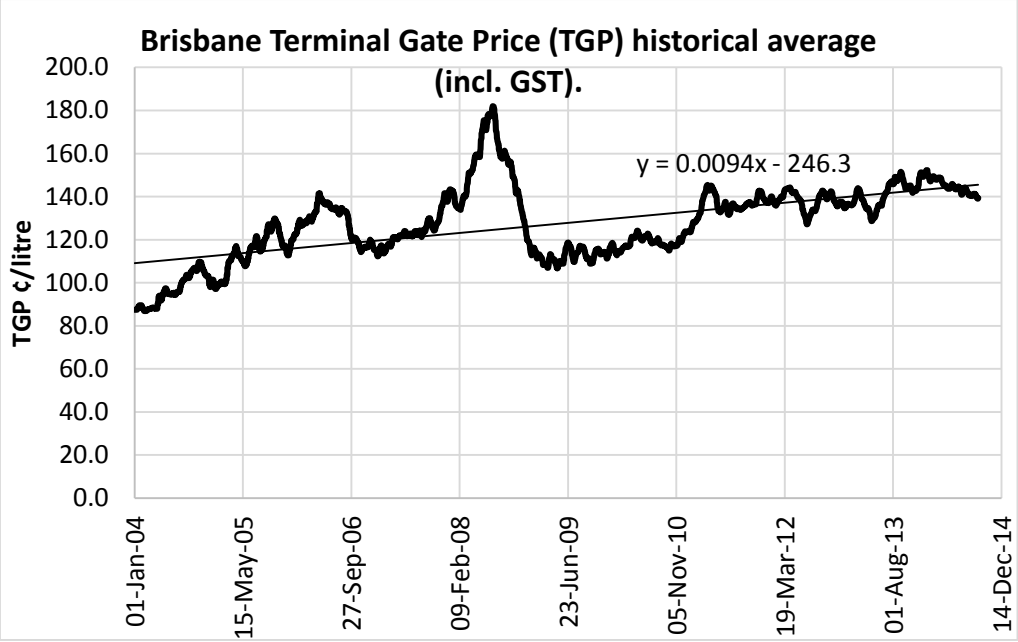


Figure 3. Brisbane Terminal Gate Price (TGP) historical average (incl. GST), Australian Institute of Petroleum, (2014).

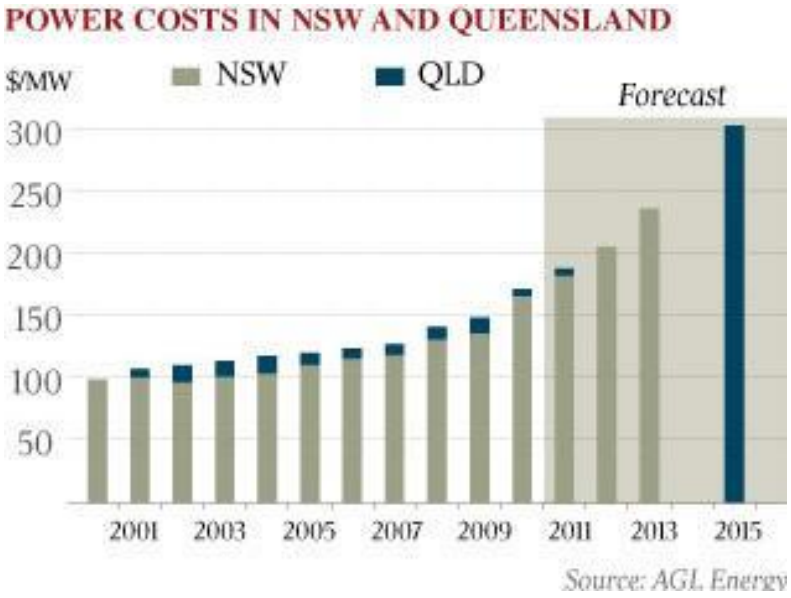


Figure 4. Recent power costs in Qld and NSW, Hepworth A., (2010).

However, the declining availability of fossil fuels and the prospect of higher energy prices in the future will limit our ability to achieve important food production growth and security targets. Miller & Sorrell (2013) predict that the world's oil supply peak will occur around 2020 to 2025. The United Nations, Department of Economic and Social Affairs, Population Division (2014) predicts that the global population will reach 9.6 billion by 2050, so the demand for food, fibre and energy will also increase significantly in this period while the availability of fossil fuel will decrease. It is therefore likely that this upward price trend will continue into the foreseeable future.

Another major problem with fossil fuels is their environmental impact. Not only does their excavation from the ground significantly alter the environment, but their combustion leads to a great deal of pollution. Widespread burning of fossil fuels (and other organic sources) has been particularly blamed for rise of CO2 concentration in the atmosphere, which causes atmospheric heat retention or "global warming."

Consumers are increasingly aware of global warming and use their purchasing power to source sustainably produced goods and services. Big brands, such as Levi Strauss, Walmart, Tommy Hilfiger and Adidas (Better Cotton Initiative, 2014) are making public comments on intent to support responsible cotton. IKEA by has publically stated that "the goal is that all cotton used for IKEA products shall be produced according to the Better Cotton Initiative's (BCI) social and environmental criteria by the end of 2015" (IKEA Group, 2014). While Australia has been proactive in this regard, it is important that this position is maintained. Cotton can have a persona of a 'dirty crop' and Australia can suffer from this (reasonable or unreasonable) perception by association, particularly as social media has dramatically changed the marketing landscape. The Australian cotton industry needs to be in a position to prove that it is actively being environmentally responsible. Any possible reductions in emissions ensures that Australian cotton will remain in this preferred 'responsible production' market.

The Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (2001) state that 'climate change and agriculture are interrelated processes, both of which take place on a global scale.' In the longer term, climate change is likely to affect agriculture in terms of: quality and quantity of productivity; water availability; availability of inputs such as herbicides, insecticides and fertilizers; land availability and other factors.

Identification of alternative energy and fuel options in the light of likely and significant increases to the cost of traditional energy sources will more favourably position the Australian cotton industry to respond to cost of production pressures.

1.1. Classification and quantification of energy sources

Energy can be broadly defined as the capacity to do work. Energy sources can be broadly classified as renewable and non-renewable, as set out in table 1, below.

Table 1. Classification of energy sources.

Non-renewable (Limited)	Renewable (Unlimited)	Biological Renewables (can be reproduced)
Oil	Solar	Wood
Coal	Wind	Energy crops
Natural gas	Hydropower	Biomass fermentation (ethanol)
Liquefied petroleum gas (LPG)	Tidal and wave energy	Bio-diesel
CSG (LNG, CNG)	Geothermal	Biogas (Anaerobic digestion)
Nuclear power (Uranium)		Animal and human power

The cotton industry uses energy and other resources throughout the production and supply chain. Chen et al (2010) show that this energy use can be differentiated as direct and indirect energy use. Direct energy relates to the energy used for undertaking a particular farming task, such as electricity used in pumping water or diesel used in a tractor. Indirect energy represents the energy embodied in the manufacture of farming inputs, such as fertilizer. This energy use can also be classified as on-farm and off-farm energy use, which provides a spatial demarcation of where this energy use occurs. Thus four categories are created:

- On-farm direct inputs (e.g. energy used in pumping, tillage and other field work).
- On-farm indirect inputs (e.g. manufacturing of fertilisers, chemicals and on-farm machinery).
- Off-farm direct inputs (e.g. ginning and transportation of goods).
- Off-farm indirect inputs (e.g. manufacturing of processing machinery and storage facilities).

The purpose of an energy source is to release energy for doing work. Because the release of fossil energy is accomplished primarily through the combustion process, the heating value of fuels is thus an important measure of energy content. Heating values are usually measured by burning the fuel in a bomb calorimeter.

The accepted unit of measurement for energy is the SI unit of energy, the joule. In addition to the joule, other units of energy include the kilowatt hour [kWh] and the British thermal unit [Btu]. For the purpose of conversion, one kWh is equivalent to 3.6 million joules [3.6 MJ], and one Btu is equivalent to about 1,055 joules.

- One joule is defined as the amount of work done by one Newton of force moving an object through a distance of one meter.
- 1 calorie is the energy needed to raise the temperature of 1 g of water by 1 degree Celsius.
- 1 calorie is equal to 4.184 joules.
- 1 round bread contains approximately 100 Calories or 100,000 calories of energy (1 Calorie = 1,000 calories, or 1 kcal. Note the difference in upper and lower case).
- 1 McChicken burger at McDonalds contains 417 Calories of energy and about 10 g of protein.
- Doing housework (eg, cleaning) uses about 200 Calories per hour (around 200 W).
- A MJ (megajoule) is a very small unit, because in the dollar terms, it will only be worth 2 to 6 cents. Thus, the unit gigajoule (GJ), equal to one billion joules is typically used. A GJ is worth $20 to $80, depending on the fuel type being used.

The embodied energy and greenhouse gas (GHG) emission factors for different energy sources are published by the Department of Climate Change and Energy Efficiency, (2013). These factors are summarised below in table 2. The greenhouse gas emissions from electricity also vary from state to state because different fuels are used for generation of electricity. Victoria has the highest emissions as most of its electricity comes from burning of brown coal, the most greenhouse-intensive energy type, while the electricity in the island state of Tasmania has close to nil emissions as it is mostly generated by hydroelectric power stations.

Table 2. Department of Climate Change and Energy Efficiency (2012) emission factors.

Fuel Type	Energy Content	Emission Factor kg CO_2–e/GJ
Ethanol	23.4 GJ/m^3	0.26
B100	34.6 GJ/m^3	0.26
Wood	16.2 GJ/t	1.28
Biogas	0.0377 GJ/m^3	4.8
CSG	0.0377 GJ/m^3	51.3
LNG	25.3 GJ/m^3	51.3
CNG	0.0393 GJ/m^3	51.3
LPG	25.7 GJ/m^3	59.9
ULP 95	34.2 GJ/m^3	67
Diesel	38.6 GJ/m^3	69.5
Black coal	27.0 GJ/t	88.4
Brown coal	10.2 GJ/t	93.1
Electricity- Qld	3.6 GJ/MWhr	239
Electricity- NSW	3.6 GJ/MWhr	244

1.2. Fossil Fuels

Fossil fuels are made from the remains of ancient plants and animals, buried deep inside the Earth where heat and pressure has turned these remains into the fossil fuels coal, oil and natural gas. Oil is refined into diesel, petrol, kerosene and various other grades of fuels, engine and transmission oils and fuel gasses. Coal and gas are usually burned to make the electricity. Fossil fuels are widely used because there is currently a good supply and they are relatively cheap to extract and refine. However, fossil fuels have considerable environmental impacts. They are also non-renewable, which means their supply is bcoming increasingly scarce and costly.

Australia's economic demonstrated resources as provided by the Bureau of Resources and Energy Economics (2012) are set out in table 3, below.

1.2.1. Peak Oil

It is well known that individual oil fields universally see a production peak followed by persistent decline. Geologically, oil is in a subterranean lake which is simply extracted at a high rate by drilling and inserting a pipe into the lake. Once this reserve is exhausted the oil exists as a viscous fluid in porous, permeable rock which resists rapid recovery. In an individual field peak oil usually occurs within a few decades of commencement of recovery.

Compounding this geological phenomena is that globally new oil fields are not being adding at a replacement rate. Because of these factors an aggregate decline in crude oil supply is expected.

Table 3. Australia's economic demonstrated resources, 31 December 2010.

Sources	Types	Energy available (PJ)	Share of World (%)	Resources Available for Production (years)
Coal	Black coal	1 255 470	10.3	128
	Lignite	3 846 895	8.6	517
Petroleum	Oil	5 685	0.2	9 +
	Condensate	12413	N/A	38
	LPG	4 063	N/A	38
Gas	Conventional gas	113 373	1.6	66
	Coal seam gas	35055	N/A	175
Uranium		648 480	33.0	134

Robert L. Hirsch (2005), an energy expert and US Department of Energy (USDOE) official made these five key points in his 2005 Report:

- World oil demand is forecast to grow by 50% by 2025 according to the USDOE.
- Some experts are warning that world oil supply will not satisfy world demand in 10 to 15 years.
- Oil production is in decline in 33 of the world's 48 largest oil-producing countries.
- U.S. oil production peaked in 1970 despite sharp price hikes in the 1970's and technology advances in the 1980's and 1990's. (This peak was predicted.)
- Analysis of regions that have passed peak oil production, including Texas and North America, the United Kingdom and Norway, shows that peaks can be sharp and unexpected.

In more recent work, Sorrell et al. (2010) compares and evaluates fourteen contemporary forecasts of global supply of conventional oil. The paper concludes that 'Given these complexities, we suggest that there is a significant risk of a peak in conventional oil production before 2020. At present, most OECD governments are failing to give serious consideration to this risk, despite its potentially far-reaching consequences.' The paper also concludes that 'forecasts that delay this peak until beyond 2030 rest on assumptions that are at best optimistic and at worst implausible.

Madureira (2014) finds that 'There is a general consensus between industry leaders and analysts that world oil production will peak between 2010 and 2030, with a significant chance that the peak will occur before 2020. Dates after 2030 are considered implausible.'

There are some critics of peak oil theory, such as Wile (2013), who claim that 'it is probably safe to say we have slayed "peak oil" once and for all, thanks to the combination new shale oil and gas production techniques and declining fuel use.' However, there seems to be little evidence to support this argument.

A more balanced approach presents the logical argument that as oil becomes increasingly scarce, the price will go up. This in turn will reach a threshold price where renewable energies become economic and thereby reduce demand and price pressure on fossil oil. For this reason it has become more economical to tap expensive oil sources like tight oil (fracking), deep-water oil and oil sands, which is currently occurring.

There is statistical evidence to support that oil production is not meeting demand. The BP Statistical Review of World Energy, 63rd Edn., (June 2014), which reflects on an analysis of the 2013 year, states that 'Global oil consumption grew by 1.4 million barrels per day (b/d), or 1.4% [per annum] – this is just above the historical average.' And that 'Global oil production did not keep pace with the growth in global consumption, rising by just 560,000 b/d or 0.6% [per annum].' Further, this report states that 'Global refinery crude runs increased by a below-average 390,000 b/d or 0.5%.' This report shows the same trends for gas: 1.4% consumption growth and a 1.1% production growth which was well below the 10-year average of 2.5%. Similarly, coal consumption grew by 3% in 2013 while global production grew by 0.8%, the weakest growth since 2002. (This was led by increases in Indonesia, 9.4% and Australia, 7.3%.)

Analysis of this report shows that only 14 out of 54 oil producing countries and regions in the world continue to increase production, while 30 are definitely past their production peak, and the remaining 10 appear to have flat or declining production. Put another way, peak oil is real in 61% of the oil producing world when weighted by production.

The BP Statistical Review of World Energy, 63rd Edn., June 2014 also states that 'Global hydroelectric output grew by a below-average 2.9%.' 'Renewable energy sources – in power generation as well as transport – continued to increase in 2013, reaching a record 2.7% of global energy consumption, up from 0.8% a decade ago.'

1.3.Climate Change and global warming

The National Research Council (2010) states that "Climate change is a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. It may be a change in average weather conditions, or in the distribution of weather around the average conditions (i.e., more or fewer extreme weather events)."

This work also states that (p1) "there is a strong, credible body of evidence, based on multiple lines of research, documenting that climate is changing and that these changes are in large part caused by human activities. While much remains to be learned, the core phenomenon, scientific questions, and hypotheses have been examined thoroughly and have stood firm in the face of serious scientific debate and careful evaluation of alternative explanations." (pp. 21–22) "Some scientific conclusions or theories have been so thoroughly examined tested, and supported by so many independent observations and results, that their likelihood of subsequently being found to be wrong is vanishingly small. Such conclusions and theories are then regarded as settled facts. This is the case for the conclusions that the Earth system is warming and that much of this warming is very likely due to human activities."

The temperatures that we experience on the surface of the earth are a balance between the incoming energy due to solar radiation and heat lost to space. The Earth is warmed because solar radiation is trapped in the land, ocean and, importantly, in gasses in the atmosphere.

Wikipedia (2014) search for Global Warming (accessed June 2014) states that "The major greenhouse gases are water vapour, which causes about 36–70% of the greenhouse effect; carbon dioxide (CO_2), which causes 9–26%; methane (CH_4), which causes 4–9%; and ozone (O_3), which causes 3–7%."

The IPCC (2013) stated that it is extremely likely (95-100%) that human influence has been the dominant cause of the observed warming since the mid-20th century. Figure 5 shows CO2 levels for the past 650,000 years and the scale of increase in CO2 levels since the industrial revolution. Multiple references exist, which use reliable evidence from ice cores, to show that these levels of CO2 have not been seen for the past 800,000 years. Other evidence suggests that these levels of CO2 have not been seen in the Earth's atmosphere for 20 million years.

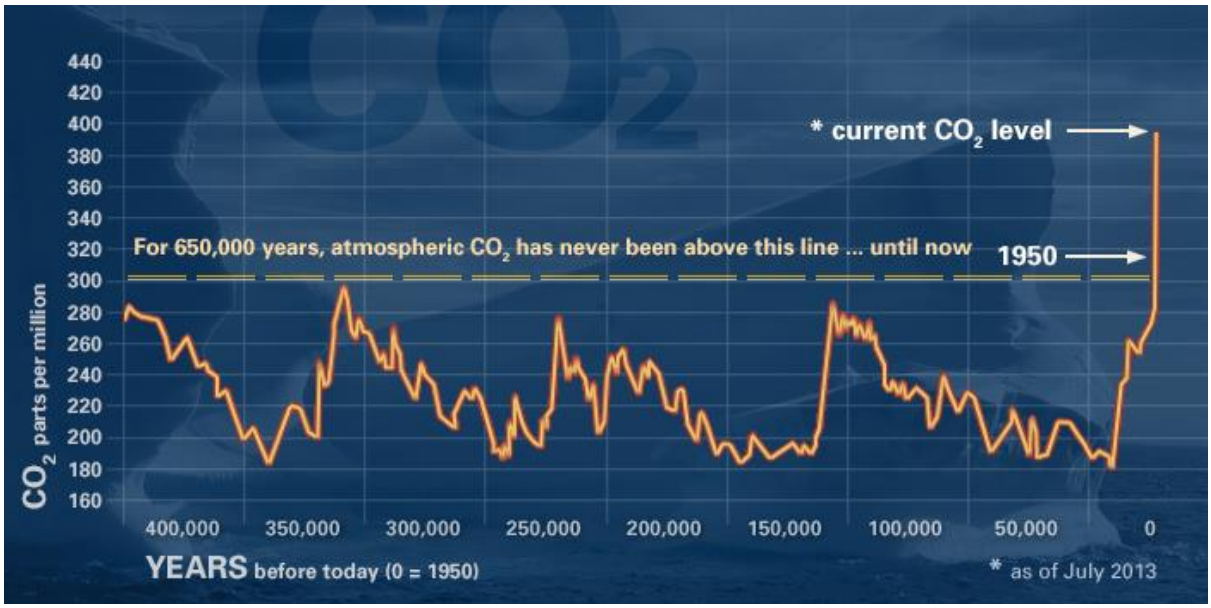


Figure 5. NASA's Jet Propulsion Laboratory, Earth Science Communications Team. Evidence of CO2.

The American EPA (2014) state that "between 1990 and 2010, global emissions of all major greenhouse gases increased. Net emissions of carbon dioxide increased by 42 percent, which is particularly important because carbon dioxide accounts for about three-fourths of total global emissions. Nitrous oxide emissions increased the least—9 percent—while emissions of methane increased by 15 percent. Emissions of fluorinated gases more than doubled." Many other references, such as the IPCC (2007) show a similar trend with a sharp rise in temperatures in the past 150 years. This rise corresponds with the rate of release of CO2 since the industrial revolution. The relationship between CO2 and temperature increase is shown below in figure 6.

The major driver for energy demand is population growth. Many references exist, such as Cunningham and Sago (1999), figure 7, which show that world population was relatively stable until the industrial revolution. With the industrial revolution, human population has grown exponentially. The United Nations, Department of Economic and Social Affairs, Population Division (2014) notes that "the current world population of 7.2 billion is projected to increase by 1 billion over the next 12 years and reach 9.6 billion by 2050". Importantly, much of the world is enjoying an increasingly high standard of living, particularly in China. This means that not only world population will increase, but per capita consumption will increase.

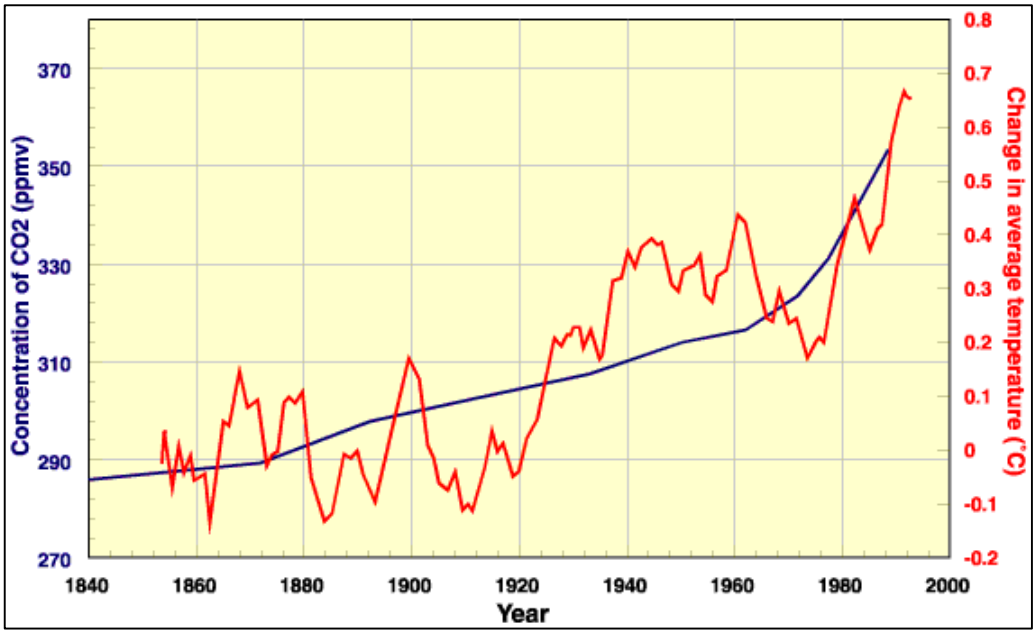


Figure 6. Correlation of the rise in atmospheric carbon dioxide concentration (blue line) with the rise in average global temperature (Honsberg and Bowden, 2014).

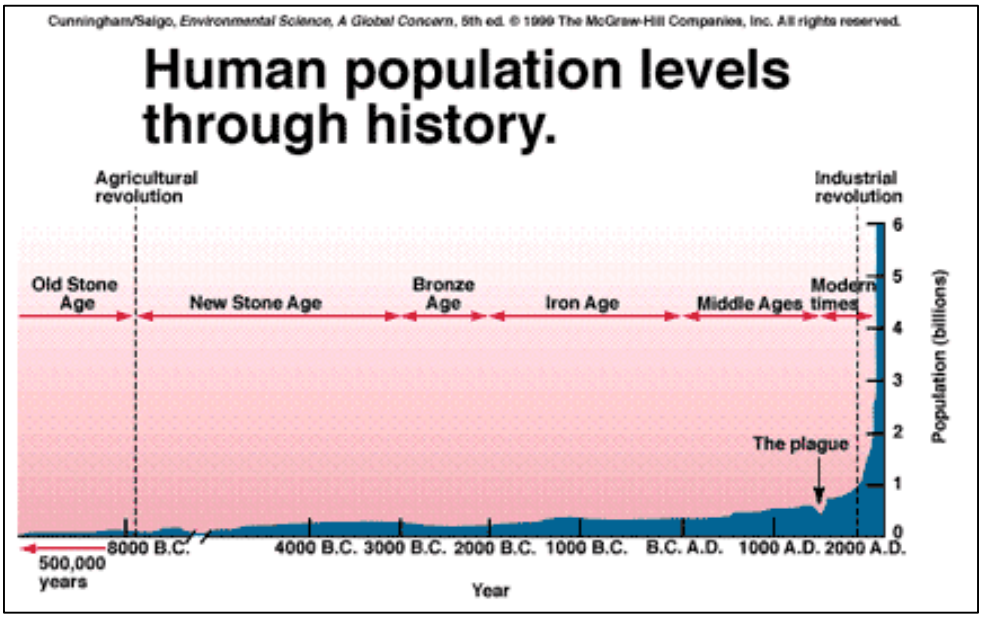


Figure 7. Human population levels through history. Cunningham & Sago (1999)

Le Quéré et al. (2012) state that Coal burning was responsible for 43% of the total emissions, oil 34%, gas 18%, cement 4.9% and gas flaring 0.7%. Herzog (2009) provides annual world greenhouse gas emissions, in 2005 by sector, as shown in figure 8, below.

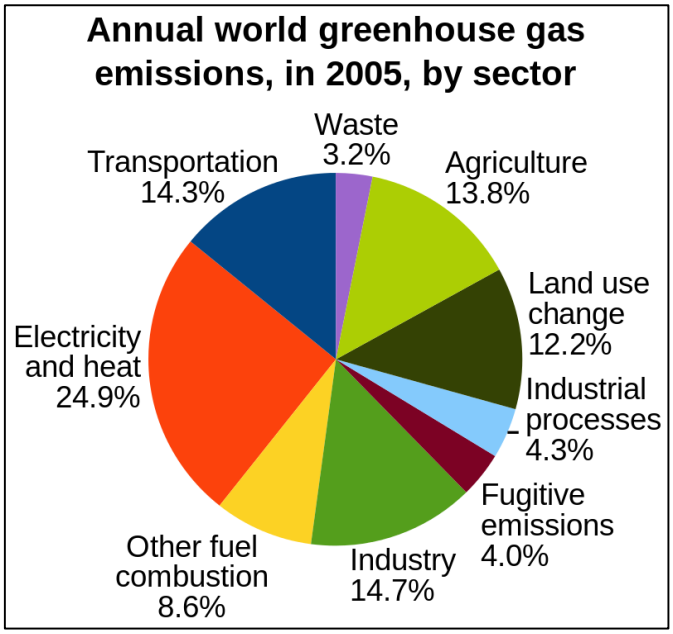


Figure 8. Annual world greenhouse gas emissions, in 2005 by sector. Herzog (2009).

Global warming projections incorporate economic, sociological and atmospheric assumptions. There will always be uncertainty when modelling something as complex as the world's climate. Results from these models will vary based on the assumptions and complexity of the model. However, all significant models confirm that surface temperature will rise between 2 °C and 5 °C by 2100 with good match between the various models. Figure 9 displays the global warming prediction of major scientific institutions. Figure 10 shows a range of prediction in sea level rise due to the associated melting of sea ice and glaciers.

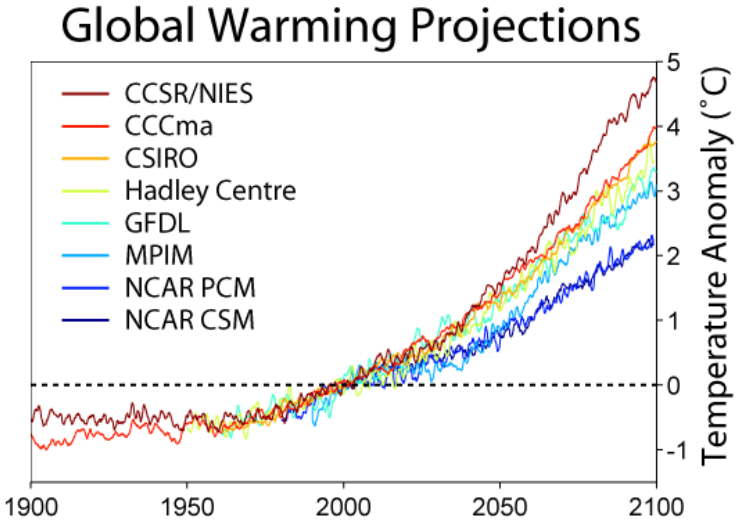


Figure 9 Wikimedia Commons - "Global Warming Predictions". Licensed under Creative Commons

Average temperature increases of this magnitude will have significant impact on the Earth. The cost of adaptation to extreme weather events such as drought or storms and the cost of retrofitting the energy infrastructure at a later stage will become too high. Internationally, few regulations have been put in place to avoid this situation.

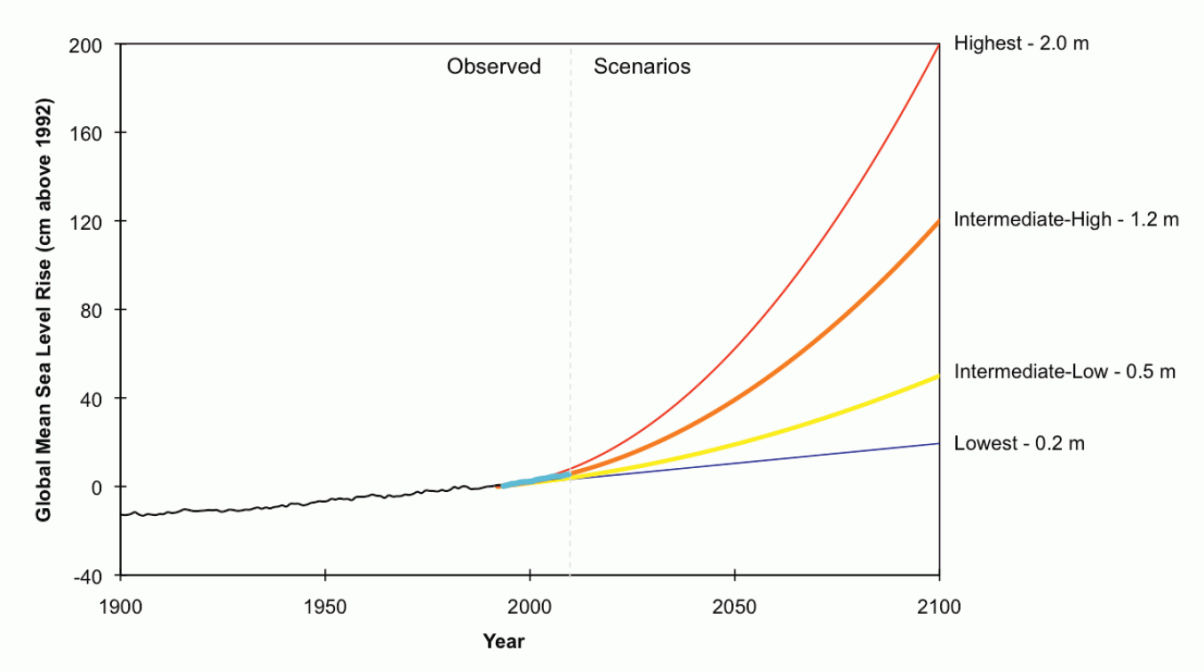


Figure 10. Projections of global mean sea level rise, Parris, A., et al. (2012).

1.4.Global Warming and cotton production

Climate change and agriculture are interrelated processes that occur on a global scale. Agriculture affects climate change through the release of greenhouse gasses such as carbon dioxide, methane, and nitrous oxide. These gasses are primarily created through the manufacture and infield volatilisation of fertilizers and chemicals and through the combustion of fossil fuels. The International Trade Centre (2011) state that "Higher temperatures will eventually reduce yields and increase the prevalence of pests and diseases. Changes in precipitation are likely to lead to crop failures and production declines. While there will be some gains depending on crops grown and regions, the overall impacts on agriculture are expected to be negative, thus threatening global food security." The International Trade Centre (2011) make the following statements:

- "Cotton production contributes to between 0.3% and 1% of total global GHG emissions.
- "Greenhouse gas emissions in the cotton value chain are derived mainly from the consumer use phase [that is, consumers washing the clothes] (30%–60%), and manufacture (20%–30%) Emissions from cotton production amount to only 5%–10% of the total emissions.
- "Approximately 90% of the technical potential to reduce emissions from agricultural production lies in carbon sequestration in the soil. Improved carbon sequestration is mainly achieved through changes to good agricultural practice. Further reductions in emissions can be achieved through increasing efficiency in the use inputs (water, fuels and agrochemicals)."

Bange and Constable (2008) note that "In cropping systems the main source of emissions result from cultivation, volatilisation from nitrogen fertiliser, and burning of stubble." Bange and Constable (2008) investigate production-focused approaches to cotton farming for climate change and make the following points:

- "While there is growing confidence in global scale observations and predictions of climate change it is still difficult to precisely determine how spatial variation in impacts of climate change will translate into impacts at regional scales.
- "Increases in CO2 concentration increased growth and yield in well watered environments.
- "Increases in daily temperature has two main influences on cotton growth and development. Firstly it determines rates of morphological development and crop growth. Secondly, it also helps determine the start and end of a growing season. Consequently climate change may increase average daily temperatures resulting in longer and better cotton growth (a positive effect). In contrast, negative effects on cotton growth from increased number and severity of days with very high temperatures during the cotton season will reduce yields by decreasing daily photosynthesis, and sometimes raising respiration at night, consuming stored assimilates which lead to increases in square and boll shedding, reducing seed numbers per boll, lower fibre lengths and higher micronaire values.
- "Increased atmospheric evaporative demand as a result of lower rainfall and relative humidity will increase transpiration and soil losses, reducing irrigation efficiency. Leaf temperatures are then increased to a point where photosynthesis and growth are impaired
- "Two regulatory issues that will impact on cotton production systems are changes in water policy and marketing which will limit water availability, and the impact of changing industrial operating climate resulting from implementation of a greenhouse emissions trading scheme."

1.5. Cotton Life Cycle Energy use.

The impacts of agriculture on the environment are increasingly being questioned, with industries being increasingly pressured to justify their status. Calculating these impacts is known as a Life Cycle Assessment (LCA), which typically measure the impact of each product from production to disposal. LCA is often used to compare the environmental damages assignable to products and services, and further, to choose the least burdensome one. LCA can identify processes that have large impacts on the environment, thereby helping to improve production. Energy use is one of the key indicators of LCA analyses.

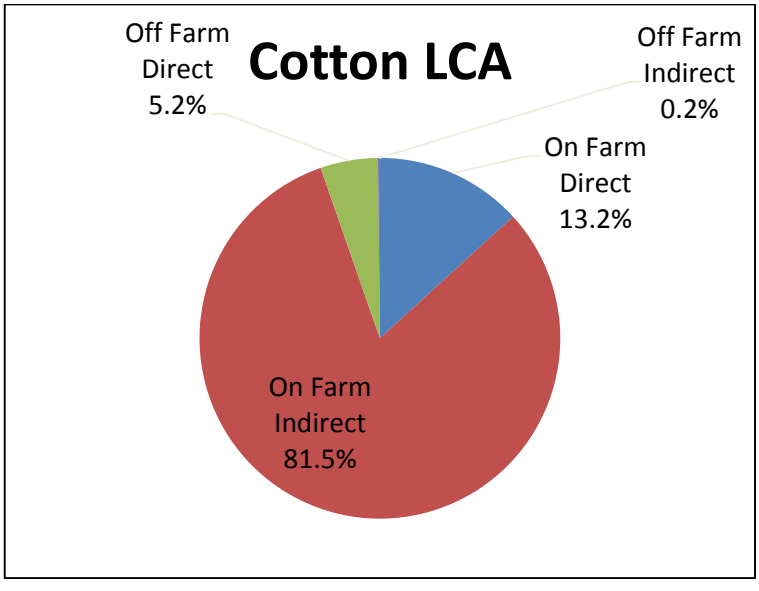


Figure 11. Life cycle assessment for Australian cotton production, (Chen at al., 2013).

Chen at al (2013) provides the average life cycle energy use for Australia cotton production (figure 11). Typically, on-farm direct energy use contributes some 10% total life cycle energy consumption. This mainly consists of fuel for irrigation pumping and application, tillage, crop harvesting and other in-field operations. Direct energy use also has a direct effect on the income and profitability of cotton growers.

1.6.Benchmarked on-farm energy use

Sandell et al. (2013) studied direct, on-farm energy use in Australian cotton farms. Although on-farm direct energy use typically only represents 10% to 15% of LCA energy use in cotton production, this area is important for the following reasons:

- To control production costs; energy is a high-cost input.
- To better understanding energy use and thus where to target savings.
- For environmental sustainability and responsibility.
- To promote Australia's 'clean and green' image.

Sandell et al. (2013) note that "there is less variation in in-field operations and pumping has a potential for up to 30% energy savings – pumping consumes 50 to 70% of all energy directly consumed on-farm. The project also identified that fertiliser and chemical account for much larger amounts of energy, which are used indirectly on-farm. Other potential areas for energy, cost and greenhouse gas (GHG) savings include tillage efficiency, water application efficiency." Sandell et al. (2013) report the following benchmarked energy uses in tables 4, 5 and 6 and figures 12 and 13, which are included as a measure of scale of energy used in cotton production.

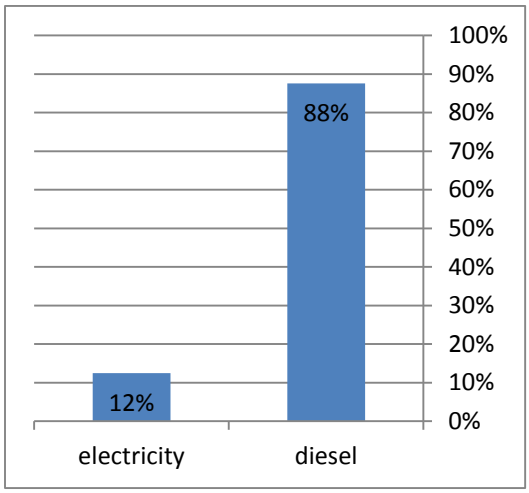


Figure 12. Sources of energy in Australian cotton, Sandell et al. (2013).

Table 4. Total energy consumption in Australian cotton production, Sandell et al. (2013).

	Energy (GJ/Ha)	Energy (GJ/Bale)	GHGs (kg CO2/Ha)	GHGs (kg CO2/Bale)	Energy Cost ($/Ha)	Energy Cost ($/Bale)
Irrigated	10.9	1.18	1,091	119	310	34
Supplementary	3.6	0.43	247	30	101	20
Dryland	3.1	0.71	212	49	87	12

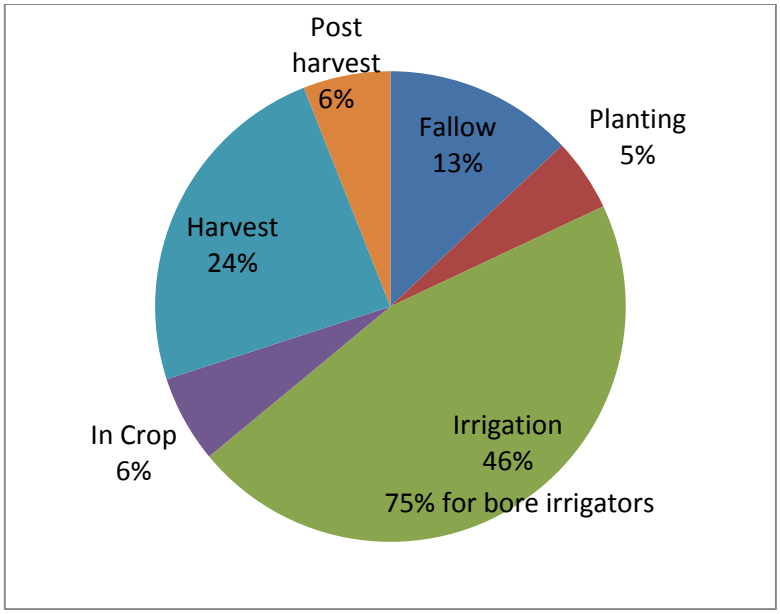


Figure 13. Average distribution of on-farm direct energy consumption for irrigated cotton, Sandell et al. (2013).

Table 5. Average distribution of energy use for irrigated cotton production, Sandell et al. (2013).

	Standard Energy (GJ/Ha)	Standard Energy (GJ/Bale)	GHGs (kg CO2/Ha)	GHGs (kg CO2/Bale)	Energy Cost ($/Ha)	Energy Cost ($/Bale)
Preparation	1.2	0.1	156.5	18.8	37.0	3.7
Establishment	0.4	0.0	52.2	6.3	12.3	1.2
In Season	0.6	0.1	78.3	9.4	18.5	1.9
Irrigation	4.6	0.5	586.9	70.3	138.6	14.0
Harvest	2.5	0.3	313.0	37.5	73.9	7.5
Post Harvest	0.8	0.1	104.3	12.5	24.6	2.5
General	0.1	0.0	13.0	1.6	3.1	0.3
Total	**10.3**	**1.1**	**1,304.3**	**156.3**	**308.1**	**31.1**

Additionally, table 6, modified from Khatri and Smith (2011) provides some quantification of energies used in various irrigation application systems.

Table 6. Irrigation application efficiency and energy costs, modified from Khatri and Smith (2011)

	Application efficiency	Water applied ML/Ha	Water Savings ML/Ha	On-farm Energy use (GJ/ha)	Change in energy use (GJ/ha)
Current surface irrigation	55%	7.3		12.8	0
Real-time optimised surface irrigation	85%	4.7	2.6	11.7	-1.1
Centre-pivot irrigation	90%	4.4	2.9	17	4.2
Drip irrigation	95%	4.2	3.1	16	3.2

2. Objectives

The broad aim of this project was to develop farmer-friendly resources to assist the Australian cotton industry evaluate alternate energy sources that can be integrated into normal farming operations to save energy, save money and reduce cotton's carbon footprint.

The specific objectives of this work include:

- Review commercially available alternative (renewable) energy and fuel options.
- Assess the feasibility of commercially available alternative (renewable) energy and fuel options.
- Examine performance / characteristics of non-commercial alternative fuel sources and mixtures.
- Reduce operating costs and emissions of non-commercial alternative fuel sources and mixtures.
- Inform the cotton industry on opportunities, costs and greenhouse gas implications of alternative (renewable) energy and fuels.

The specific milestones of this project are presented in Table 7, below. Please refer to the Preface for a guide to the correlation of these milestones and the sections in this report.

Table 7 Project objectives, milestones, performance indicators and timelines.

Objective		Milestone		Performance Indicator and Progress	Start Date	Finish Date
1	Review commercially available alternative (renewable) energy and fuel options.	1.1	Scope commercially available alternative energy options / technologies applicable to the cotton industry.	Desktop review of alternative energy options / technologies and costs.	Jul-11	Dec-11
		1.2	Assess existing use of alternative energy options currently adopted.	Identify and profile existing users of alternative energy technologies in cotton.	Jul-11	Dec-11
		1.3	Identify particular industry interests in alternative energy options / technologies.	Conduct survey on alternative energy interests within the cotton industry.	Jul-11	Dec-11
2	Assess the feasibly of commercially available alternative (renewable) energy and fuel options.	2.1	Conduct technical and market assessment of alternative energy and fuel options	Conduct economic and environmental assessment of alternative energy and fuel options	Jan-12	Jun-12
		2.2	Site specific assessment of alternative energy options and technologies	Develop case studies to demonstrate the feasibility of alternative energy options	Jan-12	Jun-12
		2.3	Establish relating policy and tariff issue to alternative energy options and technologies	Review policy and tariff issues and determine their impacts on the feasibility of alternative energy options	Jan-12	Jun-12
3	Examine performance / characteristics of non-commercial alternative fuels sources and mixtures (i.e. CSG and Biodiesel)	3.1	Evaluate alternative fuel sources and mixtures (CSG; Biodiesel).	Conduct laboratory testing to evaluate engine performance using different fuels and mixtures	Jan-12	Jun-12
		3.2	Evaluate exhaust gas emission using new fuels and technologies	Conduct laboratory testing to compare exhaust gas emissions	Jan-12	Jun-12

	Objective		Milestone	Performance Indicator and Progress	Start Date	Finish Date
				from conventional and alternative fuels and technologies.		
4	Reduce operating costs and emissions of non-commercial alternative fuel sources and mixtures (i.e. CSG and Biodiesel)	4.1	Optimise engine performance (i.e. cost, energy and emissions) for alternative fuel sources and mixtures.	Undertake testing to optimise engine performance and costs for alternative fuel sources and mixtures	Jul-12	Dec-12
		4.2	Undertake field testing of technologies utilising alternative fuel sources / mixtures	Demonstration of existing agricultural engine (water pump or tractor) using alternative fuel and / or mixture	Jan-13	Dec-13
		4.3	Conduct an economic assessment of alternative fuel options and technologies	Determine costs and benefits associated with various optimised fuel options and technologies	Jan-14	Jun-14
5	Inform the cotton industry on opportunities costs and greenhouse gas implications for using alternative (renewable) energy and fuel options	5.1	Produce technical information and identify regional opportunities for alternative energy options and technologies	Produce technical information (including geographical potential; i.e. maps where appropriate) for alternative energy and fuel options / technologies	Jul-12	Jun-14
		5.2	Develop online resources to inform investment in alternate energy options	Develop online calculators to facilitate grower assessment of their energy requirements, potential alternative energy sources and cost benefits	Jul-12	Jun-14
		5.3	Identify industry pathways to adopt alternative energy options / technologies	Final Report and workshop – "How to save energy, save money and reduce your carbon footprint"	Jul-13	Jun-14

3. Liquid and Gas (Transport) Fuels

Liquid fuels are important globally because of the need for a portable energy source for transport. This is particularly an issue in agriculture, which relies on mobile plant and the transport of inputs and final product. Most liquid fuels in widespread use are derived from fossil fuels, such as diesel, petrol and LPG. There are several types of renewable liquid fuels, such as hydrogen fuel, ethanol, and biodiesel, which are also categorized as a liquid fuel. Currently, fossil fuels are cheaper than biofuels. However, as noted in section 1.3, they cause significant environmental damage.

Cotton is very energy intensive. Sandell et al. (2013), table 4, show that Australian cotton production consumes an average of 10.9 GJ per hectare (1.18 GJ per bale) of direct on-farm energy for irrigated cotton. This study also shows (figure 12) that on average, 88% of all direct, on-farm energy consumption in Australian cotton production is supplied by diesel. These fuels are used in tractors, irrigation pumping and application and in transport. The remaining energy was largely supplied by electricity with negligible amounts of other energy sources.

3.1. Explanation of technical terms.

Calorific value (CV), *heating content*, *heating value (HV)*, or *heat of combustion* refers to the amount of the heat that can be released during the combustion process of the fuel. It is measured using a 'bomb calorimeter'. CV is measured as energy units per mole[4] of fuel [KJ/mol], energy.

The heating value per unit mass of vegetable oils is lower than that of petroleum diesel by about 15%–20%. Offsetting this is the fact that the density of the vegetable oils is slightly higher, which reduces the effect of the lower heating value of the vegetable oils. Overall, the BSFC of vegetable oils is slightly lower, 5% - 10%, than that of petroleum diesel.

Cetane number or CN is a measurement of the combustion quality of diesel fuel during compression ignition. Thus, it is the approximate equivalent of octane rating for gasoline (petrol). The CN is an important factor in determining the quality of diesel fuel, but not the only one; other measurements of diesel's quality include (but are not limited to) density, lubricity, cold-flow properties and sulphur content.

Brake Specific Fuel Consumption (BSFC), also written as Specific Fuel Consumption (SFC), is a measure of fuel efficiency of an engine and is used to rate and compare engines in terms of their fuel efficiency. It is a measure of fuel consumed per unit of power produced. Lower BSFC values are preferable because this means that less fuel is consumed to produce a unit of power. Units are commonly grams of fuel per kilowatt-hour [g/kW.h]; sometimes millilitres per kilowatt-hour [ml/kW.h] are used.

Particulate matter (PM) refers to particles of solid or liquid component suspended in air and can be classified based on the diameter of the particles that are below 10 micrometres. Fine

[4] A *mole* is a unit of measurement used to express amounts of a chemical substance. A mole is that amount of a chemical that contains 6.022×10^{23} molecules of the chemical.

particles have diameter of about 2.5 micrometres or less. Below this diameter, particles are termed ultrafine particles and soot.

The PM has a negative impact on human health because the particles have the ability to penetrate deep into the human lung. It has been reported by many researchers that PM emission from biodiesel in total is considerably lower than petroleum diesel.

Nitrogen Oxides (NOx) is a term for the mono-nitrogen oxide air pollutants nitric oxide (NO) and nitrogen dioxide (NO_2). The compounds are produced during the high temperature combustion in an engine. NOx has a major influence in the ozone in the atmosphere because it has a global warming potential (GWP) equivalent to 310 times that of carbon-dioxide. In addition NOx has the ability to react with other chemical and form toxic products that impact of human life.

The NOx resulted from biodiesel combustion can be lower or higher than that from petroleum diesel depending on many factors such as engine design, engine life and condition and so on. However in most cases biodiesel produces about 10% higher NOx emission.

Engine reliability. An engineering definition of reliability, provided by McGraw-Hill Companies Inc. (2003), is: "The probability that a component part, equipment, or system will satisfactorily perform its intended function under given circumstances, such as environmental conditions, limitations as to operating time, and frequency and thoroughness of maintenance for a specified period of time."

Engine manufacturers design specify that their engines are to be operated within a specific range of fuel specifications. Engine, reliability, durability and life are important factors for the engines user.

Exhaust Temperature is the temperature of the gasses expelled from the combustion chamber of the engine. Exhaust temperature is an important factor in engine durability. Exhaust temperatures generally range from 350 ^{o}C to 650 ^{o}C. Higher exhaust temperature reduce the life of some engine components.

Fuel stability is the ability of the fuel to remain unchanged during long-term storage. Fuel should be stable for months or longer. Fuel stability is important for agriculture because various pieces of capital equipment will remain unused for months (irrigation pumps, for example).

BP (2014) reports that petroleum diesel fuels will remain stable for 6 to 12 months under normal storage conditions. Metrohm (2014) report that biodiesels have only a limited shelf life as they are slowly oxidized by atmospheric oxygen. Oxidation stability is an important quality criterion for biodiesel because the resulting oxidised products have an undesirable effect on engine life. Several standards exist for fuel stability.

Fuel viscosity is how "thick" the fuel is (like honey compared to water). Technically the viscosity of a fluid is a measure of its resistance to gradual deformation by shear stress. Higher viscosity can affect the nozzle injection pattern and the pressure required for injection that could affect the fuel injection pump life, and the injectors. Viscosity is an important factor in cold weather starting.

Fuel purity is an indication of the level of undesired chemicals in the fuel mixture. Biodiesel should be a pure mixture of water, acid, glycerine, and methanol and content should match standard specification for biodiesel.

B20. 'B' represents a blend of biodiesel and petroleum diesel. '20' signifies that the blend is 20% biodiesel (and thus 80% petroleum diesel). Other blends, such as B5, B50, B70 and B100 exist.

E20. 'E' represents a blend of ethanol and petroleum. '20' signifies that the blend is 20% ethanol (and thus 80% petroleum). Other blends, such as E5, E50, E70 and E100 exist.

3.2.Types of liquid fuels

3.2.1. Diesel

Conventional diesel is a petroleum-based fuel used in engines ignited by compression rather than spark. Diesel fuels are heavier and produce higher emissions than petrol engines. They also provide about 10% more power per unit of volume of fuel.

Petroleum oil is characterised as being:

- Easily transportable, high energy density.
- Reliable and well known for users

Australia is becoming increasingly dependent on expensive imported oil and petroleum products. In fact, about 85 per cent of Australia's transport fuel now comes from overseas (Cribb, 2013) as either refined or crude product. Figure 14 shows this dependency will rise sharply as several domestic oil refineries are being closed. Such a rise would put enormous strain on Australia's balance of payments.

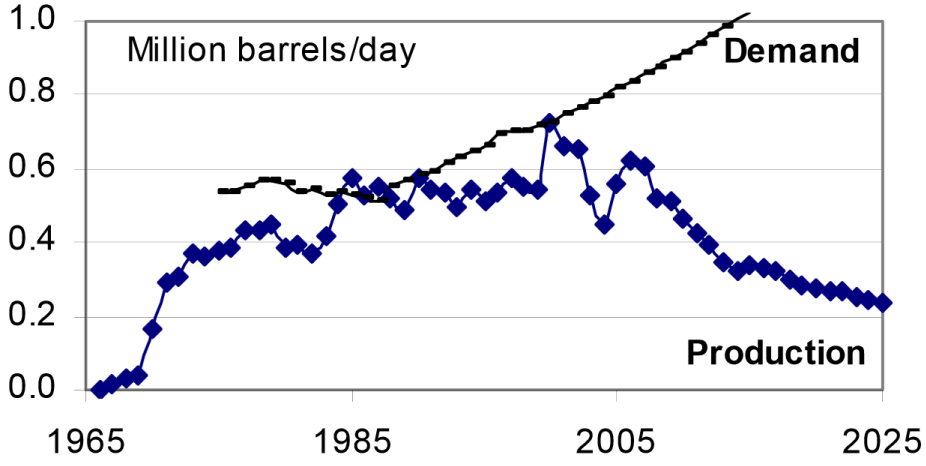


Figure 14. Australian crude oil and condensate production and demand to 2004, and forecasts, (Robinson et al, 2005).

Alternative transportation fuels to petroleum being researched include biofuels, or fuels derived from coal and natural gas, to enhance Australia' energy independence. Research is also being conducted to optimise engine performance as well as particulate trap and other exhaust gas treatments to reduce air pollution. In the USA, Tier 4 is being phased in between 2008 and 2015

(Gui, 2014). In Europe, corresponding Stage IV standards for non-road diesel engines will be enforced in 2014.

3.2.2. Liquid Petroleum Gas (LPG)

Liquefied petroleum gas (LPG) is produced from natural gas, which is a fossil gas that is either associated with an oil field or in a natural gas field. Natural gas is around 90% methane with a mixture of other hydrocarbon gases: ethane, propane, butanes, pentanes and various other hydrocarbon gasses and impurities. Natural gas is refined at the oil head and gas processing plants into individual gasses.

LPG sold in Australia is propane. Autogas is a mixture of more than 60% propane and butane. It is stored under pressure. LPG can be used straight as a fuel in spark ignition engines or as a supplement to diesel in compression ignition engines.

3.2.3. Coal Seam Gas (CSG)

CSG is an unconventional gas and is extracted by pumping up water from a coal seam, which reduces the pressure and allows the gas to be released. Individual gas wells usually have a life of about 15 years. CSG is almost pure methane. There are concerns over the impact of coal seam gas mines on water supplies and possible impacts on crop lands.

Just 15 years ago, there was virtually no coal-seam gas extraction in Australia. The rapidly developing coal seam gas (CSG) industry (Fig.15) is now adding to Australia's known economic gas resources. Geoscience Australia indicated that Australia's CSG reserves as at the end of December 2006 were 4,642 PJ. Major CSG basins in Australia are in Queensland (Bowen and Surat) and in NSW (Clarence Moreton, Gloucester, Sydney and Gunnedah) (Fig.16). For comparison, Australia's cotton production regions are shown in figure 17.

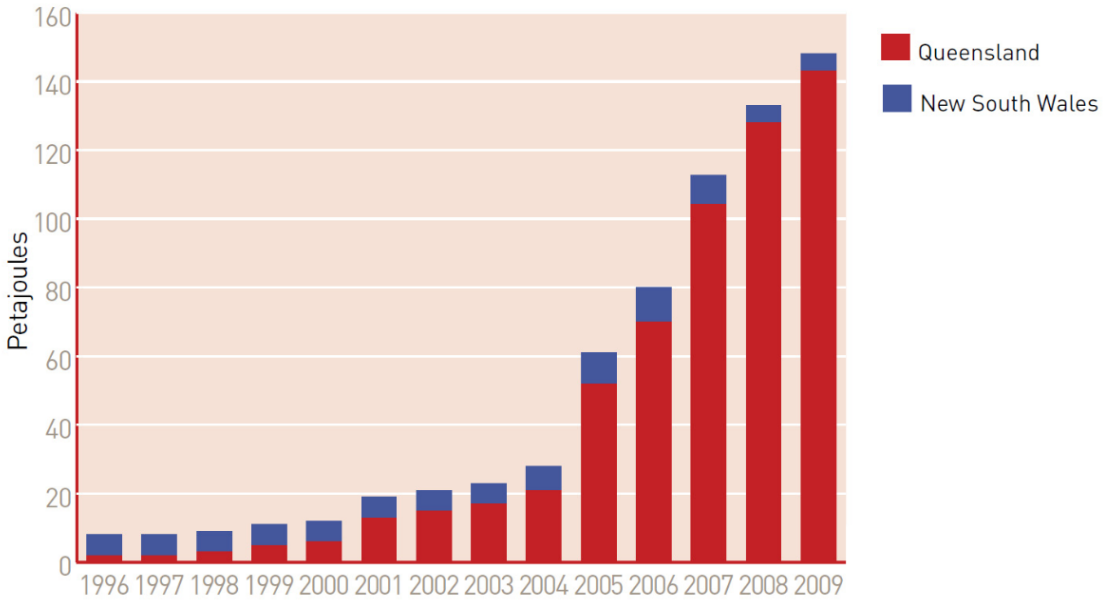


Figure 15. Increase of coal seam gas production in Australia, (Hardwicke, L. 2010).

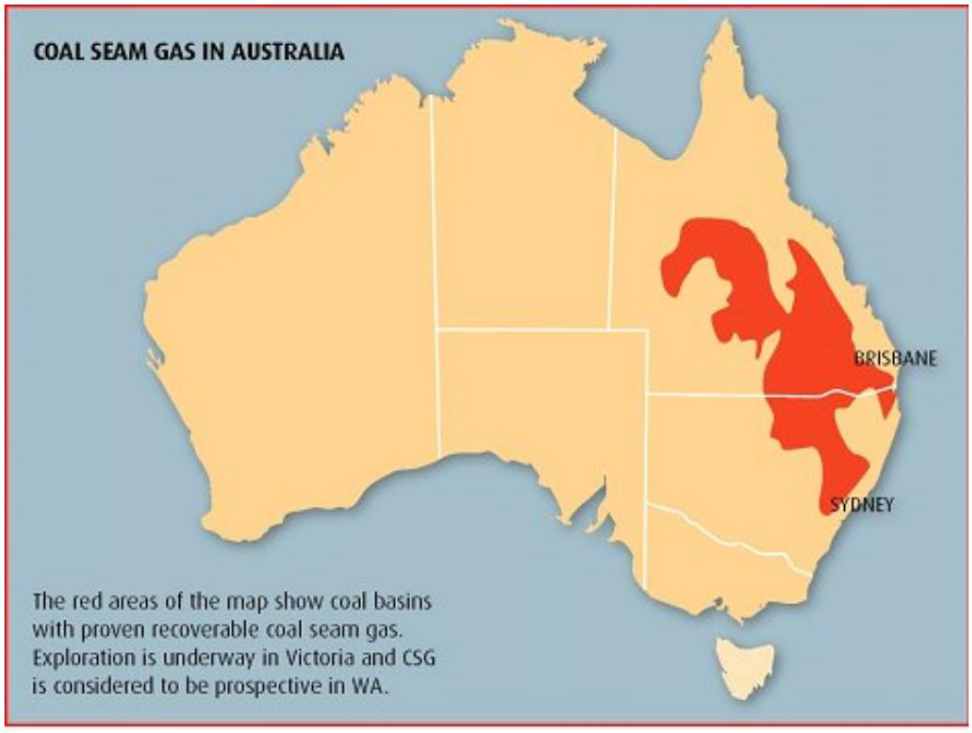


Figure 16. Coal seam gas in Australia, (Roarty, 2011).

Figure 17. Australian cotton production regions, Stiller and Wilson (2014).

Comparison of figures 16 and 17 show that CSG production areas overlap most of Australia's cotton production areas.

The development of CSG fields and then liquefying and exporting the gas contributes to the diversification of gas supply sources and economics, particularly in Queensland. Production in 2004 amounted to some 45 PJ, or about 4.5% of Australia's domestic natural gas consumption. CSG now also supplies 80-90% of the total gas market in Queensland and 35% east coast gas demand. Exports are also currently worth more than $3.2 billion a year, at around $10/GJ. (This is in comparison with coal export price of $100-150/t.) It is forecasted that CSG sales in Australia could triple in the next five years, putting the industry on par with iron ore and coal in terms of export contributions to the economy.

Coal seam gas is stored and transported in two forms: Compressed Natural Gas (CNG) and Liquidified Natural Gas (LNG). LNG is CSG that is supercooled into a liquid using liquid nitrogen. This method is preferred for transporting gas large distances, such as in pipelines and shipping. It is also used in some transport applications such as truck transport. However, LNG is subject to 'boil off', where the gas evaporates. This is only a minor loss where the gas is used continuously, such as in the truck transport industry. In cotton production much capital equipment sits idle for many months of the year, which means that boil off losses are significant. Therefore LNG is not suited to cotton production. CNG, compressed natural gas, is CSG that is compressed into a cylinder in much the same way that LPG is handled. CNG is not subject to boil off and is therefore suitable for use in cotton production. A high capital cost plant is required to convert LNG into CNG.

CNG can be used in the same manner as LPG. Engine conversions use the same hardware with modifications in the control software. The conversion of an engine to CNG is around $6,000 for engine modifications. Mobile equipment also require a tank, which costs around $2,000.

3.2.4. Biodiesel

Biodiesel is a renewable liquid fuel made from processing of either tallow (animal fat) or vegetable oil in a process called "transesterification". Biodiesel can be used in all types of compression ignition engines either directly or in a blended form.

Typical vegetable oils include canola and sunflower. The oil extraction by weight of cottonseed is 19% and 40% for Canola (Girard and Fallot, 2006). Biodiesel production is a simple process consisting in putting together the animal tallow or vegetable oil with an alcohol and a catalyst to separate the oil from the glycerine. By comparison, ethanol involves a fermenting process.

Biodiesel typically has a slightly lower calorific value, expressed and a cetane number, compared to diesel. This is partially offset by the fact the biodiesel has a slightly higher density than diesel. Aside from cost aspects there are a number of other fuel standards that a biodiesel must meet. Nabi et al. (2009) and Xue et al. (2011) show that viscosity, density, cetane number, volatility, lubricity, heating value are very important fuel properties. Other factors include performance at low temperature and levels of impurities. These factors are important to avoid higher maintenance costs, engine carbon deposits formation, fuel filter clogging and engine wear. For example, Biodiesel made from tallow or palm oil will solidify in cold weather.

Biodiesel blends up to 5% by volume in North America and 7% in Europe are now routinely used in agriculture machines without impacting machine performance or durability. Blends of up to 5% biodiesel in conventional diesel are permissible in Australia without any labelling changes or notification to the consumer.

Table 8. Physical and chemical properties of vegetable oils. Demirbaş, (2003)

	Kinematic viscosity mm^2/s at 311 K	Carbon residue wt.%	Cetane number –		Kinematic viscosity mm^2/s at 311 K	Carbon residue wt.%	Cetane number –
Cotton seed	33.7	0.25	33.7	**Castor**	29.7	0.21	42.3
Poppy seed	42.4	0.25	36.7	**Soybean**	33.1	0.24	38.1
Canola	37.3	0.31	37.5	**Bay laurel leaf**	23.2	0.2	33.6
Safflower seed	31.6	0.26	42	**Peanut kernel**	40	0.22	34.6
Sunflower seed	34.4	0.28	36.7	**Hazelnut kernel**	24	0.21	52.9
Sesame seed	36	0.25	40.4	**Walnut kernel**	36.8	0.24	33.6
Linseed	28	0.24	27.6	**Almond kernel**	34.2	0.22	34.5
Wheat grain	32.6	0.23	35.2	**Olive kernel**	29.4	0.23	49.3
Corn marrow	35.1	0.22	37.5				

Biodiesel plant location and total Australian production of biodiesel production are shown in figure 18 and table 9 respectively (Biofuels Association of Australia, 2014).

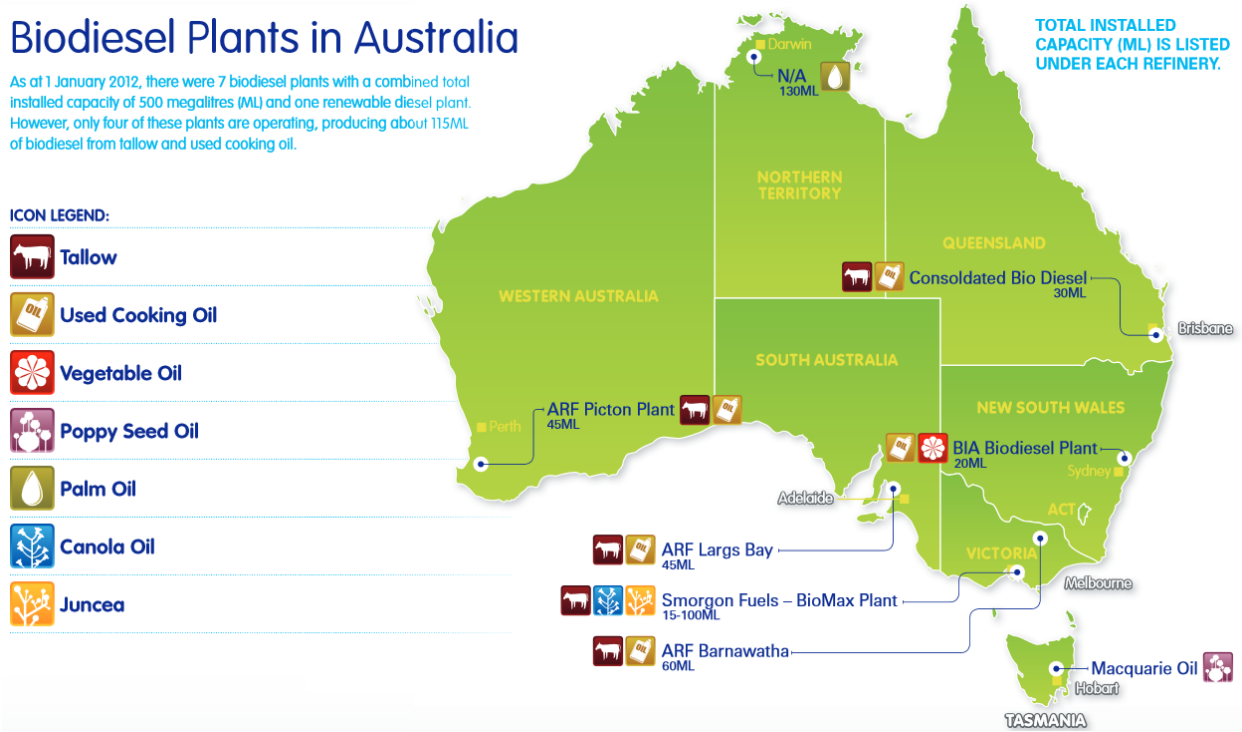


Figure 18. Map of biodiesel plants in Australia. Biofuels Association of Australia (2014).

Table 9. Table of biodiesel production in Australia, Biofuels Association of Australia, 2014.

Biodiesel plant	LOCATION	OWNER (* BAA MEMBER)	TOTAL INSTALLED Capacity (ML) at 01.12.13	Feedstock	Status (at 01.12.13)
ARfuels Barnawartha	Barnawartha, VIC	Australian Renewable Fuels*	60	Tallow, Used cooking oil	In production
Arfuels Largs Bay	Largs Bay, SA	Australian Renewable Fuels*	45	Tallow, Used cooking oil	In production
Arfules Picton	Picton, WA	Australian Renewable Fuels*	45	Tallow, Used cooking oil	In production
ASHOIL	Tom Price, WA	Ashburton Aboriginal Corportion*	Unknown	Used cooking oil	In production
Biodiesel Industries	Rutherford, NSW	Biodiesel Industries Australia Pty Ltd*	20	Used cooking oil, Vegetable oil	In production
Ecofuels Australia	Echuca, VIC	Ecofuels Australia Pty Ltd	1.5	Canola oil	In production
EcoTech BioDiesel	Narangba, QLD	Gull Group*	30	Tallow, Used cooking oil	In production
Macquarie Oil	Cressy, TAS	Macquarie Oil Co	15	Poppy Seed Oil & Waste Vegetable Oil	In production
Neutral Fuels	Dandenong, VIC	Neutral Fuels (Melbourne) Pty Ltd	Unknown	Used cooking oil	In production
Smorgon Fuels BioMax Plant	Laverton, VIC	Smorgon Fuels Pty Ltd	Prior to closure 15-100	Tallow, Canola Oil and Juncea Oil	Closed
Territory Biofuels	Darwin, NT	Territory Biofuels Ltd	140	Refined, Bleached & Deodorised (RBD) Palm Oil, Tallow, Used Cooking Oil	Restart in 2014
TOTAL CAPACITY (ML)			**360**		

3.2.5. Biogas

Biogas is a combustible gas derived from decomposing biological waste in either an anaerobic or aerobic process. Biogas normally consists of 50% to 60% methane. It is currently captured from landfill sites, sewage treatment plants, livestock feedlots and agricultural wastes. The typical conditions required are biomass combined with water in a lagoon or containment vessel, with the

combined solution being maintained between 16°C and 60°C. Biogas can either be directly burnt for thermal energy production or used in an internal combustion engine with to produce mechanical power or with a generator to produce electricity.

Isci and Demirers (2007) report that cotton gin trash can be used to produce methane by anaerobic digestion, with around 7% conversion rate. This could be a potential source of alternative energy and income, while reducing the cost associated with waste handling and storage

3.2.6. Algae fuels

Algae biodiesel is produced using particular strains of algae, such as *chlorella protothecoides*, that remove CO2 from the atmosphere via photosynthesis to produce a liquid fuel.

The farming of algae to produce biofuels is an area of active research worldwide. Both microalgae and macroalgae (e.g. seaweed) are being investigated as feedstocks for biofuels. There are also challenges limiting the commercial development of algae biofuels such as algae species that can balance the requirements of biofuel production, equipment and structures needed to grow large quantities of algae and the negative energy balance after accounting for water pumping, harvesting and extraction.

3.2.7. Alcohol fuels

Ethanol is one of the key alternatives being introduced around the world to reduce reliance on fossil fuels. The process to produce ethanol, or ethyl-alcohol (C_2H_5OH) for use as a transport fuel or a fuel additive is alcoholic fermentation. The energy content of ethanol ranges from 21 to 23 MJ/L. This is relatively low when compared to 38.6 MJ/L of diesel. By adding vegetable oils, the viscosity can be altered to ensure that it runs better in conventional engines.

Ethanol can only be produced industrially by using yeast, which are single celled organisms of the kingdom Fungi. The yeast converts sugars found in the raw products to carbon dioxide and ethanol.

Feedstocks can be divided into three categories:

- First-generation feedstocks contain simple sugars which are directly broken down by yeast, such as sugar cane and sweet sorghum.
- Second-generation feedstocks contain starches, such as corn and wheat. These starches, which are two sugar molecules bonded together, are acted on by amylase enzymes to separate the starch into simple sugars which are then acted upon by yeast.
- Third-generation feedstocks are lignocellulosic materials such as wood, straw, grasses, cotton stalks and trashes. These are broken down by adding dilute sulphuric acid to from starch, which are then broken down as above.

Table 10 (Biofuels Association of Australia, 2014) shows that 86% of Australian ethanol is produced from grain while the remaining 14% is produced from molasses. The geographic location of these plants are shown in figure 19.

Current practice in Australia is to blend 5% ethanol with petroleum based petrol. Other countries have a much higher level of ethanol blend, up to 100% in some cases. In 2012, 306 ML of ethanol was consumed in Australia, with around 90% of that being used in petrol/ethanol blends. World fuel ethanol production will reach 63 billion litres by 2012. This is a growth rate of 5% per annum. Around world 40% of ethanol was sourced from sugar (mainly Brazil), 40% from corn (mainly US)

with the remainder sourced from other countries. It is claimed that ethanol in the US and Brazil would not have occurred without government support.

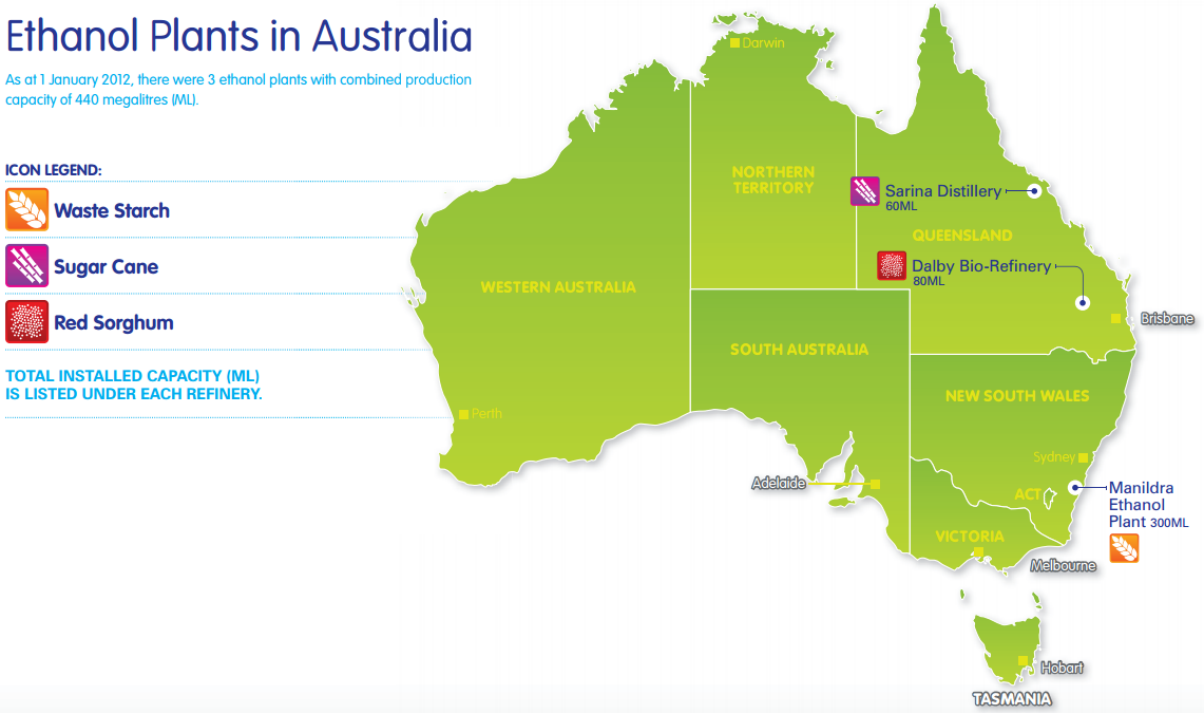


Figure 19. Map of ethanol plants in Australia. Biofuels Association of Australia (2014).

Table 10. Current Australian ethanol production as at 1 Dec 13. Biofuels Association of Australia (2014).

Owner, Location	Capacity (ML/yr)	Feedstock
Manildra Group, Nowra, NSW	300	Waste wheat starch, some low grade grain
CSR Distilleries, Sarina, Qld	60	Molasses
Dalby Bio-Refinery, Dalby, Qld	80	Sorghum

3.3.Summary of fuel testing

For the convenience of the casual reader, the summary of the fuel testing results are presented in this section. Additionally, a summary of the major terms is provided above in section 3.1. For detailed results and analysis of fuel testing please refer to *Appendix A. Performance characteristics of liquid fuels*.

Because of the of the cotton industry's heavy reliance on diesel, it is important to closely examine the performance characteristics of commercial and non-commercial alternative diesel fuel sources and mixtures. Because of the global warming problem currently facing the planet, it is necessary to also examine the emission characteristics of these fuels.

Specific aims of the fuel testing are to:

- Examine performance / characteristics of non-commercial alternative fuel sources and mixtures
- Reduce operating costs and emissions of non-commercial alternative fuel sources and mixtures

Because of sometimes conflicting research concerning biofuel emission and performance results and variations in biofuel properties a controlled testing program was conducted at the fuel laboratory at the University of Southern Queensland (USQ). This laboratory provides the high precision equipment to measure the performance and emission characteristics of liquid fuels.

The fuel testing included a variety of fuels including diesel, biodiesel, low purity ethanol, algae biodiesel and LPG. These fuels were selected because of their potential in the cotton industry and was informed by the industry survey, which is presented in section *7. Survey: Current industry interest and use of alternative fuels.*

Performance and emissions were analysed simultaneously in each test.

Because some fuels were in limited supply testing was initially conducted on smaller engines to measure the relative performance of the fuel. Once this was complete, the more promising fuels were selected for testing in larger engines which are more akin to those used in the cotton industry.

Optimisation was required for some fuels that showed potential, however could be improved in some way. For example, the relative amounts of diesel and LPG used in testing needed to be optimised to obtain optimum efficiency and minimise emissions.

Accurately measuring the performance and emissions characteristics for the range of fuels allows us to use these results in cost modelling and other scenarios presented in later sections of the report.

3.3.1. Biodiesel

Initial testing, carried out on a single cylinder engine, revealed that biodiesel blends B50 and B100 to result in satisfactory levels of emissions and lower exhaust temperatures. However this was associated with a decrease in fuel efficiency, which means that more fuel energy is consumed to achieve the same mechanical energy output.

B20 resulted in a proportionally similar performance with slightly lower efficiency compared to diesel. Emissions improved in the lower half of the engine's speed range but were worse than diesel in the upper half. This blend was selected to conduct testing in larger engines.

Cotton seed oil B20 was tested in a 3 cylinder tractor engine. The B20 resulted in lower efficiency, lower exhaust temperatures and increased carbon dioxide emissions. NOx and carbon monoxide levels were similar to diesel.

Testing of tallow B20 and cotton seed oil B20 in a 4 cylinder engine resulted in similar performance, higher efficiency, lower exhaust temperatures and lower emissions for all major pollutants.

This trend was also found in field testing, discussed in section 3.4.

3.3.2. Ethanol

Ethanol is commonly used in petrol engines wither straight or a blend. However, ethanol does not mix well with diesel due to the presence of water in the ethanol.

Ethanol is derived from yeast cells converting sugar molecules into ethanol and this occurs at a maximum concentration of around 20% ethanol with the majority of the remaining mixture being water. Fractional distillation is then used to remove the ethanol from this mixture. The theoretical maximum extraction of ethanol is around 96% of the total available ethanol. The ethanol drawn off in this process is normally close to 95% ethanol due to distillation efficiencies, with the remaining 5% to the ethanol being water. To remove the last amount of water requires vacuum distillation which is cost prohibitive for fuel use. It is the water component that limits the ability of a diesel ethanol blend to remain stable during storage.

The Fuel tested consisted of 95% purity ethanol (with the remaining 5% being water), CALTX Vortex diesel and a surfactant to ensure the constituents remained mixed. Normally a mixture of diesel and ethanol will separate into individual components during storage. Note that the surfactant is Commercial In Confidence and it is the performance results that are being tested here. The fuel was stored for some months before the fuel was tested to ensure the long term stability of the fuel.

Low purity ethanol blended with diesel achieved comparable results to diesel fuel, with slightly less performance and slightly higher exhaust temperatures being observed. Emissions were improved in the lower half of the engine's speed range, and slightly increased in the upper half.

3.3.3. LPG

Initial testing of a diesel/LPG mixture in a 4 cylinder engine resulted in large increases in power and torque, but lower efficiency, higher exhaust temperatures and significantly increased carbon monoxide emissions with reductions in NOx. Optimisation was required to reduce the flow of diesel to accommodate the LPG injection. Once this was achieved, constant power and constant torque tests were conducted. These tests revealed that a 40% LPG fumigation level was the optimum concentration. Engine efficiency increased, exhaust temperatures decreased and carbon dioxide emissions decreased. However NOx, and carbon monoxide emissions increased.

LPG injection was also trialled with cotton seed oil B20 and revealed similar gains to the addition to diesel. The B20 biodiesel blend and 40% LPG fumigation (B20G40) yielded the highest efficiency of any fuel tested, with 39.6% achieved at 1900rpm. B20G40 also resulted in the lowest exhaust temperatures throughout the range of speeds tested. However carbon monoxide levels increased dramatically. The results suggested that perhaps 30% would be a more suitable fumigation level for B20.

3.3.4. Microalgae

The microalgae and diesel fuel testing performed on the JD4410 apparatus are the results of Al-Iwayzy et al., (2013) and Al-Iwayzy et al., (2011) are presented here to increase the breadth of the discussion.

Microalgae (MCP-B20) was tested in a 3 cylinder tractor engine. MCP-B20 resulted in similar performance and efficiency to diesel, with higher exhaust temperatures and higher NOx emissions.

Carbon monoxide emissions were reduced and carbon dioxide emissions were similar to that of diesel.

3.3.5. Overall comparison

The B20 biodiesel blend produced the lowest emissions of all fuels tested, followed by B20G40. The B20G40 is also the best fuel in terms of power performance. However carbon monoxide levels increased dramatically. The results suggested that perhaps 30% would be a more suitable fumigation level for B20.

Figure 11 provides a summary of fuel performance while table 12 provides summary emissions data at each engine's most efficient operating speed.

Colour coding in fuel testing results. In the tables for the emissions comparison, green signifies a reduction in emissions of a harmful gas and pink signifies an increase in emissions of a harmful gas. In the summary tables each type of test (constant speed, constant torque etc.) has a different colour to make it easier to compare fuels for the same test.

Table 11. Fuel testing performance summary data.

Engine	Fuel Type	Test Type	Most Efficient Speed RPM	Torque Nm	Throttle %	Mechanical Power kW	Exhaust Temp °C	Efficiency %	Diesel Use L/h	LPG Use L/h	Biodiesel Use L/h	Ethanol Use L/h
Hatz	Diesel	Constant Torque	1800	169	53	31.85	472	36.4	8.7	0	0	0
		Constant Power	2100	158	67	35.00	451	35.8	9.7	0	0	0
		Full Throttle	2000	192	100	40.00	616	34.6	11.5	0	0	0
	Diesel/LPG 40%	Constant Torque	1600	170	45	28.49	430	37.5	5.9	2.53	0	0
		Constant Power	1800	183	52	35.00	471	38.9	7.3	2.53	0	0
		Full Throttle	2600	204	100	55.30	676	33.8	14.6	2.53	0	0
	Biodiesel Blend 20%	Constant Torque	2000	170	62	35.61	460	39.6	7.21	0	1.89	0
		Constant Power	2100	160	67	35.00	436	37.3	7.53	0	1.97	0
	Biodiesel Blend 20%/LPG 40%	Constant Power	1900	175	56	35.00	444	39.6	5.55	2.53	1.45	0
	Diesel/LPG 30%	Constant Torque	2000	170	59	35.61	475	35.8	8.60	2.00	0	0
		Constant Power	2000	168	57	35.00	459	36.2	8.30	2.00	0	0
	Diesel/LPG 20%	Constant Torque	2000	170	64	35.61	500	35.0	9.20	1.37	0	0
John Deere	Diesel	Constant Speed	1710	400	-	14.88	450	23.3	4.59	0	0	0
	Biodiesel Blend 20%	Constant Speed	1705	400	-	14.83	439	22.5	3.58	0	0.89	0
	Diesel	Full Throttle	1100	75.8	100	8.70	395	24.5	2.28	0	0	0
	Microalgae Biodiesel Blend 20%	Full Throttle	900	76.2	100	7.20	390	25.5	1.83	0	0.45	0
Yanmar	Diesel	Full Throttle	3670	10.15	100	3.86	493	32.7	1.17	0	0	0
	Biodiesel Blend 50%	Full Throttle	3670	8.60	100	3.30	460	32.0	0.54	0	0.54	0
	Biodiesel 100%	Full Throttle	2900	10.45	100	3.20	439	34.0	0	0	1.03	0
Farymann	Diesel	Full Throttle	2100	19.45	100	4.28	505	27.43	1.62	0	0	0
	Biodiesel Blend 20%	Full Throttle	2000	18.95	100	3.98	515	25.29	1.22	0	0.32	0
	Diesel 80%/Ethanol 10%	Full Throttle	1800	18.79	100	3.55	466	27.54	1.07	0	0	0.13

Table 12. Fuel testing emissions summary emissions data.

Engine	Fuel Type	Test Type	Most Efficient Speed RPM	CO % vol	CO_2 % vol	HC 10-4 vol	O_2 % vol	NOx ppm	CO_2-e % vol
Hatz	Diesel	Constant Torque	1800	0.02	9.7	19	7.5	292	18.8%
		Constant Power	2100	0.02	9.1	1	8.5	324	19.2%
		Full Throttle	2000	0.14	12.5	0	3.6	342	23.4%
	Diesel/LPG 40%	Constant Torque	1600	0.10	9.3	61	7.3	328	19.7%
		Constant Power	1800	0.09	10.1	28	6.8	402	22.7%
		Full Throttle	2600	0.27	13.3	0	2.2	254	21.7%
	Biodiesel Blend 20%	Constant Torque	1800	0.03	10.0	12	7.4	316	19.9%
		Constant Power	1900	0.02	9.5	0	7.9	311	19.2%
	Biodiesel Blend 20%/LPG 40%	Constant Power	1900	0.09	9.3	54	7.7	349	20.3%
	Diesel/LPG 30%	Constant Torque	2000	0.08	9.8	35	7.1	311	19.6%
		Constant Power	2000	0.08	9.4	33	7.8	351	20.4%
	Diesel/LPG 20%	Constant Torque	2000	0.06	10.0	17	6.9	306	19.6%
John Deere	Diesel	Constant Speed	1710	0.27	11.13	-	4.96	994	42.5%
	Biodiesel Blend 20%	Constant Speed	1705	0.27	11.12	-	5.10	1003	42.8%
	Diesel	Full Throttle	1100	0.74	11.68	11	3.31	961	43.0%
	Microalgae Biodiesel Blend 20%	Full Throttle	900	1.13	11.50	9	3.80	1194	50.8%
Yanmar	Diesel	Full Throttle	3670	0.13	8.61	-	-	561	26.3%
	Biodiesel Blend 50%	Full Throttle	3670	0.13	-	-	-	500	-
	Biodiesel 100%	Full Throttle	2900	0.44	8.65	-	-	505	25.2%
Farymann	Diesel	Full Throttle	2100	2.04	10.0	179	4.8	188	19.9%
	Biodiesel Blend 20%	Full Throttle	2000	1.74	10.0	164	5.4	197	19.6%
	Diesel 80%/Ethanol 10%	Full Throttle	1800	1.20	9.8	152	6.3	213	18.8%

3.4. Field Testing

Field testing was conducted using different blends of biodiesel. The purpose of the testing was to evaluate the performance of these fuels in the field for power comparison and any other problems that might occur in practice.

3.4.1. Drawbar and PTO tests

Understanding tractor performance is important to the cotton industry because of the heavy reliance on tractor for field work. Prior to field testing described in Section 3.4.2, tests were carried out using equipment at the University of Southern Queensland. The testing used a Belarus 920, which has a naturally aspirated 74.5 kW engine. Engine performance was first mapped using a NEB 400 dynamometer (AW Dynamometers Inc., 2014) driven by the tractor PTO. A full gas analysis was conducted at this time. Following this, the tractor was tested under a drawbar load test as defined in ASAE S209.5 *Agricultural Tractor Test Code*, which aims to measure the drawbar power of the tractor. Emissions were also measured during the test.

PTO tests

Different blend of biodiesel were tested using a NEB 400 dynamometer (AW Dynamometers Inc., 2014): diesel, B50 and B100. These test resulted in no significant difference in power between the different fuels (figure 20). Brake specific fuel consumption (BSFC) is millilitres of fuel used per kilowatt of power produced; it is a measure of the efficiency of the fuel. Figure 21 shows that B50 and B100 each use slightly more fuel per kilowatt produced. This is consistent with the slightly lower energy density of these fuels.

Carbon dioxide emissions (CO2) were progressively less for B50 and B100 when compared to diesel (figure 22). Similarly, carbon-monoxide (CO) emissions were progressively lower for B50 and B100 when compared to diesel (figure 23). Nitrous Oxide emissions (NOx), shown in figure 24, increase with the use of B50 and B100 when compared to diesel. These emissions also increase with engine rpm. These results are consistenet with the laboratory tests summarised in section 3.3.

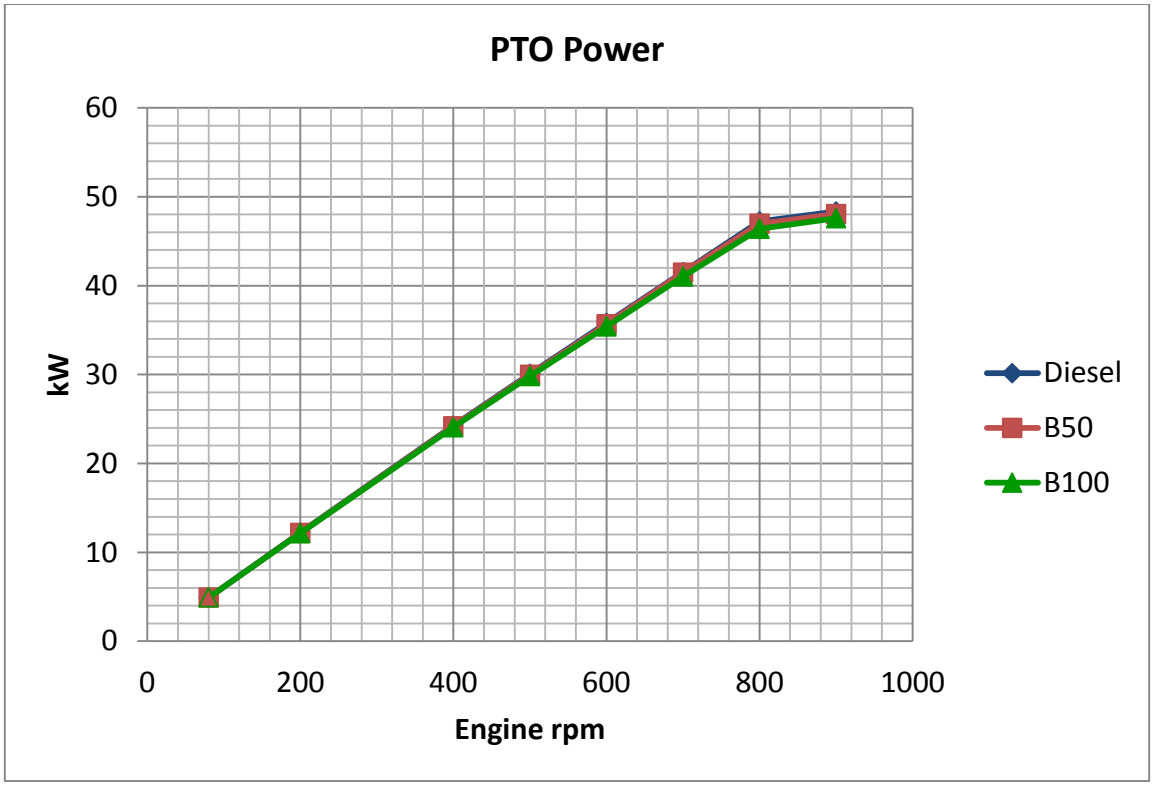


Figure 20. PTO Power test, diesel, B50 and B100.

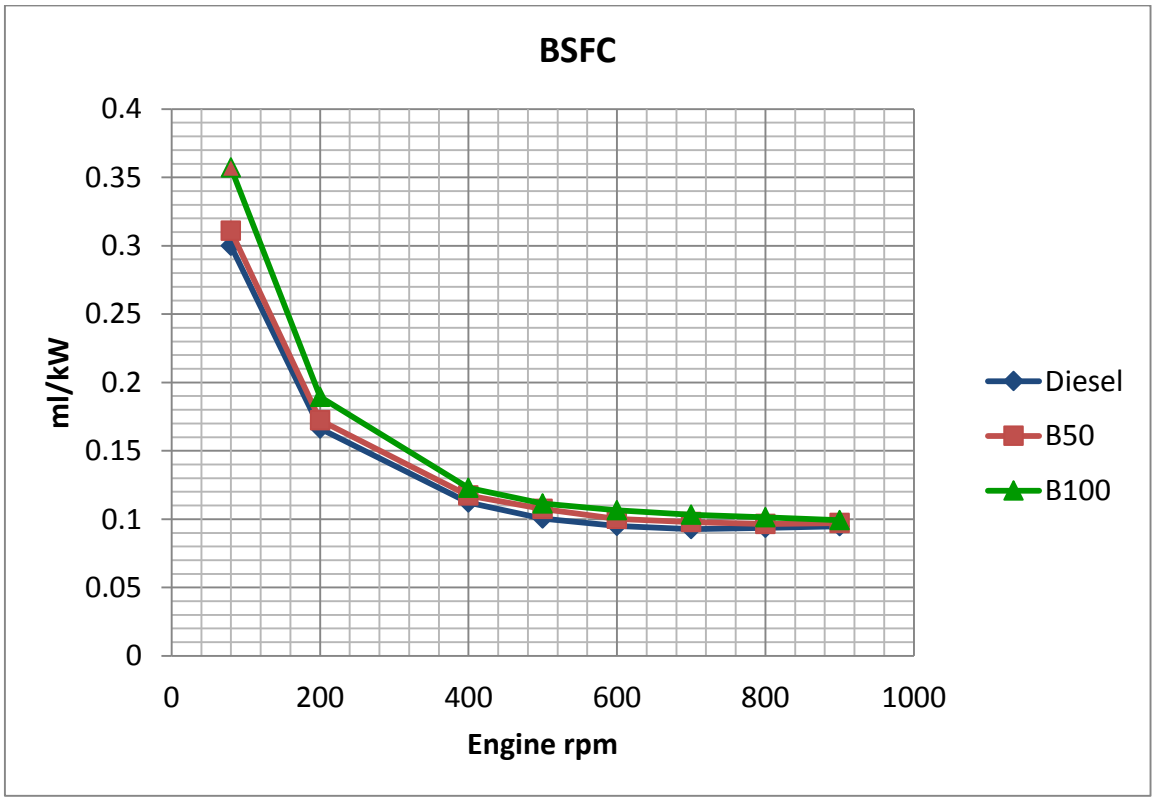


Figure 21. Brake Specific Fuel consumption [ml fuel /kW] for diesel, B50 and B100.

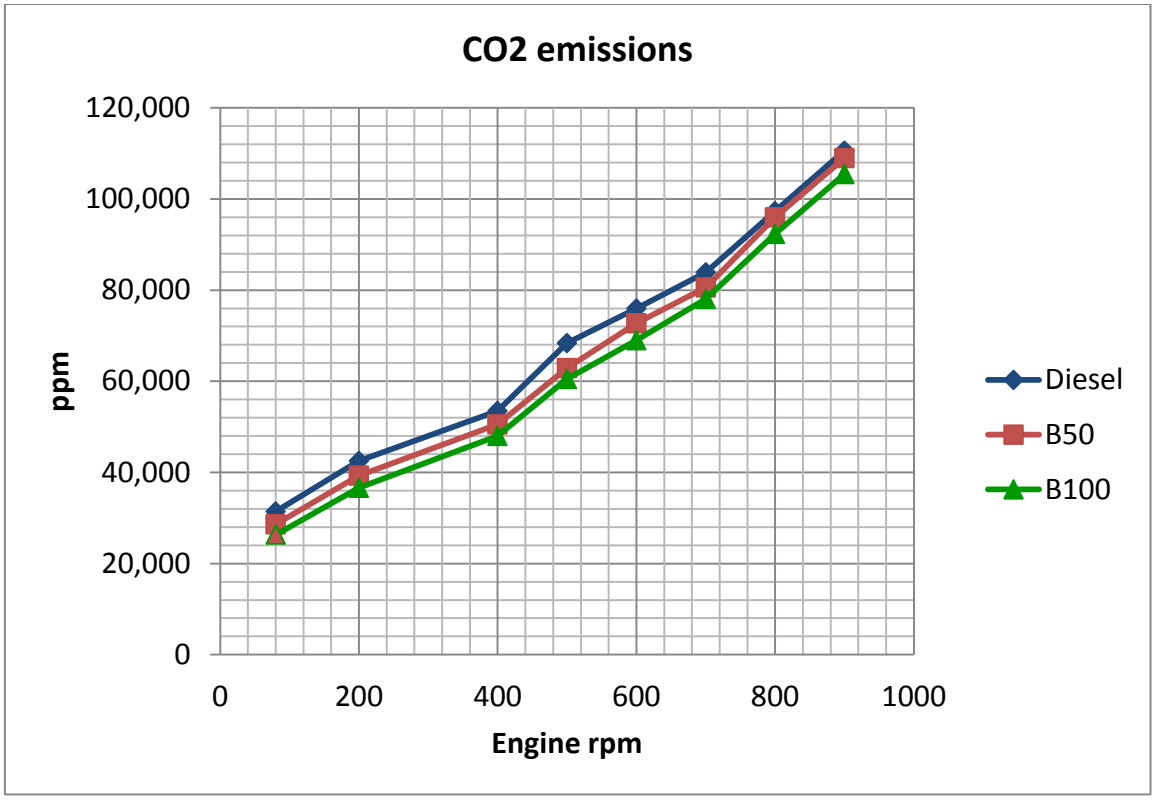


Figure 22. CO2 emissions [ppm] for diesel, B50 and B100.

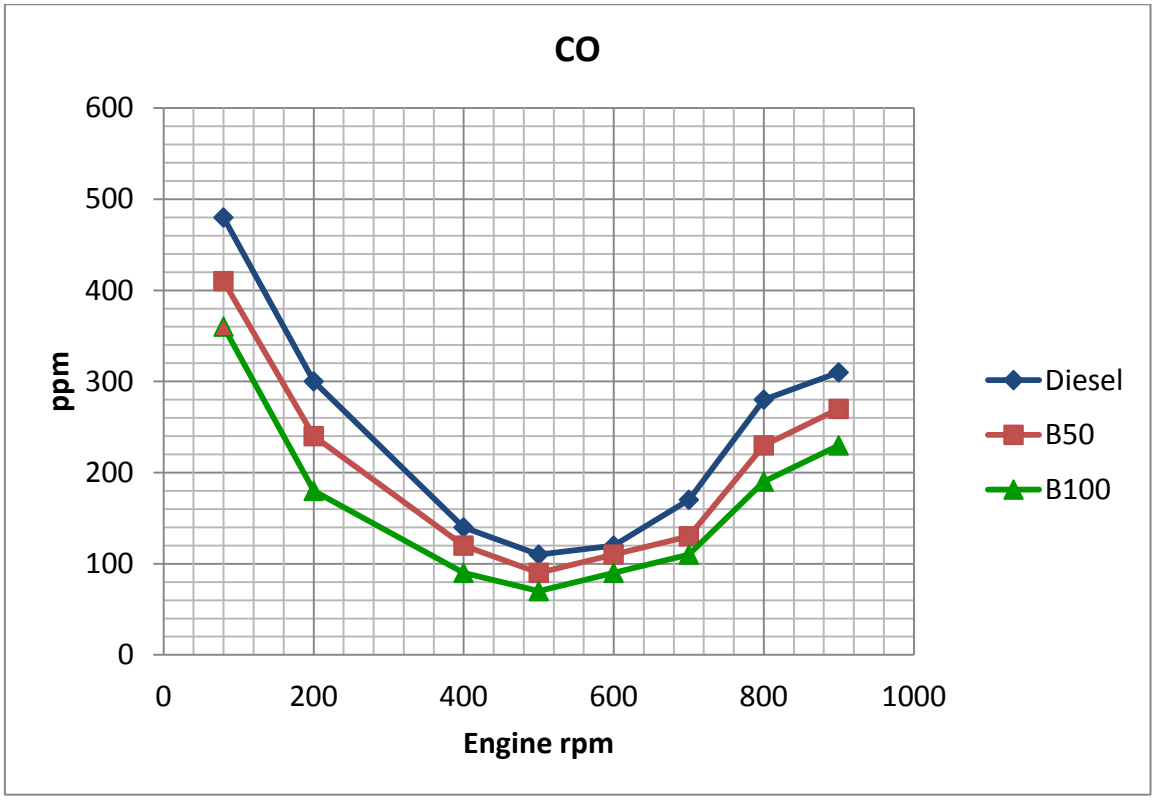


Figure 23. CO emissions [ppm] for diesel, B50 and B100.

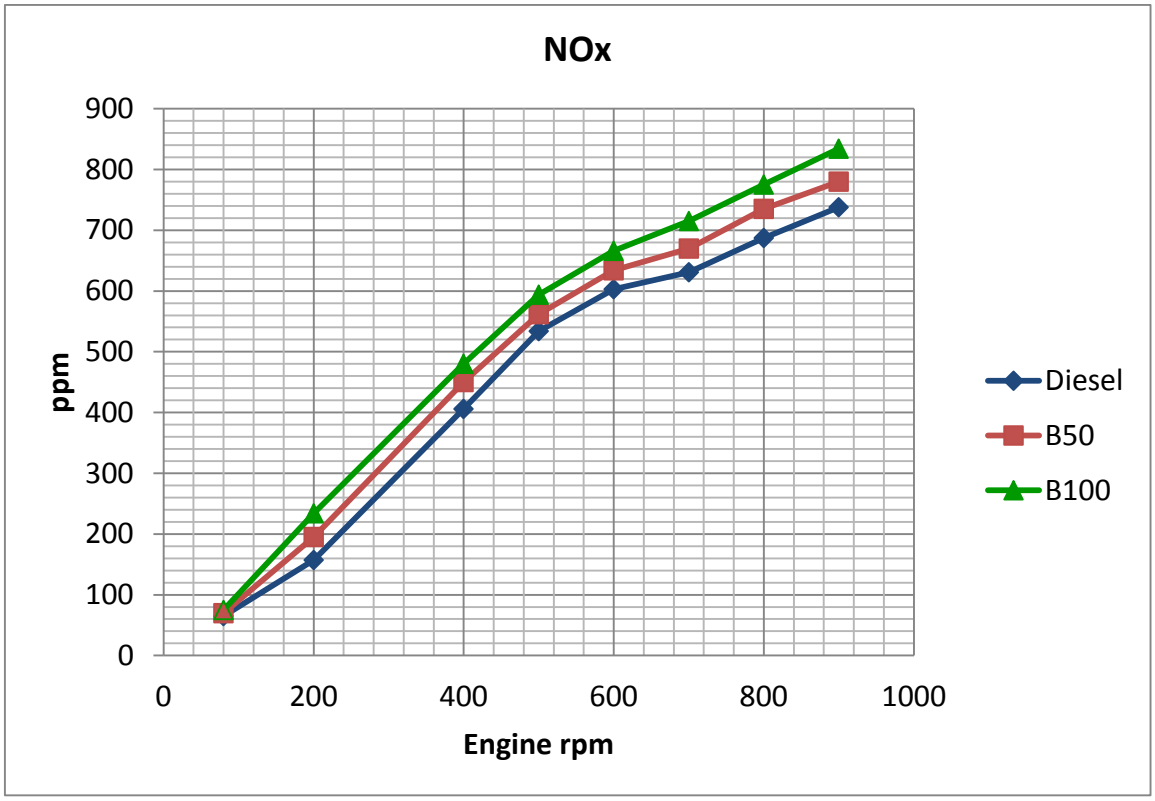


Figure 24. NOx emissions [ppm] for diesel, B50 and B100.

Drawbar testing methodology

Having completed testing of the engine via the PTO dynamometer, the tractor was examined in the field using a drawbar test according to ASAE S209.5 *Agricultural Tractor Test Code*. This is a standard tractor testing practice where a second, larger tractor is connected to the test tractor and is used to apply a load to the test tractor. This apparatus is shown in figure 25; the test tractor is left of picture and the load tractor is on the right. By selecting a slightly lower speed in the load tractor than in the test tractor, the test tractor must pull the load tractor, thereby inducing a consistent load on the test tractor. The method is chosen over a plough or other draft implement because the load is controllable, constant and repeatable. Conversely, a draft implement might strike harder and softer patches of ground and so the load applied to the tractor is not constant.

A portable Coda gas analyser (Coda Products, 2014) was used to measure the exhaust Gas emission for the test tractor. Two McNaught M006 fuel flow meters were used to measure fuel inflow and return flow in the test tractor. The output was recorded on a Campbells 1000 data logger. Ground speed was measured using the ground speed radar fitted to the load tractor.

During each 100 meter test run, the test tractor was driven in the same gear. The load tractor was driven in different gears to apply three different loads. Thus, different drawbar loads were applied on the test tractor for each 100 m test. This combination of gear selection in the load tractor allowed the test tractor to operate at 5.8 km/h, 4.8 km/h and 4.0 km/h, which were termed light, heavy and very heavy, respectively. Three repetitions for each speed were made.

Figure 25. Drawbar test apparatus.

The fuel consumption rate was measured for three different blends of cotton seed oil biodiesel (B100, B50, B20) and for diesel. An auxiliary fuel tank was fitted to supply the alternative fuels to the tractor. For each fuel blend, the tractor was started and allowed to warm up for several minutes to ensure that the new fuel was flushed through the system.

Drawbar testing results

Soil conditions affect traction performance and these were measured as part of the trial. These results are shown in table 13. The soil was a Red Ferosol, clay-loam at the Agricultural Plot, USQ.

Table 13. Drawbar test soil properties

soil profile	Bulk Density (ρ) (gm/cm^3)	Soil water content %
0-10 cm	1.26	10.5 %
10-20 cm	1.27	18.6 %
20-30 cm	1.30	18.8 %

Figure 26 shows fuel consumption [l/hr] for the different fuels under different loads. Recalling that an increasing load resulted in a reduced ground speed, this figure shows that fuel consumption increases in proportion to load for all fuel types. Figure 26 also shows that an increasing blend of CSO increased the amount of fuel required due to a slightly lower calorific value.

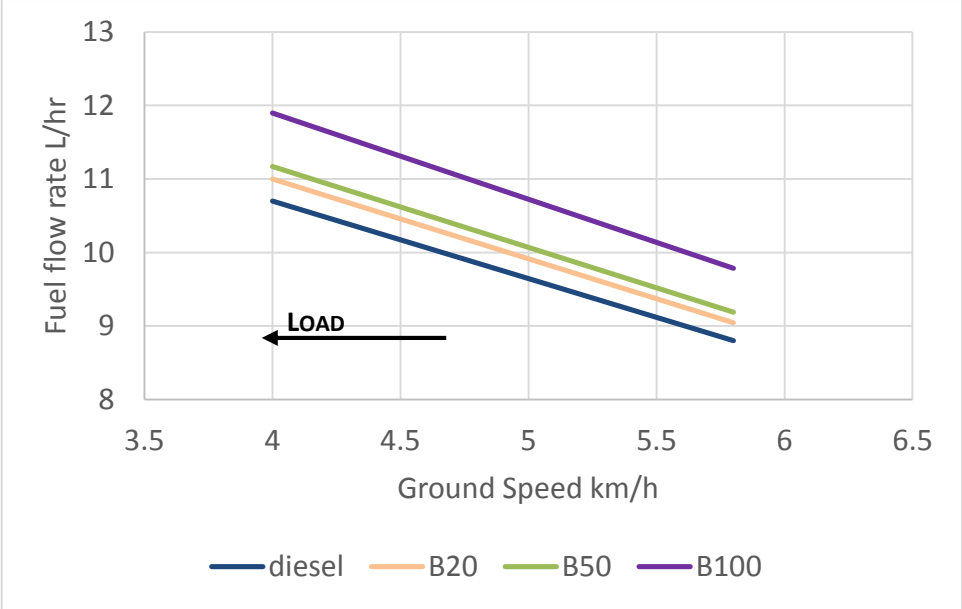


Figure 26. Fuel consumption rate [L/h] for the drawbar test.

Both carbon monoxide (CO) and carbon dioxide (CO2) emissions were lower for biodiesel, which is presented in figures 27 and 28 respectively. This is consistent with the PTO test conducted on the same tractor (figures 22 and 23). Emissions of nitrous oxides (NOx), presented in figure 29, were lower for light blends of biodiesel but increased as the proportion of biodiesel increased and as load increased. This is reasonably consistent with the PTO test conducted on the same tractor (figure 24).

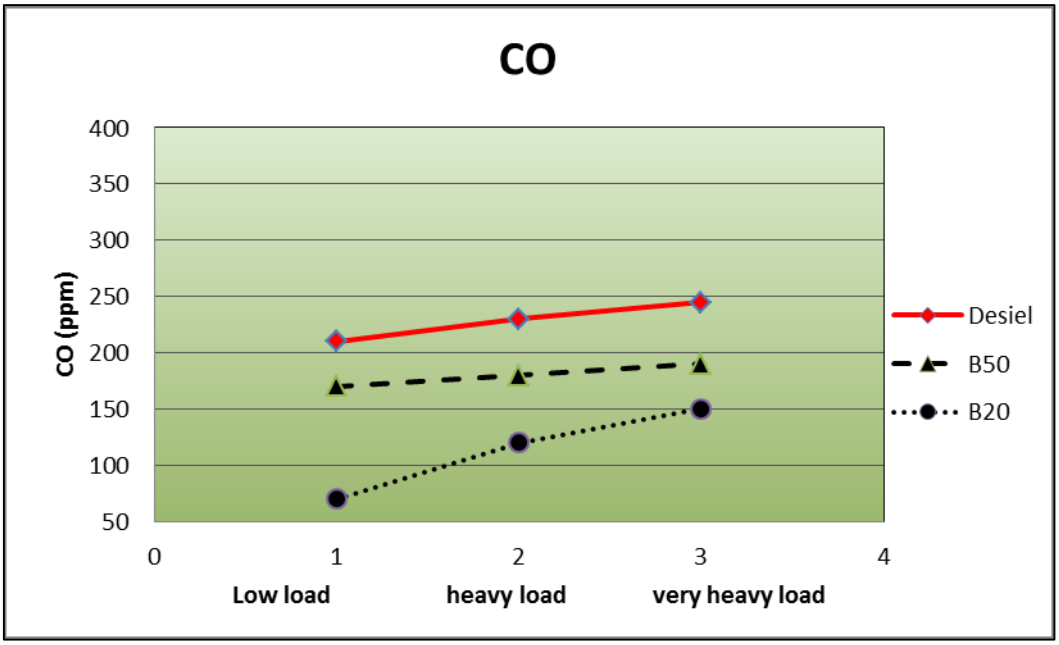


Figure 27. Carbon monoxide emissions for diesel, B20 and B50 in drawbar testing.

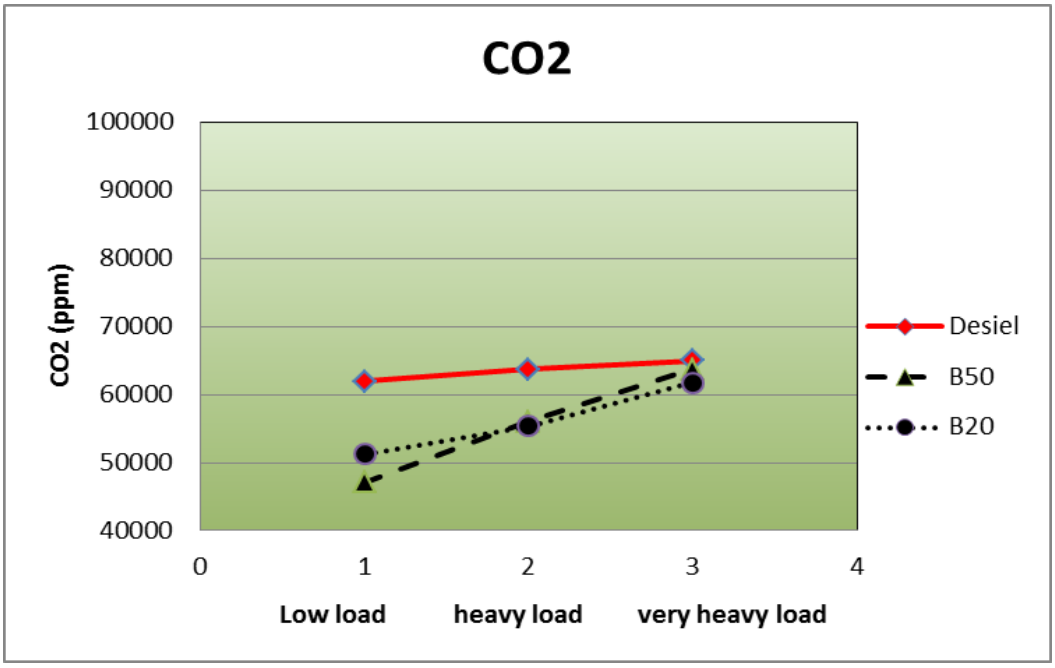


Figure 28. Carbon dioxide emissions for diesel, B20 and B50 in drawbar testing.

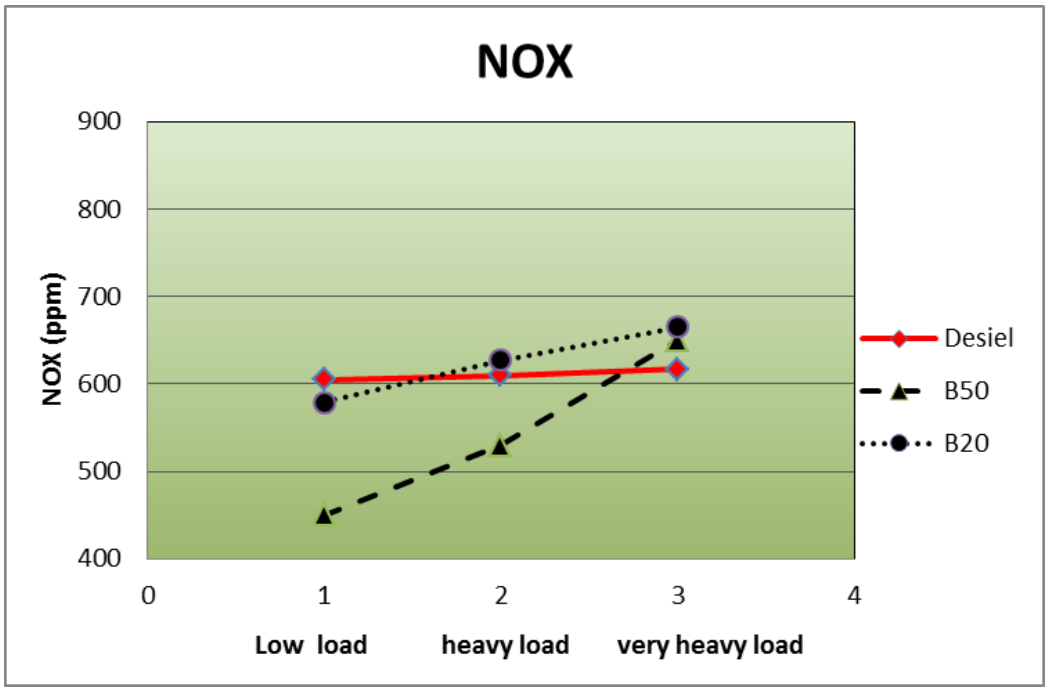


Figure 29. Nitrous oxide emissions for diesel, B20 and B50 in drawbar testing.

The test results from the in-field testing are consistent with the PTO test results on the same tractor (section 3.4.1) and the laboratory tests (section 3.3.1).

3.4.2. B20 and diesel fuel use for deep ripping

The performance of B20, compared to diesel, was investigated with Kim and Andrew Bremner at their farm near Dalby, Queensland. A 2010 John Deere 8220, which has an 8.1 litre, turbo charged engine with a rated power of 225 kW (167.8 hp). The tractor was fitted with a 4.0 m wide fixed-tyne ripper.

The biodiesel is produced from tallow. Both the diesel and the B20 was sourced from Shell Australia. The tallow biodiesel used in the experiment is the same batch of B20 tallow that was tested in the laboratory.

Minimum delivery of this fuel is normally 8,000 litres, which is the capacity of a compartment in a commercial fuel tanker. (However, a smaller volume of 500 litres was sourced for this test.) The Brisbane Terminal Gate Price (TGP) (Australian Institute of Petroleum, 2014) on the day of purchase, including GST and before rebate, was 139.721 ¢/litre for diesel, 137.521 ¢/litre for B20 (and 128.721 ¢/litre for B100).

Tests were conducted at a range of cultivation depths over a range of ground speeds. Fuel use was measured using a McNaught 009 flow meters each for fuel inflow and return flow. The output was recorded on a Campbells 1000 data logger. Ground speed was measured using the ground speed radar fitted to the tractor.

Testing was conducted on a heavy black cracking clay soil which had a low soil moisture. Testing was conducted using a randomised complete block design.

Figure 30, below shows the change in diesel fuel use [litres per hectare] as ground speed is changed. The darker set of lines present the results of 1830 engine rpm while the lighter set of lines show fuel use at 2300 engine rpm. These speeds are nominal rpm; the maximum throttle setting was set while the engine was under no load. While in operation, actual engine rpm during the tests was slightly lower than these nominal maximum settings due to governor response. Also shown in figure 30 are three different tillage depths: 350 mm (triangles), 250 mm (circles) and 200 mm (stars).

It can be seen from figure 30 that reducing engine rpm reduces fuel consumption per hectare. Increasing depth has a large effect on fuel use per hectare and increasing ground speed reduces fuel consumption per hectare.

These trends are maintained when a total cost of cultivation [$/Ha] is calculated. Using an hourly operating cost, excluding fuel, of $60.00 per hour (wages $35, depreciation $15, finance $5 and R&M $5), assuming a turn time of 60 seconds and fuel consumption results from the trial with the length of the field of 850 meters, total cost per hectare is calculated and presented in figure 31.

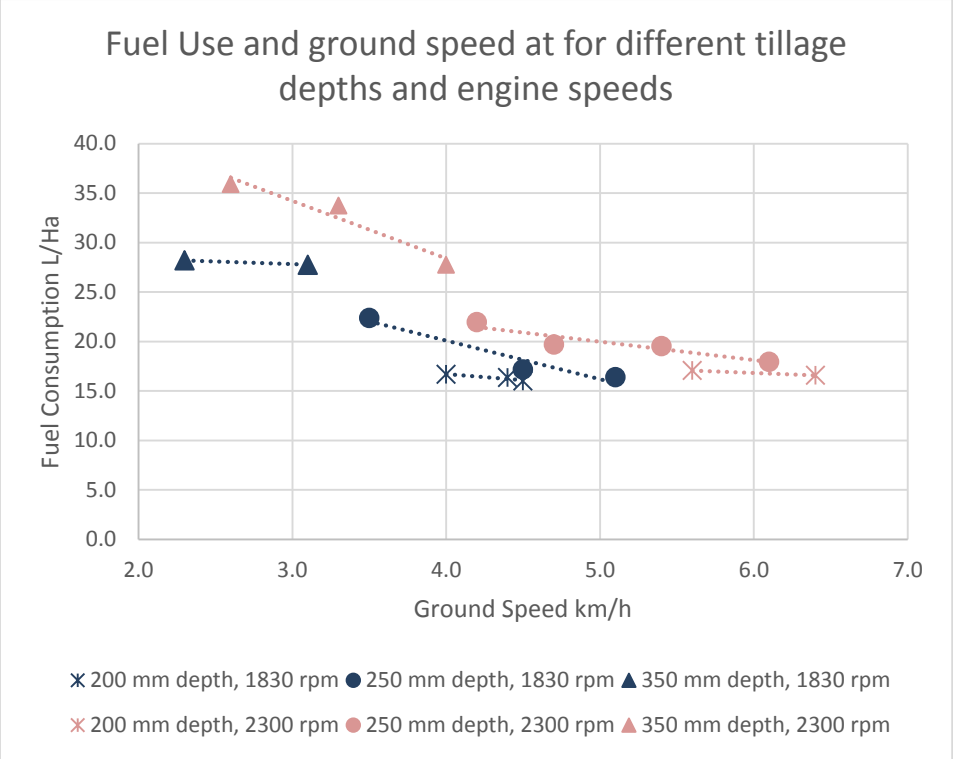


Figure 30. Field Testing diesel fuel use at different ground speeds and tillage depths.

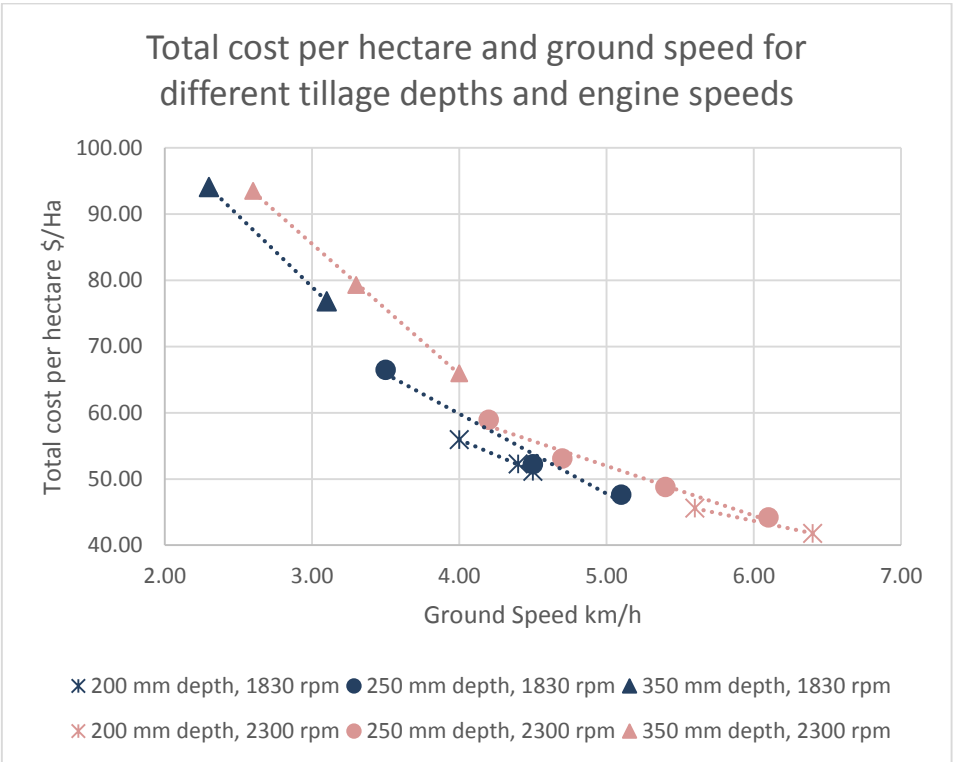


Figure 31. Total cost per hectare and ground speed at for different tillage depths and engine speeds.

Once the diesel tests were complete the tank of the tractor was drained and filled with B20. The same process was repeated with B20 fuel. Note that there was a delay of approximately one week between the tests due to delays in sourcing the B20 fuel. There was a light fall of 10 mm of rain during this time. The results for 200 mm and 350 mm cultivation depths at 2300 engine rpm and 1850 engine rpm are presented below in figures 32 and 33, respectively.

The previously stated cost assumptions were maintained for B20. The total cost [$/Ha] of B20 is compared to diesel for 200 mm and 350 mm cultivation depths at 2300 engine rpm. This is presented in figure 34. Similarly, the cost difference for B20 and diesel, without any other costs, was calculated and is presented in figure 35.

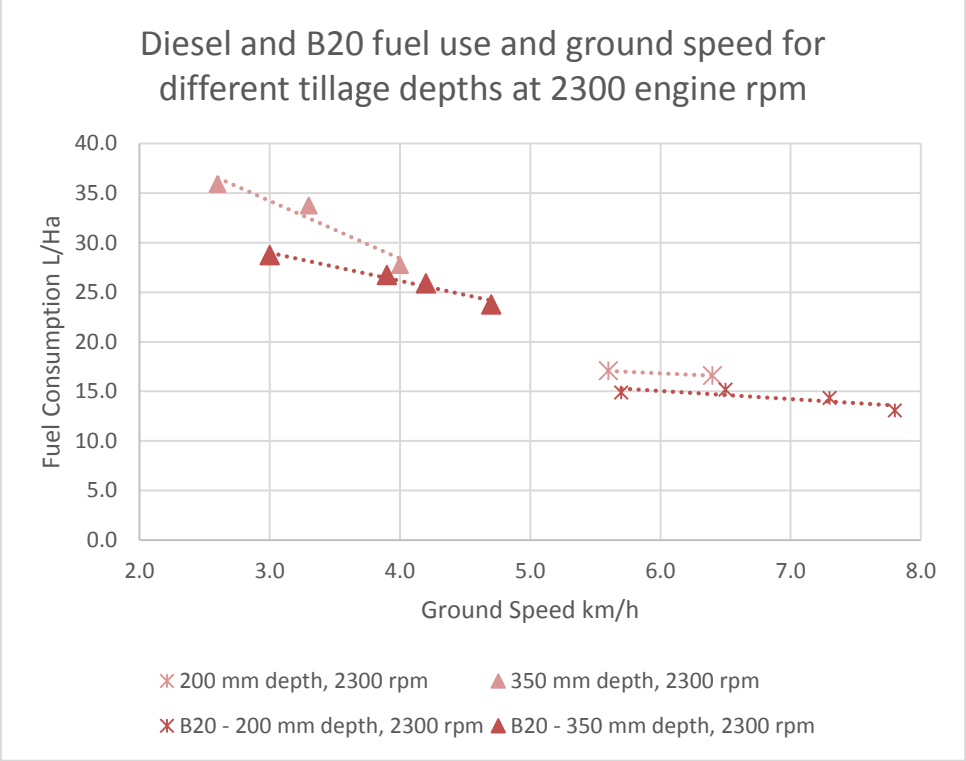


Figure 32. Diesel and B20 fuel use and ground speed at for different tillage depths at 2300 engine rpm.

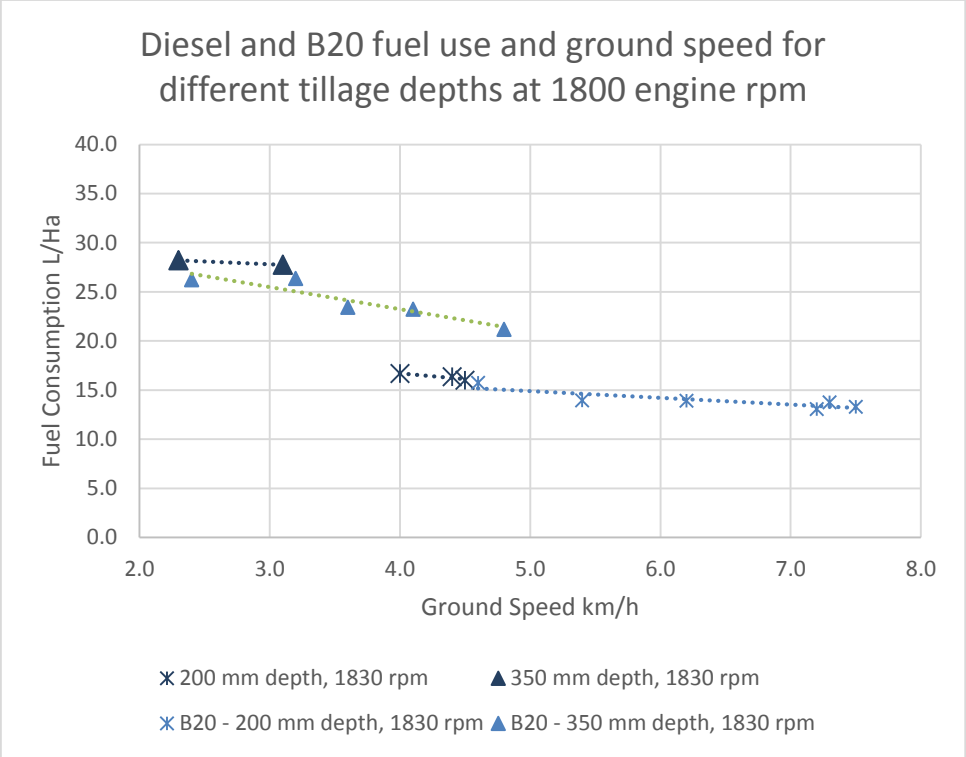


Figure 33. Diesel and B20 fuel Use and ground speed at for different tillage depths at 1800 engine rpm.

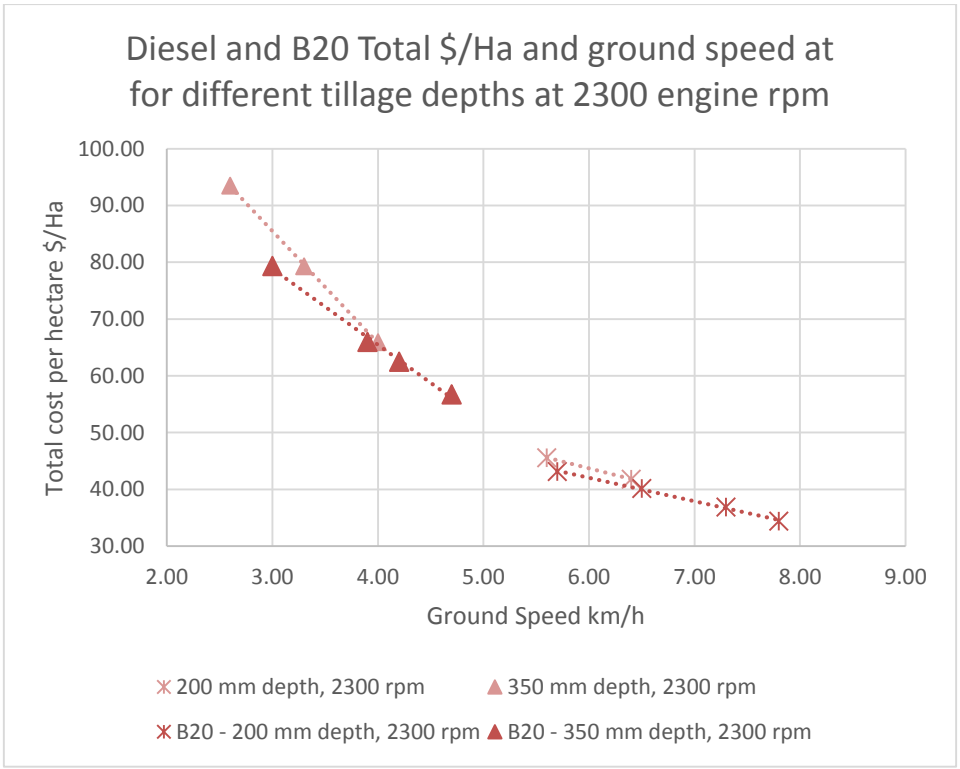


Figure 34. Diesel and B20 Total $/Ha and ground speed at for different tillage depths at 2300 engine rpm.

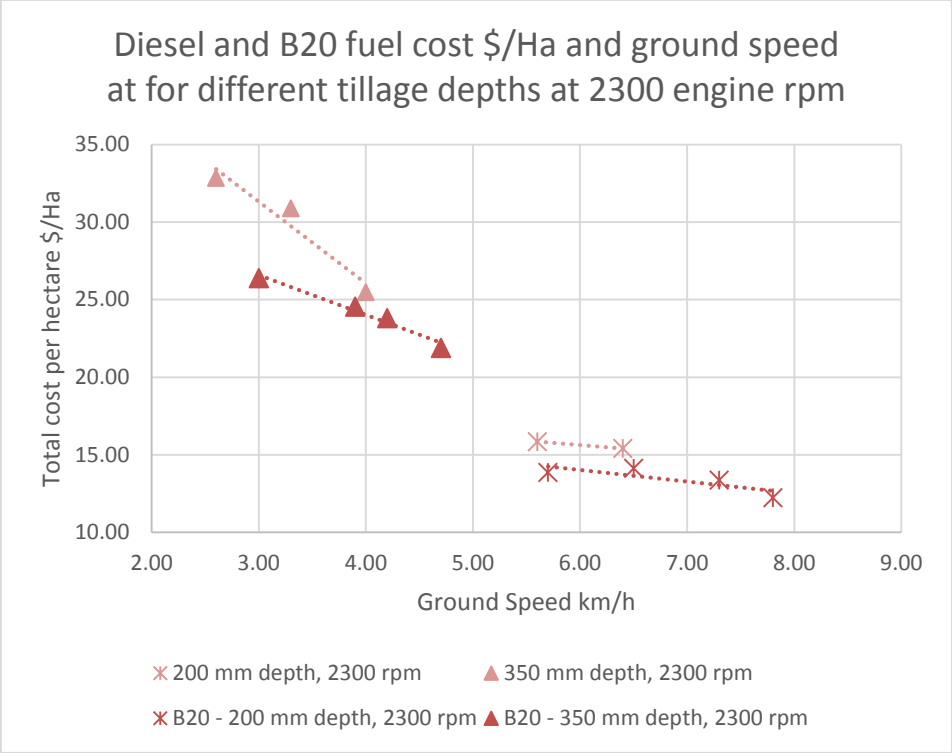


Figure 35. Diesel and B20 fuel cost $/Ha and ground speed at for different tillage depths at 2300 engine rpm.

These results show that slightly less B20 was used when compared to diesel. This is counterintuitive to what would be expected as B20 has a slightly lower calorific value than diesel. This unexpected difference may be explained by the 10 mm of rainfall between the two tests, making conditions slightly more favourable for the B20 tests. All other trends were identical to diesel. There is very little difference in cost between B20 and diesel.

Importantly, there were no immediate operational issues with using B20. However, this was a very short-term experiment.

3.5.Policy and Tariff Issues

Energy is fundamental to modern economy and society. Reliable and efficient energy supply underpins economic activity. Nearly 90% of energy source for cotton production is supplied from liquid fuel (figure 12).

In recent years, there have been significant changes in the Australia's energy sector. These include:

- Australia's growing reliance on oil importation
- The gas sector is rapidly evolving unconventional gas resources and liquefied natural gas (LNG) markets on the east coast
- The investment environment in the electricity sector, particularly in the context of renewable energy policies and tariff reform.
- There has also been a significant change of government policy in the last 3 years. These have included:
- Carbon tax introduced by the Labor Government has now been abolished, and replaced by "direct action" plan of the Coalition Government.

- The target of emission reduction has been significantly adjusted by the Coalition government.

3.5.1. Diesel

The supply of oil in Australia is already on the decline and Australia is becoming increasingly dependent on imported oil and petroleum products. About 85 per cent of Australia's transport fuel now comes from overseas. Driven by global demand and also political uncertainty in the Middle East, the world crude oil prices may remain high in the foreseeable future.

The Australian Government enforces excises on petrol and diesel. These excises are levied in order to raise revenue, and also to recover the costs they impose on society, such as wear and tear on road pavements and air pollution. Currently, businesses using petrol and diesel as inputs into production processes pay excise of 38.143 cents per litre. Under the fuel tax credits scheme, cotton growers can claim a rebate of the excise that they have paid for the portion of these fuels that are not consumed on public roads. For example, pumping water or in-field tractor operations. In 2010-11, the value of these credits amounted to $5.1 billion (Webb, 2012). The main industries were mining ($2.031 billion), transport, postal and warehousing ($988 million), and agriculture, forestry and fishing ($646 million).

Information on fuel tax credits can be found at the Australian Taxation Office (2014a). *Quick Code: QC18875, Can your business claim fuel tax credits?* or by searching for 'QC18875' at ato.gov.au

3.5.2. Liquid Petroleum Gas (LPG)

The value of LPG industry in Australia is currently around $3.5 billion.

From 1 July 2013 no duty for non-transport gaseous fuels is claimable. This is also found under QC18875. LPG installation rebates for all vehicles were also phased out in 2013.

3.5.3. Coal Seam Gas (CSG)

Coal seam gas is predominantly methane gas stored within coal deposits or seams. Coal seam gas is formed as part of the same natural processes that produced coal over millions of years.

The conversion of an engine to CNG is around $4,000. This means it will need to run 50,000 to 100,000 km to recover the capital cost. Professionally qualified commercial suppliers are able to design a system that avoids engines occasionally de-rating and backfiring and maintains engine reliability. For irrigation pumps, the payback period has earlier been estimated to be about 2 years using CNG and 4 years using LNG (Yusaf et al, 2010). The conversion cost for LNG would be around $6,000.

In many communities, there are concerns over the impact of coal seam gas mines on water supplies and possible impacts on crop lands. A recent CSIRO survey of 400 Queensland's Western Downs residents indicated that "Fifty per cent of people think their community is struggling to cope with coal seam gas development" (Walton, 2014). This is similar to the farmer survey finding of this project which indicates that "CSG had the highest level of resistance. There is no current use. 57% of farmers also rate it as not an option and a further 4% state that it has potential, but I would not use it". However other authors, such as Bialek (2014) state that "in order to mitigate against climate change, apart from increasing the uptake of renewables, replacing coal with gas, is also identified as an important and less expensive option."

3.5.4. Biodiesel

Fuel tax credits for fuel blends are prescribed by the Australian Taxation Office (2014b). *Quick Code: QC25200, Fuel tax credits – fuel blends*. The relevant points of this legislation are that:

- For blends of biodiesel and diesel that are invoiced as B5 or B20, the effective fuel tax of 38.143 cents per litre is calculated as if the fuel is entirely diesel.
- There is no fuel tax credit claimable on straight biofuels (B100) because there was effectively no fuel tax paid on the fuel.
- If a fuel blend that is not invoiced as B5 or B20 the fuel tax credit rate will be dependent on the blend ratio and calculated on the diesel component only.

It was recently announced that this scheme will stop operating from July 1, 2016, five years earlier than a previous 2021 time-frame.

3.5.5. Biogas

Biogas is a combustible gas derived from decomposing biological products and waste in the absence of oxygen.

There are no tariffs payable or claimable on biogas.

3.5.6. Algae fuels

Feasibility studies are being carried out at CSIRO and other organisations around Australia to examine the quantity and quality of potential algal resources from ponds and bioreactors, and sources of algae from locations such as waste water facilities, algal blooms and seaweed.

Overall, algal biofuel is still in the research stage and not yet commercially available. The costs are currently high, and there is a lack of a user base for growing and harvesting the algae.

The fuel exercise and production grant applicable to other biofuels are also available for algal biofuel.

3.5.7. Alcohol fuels

Fuel tax credits for fuel blends are prescribed by the Australian Taxation Office (2014b). *Quick Code: QC25200, Fuel tax credits – fuel blends*. The relevant points of this legislation are that:

- For blends of ethanol and petrol that are invoiced as E10, the effective fuel tax 7.6 cents per litre is calculated as if the fuel is entirely petrol.
- There is no fuel tax credit claimable on straight ethanol fuels (E100) because there was effectively no fuel tax paid on the fuel.
- If a fuel blend that is not invoiced as E10 the fuel tax credit rate will be dependent on the blend ratio and calculated on the petrol component only.

It was recently announced that this scheme will stop operating from July 1, 2016, five years earlier than a previous 2021 time-frame.

4. Electrical energy

Currently in Australia, grid-supplied electricity is mostly generated from fossil fuels (mostly coal or gas). Renewables contributes 8% to 10% of Australian electricity generation, mostly by hydro-

electricity, bagasse (sugar cane waste), wood and wood waste, and increasingly wind energy and solar energy etc.

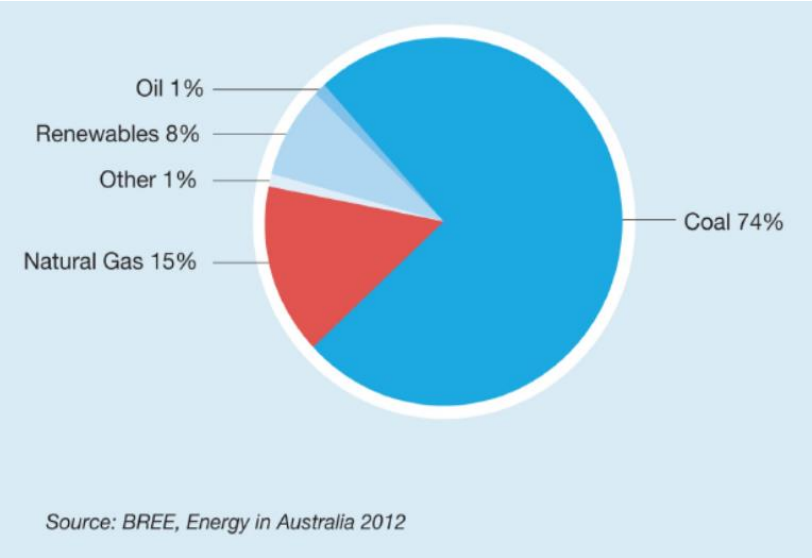


Figure 36. Sources of energy in Australia, Bureau of Resources and Energy Economics (2012)

Electrical energy is currently used in both cotton ginning operations and some pumping operations. The cost of electricity to the Australian cotton industry is estimated to be in excess of $12 m annually. Ismail et al (2011) also found that electricity use (kWh) for ginning each bale of cotton was between 44-66 kWh, with national average around 52.3 kWh.

Electricity is a common power source for agriculture. Compared with fuels, electricity is a high grade energy and is clean for on-site use. It is a high emissions energy source. Electricity is also generally not suitable for mobile plant. It has prohibitive capital cost if it is located further from the grid. Because of this, the policy and tariff of electricity can significantly influence the risk of future investment.

Electricity tariffs are based on the concept that the users will pay not only for the amount of energy consumed, but also for the use of the distribution and metering equipment that connects the load to the supply system. Thus, the fees charged for electricity uses will typically consist of energy costs, network costs, and metering and service costs including both demand charge and service fee. The network costs may make up 50% of the total electricity costs.

Overall, there are three broad types of tariff available:

- General tariff: all electricity use is charged at the same “unit charge” rate. Currently, the most common residential electricity tariff is tariff 11 which is approximately 23 c/kWh. This tariff can be the best option for small residential electricity users and also for some irrigation pumping. This tariff may be used in conjunction with a “controlled load”.
- Time of use tariff (TOU): charges will depend on the actual time that power is being consumed. Generally, electricity consumed in the off-peak period will be considerably cheaper (14 cents/kWh) than electricity consumed in the peak period (40 cents/kWh). This allows the customer to take advantage of cheaper off-peak electricity and benefit from lower electricity costs. To use this tariff, polyphase meters (smart meters) with TOU capability will need to be installed to record both the time and kilowatt hours used. The

demand charge is around $22 per kW per month, plus a daily service fee etc. Currently, the gross retail margin between the retailer's price and its wholesale supply cost (in c/kWh) is around 30% (Essential Services Commission, 2013). This is in comparison with the gross margins for TOU tariff rates of 11-14%.

- Demand based tariffs which are charged both on actual total kWh used and also the rate at which that energy is consumed (kW or kVA demand). The consumption charge is usually at a low rate (13 cents/kWh) when compared to the General and Time of use tariffs, but the Demand charge ($38 per kW demand per month) is high to encourage consumers to avoid large peaks and therefore underutilise the infrastructure provided. If power is used wisely or control measures used, demand tariffs are often the most economical solution for medium to large customers.

If a customer is using less than 50 MWh pa, then they are regarded as a retail customer, currently paying around $60/GJ. If he uses more than 50 MWh p.a. then he can become a 'contestable customer', which means they he can buy electricity on the wholesale market and would pay the electricity at a cheaper rate in the region of $40/GJ. If he consumes more than 100 MWh p.a., then he must move to a larger business plan or non-standard contract. These contracts will contain different terms and conditions to a 'standard' contract and may include variations in price, fees, charges, contract length, payment options and early termination and exit fees. This has implications not only in the cost of power purchase but also on the income received from power generated and sold to the grid.

Australia's electricity prices have increased by 80% in the last 5 years. A significant proportion of it may be due to the upgrade of network infrastructure and new metering service costs. Other additional costs were the State and Federal "green" schemes such as the renewable energy target schemes, feed-in tariffs and energy efficiency schemes.

Increasing grid electricity price has been a major problem facing the Australian cotton industry for the last couple of years which is competing with 75 other cotton producing countries (some of them are subsidized cotton production). The abolition of carbon tax will reduce the electricity prices. However, electricity price is still predicted to rise in the next couples of years. This was predicted to be around 1.2 per cent a year for the three years from 2012/13 to 2015/16 by the Australian Energy Market Commission (2013).

4.1.Available options

4.1.1. Solar Photovoltaic (PV)

Renewable energy is a source of energy which is naturally occurring and inexhaustible. Solar photovoltaic (PV) converts sunlight directly into electricity using photvoltaic cells. PV systems can be installed on rooftops, integrated into building designs and vehicles or scaled up to megawatt scale power plants. Figure 37 (Geoscience Australia and Bureau of Resources and Energy Economics , 2012) shows the energy flows in solar PV production. Currently, commercial photovoltaic efficiency typically ranges from 10% to 18%. Depending on feed-in tariffs and locations, photovoltaics currently may require between 4 and 10 years to recoup their investment and 2 to 3 years to recoup the energy used in their manufacture.

Figure 38 shows a simplified map of average solar radiation in Australia.

Recent research is also enabling progress toward achieving 20% to 25% and up to 30% efficiency. Research is also being conducted to manufacture solar cells from more plentiful, cheap and non-toxic materials. With the new technologies currently under development, electricity generation costs from solar energy are expected to fall significantly in the future as shown in figure 39.

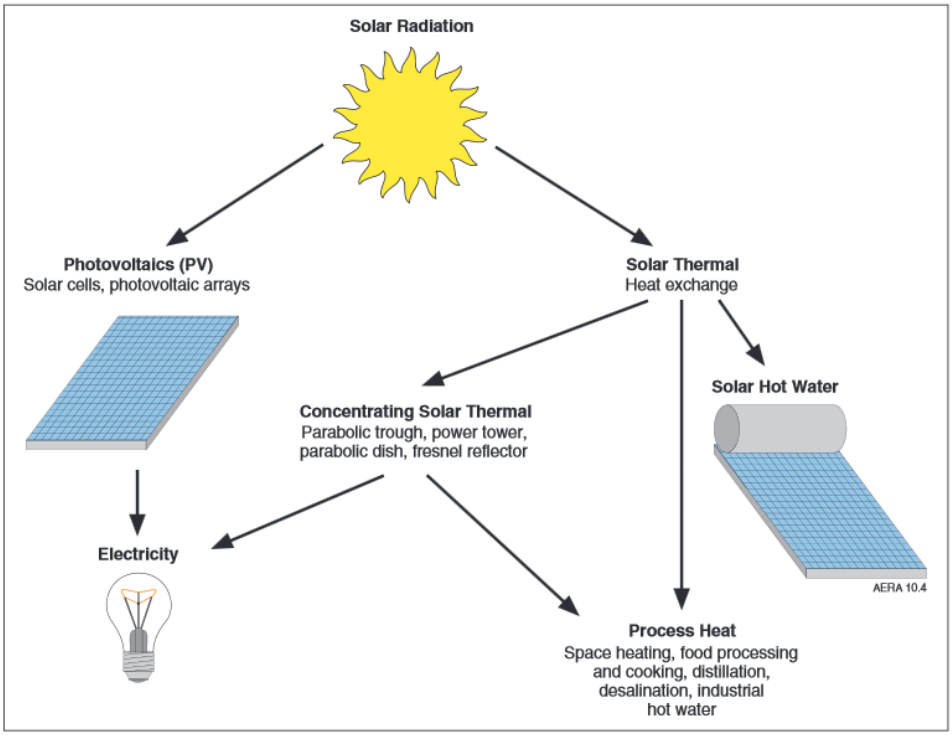


Figure 37. Solar energy flows, Geoscience Australia and Bureau of Resources and Energy Economics, 2012.

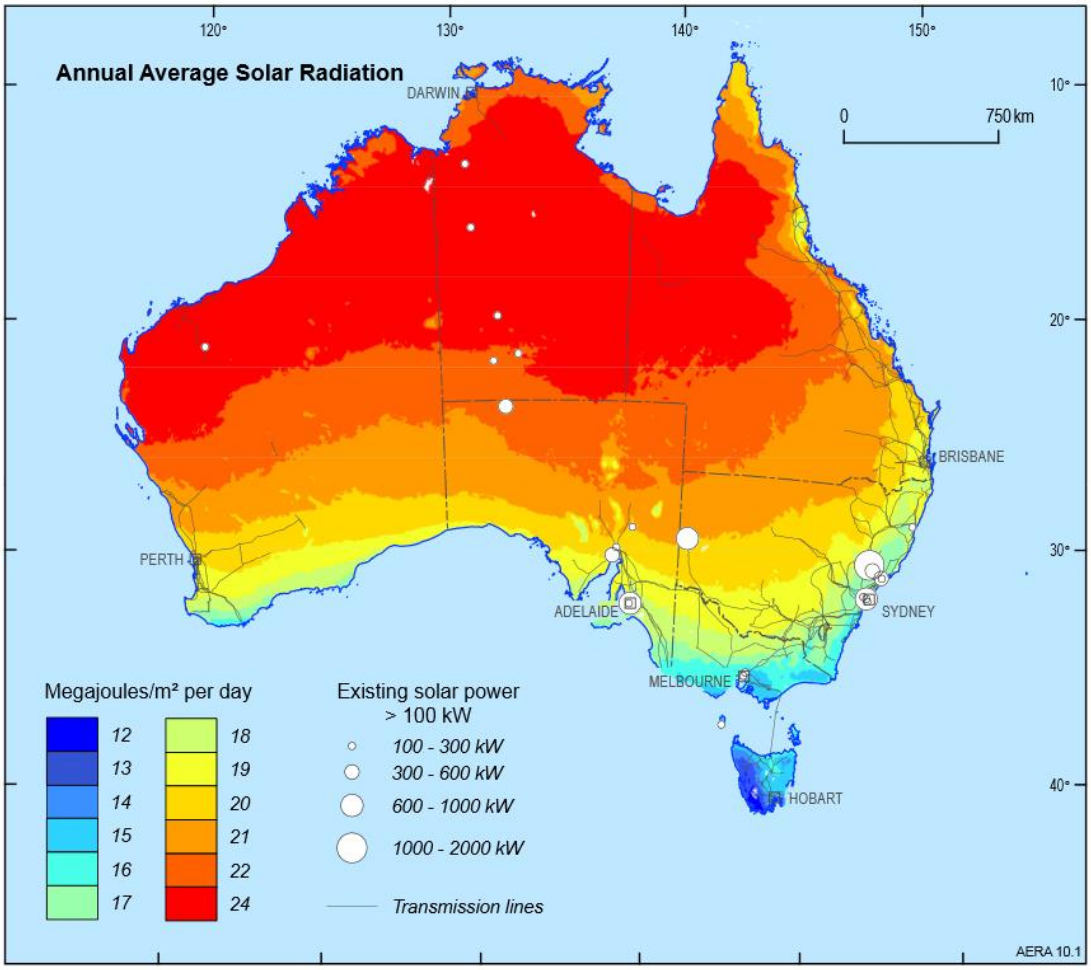


Figure 38. Average solar radiation in Australia, Geoscience Australia & Bureau of Resources and Energy Economics, 2012

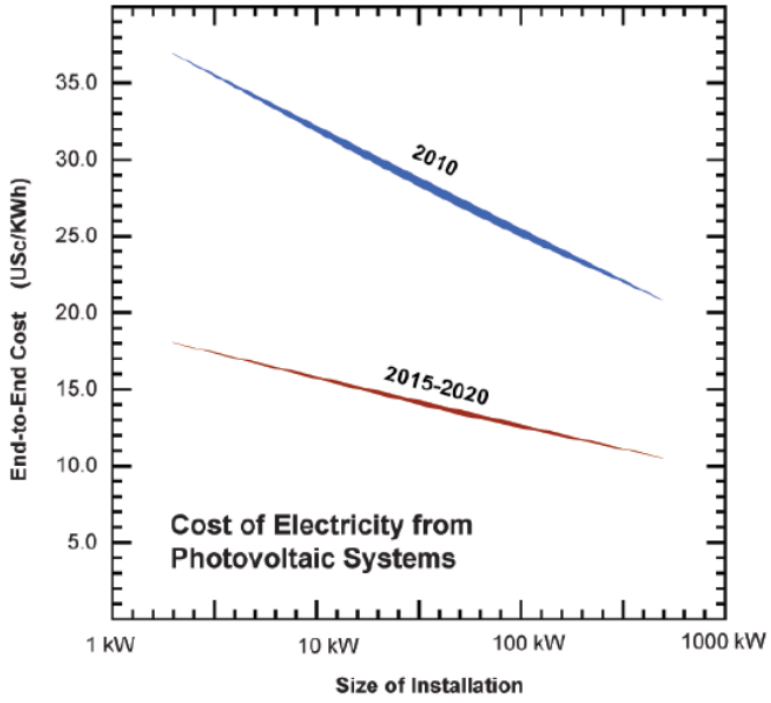


Figure 39. The whole of lifetime costs of energy production from photovoltaic systems as a function of size of the installed system (Dopita and Williamson, 2010).

4.1.2. Solar Thermal

This technology uses concave mirrors to focus and intensify solar energy on one point and this energy is used to produce super-heated steam. Usually this is used to drive steam turbines to run electrical generation systems.

Solar thermal technology is much more efficient than photovoltaics. Solar to electric conversion by high-temperature solar thermal technology can achieve efficiencies of up to 30%, in comparison with 10% to 18% of PV technology. Australia would be well suited to solar thermal.

The main limitations are:

- Still relatively expensive compared with fossil energy
- Produces power intermittently
- Performance is location-dependent
- Very high capital requirements

4.1.3. Wind

Wind is an indirect form of solar energy. Wind is created by the unequal heating of the Earth's surface by the sun. Wind turbines convert the kinetic energy in wind into mechanical power that runs a generator to produce clean electricity. These blades are aerodynamically designed to capture the maximum energy from the wind. The wind turns the blades, which spin a shaft connected to a generator that makes electricity.

- Gaining worldwide popularity as a large scale energy source. World wind generation capacity more than quadrupled between 2000 and 2006 and is doubling about every three years. Although it still only provides around 2.5% of global energy consumption. Large scale wind based electricity production at good sites can economically compete head to head with coal fired production.
- Storage technologies and optimisation of blade designs are being actively researched to improve reliability and efficiency

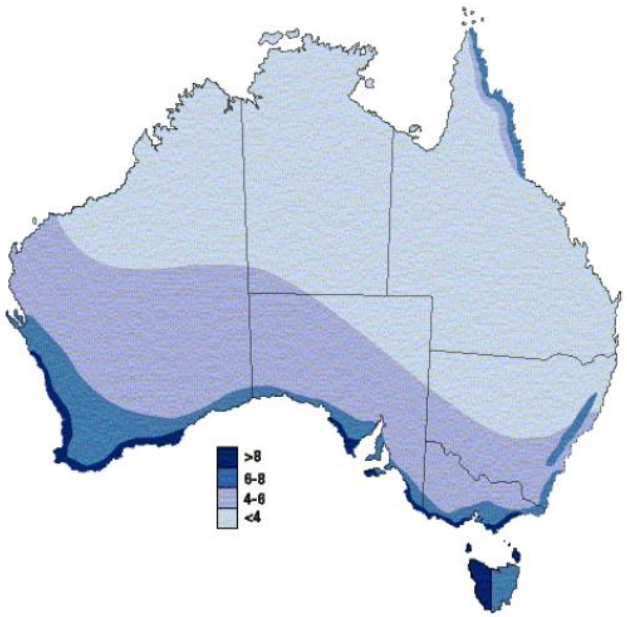


Figure 40. Simplified picture of background winds in Australia, Coppin et al., 2003.

Figure 40 shows a simplified map of background winds in Australia. To be commercially viable, winds must be reliable year-round and must be at least 5 m/s, preferably 6 to 8 m/s or more.

4.1.4. Hydroelectricity

Hydroelectricity is a well proven and advanced technology, with more than a century of experience. Modern power plants provide extremely efficient energy conversion.

Small-scale micro hydro power is both an efficient and reliable form of energy, most of the time. However, there are certain disadvantages that should be considered. These include that hydropower is only suitable for sites with large volumes of flowing water. Considerable capital investment is required, especially for large schemes. It is crucial to have a grasp of the potential energy benefits as well as the limitations of hydro technology.

The amount of electricity generated from a system also depends not only on its capacity (size of turbine and generator) but also on the amount of water available. In times of drought, water to hydroelectricity systems is limited and they have a reduced electricity output. Overall, Australia is a dry continent and has limited hydro-electric resources. Much of the best large-scale hydro sites have already been developed, although opportunities remain for small-scale hydro projects utilising existing infrastructure.

- Require a suitable site
- Require a reliable flow of water; reduced capacity in times of drought.
- Much of the best large-scale hydro sites have already been developed in Australia, although opportunities remain for small-scale hydro projects utilising existing infrastructure.

4.2.Policy and Tariff issues

Government policy affect the pace of energy growth and the type of energy used. In Australia there are two key pieces of legislation that influence the energy market. These are the Mandatory Renewable Energy Target (MRET) and a carbon emissions trading scheme. Additionally Feed-in Tariffs (FiT) apply to small scale electricity production that is fed back into the grid.

Carbon pollution reduction scheme

On December 15th 2008 the Australian Government released a white paper on the Carbon Pollution Reduction Scheme which presented two scenarios: a 5% reduction in emissions below 2000 levels by 2020 and a 15% reduction in emissions below 2000 levels by 2020. The scheme was intended as a cap and trade system.

The former Rudd Government deferred the CPRS to at least 2013 due to the slow progress of global emissions control efforts and the political difficulty of gaining Senate approval for this scheme. The Gillard Government promised no more than to work towards the introduction of a carbon price over an undefined time frame. Effectively the CPRS. The Abbott government is intending to stick to the low target of 5 per cent reduction of greenhouse gas emissions by 2020 and any Carbon Tax plans have been scrapped. Thus, the CPRS is currently stagnating.

Mandatory Renewable Energy Target (MRET)

The Mandatory Renewable Energy Target (MRET) which was introduced in 2001 aims to ensure that renewable energy obtains a 20% share of total electricity supply in Australia by 2020. The MRET requires wholesale purchasers of electricity to demonstrate their compliance by either generating

renewable electricity or purchasing a Renewable Energy Certificates (REC). A REC is equivalent to 1MWh of electricity generation from a certified renewable energy source. Currently RECs trade around $26 to $40 each. The scheme will last until 2030 (when it is expected that the CPRS would take over by making renewable energy more cost effective).

Since the passage of new legislation on 24 June 2010, two types of RECs exist:

- The Large-scale Renewable Energy Target (LRET); only large-scale renewable energy projects are eligible.
- The Small-scale Renewable Energy Scheme (SRES); only to small-scale or household installations are eligible.

It was recently announced that the Government will be conducting a review of the Renewable Energy Target in 2014 to "ensure it is operating efficiently and effectively". The review will focus on "its economic, environmental and social impacts".

Feed-in-tariffs (FiT)

Feed-in-tariffs (FiT) have been introduced by a number of states to increase the amount of solar PV power generated. The New South Wales State (Labor) Government originally announced details of the state's feed in tariff incentive on June 23, 2009. However, on May 13, 2011, after the election, the new NSW Government (Liberal-National coalition) announced the NSW Solar Bonus Scheme was closed to new applications. The Queensland Government Solar Bonus Scheme commenced on 1 July 2008. However, the new Queensland LNP Government after the March 2012 election announced that from midnight on July 9, 2012, the generous 44 cents/kilowatt scheme will be reduced to 8 cents/kilowatt hour to new installations. Existing Solar Bonus Scheme participants will continue to receive 44 cents/kilowatt hour feed-in tariff. Electricity retailers are also obligated to contribute an additional 6 - 8c per kilowatt hour. The Solar Bonus Scheme is limited to 5kW capacity and one system per premises.

Overall, FITs focus the renewables industry on small-scale technologies. This focus creates issues regarding equity, network stability, and efficiency. Generally, only home owners have the capacity to afford and install household scale renewables which can disadvantage people who cannot afford them or are prevented from installing due to their living arrangements (e.g. renting). This imposes additional networks costs that are borne by people who have not caused them and (generally) have a lesser capacity to pay.

The Queensland Competition Authority estimates the Federal carbon price and renewable energy target (together) add about $259 a year to a typical 6.3MWh household bill. Australian Energy Market Commission (2013) estimated that the carbon pricing mechanism, renewable energy target and state and territory feed in tariff and energy efficiency schemes impact on electricity prices and currently make up around 17 per cent of the national average residential electricity price.

Both the above programs are currently under review and may be changed or removed.

5. Solid fuels and other energy sources

Soil fuels include fossil and renewable fuels. Solid fossil fuel is essentially coal. Renewable energy sources are essentially biomass, such as plant material and manures and sewerage wastes.

5.1. Solid fuel available options

5.1.1. Coal

Coal is a combustible rock of organic origin, composed mainly of carbon (50% to 98%), hydrogen (3% to 13%) and oxygen, with lesser amounts of nitrogen, sulphur and other elements.

Australia has relatively large reserves of coal (figure 41). Coal is currently a relatively cheap energy source. The life of Australia's coal deposits has been estimated to be between 128-517 years (table 3).

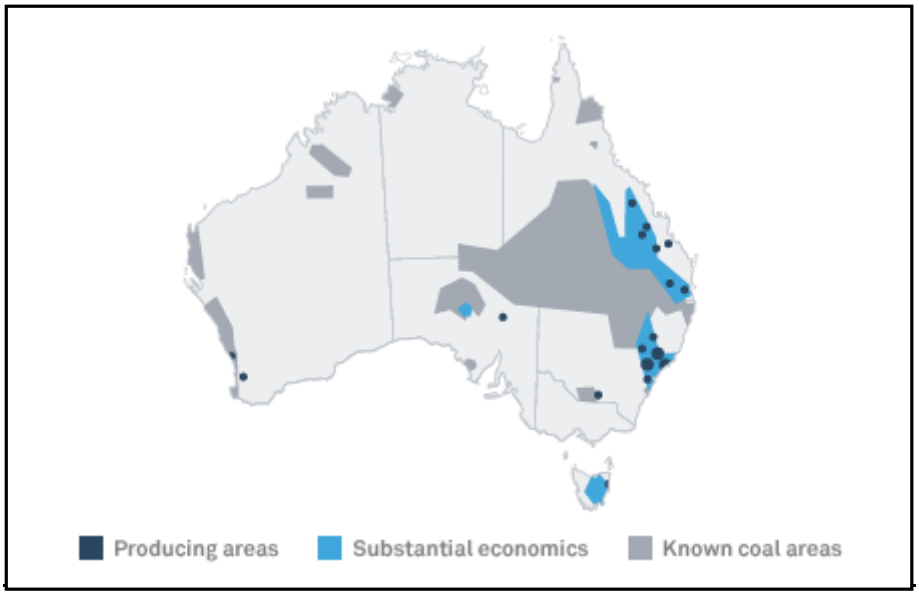


Figure 41. Australian coal reserves, Bengwayan, 2011.

Coal in Australia is used to generate electricity and is also exported. 75% of the coal mined in Australia is exported, mostly to eastern Asia. Two forms of coal are mined in Australia, depending on the region: high quality black coal and lower quality brown coal. Black coal is found in Queensland and New South Wales, and is used for both domestic power generation and for export overseas. Black coal was also once exported to other Australian states for power generation and industrial boilers. Brown coal is found in Victoria and South Australia, and is of lower quality due to a higher ash and water content. Today, there are three open cut brown coal mines in Victoria which are used for base load power generation.

The World Nuclear Association (2012) state that in 2009, 78% of the electricity generated was produced from coal, 14% from natural gas, and 4.7% from hydroelectricity. While providing a secure, affordable and uninterrupted supply of energy, coal is also a major source of Australia's greenhouse gas emissions, contributing up to 37% of total emissions Carbon Neutral (2011). Clean

coal technologies are currently under active research, which include various chemical and physical treatments applied pre or post combustion.

5.1.2. Biomass

Biomass can be converted to different types of bio-fuels, including bio-ethanol, bio-gas and bio-diesel. Bio-ethanol can be used to replace petrol, and biogas to substitute natural gas. Bio-diesel can be produced from oil-rich plants such as canola and cottonseed, and used to substitute fossil fuel based diesel used in agricultural and other activities. Figure 42 provides a broad classification of processing options for biomass.

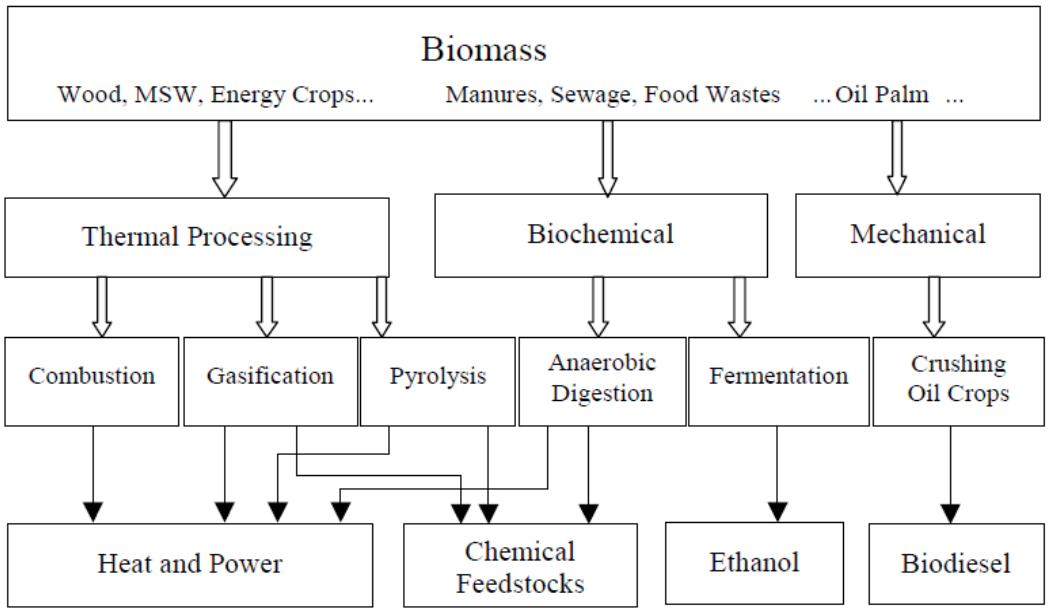


Figure 42. Broad classification of processing options for biomass, (Schuck, 2007).

Each year, for a median production area of 330,000 Ha an estimated 230,000 to 330,000 tons of cotton gin trash (CGT) are produced (section 6.2), which has a calorific value of 15.5 GJ per ton (Alison, pers. com., 2012). (Other authors quote 16.6 MJ/kg: Aquino, F. L., et al., 2007; Sadaka, S., 2013). CGT is currently a waste stream accumulating in large disposal sites, which present environmental, fire and pest and disease issues for cotton ginners.

In addition to CGT, Sharma-Shivappa & Chen (2008) state that 5.2 to 5.6 t/Ha of cotton stalk are produced. For a median production area of 300,000 hectares this equates to 1.7 to 1.8 million tonnes of biomass. This biomass must be removed by cotton growers because of pest and disease issues and because this large amount of biomass is obtrusive for machinery in following seasons. Growers often burn the stubble, which contributes to global warming. Cotton stalk has a similar calorific value to that of CGT.

5.2.Policy and tariff issues

There are no policy or tariff issues specific to biomass for energy generation. However, the energy that it produces, electricity, methane or ethanol, for example, is subject to the respective policy and tariff issues outlined in preceding sections.

6. Feasibility of commercially available energy options

Having investigated the technical feasibility of a variety of energy source, attention is now turned to the economic performance of these energy sources.

6.1. Economic and environmental feasibility of alternative liquid fuels

It is important to note that the following analyses rely on a range of assumption which all vary within ranges. Changing any of these assumptions can affect the final outcomes of the modelling. The results presented attempt to use median assumptions to determine the overall economic performance of the scenarios studies. While the authors believe that these broader results are reliable, individual situations will differ from those presented here. For example, electricity cost can vary significantly between users. Therefore, the reader must be cautious about interpreting these results for their individual situation. The sensitivity analyses presented in section 6.1.3 will assist in this regard. Modelling assumptions are listed in tables 14 to 16.

Table 14. Modelling assumptions.

Yield			
average yield	9.7	bales/Ha	Cotton Australia (2014b)
average lint yield	2.2	t/Ha	Calculated
average seed per bale	250	Kg/bale	Assumed
average seed yield	2.43	t/Ha	Calculated
bale weight	227	kg	Industry standard
average farm size	467	Ha	Cotton Australia (2014b)

Energy Use per hectare			
Total production energy use	10.9	GJ/Ha	Sandell et al. 2013
average GHG Emissions	1.30	t CO2/Ha	Sandell et al. 2013
Field sector energy use	5.7	GJ/Ha	Sandell et al. 2013
Σ Ldiesel / Ha @ 88% diesel	248	L diesel /Ha	Calculated from Sandell et al. 2013
Σ kWh / Ha @ 12% elec.	363	kWh / Ha	Calculated from Sandell et al. 2013

Energy Cost after GST and rebate	$/litre or kWh	$/GJ	
Diesel	$ 0.9334	24.18	Bris. TGP 16/7/14, $/GJ via Table 2
B100 tallow biodiesel	$ 1.1802	34.11	Bris. TGP 16/7/14, $/GJ via Table 2
LPG	$ 0.6900	26.85	Assumed cost, $/GJ via Table 2
ULP 95	$1.3300	38.89	Assumed cost, $/GJ via Table 2
Electricity	$ 0.2400	68.67	Assumed cost, $/GJ via Table 2
fuel rebate	$ 0.38143		ATO 2014 a,b
Wholesale elec.	$ 0.0111	40.00	Ismail et al. (2011)
cotton seed value	380	$/t	Assumed
canola value	550	$/t	Assumed

Water			
Water use	8.0	ML/Ha	Assumed
pump efficiency	60.0%		Assumed
river lift	10	m	Assumed
bore lift	50	m	Assumed
tail water re-lift	10	m	Assumed
portion of tail water re-lift	15%	%	Assumed
portion of river water re-lift	**235%**	%	Assumed

Engine fuel efficiency on various fuel sources			
electric motor efficiency	92.0	%	Assumed
diesel engine efficiency	34.1	%	From test data
$B20_{CSO}$	33.8	%	From test data
$B100_{tallow}$ efficiency	32.3	%	From test data
diesel/LPG efficiency	37.2	%	From test data
$B20_{CSO}$/LPG efficiency	37.0	%	From test data

To provide scale, the size and production of the Australian cotton industry is estimated in table 15, below. Upper, lower and median production areas are assumed from Cotton Australia (2014b) and lint and seed yields are from table 14.

Table 15. Total Australian cotton production.

		Upper	Median	Lower	source
Area	Ha	600,000	330,000	100,000	Cotton Australia (2014b)
Yield	10^6 bales	5.8	3.2	1.0	Cotton Australia (2014b)
lint	10^6 tonnes	1.3	0.7	0.2	Bale weight =227 kg
seed	10^6 tonnes	1.5	0.8	0.2	Table 14

Total energy use, presented in table 16, is calculated using: area and production figures from table 15; industry average energy consumption of 10.9 GJ/Ha (Table 4) and 88% energy supply from diesel and 12% from electricity (fig. 12) (Sandell et al., 2013); GHG emission factors are taken from the Office of Climate Change and Energy Efficiency (2012) (table 2); and costs are assumed by the author (table 14) from industry knowledge, terminal gate price and bowser prices.

Table 16. Total cotton industry energy use.

		Upper	Median	Lower	source
Area	Ha	600,000	330,000	100,000	Cotton Australia (2014b)
Av. Σ Energy use GJ/Ha		10.9	10.9	10.9	Sandell et al. (2013)
10^6 L diesel		149	82	25	Sandell et al. (2013)
GWhrs of elec.		218	120	36	Sandell et al. (2013)
10^6 tonnes CO2e	diesel	0.40	0.22	0.07	Table 2.
	elec.	0.19	0.10	0.03	Table 2.
	Total	0.59	0.32	0.10	Table 2.
cost 10^6	diesel	139	77	23	Table 14.
	elec.	52	29	9	Table 14.
	Total	191	105	32	Table 14.

6.1.1. Fuel cost comparison

Table 17 compares the cost per litre of cotton seed oil, canola oil and tallow biofuels, as B100, to diesel. The cost of the biofuel oil, in dollars per litre, is calculated by accounting for the cost of the raw product, oil extraction rate and density for each fuel. These figures do not account for any costs of production of the various biofuels. Costs are presented before GST and fuel tax rebates.
Table 17 also estimates the total annual Australian production of Canola and cotton seed oil and presents a nominal per hectare yield for each.

Table 17. Annual Australian production of Cotton Seed Oil (CSO) and canola.

		Diesel	B100 CSO	B100 canola	B100 tallow
Total Australian production	Mt		0.80[1]	2.00[2]	-
nominal yield	t/Ha		2.43[1]	1.57[2]	-
cost of raw product	$/t		380[3]	550[2]	-
oil extraction efficiency	%		19%[4]	41%[4]	-
density	kg/m3		925[5]	920[6]	-
total oil production	ML		141[7]	754[7]	90[9]
value of fuel before tariff & GST	$/L	1.41[10]	2.16[8]	1.46[8]	1.30[10]

1. Tables 14 and 15, median value.
2. Seberry et al. (2014)
3. Assumed.
4. Girard & Fallot (2006).
5. http://en.wikipedia.org/wiki/Cottonseed_oil (Average of upper and lower values.)
6. http://en.wikipedia.org/wiki/Canola
7. Calculated.
8. Calculated. No processing costs are included.
9. Total Australian production = 180 ML, Biofuels Association of Australia (2014). 30 ML is produced in Brisbane & 60 ML produced in Albury Wodonga with the balance coming from SA and WA. Thus 90 ML assumed available to the cotton industry. Total availability of raw tallow (and therefore potential for increased supply) is unknown.
10. Assumed from Brisbane TGP.

Total CSO production is 141 million litres for a median cotton production area, which equates to 116 million litres of diesel once differences in calorific value and combustion efficiency are accounted for. This exceeds the required 82 million litres of diesel for the same scenario, which means that the cotton industry could be self-sufficient in CSO biofuel.

While annual median canola production is 2 million tonnes, this value often falls to 0.5 million tonnes. This equates to 694 and 174 million litres of diesel respectively once differences in calorific value and combustion efficiency are accounted for. Canola could generally supply the liquid fuel needs for the cotton industry but would require a significant portion of the crop.

The Biofuels Association of Australia (2014) report a total annual Australian production of tallow as 180 million litres, however only 90 million litres is geographically available to the cotton industry. This available 90 million litres equate to 88 million litres of diesel respectively once differences in calorific value and combustion efficiency are accounted for. The median production area of 330,000 Ha would require 82 million litres of diesel.

Different energy sources have different calorific values and, importantly, behave differently during combustion. Additionally, different fuels have different levels of rebate available. To account for this, table 18 calculates the cost of energy and emissions in terms of the mechanical energy produced at the flywheel. These results are presented graphically in figure 43.

Table 18. Cost of various energy sources per GJ of flywheel energy.

		70% $B20_{tallow}$ + 30% LPG	diesel	Elec. NSW	elec. Qld	B20 tallow	B20 canola	70% diesel + 30% LPG	B100 tallow	B20 CSO	B100 canola	B100 CSO
value of fuel before tariff & GST	$/L	1.20	1.41	-	-	1.39	1.42	1.13	1.30	1.56	1.46	2.16
available rebate	$/L	0.27	0.38	-	-	0.38	0.38	0.27	0.00	0.38	0.00	0.00
value of fuel after tariff & GST	$/L	0.85	0.93	-	-	1.00	1.04	0.78	1.18	1.18	1.46	2.16
calorific value	MJ/L	34.17	38.60	-	-	38.85	38.38	25.70	39.86	37.62	37.50	33.70
GHG emissions	$kgCO_2e$ /GJ	56.89	69.4	244	239	55.60	55.60	59.9	0.260	55.60	0.260	0.260
cost per GJ of energy	$/GJ	24.77	24.18	66.67	66.67	25.84	27.06	30.36	29.61	31.34	38.88	64.16
engine efficiency	%	37.0%	34.1%	92.0%	92.0%	33.7%	33.7%	37.2%	32.3%	33.8%	32.3%	32.3%
GHG per flywheel GJ	kg CO2e/ $GJ_{flywheel}$	154	204	266	260	165	165	161	1	165	1	1
Cost per flywheel GJ	$ / $GJ_{flywheel}$	67	71	72	72	77	80	82	92	93	120	199

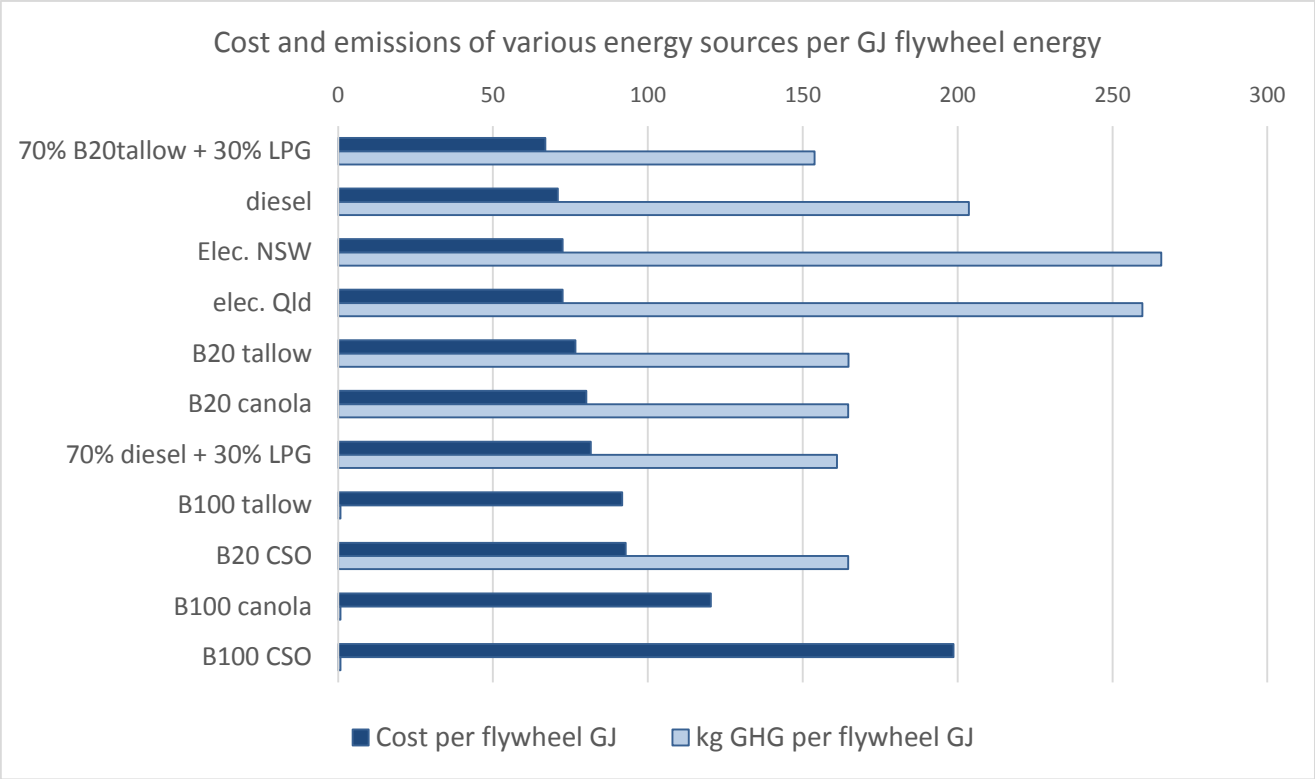


Figure 43. Cost and emissions of various fuels per GJ of flywheel energy.

Table 18 shows that diesel, LPG and electricity are similar in cost when expressed per GJ of energy output at the flywheel. Of these, LPG has the lowest emissions, followed by diesel and then electricity. The reader is reminded that these are general conclusions and each of these alternatives may be more viable in individual circumstances. Recalling that these analyses use broad assumptions, each of these options would be viable given different values for engine efficiency and so on.

Conversely, B100 biofuels have negligible contribution to global warming, however their costs are much higher than traditional alternatives. Straight biofuels are hampered by the fact that there is no fuel rebate available because there was, effectively, no rebate paid on the fuel. Cotton seed oil is the most expensive energy option due to the low extraction rate of the oil. Canola, which has a higher extraction rate is the next cheapest option. B100 tallow is closer to being economic due to the low cost of the feedstock.

B20 blends, especially tallow, are close to being economic because (B5 and) B20 fuel blends still attract the full fuel rebate on the total amount of fuel.

6.1.2. Scenario analysis

Having established the total availability, cost and required quantity of each energy source in section 6.1.1, these figures are used to establish the total effect for a 'typical' cotton farm. Sandell et al. (2013) show that most direct, on-farm energy consumption is used in pumping water - 50% to 75% - and this varies considerably with the type of irrigation pumping system employs. This work shows that differences in energy used in-field (eg. tractors, transport, picking) is relatively small compared to differences in pumping energy. Thus this analysis assumes that in-field energy use is constant in all cases. Similarly, electrical energy use of domestic and/or workshop purposes, which is significantly smaller than in-field energy use, is ignored. All assumptions are listed in tables 14 to 18.

In this section three scenarios are examined:

- A scheme irrigator; table 19.
- A river irrigator; table 20.
- A bore irrigator; table 21.

All scenarios are calculated on a per hectare basis. These results are multiplied by the average farm size (Cotton Australia, 2014b) to calculate the total emissions and cost for a typical grower. Assumptions relating to each scenario are listed above the relevant table.

The energy cost and emissions per hectare for an average river irrigator using the various fuel sources tested is summarised in figure 44, page 66.

- Water is delivered to the head of the field by the scheme with no pumping cost. 15% of this water is returned over a ten meter lift.
- LPG scenarios are across the entire farm

Table 19. Energy cost from various sources for a scheme irrigator.

		diesel	Elec. NSW	Elec. Qld	70% diesel + 30% LPG	B20 tallow	70% $B20_{tallow}$ + 30% LPG
Water applied	ML/Ha	8.0	8.0	8.0	8.0	8.0	8.0
River lift	GJ/Ha	-	-	-	-	-	-
Bore lift	GJ/Ha	-	-	-	-	-	-
Tail water relift	GJ/Ha	0.575	0.2	0.2	0.5	0.6	0.5
Total Irrigation energy	GJ/Ha	0.6	0.2	0.2	0.5	0.6	0.5
Field sector diesel energy	GJ/Ha	5.7	5.7	5.7	5.7	5.7	5.7
Field sector litres of diesel	L_{diesel}/Ha	148	148	148	148	148	148
Total enterprise energy	**GJ/Ha**	**6.3**	**5.9**	**5.9**	**6.2**	**6.3**	**6.2**
Total litres of diesel per Ha	L_{diesel}/Ha	163	148	148	113	-	-
Total litres of LPG per Ha	L_{LPG}/Ha	-	-	-	73	-	73
Total litres of B20 per Ha	L_{B20}/Ha	-	-	-	-		126
Total litres of B100 per Ha	L_{B100}/Ha	-	-	-	-	182	-
Total kW.Hr of elec per Ha	kW.hr/Ha	-	59	59	-	-	-
Total emissions per Ha	kg CO2e/Ha	436	448	447	415	22	382
Total cost of energy per Ha	**$/Ha**	**152**	**152**	**152**	**156**	**215**	**165**
Average farm size	Ha	467	467	467	467	467	467
Total emissions	Σ Tonnes CO2e	204	209	209	194	10	179
Total cost of energy	**Σ $**	**70,900**	**71,000**	**71,000**	**72,700**	**100,500**	**77,200**

- Water is pumping from a river or creek over a ten meter lift. Water is typically pumped more than once on a cotton farm. This scenario assumed that water is pumped 2.35 (including the initial river harvest) times over a ten meter lift plus 15% of water is returned over a ten meter lift. This accounts for water pumped into storage, loss on that water, second lifts to the field etc. Thus, in total, all water is pumped 2.5 times over a ten meter lift.
- LPG scenarios are across the entire farm

Table 20. Energy cost from various sources for a river irrigator.

		diesel	Elec. NSW	Elec. Qld	70% diesel + 30% LPG	B20	70% $B20_{tallow}$ + 30% LPG
Water applied	ML/Ha	8.0	8.0	8.0	8.0	8.0	8.0
River lift	GJ/Ha	9.0	3.3	3.3	8.3	9.5	8.3
Bore lift	GJ/Ha	-	-	-	-	-	-
Tail water relift	GJ/Ha	0.6	0.2	0.2	0.5	0.6	0.5
Total Irrigation energy	GJ/Ha	9.6	3.6	3.6	8.8	10.1	8.8
Field sector diesel energy	GJ/Ha	5.7	5.7	5.7	5.7	5.7	5.7
Field sector litres of diesel	L_{diesel}/Ha	148	148	148	148	148	148
Total enterprise energy	**GJ/Ha**	**15.3**	**9.3**	**9.3**	**14.5**	**15.8**	**14.5**
Total litres of diesel per Ha	L_{diesel}/Ha	396	148	148	263	-	-
Total litres of LPG per Ha	L_{LPG}/Ha	-	-	-	169	-	170
Total litres of B20 per Ha	L_{B20}/Ha	-	-	-	-	-	294
Total litres of B100 per Ha	L_{B100}/Ha	-	-	-	-	457	-
Total kW.Hr of elec per Ha	kW.hr/Ha	-	987	987	-	-	-
Total emissions per Ha	kg CO2e/Ha	1,062	1,265	1,245	965	55	892
Total cost of energy per Ha	**$/Ha**	370	375	375	362	540	386
Average farm size	Ha	467	467	467	467	467	467
Total emissions	Σ Tonnes CO2e	496	591	581	451	26	417
Total cost of energy	**Σ $**	**172,700**	**175,000**	**175,000**	**169,100**	**252,100**	**180,100**

- This scenario assumes that all water is pumped once from a bore over a 50 meter lift and an additional 15% is pumped as tail water over a ten meter lift.
- LPG scenarios are across the entire farm

Table 21. Energy cost from various sources for a river irrigator.

		diesel	Elec. NSW	Elec. Qld	70% diesel + 30% LPG	B20	70% $B20_{tallow}$ + 30% LPG
Water applied	ML/Ha	8.0	8.0	8.0	8.0	8.0	8.0
River lift	GJ/Ha	-	-	-	-	-	-
Bore lift	GJ/Ha	19.2	7.1	7.1	17.6	20.2	17.7
Tail water relift	GJ/Ha	0.6	0.2	0.2	0.5	0.6	0.5
Total Irrigation energy	GJ/Ha	19.8	7.3	7.3	18.1	20.9	18.2
Field sector diesel energy	GJ/Ha	5.7	5.7	5.7	5.7	5.7	5.7
Field sector litres of diesel	L_{diesel}/Ha	148	148	148	148	148	148
Total enterprise energy	**GJ/Ha**	**25.5**	**13.0**	**13.0**	**23.8**	**26.6**	**23.9**
Total litres of diesel per Ha	L_{diesel}/Ha	659	148	148	432	-	-
Total litres of LPG per Ha	L_{LPG}/Ha	-	-	-	278	-	279
Total litres of B20 per Ha	L_{B20}/Ha	-	-	-	-	-	484
Total litres of B100 per Ha	L_{B100}/Ha	-	-	-	-	767	-
Total kW.Hr of elec per Ha	kW.hr/Ha	-	2,034	2,034	-	-	-
Total emissions per Ha	kg CO2e/Ha	1,767	2,186	2,145	1,585	92	1,467
Total cost of energy per Ha	**$/Ha**	616	626	626	595	906	634
Average farm size	Ha	467	467	467	467	467	467
Total emissions	Σ Tonnes CO2e	825	1,021	1,002	740	43	685
Total cost of energy	**Σ $**	**287,500**	**292,300**	**292,300**	**277,800**	**423,000**	**296,200**

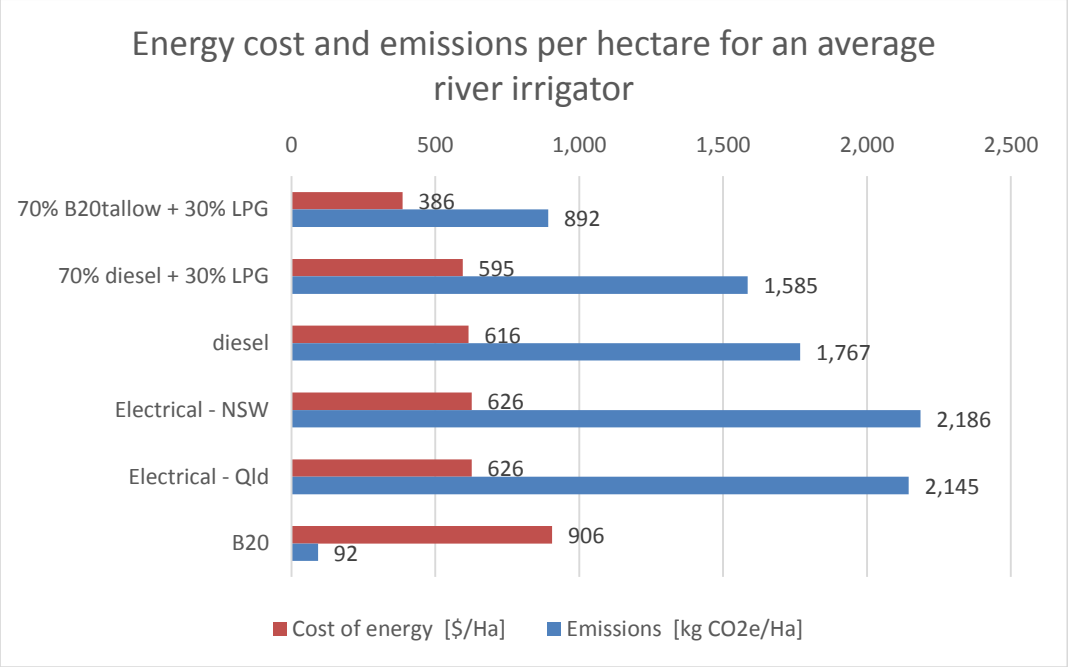


Figure 44. Energy cost and emissions per hectare for an average river irrigator using the various biofuels tested.

6.1.3. Sensitivity analysis

The following figures, 45 to 50, were derived by keeping all variables constant other than the variable in question. While this does not account for multi-variable interactions, it does provide some insight into the sensitivity of changes in cost or performance of the main economic drivers. Cost of power is expressed in dollars per GJ of flywheel energy to account for differences in calorific value and combustion efficiency.

Diesel fuel price

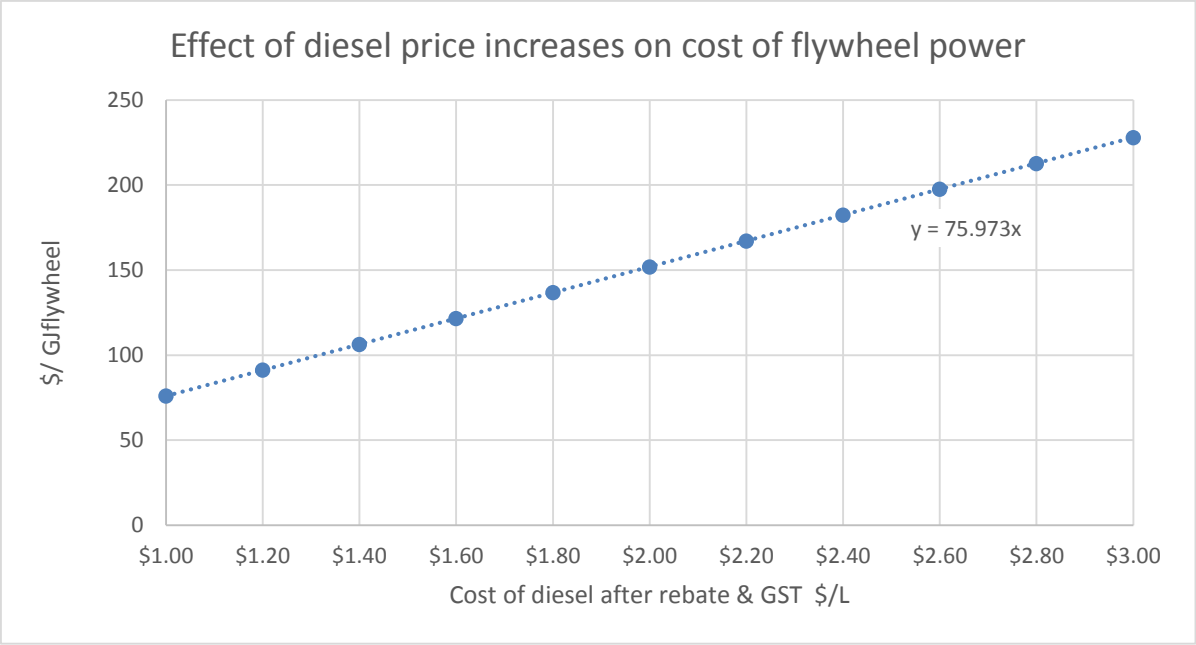


Figure 45. Effect of diesel price increases on cost of flywheel power.

Engine efficiency

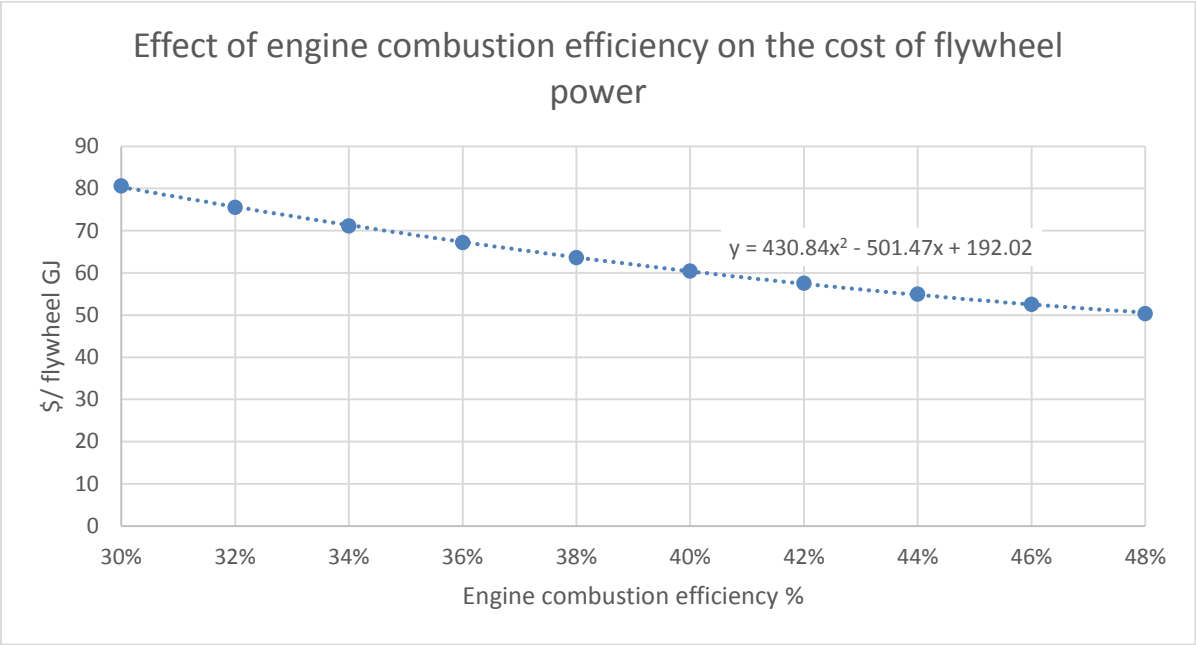


Figure 46. Effect of engine combustion efficiency on the cost of flywheel power.

Electricity price

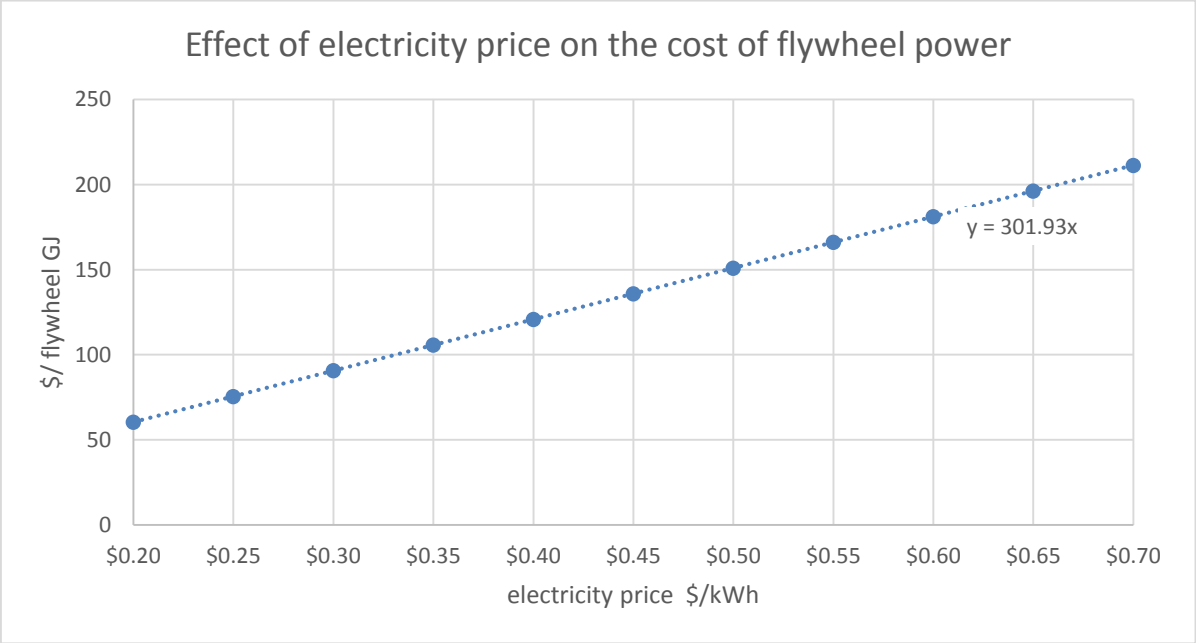


Figure 47. Effect of electricity price on the cost of flywheel power.

Canola price

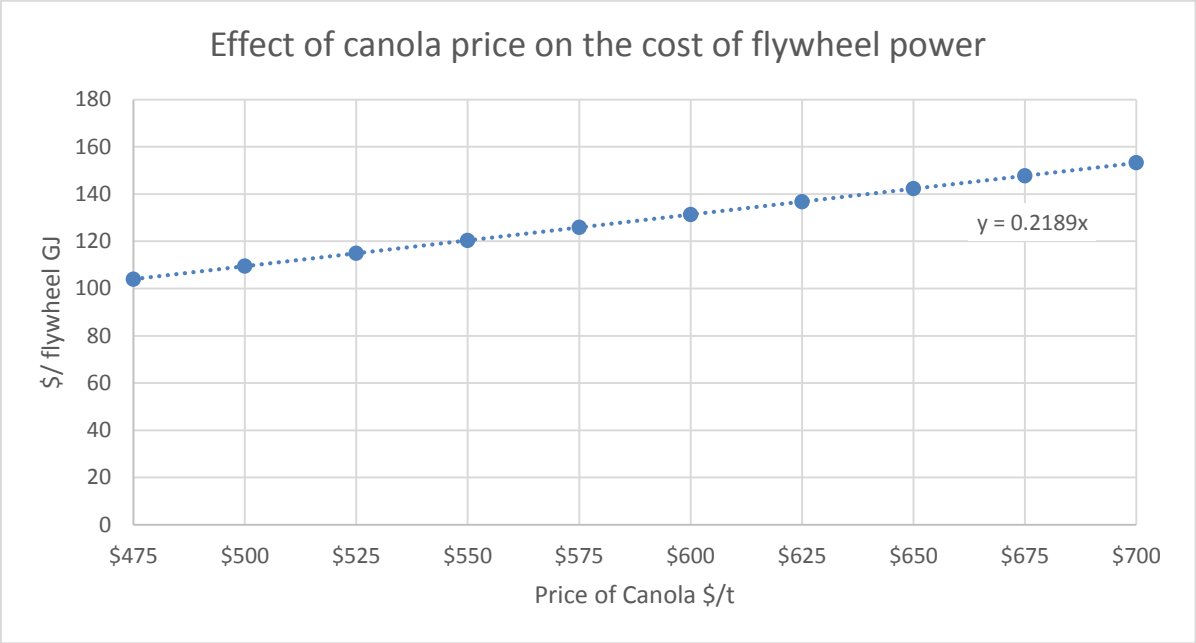


Figure 48. Effect of canola price on the cost of flywheel power.

Cotton seed price

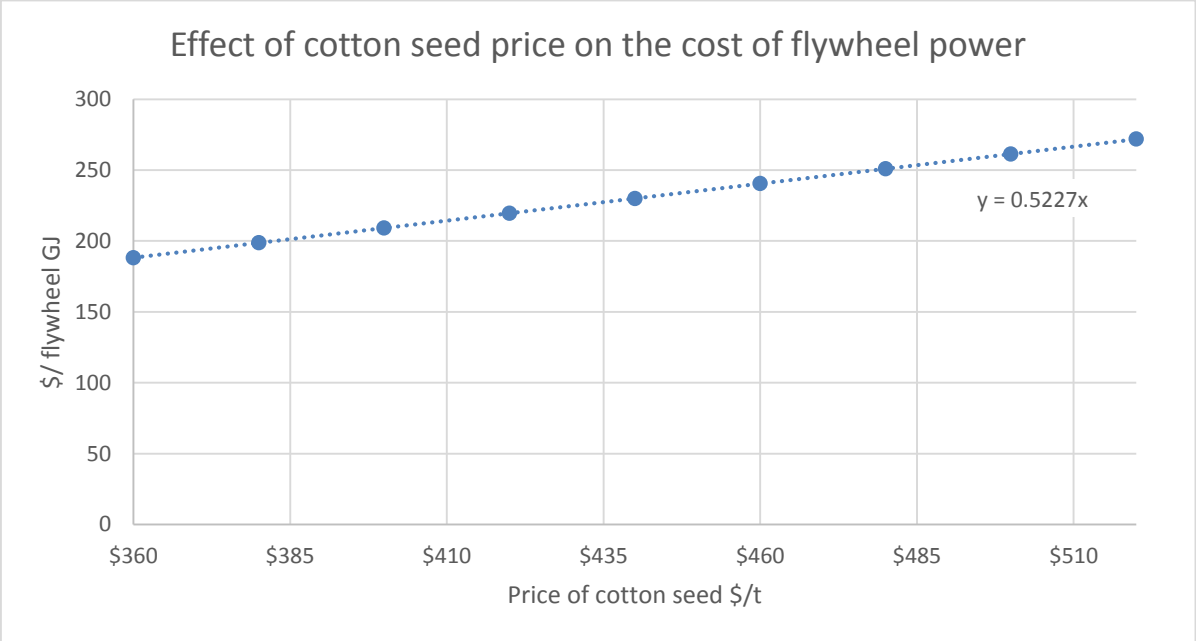


Figure 49. Effect of cotton seed price on the cost of flywheel power.

Tallow price

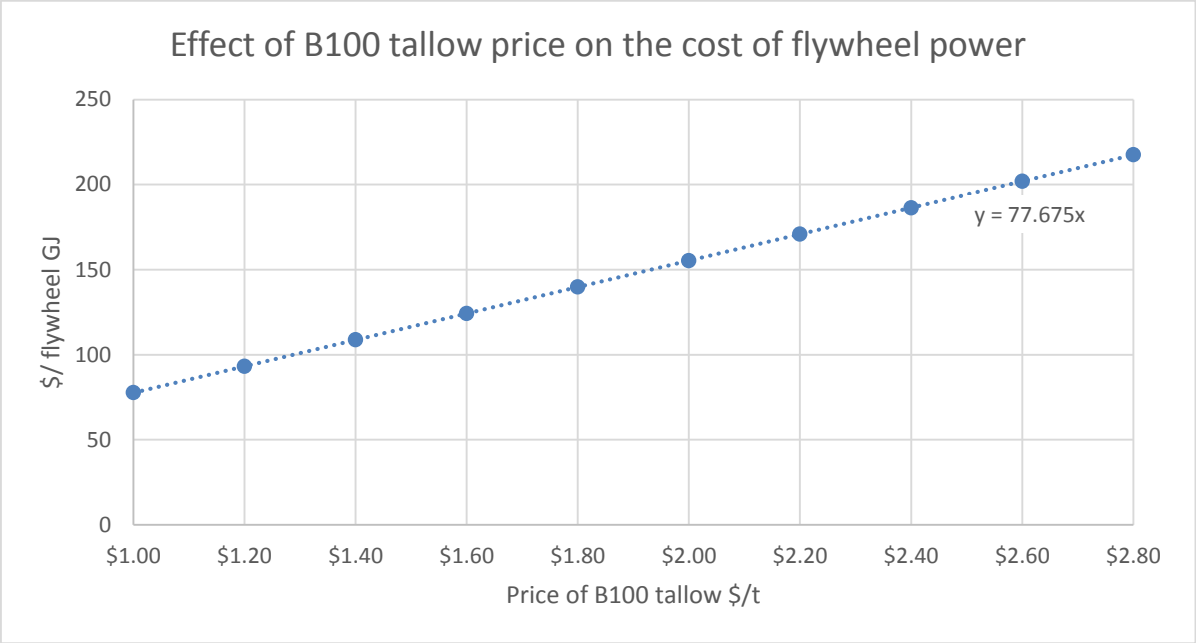


Figure 50. Effect of B100 tallow price on the cost of flywheel power.

Pump efficiency

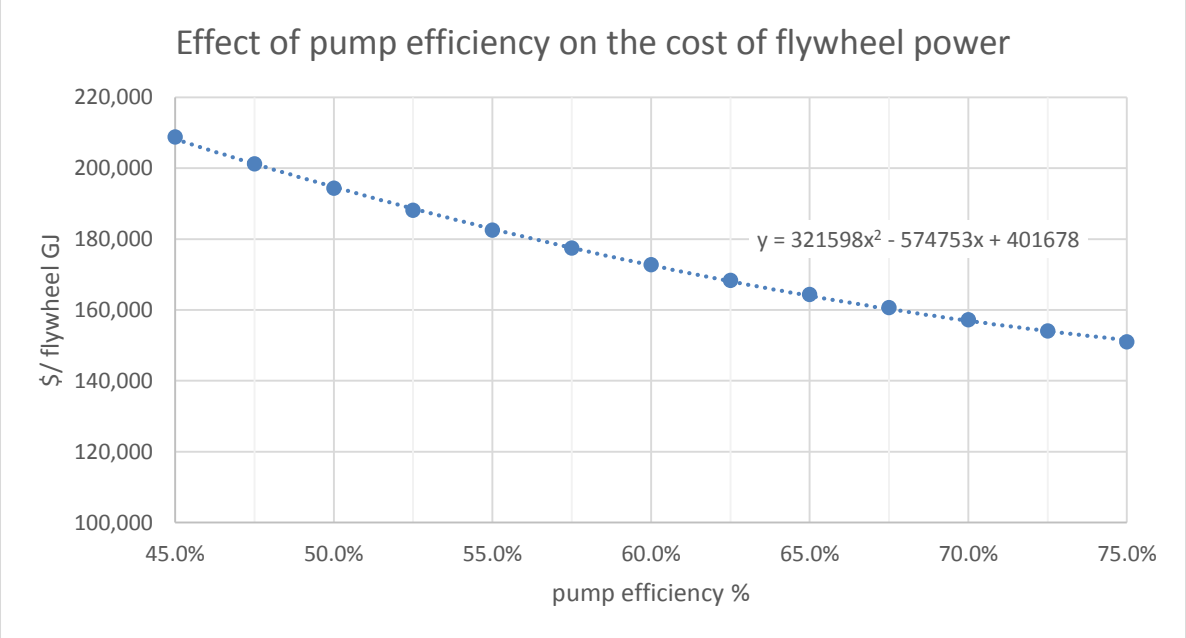


Figure 51. Effect of pump efficiency in the total cost of flywheel power.

All variables linearly increase the cost of energy at the flywheel except for increases in engine combustion efficiency and increases in pump efficiency.

Improving engine efficiency reduces the cost of energy at the flywheel significantly. This can be achieved by changing to electronically injected, turbo charged engines. For example, an improvement in engine combustion efficiency from 34% to 42% will reduce the cost of energy at the flywheel from $71.12/GJ to $57.58/GJ. For the average 467 Ha river irrigator using diesel as assumed in table 20 this will reduce the total cost of diesel from $173,000 to $152,300 p.a.

Improvements in pump efficiency will similarly achieve the same results by reducing the total energy required. An improvement in pump efficiency from 60% to 68% for a 467 Ha river irrigator using diesel (as assumed in table 20) will reduce the cost of diesel from $173,700 to $159,900. Replacement of worn and/or poorly designed pump stations can make large savings in costs. For the average 467 Ha river irrigator using diesel as assumed in table 20, replacing a pump operating at 50% efficiency to a correctly designed pump operating at 70% efficiency will save this will around $37,100 per annum.

Similarly, improvements in water application efficiency will result in less water being pumped for the same result. Imporvements in water application efficiency will result in a larger crop area availe for a given quantity of water.

6.2. Cotton trash

This section relies on assumptions presented in this section, specifically tables 14 to 22. Gross values such as trash composition, heating values, extraction efficiencies and the range of variation in these values are either largely unknown to the Australian Cotton industry or are difficult to estimate without specific scenarios. This section attempts to broadly quantify these variables, however the following analyses should be treated with caution and regarded as broad, indicative numbers only.

Cotton production and processing produce large amounts of biomass. Large amounts of trash are removed from raw cotton – cotton gin trash (CGT) - in the ginning process. This by-product is currently a waste stream which presents an increasing disposal problem for ginners. The cotton plant itself, which is left in the field after picking, represents a much larger source of biomass. This biomass represents a problem in the field sector with many growers resorting to burning the trash.

Utilisation of cotton biomass presents a large potential energy source that is essentially carbon neutral (and certainly far more favourable than fossil fuels). Utilisation of this resource represents a reduction in the disposal cost of what is now a waste stream. There are a range of options available to use these biomass sources as a source or renewable energy. Application of these to the cotton industry are in various stages of research and commercialisation and will be outlined below.

Assumptions regarding annual production of Cotton Gin Trash (CGT) resources are presented in tables 22 and 23. Poor, median, and excellent lint turn-out figures were assumed by the authors after consultation with cotton industry personnel such as gin managers and researchers. Total raw cotton yield was calculated by applying the assumed median lint turn-out of 39% to the median production of 9.7 bales/Ha. This raw cotton yield of 5.6 t/Ha was assumed to be constant for each lint turn-out scenario. Cotton seed yield was also calculated using the median yield of 9.7 bales per hectare and assumes that 250 kg of seed per bale is realised. Cotton seed yield was also assumed to be constant in each lint turn-out scenario. Thus, 2.4 t/Ha of cotton seed production is assumed in each lint turn-out scenario. CGT yield is then calculated as total raw cotton yield less lint yield and

less cotton seed yield. The CGT yield associated with a median lint turn-out of 39% of 1.0 t/Ha is assumed in this report as an upper estimate.

A literary search revealed no Australian data and no recent data on CGT production. Sharma-Shivappa & Chen (2008) quote equivalent CGT yields of 0.7 to 0.9 t/Ha. This study is based on American cotton production, is now eight years old and quotes a seed yield of 350 kg per bale. Contemporary Australian cotton production yields close to 250 kg of cotton seed per bale. The CGT yield of 0.7 t/Ha is assumed in this report as a lower estimate.

Table 22. CGT, lint and seed yield calculated from assumed lint turn-out.

	poor	median	excellent
lint turn-out	34%	39%	42%
bales/Ha		9.7	
lint t/Ha		2.2	
Raw cotton t/Ha	5.6	5.6	5.6
lint t/Ha	1.9	2.2	2.4
Seed kg/bale	250	250	250
Seed t/Ha	2.4	2.4	2.4
CGT t/Ha– upper	1.3	1.0	0.8
CGT t/Ha– lower		0.7	

Table 23. Cotton gin trash assumptions.

	Qty	Units	Source
lower CGT yield	0.70	t/Ha	Sharma-Shivappa & Chen (2008)
upper CGT yield	1.00	t/Ha	Table 22
lower CGT production	230,000	t	Derived
upper CGT production	330,000	t	Derived
CGT calorific value	15.5	MJ/kg	Alison (Pers. Comm., 2012)
Av. MJ per bale	308.7	MJ/bale	Ismail et al. (2011)
electricity contribution	61%	%	Ismail et al. (2011)
LPG contribution	39%	%	Ismail et al. (2011)
Wholesale electricity price	40	$/GJ	Ismail et al. (2011)
cotton stalk yield- lower	5.2	t/Ha	Sharma-Shivappa & Chen (2008)
cotton stalk yield- upper	5.6	t/Ha	Sharma-Shivappa & Chen (2008)
litres of ethanol / tonne CGT	143	$L_{ethanol}/t_{CGT}$	Sharma-Shivappa & Chen (2008)
lint value	400	$/bale	Assumed
stalk calorific value	14.5	MJ/kg	Alison (Pers. Comm., 2012)

Based on the preceding assumptions and a median, 330,000 Ha production area, 230,000 to 330,000 tonnes of CGT are produced each year. This causes considerable disposal problems for cotton ginners because of limited disposal options. Soil-borne disease problems, such as *verticillium wilt* make it impossible to directly return this biomass to the field. Using CGT as an energy source has some advantages because cotton ginning requires large amounts of electrical energy to run

processing equipment and thermal energy (typically supplied by LPG) to dry the raw cotton. CGT has already been transported to the gin where some material handling equipment exists to handle the product. Utilisation of CGT would recycle a waste source and thereby reduce operating costs and management issues.

Sharma-Shivappa & Chen (2008) quote equivalent in-field stalk yields of 5.2 to 5.6 t/Ha. For a median production are of 330,000 hectare this represents 1.7 to 1.8 million tonnes of biomass annually. Utilisation of in-field biomass presents a number of problems. Firstly, a system for conversion of this biomass to energy needs to be identified and commercialised. Secondly, any conversion systems developed for the gin may or may not apply to in-field biomass where a mobile plant could be appropriate because the biomass is spatially distributed. The harvesting and collection of in-field biomass collection presents more issues. Specifically, if the energy to collect, transport and process the biomass is greater than the output energy then the net balance is negative and not worthwhile. There has been some work conducted on gathering in-field trash in the sugar industry which shows mixed results. Additionally, in-field biomass typically has a higher moisture content and may present higher ash levels due to soil entrainment in the stalk biomass. Notwithstanding these issues, in-field biomass does simultaneously present a valuable energy source to the cotton grower and an opportunity to reduce the current costs and environmental negatives of current disposal systems. Because of the higher degree of complications involved with processing of in-field cotton plant residue and the more immediate advantages of processing CGT, the following sections investigate CGT options.

6.2.1. Composting

Composting of cotton gin trash is a method of waste utilization that has some interest due to the growing interest in the role of composts in soil health. Proponents of CGT assert the elevated temperatures of the compost heap (up to 70 ^{o}C) are sufficient to kill soil-borne diseases. Other argue that this is not the case with large differences in temperature zones. Composting, either by the gin owner or a commercial contractor currently plays a minor role in Australia.

6.2.2. Ethanol production (biochemical fermentation)

Use of CGT for ethanol production involves three main steps: pre-treatment with dilute sulphuric acid to convert lignocellulosic material into starch; use of amylase enzymes to convert the starch into simple sugars; and, fermentation with yeast. Sharma-Shivappa and Chen (2008) report a potential yield of 143 litres of ethanol per tonne of CGT. Using upper and lower CGT production values stated in table 23, this equates to 100 to 143 litres of ethanol per hectare. Based on a median production area of 330,000 hectare, this would generate 33 to 47 million litres of ethanol. If this is valued at price parity with ULP this equates to 23 to 32 million litres of ULP, which is valued at $30 to $43 million dollars and a reduction of 51,000 to 74,000 tonnes of CO2e. Other work questions the economic viability of cellulose to ethanol production.

6.2.3. Biogas production (biochemical anaerobic digestion)

Biogas, principally methane, can be produced via anaerobic digestion of CGT. Biogas is useful to cotton ginning as a fuel gas for cotton drying, which is currently met by LPG, or to generate electricity. Once the methane is produced, only very minimal other changes are required inside the factory to use methane in place of LPG.

Isci and Demirer (2007) investigated anaerobic digestion processes for the methane (CH_4) generation potential of three different cotton wastes: cotton stalks, cotton seed hull and cotton oil cake. The results show that cotton wastes can be treated in anaerobic digester and are a good source of biogas. Approximately 65, 86 and 78 ml of CH_4 were produced in 23 days from 1 g of cotton stalks, cotton seed hull and cotton oil cake respectively.

High ammonium and protein levels of municipal and animal waste bio-digesters present a problem for these operators. Cotton gin trash (CGT) additions offer the potential to improve the carbon-nitrogen ratio for these operator. CGT has been studied as a co-digestion with other wastes such as the organic fraction of municipal solid waste (OFMSW) (Macias-Corral et al. 2008). The results of this study showed that biogas produced from the OFMSW digested as single wastes were around 37 m3 methane/ton of waste. Co-digestion of OFMSW with CGT resulted in 172 m3 methane/ton.

Using an industry production of CGT (based on 330,000 Ha of production) of 230,000 to 330,000 tonnes annually and the lower methane conversion value from Isci and Demirer (2007) of 65 ml/g, 564,000 to 809,000 GJ of methane energy could be produced. Assuming a median production area of 330,000 Ha, 385,000 GJ of LPG would be consumed in cotton ginning (Ismail et al., 2011). This would displace $10.3 million in LPG costs and 23,000 tonnes of CO2e.

Biodigestion opens the possibility of using the methane to run a diesel generator to generate electricity. Moderate modifications to the diesel engine are required. Assuming price parity with the average ginner's cost of electricity of $40/GJ (Ismail et al., 2011), an engine efficiency of 34% and a generator efficiency of 92% this would yield a gross annual revenue of $7.0 to $10.1 million dollars and save 40,000 to 58,000 tonnes of CO2e.

6.2.4. Low pressure boilers for thermal energy

This section relies on the *Cotton gin waste to offset non-renewable energy sources.* (John Allison, pers. comm., 2012). This report investigates the use of CGT, cotton stalk and cotton seed as fuel stock to provide thermal energy needs for cotton drying. Various thermal combustion methods are investigated.

The report presents the moisture content, ash content and calorific value of cotton seed, cotton stalk and CGT, which is repeated in table 24. (Ash content is the remaining residue after combustion.)

Table 24. Energy, ash and moisture content of cotton seed, stalk and CGT. Allison, 2012.

Description	Moisture content %	Ash Content %	Net Calorific Value MJ/kg
Pima cotton seed[1]	9.6	4.1	19.3
Upland cotton seed[1]	8.7	3.4	19.3
Dried cotton stalks	11.3	10.5	14.5
Cotton gin trash	8.0	10.0	15.5

1. *Pima* and *Upland* refer to different species of cotton.

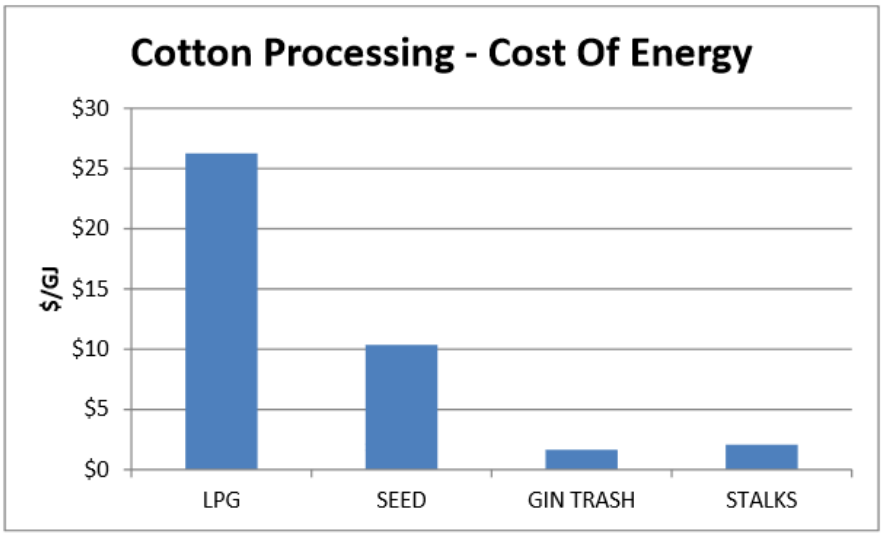


Figure 52. Processing costs of energy sources. Allison 2012.

The report concludes that low pressure thermal processing of CGT is a system that "is neither complex nor overly capital intensive". Additionally, use of CGT would reduce or remove waste stream problems and improve the carbon foot print of cotton production.

Assuming 15.5 GJ/t of CGT and a boiler efficiency of 75% a median production area of 330,000 Ha would supply 2.7 to 8.8 million GJ of thermal energy, which is far in excess of the 385,000 GJ of thermal energy supplied by LPG. Assuming cost parity with LPG, this method would displace (as in 6.2.3) $10.3 million in LPG costs and 23,000 tonnes of CO2e with the remaining CGT available for electricity generation or other uses.

6.2.5. High pressure boilers

High pressure boilers are much higher in capital and complexity and have legislative requirements concerned with the boiler. The boilers are used to produce high pressure steam, which is used to run a turbine/generator combination. Equally these boilers are relatively efficient at generating electricity. Wholesale electricity is worth around 40 $/GJ, which is 1.5 times the value of LPG. Thus, revenues are much higher. Additionally this method allows for the use of all CGT produced and the use of existing stockpiles and greater potential to process in-field cotton stalk with year-round generation capacity.

If it is assumed that the 230,000 to 330,000 tonnes of CGT was processed in a high pressure boiler with a combined electrical efficiency[5] of 28%, 1.0 to 1.5 million GJ of electrical energy would be produced. Gross annual revenue from high pressure boiler operation would be in the order of 40 to 57 million dollars per annum with an associated saving of 227,000 to 326,000 tonnes of CO2e. This is around twice the industry requirement of 0.6 million GJ of electrical energy.

[5] The ratio of electrical energy generated to fuel consumed.

6.2.6. Pyrolysis

Pyrolysis, represented schematically in figure 53, uses high temperatures and a small amount of oxygen to convert volatile compounds within the biomass feedstock into a fuel gas. The remains of the biomass are biochar, which has application as a soil amendment, water and air filtration as well as industrial uses. Gasification efficiency reaches 20% in the simplest systems and 90% in complex installations. Capital cost rises with the complexity of the installation. If pyrolysis is used to replace LPG, using the same assumptions as for 6.2.3, pyrolysis will provide the same gross value because CGT is oversupplied and the same amount of LPG is replaced. That is, pyrolysis would displace $10.3 million in LPG costs and 23,000 tonnes of CO2e. Additionally, this process would provide additional value in the biochar product.

Pyrolysis can be used to generate fuel gas to run a (modified) diesel generator to generate electricity. Assuming a pyrolysis efficiency of 60%, an engine efficiency of 35% and a generator efficiency of 94% with $40/GJ for wholesale electricity, pyrolisation of 230,000 to 330,000 tonnes of CGT would yield a gross annual revenue of $28 to $40 million dollars and save 160,000 to 230,000 tonnes of CO2e.

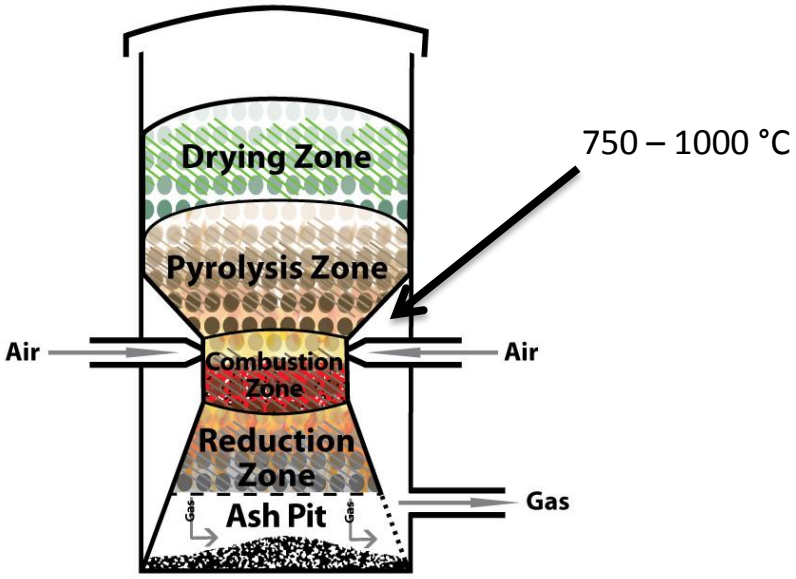


Figure 53. Schematic of pyrolysis process.

7. Survey: Current industry interest and use of alternative fuels

A survey was designed to assess existing use of alternative energy options, and, to identify particular industry interests in alternative energy options and technologies. The survey was conducted as part of the CRDC report Cotton Growing Practices 2013: Findings of CRDC's survey of cotton growers. (Roth Rural 2013). This survey was designed to be a single, coordinated survey of cotton growers conducted by CRDC and its research partners in 2013. The survey was mailed to 1,000 people identified as growers on CRDC's mailing list. The survey was conducted in late winter 2013, focusing on the 2012-13 cotton crop. Further details in demographics and other study areas can be found in the above document.

7.1. Survey response and demographics.

Survey responses cover approximately 23% of the irrigated cotton area grown industry wide in 2012-13 and 27% of the dryland cotton area (based on survey responses and the total crop area reported in 2013 cotton yearbook). Table 25 shows that the survey covers 16% of all cotton growers and 23% of those that grew cotton in that year. The survey is therefore a representative sample of cotton growers. The survey is also representative of all growers in each region other than the Burdekin.

Table 25. Regional distribution of surveyed growers.

Cotton producing area	Number of responses	Number of growers on mailing list	Number of growers less those who replied they did not grow cotton 2012-13	Responses as %growers on mailing list
Burdekin	0	8	8	0%
Central Queensland	11	105	90	10%
Darling Downs	33	231	195	14%
Border Rivers	14	75	53	19%
St George / Dirranbandi	10	44	39	23%
Gwydir	18	119	101	15%
Lower Namoi	22	145	120	15%
Upper Namoi	15	89	70	17%
Macquarie	27	119	90	23%
Bourke	1	6	6	17%
Southern NSW	14	61	54	23%
TOTAL	**165**	**1,002**	**826**	**16%**

Each of the survey questions was cross-tabulated with region, area developed for irrigation and grower age to investigate the possibility of different characteristics for each of these groups. Cross-tabulating results showed that responses were the same between region, age and farm size. Each survey question is discussed below.

Initially it was intended to investigate the number, type and use of irrigation pumps due to the fact that they consume the majority of direct, on-farm energy. However, it was decided by the survey team not to proceed with this question. Additionally the survey team decided to include Question 35 (section 7.2) with the intention of quantifying total on-farm direct energy use. Although

this is outside the scope of this investigation into alternative energy is included below for the sake of completeness.

7.2. Energy benchmarking.

35. Please estimate the energy usage for your 2012-13 cotton crop.

(Either usage or cost or both, approximate estimates are all that is needed.)

	Usage		and/ or	Cost
Diesel		L	$	
Petrol		L	$	
Gas		L	$	
Electricity		KwH	$	
Solar		KwH	$	
Other Please define			$	

OR

☐ I don't know

Figure 54. Survey question 35. Estimate current energy use.

There were 77 of the 165 participants that responded to this question. This indicates that half of the respondents were unable or unwilling to share energy use for their crop. This is congruent with the fact that an energy audit requires significant effort to provide meaningful results. This is congruent with the result that only 11% of respondents reported that they have measured or benchmarked energy use, as shown in figure 56.

It was intended to use the cost of energy and "convert" these data into units of energy. The major flaws with this methodology were that:

- The average unit cost of each energy source is not known. Assuming a cost of diesel and using it for conversion introduces an unknown error into the figures. Individual purchases range from 230 litres to 1.8 million litres. The difference in the unit cost of diesel between these farms is in the order of 20%. Similarly, the unit cost of electricity can vary between 5 ¢/kWh and 50¢/kWh.
- It is not known if GST is included or excluded in the figures, which introduces a 10% error into the cost of diesel.
- It is not known if fuel rebate is included or excluded in the figures, which introduces a further error in the order of 33% into the cost of diesel.

For those 28 respondents that provided both a diesel fuel cost and a diesel fuel volume, the price per litre of diesel ranged from $0.93/L to $1.80 /L. There was no correlation between volume purchased and unit cost of diesel. Therefore, all cost information was discarded.

The data was filtered to only include the 62 respondents that gave litres of diesel. Of these, there were only 5 that provided usage of ULP and electricity. This sample is too small to make any

meaningful conclusions from the data. The lack of response and wide variability in the results show that a survey is an unreliable method of benchmarking energy use.

7.3. Current energy saving strategies.

36. In the last five years have you:

- ☐ measured and/or benchmarked total energy use per bale or hectare?
- ☐ measured and/or benchmarked energy use for individual operations?
- ☐ had a pump efficiency investigation?
- ☐ used autosteer for most machinery operations?
- ☐ Used a traction control systems for most machinery operations?

Figure 55. Survey Question 36. Energy saving options currently adopted.

Participants were asked if any of these options applied in the last five years. It was decided by the survey team to remove four questions investigating amount of cultivation, total number of passes, total chemical use and fertilizer use efficiency. Of the 165 responses, 122 people answered this question.

Figure 56, below, indicates that there is a focus on tractor operations with most operators using auto-steer and 42% having some form of traction control.

Figure 13 shows that pumping water is typically half to three-quarters of direct, on-farm energy use yet the survey reveals that only 19% of farmers (23 out of 122) have had a pump investigation in the last five years. Of these 23 farmers, only two had dryland cotton and both of these also had irrigated cotton. Therefore, this 19% is not skewed by dryland-only farmers. The survey did not detail how many of a grower's pumps were investigated or what prompted the investigation or the degree of detail to which the pump was investigated.

Figure 56 shows that most growers do not have measured energy consumption figures for individual operation or even at level one, total energy per hectare level. There were 9 growers out of the 122 respondents (7%) that benchmarked both total energy use and itemised energy use.

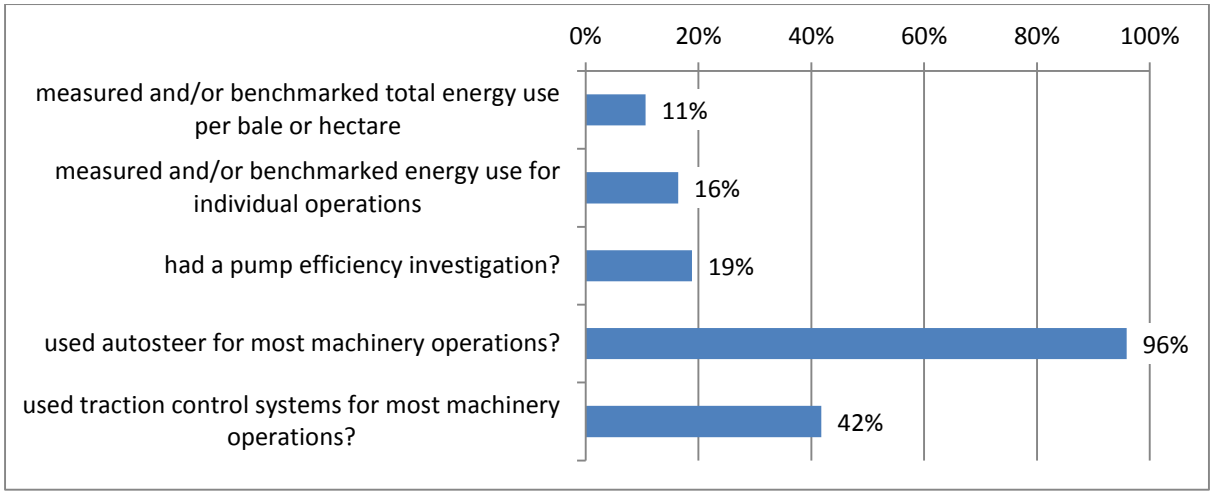


Figure 56. Energy saving options currently adopted.

Figure 57, below, shows that half of the respondents used only one of the five strategies presented. The non-response rate of 43 of 165 participants shows that up to 26% of growers did not use any energy mitigation strategy. Conclusions regarding fertilizer and chemical use, which contribute the majority of on-farm energy use, are not able to be made because they were not included in the survey.

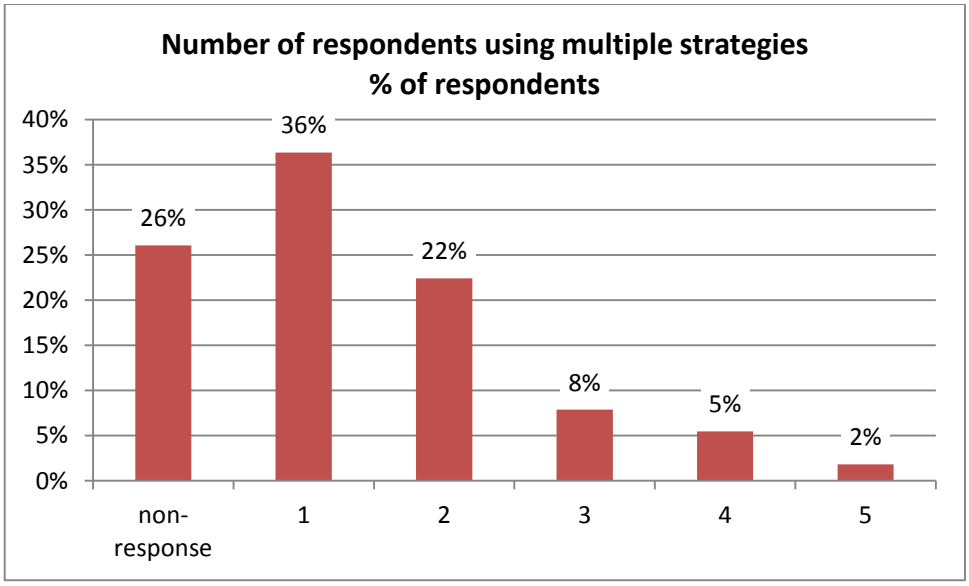


Figure 57. Number of respondent using multiple strategies.

7.4. Perceived relevance of various alternative energy sources

37. Please indicate how relevant each of these energy types are for your farm. For those with relevance, please indicate how you would use them.

Please tick one per line for those that you do or may use. Also list the likely application for this energy source on your farm.

	Not an option	Potential option and plan to install/ use this	Potential option for your farm, have not really investigated it yet	Potential but would not use it	In use now	Application/s **eg irrigation pumping, machinery fuel**
LPG	○	○	○	○	○	
Coal Seam Gas	○	○	○	○	○	
Biogas	○	○	○	○	○	
Biodiesel	○	○	○	○	○	
Ethanol	○	○	○	○	○	
Solar	○	○	○	○	○	
Wind	○	○	○	○	○	
Micro-hydro	○	○	○	○	○	
Biomass	○	○	○	○	○	

Figure 58. Survey question 37. Usefulness of different energy sources.

To identify particular industry interests in alternative energy options and technologies, a list of alternative energies with potential for the cotton industry was presented in question 37. Growers were asked to rate their perception of the usefulness of each alternative energy source. Of the 165 survey respondents, 123 growers responded to this question, which is a response rate of 75%. Of these 123 respondents, 77 (60%) answered all categories.

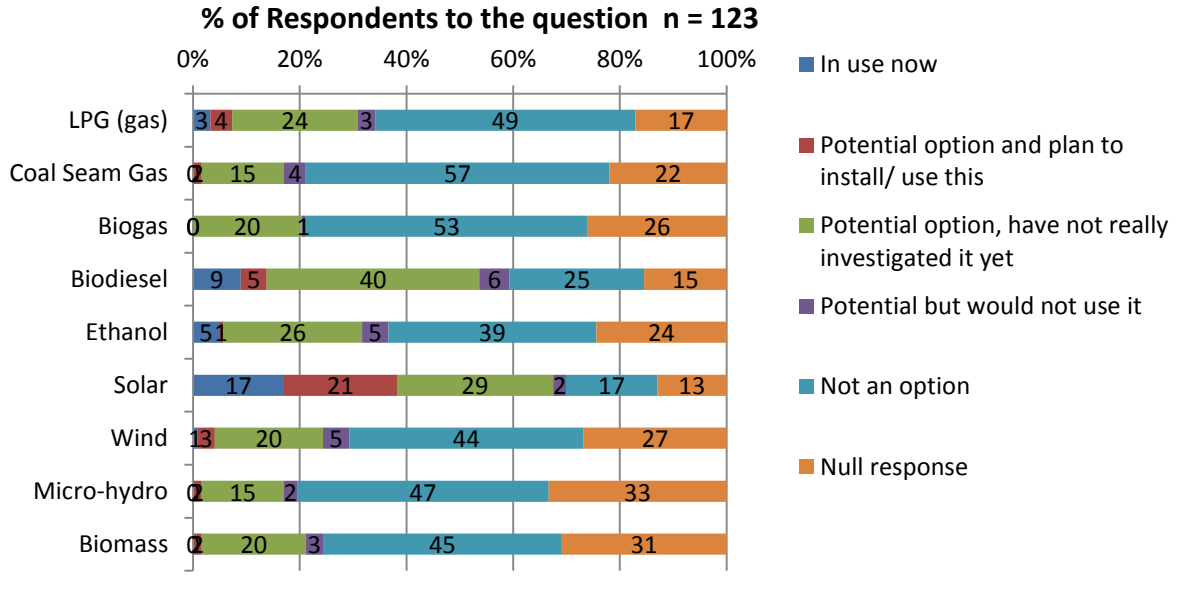


Figure 59. Grower perception of the usefulness of various alternative energy sources.

35% of respondents to this question (43/123) currently use some form of alternative energy, which includes 7% of respondents to this question that use two forms of alternative energy. 74% of respondents to this question (91/123) either currently use or plan to use some form of alternative energy.

7.4.1. Solar energy.

Solar energy is the most popular alternative energy type with 17% of respondents to this question currently using solar and a further 21% planning to use solar. However, 17% stated that solar was not an option and 2% stated that solar had potential but they would not use it. Solar had the lowest null response of 13% of respondents.

15% of respondents to this question (18/123) provided a comment and these are compared to their perception of solar energy in Figure 60. 11% of respondents believed that solar energy was useful to offset their domestic and workshop electricity cost. 3% believed that solar energy had a role to play in water pumping and one respondent felt that solar energy might be useful for machinery operations.

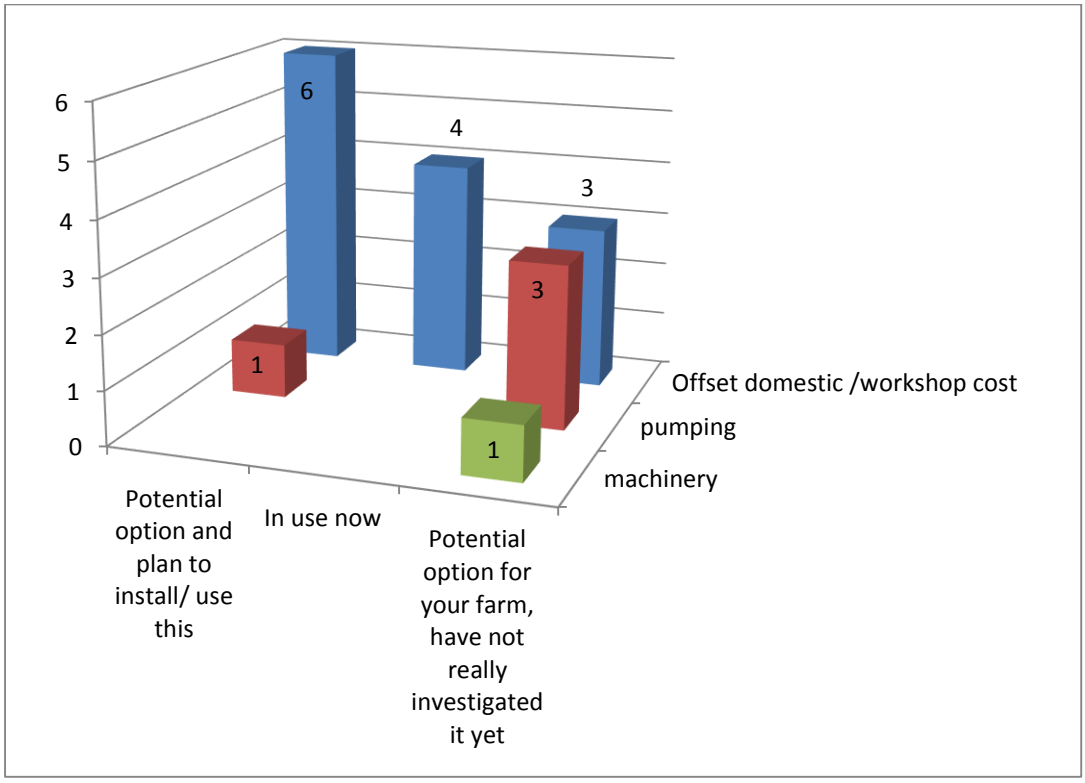


Figure 60. Grower comments on the application of solar energy compared to their perceived usefulness of solar energy.

7.4.2. Biodiesel.

Biodiesel was the next most popular option with 9% of respondents to this question (19/123) currently using biodiesel, another 5% planning to use biodiesel and a further 2% had used it in the past. However, 25% stated that biodiesel was not an option and 6% stated that biodiesel had potential but they would not use it. Biodiesel had a comparatively low null response rate of 15% of respondents.

20% of respondents to this question (25/123) provided a comment and these are compared to their perception of biodiesel in Figure 61. 16% of respondents believed that biodiesel was useful for pumping and/or tractor operations. . Four respondents had used biodiesel in the past; three were still using it and one would not use it. One respondent saw biodiesel as not an option

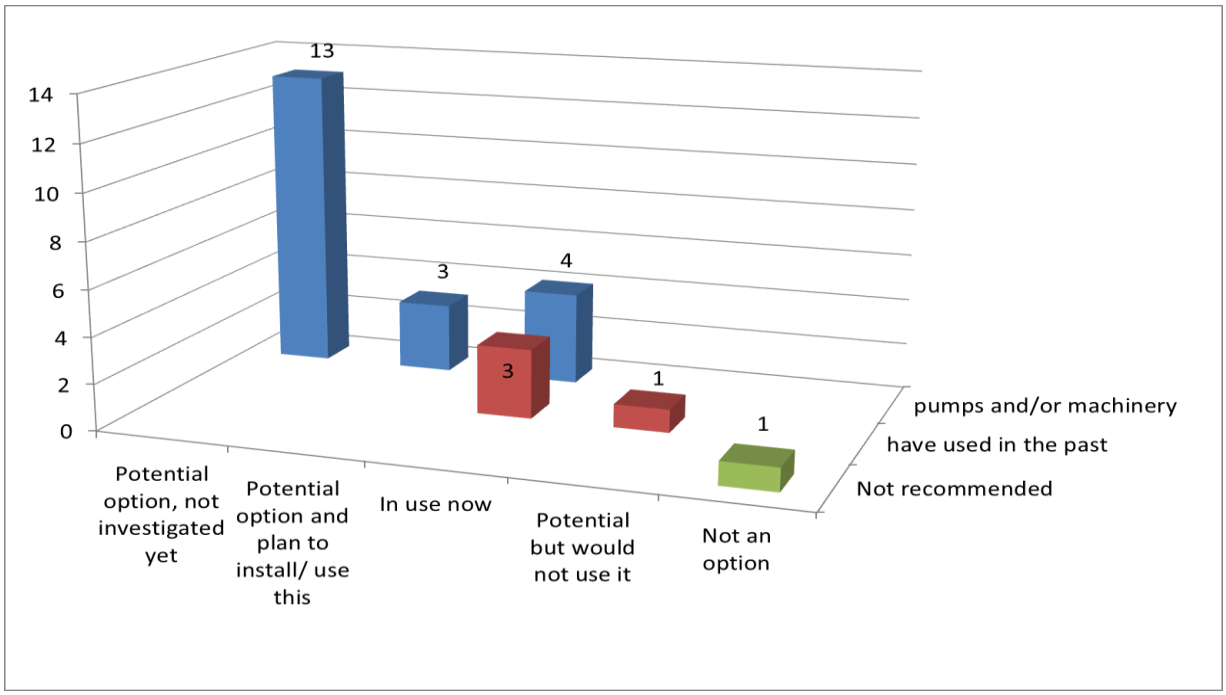


Figure 61. Grower comments on the application of biodiesel compared to their perceived usefulness of biodiesel.

7.4.3. Ethanol.

Ethanol is currently used by 7 farmers and a further 3 are planning to use it. 39% of farmers felt that ethanol was not an option and a further 5% felt that ethanol had potential but they would not use it. Ethanol had a null response rate of 30%. A comment was provided by 7% of respondents (7/123). Six indicated that it was useful for pumping and machinery use and all of these felt that ethanol was a 'Potential option, have not really investigated it yet. The seventh respondent is currently using ethanol as E10 petrol.

7.4.4. LPG

LPG had a similar response to ethanol with 3% of respondents currently using LPG and 4% planning to. 49% of respondents felt that LPG was not an option and 4% felt that LPG had potential but they would not use it. LPG had a null response rate of 17%. Figure 62 shows that 12% of respondents to the question commented that LPG was useful for irrigation and pumping, 2% for domestic/workshop and 1% each for grain drying and machinery.

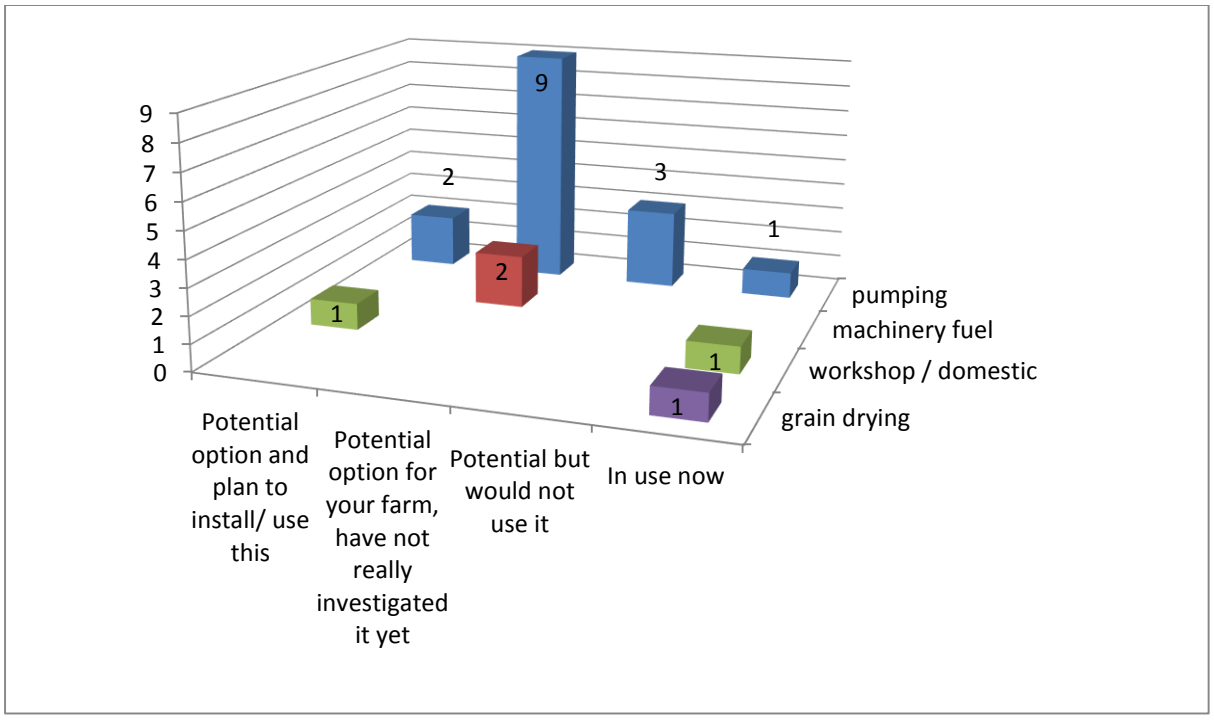


Figure 62. Grower comments on the application of LPG compared to their perceived usefulness of LPG.

7.4.5. Coal seam gas.

Coal Seam Gas (CSG) had the highest level of resistance to adoption. There is no current use and 2% of respondents to the question (2/123) plan to use CSG. It was rated as 'Not an option' by 57% of respondents to this question with a further 4% selecting *Potential but would not use it* (73% and 5% respectively of those that responded to this energy type). This is consistent with the environmental concerns over CSG. However, CSG had a median null response rate of 22%. 6% of respondents to the question commented that CSG would be useful for pumping and 1% for use in machinery or machinery and pumping. The remaining two comments were "Wells on farm but don't produce" and "never ever".

7.4.6. Other sources

Wind power, micro-hydro, biomass and biogas all received similarly low levels of acceptance as a relevant energy source. Apart from one wind user, there is no current us of any of these technologies. Between 36% and 43% of respondents rated each of these technologies as 'not an option. Null response rate was high at between 21% and 26%. There were no comments for hydro. Two comments for wind suggested workshop use. Biogas had seven comments, all suggesting machinery and pumping as potential uses. Biomass had three comments, one each for machinery, soil and workshop.

7.5. Decision factors in using alternative energies.

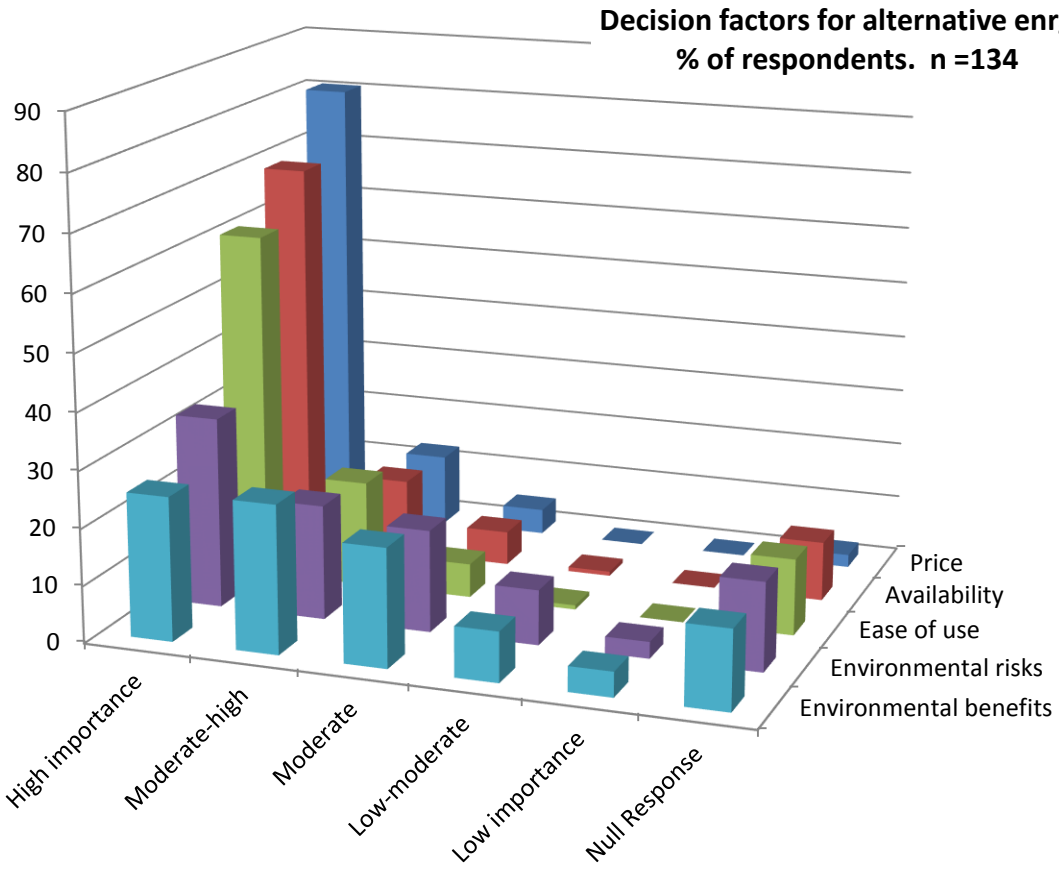
38. How important are each of these factors in your decision about using alternative energy sources on your farm?

	Low	High
Price		
Availability		
Ease of use		
Environmental benefits		
Environmental risks		
Other		

Please define 'other' …….

Figure 63. Question 38. Decision factor in choosing an alternative energy.

Because there are many more aspects to the adoption of alternative energy sources beyond technical performance, Question 39 of the survey (Figure 63) investigates decision factors in moving to an alternative energy. Growers were asked to assess the importance of various factors concerning the adoption of alternative energies and these are presented below in figure64. Of the total 165 surveys evaluated, 134 answered this question, which is a low non-response rate. Of these 134 replies to this question, 104 responses (78%) rated each factor. Of the 30 responses that did not rate all factors, most rated most of the factors. The non-responses to each factor were ignored in this analysis and are included in figure 64, below.



	High importance	Moderate-high	Moderate	Low-moderate	Low importance	Null Response
Price	81	13	4	0	0	2
Availability	69	13	6	1	0	10
Ease of use	61	19	6	1	0	13
Environmental risks	34	20	18	10	3	16
Environmental benefits	25	26	21	9	4	14

Figure 64. Importance of various decision factors in the adoption of alternative energies, % of respondents.

Price, availability and ease of use were identified as highly important by the majority of respondents (81%, 72% and 64% respectively). Price is clearly then main driver as it has the highest importance with a very low null response rate (2%). Environmental benefits and risks had some importance with around 25% of respondents rating these factors as moderate, moderate-high or high. 'Other' factors were listed as: performance, current alternatives not yet economically feasible and long-term expense.

7.6. Previous experience with alternative energy.

39. Please describe any experiences you have had with adoption of alternative energy sources or any additional comments that you might like to add.

eg 20% reduction in energy costs in 2012; bad experience due to technical problems.

_____

Figure 65. Question 39. Experiences in the adoption of alternative energies.

Participants were asked to 'describe any experiences you have had with adoption of alternative energy sources', to which 22 people responded. Of the 22 responses to this question, one respondent commented on two energy types and these two responses were considered separately making a total of 23 comments from 22 responses. Of these, 20 also provided a response at question 37 so individual responses were cross-referenced and the results are presented in tables 26 to 30. Where a comment was also provided at question 37, it is included in brackets. This provided a much greater insight as to the intent of the respondent. These qualitative responses were grouped by the energy source that they were addressing. There was no correlation with district or any other demographic.

The high non-response rate to this question might indicate a lack of industry experience in alternative energies.

The responses for solar energy were varied and are presented below. Considering the response to question 30 alone it appears that solar comments were reasonably balanced between positive, neutral and negative. However, considering responses in conjunction with their responses to question 37 it appears that solar is mostly positive with only one negative experience.

Table 26. Experiences with solar energy.

Response to Q39.	Response to Q 37.
Pleased with 60c feed in from Govt. Hoping that there will be some incentive going forward to increase use of solar.	Potential option and plan to install/ use this
We have [had a] very positive experience with 10kw solar panel sites	In use now
Solar grid connected – cost effective in reducing general workshop/ house electricity bill	Null response to solar question. A response was only provided for biodiesel.
2x 1.5kw Solar panels – haven't guarantied savings	In use now
Solar-maintenance, installation contractors	In use now
Solar perhaps, not achieved levels of energy promoted	In use now (workshop)
Solar industry is a rip off.	Potential option and plan to install/ use this (supplementary pumping)
Spent a lot of money putting solar panels on 6 houses - very disappointed with process and the gain is uneconomic	Not an option

The responses to biodiesel were varied. Three of the six responses indicate that they plan to use / support the use of biodiesel. Of these, one has tried biofuel, one has investigated it and the third had no experience. Two responses stated that biodiesel blocks filters and voids warranty et stated at question 37 that is was a 'Potential option, have not really investigated it yet.' One respondent had tried biodiesel, had a bad experience and would not use it.

Table 27. Experience with biodiesel.

Response to Q39.	Response to Q 37.
Investigated Bio-diesel and found the red-tape and costs to comply with Govt standards are prohibitive and are designed to deter you from using Bio-diesel 'legally'.	Potential option and plan to install/ use this. (Irrig Pumps & Tractors)
Tried biodiesel - Bad experience with injectors on machinery. Would use again if available	Potential option, have not really investigated it yet. (Machinery and pumps)
No experience. need biodiesel option from Cottonseed, Sunflower, Canola. (On farm or Gin Biodiesel plant)	Potential option, have not really investigated it yet.
Use of biodiesel blocked filters	Potential option, have not really investigated it yet.
Biodiesel not suitable for newer common rail diesel engines in some of our machines- voids warranty	Potential option, have not really investigated it yet.
B20 diesel clogged filters and injector pump on truck	Potential but would not use it (Have used B20)

One respondent indicated that the cost of LPG was uneconomical and provided a null response at question 37. No conclusions can be drawn from this response.

Table 28. Experience with LPG

Response to Q39.	Response to Q 37.
Diesel /Gas pump Motor and cost of gas to high for any pump in costs	Indicated that solar was 'currently in use.' No other responses.

The following two comments were provided on electricity tariff issues:

Table 29. Experience with electricity tariffs.

Response to Q39.	Response to Q 37.
Using electricity on 6 of 12 high volume bore pumps is not worth the problems of a change over from diesel pumping	LPG: 'Potential option and plan to install/ use this.' (Workshop) Otherwise null responses.
Slightly reducing flow from electric bores to save on power bills during peak power periods	Wind: 'Potential option and plan to install/ use this.' Biodiesel & solar 'Potential option, have not really investigated it yet'.' All other sources as 'Not an option.'

The following 'other' comments were provided. No conclusions can be drawn from these responses.

Table 30. Other experiences with alternative energies.

Response to Q39.	Response to Q 37.
no experience	No response to Q37.
Solar powered bores	No response to Q37.
Lower Energy Costs	Solar is currently in use. CSG is a potential option. All other sources 'not an option.'
Practicality, reliability	LPG, solar & wind 'potential, not investigated.' Biogas & biodiesel 'not an option.' Others 'potential but would not use.'
never tried	Everything is 'Not an option.'

7.7. Perceived limitations in improving energy use efficiency.

40. What is the greatest limitation in improving your energy use efficiency?

_____

Figure 66. Question 40. Greatest limitations to adoption.

Participants were asked to provide an open response to the question "What is the greatest limitation in improving energy use efficiency?" The 82 people who responded to this question provided a total of 96 responses. For example, the response "Price, Knowledge, Availability" would count once in each category. Responses were classified into the following broad groups based on key words and theme of the response and are presented in Table 31. Most responses were one to three words and classification was a straightforward process.

Table 31. Greatest limitation to adoption of alternative energies.

Category	Count	percent
Cost	52	54%
Availability/Technology	16	16%
Knowledge	11	11%
Intensity/Power required	7	7%
Time	3	3%
Location	3	3%
Ease	2	2%
Measurement	2	2%
Reliability	1	1%

Of the people who responded to this question, 54% listed the cost of alternatives as the greatest limitation to improving energy use. (This group included any of three words 'cost', 'price', 'money' or 'funds'.) It is reasonable that any changes to energy use must be economically sound. Of those that listed cost as the greatest limitation to the adoption of an alternative energy source, exactly half provided more detail. Of this subgroup of respondents, 70% listed the capital cost of change as the

greatest impediment. A further 15% listed access to investment capital as the greatest impediment and 4% return on investment. 15% commented on the cost of electrical tariffs.

A further 17% or responses indicated that availability of alternatives was the greatest limitation to the adoption of alternative energies. (Two responses included the word “technology” otherwise they included the word “availability”. There were no further details provided.

Seven responses alluded to the power intensity or total volume of energy required. This classification was far less clear-cut than the others as there were no key words and some inference was made to associate the comments with the category. Therefore the individual comments are included below

- *We have to work ground (cultivate)*
- *need to pump large volumes of water in a short water harvest period*
- *Place power high, horsepower needs*
- *Total amounts used is in high usage bracket*
- *You still need to get a certain amount of job done on the farm*
- *Water is too heavy to move*
- *Pupae Busting*

‘Knowing how to go about it’ was the greatest impediment for 11% of responses and time demands were the greatest impediment for 3% of responses. “Location’ was given in three responses and were given to mean: location relative to the electrical grid, location relative to energy deliveries and isolation. Ease of use and measurement were the greatest impediment for 2% and reliability was the greatest impediment for 1%.

8. Conclusions

This report, commissioned by the Cotton Research and Development Corporation, is exploratory research designed to shed light on possible solutions or new ideas in the alternative energy space as applied to the Australian cotton industry.

Overall, it is readily accepted that new and sustainable fuel supplies to power the ever growing agricultural sector need to be found. By exploring available options now the cotton industry will be better placed to provide energy to power the cotton industry to meet future energy challenges. Alternative energies will help meet the cotton industry's corporate social responsibilities in the challenge of climate change. Any possible reductions in emissions ensures that Australian cotton will remain in this preferred 'responsible production' market.

8.1. General conclusions

8.1.1. Energy Benchmarking

Figure 56 shows that there is relatively low adoption of energy benchmarking practices. Benchmarking does improve the profitability for those involved because it identifies where improvements can be made. Benchmarking provides a relative assessment of performance with others in similar circumstances, therefore identifying high or low performing areas at an enterprise level. While benchmarking does take some effort, it is not a difficult exercise. It is recommended that energy measurement and benchmarking strategies be implemented in the cotton industry.

8.1.2. Engine efficiency

Sensitivity analyses in section 6.1.3 show that improving engine efficiency significantly reduces the cost of energy at the flywheel. This can be achieved by changing to electronically injected, turbo charged engines. For example, an improvement in engine combustion efficiency from 34% to 42% will reduce the cost of energy at the flywheel from $71.12/GJ to $57.58/GJ. For the average 467 Ha river irrigator using diesel as assumed in table 43 this will reduce the total cost of diesel from $173,000 to $152,300 p.a.

Similarly, electric motors have a range of efficiencies, nominally from 90% or less up to 95% or slightly more. Changing to a more efficient electric motors will directly reduce the total energy consumed and therefore cost and emissions of energy.

8.1.3. Pumping and irrigation efficiency

Regardless of the energy source, improvements in pump efficiency will reduce the total energy required. An improvement in pump efficiency from 60% to 68% for a 467 Ha river irrigator using diesel (as assumed in table 44) will reduce the cost of diesel from $173,700 to $159,900 as demonstrated in figure51. Similarly, a river irrigator using electricity in NSW will reduce pumping energy costs from $175,000 to $162,000.

The response to survey *Question 36. Energy saving options currently adopted* (Figure 55) are shown in Figure 56. This indicates that there has been considerable investment in energy savings in tractor fleets as most people use auto-steer and 42% of growers also use traction control systems. Figure 56 also shows that only 19% of participants have had a pump efficiency test in the last five years. Figure 13 *Benchmark on-farm energy use* shows that tractor operations account for around 30% of on-farm direct energy consumption while pumping consumes 45% to 75% of on-farm direct energy

consumption. This indicates that the energy used in pumping has received comparatively little attention despite pumping being the largest single energy consumer on-farm. It is known that good to very good efficiency gains can be made in many cases. Therefore, the investigation of pumping efficiencies should be an extension priority.

Importantly, improvements in water application efficiency will lower energy cost and demand because less water being pumped for the same result. For example, if an irrigator realises a 5% improvement in irrigation application efficiency by better management of their current system then a 5% reduction in energy costs is also realised.

It is recommended that improvement in pump efficiency and irrigation application efficiency be continued.

8.2.Liquid fuel conclusions

8.2.1. LPG gas injection in diesels with mechanical fuel injection

Diesel engines inject one metered amount of fuel into the engine cylinder at the correct time once the piston has moved up the cylinder and compressed the intake air sufficiently to combust the fuel. The volume and timing of diesel delivered into the cylinder using a mechanical injection system is a pre-determined amount of fuel that is delivered in the cylinder. This system is commonly referred to as simply “mechanical injection” or a “mechanical diesel engine”. The system is only sensitive to load and engine speed and cannot detect the presence of additional fuel, such as LPG injection. LPG injection into engines with mechanical injection systems will ‘over-fuel’, which means that more fuel than required in injected into the cylinder. This results in increased costs and GHG emissions and decreased efficiencies. LPG injection is not recommended for mechanically injected engines.

8.2.2. LPG gas injection in electronic fuel injection

Modern diesel engines use a ‘common rail’ system where high pressure diesel is constantly available to the injector. Timing and volume of diesel injected into the cylinder is controlled by opening and closing the injector and this is controlled via a small computer called an ECU, or Electronic Control Unit. This system is usually referred to as simply “electronic injection” or an “electronic diesel engine”. The ECU monitors things such as load, engine speed and, importantly, exhaust gas emissions. This last fact means that an electronic diesel can sense that it is over-fuel when LPG is injected into the engine. The ECU reacts by reducing the volume of diesel injected into the cylinder. Thus, diesel consumption is reduced to compensate for the additional LPG fuel.

LPG gas injection is recommended in electronic diesel engines because the engine, via the ECU, has the ability to reduce the amount of diesel consumed in response to the addition of LPG gas.

Electronic injection is much more precisely controlled than mechanical injection. Particularly, the electronic injection system allows for “multi-point injection”, which is where four or five smaller amounts of diesel are injected into the air compressed in the cylinder. This increases the combustion efficiency of the fuel. Section *A8.2 Fuel efficiency – electronic fuel injection* shows that gains in engine efficiency in the order of 4.7% for LPG gas injection in electronic diesel engines. Because of the higher combustion efficiency of the engine, the use of electronically injected engines is recommended. Tractors typically have electronically injected engines.

8.2.3. Liquid fuel policy and tariff issues

The Australian Taxation Office (2014b) state that the full fuel rebate is available on the entire amount of biodiesel blends that are invoiced as either B5 or B20. For blends other than these specific blends (B5 and B20) the fuel tax rebate is claimable only on the portion of diesel contained in the fuel Thus, it recommended that biofuel blends of B5 or B20 be used.

8.2.4. Biofuels

A survey of 165 cotton growers, presented in section 7.4 *Perceived relevance of various alternative energy sources* shows that price, availability and ease of use are the most import decision factors when choosing an alternative energy source. Environmental concerns are of important, but to a lesser degree (figure 120).

Table 18 shows that diesel, LPG injection and electricity are similar in cost when expressed per GJ of energy output at the flywheel. Of these, LPG injection has the lowest emissions, followed by diesel. Electricity has the highest emissions of any energy source. Recalling that these analyses use broad assumptions, each of these options could be viable given different values for engine efficiency, electrical tariff and so on. Growers will need to evaluate their own specific circumstances in light of these results. LPG gas injection with B20 provided the highest fuel efficiency and lowest emissions.

Conversely, B100 biofuels (100% biofuel) have negligible contribution to global warming, however their costs are much higher than traditional alternatives. Straight biofuels are hampered by the fact that there is no fuel rebate available because there was, effectively, no rebate paid on the fuel. Cotton seed oil is the most expensive energy option due to the low extraction rate of the oil. However, it is possible for the industry to be self-sufficient with cotton seed oil. Canola, which has a higher extraction rate is the next cheapest option. Australian canola production would generally meet the energy demands for cotton, however this would require most of the canola crop. B100 tallow is closer to being economic due to the low cost of the feedstock. Obviously, such high demands on any of these feed stocks would increase the cost of the feed stock and therefore the cost of the fuel.

B20 blends, especially tallow, are close to being economic because fuel blends up to 20% still attract the full fuel rebate. These blends may be economical at different times depending on the relative pricing of B20 and diesel. Growers need to be aware that due to differences in calorific value and viscosity, biofuels have a slightly lower combustion efficiency than diesel. Results from the B20 tallow biofuel tests show that this has a combustion efficiency 1.8% lower than that of diesel. Thus this fuel would need to be 1.8% cheaper than diesel for price parity. These results are summarised in figure 43, which is repeated below.

Engine durability

Engine durability is the ability of the engine to operate efficiently throughout and beyond the design lifetime, which is generally in the order of 10,000 hours. Testing of fuels in this study were conducted over a very short time frame. Thus no adverse engine wear effects became apparent during testing. Long term engine durability testing of biofuels requires at least 2,000 hours of operation. Fuel properties other than calorific value are important to ensure engine durability. To mitigate and avoid engine durability issues it is recommended that growers only source biodiesel from reputable commercial fuel suppliers. Fuel tariff issues which limit the rebate in fuel to less than or equal to a 20% concentration of biofuel thus economically limit biofuels to B20 (20%

concentration of biofuel). The use of these B20 fuels, which are 80% diesel, mitigate engine durability problems.

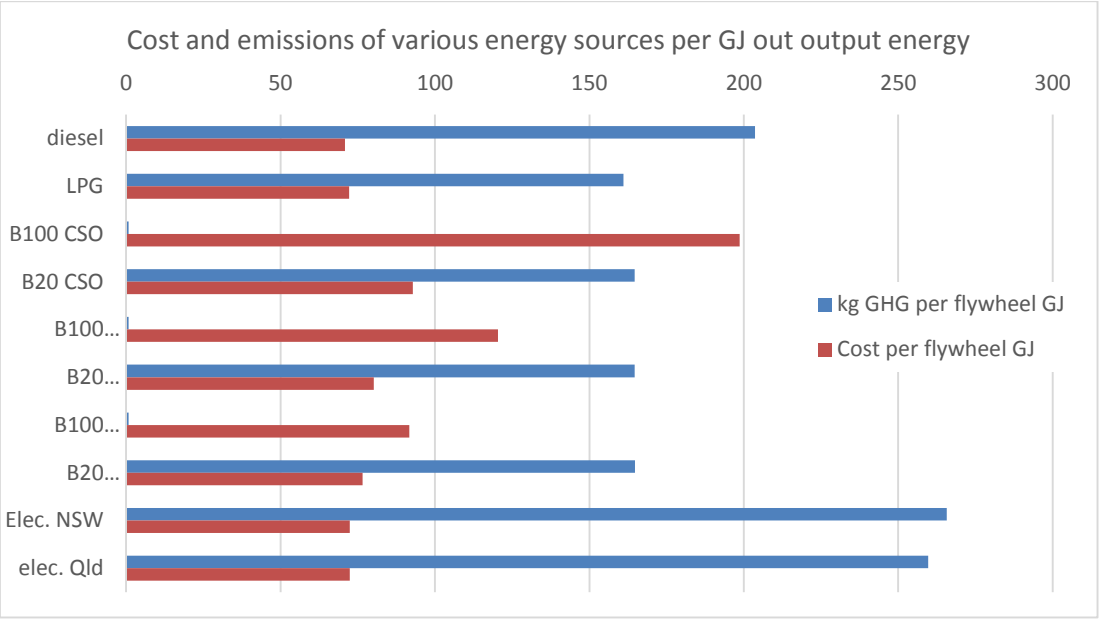


Figure 43. Cost and emissions of various fuels per GJ of output energy.

Longer-term potential of Algae fuels

Pitman et al (2011) suggest that 'Based on current technologies algal cultivation for biofuel production alone is unlikely to be economically viable or provide a positive energy return.' However, Pitman et al (2011) also suggests that several strategies exist to overcomes current limitations and suggest that algae fuel offer real potential at around a ten-year horizon.

8.3. Electrical energy conclusions

Historically, Australia as a country has formulated strong energy policies in order to reduce dependence on fossil fuel and increase domestic energy production by various clean energy and renewable energy. It is noticeable that there has been a significant change of government policy in the current term.

An online renewable energy calculator (Chen et al, 2011) has been developed at the National Centre for Engineering in Agriculture (NCEA), University of Southern Queensland (USQ), to provide an indication of potential for solar or wind systems to replace purchased electricity and feed electricity into the grid. The calculator can select the appropriate size of solar or wind turbine system and provide a simple cost benefit analysis based on available information of expected energy demand, renewable energy to be generated, electricity costs and system capital and operating costs.

8.3.1. Reducing the cost and increasing the efficiency of electricity

Analysis of the data set obtained by Sandell et al, 2013, and observations by the authors show that there is large variability in the total cost of electricity[6] between individual users. Therefore individual cotton growers should investigate their electricity tariff and how other tariffs would work for their situation. Energy benchmarking (Section 8.1.1) is particularly helpful in this regard.

Practical steps that a grower can take include:

- Getting quotes from a number of suppliers.
- Look at changing to other tariffs.
- Take into account the extra service fees charged for the other tariffs.
- Take meter readings of the times you actually run the equipment.
- From your bills, calculate your peak, off-peak use and controlled load use.

In addition to tariff and cost management, above, and energy measurement and efficiency measures mentioned in section 8.1 there are some efficiency measures specific to electric motors. In particular, Variable Speed Drives (VSD) will reduce total energy demand where the load on the motor changes, such as when a river of tail water level varies between upper and lower limits. Soft start switching reduces the peak demand that a motor requires on start up. Often, electricity retailers will invoice an additional charge based on peak current draw over a billing cycle. Soft start switching systems reduce this peak load and associated charge. It is recommended that these strategies be part of an awareness campaign for the cotton industry.

8.3.2. Solar photovoltaics

Most of respondents (cotton growers) to the survey also felt that solar was useful to offset the cost of domestic and workshop electricity. Some growers were supportive of the idea of using solar energy for water pumping.

Overall, solar energy is:

- Very competitive for remote, rural locations where connection to the grid is difficult or expensive
- With the new technologies currently under development, prices will further reduce in the near future.

However, all current renewable electrical energy rebates are currently under review and may be changed or removed.

Solar PV has a low energy density and is available only during daylight hours. Solar energy is not well suited to pumping water for the cotton industry under most circumstances.

Recent research is also enabling progress toward achieving 20~% to 25% and up to 30% efficiency. Research is also being conducted to manufacture solar cells from more plentiful, cheap and non-toxic materials. With the new technologies currently under development, electricity generation costs from solar energy may are expected to fall significantly in the future.

[6] The total cost of electricity is defined by the authors and the invoice total, including network and other charges, divided by the total invoiced kilowatt hours. The unit rate of electricity does not reflect the true cost of electricity because of network and other charges.

8.3.3. Solar thermal

The capital cost of solar thermal would is prohibitive for this technology. The uncertainty of policy and tariff issues make economic viability questionable.

8.3.4. Wind

From comparison of figures 17 and 40 show that wind reliability and speed is unlikely be high enough in cotton growing regions of Australia.

8.3.5. Hydroelectricity

Hydroelectricity generation requires a suitable site and a reliable flow of water. Because capital investment is moderate to high, around $1,000 per kilowatt of capacity, a reliable flow of water is required to ensure a return on investment. Unfortunately there are few sites in the cotton industry that would meet this requirement.

8.4.Solid fuels conclusions

It is recommended that options for utilising the significant cotton gin trash (CGT) biomass resource be investigated and quantified. While there are several options to utilise this resource to generate electrical and/or thermal energy, such as those listed in section 6.2, there is little evidence as to the relative merit of each system. In particular, major parameters such as CGT production, CGT calorific value, process efficiencies and capital and operating costs would need to be identified for each system. A brief scoping review into the viability of collecting in-field plant residue should be conducted in conjunction with such an investigation. Utilisation of cotton biomass presents a large potential energy source that is essentially carbon neutral.

Annual industry production of Cotton Gin Trash (CGT), based on 330,000 hectares of production, is in the order of 230,000 to 330,000 tonnes of biomass. With a calorific value of around 15.5 GJ/t this is a total of 3.6 to 5.1 million GJ of energy. CGT is currently a waste stream accumulating in large disposal sites, which present environmental, fire and pest and disease issues for cotton ginners.

The cotton plant itself, which is left in the field after picking, represents a much larger source of biomass. This biomass represents a problem in the field sector with many growers resorting to burning the trash. In-field plant residues of 5.2 to 5.5 tonnes per hectare, at a calorific value of 14.6 GJ/t, would add another 25 to 27 million GJ of energy for the same production area of 330,000 Ha. However, added complexity and costs of collecting and processing in-field biomass exist.

Options for capitalising on the CGT resource (section 6.2) to replace thermal demands at the cotton gin (currently supplied largely by LPG) or to generate electricity summarised in table 32 and in figure 67, below. These figures are based on 330,000 Ha of cotton and the total industry value of lint and seed are also presented in table 32 to provide scale.

Solid fuel policy and tariff issues

There are no policy or tariff issues specific to biomass for energy generation. However, the energy that it produces, electricity, methane or ethanol, for example, is subject to the respective policy and tariff issues outlined in preceding sections.

Table 32. Summary of Cotton Gin Trash options based on 330,000 Ha of production.

	Gross revenue, $millions	Thousand tonnes CO2e avoided	Notes
any method to replace LPG	10	23	CGT resource oversupplies LPG need. Value is therefore limited to LPG cost.
ethanol	30	51	Questions as to economic viability of process
Bio-digester to generate electricity	7	40	Low capital and low to moderate complexity
pyrolysis for electricity generation	28	160	moderate capital and moderate complexity
high pressure boiler for electricity generation	40	227	high capital and complexity
lint	1,280		
cotton seed	304		

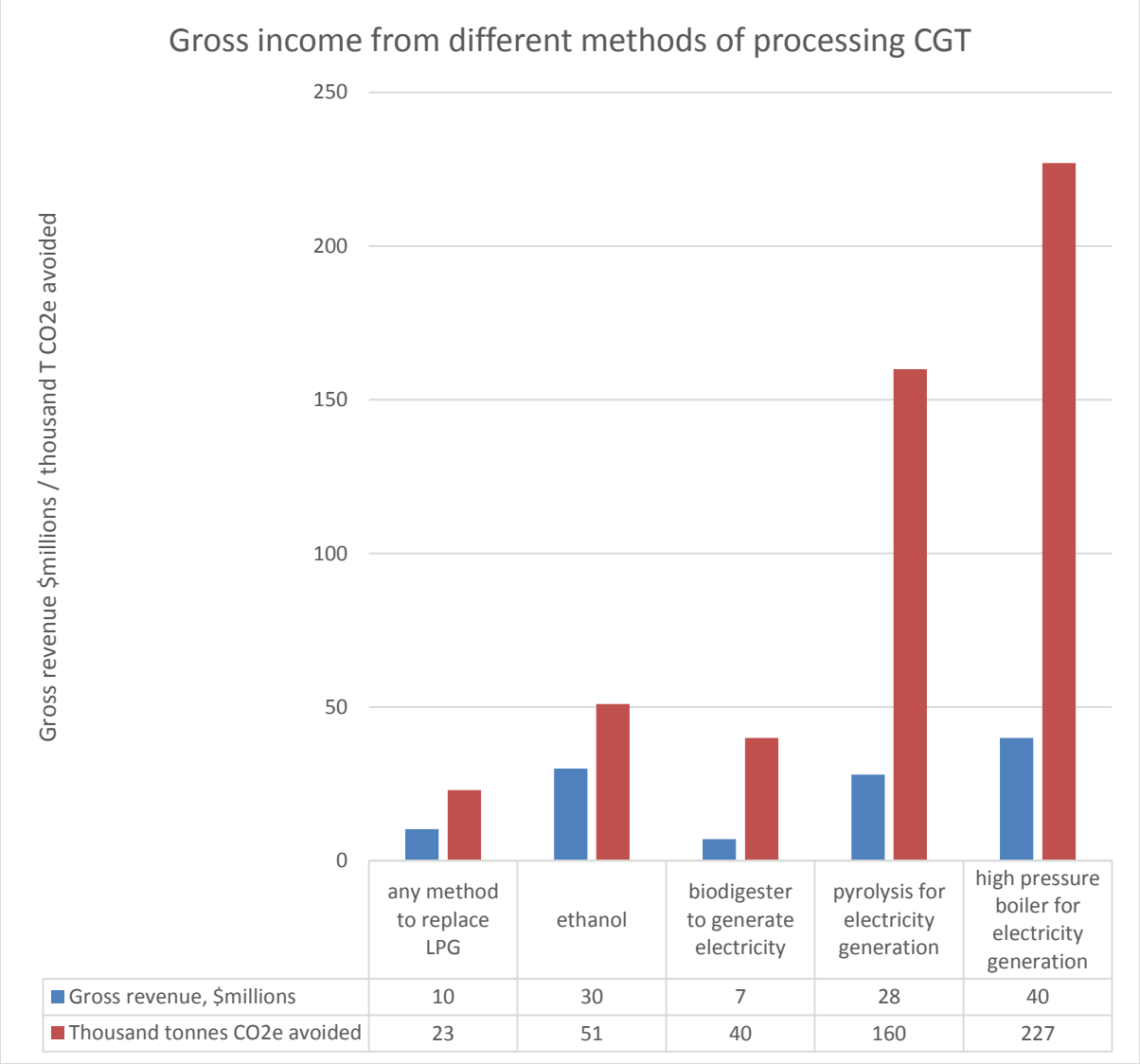


Figure 67. Gross revenue and emissions from various CGT processing options.

Glossary

AIP. Australian Institute for Petroleum.

Aerobic. Relating to, involving, or requiring free oxygen

Anaerobic. Relating to or requiring an absence of free oxygen

ATO. Australian Tax Office.

B20 A mixture, by weight, of 20% biodiesel and 80% diesel. Similarly, other blends such as B5 and B50 are made.

BCI Better Cotton Initiative. See http://bettercotton.org/

Biodiesel. Biodegradable transportation fuel for use in diesel engines that is produced from biomass (organically derived vegetable oils or animal fats). The oil or fat is reacted with alcohol to produce a fuel that can be used on its own or mixed with petro-diesel.

Biofuel. Liquid fuels, such as ethanol and biodiesel, made from biomass. These fuels can be used in their pure form or blended with petrol or petro-diesel. First generation biofuels are based on fermentation and distillation of ethanol from sugar and starch crops or chemical conversion of vegetable oils and animal fats to produce biodiesel. First generation technologies are proven and are currently used at a commercial scale. Second generation biofuels use biochemical or thermochemical processes to convert lignocellulosic material (non-edible fibrous or woody portions of plants) and algae to biofuels. Second generation technologies and biomass feed stocks are in the research, development and demonstration (RD&D) stage. Third generation biofuels are in research and development (R&D) and comprise integrated biorefineries for producing biofuels, electricity generation and bioproducts.

Biogas. A combustible gas derived from decomposing biological waste, including digester gas. Biogas normally consists of 50% to 60% methane. It is currently captured from landfill sites, sewage treatment plants, livestock feedlots and agricultural wastes.

BSFC, Brake specific fuel consumption, also written as Specific Fuel Consumption (SFC), is a measure of fuel efficiency of an engine and is used to rate and compare engines in terms of their fuel efficiency. It is a measure of fuel consumed per unit of power produced. Lower BSFC values are preferable because this means that less fuel is consumed to produce a unit of power. Units are commonly grams of fuel per kilowatt-hour [g/kW.h]; sometimes millilitres per kilowatt-hour [ml/kW.h] are used.

Calorific Value refers to the amount of the heat that can be released during the combustion process of the fuel. Also referred to as the heating content, heating value (HV), or heat of combustion.

Carbon Dioxide See **CO2**.

Carbon Monoxide See **CO**.

CGT. Cotton Gin Trash. This is the plant material removed from raw cotton in the ginning process.

CGW, Cotton Gin Waste. See *CGT*.

CH4 Methane, CH_4 is a compound of four hydrogen atoms bonded to a carbon atom. It is the main component of natural gas and is often used as a fuel. Other than natural gas, methane is commonly produced from ruminant animals (eg cattle) and anaerobic respiration of wastes such as landfill and animal wastes.

CI Compression Ignition. CI is the method used in diesel engines where the fuel is ignited due to high levels of compression in the cylinder chamber. Conversely, petrol engines have a lower level of ignition and use a spark to ignite the petrol in the combustion chamber.

Climate Change Long term change in the overall climate trends.

CO Carbon monoxide.

CO2 Carbon dioxide. A naturally occurring gas that is a compound of two oxygen atoms and one carbon atom. More correctly written as CO_2. CO2 is important in plant respiration processes and is a major contributor to global warming as it is released through burning fossil fuels.

Coal. A hydrocarbon-based fossil fuel composed of the remains of land plants which have been transformed into a solid mass of carbon, hydrogen and oxygen through the heat and pressure resulting from burial. Coal is found in seams that can be extracted either by surface or underground mining.

Coal seam gas (CSG). Natural gas extracted from underground coal seams. CSG can be processed as LNG and CNG. The Coal Seam Gas industry has the potential to offer substantial economic and other benefits to Australia. However, if not adequately managed and regulated, it also risks having significant adverse impacts on adjacent surface and groundwater systems.

Compressed Natural Gas (CNG). Natural gas that has been compressed under high pressures and held in a container; expands when released for use as a fuel. CNG is also a cleaner alternative to other fuels such as petrol and diesel.

CRPS. Carbon Pollution Reduction Scheme. See section 4.2.

Crude oil. Complex liquid mixture of hydrocarbons, with small amounts of S, O, N impurities. Crude oil can be refined to produce heating oils, gasoline, diesel, jet fuels, lubricants, asphalt, ethane, propane, butane and many other products.

CSG See Coal Seam Gas.

CSO. Cotton seed oil.

Diesel. A petroleum-based fuel used in engines ignited by compression rather than spark. Diesel fuels are heavier and produce higher emissions than petrol. They also provide more power per unit of volume.

Digester gas. Biogas that is produced using a digester which is an airtight vessel or enclosure in which bacteria decomposes biomass in water to produce biogas.

Electricity. Electric current generated by (mostly) coal-fired power stations and used as a power source.

Emissions. The release or discharge of gases or particulate matter into the air or water.

Energy crops. Crops grown specifically for their fuel value. These include food crops such as corn and sugarcane and non-food crops such as poplar trees and switch grass. Currently, energy crops under development in the U.S. include short-rotation woody crops, which are fast-growing hardwood trees harvested in five to eight years, and herbaceous energy crops, such as perennial grasses that can be harvested annually after reaching full productivity in two to three years.

Energy source. Any substance that supplies heat or power (e.g. petroleum, natural gas, coal, renewable energy and electricity).

Esterification. Esterification and transesterification are the primary chemical reactions used in producing biofuel.

Ethanol. An alcohol compound with the chemical formula C2H5OH formed during sugar fermentation by yeast. Also known as grain alcohol. Blends of 90% unleaded petrol and 10% fuel ethanol are commonly referred to as E10.

FiT. Feed-in Tariff; a rebate available for small and large scale producers of renewable electricity.

Fossil fuel. Fuels produced by the decomposition of deeply buried organic matter from plants & animals

Fuel calorific value. See *calorific value*.

Fuel consumption rate, is how quickly fuel is consumed by a power source, such as a diesel engine. It is usually measued in grams per hour, but is also measured in litres per hour or other similar units.

Fuel density is the weight of fuel per unit volume and is usually measued in grams of fuel per litre or tonnes per cubic meter.

Engine fuel efficiency is the ratio of energy input into the engine as fuel divided by the output power as measured by the dynamometer, expressed as a percentage. Higher efficiency values are preferred as this gives more mechanical energy output per unit of energy input.

Gigajoule (GJ). A unit of measurement of energy consumption. A gigajoule is equal to one billion joules. At the current market condition, 1 GJ of energy would typically cost around $10 to $40. The corresponding greenhouse gas emissions range from zero (using 100% renewable energy) to around 78 kg CO2/GJ (using diesel fuel).

GJ See Giga Joule.

Global Warming Google (June 2014) provides a definition of global warming as ‘a gradual increase in the overall temperature of the earth's atmosphere generally attributed to the greenhouse effect caused by increased levels of carbon dioxide, CFCs, and other pollutants.’

Global Warming Potential (GWP). Some atmospheric gasses will retain more heat in the atmosphere than others. GWP is a measure of how much heat a particular gas will trap in the

atmosphere. It is relative to the GWP of carbon-dioxide. For example, one kilogram of methane traps 310 times more heat than one kilogram of carbon-dioxide. Thus, methane has a GWP of 310. GWP is measured in kilograms (sometimes grams or tonnes) of carbon-dioxide equivalent [kgCO2e]. Refer to table 2.

HC Hydrocarbon(s).

hp. Horse power. An imperial unit of power measurement equivalent to 0.7457 kW

hr Hour

IP Intellectual Property.

IPCC Intergovernmental Panel on Climate Change.

ITC International Trade Centre

kgCO2e. See *Global Warming Potential (GWP)*.

kW. KiloWatt. A measure of power equivalent to 1,000 joules of energy per second and equivalent to 1.341 horsepower (hp).

kWh. A measure of energy equal to one kW of power being consumed (or produced) continuously for one hour.

LCA. Life-cycle assessment.

Liquefied Natural Gas (LNG). Natural gas which has been cooled to its boiling point of minus 161ºC at which it liquefies, reducing its volume to one 600th. Exports are currently worth more than $3.2 billion a year and it is forecasted that LNG sales in Australia could triple in the next five years, putting the industry on par with iron ore and coal in terms of export contributions to the economy.

Liquefied Petroleum Gas (LPG). LPG is usually derived from fossil fuel sources, being manufactured during the refining of crude oil, or extracted from oil or gas streams as they emerge from the ground.

Mandatory Renewable Energy Target (MRET). A target level of renewable energy to be produced and used. Usually expressed as a percentage of total electricity usage, e.g. 15% by 2020.

Methane See **CH4**.

Micrometre. 10^{-6} meters, or 0.001 millimetres.

MW. MegaWatt. A measure of power equivalent to 1,000,000 joules of energy per second and equivalent to 1,341 horsepower (hp).

MWh. A measure of energy equal to one MW of power being consumed (or produced) continuously for one hour.

Natural gas. Underground deposits of gases consisting of 50% to 90 % methane (CH_4) and small amounts of heavier gaseous hydrocarbon compounds such as propane (C_3H_4) and butane (C_4H_{10}). As a fuel, natural gas is convenient and efficient. It is currently used primarily for heat. It is also used to produce electricity, in some cases using gas fired turbines, in others to fire steam boilers.

NCEA The National Centre for Engineering in Agriculture. (A wholly owned subsidiary of The University of Southern Queensland.)

NOx

PD Petroleum diesel

Petajoule (PJ). A unit of measurement of energy consumption. One petajoule is equal to one million gigajoules, or 10^{15} joules. One petajoule is also the heat energy content of about 43 000 tonnes of black coal or 29 million litres of petrol.

Petrol. A fuel refined from oil that is used in internal combustion engines.

Photovoltaic. A system that converts direct sunlight to electricity using semi-conductor materials.

ppm Parts per million.

PJ. See *Petajoule(PJ).*

PTO. Power take-off. A mechanical drive shaft located at the rear of all modern tractors that can be used to power equipment.

R&M. Repairs and maintenance.

Renewable energy. Naturally occurring energy sources that are continually replenished. Examples of renewable energy are wind, solar and water.

rpm. Revolutions per minute.

Solar energy. The radiant energy of the sun, which can be converted into other forms of energy, such as heat or electricity.

Solar thermal collector. A device designed to receive solar radiation and convert it into thermal energy. Normally, a solar thermal collector includes a frame, glazing, and an absorber, together with the appropriate insulation. The heat collected by the solar thermal collector may be used immediately or stored for later use.

Specific fuel consumption (SFC). See *BSFC Brake Specific Fuel Consumption.*

Tallow. Animal fat, usually sourced from abattoirs where it is a waste stream.

TGP. Terminal Gate Prices. The price of fuel at the portside fuel terminal, which are located in each Australian costal capital city.

Transesterification. Transesterification and esterification are the primary chemical reactions used in producing biofuel.

ULP. Unleaded Petrol

USQ. The University of Southern Queensland

Wind energy. Energy present in wind motion that can be converted to mechanical energy for driving pumps, mills, and electric power generators. Wind pushes against sails, vanes, or blades radiating from a central rotating shaft.

Wind turbines. Converts the wind's kinetic energy into mechanical power that a generator, in turn, converts into electricity.

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Appendix A. Performance characteristics of liquid fuels

Because of the of the cotton industry's heavy reliance on diesel, it is important to closely examine the performance characteristics of commercial and non-commercial alternative diesel fuel sources and mixtures. Because of the global warming problem currently facing the planet, it is necessary to also examine the emission characteristics of these fuels.

Specific aims of the fuel testing are to:

- Examine performance / characteristics of non-commercial alternative fuel sources and mixtures
- Reduce operating costs and emissions of non-commercial alternative fuel sources and mixtures

Because of sometimes conflicting research concerning biofuel emission and performance results and variations in biofuel properties a controlled testing program was conducted at the fuel laboratory at the University of Southern Queensland (USQ). This laboratory provides the high precision equipment to measure the performance and emission characteristics of liquid fuels.

The fuel testing included a variety of fuels including diesel, biodiesel, low purity ethanol, algae biodiesel and LPG. These fuels were selected because of their potential in the cotton industry and was informed by the industry survey, which is presented in section 7.

Performance and emissions were analysed simultaneously in each test. Each fuel test was conducted in relation to a diesel base line. Because tests were carried out on different engines, using a diesel baseline in each case allows us to normalise the data. That is, compare each result against a common baseline of diesel.

Because some fuels were in limited supply testing was initially conducted on smaller engines to measure the relative performance of the fuel. Small engines were to establish the performance of different blend ratios. Once this was complete, the more promising fuels were selected for testing in larger engines which are more akin to those used in the cotton industry. A larger four cylinder engine was used to determine the performance of the fuels, similar to those used for pumping water on cotton producing properties. PTO testing was carried out to determine the performance of the fuels for tractor applications.

Optimisation was required for some fuels that showed potential, however could be improved in some way. For example, the relative amounts of diesel and LPG used in testing needed to be optimised to obtain optimum efficiency and minimise emissions.

Accurately measuring the performance and emissions characteristics for the range of fuels allows us to use these results in cost modelling and other scenarios.

The algae and other fuel testing performed on the JD4410 apparatus are the results of Al-lwayzy et al., (2013) and are presented here to increase the breadth of the discussion.

Colour coding in fuel testing results. In the tables for the emissions comparison, green signifies a reduction in emissions of a harmful gas and pink signifies an increase in emissions of a harmful gas. In the summary tables each type of test (constant speed, constant torque etc.) has a different colour to make it easier to compare fuels for the same test.

A1. Testing Apparatus

A1.1 HATZ

The primary testing apparatus used a HATZ 4M41 four cylinder, 3.43L air cooled diesel engine. This engine is mechanically injected, with four injector pumps and centrifugal variable speed governor (HATZ, 2014). The engine operates with a compression ratio of 20.0:1, and its injector timing is automatic (HATZ, 2014). This engine was connected to a Dyno Dynamics 450kW Eddy Current Dynamometer (Dyno Dynamics, 2014) to apply and measure the load induced on the engine. A FLOSCAN Series 75/76000 MFI fuel monitoring system and K201 fuel flow sensors (FLOSCAN, 2014) measured the inflow and return flow of liquid fuel to the engine. A Land & Sea (Land and Sea Inc., 2014) gas analyser was used to dynamically measure emissions during testing. Thermocouples with digital displays were used to measure exhaust temperature. Figure 68 shows the engine and dynamometer apparatus.

Figure 68. HATZ engine and dynamometer testing apparatus, USQ, 2014.

A1.2 Farymann / GUNT

A Farymann diesel engine (Farymann Diesel Systems, 2013) modified by G.U.N.T to enable a variable compression ratio (G.U.N.T, 2005), and a G.U.N.T CT300 test stand (G.U.N.T, 2005) apparatus was used for testing fuels that were in limited supply. This apparatus is shown in figure 69. The Farymann engine is a water cooled single cylinder engine of 290cc displacement, connected to an asynchronous electric motor which applies a load to the engine. The speed of the engine and torque applied to the engine can be controlled by the operator via the CT300 test stand. A load cell and revolution counter provide torque and power output measurements through both the control panel and the software package. Thermocouples provide exhaust, intake and cooling water temperatures. An Emissions Systems 5002 exhaust gas analyser (Emissions Systems Inc., 2013) measures the composition of the discharged gases. Fuel flow rate is measured using the G.U.N.T CT300 engine test stand. The compression ratio of this engine in diesel mode can be adjusted from 16.0:1 to 20.0:1. For this testing a compression ratio of 16.0:1 was selected in order to ensure engine safety while testing alternative fuels.

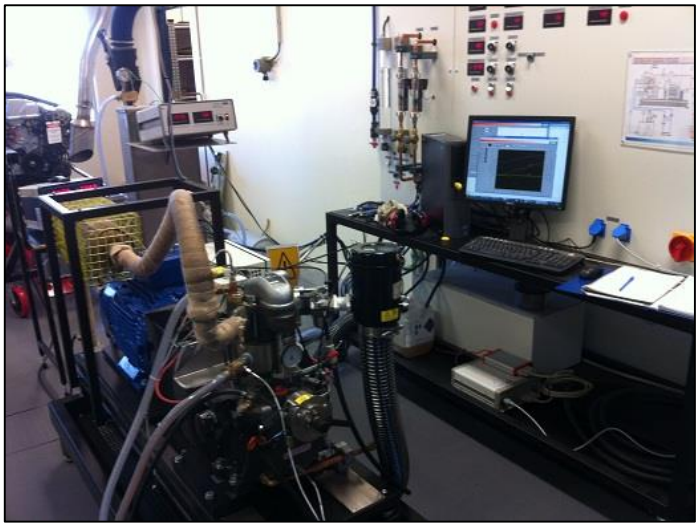


Figure 69. GUNT Variable Compression Engine & Test Bed

A1.3 JD4410

The third testing apparatus, used by Al-lwayzy et al., (2013), is a John Deere 4410 tractor, powered by a 1.6L Yanmar 3TNE88, 3 cylinder, water cooled diesel engine (E.P. Barrus Limited, 2014a). The compression ratio of the engine is 18.5:1 and the rated power of the engine is 25.8kW, with 105Nm of torque (E.P. Barrus Limited, 2014a). An AW400 dynamometer (AW Dynamometers Inc., 2014) is to be used and calibrated prior to use using standard weights. An optical tachometer measures the speed of the PTO shaft. A Bosch BEA460 gas analyser (Bosch, 2014) determines the exhaust gas composition. Fuel usage is measured by manually recording the time taken to consume a quantity of fuel measured from a glass cylinder. This apparatus is shown in figure 71, below.

Figure 70. John Deere 4410, PTO Dynamometer & Gas Analyser.

A1.4 Yanmar

The final apparatus used was the single-cylinder air-cooled diesel Yanmar L48N6 engine (E.P. Barrus Limited, 2014b). The engine has a displacement of 219cc, and produces 3.5kW@3600rpm and 11.5Nm@2600rpm (E.P. Barrus Limited, 2014b). This engine consumes considerably less fuel than a tractor engine, which allowed testing of different fuel blends with more replications with the limited amount of fuel and under controlled conditions. Engine performance and exhaust gas emission parameters, were measured using a Land & Sea 7" water brake dynamometer (Land & Sea Inc., 2014a), air flow meter (Land & Sea Inc., 2014b), manual fuel flow measuring components, exhaust

gas temperature K type thermocouple and display, and exhaust gas port sampling point to the Emissions Systems 5002 gas analyser (Land Emissions Systems Inc., 2013). This apparatus can be seen in figure 71 below.

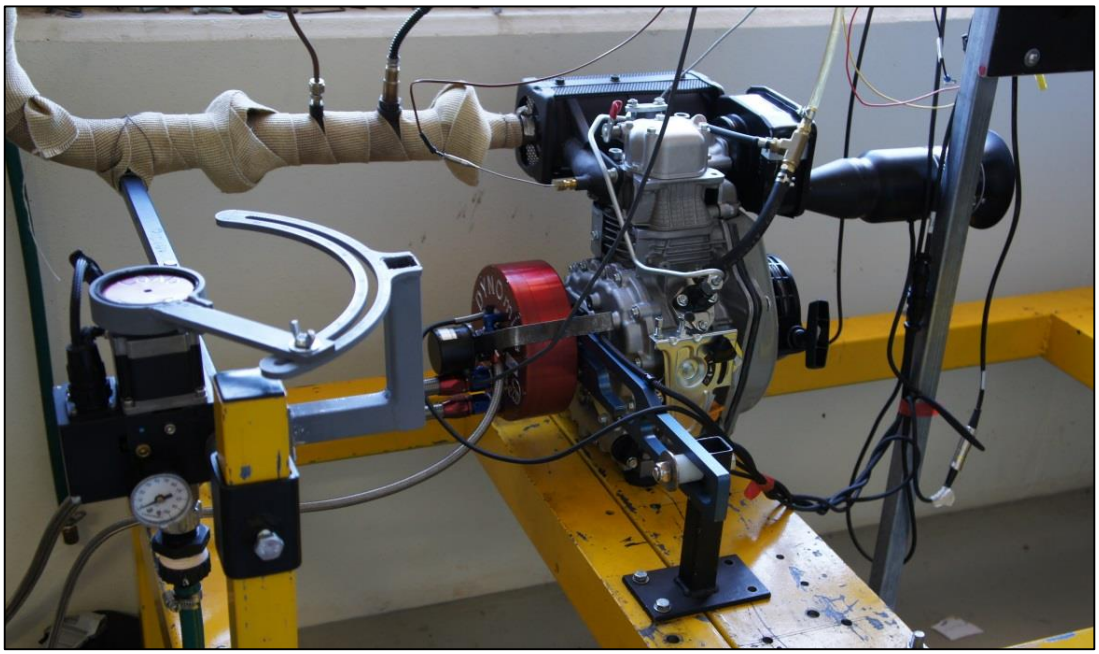


Figure 71. Yanmar Engine, Land & Sea Dynamometer and Instrumentation.

A2. Test Methodology

To establish a baseline for comparison of alternative fuels, testing was first carried out using CALTEX Vortex diesel (Caltex Australia, 2013) on each apparatus detailed above. The testing consisted of a power curve at full throttle over the operating range of 1200-3000rpm for the G.U.N.T apparatus, 1100-2700rpm for the HATZ apparatus, 900rpm-2700rpm for the John Deere apparatus, and 1700-3800rpm for the Yanmar apparatus. The torque curves and exhaust temperatures were also plotted. The specific fuel consumption (g/kWh) and efficiency (% of energy input converted to energy output) were calculated at each engine speed. The exhaust gas composition, including unburned hydrocarbons, carbon monoxide, carbon dioxide, oxygen, nitrous oxides (NOx) and air fuel ratio were measured.

Diesel specifications

The diesel used for the testing was CALTEX Vortex diesel. The fuel has a density range of between 0.82g/cm3 and 0.85g/cm3 (Caltex Australia, 2013), due to variances in ingredients. A sample of fuel purchased for the testing was measured to have a density of 0.84g/cm3. The calorific value of the fuel is 36,240kJ/L, (Morris, R., pers. Comm. lubelink@caltex.com.au, 4 June 2014), equating to 43,143kJ/kg using the measured density. These values are to be used in all calculations.

Alternative fuels are compared against the relevant diesel base line.

A3. Conventional Diesel Results

A3.1 HATZ

A baseline performance was established for the HATZ using CALTEX Vortex diesel at full throttle (that is, full fuel) operation. This full throttle data is shown below in table 33. The testing using the HATZ

engine yielded a peak power of 48kW@2600rpm, and a peak torque of 208Nm@1100rpm. These results are shown in figures 72 and 73 respectively. Exhaust temperatures reached 654°C@2400rpm and efficiency peaked at 34.3%@2000rpm.

NOx emissions reached 352ppm@1600rpm and equivalent CO2e emissions peaked at a concentration of 19.26% CO2e at 1500rpm. Because it is measured as a percentage of the volume of exhaust gases, mass of gases emitted increase as a function of engine speed. The exhaust gas composition results are shown below in table 34.

Table 33. Full Throttle Data of HATZ Engine Using CALTEX Vortex diesel.

Speed (RPM)	Exhaust Temp (°C)	Diesel Consumption (L/h)	Specific Fuel Consumption (kg/kWh)	Efficiency (%)
1400	550	8.6	0.244	34.0
1500	565	10.0	0.264	31.4
1600	579	9.7	0.245	33.8
1700	586	10.2	0.243	34.1
1800	595	11.2	0.256	32.4
1900	606	11.3	0.247	33.6
2000	616	11.5	0.242	34.3
2100	623	12.9	0.264	31.4
2200	633	12.5	0.242	34.3
2300	643	13.4	0.254	32.6
2400	654	14.0	0.258	32.1
2500	651	13.9	0.253	32.8
2600	641	14.3	0.250	33.1

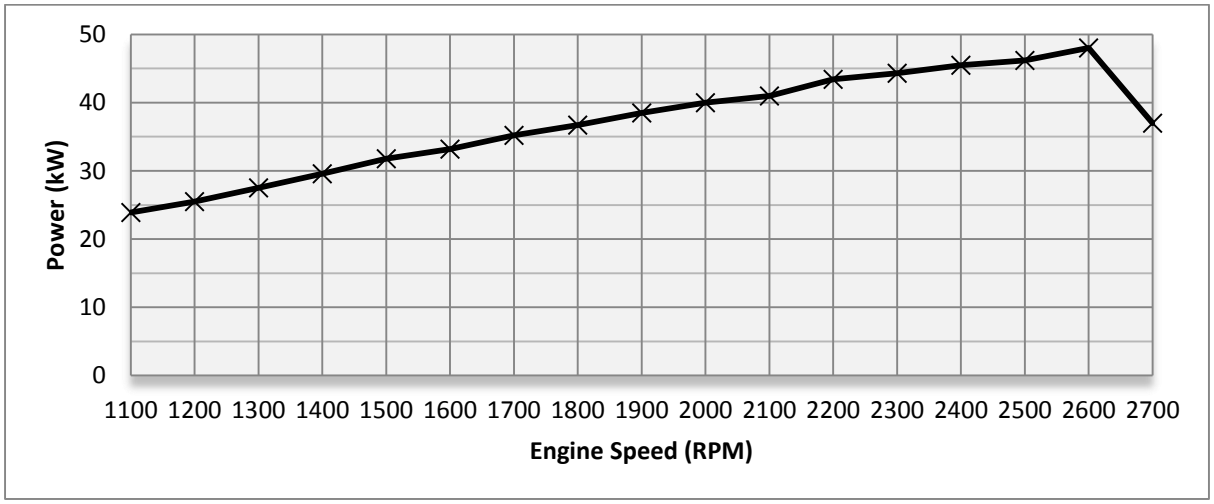


Figure 72. Power Curve of HATZ Engine Using CALTEX Vortex Diesel.

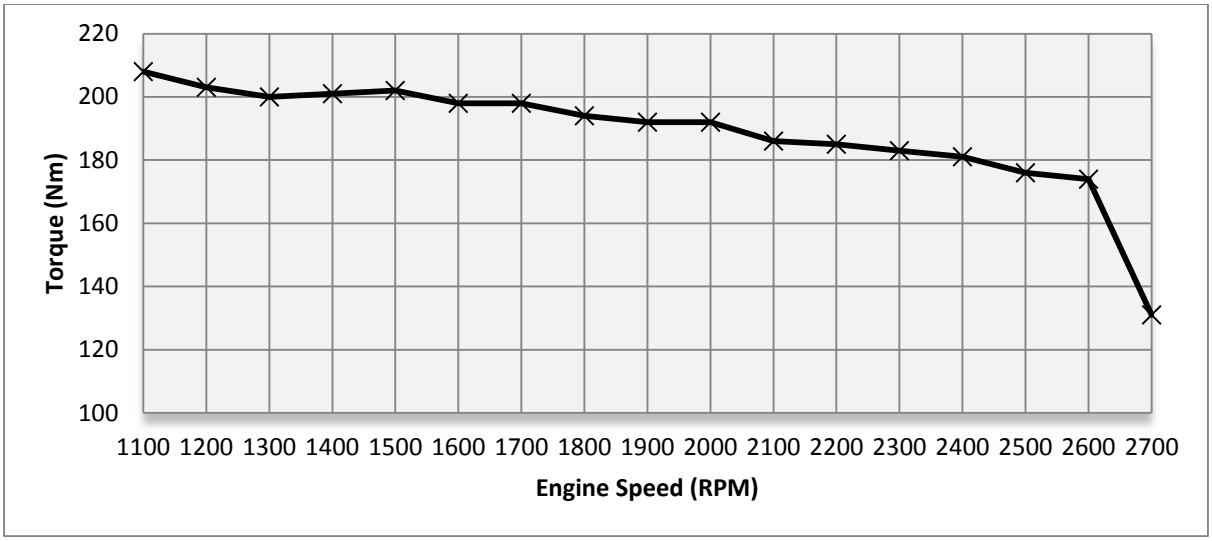


Figure 73. Torque Curve of HATZ Engine Using CALTEX Vortex diesel.

Table 34. Exhaust Gas Composition of HATZ Engine at Full Power Using CALTEX Vortex

Speed (RPM)	CO (% vol)	CO_2 (% vol)	HC (10^{-4} vol)	O_2 (% vol)	NO_x (ppm)
1400	0.32	12.6	1	3.4	350
1500	0.28	12.7	1	3.3	348
1600	0.22	12.6	1	3.4	352
1700	0.19	12.6	0	3.4	351
1800	0.17	12.5	0	3.4	347
1900	0.14	12.4	0	3.7	351
2000	0.14	12.5	0	3.6	342
2100	0.13	12.4	0	3.6	333
2200	0.12	12.4	0	3.7	330
2300	0.13	12.5	0	3.7	324
2400	0.10	12.1	0	4.0	322
2500	0.09	12.0	0	4.2	325
2600	0.07	11.9	0	4.3	327

A3.2 Farymann/GUNT

A baseline performance was established for the Farymann/GUNT apparatus using CALTEX Vortex diesel at full fuel (that is, full throttle) operation. This full throttle data is shown below in table 35. This testing yielded a peak power of 4.89kW@2600rpm and a peak torque of 19.69Nm@2000rpm. These results are shown below in figures 74 and 75 respectively.

Exhaust temperature reached 555°C @2700rpm and peak efficiency was achieved of 27%@2100rpm. Fuel consumption figures, and therefore efficiency values, were not as accurate as those obtained from the HATZ engine. This was due to the measurement apparatus measuring volume over a period of time, rather than the instantaneous reading from a rotor style meter. Despite allowing the engine to run through a few measurement cycles at each speed, some data was

obviously erroneous and were excluded from the analysis. The remaining results should be treated with caution.

NOx emissions peaked at 262ppm@1200rpm and equivalent carbon dioxide emissions peaked at 0.199kgCO2e per kilogram of exhaust emissions at 2100rpm. Full exhaust gas composition across the whole range of speeds is tabulated in Table 36.

Table 35. Full throttle data of the Farymann/GUNT apparatus using CALTEX Vortex diesel.

Speed (RPM)	Exhaust Temperature (°C)	Fuel Consumption (kg/h)	Efficiency (%)
1200	355.08	1.14	17.44
1300	386.72	0.88	24.16
1400	410.19	0.98	23.84
1500	424.34	0.95	26.08
1600	434.53	0.50	52.73
1700	446.84	1.26	22.56
1800	459.84	0.86	35.06
1900	476.37	1.32	24.69
2000	492.36	1.54	22.67
2100	505.11	1.36	27.43
2200	512.93	1.43	26.28
2300	524.09	1.75	22.91
2400	538.59	1.80	22.98
2500	543.08	1.90	21.73
2600	550.99	1.70	24.68
2700	555.12	1.74	23.95

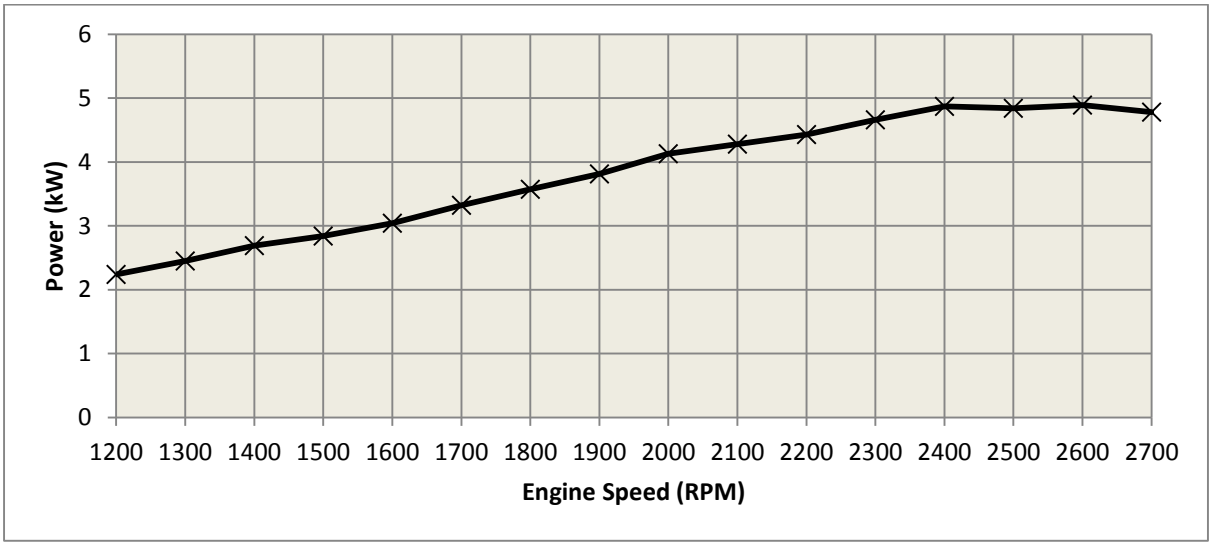


Figure 74. Power Curve of the Farymann/GUNT apparatus using CALTEX Vortex diesel.

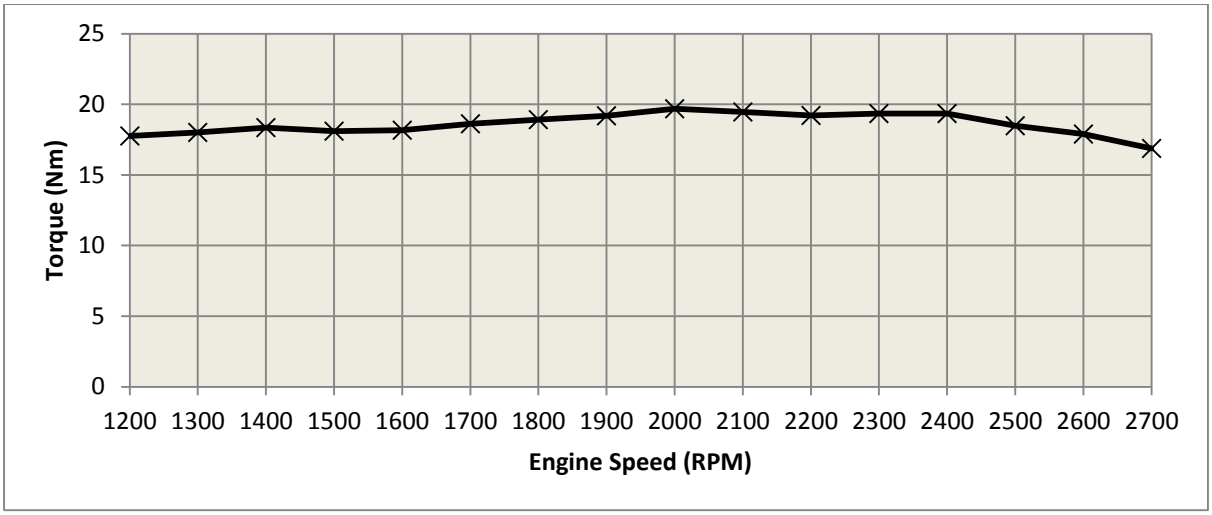


Figure 75. Torque Curve of Farymann Engine Using CALTEX Vortex diesel.

Table 36. Emissions Data Farymann/G.U.N.T Caltex Vortex Diesel Full Throttle.

Speed	Hydrocarbons	Carbon Dioxide	Nitrogen Oxides	Carbon Monoxide	Oxygen	Air Fuel Ratio	Carbon Equivalence
RPM	10^{-6} vol	% vol	10^{-6} vol	% vol	% vol		CO2e % vol
1200	232	10.1	262	0.8	7.7	21.16	19.8%
1300	176	9.3	212	0.89	7.5	21.6	17.7%
1400	176	9.2	204	1.06	7.1	20.87	17.6%
1500	165	9.4	204	1.17	6.7	20.28	18.1%
1600	161	9.5	206	1.25	6.5	19.84	18.4%
1700	160	9.6	218	1.32	6.2	19.4	19.0%
1800	164	9.6	219	1.36	6	19.4	19.1%
1900	174	9.9	209	1.61	5.5	18.66	19.6%
2000	178	9.9	197	1.75	5.2	17.93	19.5%
2100	179	10	188	2.04	4.8	17.49	19.9%
2200	171	10	183	1.93	4.8	17.34	19.5%
2300	165	10	179	2.03	4.6	17.19	19.6%
2400	159	10.2	159	2.05	4.5	17.19	19.2%
2500	154	10.3	162	1.92	4.6	17.34	19.2%
2600	143	10.3	151	1.88	4.6	17.49	18.7%
2700	128	10.4	143	1.69	4.7	17.78	18.2%

A3.3 JD4410

A baseline performance was established for the JD4410 apparatus using CALTEX Vortex diesel at full fuel (that is, full throttle) operation. This test yielded a maximum power output of 15.8kW@2500rpm and 79.1Nm of torque at 1300rpm and 1500rpm. These results are shown in figures 76 and 77 respectively. Efficiency peaked at 24.4% at 1500rpm, and exhaust temperature

peaked at 535°C@1900rpm. Carbon monoxide emissions were measured at a maximum of 1.189% at 1300rpm, carbon dioxide was 12.11% at 1500rpm, nitrous oxides peaked at 1126ppm at 900rpm and unburnt hydrocarbons peaked at 11ppm at 1100rpm.

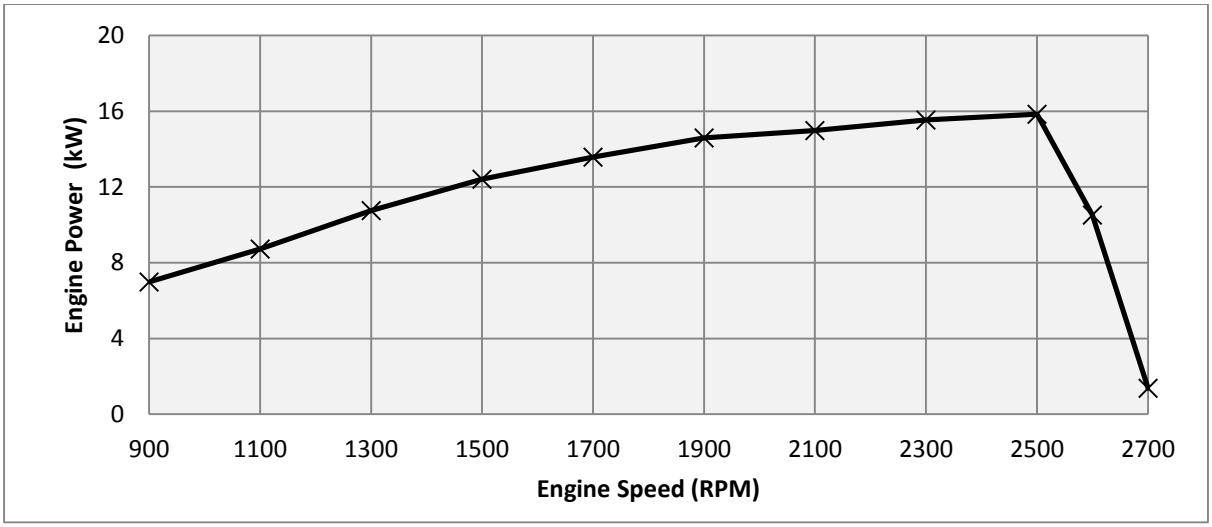


Figure 76. JD4410 Power Curve Output at Full Throttle using CALTEX Vortex diesel.

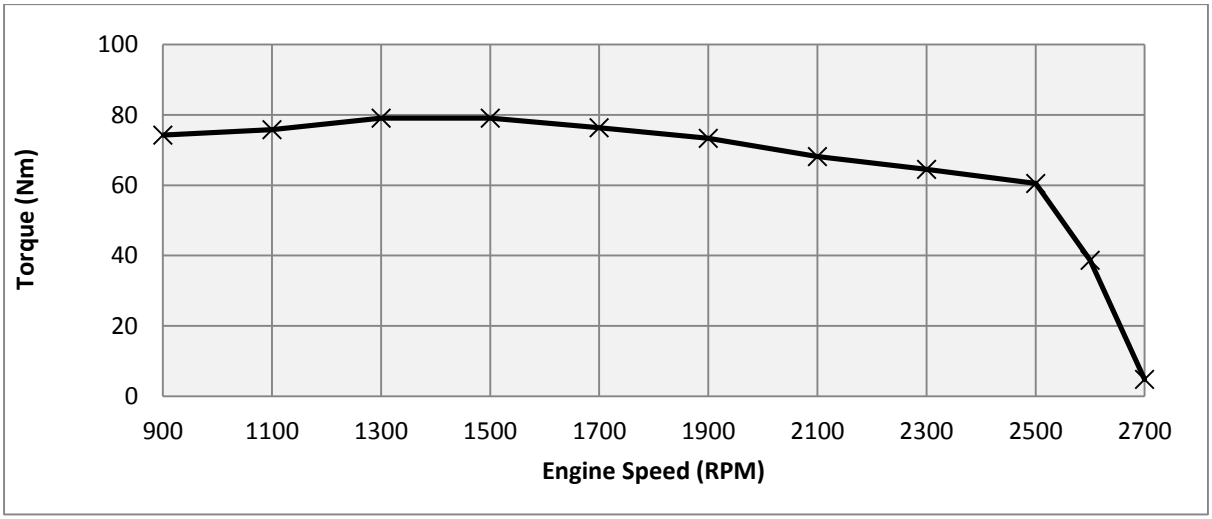


Figure 77. JD4410 Torque Curve Output at Full Throttle using CALTEX Vortex diesel.

A3.4 Yanmar

A baseline performance was established for the Yanmar apparatus using CALTEX Vortex diesel at full fuel (that is, full throttle) operation. This test yielded a maximum power output of 3.86kW@3860rpm and 12Nm of torque at 2350rpm. These results are shown in figures 78 and 79 respectively. Efficiency peaked at 37.9% at 3670rpm, and exhaust temperature peaked at 538°C@2900rpm. Carbon monoxide emissions were measured at a maximum of 0.048% at 2350rpm, carbon dioxide was 9.4% at 2900rpm, and nitrous oxides peaked at 576ppm at 2900rpm.

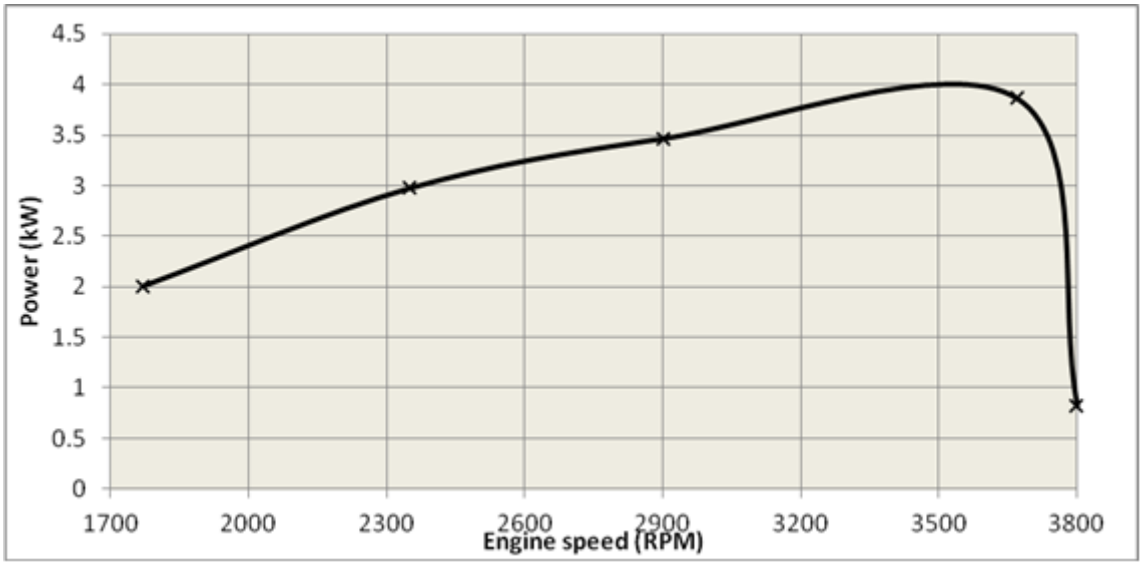


Figure 78. Yanmar Full Throttle Power Curve CALTEX Vortex Diesel.

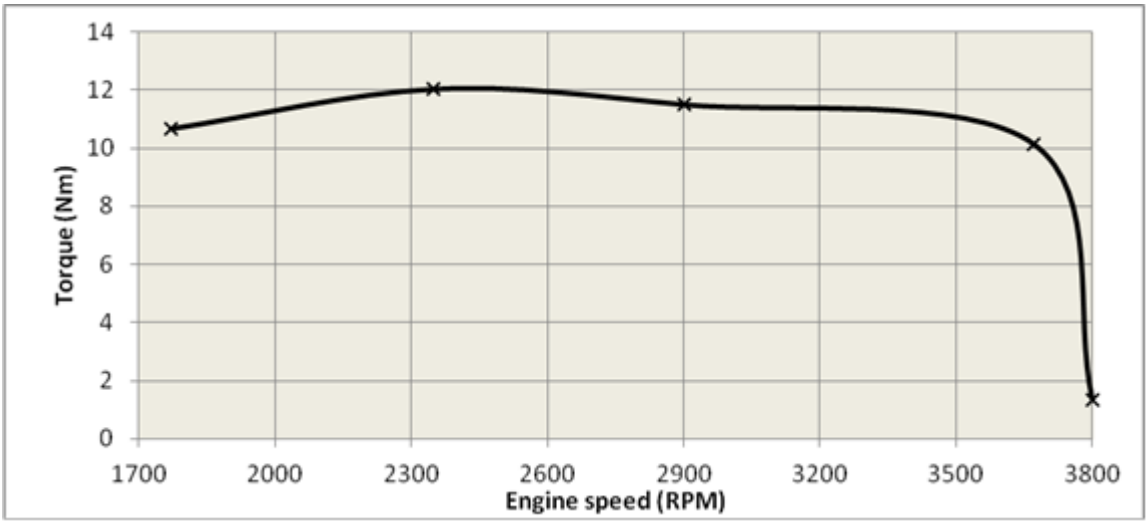


Figure 79. Yanmar Full Throttle Torque Curve CALTEX Vortex Diesel.

A4. LPG testing and results

A4.1 Apparatus and Method

The HATZ apparatus outlined in the preceding sections was used for testing this fuel. CALTEX Vortex diesel was used in this test. Additionally, a Diesel/Gas Australia LPG kit (Diesel/Gas Australia, 2005) was installed to the engine to control the injection of LPG gas. This apparatus consisted of a LPG vapour injector, an electronic control unit, associated plumbing, wiring and safety components.

Once again a full throttle run was performed over the operational range of the engine, measuring the same parameters as for diesel for direct comparison. The amount of LPG injected into the engine was left at the default setting of 40% duty cycle of the injector at all speeds and loads above idle. This means that when the injector pulses it is open 40% of the time, allowing LPG to flow into the intake manifold of the engine. At low load and low speed the default injection map provided by the

manufacturer decreases the injection to 0% to avoid engine damage. 40% fumigation is the maximum recommended by the manufacturer for the best performance of the engine. Figure 80 shows the LPG injection system installed to the HATZ apparatus.

Figure 80. HATZ apparatus with a Diesel/Gas LPG injection system installed.

A4.2 LPG testing results

Power and torque

The power output of the HATZ engine was consistently higher with the addition of LPG to the diesel. This increase was greater than 8% at low speeds and peaked at 17% at the higher speeds of the engine's operational range. Torque was therefore higher and followed the same trend at the same percentages as the power increase. Figures 81 and 82, respectively, show these results.

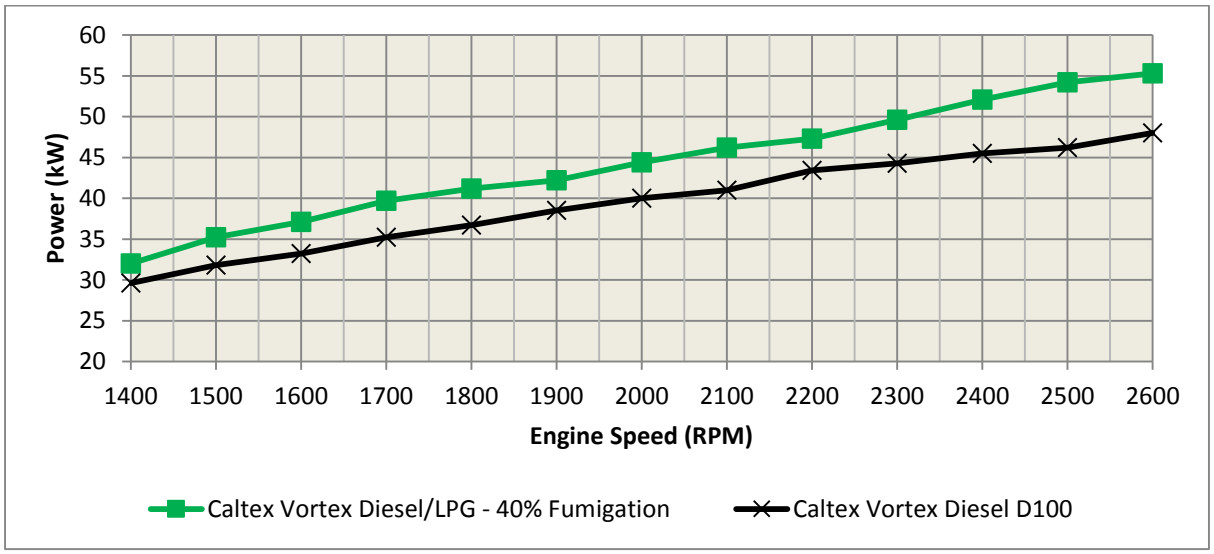


Figure 81. Power curve of HATZ Engine using CALTEX Vortex Diesel, with and without a 40% LPG fumigation.

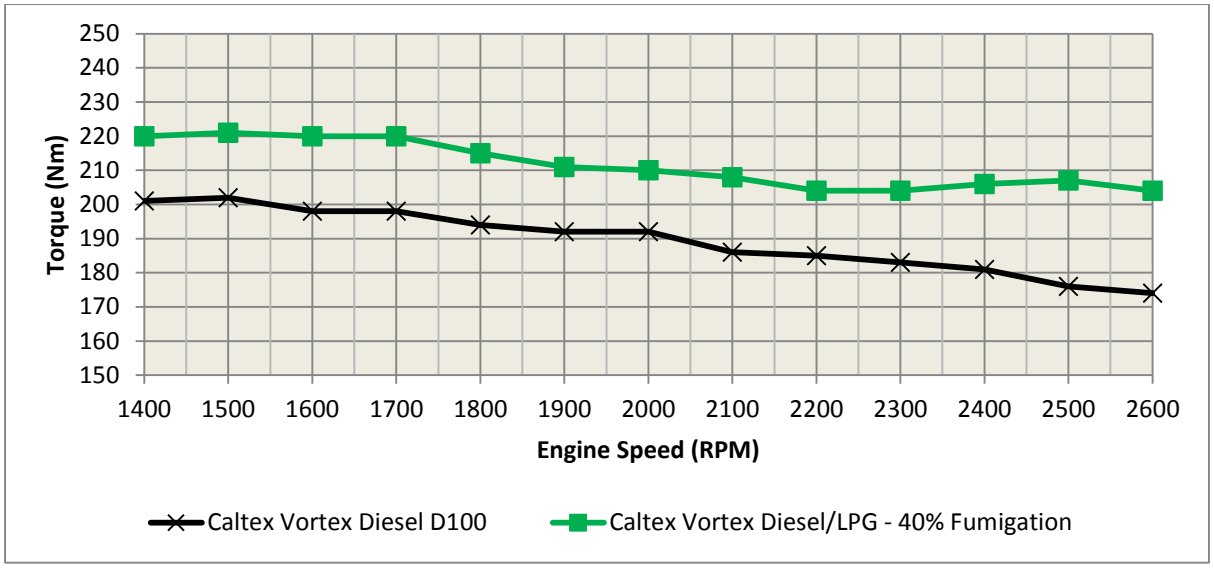


Figure 82. Power curve of HATZ Engine using CALTEX Vortex Diesel, with and without a 40% LPG fumigation.

Fuel efficiency

There are several measurable parameters relating to fuel efficiency: fuel consumption rate; specific fuel consumption (which is the fuel consumed per kW of power output); fuel calorific value and fuel density. All of these are encompassed in the overall efficiency of the engine, which is the ratio of energy input into the engine as chemical energy embodied in the fuel (as measured by the fuel specifications) divided by the output energy as mechanical flywheel power (as measured by the dynamometer), expressed as a percentage. Figure 83 compares the total mass of fuel consumed for both diesel and diesel/LPG.

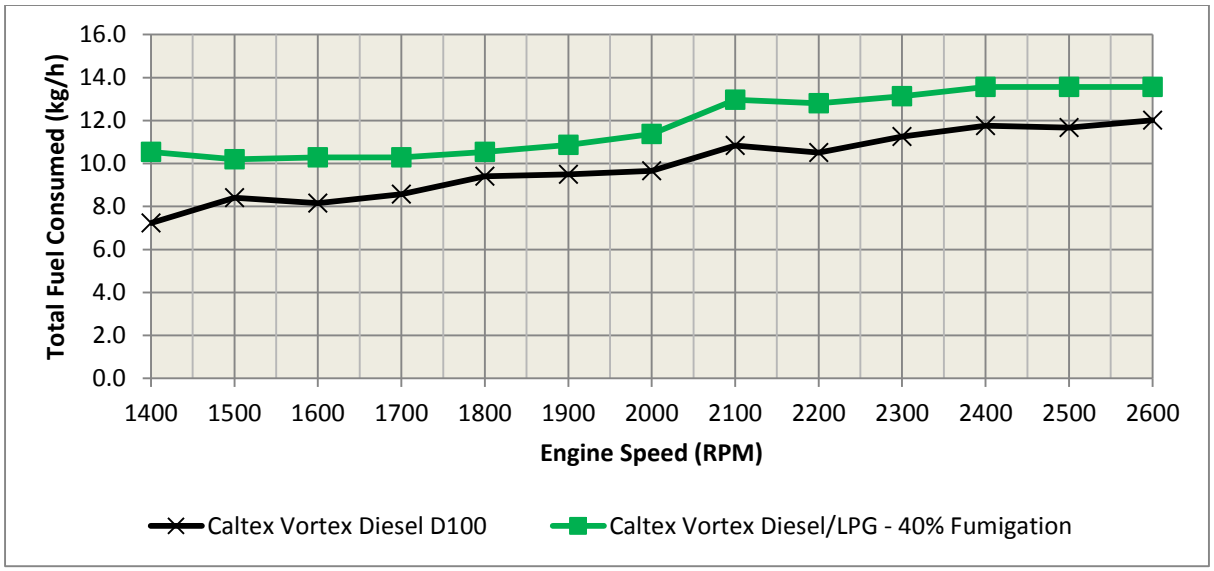


Figure 83. – HATZ total fuel consumption at full throttle.

The total mass increases with the addition of LPG because the mechanical injection system of the HATZ engine. The mechanical injection system relies on throttle position and feedback from the engine's governor (which is responsive to load) to deliver a predetermined amount of fuel to the engine at each injection cycle. This mechanical system does not detect the presence of additional LPG fuel and is therefore not responsive to it. In contrast, an electronically controlled diesel

injection system can detect the presence of additional (LPG) fuel via the oxygen sensor in the exhaust and reduce the amount of LPG injected into the engine, thus bringing the total fuel consumption back to the same point as if there were no LPG injection.

While the overall fuel consumption is higher with the LPG system installed, the power output is also higher, meaning that the most accurate representation of the effect of adding LPG can be seen from a comparison of engine efficiencies with and without the addition of LPG, which is shown in figure 84, below.

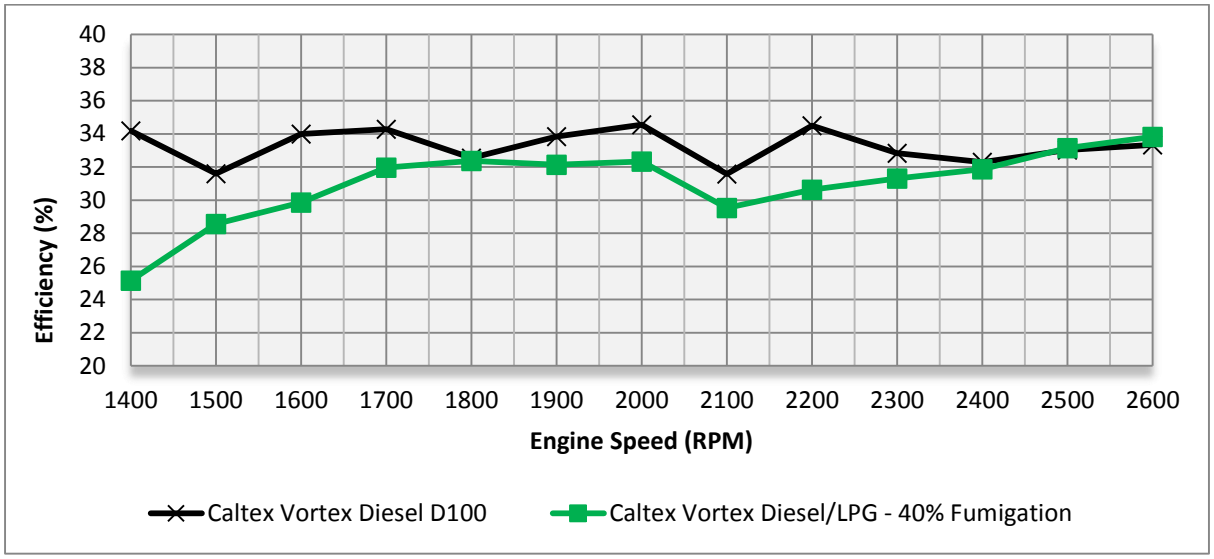


Figure 84. HATZ engine efficiency at full throttle with and without LPG injection.

Figure 84 shows a decrease in efficiency at all engine speeds except 1800rpm and 2400-2600rpm. The increase in power from the addition of the LPG was not enough to compensate for the increase in overall fuel consumption. The most efficient point in the range of engine speeds shifted from 2000rpm with diesel only to 2600rpm with the addition of LPG.

Exhaust temperature

Exhaust temperatures increased with the addition of LPG from 1600rpm through to 2200rpm. Temperatures were also higher at speeds above 2400rpm. The difference peaked at a 5.5% increase at 2600rpm. Exhaust temperature at the most efficient speed was 616°C for diesel, and 676°C for diesel/LPG. The results can be seen in Figure 85. The higher exhaust temperatures suggest that the LPG has a higher combustion temperature than diesel. The effect of this is a lower knock limit, especially when engine loads are high, which can result in engine damage.

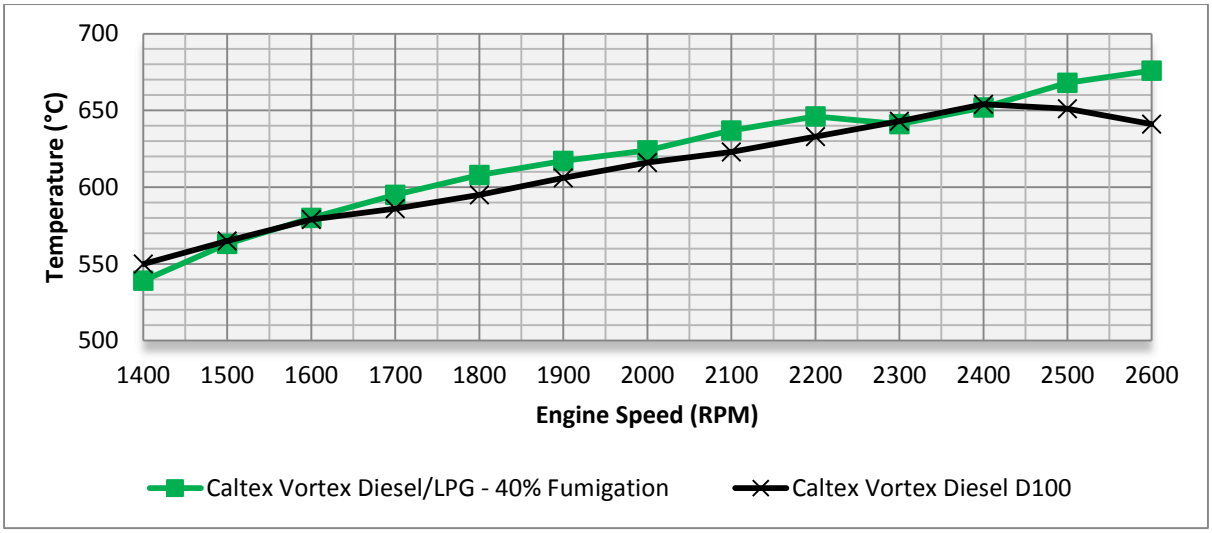


Figure 85. HATZ exhaust temperature at full throttle with and without LPG injection.

Emissions

NOx emissions from the HATZ engine with the addition of LPG were significantly reduced across all engine speeds, as shown in Figure 86. Diesel peaked at 352ppm at 1600rpm and diesel/LPG peaked at 290ppm at 1700rpm, a 17.5% reduction in peak NOx emissions. At the most efficient speeds the difference was even greater, with diesel producing 342ppm at 2000rpm and diesel/gas producing just 254ppm at 2600rpm. This is a reduction of 25.7% for diesel/LPG. More NOx is produced from an engine running under a lean condition, and these results show that the engine is being over-fuelled by the addition of LPG. Air fuel ratio measurements from the engine support this, with the air fuel ratio reading 14.55 at low speeds, and 16.17 at 2600rpm. Considering the stoichiometric ratio for diesel is 14.6, the engine was in fact running very rich at low speeds. Comparing this with the diesel only ratios in the region of 20, the extent of the over-fuelling is apparent.

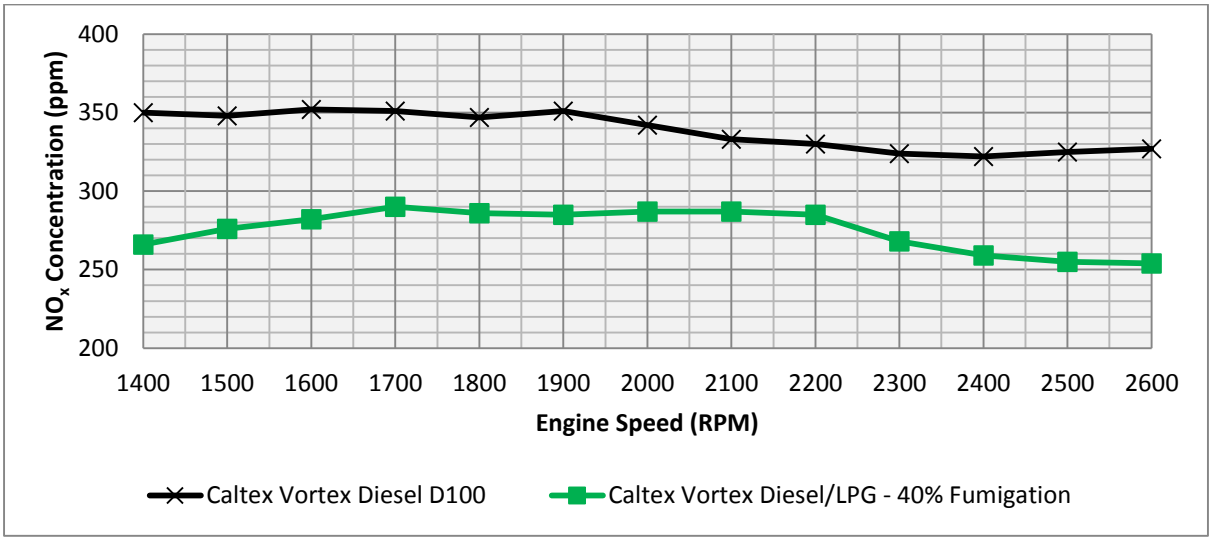


Figure 86. HATZ NOx emissions at full throttle with and without LPG injection.

Other exhaust gases measured also varied between the use of diesel alone and the addition of LPG. Table 37 compares the measured emissions of the diesel/LPG mixture relative to the emissions from diesel only at each engine speed. The most notable observation from these figures is the significant

increase in carbon monoxide emissions for diesel/LPG, peaking at almost 7 times those of diesel. This increase reduces with increasing speed, but was still significant at maximum speed. This is consistent with the increased production of NOx as outlined above, because the air to fuel ratio is low the over-fuelling causes excess carbon monoxide emissions. The IPCC (2007) quote a GWP of Carbon Monoxide of 1.6 to 2.0, meaning the global warming effects are only marginally higher than carbon dioxide, however concentrations are 5 to 50 times less than carbon dioxide. Carbon monoxide is however a very poisonous gas, and its emissions need to be reduced as much as possible.

Comparing the most efficient speeds of 2000rpm for diesel and 2600rpm for diesel/LPG, diesel resulted in carbon monoxide comprising 0.14% of exhaust volume, and diesel/LPG yielded a concentration of 0.27% of exhaust volume. It should be noted that exhaust flow volume will be greater at the higher speed of the diesel/LPG efficiency peak, meaning an even greater mass of carbon monoxide will be emitted than these figures show when compared to diesel alone.

Carbon dioxide emissions were also higher, peaking at a 26% increase at 1900rpm. At the most efficient speeds of the two fuels, 13.3% of exhaust volume was carbon dioxide when using LPG at 2600rpm, and 12.5% without at 2000rpm. Hydrocarbons were significantly higher at speeds below 1700rpm, and oxygen content was 49-73% less throughout. Nitrous oxides were also significantly less using LPG as discussed above, with a reduction of between 14% and 24% across the range of engine speeds tested. The equivalent carbon dioxide output is also lower for diesel/LPG, with a 21.7% concentration of CO2e at 2600rpm compared to 23.4% CO2e at 2000rpm for diesel.

Table 37. HATZ emissions with LPG injection relative to diesel only emissions

Speed (RPM)	Carbon Monoxide	Carbon Dioxide	Hydrocarbons 10^{-4} vol	Oxygen	Nitrous Oxides
1400	600%	-1%	+17	-56%	-24%
1500	600%	1%	+11	-61%	-21%
1600	668%	4%	+6	-65%	-20%
1700	632%	6%	+1	-68%	-17%
1800	676%	8%	0	-71%	-18%
1900	671%	26%	0	-73%	-19%
2000	500%	10%	0	-69%	-16%
2100	385%	12%	0	-69%	-14%
2200	342%	12%	0	-68%	-14%
2300	285%	6%	+3	-49%	-17%
2400	370%	12%	0	-58%	-20%
2500	289%	12%	+1	-55%	-22%
2600	**286%**	**12%**	**0**	**-49%**	**-22%**

A5. Biodiesel testing results

An initial evaluation of several biodiesel blend ratios was conducted with the Yanmar and Farymann/GUNT engine, which are single cylinder engines. This was to reduce the amount of fuel needed to perform the testing. The Yanmar apparatus was used to test B50 and B100 blends cotton seed oil. A full throttle run was completed at the engine's operational speeds and parameters

measured to compare to the diesel baseline. The change in fuel did not necessitate any further adjustments to the apparatus.

B20 was selected to be tested further in the larger HATZ engine and John Deere tractor for the following reasons. Testing from the Farymann/G.U.N.T and Yanmar apparatus showed reduced emissions results for biodiesel blends. However, due to the lower calorific value of these fuels, performance was reduced and fuel consumption was increased. Blends of biodiesel above 20% by volume showed these unfavourable aspects more prominently. For this reason The HATZ testing was conducted at full throttle throughout the various engine speeds. The John Deere testing was conducted at a constant speed with varying loads placed on the PTO.

A5.1 Fuel types

The biodiesel used in the Yanmar, Farymann/GUNT and John Deere engines was sourced from Queensland University of Technology in Brisbane. The biodiesel had been produced from cotton seed oil (CSO) by a transesterification process. For calculation purposes, the density was measured at 0.88g/cm^3 and the calorific value of the fuel was 37270kJ/kg. The biodiesel was mixed with CALTEX Vortex diesel by weight to produce the blends for testing in B20, B50 and B100 ratios.

The B20 used in the HATZ apparatus was commercially available Shell Australia B20 blend obtained from the Brisbane terminal. This fuel is manufactured from tallow (animal fat).

A5.2 Cotton seed oil B20 – Faryman/G.U.N.T.

Power and torque

The power output of B20 was very closely matched to that of diesel alone. Throughout the range of engine speeds, the difference between the two peaks at 0.15kW@2000rpm in the favour of diesel. The overall peak power output only differs by 0.02kW. Torque is therefore also very evenly matched, with slight differences at 2000rpm and 2400rpm. Figures 87 and 88 show these differences. The measurement accuracy of the load cell on the G.U.N.T. CT300 test stand is ±0.03%, and the power difference peaks at 3.6%, meaning that the results indicate there is a slight power loss from using B20.

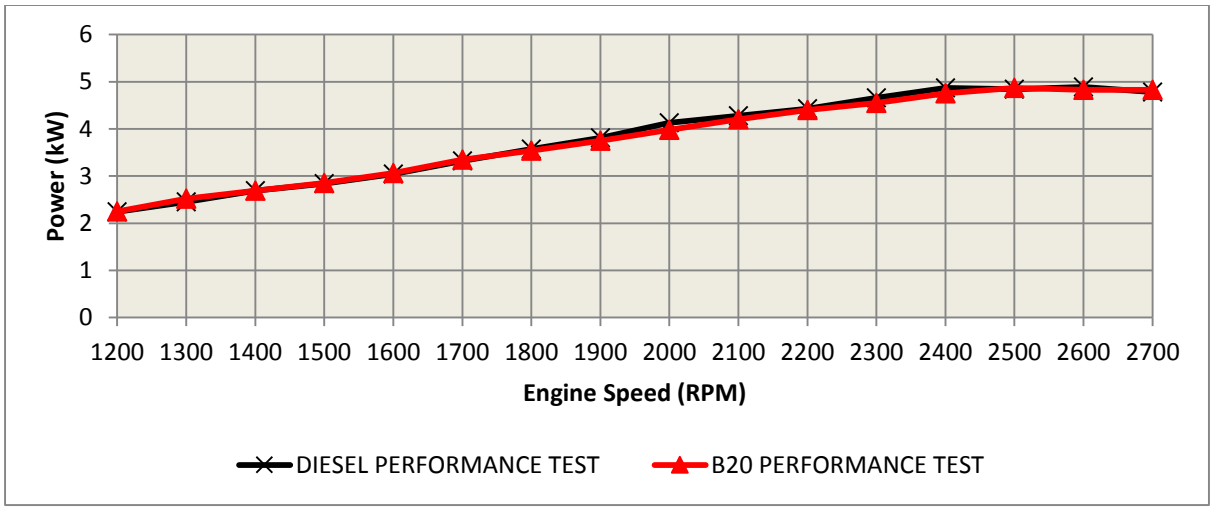


Figure 87. Farymann/Gunt full throttle power comparison between B20 and diesel.

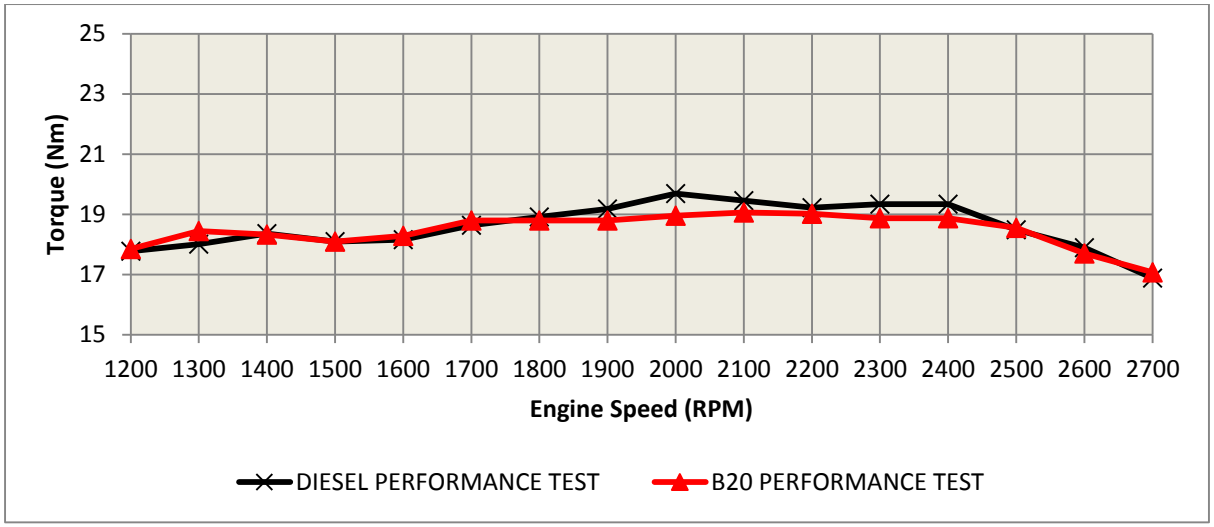


Figure 88. Farymann/Gunt full throttle torque comparison between B20 and diesel.

Fuel efficiency

As mentioned in preceding sections, the fuel consumption data for the Farymann/Gunt test apparatus is not as accurate as that for the HATZ, and caution is needed when analysing the results. After removing obvious erroneous data points, the data indicates that the B20 blend results in a 5% increase in fuel consumption. This increased consumption, coupled with the lower calorific value of biodiesel compared to diesel, means that efficiency is reduced. The most efficient engine speed using biodiesel is 2.14% less efficient than the most efficient speed using diesel. These results are shown in figure 89.

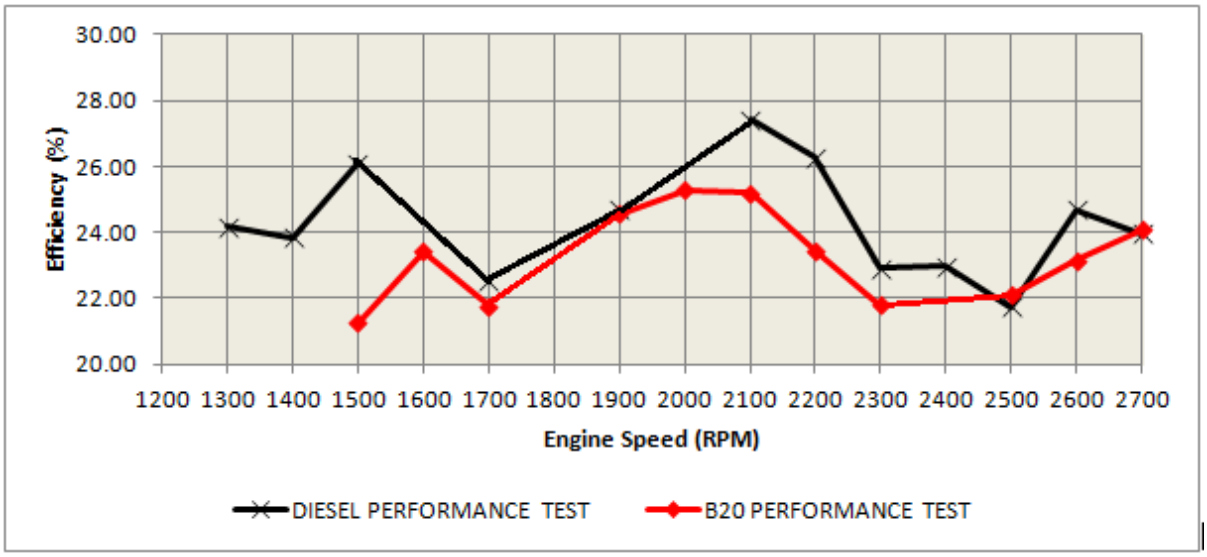


Figure 89. Farymann/Gunt full throttle engine efficiency comparison between B20 and diesel.

Exhaust temperature

Test results show that exhaust temperature was higher when using the B20 blend. Table 38 shows the exhaust temperature when using the B20 blend relative to the exhaust temperature using diesel. The temperature is higher at every engine speed, however the peak value is only 1°C higher. At the most efficient speed for each fuel, B20 resulted in an increase of 10°C.

Table 38. B20 Exhaust Temperature Relative to Diesel

Speed (RPM)	Exhaust Temperature Difference (°C)
1200	56
1300	43
1400	27
1500	23
1600	27
1700	26
1800	22
1900	21
2000	23
2100	18
2200	20
2300	14
2400	8
2500	7
2600	2
2700	1

Emissions

Table 39 shows how the emissions measured using B20 differed from those using diesel. The most obvious difference is the reduction in hydrocarbons throughout most of the range of engine speeds, which is due to 20% less hydrocarbons being present in the fuel. Carbon monoxide, carbon dioxide and nitrous oxides are all reduced slightly at lower speeds, before equalising at around 2000rpm, and then increasing at higher speeds. At the most efficient speed, hydrocarbons were 18ppm for diesel and 16ppm for B20. The concentration of carbon dioxide was 10.0% for both fuels, while NO_x was 197ppm for B20 and 188ppm for diesel. The concentration of carbon monoxide was 2.04% by volume for diesel compared with 1.74% by volume for B20. There was also more oxygen in the exhaust gases when the engine was using B20, suggesting slightly leaner combustion than diesel. Carbon equivalence for the most efficient speed for each fuel was a 19.9% concentration of CO2e at 2100rpm for diesel while B20 resulted in a 19.6% concentration of CO2e at 2000rpm.

Table 39. Emissions of B20 Relative to Diesel in Farymann/Gunt.

Speed (RPM)	Hydrocarbons	Carbon Dioxide	Nitrogen Oxides	Carbon Monoxide	Oxygen
1200	-40%	-12%	-4%	-18%	4%
1300	-17%	-3%	2%	3%	-1%
1400	-14%	-1%	1%	-5%	3%
1500	-7%	-2%	0%	-7%	6%
1600	-4%	-3%	-2%	-2%	6%
1700	-4%	-2%	-3%	-9%	6%
1800	-4%	0%	-3%	-4%	5%
1900	5%	0%	-3%	3%	0%

Speed (RPM)	Hydrocarbons	Carbon Dioxide	Nitrogen Oxides	Carbon Monoxide	Oxygen
2000	-8%	1%	0%	-1%	4%
2100	-3%	0%	0%	-4%	6%
2200	0%	0%	0%	3%	6%
2300	3%	1%	2%	8%	0%
2400	8%	2%	14%	3%	-2%
2500	-3%	1%	7%	4%	-2%
2600	-20%	2%	9%	-1%	0%
2700	-25%	1%	13%	-1%	2%

A5.3 Cotton seed oil B50– Yanmar

Power and torque

Power output from B50 is consistently lower than that of diesel fuel. The difference is between 5% and 15% across the speed range. At peak power, the difference between the two fuels is 0.56kW@3670rpm. This result indicates that the slight power loss from B20 observed on the Farymann/G.U.N.T apparatus was indeed due to the addition of biodiesel. Torque is also lower for B50 across the entire speed range by the same percentages. Peak torque occurs at 2350rpm for both fuels, with diesel producing 0.93Nm more than B50. The power and torque curves are presented in figures 90 and 91 below.

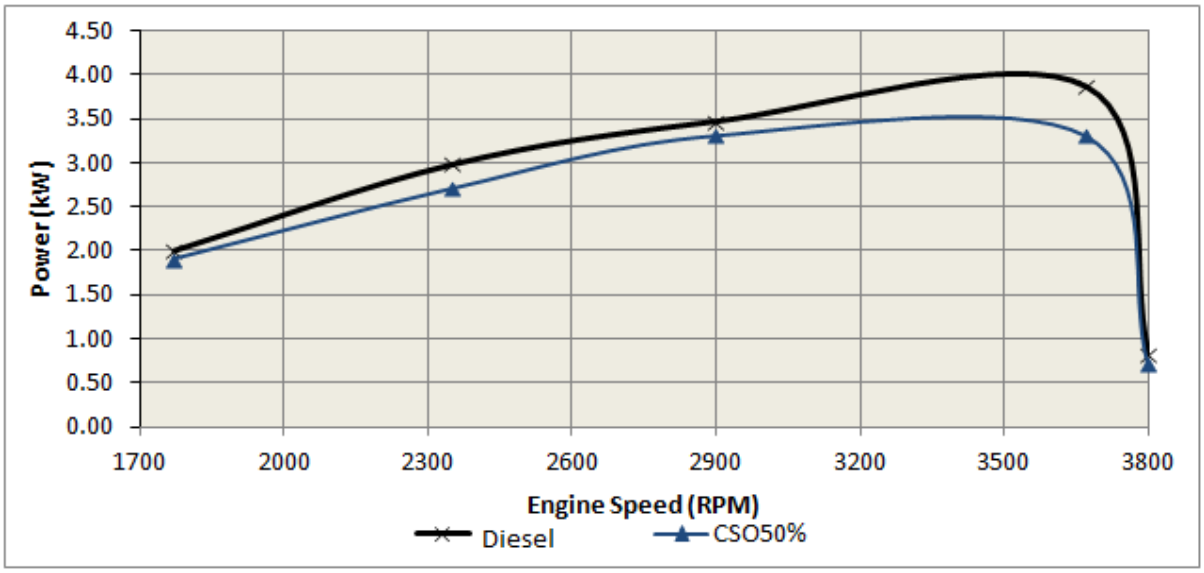


Figure 90. Power Curve Full Throttle Yanmar Apparatus for B50 and diesel.

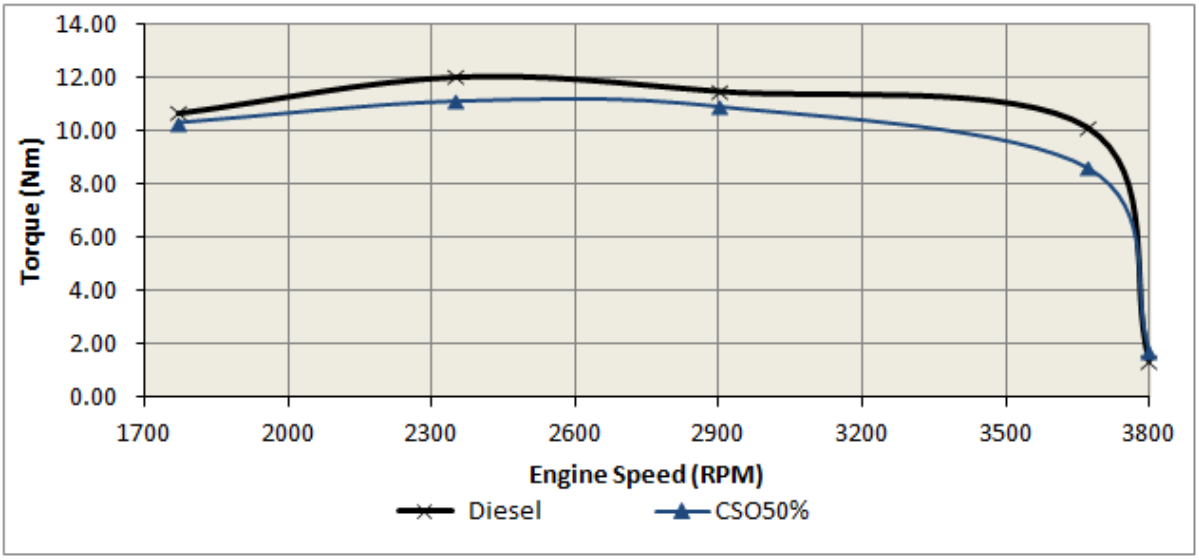


Figure 91. Torque Curve Full Throttle Yanmar Apparatus for diesel and B50.

Fuel efficiency

Brake specific fuel consumption increased throughout the whole range of engine speeds, with the largest difference of 20.3% occurring at 2900rpm. At the most efficient engine speed of 3670rpm, the difference between the fuels was 9.7%. The difference is due to the 7% lower calorific value of the B50 blend, meaning more fuel is required to produce the same amount of power output as diesel. Engine efficiencies reflect the lower calorific value of B50, and at the most efficient speed of 3670rpm, diesel achieves a 32.7% efficiency, and B50 a 32.0% efficiency. Figure 92 shows the brake specific fuel consumption results.

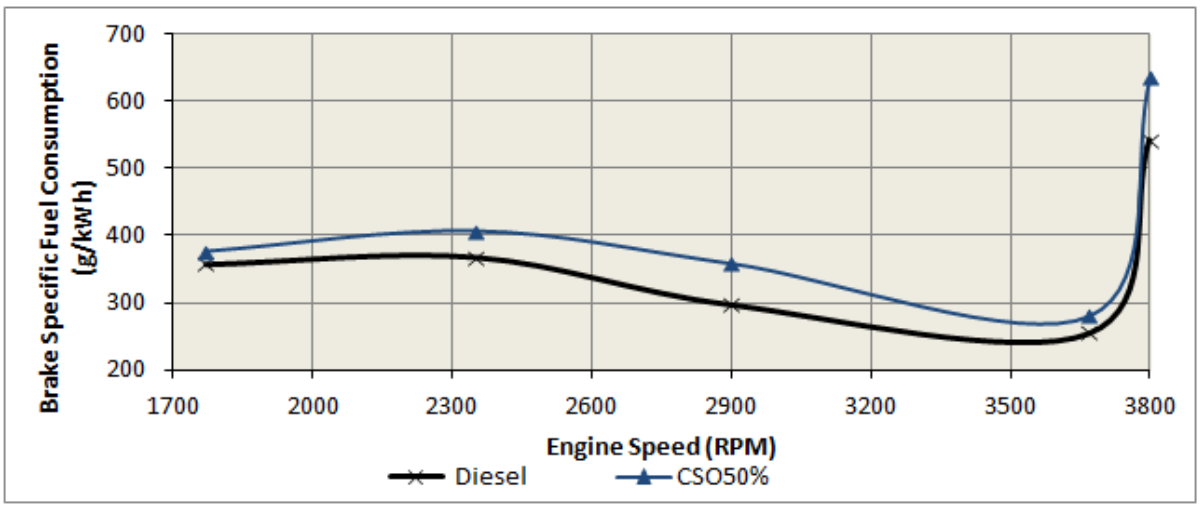


Figure 92. Brake Specific Fuel Consumption Full Throttle Yanmar Apparatus for diesel and B50.

Exhaust Temperatures

Exhaust gas temperatures were consistently lower using B50 than diesel. The largest difference occurred at 2350rpm, where diesel resulted in a 24°C higher temperature than B50. At the most efficient engine speed of 3670rpm, the difference between the two fuels was 23°C, a 7% reduction. Figure 93 shows the differences over the operating speeds of the engine.

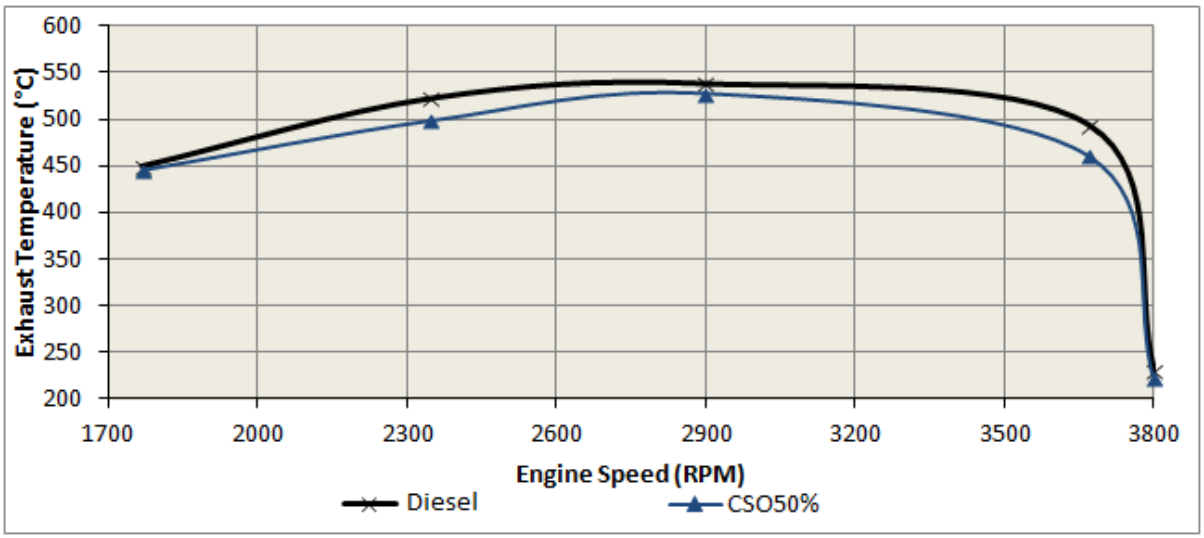


Figure 93. Exhaust Gas Temperature Full Throttle Yanmar Apparatus for diesel and B50.

Emissions

Emissions data was only recorded for carbon monoxide and nitrous oxides for this apparatus. This means carbon equivalent emissions cannot be calculated. The use of B50 resulted in an increase in carbon monoxide emissions above 2350rpm, with the largest difference occurring at 2900rm. At this speed, 0.003% more carbon monoxide was produced. below 2350rpm, carbon monoxide emissions were slightly reduced with B50. At the most efficient speed of 3670rpm, the carbon monoxide concentrations were equal. Figure 94 below shows the carbon monoxide emission data.

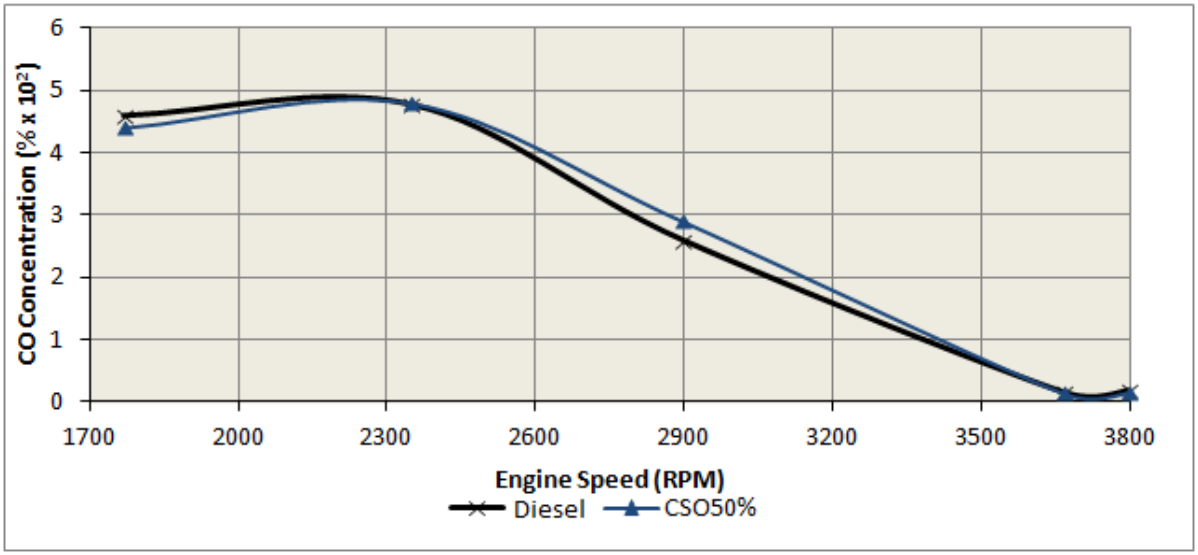


Figure 94. Carbon Monoxide Emissions Full Throttle Yanmar Apparatus for diesel and B50.

Nitrous oxide emissions were reduced by the use of B50. Below 2900rpm this reduction is small, with a 16ppm difference at 1770rpm and no difference at 2350 rpm. The largest difference is at the most efficient engine speed of 3670rpm, where a 61ppm difference was observed. See figure 95.

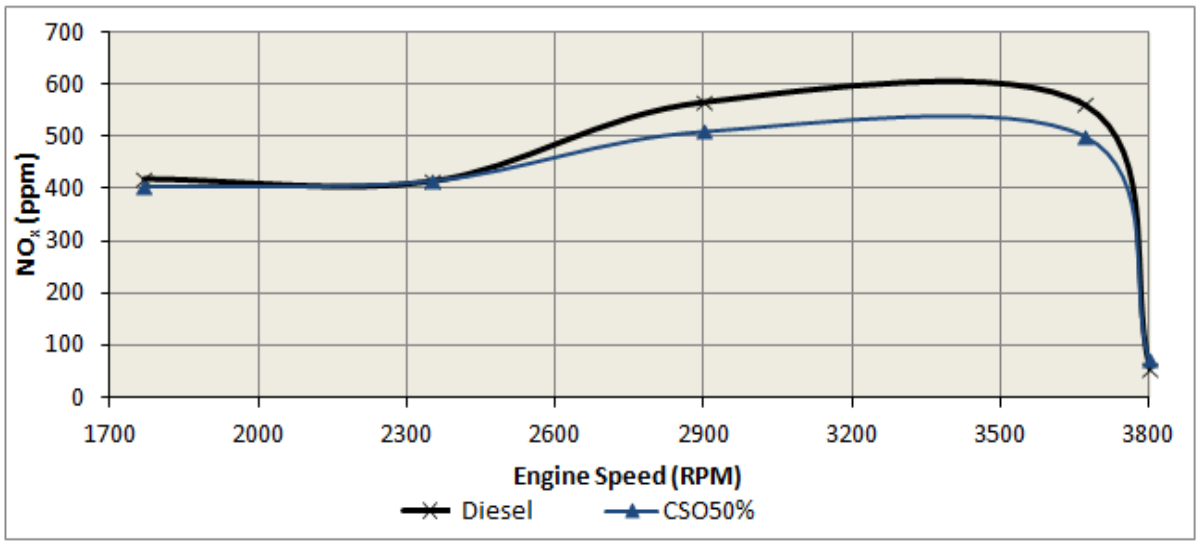


Figure 95. NOx Emissions Full Throttle Yanmar Apparatus for diesel and B50.

A5.4 Cotton seed oil B100 – Yanmar

Power and torque

Power output was significantly reduced using B100 fuel in the test apparatus. Peak power reduced 0.66kW, a 17% drop. Also, the point at which peak power was generated shifted from 3670rpm for diesel to 2900rpm for B100. More data points need to be recorded at speeds between 2900rpm and 3670rpm to more accurately measure the differences, however the design of the Yanmar engine meant that only certain speeds were able to be tested. Despite this it is clear that B100 results in a significant power drop over diesel. Torque is also less, with a 29% reduction at 3670rpm. Figures 96 and 97 show these results.

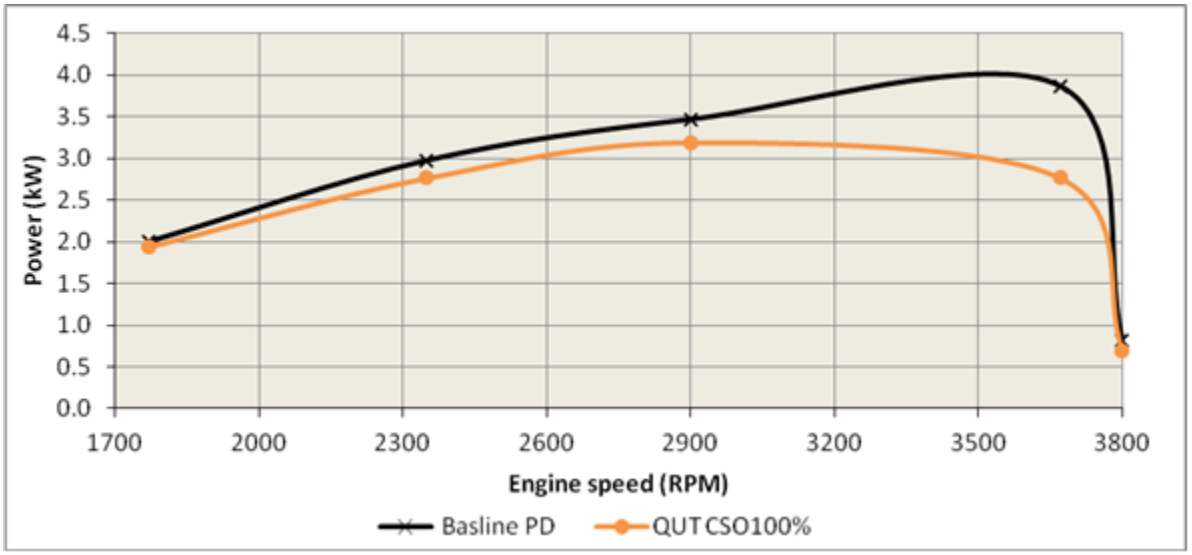


Figure 96. B100 CSO Power Curve Full Throttle Yanmar Apparatus

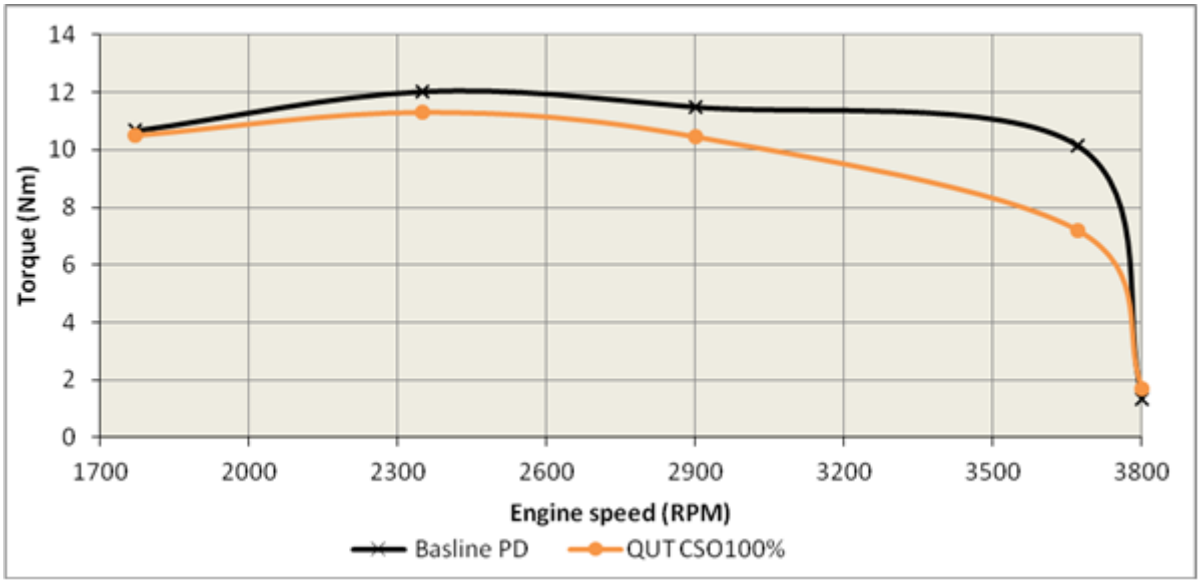


Figure 97. B100 CSO Torque Curve Full Throttle Yanmar Apparatus

Fuel efficiency

Brake specific fuel consumption for B100 was 5% more than diesel at 1770rpm, 1% less at 2350rpm, 5% less at 2900rpm, 22% more at 3670rpm and 23% more at 3800rpm. The result of this was that for B100 the most efficient speed of operation was 2900rpm, with 34% efficiency at that speed. For diesel, the most efficient speed was 3670rpm, giving an efficiency of 32.7%. Efficiency of the engine running on B100 was 30.9% at 3670rpm.

Exhaust temperature

Exhaust temperatures using B100 were slightly higher at 1770rpm, however were significantly reduced at 2900rpm and 3670rpm. The reductions at these speeds were 18% and 19% respectively. A graphical representation of these results is presented in figure 98 below.

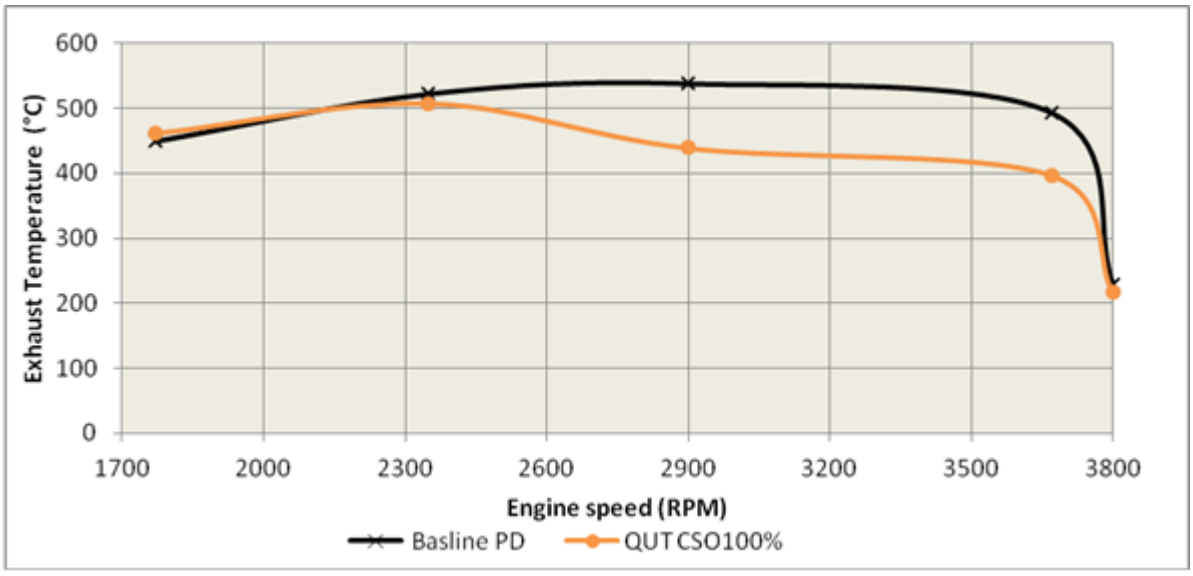


Figure 98. B100 CSO Exhaust Temperature Full Throttle Yanmar Apparatus

Emissions

For this fuel, carbon monoxide, carbon dioxide, and NOx were measured. Carbon monoxide was significantly reduced across the operating speed range when using B100, as shown in figure 99. The reduction peaked at 85% at 2900rpm, before equalising at a very low level at 3670rpm. Carbon dioxide emissions were higher at 1770rpm and 2350rpm, before reducing to lower levels than for diesel at 2900rpm and 3670rpm. There was a 21% reduction at 3670rpm and a 8% reduction at 2900rpm. The data for carbon dioxide can be seen in figure 100. NOx emissions were less for B100 at all speeds except 3800rpm. At 3670rpm, the reduction was 43%. Figure 101 shows the NOx emissions data. Overall the emissions from B100 were lower than those for diesel for the three key exhaust gases.

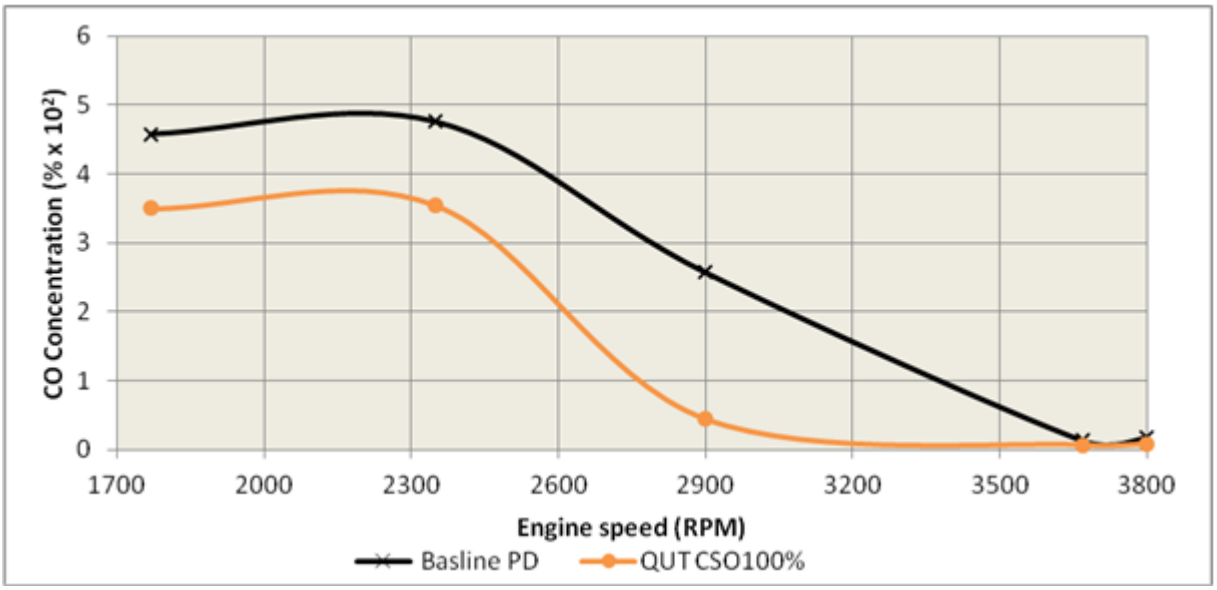


Figure 99. B100 CSO Carbon Monoxide Full Throttle Yanmar Apparatus.

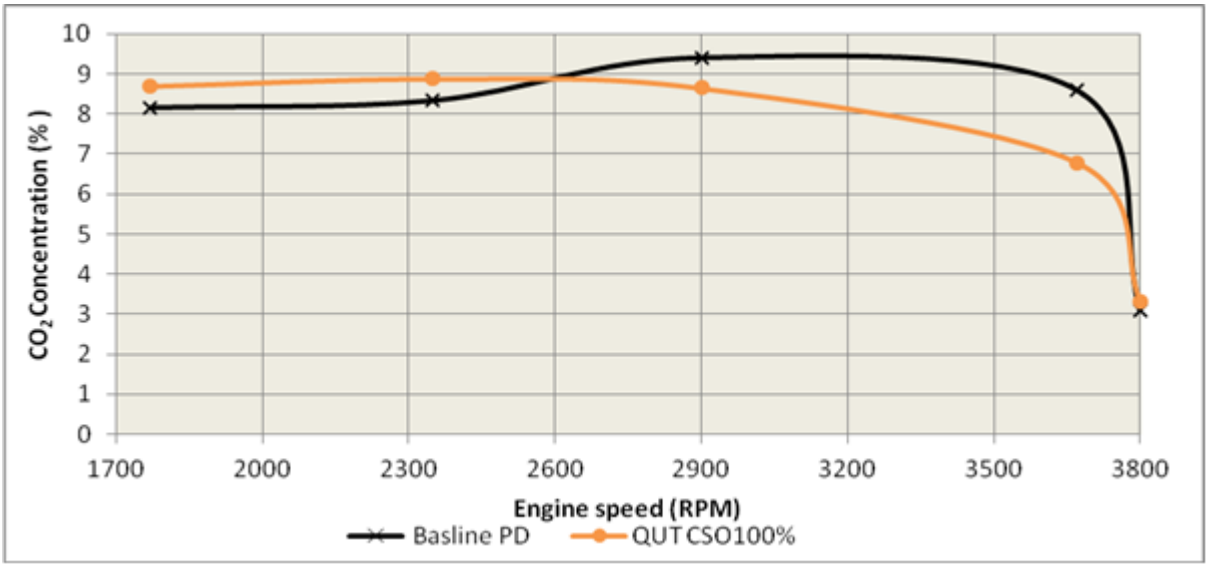


Figure 100. B100 CSO Carbon Dioxide Full Throttle Yanmar Apparatus.

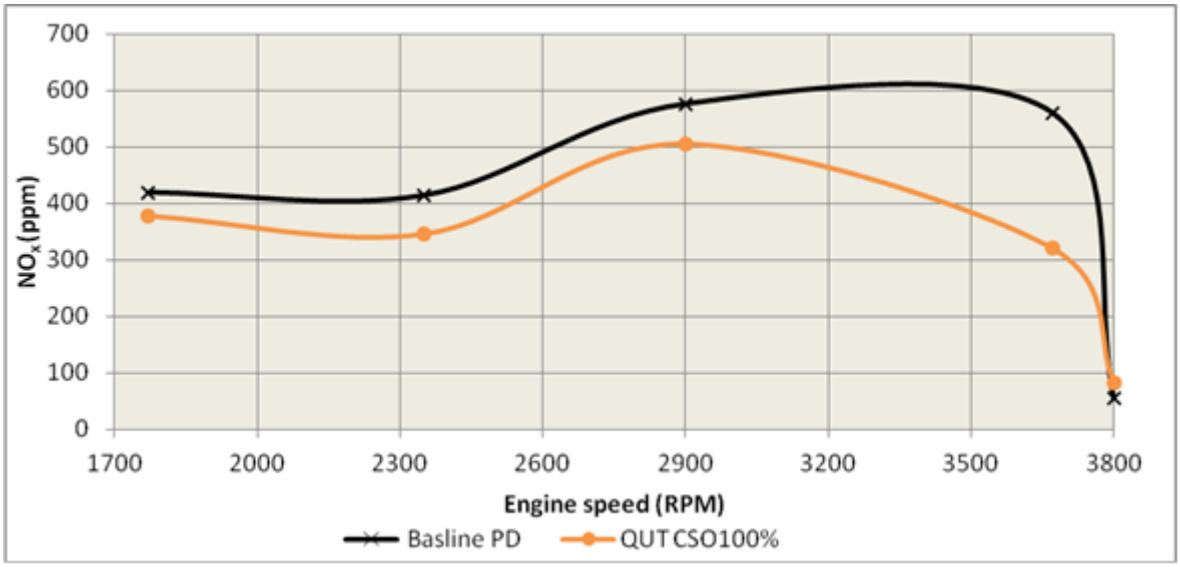


Figure 101. B100 CSO Nitrous Oxides Full Throttle Yanmar Apparatus.

A5.5 Tallow B20 - HATZ

Power and torque

As with the Farymann/G.U.N.T results, power output across the engine's operational range was very closely matched to that of diesel. However, unlike the Farymann/G.U.N.T apparatus, the HATZ relies on the operator to manually record the power output. As the displayed value on the dynamometer software does not remain constant (possibly due to vibrations affecting the load cell reading), there is an error of ±0.5kW when reading the value on the screen. 2600rpm is the only data point to exceed a 1kW difference between the two fuels, therefore the difference between the fuels at all other points is not measureable by the HATZ apparatus. Figure 102 shows the power curves of the two fuels. The torque readings obtained from the two fuels follow a similar trend, with the two curves crossing each other three times throughout the engine's operating speeds. The torque values were also read from the dynamometer software, and as such are also subject to a read error of approximately ±1Nm. Even though the figures recorded do exceed 2Nm in difference, there is not a clear trend, and no reliable conclusions can be drawn from the data. The torque curve can be seen in figure 103 below.

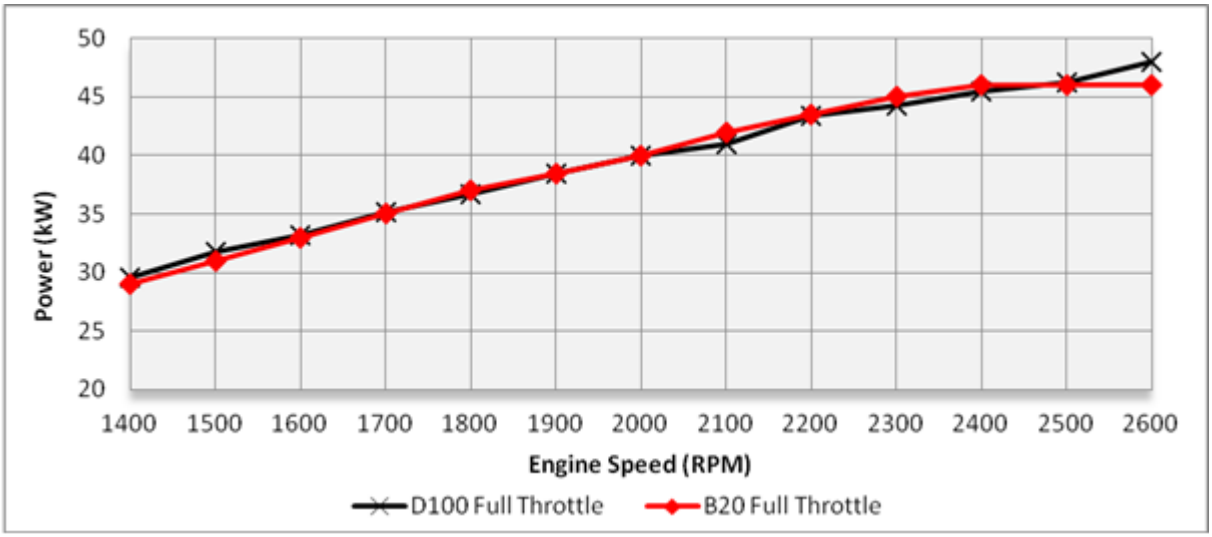


Figure 102. B20 tallow Power Curve Full Throttle HATZ

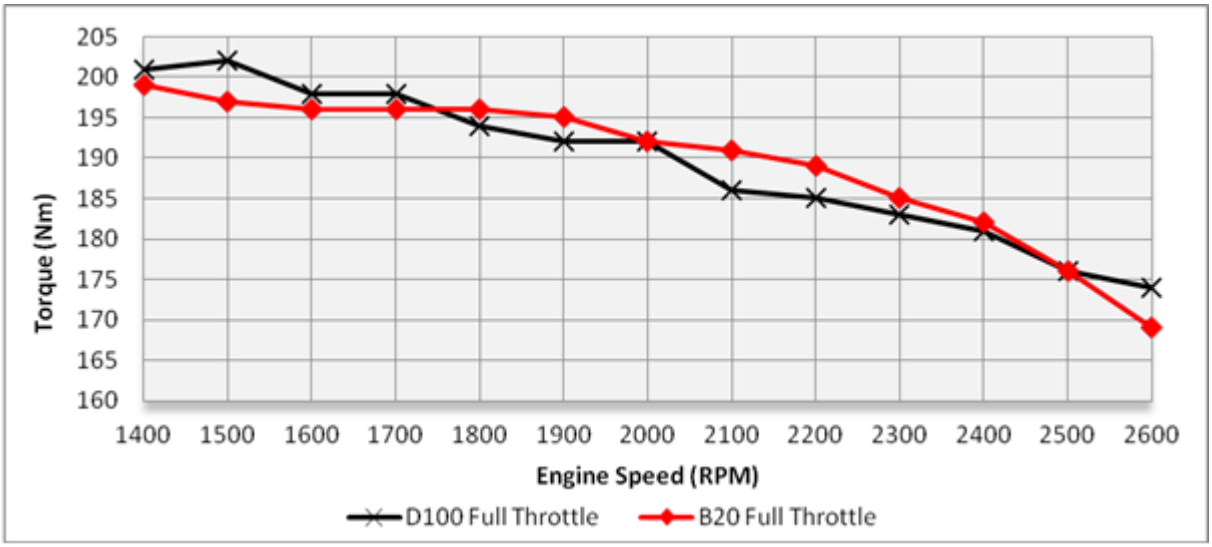


Figure 103. B20 tallow Torque Curve Full Throttle HATZ.

Fuel efficiency

Brake specific fuel consumption was very similar between the two fuels, with only small differences throughout the operational range. Once again these results were limited by the accuracy of the power reading from the dynamometer software, which equated to approximately 5% in the calculations. The largest difference between the two fuels was 5.3%, therefore once again the apparatus is not accurate enough to make a determination based on the data. B20 resulted in the greatest overall efficiency, peaking at 35.4% with diesel only managing 34.6%. Once again the read error of the engine's power output is significant, however the similar power output, similar fuel consumption and lower calorific value of the biodiesel means that the efficiency is superior for B20 on this apparatus. Figure 104 below shows the calculated efficiencies of the HATZ apparatus.

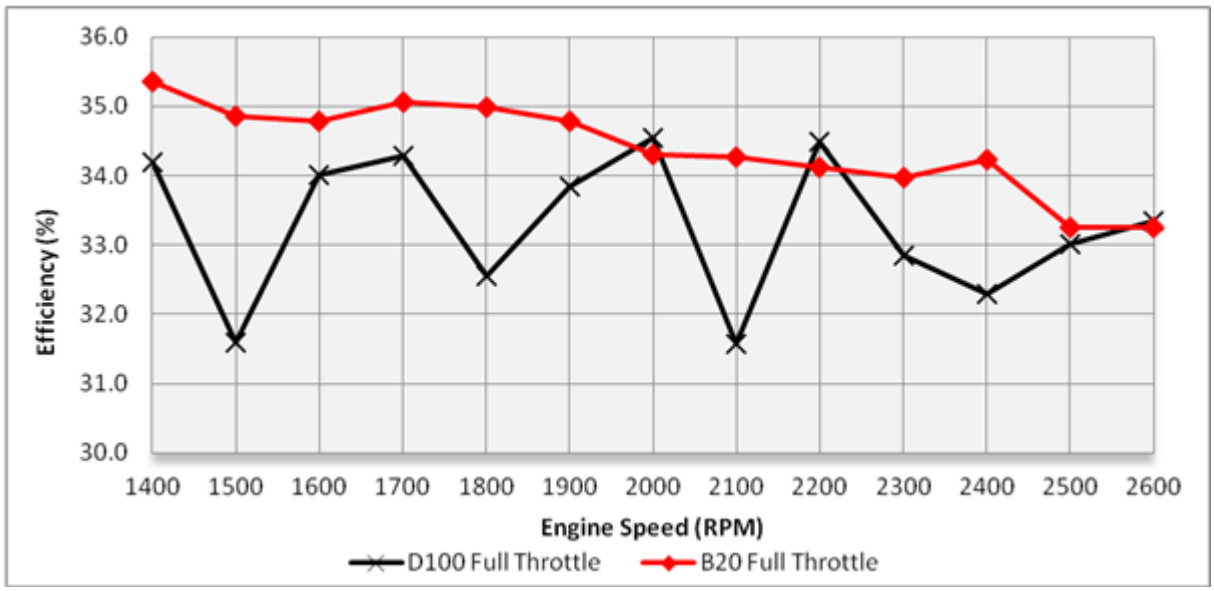


Figure 104. B20 tallow Fuel Efficiency Full Throttle HATZ.

Exhaust temperature

The exhaust temperature was clearly lower for B20 than for diesel, with a peak difference of 82°C, a 12.5% reduction. This correlates with what was found on the Farymann/G.U.N.T apparatus. This data can be seen in figure 109 below.

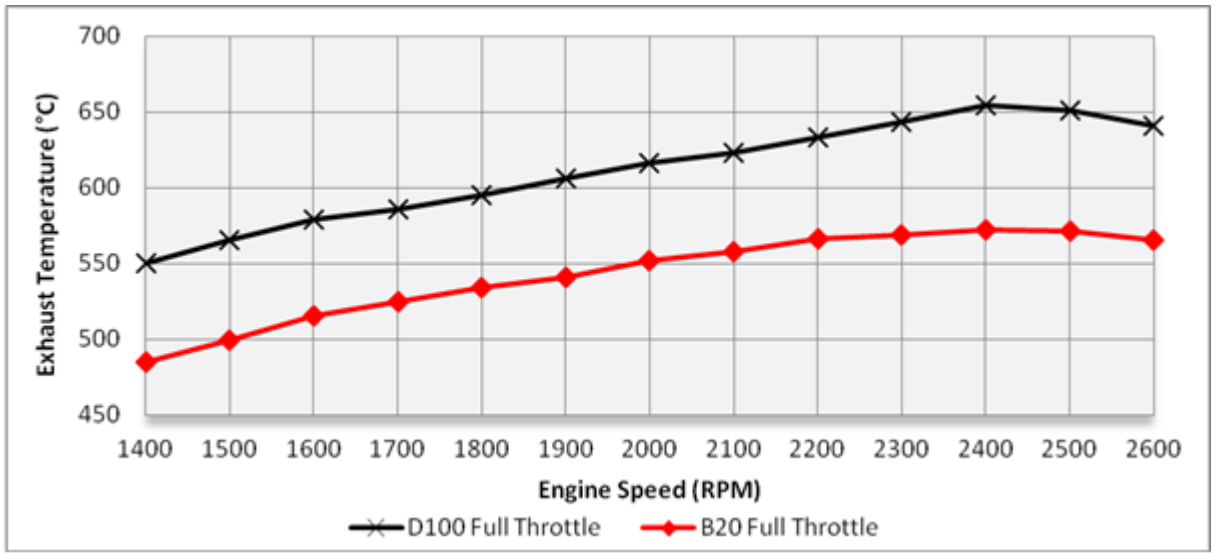


Figure 105. B20 tallow Exhaust Temperature Full Throttle HATZ.

Emissions

The use of B20 in the HATZ apparatus resulted in reductions in all three main pollutant gases. The reduction in carbon monoxide was significant, with three times less at low speeds and less than half at top speed. Carbon dioxide was also reduced by up to 11%, with at least a 6% reduction across all engine speeds. NOx also saw reductions at every speed, peaking at a 15% reduction at 2600rpm. Oxygen levels increased for B20, indicating that the engine operated leaner on B20 than on diesel. Equivalent carbon dioxide emissions were down, with a maximum 13% reduction over diesel at 2600rpm. B20 produced a 22.6% concentration of CO2e at its most efficient speed of 1400rpm,

compared to diesel producing a 23.4% concentration of CO2e at its most efficient speed of 2000rpm. The relative differences between the exhaust gas outputs are tabulated in table 40 below.

Table 40. Emissions From B20 tallow relative to diesel.

Speed (RPM)	CO (% vol)	CO_2 (% vol)	HC (10^{-4} vol)	O_2 (% vol)	NO_x (ppm)	CO2e (% vol)
1400	-300%	-8%	0%	29%	-1%	-7%
1500	-300%	-8%	0%	31%	-1%	-6%
1600	-267%	-7%	0%	29%	-2%	-6%
1700	-217%	-6%	100%	28%	-3%	-6%
1800	-183%	-6%	0%	28%	-4%	-6%
1900	-180%	-6%	0%	23%	-5%	-6%
2000	-180%	-7%	0%	25%	-5%	-7%
2100	-160%	-6%	0%	27%	-4%	-6%
2200	-140%	-7%	0%	24%	-5%	-7%
2300	-160%	-9%	0%	26%	-7%	-8%
2400	-150%	-6%	0%	25%	-8%	-7%
2500	-125%	-8%	0%	26%	-12%	-10%
2600	-75%	-11%	0%	32%	-15%	-13%

5.6 Cotton seed oil B20 - John Deere 4410

Power

Because the test was conducted at a constant speed with varying torque applied by the PTO, the power outputs of the two fuels are identical. The applied torque does reduce engine speed as torque increases, however the reduction follows and almost identical path for both fuels with variations in the vicinity of 5rpm.

Fuel efficiency

Since the power outputs are close to identical through the range of loading, a direct comparison of fuel consumption can be made. Figure 106 shows the total energy being input into the engine at each PTO loading condition. The B20 blend required more energy input than diesel to produce the same output power throughout most of the load range, with a difference of 2kW at the peak. This indicates a lower efficiency for B20, as seen in figure 108 where efficiency is 0.8% lower for B20 than diesel at the peak and is lower at all other loadings as well. Figure 107 shows the brake specific fuel consumption for the two fuels throughout the test. Since B20 has a lower calorific value than diesel, it follows that the BSFC is higher for B20. Since B20 has a higher gross energy input as seen in figure 106, the BSFC difference between the two fuels is greater than the difference between the calorific values of the fuels.

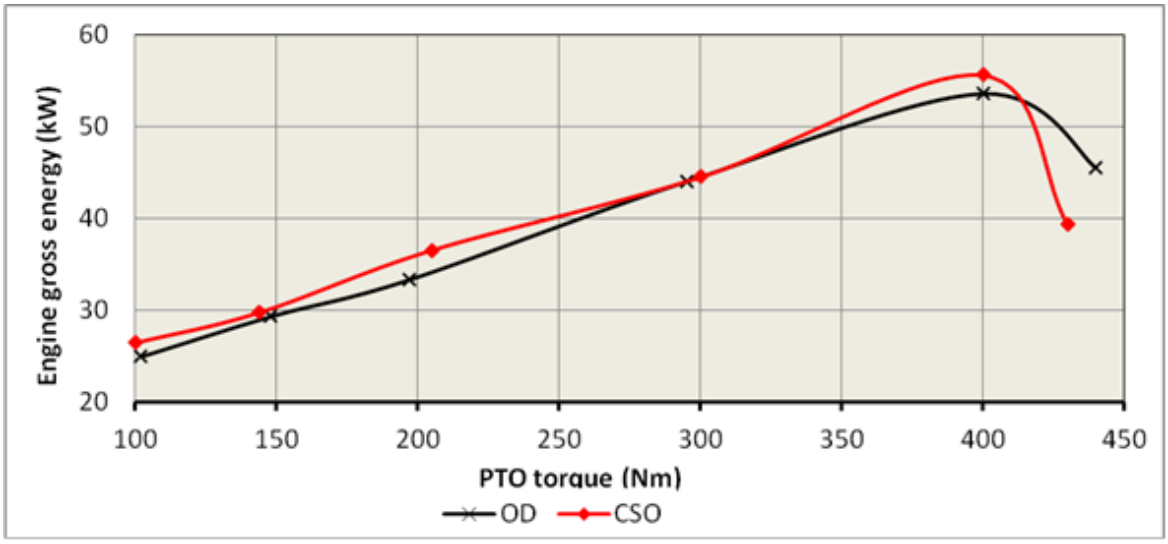


Figure 106. B20 CSO Power Curve Full Throttle JD4410.

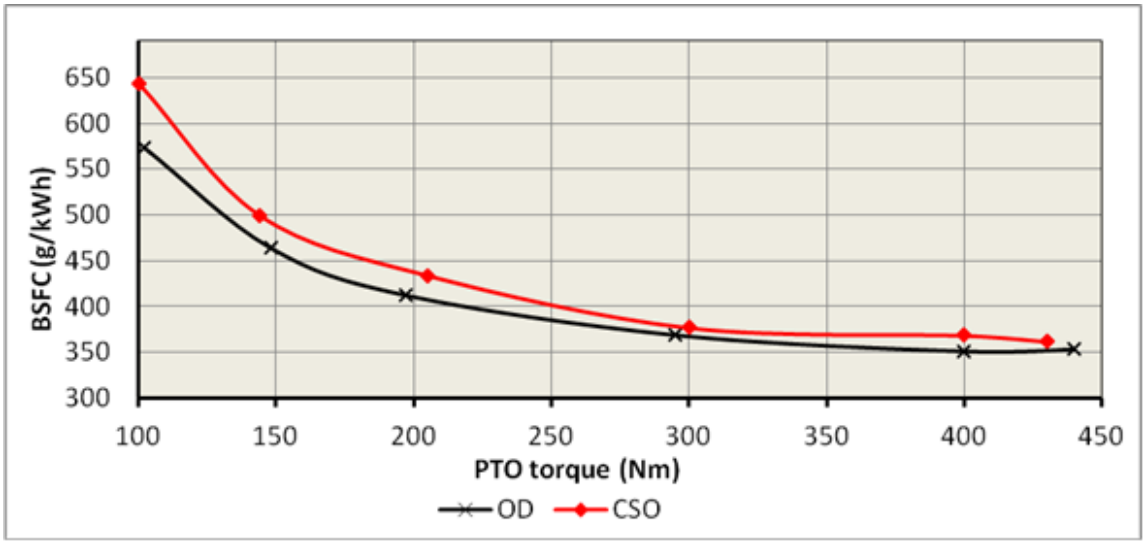


Figure 107. B20 CSO BSFC Full Throttle JD4410.

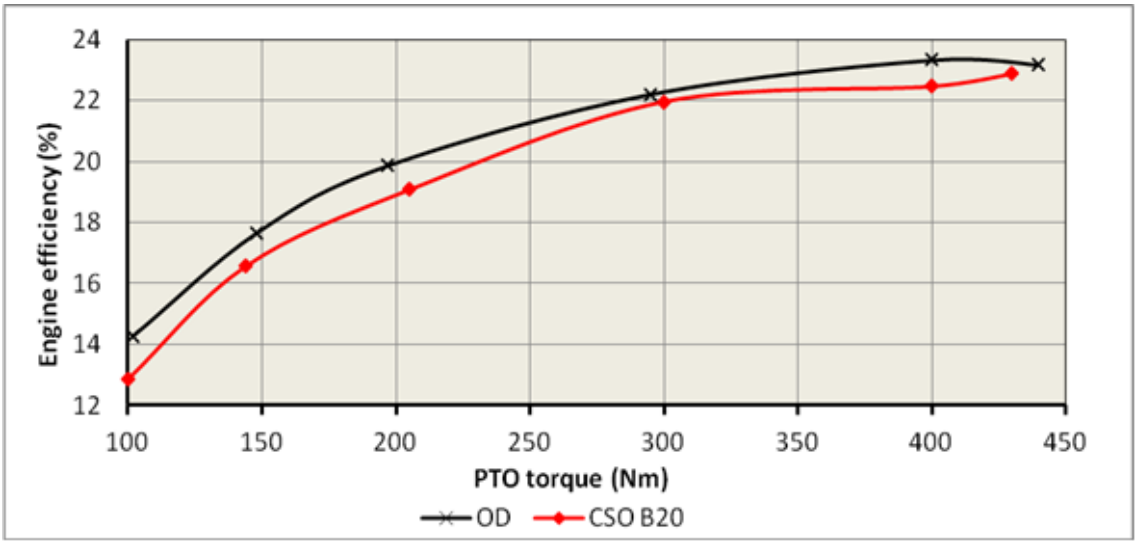


Figure 108. B20 CSO Engine Efficiency Full Throttle JD4410.

Exhaust temperature

The exhaust temperatures when using B20 are lower than those when using diesel. The maximum difference between the two is 19°C, occurring at torque loads of 100Nm and 150Nm. Peak temperatures are reached at a torque load of 400Nm, with 11°C separating the two fuels. The reason for the lower exhaust temperatures for B20 is the lower adiabatic flame temperature of biodiesel. Figure 109 shows these results.

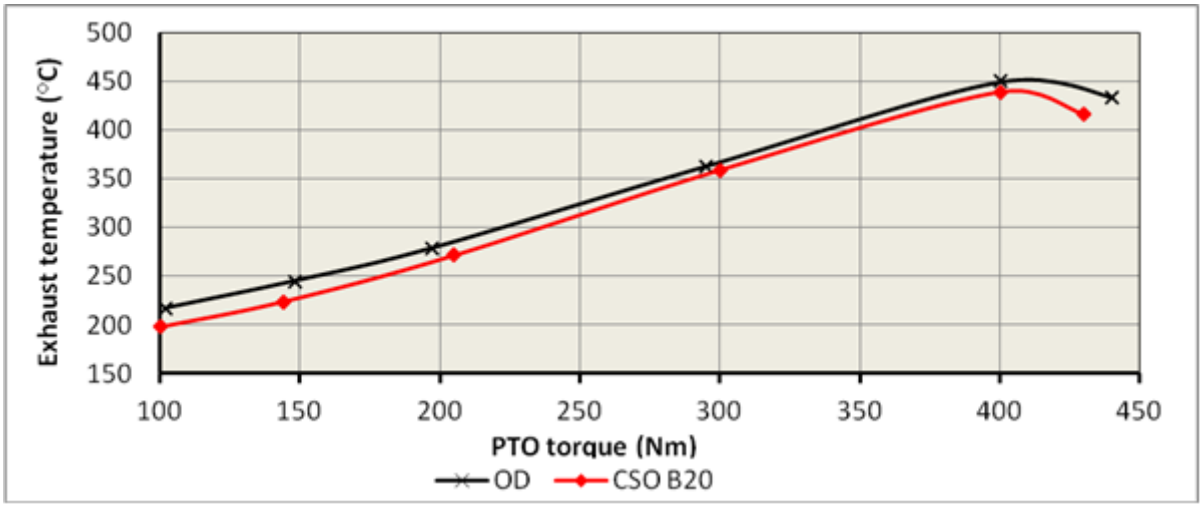


Figure 109. B20 CSO Exhaust Temperature Full Throttle JD4410.

Emissions

Measured emissions from this test showed very little difference between the fuels. Carbon monoxide measurements showed no significant difference between the fuels up to 400Nm loading, as was the case with NOx. A slight increase in carbon dioxide was observed for B20 up to a load of 300Nm, with the largest difference being 4% at 200Nm. These results can be seen in figure 110 below.

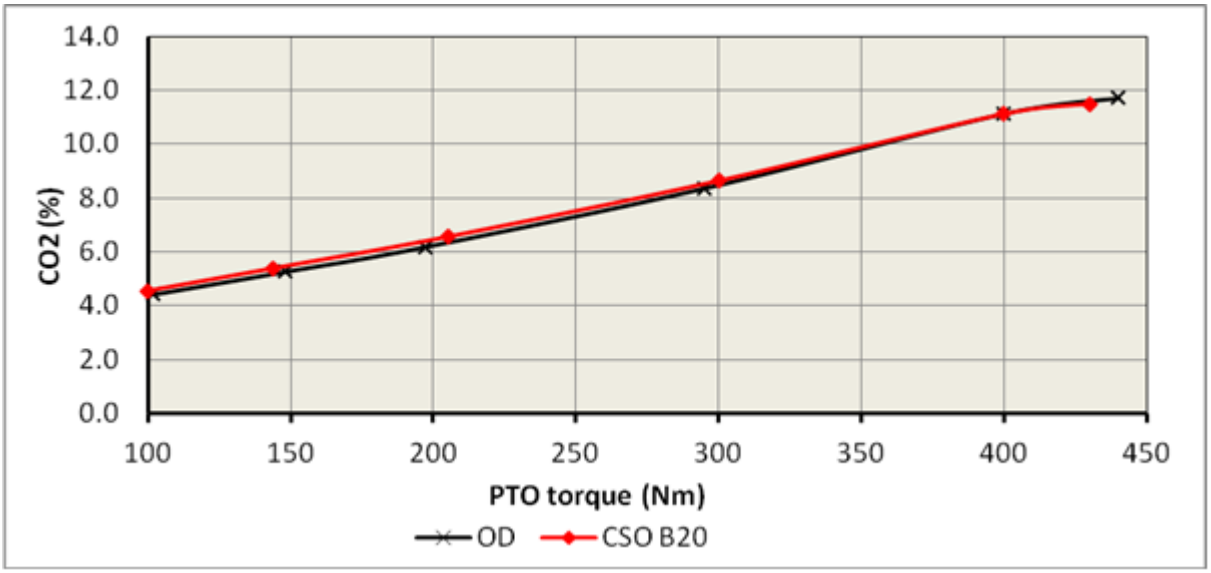


Figure 110. B20 CSO Carbon Dioxide Emissions Full Throttle JD4410.

A6. Algae biodiesel results

The algae and other fuel testing performed on the JD4410 apparatus are the results of Al-lwayzy et al., (2013) and are presented here to increase the breadth of fuels tested.

Apparatus and method

The John Deere tractor and stationary PTO test apparatus was used for the testing of the microalgae fuel, designated as *MCP-B20* (microalgae *chlorella protothecoides*, 20% blend) . The microalgae biodiesel was produced by the transesterification of *chlorella protothecoides* oil obtained from Turkey. This was then blended with diesel to a concentration of 20% by volume. The properties of the fuels are summarised in Table 41.

Table 41. Algae fuel properties.

Property	Petroleum Diesel (PD)	MCP-B100	MCP-B20
Cetane Number	49	52	49.6
Calorific Value MJ/kg	46	37.49	44.298
Density at 15ºC kg / L	0.83	0.867	0.8374
Viscosity at 40ºC mm² / s	3.9	3.8	3.88
Flash point ºC	79	124	88
Carbon residue (on 10% distillation residue) % (m/m)		0.2	
Total contamination mg / kg		2	
Oxidation stability, 110ºC Hours		12	
Acid value mg KOH / g	<0.1	0.3	0.14
Iodine value		47	
Sulfated ash content%		0.01	
Water content mg / kg		80	
Methanol content%		0.04	
Sulfur content mg / kg	8	2	6.8
Phosphorus content mg / kg		3	
Linolenic acid methyl ester%		2	
Polyunsaturated (>=4 double bonds methyl ester) %		0.1	
Monoglyceride content%		0.2	
Diglyceride content%		0.04	
Triglyceride content%		0.02	
Free glycerol%		0.008	
Total glycerol%		0.02	

Power and torque

Both the petroleum diesel and the algae biodiesel blend (MCP-B20) produce the same amount of peak power, with 15.8kW@2500rpm recorded for both fuels. At the rated PTO speed, corresponding to 2600rpm engine speed, the MCP-B20 falls 0.77kW short of matching the petroleum diesel's power output. However, the relative difference is small. These results are shown below in figure 111.

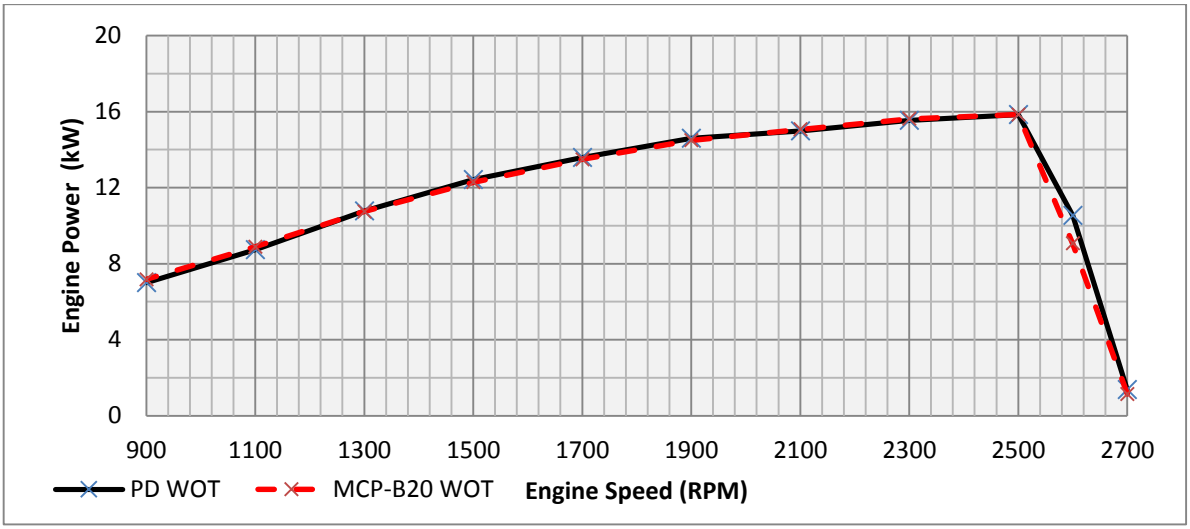


Figure 111. Algae biodiesel and diesel power output.

It follows that the torque output follows the same trend, with 5.4Nm less torque at 2600rpm from the MCP-B20. The maximum torque for both fuels is at 1300rpm, with 78.9Nm for the MCP-B20 and 79.1Nm for the petroleum diesel. This is shown below in figure 112.

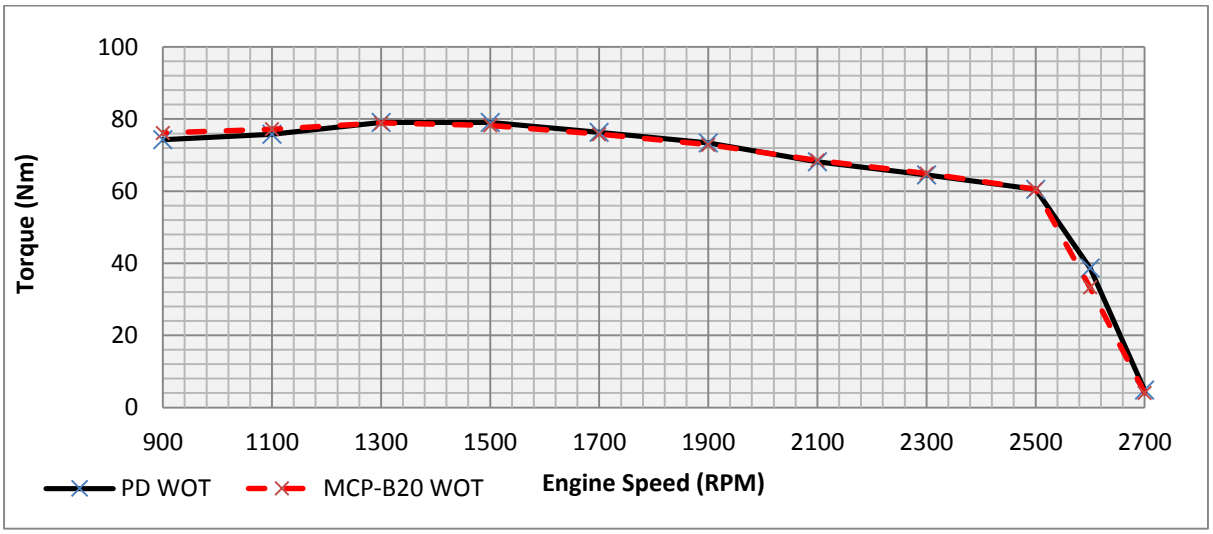


Figure 112. Algae biodiesel and diesel torque output.

Fuel efficiency

Engine efficiency peaked at 25.5%@900rpm for the MCP-B20 and 24.4%@1500rpm for the petroleum diesel. From 900rpm until 1300rpm the microalgae fuel was more efficient, before dropping slightly behind the diesel until 1900rpm, and then being higher again until 2500rpm. At the rated PTO speed of 2600rpm, the difference between the fuels is 1% efficiency. It is important to note that the lower calorific value of the microalgae biodiesel means that it has a higher brake

specific fuel consumption than diesel alone. The difference is around 15g/kWh from 1500-1900rpm, and 36g/kWh at 2600rpm.

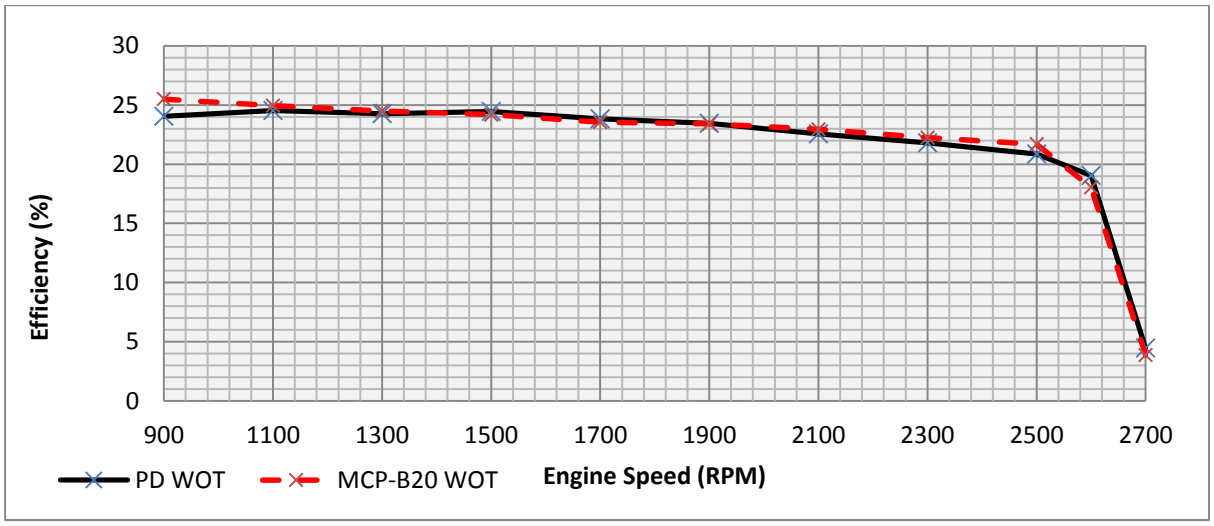


Figure 113. Algae biodiesel and diesel efficiency.

Exhaust temperature

Exhaust Temperature peaked at 545°C for MCP-B20 at 2100rpm, and 535°C at 1900rpm diesel. The two fuels were quite evenly matched from 1500rpm upwards, with differences of -31°C and 25°C at 1300rpm and 1100rpm respectively being the largest variances between MCP-B20 and diesel. There is not a clear trend throughout the speed range, with temperatures varying. Diesel was 6°C higher at the rated PTO speed of 2600rpm. This is shown below in figure 114.

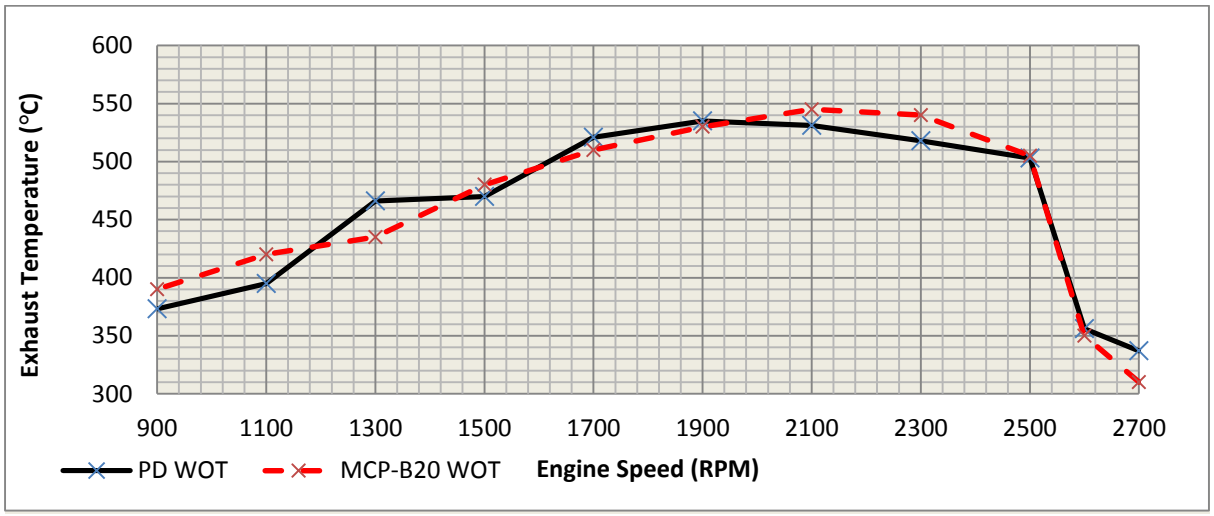


Figure 114. Algae biodiesel and diesel exhaust temperature.

Emissions– Carbon monoxide (CO)

Carbon monoxide emissions were lower whilst using MCP-B20 across all engine speeds, with the most significant reduction occurring at 1300rpm. A 0.264% reduction in carbon monoxide concentration occurs at this point, a reduction of over 22%. There was only a 0.011% difference at the rated PTO speed, with diesel producing the higher concentration. This is shown below in figure 115.

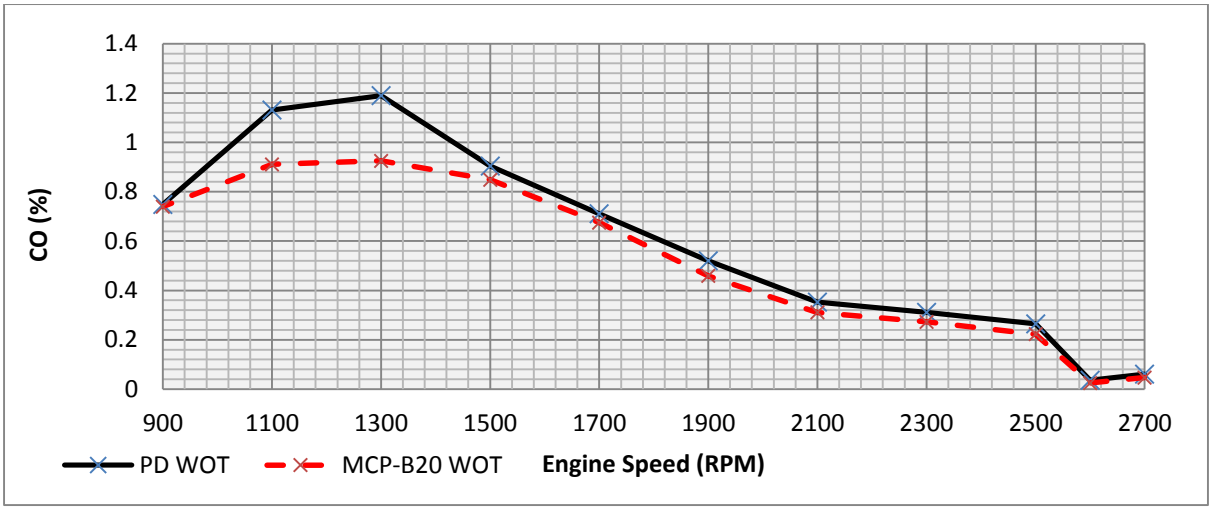


Figure 115. Algae biodiesel and diesel carbon monoxide (CO) emissions.

Emissions - Carbon dioxide (CO2)

Carbon dioxide emissions were almost identical throughout the speed range, with diesel peaking at 12.11% at 1500rpm, and the algae biodiesel blend peaking at 12.12% at 1700rpm. The biggest difference occurred at 2600rpm, with 0.73% separating the two fuels, with diesel producing the higher concentration. This is shown below in figure 116.

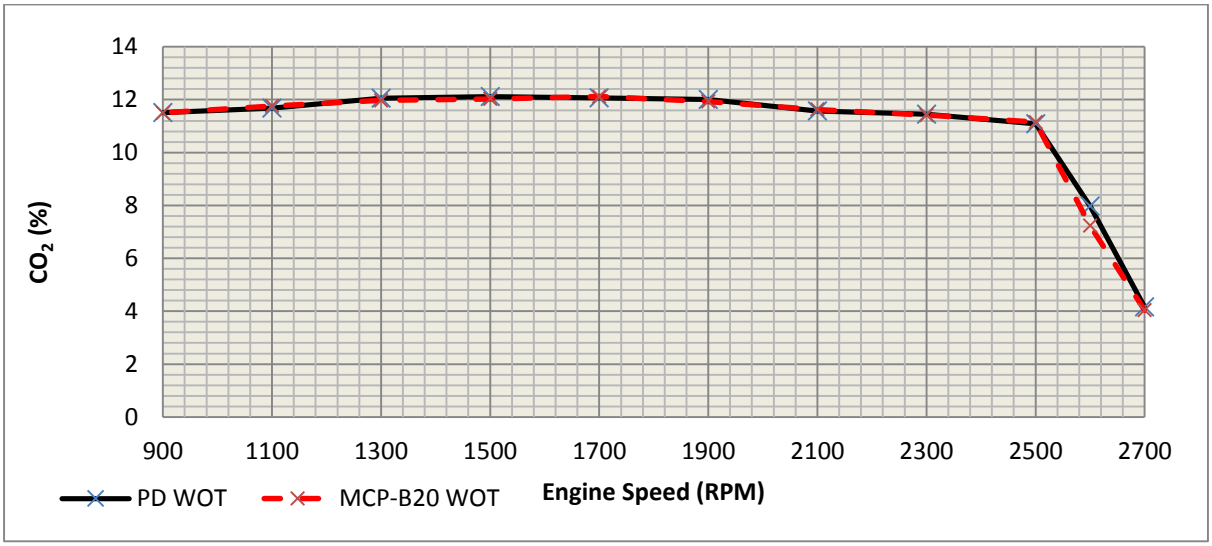


Figure 116. Algae biodiesel and diesel carbon dioxide (CO2) emissions.

Emissions - Nitrous Oxides (NOx)

NOx emissions were higher for the microalgae biodiesel blend up to 2500rpm. For both fuels, the peak was at 900rpm, with 68ppm difference between the two fuels. At 2600rpm, the was 92ppm difference in favour of the microalgae biodiesel blend. Notably, this engine and gas analyser combination resulted in NOx levels of over 1000ppm, more than double that measured from the Farymann/Gunt and HATZ engines. Own below in figure 117.

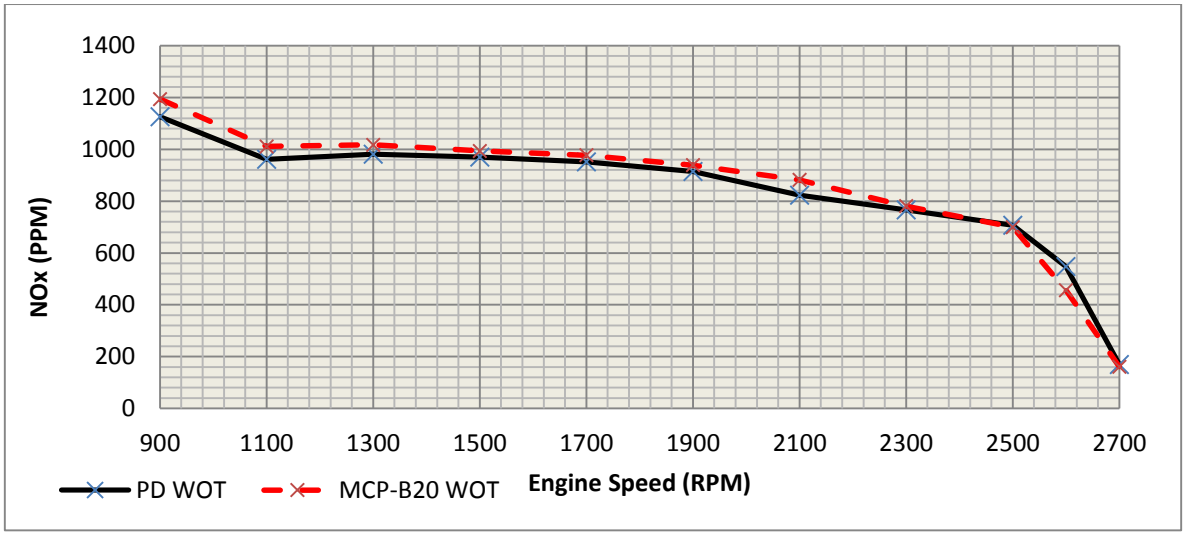


Figure 117. Algae biodiesel and diesel nitrous oxides (NOx) emissions.

Emissions - Unburnt Hydrocarbons

There was little difference between the two fuels, with diesel resulting in a peak of 11ppm, and MCP-B20 10ppm. Over the speed range the results were very similar, with only a 3ppm maximum difference between the two at the rated PTO speed of 2600rpm. This is shown below in figure 118.

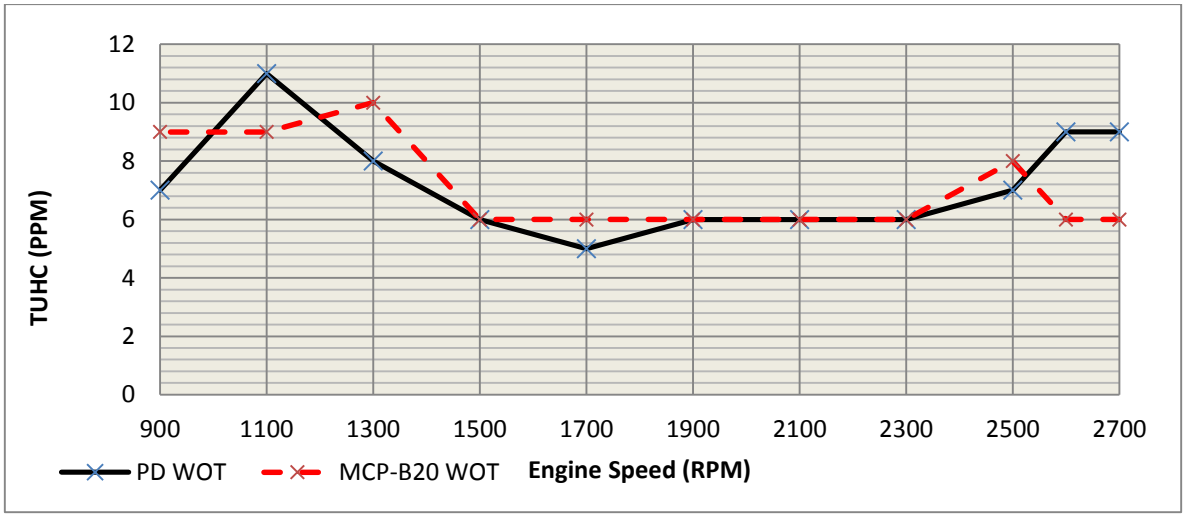


Figure 118. Algae biodiesel and diesel hydrocarbon emissions.

A7. Alcohol fuels results

Apparatus and method

The Fuel tested consisted of 95% purity ethanol (with the remaining 5% being water), CALTX Vortex diesel and a surfactant to ensure the constituents remained mixed. Note that the surfactant is Commercial In Confidence and it is the performance results that are being tested here. This fuel is noted as *D80E10*, being 80% diesel and 10% ethanol. The resulting concentrations are summarised in Table 42. After the fuel was mixed, it was left for four months in varying temperatures to test the surfactant's effectiveness. After the four months the fuel was still completely mixed, and testing was

then carried out as for other fuels. These tests used the Farymann/Gunt engine and dynamometer, once again operating with a 16.0:1 compression ratio for engine safety.

Table 42. D80E10 Constituent concentrations by weight.

DIESEL/ETHANOL D80E10 MIXTURE		
Ingredient	**Weight (g)**	**Concentration (%)**
Diesel	900	81.82
Ethanol	95	8.64
Water	5	0.45
Surfactant	100	9.09
TOTAL	**1100**	**100.00**

Power and torque

Power and torque were evenly matched between diesel and the ethanol blend until 1900rpm, where there was a difference of 0.43kW. The gap reduced as the engine speed increased, with a peak difference of only 0.05kW. Torque peaked at 0.28Nm less for the ethanol blend, at 2200rpm instead of 2000rpm for diesel. This is shown below in figure 119.

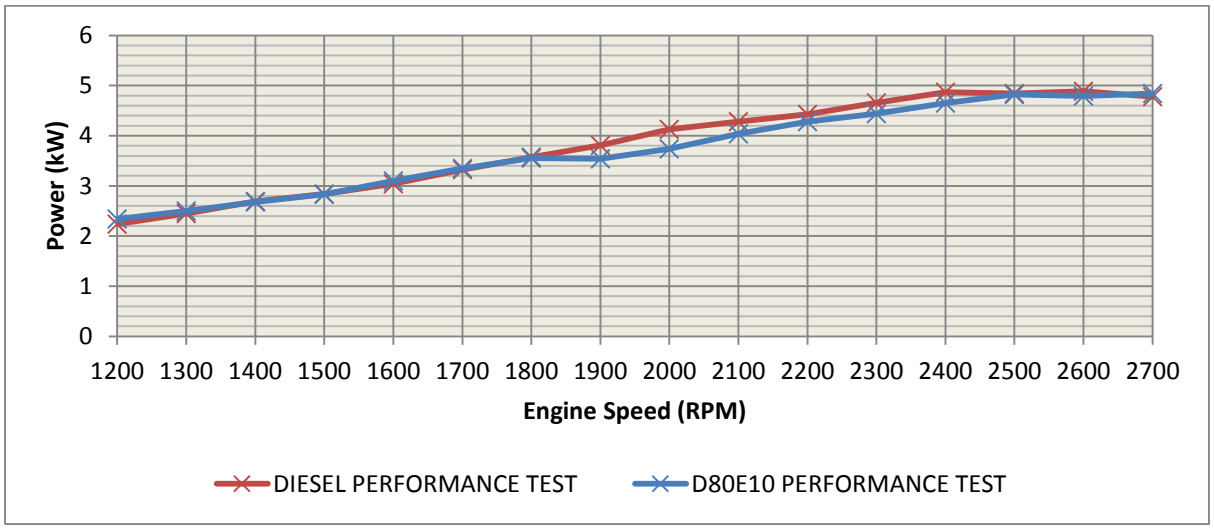


Figure 119. Diesel/ethanol and diesel power output.

Fuel efficiency

The exact composition of the surfactant is Commercial in Confidence and therefore not available for publication. Because of this, the calorific value of the fuel has had to be estimated and the fuel efficiency calculations are based on this estimate. For the purpose of the calculations it has been assumed that the ethanol and surfactant have the same calorific value. It is most likely that the surfactant has a lower calorific value than ethanol, therefore the efficiency calculations are most probably slightly understating efficiency. Using this estimation, the efficiency of the ethanol blended fuel is higher than that of diesel for most speeds. Once again erroneous data was produced from the measuring equipment which was discarded, and the data in figure 120 need to be treated with caution. Peak efficiency for the ethanol blend was 0.11% higher at a much lower speed of 1800rpm compared to 2100rpm for diesel.

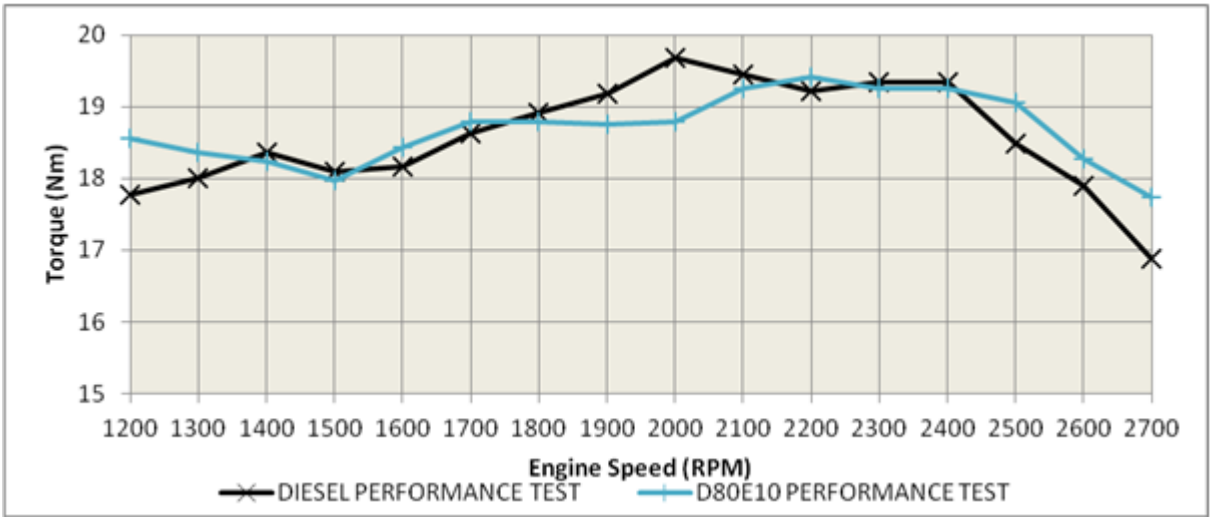


Figure 120. Diesel/ethanol and ethanol efficiency

Exhaust temperature

Exhaust temperature was higher for the ethanol blend at 1200-1300rpm, before reducing to be slightly higher up until 1900rpm. From 1900rpm until 2100rpm the temperature was lower, before hovering around the same level as diesel for the remaining speeds. This is shown below in table 43.

Table 43. Ethanol/diesel exhaust temperatures relative to diesel exhaust temperature.

Speed (RPM)	Relative Exhaust Temperature (°C)
1200	+33
1300	+11
1400	+2
1500	+2
1600	+3
1700	+5
1800	+6
1900	-10
2000	-7
2100	-6
2200	+3
2300	+4
2400	-2
2500	0
2600	-4
2700	0

Emissions

Hydrocarbons, carbon dioxide, nitrous oxides and carbon monoxide were all reduced with the ethanol blended diesel at the lower engine speeds. Hydrocarbons showed the greatest reduction, with up to 41% less than diesel. As with the biodiesel blend, this is because there are fewer hydrocarbons in the fuel, so therefore there are less in the exhaust gases. Also significant was the carbon monoxide reduction, with a 10%-18% reduction between 1400rpm and 1800rpm. However, at engine speeds above 2200rpm, all of these pollutants were increased. Nitrous oxides sharply increased from 2400rpm upwards, while the others showed milder increases. At the most efficient speed for each fuel, hydrocarbons were 152ppm for B80E10 and 179ppm for diesel. Similarly, carbon dioxide was lower at 9.8% versus 10.0% for diesel. Nitrous oxides however resulted in 213ppm over diesel's 188ppm. Carbon monoxide was much less from the ethanol blend, with it making up 2.04% of the exhaust gases compared to 1.2% for diesel at the most efficient speed. The diesel/ethanol blend resulted in a carbon equivalence of 0.188kgCO2e per kg of exhaust gas, compared to 0.199kgCO2e per kg for diesel. These results are presented below in table 44.

Table 44. Ethanol/diesel emissions relative to diesel emissions.

Speed (RPM)	Hydrocarbons (10^{-4} vol)	Carbon Dioxide (% vol)	Nitrogen Oxides (10^{-6} vol)	Carbon Monoxide (% vol)	Oxygen (% vol)
1200	-41%	-11%	-9%	-8%	1%
1300	-23%	-2%	3%	4%	1%
1400	-20%	-1%	0%	-10%	7%
1500	-13%	-2%	-1%	-18%	10%
1600	-12%	-2%	0%	-14%	9%
1700	-8%	-1%	-4%	-17%	8%
1800	-7%	2%	-3%	-12%	5%
1900	-6%	1%	-4%	-7%	4%
2000	-7%	2%	0%	0%	4%
2100	-4%	1%	-1%	-4%	4%
2200	4%	3%	-1%	13%	-2%
2300	8%	4%	1%	7%	-2%
2400	10%	2%	13%	2%	0%
2500	2%	2%	8%	-3%	4%
2600	1%	2%	10%	3%	2%
2700	6%	2%	10%	5%	-2%

A8. Optimising cost, performance and emissions

Following the testing outlined above, optimisation was required for some fuels that showed potential to be improved in some way. The comparison of B20, B50 and B100 in the preceding section resulted in the selection of B20 as the optimum blend ratio of biodiesel with diesel to minimise the performance loss caused by biodiesel. Because of this, no further work was required optimising biodiesel blends in this section.

The results obtained from the addition of LPG to the HATZ engine did not correlate with what was expected and what was claimed by the manufacturer. This was because at full power, the engine's mechanical injection and governor system meant that the amount of diesel being injected did not reduce to compensate for the additional LPG. LPG was simply being injected as an additional fuel. Therefore, optimisation is necessary to reduce the diesel being injected.

Ethanol blending proved to be a comparable alternative to diesel, with similar performance and emissions and no obvious drawbacks. Concerns over engine safety due to knocking from higher blend ratios meant that no further optimisation of blending ratios was required for this fuel.

A8.1 Optimising LPG injection with diesel

To reduce the amount of diesel being injected into the engine, it was necessary to throttle back to produce an output, with LPG injection, equal to that of diesel alone. Two series of tests were conducted to achieve this: constant torque and constant power. For constant torque, this was achieved by keeping the load constant and varying the speed throughout the operational range using the throttle. For constant power output, the speed was set using the dynamometer controller and the throttle used to achieve a required power output.

Fuel efficiency

The constant torque test with the HATZ engine and 40% LPG fumigation resulted in a fuel efficiency peak of 37.5%, compared to 36.4% for diesel. This peak was at 1600rpm, with the diesel peaking at 1800rpm. Lower fumigation levels failed to match the peak efficiency of diesel, however 30% LPG fumigation was more efficient than diesel between 1900rpm and 2500rpm, and 20% LPG fumigation marginally more efficient than diesel from 2100rpm to 2500rpm. Clearly 40% fumigation is the most efficient option of those tested, and this can be seen in figure 121.

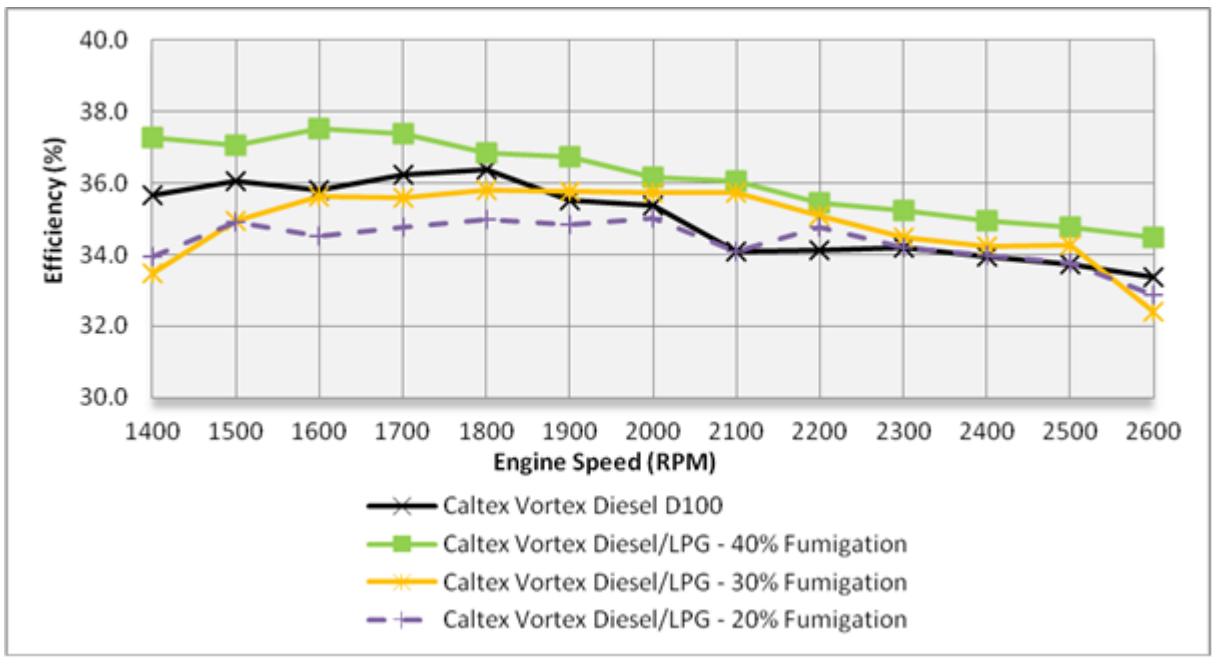


Figure 121. Fuel efficiency of different levels of LPG fumigation at constant engine torque.

A constant power test was performed for the range of engine speeds between 1500rpm and 2200rpm, as this is the region which is typically the most efficient. This test yielded the same trend

as the constant torque test, with the addition of 40% LPG fumigation yielding a fuel efficiency of 38.9%, compared to 35.8% for diesel. The most efficient speed for diesel was 2100rpm, and for diesel/gas was 1800rpm. Figure 32 shows the comparison of the efficiency graphs for the two fuels.

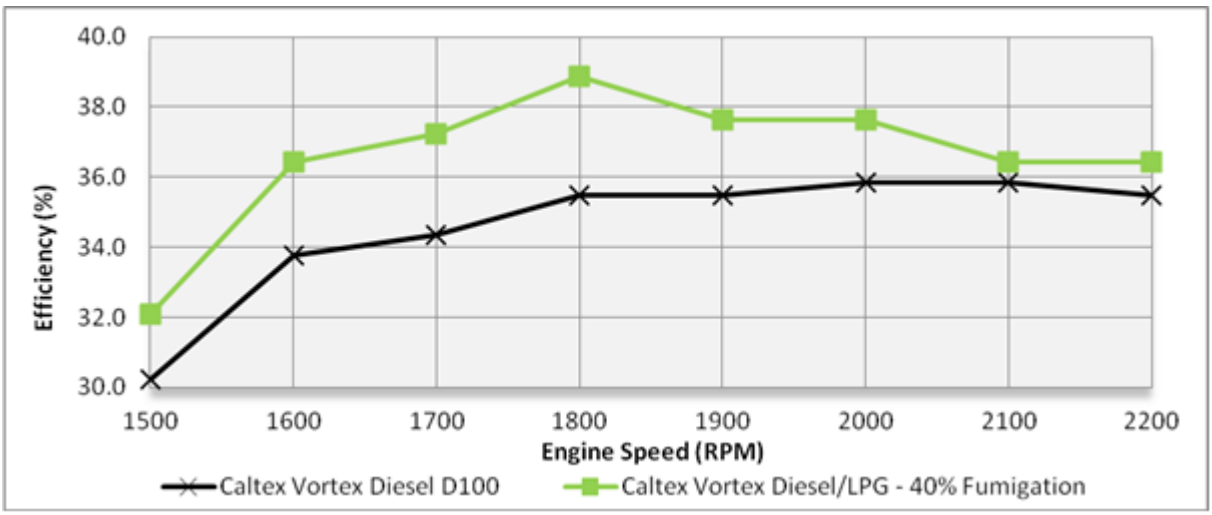


Figure 122. Fuel efficiency 40% LPG fumigation at constant engine power.

Exhaust temperature

Exhaust temperatures with LPG during the constant torque test were less than those using just diesel for all speeds with the exception of 20% LPG fumigation, which resulted in higher temperatures over the whole speed range. At the most efficient diesel speed of 1800rpm, the exhaust temperature was 472°C. At the most efficient speed of 1600rpm for LPG, the temperature was 430°C. This is shown below in figure 123

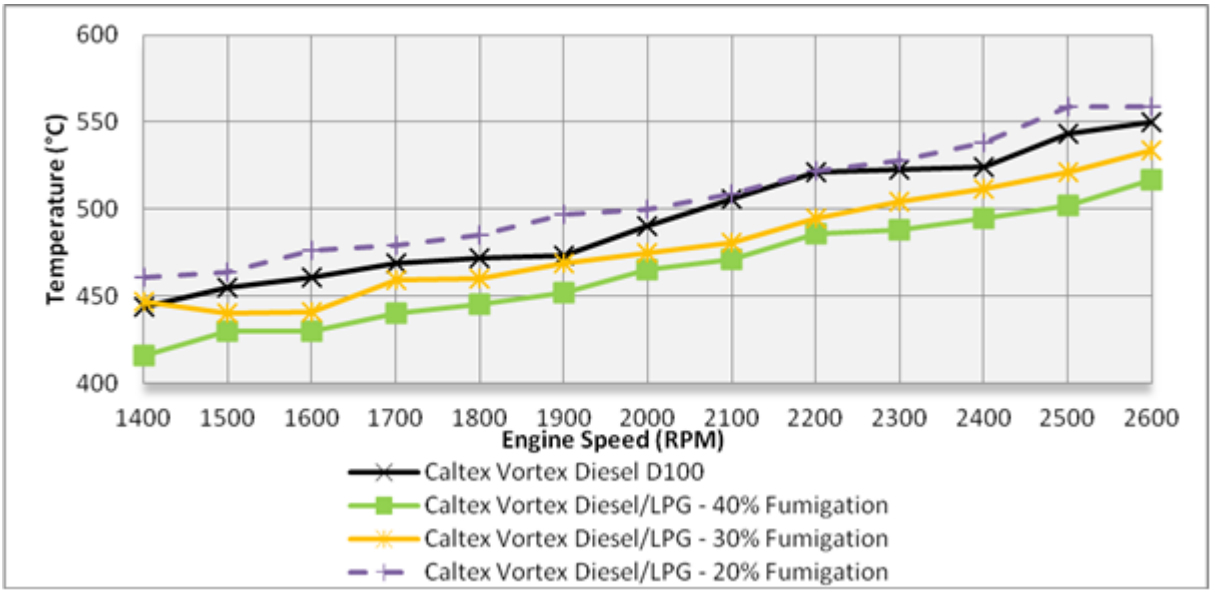


Figure 123. Exhaust temperature of different levels of LPG fumigation at constant engine torque.

In general, exhaust temperatures were lower using LPG during the constant power test. However at the most efficient speeds, diesel resulted in 441°C at 2100rpm, and LPG 455°C at 1800rpm. This is shown below in figure 124.

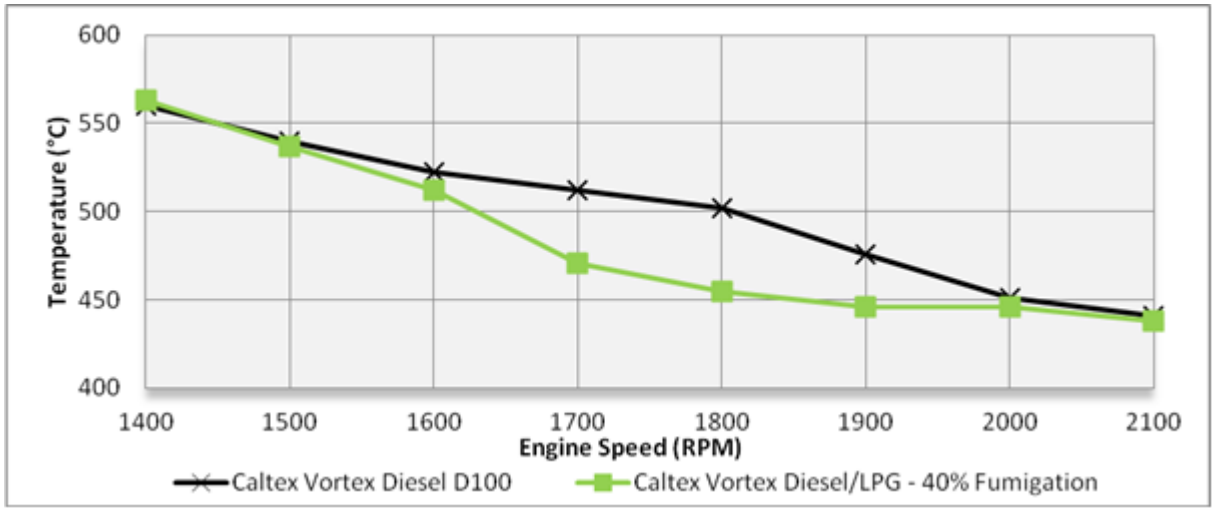


Figure 124. Exhaust temperature at 40% LPG fumigation at constant engine power.

Emissions

Above 1600rpm the NO_x emissions from the HATZ engine were significantly higher, at all levels of fumigation, than diesel alone. At the most efficient point of 40% fumigation, 1800rpm, NO_x was almost 8% higher. These results are presented below in figure 125.

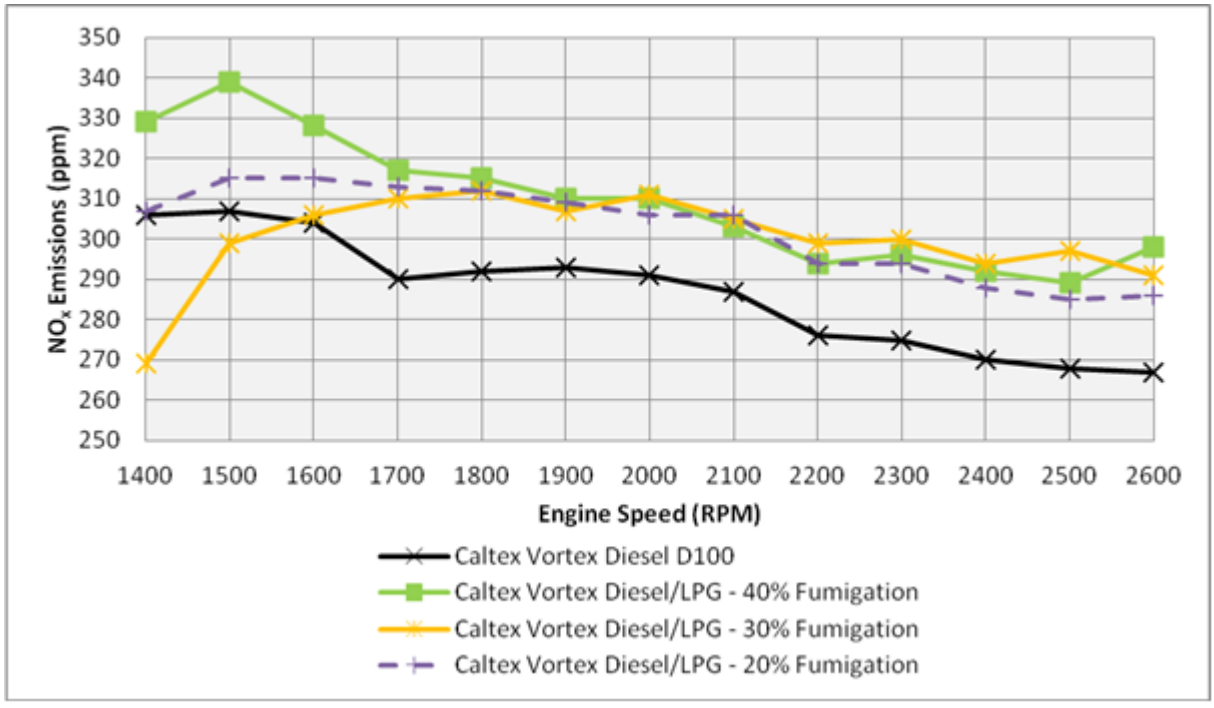


Figure 125. NOx emissions of different levels of LPG fumigation at constant engine torque.

Table 45, below, shows the change in emissions relative to the diesel baseline after adding 40% LPG and performing a constant torque test. Carbon monoxide rose significantly throughout all engine speeds, as did hydrocarbons. NOx also increased across all speeds, whereas carbon dioxide marginally reduced across all speeds.

Table 45. Emissions of 40% LPG fumigation at constant engine torque, relative to diesel.

Speed (RPM)	CO (% vol)	CO_2 (% vol)	HC (10^{-4} vol)	O_2 (% vol)	NO_x (ppm)
1400	80%	-3%	90%	-5%	7%
1500	80%	-3%	83%	-4%	9%
1600	70%	-4%	79%	0%	7%
1700	80%	-3%	80%	-4%	9%
1800	80%	-4%	58%	-3%	7%
1900	78%	-3%	56%	-6%	5%
2000	78%	-2%	63%	-4%	6%
2100	67%	-6%	58%	6%	5%
2200	63%	-3%	48%	0%	6%
2300	50%	-5%	48%	3%	7%
2400	50%	-5%	24%	6%	8%
2500	43%	-5%	8%	10%	7%
2600	43%	-4%	-11%	8%	10%

The constant power test yielded similar results, with the addition of LPG increasing NOx across all speeds. At the most efficient speed, which was 2100rpm for diesel, NOx was 324ppm. For LPG, at the most efficient speed of 1800rpm, NOx was 402ppm. Table 46, below, shows the change in emissions relative to the diesel baseline after adding 40% LPG and performing a constant power test.

Table 46. Emissions of 40% LPG fumigation at constant engine power, relative to diesel.

Speed (RPM)	CO (% vol)	CO_2 (% vol)	HC (10^{-4} vol)	O_2 (% vol)	NO_x (ppm)
1500	20%	-3%	36%	-7%	11%
1600	30%	-2%	82%	-3%	8%
1700	44%	-5%	95%	6%	7%
1800	78%	-8%	96%	9%	8%
1900	33%	-6%	97%	4%	6%
2000	80%	-4%	98%	3%	4%
2100	80%	-2%	98%	-2%	4%
2200	80%	-5%	100%	1%	2%

These results do not correlate with those found in the Keytah study (DieselGas Technologies, Pers. Comm., 2011), where a reduction in NOx of 26.7% was observed. It should be noted however that the absolute level of NOx was significantly higher in the Keytah study, with 453ppm of NOx, compared to the HATZ, with 328ppm NOx at the point of highest efficiency. Once again this is due to the Keytah study's engine being turbocharged, resulting in higher in cylinder temperatures and more NOx generation.

A8.2 Fuel efficiency – electronic fuel injection

The study of the Keytah pump station performed by DieselGas Technologies (Pers. Comm., 2011) (Similar reference: DieselGas Technologies, 2011.), revealed a reduction of fuel energy (kJ) being input into the pump station engine of 10.5% and 11% for the two engine speeds presented. Though not explicitly stated, it is assumed that the load applied to the engine in the tests was the same before and after the addition of the LPG. If this is the case, the results can be directly compared to the HATZ constant torque results, where a 4.7% reduction in input energy resulted with the addition of the Diesel/Gas system. The larger gains in the Keytah study are due to the Keytah engine being turbocharged, increasing the beneficial effects of the addition of LPG. The Keytah study does not state efficiency figures or power outputs, however constant load and reduced specific fuel consumption means that efficiency must have improved, and by a greater margin than observed with the HATZ.

A8.3 LPG with biofuels

Following the results from the addition of LPG to diesel, LPG was tested with a biodiesel blend to determine whether the same effects would be observed. The fuel used was cotton seed oil biodiesel obtained from Queensland University of Technology blended with CALTEX Vortex diesel, as used in the Farymann/G.U.N.T apparatus in the preceding section. Fumigation levels were set at 40%, as this had been proven to be the most successful level in previous tests. A constant power test was conducted to investigate this.

Fuel efficiency

Peak fuel efficiency for LPG fumigation was observed as 39.6% between 1600 rpm and 1900 rpm; peak fuel efficiency for biodiesel was observed as 39.4% at 1900 rpm. These results are presented below in figure 126. This is misleading however, due to the addition of LPG resulting in much higher efficiencies from 1500rpm through to 2100rpm as can be seen in figure 60. It is important to note that the values obtained using the biodiesel blend and LPG were higher than those obtained with diesel/LPG. Diesel/LPG's efficiency peaked 0.7% less at 38.9%.

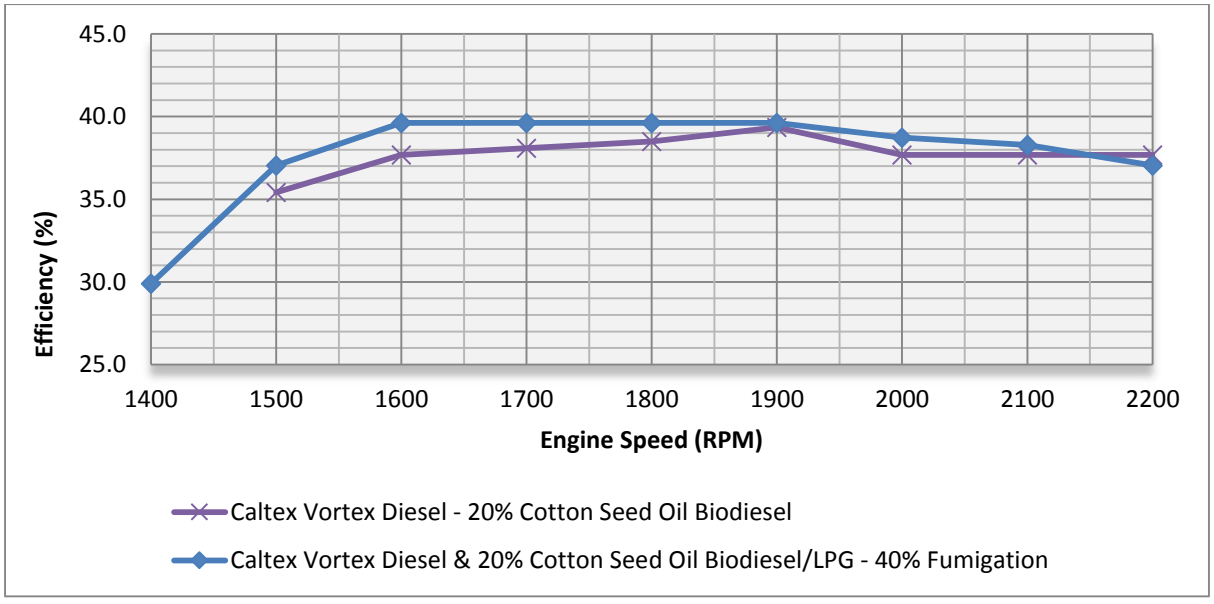


Figure 126. Fuel efficiency for 40%LPG/60%B20 and for B20.

Exhaust temperature

At 1500rpm, B20 is 4°C higher than the B20/LPG blend. This trend increases with increasing rpm, with the maximum gap reaching 23°C at the most efficient speed of 1900rpm. The trend reverses above this speed with B20 being only 2°C higher at 2200rpm. These results are presented below in figure 127.

As the test was a constant power test, it follows that the highest exhaust temperatures are experienced at the lowest speeds. At lower speeds, the air volume displaced through the engine is reduced. The constant power output and relatively constant efficiencies means the amount of heat expelled is also almost constant. Thus, there is less volume carrying a relatively constant amounts of heat, which results in higher temperatures.

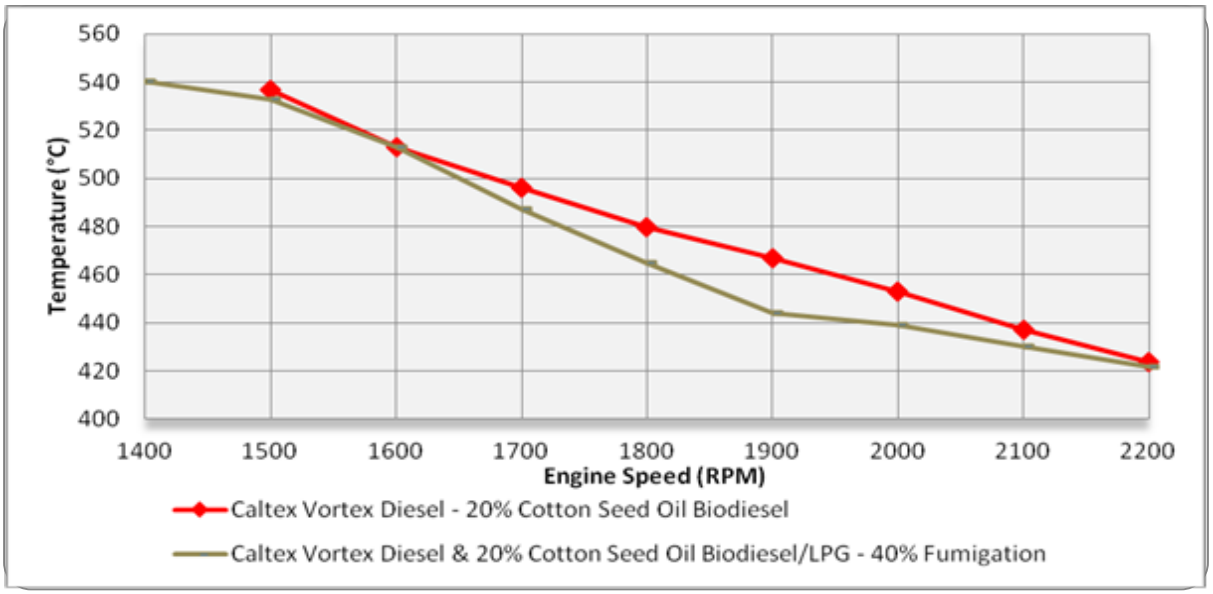


Figure 127. Exhaust temperature for 40%LPG/60%B20 and for B20.

Emissions

Table 47 summarises the emissions from the B20 biodiesel blend with LPG fumigation as a change relative to the B20 biodiesel blend without LPG. There was a significantly large increase in carbon monoxide emissions from the addition of LPG, with the level increasing almost exponentially with increasing engine speed. At the most efficient engine speed, carbon monoxide emissions are three and a half times those without LPG.

Unburnt hydrocarbons also increased significantly, with the level increasing by up to 74ppm over the speed range tested. This was the highest unburnt hydrocarbons measured during any of the testing, and is due to a reduction in diesel without a reduction in LPG. This suggests that too much LPG may be being injected, and lower fumigation rates may reduce the hydrocarbon emissions.

Nitrous oxides also increased by up to 16%, with a 12% increase at the most efficient engine speed of 1900 rpm. Despite the increase, the NOx concentration was still less than that recorded at the most efficient speed for diesel/LPG by 53ppm. This is a 13% reduction for B20/LPG over diesel/LPG.

Carbon dioxide emissions, however, were slightly reduced with the addition of LPG with up to a 5% reduction, and a 2% reduction at the most efficient engine speed of 1900 rpm.

Table 47. Emissions of 40% LPG fumigation with B20 at constant engine power, relative to B20.

Speed (RPM)	CO (% vol)	CO_2 (% vol)	HC (10^{-4} vol)	O_2 (% vol)	NO_x (ppm)
1500	31%	-1%	4	-13%	14%
1600	63%	-2%	12	-6%	16%
1700	125%	-4%	28	2%	13%
1800	200%	-2%	43	-4%	15%
1900	**350%**	**-2%**	**54**	**-3%**	**12%**
2000	400%	-2%	58	-4%	11%
2100	900%	-5%	65	-4%	6%
2200	800%	0%	74	-7%	1%

Appendix B: Ideas Warehouse

Tech-nology	Typical Industry	Typical Application	Benefits	Critical Factors	Cost	More details	Source	Keywords
Pump Test	Cotton, Feedlot, Horticulture, Viticulture	Pumps	Confirm operating point for maximum efficiency and performance	The pump must be suited to the task it is to perform.	These range in pricing depending on the provider. Expect to pay up to $4000 for a large installation.	It is critical that a professionally qualified person inspects the pump and the suction and discharge pressures along with water flow rate and diesel of electrical consumption are all measured. This is usually outside the capability of a local pump distributer.	http://www.escholarship.org/uc/item/7fw2p0zt#page-2	Pump, Efficiency, Test, Irrigation
Higher efficiency diesel engines	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	light vehicles, tractors, pumping	Reduced energy consumption through selection of more fuel efficient engines. Old naturally aspirated engines many output, as flywheel power, only 35% of the energy they consume in fuel. Modern electronic diesels output around 45% of the energy they consume in fuel.	Costs are incurred purchase of capital equipment, which are offset by the sale of old capital. Savings are obtained through more fuel efficient vehicles.	Dependent on exact capital requirements.	Sandell G.R., Szabo P.M., Baillie C.P., Woodhouse N.P. and Schmidt E., (2013). North-East Farming Futures R&D Support: Increasing the knowledge and adoption of energy saving initiatives amongst farming enterprises in Western Australia. National Centre for Engineering in Agriculture, Publication 1005089/1, USQ, Toowoomba.	Sandell G.R., Szabo P.M., Baillie C.P., Woodhouse N.P. and Schmidt E., (2013). North-East Farming Futures R&D Support: Increasing the knowledge and adoption of energy saving initiatives amongst farming enterprises in Western Australia. National Centre for Engineering in Agriculture, Publication 1005089/1, USQ, Toowoomba.	engine efficiency
Increase work width, reduce work speed.	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Tractors	Increases the tractive efficiency of the tractor and has the engine operating at peak efficiency. Increases field efficiency through reduced turning time.	Availability of wider equipment.	Dependent on equipment type and width.	Greater work speed requires greater traction increases wheel slip	http://efficient20.eu/files/2012/06/Fuel-efficiency-guide.pdf	tractor, planter, tractive efficiency, field efficiency
Gear up Throttle back	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	tractors, trucks, pumping	For a 20% drop in RPM, a 15 to 30 % drop in fuel use	Every engine has an optimum efficiency operating point where maximum horsepower is produced for every gram of fuel consumed. Reducing engine speed allows the engine to operate at or close to this point. This is highly applicable to older mechanically injected diesels and less to modern, electronically controlled diesels.	Nil, just move the throttle back.	1. Reduce the RPM up to 20% (more for lighter loads) 2. Shift to a higher gear to maintain the same ground speed 3. Check for overloading of the engine by opening up the throttle. If the engine responds it is not overloaded. If it does not, choose a lower gear and increase the throttle slightly.	http://www.wvu.edu/~exten/infores/pubs/ageng/pm18-3n.pdf http://fyi.uwex.edu/news/files/2010/07/matt_digman_fuel_savings.mp3	tractor, tillage, seeding, transport, trucks

Tech-nology	Typical Industry	Typical Application	Benefits	Critical Factors	Cost	More details	Source	Keywords
Variable Speed Drives	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	electrical motors, pumping	If, for a 100-kW pump, the flow needed is only one-half of rated capacity then the motor could be operated at half speed. The power [kW] needed to operate the pump would be (0.5)3 = 12.5 kW, or 12.5% of current power.	The affinity laws tell us that: 1.Flow is proportional to motor speed, 2.Pressure is proportional to motor speed squared and 3.Power is proportional to motor speed cubed.	While cost is completely dependent on the installation, pay-back periods are usually measured in months and sometimes in weeks. Cost is typically $100 to $1000 per drive per motor	http://www.ehp.qld.gov.au/ecobiz/network/previous-forums/pdf/toowoomba-manf-2012/peter-holborn.pdf	http://www.ehp.qld.gov.au/ecobiz/network/previous-forums/pdf/toowoomba-manf-2012/peter-holborn.pdf	electrical motors, pumping
General Information	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	trucks, tractors, HVAC, heating, cooling, lighting, light vehicles	General Information	General Information	General Information	http://www.ehp.qld.gov.au/ecobiz/network/previous-forums/index.html	http://www.ehp.qld.gov.au/ecobiz/network/previous-forums/index.html	trucks, tractors, HVAC, heating, cooling, lighting, light vehicles
Measure Fuel Usage	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	All Fuel consuming items	Dependant on current practice	A bench mark must be established before any energy savings can be made.	less than $2,000 typically	Start with a full tank then refill after each activity and record details	http://efficient20.eu/files/2012/06/Fuel-efficiency-guide.pdf	Usage, Fuel, Electricity, Measurements
Maintenance Schedule	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Tractor / Light Vehicles	Dependant on current practice	Old oil has reduced capacity to remove carbon deposits and forms a sludge that can potential block oil galleries	Negligible. Usually a paper record will suffice.	Oils and filters should be replaced in accordance with manufactures recommendations.	http://efficient20.eu/files/2012/06/Fuel-efficiency-guide.pdf	Maintenance, oil, filter, schedule, manufacturer
On-board Computers	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Tractors / Trucks	Displays spot fuel use	Incorporated into modern equipment. Expensive to retro fit to old equipment.	Incorporated into modern equipment. Expensive to retro fit to old equipment.	Provides an assortment of data to help reduce fuel consumption	http://efficient20.eu/files/2011/02/D3.3-final.pdf	fuel use, display
Training on operation of technology	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Tractors /Trucks / Light Vehicle	Up to 27% increase in fuel efficiency	An operator that has received a level of training on advanced technology is able to achieve greater efficiency than an untrained operator.	Generally around $1,000 per participant depending on course and travel costs.	An operator that has received a level of training on advanced technology is able to achieve greater efficiency than an untrained operator.	https://docs.google.com/file/d/0B100XSl3uhsFeWhCOGNnNEtwWjA/edit?pli=1	Training, operator, advanced, technology, tractor

Tech-nology	Typical Industry	Typical Application	Benefits	Critical Factors	Cost	More details	Source	Keywords
Tractor Ballast	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Tractor	Up to 10% increase in fuel efficiency	A tractor needs to be correctly weighted to achieve optimum tractive efficiency. Wheel slip should be between 8% and 15% for 2WD tractors and between 8% and 12% for FWA and 4WD tractors. Ballast can sometimes be removed for low-draft operations.	Varies between nil and minimal. Sometime adding water to the tyres is adequate and sometimes addition weight needs to be attached to the tractor	A system needs to be developed for addition and removal of weights for varying on farm practices to reduce weight handling time.	https://docs.google.com/file/d/0B100XSl3uhsFeWhCOGNnNEtwWjA/edit?pli=1	tractor ballast, wheel slip, tractive efficiency
Vehicle Weight Reduction	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Tractor / Light Vehicles	Up to 20% increase in fuel efficiency	It's important to carry what is required for the task as an extra 500kg can add 20% to fuel consumption.	Generally nil. Some time and thought into what is essential to carry on the vehicle and what can be discarded is required.	Removing unnecessary weight from any vehicle will reduce fuel consumption.	http://www.autonomie.net/docs/6%20-%20Papers/Light%20duty/fuel_econom_sensitivity.pdf	Vehicle, weight, reduction,
Engine and traction managemen t systems	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	tractors	Electronic control systems continuously monitor engine load and speed as well as wheel slip to minimise fuel consumptions in all conditions. No operator input required. Minimises operator fatigue.	Fitted as part of the machine and available in later model tractors. While there are no retro-fit kits available, it is sometimes possible to 're-chip' a tractor to upgrade performance.	Inherent in the cost of new or late model tractors.	Contact your local machinery dealer.		
Precision Sprayers	Cropping, Cotton, Beef, Horticulture, Sheep, Viticulture	Fallow herbicide spray.	Significant reductions in chemical use: - both manufactures producing grower testimonials of 50% to 90% reduction in fallow herbicide use. ** One litre of herbicide will embody the equivalent of 7 to 30 litres of diesel. ** Reduction in fuel use, through decreased number of tank refills, in the order of 10 to 15%. Similarly, time savings are in the order of 10% to 20%, which allows for timelier weed control. Possible to retro-fit to an existing boom. Possible to have a 100% coverage spray system on the same spray with the same major components to apply in-season sprays.	Suitable for fallow spraying. Sensors analyse light reflected from plants to detect a weed and activate the sprayer. Manual calibration required for the *Weedseeker* and not for *WeedIt*. High time cost for initial set up with little on-going maintenance costs.	Approximately $4,000 to $4,500 per meter of boom to retro-fit an existing boom. Approximately $230,000 to $250,000 for a new, entire spray unit fitted with precision sprayers.	http://www.weedit.com.au/index.php http://www.cropoptics.com.au/weedseeker.html	http://www.weedit.com.au/index.php http://www.cropoptics.com.au/weedseeker.html	precision spraying, chemical spraying

Tech-nology	Typical Industry	Typical Application	Benefits	Critical Factors	Cost	More details	Source	Keywords
Precision Agriculture (PA)	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	GPS guidanceVRT chemical and fertilizer applicationYield mappingGIS mapping systemsYields potential predictive models	Benefits from VRT fertilizer application $1 to $22 per hectare per year.Benefits from reduced overlap on spraying typically 10% of spray costs.Reduced overlap at planting providing a more consistent plant cover.Reduced traffic associated with tramlining to reduce compaction.Reduced operator fatigue.Shielded spraying of pesticides in row crops.Production of yield maps.Supports within-paddock zone management for agricultural operations.Less fuel use. Less soil compaction.Lower labour requirements.Timelier sowing.The ability to conduct on-farm trials.Increased knowledge of in-paddock variability.Increased confidence in varying fertilizer rates.Better in-crop weed control.	Benefits from VRT fertilizer application explained by (1) weather or not starter fertilizer was being varied and not just nitrogen topdressing fertilizer, and (2) the degree of within-paddock variation.Literacy in using computers, GPS technology and VRT controllers.Routine soil testing.Good farm records.Considerable time investment (and teething problems) in initial system establishment.Minimal on-going labour demands.Consultants are generally locally available and offer considerable support.	$14 to $44 per hectare or $17,500- $75,000 depending on level of modifications.Payback period for PA technology 2 to 5 years and generally within 2 to 3 years.	The economic benefits of precision agriculture: case studies from Australian grain farms. M Robertson, P Carberry, L Brennan - Report to GRDC. CSIRO, Perth, 2007 - grdc.com.auISSN: 1883-4563Precision Agriculture - opportunities, benefits and pitfalls of site-specific crop management in Australia.S. E. Cook and R. G. V. BramleyAustralian Journal of Experimental Agriculture Vol. 38. CSIRO 1998	http://www.spaa.com.au/pdf/5721_pa_in_practice_final.pdf http://www.grdc.com.au/pamanual/ http://www.kondiningroup.com.au/web_files/RR_SEP-2011.pdf http://www.grdc.com.au/uploads/documents/Economics%20of%20Precision%20agriculture%20Report%20to%20GRDC%20final.pdf http://www.publish.csiro.au/?act=view_file&file_id=EA97156.pdf http://www.liebegroup.org.au/wp-content/uploads/2012/09/Frameworks-For-Forward-Farming-reduced-version.pdf	Precision Agriculture, (PA), GPS guidance, VRT chemical application, VRT fertilizer application, Yield map, GIS mapping, predictive model, grain, dryland, broad acre, variable rate technology

Tech-nology	Typical Industry	Typical Application	Benefits	Critical Factors	Cost	More details	Source	Keywords
VRT fertilizer	Cropping, Cotton, Horticulture, Viticulture	Fertilizer application	Benefits from VRT fertilizer application $1 to $22 per hectare per year. Benefits are variable depending on previous approach to fertilisers and soils/yield variability on farm and within paddocks. The benefit of VRT increases as the level of variability in soil type increases.	Requires yield mapping, a map of intended fertilizer application, a fertilizer rate controller and a GPS system. VRT adds a level of complexity to farming that requires further training and computer literacy. There are always teething problems that need to be worked through. Collaboration with equipment suppliers and industry specialists is recommended to reduce technology risk and achieve maximum benefit from the investment. Once established, little on-going maintenance is required.	$14 to $44 per hectare or $17,500- $75,000 depending on level of modifications	The economic benefits of precision agriculture: case studies from Australian grain farms. M Robertson, P Carberry, L Brennan - Report to GRDC. CSIRO, Perth, 2007 - grdc.com.au ISSN: 1883-4563 Precision Agriculture - opportunities, benefits and pitfalls of site-specific crop management in Australia. S. E. Cook and R. G. V. Bramley Australian Journal of Experimental Agriculture Vol. 38. CSIRO 1998	http://www.grdc.com.au/uploads/documents/Economics%20of%20Precision%20agriculture%20Report%20to%20GRDC%20final.pdf http://www.publish.csiro.au/?act=view_file&file_id=EA97156.pdf http://www.grdc.com.au/uploads/documents/GRDC_ImpAss_PrecisionAgricultureAnalysis.pdf	Precision Agriculture, (PA), GPS guidance, VRT fertilizer application, Yield map, GIS mapping, grain, dryland, broad acre, variable rate technology, Variable rate, Fertiliser
Autosteer	Cropping, Cotton, Horticulture, Viticulture	Machinery control for grain and pasture	Variable, however, typically 8-15% reduction in inputs due to reduced overlap	Nature and size of paddocks, size of operation and utilisation affect benefits. It may be possible upgrade to a new tractor with the auto-steer technology.Auto-steer increases the effectiveness of labour as it reduces operator fatigue	$10,000-$32,000 per vehicle	Auto-steer uses GPS signals to automatically control the tractor in seeding, spraying, fertiliser application and harvesting. Some tractor come standard with auto-steer now, however, many aftermarket kits are available for conversion.	The use of auto-steer is typically wrapped up in research publications around precision agriculture as it is the first step in pursuing tramlining or VRT type technologies. As a result the resources on tramlining and VRT contain significant amounts of information on auto-steer	Auto-steer, Reduced inputs, GPS

Tech-nology	Typical Industry	Typical Application	Benefits	Critical Factors	Cost	More details	Source	Keywords
Tramlining	Cropping, Cotton, Horticulture, Viticulture	Grain and pasture traffic control	Variable depending on technology used (conservative estimate of around 5% saving from less overlap, and around 10% benefits from yield increase.)	The accuracy of the GPS system as well as the type of tramlining guidance system (i.e. simple mechanical, video, GPS) both affect the final accuracy of the equipment. The nature of the soil, especially those pre-disposed to compaction will greatly benefit from tramlining. May require vehicle track modification to maximise benefits of new guidance systems, which is usually a matter of adjusting wheel spacing.	$600 - $32,000 per vehicle. This depends on the type and quality of guidance system.	Tramline farming involves the setting up of predefined 'tracks' that all machinery travels on during seeding, fertiliser and chemical application and harvesting. Tramlining improves efficiency by confining compaction to permanent tramlines and reducing overlap. In addition to these benefits significant reductions in fuel consumption are achieved because of greater traction on the tramline.	http://www.agric.wa.gov.au/objtwr/imported_assets/content/lwe/land/cult/bulletin4607_complete.pdf http://www.liebegroup.org.au/wp-content/uploads/2012/03/Adoption-Improvement-Package-booklet.pdf	Tramlining, Controlled traffic, Precision agriculture,
LPG and CNG	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	tractors, trucks, light vehicles, pumping	Reduced GHG emissions of 71.5 to 74.7 grams of CO2-e per tonne.kilometer [g CO2-e/t km] compared to 81.2 for Ultra-Low Sulphur (ULS) diesel.	cost and availability	Contact your local fuel distributer for pricing and availability	Fuel-cycle greenhouse gas emissions from alternative fuels in Australian heavy vehicles.Tom Beer, Tim Grant, David Williams, Harry Watson.Energy Transformed Flagship, Division of Marine and Atmospheric Research, Centre for Australian Weather and Climate Research, CSIRO, PB1, Aspendale VIC 3125, Australia	http://www.sciencedirect.com/science/article/pii/S1352231001005143	Alternative fuels, Greenhouse gas emissions, Life-cycle, Heavy vehicles, Australian emissions, Tractors, Trucks, light Vehicles, Liquid Petroleum Gas, LPG, Compressed Natural Gas, CNG, Alternative fuel
Other Biodiesels	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	tractors, trucks, light vehicles, pumping	Energy sourced from tallows and waste cooking oil. Offers reduced GHG emissions.	Cost and availability. There are five large biodiesel plants in Australia. One of which is at Picton, WA, which produces around 45 ML of biodiesel p.a., which is around one quarter of Australia's total production.	Normally sold through the bowser as B20 or similar blends. Contact your local fuel distributer for price and availability.	http://www.arfuels.com.au/biodiesel.asp	http://www.biofuelsassociation.com.au/index.php?option=com_content&view=article&id=59&Itemid=67	biodiesel

Tech-nology	Typical Industry	Typical Application	Benefits	Critical Factors	Cost	More details	Source	Keywords
Renewable energy	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Information source	Various	Various	Various	Australia's Renewable Energy Future Australian Academy of Science. ISBN 085847 280 5	http://www.science.org.au/reports/documents/AusRenewableEnergyFuture.pdf	renewable energy, wind turbines, solar thermal, solar photovoltaic, biomass, fuel cells, geothermal, wave, tidal, energy
Solar Voltaic	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Pumping, electrical power generation	Renewable and clean with little emissions. A very reliable system (no moving parts). Particularly suitable for remote locations where diesel generators may cost 50c/kWh.	Still relatively expensive compared with fossil energy. Produces power intermittently. Performance is location dependent, although most areas in WA are suitable. More suitable for low power requirement applications	8.5¢ to 35¢/kWh Costs are rapidly decreasing.	http://www.solarchoice.net.au/blog/category/solar-and-renewables-policy/feed-in-tariff/wa-western-australia/	Chen, G., Sandell, G., Yusaf, T., Baillie, C., (2012), Evaluation of Alternative Energy Sources for Cotton Production in Australia National Centre for Engineering in Agriculture Publication 1004527, USQ, Toowoomba.	Solar, solar voltaic
Biomass	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Renewable with low carbon emissions.	Biomass as an energy source involves two different methods: burning vegetative material and burning biogas (methane) produced by the breakdown of organic matter.	Difficult to compete the low cost of fossil fuels, specifically coal. Need to develop an efficient harvesting and transport technology. Location dependent.	$8-15 /GJ for wood or sugarcane bagasse (cane stalks).	http://www.adelaide.edu.au/biogas/	Chen, G., Sandell, G., Yusaf, T., Baillie, C., (2012), Evaluation of Alternative Energy Sources for Cotton Production in Australia National Centre for Engineering in Agriculture Publication 1004527, USQ, Toowoomba.	piggeries, chickens, intensive livestock, abattoir, slaughter house, flour milling, heating
Vehicle Selection	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Light vehicle	Reduced energy consumption through selection of more fuel efficient and more appropriate light vehicles.	Vehicle type and number needs to be matched to duty. Consider fuel consumption: a Landcruiser workmate consumes 11.9 L/100 km whereas an Isuzu Dmax consumes 8.0 L/100 km. Consider the use of a large ATV in place of a vehicle. Consider having two-wheel drive vehicles that complete the majority of work and a four-wheel drive to use at specific times. Consider if registration is required for all vehicles.	Costs are incurred purchase of capital equipment, which are offset by the sale of old capital and possibly a reduction in total capital. Savings are obtained through more fuel efficient vehicles, less vehicles and possibly reduced registration.	http://www.redbook.com.au/	Sandell G.R., Szabo P.M., Baillie C.P., Woodhouse N.P. and Schmidt E., (2013). North-East Farming Futures R&D Support: Increasing the knowledge and adoption of energy saving initiatives amongst farming enterprises in Western Australia. National Centre for Engineering in Agriculture, Publication 1005089/1, USQ, Toowoomba.	light vehicle, fuel efficiency, green star rating, engine capacity

Tech-nology	Typical Industry	Typical Application	Benefits	Critical Factors	Cost	More details	Source	Keywords
Electrical time clock	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	pumping, HVAC	Reduced cost of electricity by using lower tariff electricity.	An electrical time clock (either mechanical or digital) is installed into the pump (or other electrical item) power supply circuit. The timer is then set to only pump during off-peak times. If it is not possible to pump the required amount of water during off-peak times alone, this system can at least reduce the total pumping during an on-peak tariff.	The cost of supply and installation of an electrical time clock is minor.	Reliability can be an issue	Sandell G.R., Szabo P.M., Baillie C.P., Woodhouse N.P. and Schmidt E., (2013). North-East Farming Futures R&D Support: Increasing the knowledge and adoption of energy saving initiatives amongst farming enterprises in Western Australia. National Centre for Engineering in Agriculture, Publication 1005089/1, USQ, Toowoomba.	pumping, tariff, electrical, time clock
Legume rotation	Cropping, Cotton, Horticulture	Production diversification and altering input requirements	Amount of Nitrogen added in the following year is often reduced. Generally an increase in wheat yield in the following year without extra nitrogen addition (up to 24% in the first year and 10% in the second year). Energy inputs from 38% lower (for a rotation with a low N-benefit legume) to 63% lower (a high N-benefit legume rotation) per hectare per year, compared with no-till wheat. This translates to 25 and 40% savings per tonne produced each year, which could be improved using a high N-benefit legume that produces a crop. In a 1:1 canola rotation with wheat, using 10% of the canola for biodiesel can save approximately 20% of total energy input, while combining biodiesel production and legume rotations can achieve energy savings upwards of 70%.	This needs to fit into the rotation strategy of the entire farm, especially in regards to weed and pest management. Cultivation practices may change depending on the crop.	Possible adoption costs for new equipment or loss in harvested wheat.	The use of field peas and chick peas can be used as a replacement for lupins as a rotation crop in wheat. This rotation fixes nitrogen which can improve yield by 24% in the first year, and 10% in the second year, while also improving protein by 1% and assisting in weed and pest control	www.liebegroup.org.au/wp-content/uploads/2012/01/Growing-field-Peas-and-chickpeas-in-low-rainfall-zones.pdf http://www.liebegroup.org.au/wp-content/uploads/2012/08/fwff3.pdf Farine, D. R., O'Connell, D. A., Grant, T., Poole, M. L., (2010). *Opportunities for energy efficiency and biofuel production in Australian wheat farming systems.* Biofuels.1, 547-561, 10.4155/bfs.10.29. http://www.future-science.com/doi/pdf/10.4155/bfs.10.29	Nitrogen fixing, Crop rotation, Fertiliser, Field pea
Farm fuel calculator	Cropping, Cotton, Horticulture, Viticulture	Allows for the comparison of fuel use for various farming practices.	Useful when considering new farming practices	Some knowledge of computers is required.	Free download	The calculator is available on request from RIRDC.	https://rirdc.infoservices.com.au/downloads/10-180.pdf	fuel efficiency, calculator, planting, hay, harvest, transport

Tech-nology	Typical Industry	Typical Application	Benefits	Critical Factors	Cost	More details	Source	Keywords
Harrington seed destructor	Cropping	harvest	Future energy saved in managing herbicide resistance.Benefits increase with precision spraying as more weeds are destroyed.Depending upon a farms weed control practices, diesel for spraying operations may be decreased by around 0.75 litres per hectare.	Trash from the harvester is milled by 3 rows of 2 counter rotating cages and spread out evenly to the paddock. Trials have shown a 95% weed seed destruction of seed entering the harvester.Machine tows behind harvester and has its own diesel engine.Modification to the trash chutes required.	$150 000 plus $3 per hectare	http://www.ahri.uwa.edu.au/files/files/542_Walsh_et_al_2012_HSD.pdf	http://www.debruinengineering.com.au/content_common/pc-harringtonseeddestructor.seo	harvester, weeds, herbicide resistance
Alternative electricity tariff	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture, Residential	Electrical tariff	It might be possible to reduce the cost of electricity by switching to a better tariff.	**Applicable to non-contestable customers, those using <u>less</u> than 50 MWh (approx. $11,000) per year.**	No cost to change tariffs. Exercise caution before changing tariffs as sometime it is not possible to change back to your original tariff.	Customers with three phase power are required to use the R1 tariff (or an alternate and more expensive M1 tariff). Farms that use less than 50 MWh per year are only able to select regulated tariffs from Synergy.	http://www.synergy.net.au/docs/Standard_Electricity_Prices_Charges_brochure_MSF.pdf	electrical tariff
		A1 tariff	Lowest cost tariff unless off-peak usage is very high	Only available for residential customers. (If farms are on this tariff, it is suggested they stay on until asked to change as it is generally cheaper than both K1 and L1)				
		Smart Power tariff	Lower cost of power during some shoulders and off-peak times	Meter installation cost ($176-276). Large penalties for on-peak consumption. Increased management required.				
		K1 tariff	Cheaper than the L1 tariff due to the first 20 units being charged at the A1 tariff rate	More expensive then A1. No benefit for off-peak usage.				
		L1 tariff	Only an option if it is a straight business. It is slightly cheaper than R1 if all the power consumption occurs during the day.	More expensive then K1 tariff				
		R1 tariff	Significant rewards for reduced on-peak consumption and high off-peak consumption.	Beneficial when off-peak power is greater than 30% of supply. High meter install cost ($810 per installation fee for time of use meter), and higher peak costs. Tariff cannot be changed for 12 months.				
Domestic power consumption	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture, Residential	domestic electrical consumption	Domestic power consumption will reduce your non-tax deductable and direct expense and any savings will improve net farm income and reduce GHG emissions.	Dependent on individual circumstances	Generally low cost - low return. Actual cost is variable depending on exact application.	http://reg.energyrating.gov.au/comparator/product_types/35/search/	http://reg.energyrating.gov.au/comparator/product_types/35/search/	domestic electrical consumption

Tech-nology	Typical Industry	Typical Application	Benefits	Critical Factors	Cost	More details	Source	Keywords
Stand-by power killers	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture, Residential	domestic electrical consumption	Reduction in electrical cost by turning off household and office devices while in standby mode.	Low cost, simple to install.	$20 to $80	Many types of standby power reduction devices are available and include remote control and foot operated devices. One example is included here.	http://techstyles.com.au/belkin-conserve-range-standby-power-killers/gadgets/	domestic electrical consumption
Replace Desktop Computers with Laptop Computers	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture, Residential	domestic electrical consumption	Reduces power consumption by up to 80%	The cost of a laptop with the same processing power as a desktop can be slightly more	Dependant on the type of laptop required.	It is best done at the next upgrade of equipment.	http://www.eu-energystar.org/en/en_022.shtml	domestic electrical consumption, computer, laptop
Insulation of residential and commercial buildings	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture, Residential	domestic electrical consumption	Reduce heating and cooling energy consumption by 45-55%	Must be installed by insulation specialist.	The cost is dependent on the size of the build, see Insulation Australia link for quotes	Varying types of insulation can be used.	http://www.insulationaustralia.com.au/get-a-quote/diy-quote-calculator/ http://www.sustainability.vic.gov.au/resources/documents/insulation_benefits.pdf	insulation, buildings
LED Lights	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture, Residential	domestic electrical consumption	Reduce electricity consumption by 90%	LED are around twice the price of CFL bulbs but have around five times the life.	$18-20 per blub	Most bulbs can be purchased from a retailer and changed like any normal light bulb.	http://www.nextgenled.com.au/uploads/Comparison_chart_LED_INC_CFL.pdf	lights, incandescent, LED, CFL
Snorkel	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Light Vehicle	Up to 12% increase in fuel efficiency	Cleanliness of air filter. All joints must be sealed. Pre-filter maybe installed in dusty conditions	$600-$800	Moves air intake from wheel arch to a higher position free from dust and debris and cooler temperatures. Increases the ramming effect of the air.	http://www.safarisnorkel.com/docs/product.htm	Snorkel, Ram Air, Density

Tech-nology	Typical Industry	Typical Application	Benefits	Critical Factors	Cost	More details	Source	Keywords
Turbo Charger Intercooler	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Trucks / Tractors / Light Vehicles	Up to 10% increase in fuel efficiency	Engine mileage and condition. Requires mechanic / dyno run. Between efficiency and power. Using the extra power can negate the fuel efficiency	$4,000	Turbo charger provides a greater density of air while the intercooler cools the charged air. This process allows more air into the combustion chamber for increase power torque and fuel efficiency	http://www.turbotech.com.au/index.ews	Turbo charger, Intercooler, power, torque Fuel Efficiency
Exhaust Upgrade	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Light Vehicle	Up to 10% increase in fuel efficiency	Cleanliness of air filter / fuel quality / injector condition. Requires dyno run to optimise fuel settings	$1000-$1200	Removes restriction from exhaust system. Allows gases to expel quickly	http://papers.sae.org/810858/	Exhaust, Mandrel Bent, Extractors
High Flow Air Filters	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Light Vehicle	Up to 12% increase in fuel efficiency	Fuel quality / Injector Condition. Must be cleaned every 10,000km	$100-$200	Allows a high volume of clean fresh air into the engine	http://knfilters.com.au/	Air Filters, High Flow, Intake,
ECU Chips	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Light Vehicle	Up to 12% increase in fuel efficiency	Engine mileage and condition. Requires mechanic / dyno run. Some may void manufactures new car warranty. Some allow for re-mapping on the go. Between efficiency and power. Using the extra power can negate the fuel efficiency.	$1000 - $2000	Alters the fuel mapping of the ECU	http://www.dieselcare.com.au/steinbauer-power-module	ECU, chip, fuel
Fuel Additives	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Light Vehicle	Up to 5% increase in fuel efficiency	Quality of diesel/condition of injectors. Must be measured and add to every tank fill	$30-$40/ 1000L diesel	Conditions the fuel and reduces carbon deposits on the injectors	http://www.chemtech.net.au/Diesel%20Power%20Features%20&%20Benefits%20NOV09.pdf	Fuel Additives, Chemicals, Contamination, Quality
Increase Tyre Size	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Tractors	Up to 30% increase in fuel efficiency	Change in tyre size changes gearing.	Contact your local tyre retailer for pricing.	Increase tyre foot print	http://uk.efficient20.eu/2011/10/26/tyres-can-make-a-big-impact-on-fuel-usage/	Tyre, Size, Foot Print

Tech-nology	Typical Industry	Typical Application	Benefits	Critical Factors	Cost	More details	Source	Keywords
Automatic Tyre Inflation	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Light Vehicles / Trucks	Up to 15% increase in fuel efficiency	Tyre pressures need to be changed for various processes. Low pressures can cause tyres to roll off the bead.	nil	An in cab device can set tyre pressures to the required level.	https://docs.google.com/file/d/0B100XSl3uhsFeWhCOGNnNEtwWjA/edit?pli=1	Tyre, Pressure, Inflation, Deflation, Foot Print
Lower Rolling Resistant Tyres	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Light Vehicles / Trucks	Up to 5% increase in fuel efficiency	The price of the tyre may negate any fuel savings on small vehicles. Better suited to multiple axle vehicles	Dependant on vehicle	Reduces the heat build-up in the tyres.	http://www.bridgestone.com.au/tyres/premium/ecopia.aspx	Tyre, Rolling Resists
LPG-diesel injection	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Tractor / Truck / Light Vehicle	Saving of 15% from total fuel bill	Must be installed by diesel gas specialist	$4,000 to $8,000 depending on vehicle and travel requirements	Provides better combust and less GHG's. Does require specialist installation.	http://dieselgas.com.au/ http://www.dpi.nsw.gov.au/archive/agriculture-today-stories/may-2012/diesel-to-gas-conversions-cut-pump-	Diesel, Gas, LPG
Biodiesel	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Tractor / Truck / Light Vehicle	Reduces GHG	There is 8% less energy in biodiesel. This can result in 1-2% reduction in power, torque and fuel efficiency.	The cost of biodiesel (B100) depends on price of the crop used to produce the biodiesel. It is independent of the price of crude oil.	Produced from a renewable source.	http://www.bluediesel.com.au/downloads/Biodiesel-MythsandFacts.pdf	Biodiesel, diesel, Biofuel
Solar Pumps	Cotton, Feedlot, Horticulture, Viticulture	Pumps	Reduces reliance from the grid	Pump still requires a connection to the grid for operation at night. Alternatively, batteries can be connected.	Dependent on requirements. Contact your local distributer for pricing.	A solar operated pump has the ability to operate on or off the grid.	http://www.energymatters.com.au/renewable-energy/solar-power/pumping/	Solar, Pump, Water
Solar panels	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture, Residential	Electricity Production	Reduce reliance on electricity from the grid	Electricity is only generated during daylight hours. It is best to determine the capacity required to meet day time usage and install a system to suit.	Dependant on system size	There are many companies selling solar panels it is important to buy a quality panel. As the efficiency of an inferior panel can reduce rapidly.	http://www.energymatters.com.au/renewable-energy/solar-power/	Solar, Panel, Electricity, Generation, Grid

Tech-nology	Typical Industry	Typical Application	Benefits	Critical Factors	Cost	More details	Source	Keywords
Aerodyna-mics	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Trucks	Up to 15% increase in fuel efficiency	A load that protrudes out into the air flow will increase the drag on a vehicle.	Depends on your exact requirements. Contact a reputable truck supplier for detailed pricing.	Light weight aerodynamic components and load structure has an effect on reducing aerodynamic drag.	http://eex.gov.au/resource/potential-energy-efficiency-opportunities-in-the-australian-road-and-rail-sectors/improved-vehicle-aerodynamics/	Drag, vehicle, air, flow
Lifting Axles	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Trucks	Up to 1.8% increase in fuel efficiency	Axles are lifted when empty so that only one rear axle remains on the ground. The system will need to be installed by qualified personal.	Dependent on vehicle type. Contact your local supplier for exact pricing.	By lifting an axle the drag is reduced on the truck plus it reduces the wear and tear on the axle.	http://www.rta.nsw.gov.au/heavyvehicles/downloads/greentruck/case-study-lift-axles.pdf	Lift, Axle, Truck, Drag, Tyre
Air Conditionin g APU at idle	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Trucks	Up to 8% increase in fuel efficiency	A system is installed that does not require the engine running yet keeps the air conditioning operating.	Dependent on vehicle type. Contact your local supplier for exact pricing.	An APU will need to be installed plus associated hardware.	http://www.cggc.duke.edu/environment/climatesolutions/greeneconomy_Ch3_AuxiliaryPowerUnits.pdf	Air Conditioning, Auxiliary Power Unit, Idle, Truck, Tractor
Sustainable Trucking Best Practice Guide	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Trucks	Reduce fuel consumption	The drive needs to be aware of the best practices	Minimal cost as it is providing awareness	Certain parameters of the equipment and driver can be check to ensure maximum fuel efficiency	http://www.atatruck.net.au/industry-resources/environmental-best-practice-guide	trucks, driver
Algae biodiesel	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	Alternative fuel, tractors, trucks, light vehicles, pumping	Reduced GHG emissions of −27.6 to 18.2 grams of CO2-e per tonne.kilometer [g CO2-e/t km] compared to 81.2 for Ultra-Low Sulphur (ULS) diesel	cost and availability	2.2 to 4.8 cents per tonne.kilometer [¢/t km] compared to 3.8 [¢/t km] for ULS diesel	Life cycle assessment of biodiesel production from microalgae in ponds. Peter K. Campbell, Tom Beer, David Batten Energy Transformed Flagship, Division of Marine and Atmospheric Research, Centre for Australian Weather and Climate Research, CSIRO, PB1, Aspendale VIC 3125, Australia	http://www.sciencedirect.com/science/article/pii/S0960852410010291	Life cycle assessment, Algae, Greenhouse gas, Biofuels, Biodiesel, Alternative fuel

Tech-nology	Typical Industry	Typical Application	Benefits	Critical Factors	Cost	More details	Source	Keywords
Canola biodiesel	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	tractors, trucks, light vehicles, pumping	Reduced GHG emissions of 35.9 grams of CO2-e per tonne.kilometer [g CO2-e/t km] compared to 81.2 for Ultra-Low Sulphur (ULS) diesel.	cost and availability	4.2 cents per tonne.kilometer [¢/t km] compared to 3.8 [¢/t km] for ULS diesel	Life cycle assessment of biodiesel production from microalgae in ponds. Peter K. Campbell, Tom Beer, David Batten Energy Transformed Flagship, Division of Marine and Atmospheric Research, Centre for Australian Weather and Climate Research, CSIRO, PB1, Aspendale VIC 3125, Australia	http://www.sciencedirect.com/science/article/pii/S0960852410010291	Life cycle assessment, Algae, Greenhouse gas, Biofuels, Biodiesel, Canola, Alternative fuel
Ethanol fuels	Cropping, Cotton, Beef, Feedlot, Horticulture, Sheep, Viticulture	tractors, trucks, light vehicles, pumping	Reduced GHG emissions of 39.7 to 44.7 grams of CO2-e per tonne.kilometer [g CO2-e/t km] compared to 81.2 for Ultra-Low Sulphur (ULS) diesel.	Cost and availability. There are three large ethanol plants in Australia, which are all on the Eastern seaboard - Sarina Qld., Dalby Qld., Manildra, NSW.	Contact your local fuel distributer for pricing and availability	Fuel-cycle greenhouse gas emissions from alternative fuels in Australian heavy vehicles. Tom Beer, Tim Grant, David Williams, Harry Watson. Energy Transformed Flagship, Division of Marine and Atmospheric Research, Centre for Australian Weather and Climate Research, CSIRO, PB1, Aspendale VIC 3125, Australia	http://www.sciencedirect.com/science/article/pii/S1352231001005143	Alternative fuels, Greenhouse gas emissions, Life-cycle, Heavy vehicles, Australian emissions, Tractors, Trucks, light Vehicles, ethanol, Alternative fuel

Appendix C: Scoping study

National Centre for Engineering in Agriculture

University of Southern Queensland

Toowoomba

Evaluation of Alternative Energy Sources for Cotton Production in Australia

NCEA Project 1004527

Principal Investigator: Guangnan Chen

Co-investigators: Gary Sandell, Talal Yusaf, Craig Baillie

Final Report for the

Cotton Research and Development Corporation

November 2012

Disclaimer

Published in November 2012 by the National Centre for Engineering in Agriculture, Toowoomba.

This document should be cited as follows:

Chen, G., Sandell, G., Yusaf, T., Baillie, C., (2012), Evaluation of Alternative Energy Sources for Cotton Production in Australia, National Centre for Engineering in Agriculture Publication 1004527, USQ, Toowoomba.

Acknowledgments

This project was funded by the Cotton Research and Development Corporation

University of Southern Queensland

Executive Summary

Agriculture requires energy as an important input. In Australia, to produce 1 bale (227kg) of cotton, it is estimated that up to 11.4 gigajoule (GJ) of primary energy (equivalent to 300 L of fuel) may be required and 900 kg of greenhouse gases emitted in its life cycle from farm gate to export shipping port. Among them, direct on-farm diesel energy consumption ranges from 95 to 365 litres/ha, depending on farming and irrigation practices.

The potential of traditional and alternative energy supply for agriculture and cotton production in Australia is evaluated in this report. The current average prices per GJ of energy are estimated and ranked as (see also Appendix 1): grid electricity ($40), coal ($10), petrol ($40), diesel ($40), LPG ($27), natural gas ($13), CNG ($10), LNG($20), solar photovoltaic ($24-97), wind power ($20), biomass ($10-15), ethanol ($32-36), biodiesel ($25-41), hydro power ($20), and geothermal energy ($14-16.5). These energy sources have also very different intensities of greenhouse gas emissions, ranging from close to zero emission for renewable energy, to 51.3 kg CO_2–e/GJ for natural gas, 69 CO_2–e/GJ for petrol or diesel, and 244 kg CO_2–e/GJ for grid electricity. At present, 1 tonne of CO_2 is $23 in Australia. It is also noted that although the retail prices of grid electricity and diesel are both around $40/GJ, when applied for pumping operations, the efficiency of electric motors is generally much higher (typically around 90%) than that of diesel engine (30-35%).

In 2009, 78% of the electricity generated in Australia was produced from coal, 14% from natural gas, 4.7% from hydro. The supply of oil in Australia is on the decline and Australia is currently less than 50% self-sufficient in oil and petroleum products. Natural gas use is increasing rapidly and is identified as one of the most important alternative energy sources in the future. Its price for per unit of energy is only about one third of petrol, diesel and electricity. It also has significant environmental benefits over both coal and oil in terms of lower greenhouse gas and other emissions. When sourced from local gas supplies, the cost of compressed natural gas (CNG) could be as low as 30% of the cost of diesel, and 50% of the cost of LNG.

Renewable energy is an important direction for the future. At the present, the viability of renewable energy may be subject to uncertainty in the government policies. However, the long-term future for renewable energy will be positive, since the prices of fossil fuels will continue to rise as the resources are depleted, while the prices of renewable energy will continue to decrease. This may be demonstrated by the examples that the electricity price in Australia has been increasing at a rate of 10 to 20% per annum in the last couples of years, while the price of solar PV has been steadily decreasing at a rate of over 10% per annum in the same period of time.

It has been found that in the cotton growing regions of Australia, the preferred alternative energy sources may be solar and bioenergy, rather than wind energy. The following table shows the suitability of selected energy sources for different cotton production regions in Australia.

Agriculture can also contribute to energy security, farming incomes and carbon sequestration through the production of biofuels and bioenergy. For cotton, this may be achieved through the effective utilisation of cotton by-products. Although the oil content of cottonseed is relatively low at 19%, it is estimated that it has the potential to produce up to 100 ML of cottonseed biodiesel per year or 500 L per ha or up to about 3 times the cotton direct on-farm fuel demand. The annual ethanol and methane biogas production via fermentation or digester bioconversion of cotton stalk waste is also calculated as up to 80 ML ethanol or 30 million m^3 methane biogas, containing 12 PJ of primary energy. The

drying energy demand of cotton ginning operation can be largely provided by the combustion energy of gin trash which is readily available at the ginning sites, avoiding the current reliance on LPG or natural gas.

	Northern Region (Emerald and Dawson-Callide districts)	**Central Border Region (Macintyre Valley, Darling Downs, St George-Dirranbandi, Namoi Valley and Gwydir Valley)**	**Southern Inland Region (Macquarie Valley, Bourke and Southern NSW)**
Solar	High	High	High
Wind	Low	Low	Low
Ethanol	High	High	High
Biodiesel	High	High	High
CNG	Excellent	High	Fair
LPG	Widely available	Widely available	Widely available

There are already a good number of successful examples of application of alternative energy sources in the cotton industry, including the use of biodiesel and LPG for water pumping operations. To use these alternative fuels, some machinery modifications may be necessary. Current research is focused on the conversion technology for diesel engine to use these energy sources, particularly the design of vehicle fuel and tank systems. Further research is also required on the methods of collection, storage and conversion of cotton stalks and other by-products for energy production.

	Potential available energy	**Potential contribution to direct on-farm energy demand**	**Potential contribution to life cycle primary energy demand**
Biodiesel from cottonseed	500 L/ha	1.5 to 5 times (average may be around 3 times)	20 to 45% (average may be 30 to 35%)
Ethanol or methane biogas produced from cotton stalks and other by-products	500 L/ha ethanol or alternatively 300 m^3 or 200 kg/ha methane biogas		10 to 20%
Energy from direct combustion of gin trash for cotton drying	200-300 MJ/bale or 2-3 GJ/ha or $50 to 75/ha to replace LPG, or $25 to 35/ha to replace natural gas	1 to 3 times of cotton drying energy need, depending on moisture removal (average may be around 3 times)	2 to 5%

The purpose of this report is to introduce the basics of energy and renewable energy. The uses of traditional energy and alternative energy in agriculture, and their impacts on agricultural production and environment are evaluated. Specific applicability of alternate energy sources in cotton production is explored. Future research and development in the alternate energy sources is also identified and discussed.

1. Farming and Energy

Farming is often an energy intensive operation. Within highly mechanised agricultural productions systems such as the Australian cropping industry, energy inputs represent a significant cost to growers (20% to 50% of total operating cost). In agriculture, some heavy tractors or harvesters may use up to one litre of fuel per minute. The cost of nitrogen fertiliser is also mostly a reflection of energy costs. In the United States, it has been found that the operations of food systems, including agricultural production, food processing, packaging, and distribution, accounted for approximately 19% of America's national fossil fuel energy use (Pimentel, 2006). In another study, it was estimated that in the United States, about 1,500 litres of oil equivalents are expended annually to feed each American (as of data provided in 1994).

The increasing uses of energy resources are one of the major challenges to agriculture. Continuous high fuel price, the needs for "green food" and significant reductions in greenhouse gas emissions make the improvement of farming energy efficiency essential. Exploration of new alternative and renewable energy sources is also essential.

2. Energy Uses in Agriculture

Agriculture and food systems play an important role in fossil fuel consumption and climate change because of both their significant energy use and agriculture's potential to serve as a sink for the negative externalities of energy use and a possible source for renewable energy.

Energy can be broadly defined as the capacity to do work. The energy consumed in agriculture consists of all direct and indirect energy used on the farm. Direct energy includes electricity, heating fuel and machinery fuel used in crop production, irrigation and transportation. Indirect energy consists of the energy used in the manufacture, packaging and transport of fertilizers, pesticides, and farm machinery. Some studies have also included the energy used in farm buildings, machinery repairs, manpower and animal power, of which the contribution may be relatively small.

3. Energy Sources for Agriculture

Agriculture and food systems rely on a variety of energy sources, including renewable and non-renewable resources, such as fossil fuels as well as human and animal labour (Table 1). At present, fossil fuels, in the various forms, supply most of the energy required by the mechanized agriculture that feeds the world.

The name "fossil fuel" applies to solid, liquid, and gas fuels that are the products of the decomposition of ancient plants and animals. These include coal, petroleum (or fuel oil), natural gas, and more recently the coal seam gas (CSG) and its derivatives such as liquefied natural gas (LNG) and compressed natural gas (CNG). Overall, liquid and gaseous forms derived from petroleum deposits are convenient for compact, portable applications. In comparison, mineral forms (primarily coal)

require more bulky conversion equipment and therefore are better suited to transformation into electricity for distribution by wire to stationary uses.

Table 1: Classifications of Energy Sources

Limited (Non-renewable)	Unlimited (Renewable)	Biological renewables
Oil	Solar	Wood
Coal	Wind	Energy crops
Natural gas	Hydropower	Biomass fermentation (ethanol)
Liquefied petroleum gas (LPG)	Tidal and wave energy	Bio-diesel
CSG (LNG, CNG)	Geothermal	Biogas (Anaerobic digestion)
Nuclear power (Uranium)		Animal and human power

Fossil fuels have been the primary energy source of civilization for about one century, and they will continue to be the primary energy source for the foreseeable future. However, fossil fuels are a limited resource and the world will be experiencing peak oil if no significant new fields are found and developed (Fig.1). CSIRO modelling (CSIRO, 2008) showed that a slow response to a peak event may lead to fuel prices of up to $8 per litre in Australia by 2018.This is not unthinkable, as we have witnessed that the world oil price increased from $20 to $30 USD per barrel in 2002 to a peak of $140 in 2008 and now to around $90 to $100 USD per barrel when the world demand is at a weak point (Fig. 2).

Figure 1: Global oil production as forecast by International Energy Agency (IEA)

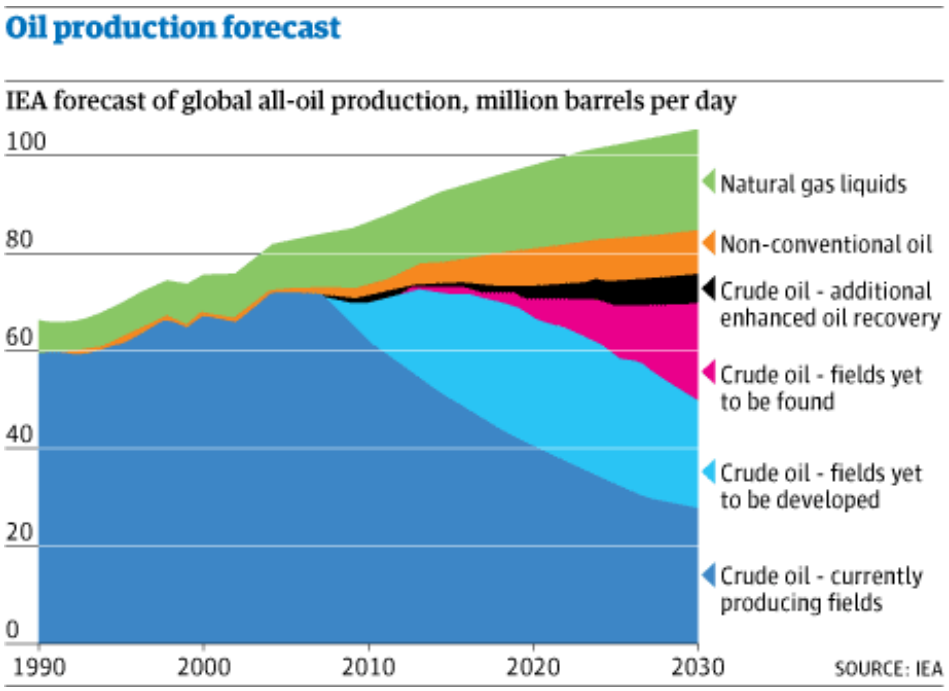
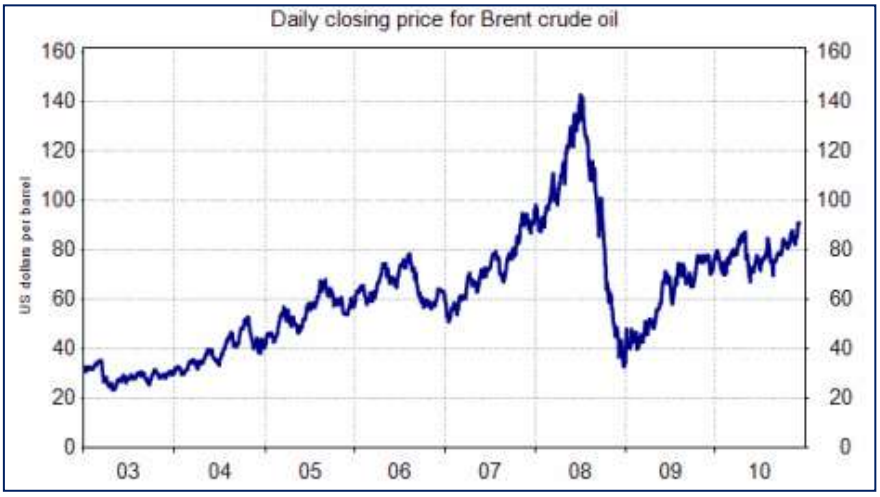
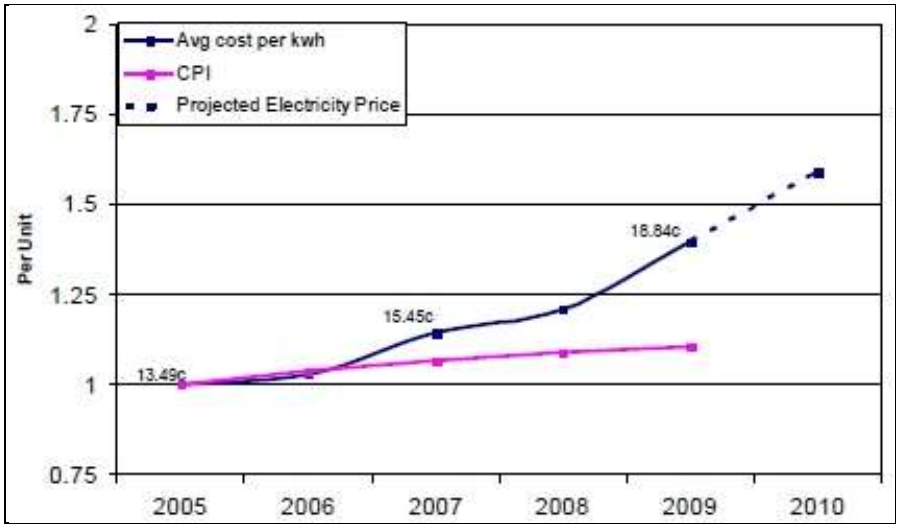


Figure 2: Variation of world crude oil prices (US$/barrel) between 2003 to 2010
Source: http://www.tutor2u.net/blog/index.php/economics/C156



Australia's electricity costs have at least increased by 30% in the last four years, and may be expecting a further increase of 20% or more as a result of the carbon tax and other price pressures (Fig. 3). Identification of alternative energy sources in light of significant and likely increases to the cost of traditional energy sources will therefore position the Australian cotton industry to well respond to these challenges.

Figure 3: Variation of electricity price in Queensland
Source: http://www.abcdiamond.com/australia/electricity-costs-in-queensland/



Another major problem with fossil fuels is their environmental impact. Not only does their excavation from the ground significantly alter the environment, but their combustion leads to a great deal of pollution. Widespread burning of fossil fuels (and other organic sources) has been particularly blamed for rise of CO_2 concentration in the atmosphere, which causes atmospheric heat retention or "global warming."

The renewable energy sources including solar, wind, hydropower, biomass, biogas and geothermal power are now also being actively explored to provide alternative and clean energy for the future.

4. Energy Content of Fuels

The purpose of fuels is to release energy for doing work. Because the release of fossil energy is accomplished primarily through the combustion process, the heating value of fuels is thus an important measure of energy content. Heating values are usually measured by burning the fuel in a bomb calorimeter.

- One joule is defined as the amount of work done by one Newton of force moving an object through a distance of one meter
- 1 calorie is the energy needed to raise the temperature of 1 g of water by 1 degree Celsius.
- 1 calorie is equal to 4.184 joules
- 1 round bread contains approximately 100 Calories or 100,000 calories of energy (1 Calorie = 1,000 calories, or 1 kcal. Note the difference in upper and lower case)
- 1 M^{c}Chicken burger at McDonalds contains 417 Calories of energy and about 10 g of protein
- Doing housework (eg, cleaning) may use about 200 Calories per hour (around 200 W).
- MJ (megajoule) is also a very small unit, because in the dollar terms, it will only be worth 1 to 4 cents. Thus, we usually use the unit GJ (gigajoule or one billion 10^9 joules), which is worth $10 to $40, depending on the fuel type being used.

The accepted unit of measurement for energy is the SI unit of energy, the joule. In addition to the joule, other units of energy include the kilowatt hour [kWh] and the British thermal unit [Btu]. For the purpose of conversion, one kWh is equivalent to 3.6 million joules [3.6 MJ], and one Btu is equivalent to about 1,055 joules. Table 2 shows the energy content (heating values) and average retail prices of several common fuels used in agriculture. It is also noted that although the retail prices of grid electricity and diesel are both around $40/GJ, when applied for pumping operations, the efficiency of electric motors is generally much higher (typically around 90%) than that of diesel engine (30 to 35%). Table 2 has also not considered the capital and possible maintenance costs of different energy systems.

Diesel

Diesel is often the only source of energy in agricultural field operations. The energy content of diesel in Australia may be calculated as of 38.6 MJ/L or 45.6 MJ/kg of diesel. The preferred fuel for diesel farm tractors and heavy trucks is no. 2 diesel during most of the year. Burning one litre of petrol also emits about 2.5 kg of CO_2-e into the atmosphere.

Electricity

Electricity is a common power source in agriculture. Electricity is a clean (on-site), high-grade energy, and is therefore more expensive. In Australia, grid-supplied electricity is mostly generated from fossil fuels (mostly the coal and gas). The use of 1 kWh of electricity in Australia emits, on average, around 1 kg of CO_2-e.

Selecting fuel sources is more complicated than simply selecting the source with the lowest price. Nowadays, fuel selection also involves the environmental considerations, primarily air pollution and carbon dioxide emissions. These issues may limit your choices of fuels, or make it more expensive and more difficult to do so, particularly after the introduction of Emissions Trading Scheme from 1 July 2012.

Table 2: Energy content and average retail prices of common fuels used in agriculture

Fuel Type	Form	Density	Energy Content	Retail Price
Grid Electricity				$40/GJ (15c/kWh)
Petrol	Liquid	0.72 kg/L	46.4 MJ/kg (34.2 MJ/L)	$40/GJ
Diesel	Liquid	0.84 kg/L	45.6 MJ/kg (38.6 MJ/L)	$40/GJ
LPG	Liquid	0.51 kg/L	49.4 MJ/kg (25.7 MJ/L)	$27/GJ
Natural Gas	Gas	0.67 kg/m^3	53.6 MJ/kg 38.7 (MJ/m^3)	$13/GJ
LNG (at −160°C)	Liquid (at −160°C)	0.41~0.5 kg/L	53.6 MJ/kg (22.2 MJ/L)	$20/GJ
CNG (compressed to 250 bar)	Liquid	0.129 kg/L	53.6 MJ/kg (9 MJ/L)	$10/GJ
Coal	Solid	1.4 t/m^3	29.2 MJ/kg	$10/GJ
Wood Pellets	Solid	0.4-0.8 t/m^3	19.8 MJ/kg	$8/GJ

The emission factors for different types of energy fuel sources are summarised in Table 3 (Department of Climate Change and Energy Efficiency, 2010). It is noted that for the same heat output, the greenhouse gas emissions from natural gas may be only 60% of coal. The greenhouse gas emissions from electricity also vary from state to state because different fuels are used for generation of electricity. Victoria may have the highest figure as most of its electricity comes from burning of brown coal – the most greenhouse-intensive energy type, while the electricity in the island state of Tasmania has close to nil emissions as it is mostly generated by the hydro-power stations. Change of electricity energy use in Tasmania will therefore have little impact on its greenhouse gas emissions.

Table 3: Average energy contents and emission factors for several types of energy sources in Australia

Fuel Type	Energy Content	Emission Factor
Electricity		244 kg CO_2–e/GJ (or 0.88 kg CO_2–e/kWh)
Petrol (transport)	34.2 GJ/kL	68.9 CO_2–e/GJ (or 2.35 kg CO_2–e /litre petrol)
Diesel (transport)	38.6 GJ/kL	69.9 CO_2–e/GJ (or 2.70 kg CO_2–e /litre diesel)
Natural Gas	53.6 GJ/km^3	51.3 CO_2–e/GJ
LPG	25.7 GJ/kL	59.9 CO_2–e/GJ (or 1.54 kg CO_2–e/litre LPG)
Black coal	27.0 GJ/t	88.4 CO_2–e/GJ
Wood (air dry)	10.4 GJ/t	1.28 CO_2–e/GJ

By fuel switching, it is possible to reduce energy cost. For example, LPG, or autogas as it is known, is becoming more popular as it can save car owners up to 30 to 40 per cent off their fuel bills. Depending on where you live, unleaded petrol costs around $1.50 a litre versus 70 to 80 cents a litre for LPG. The demonstrated safety of an LPG vehicle is also well established. Because the cost of converting to LPG is likely to be quite expensive, it may not be economic unless you have a very high annual mileage (such as a taxi).

5. Indirect Energy Uses of Farms

Table 4 shows the estimated embodied energy content for manufacturing various chemical fertilisers. It is estimated that with the current manufacturing technology, the production of one kg of nitrogen fertilizer would require the energy input equivalent to 1.5 to 2 kg of fuel, while 1 kg of pesticides would require the energy input equivalent to up to 5 kg of fuel. It is therefore very important to reduce not only the on-farm energy uses but also the embodied energy in consumables. The latter may account for up to 50% to 80% of the total energy input in agricultural production, which is significantly higher than that due to the direct on-farm fuel use (Khabbaz , 2010). In this regard, the precision agriculture technology such as the variable-rate fertilizer applications and crop rotations may offer significant benefits. Crop breeding research is also being actively conducted to improve the nitrogen use efficiency (NUE) of crops, by increasing the efficiency of mechanisms plants use to accumulate and utilise nitrogen.

Table 4: Embodied energy content for various agricultural fertilizers and herbicides

Chemicals	Energy Content [MJ/kg of element or active ingredient]
N	65
P	15
K	10
S	5
Generic herbicide	270

A Life Cycle Analysis (LCA) is a comprehensive assessment of a given product for the purpose of detailing environmental impact, energy use, or economic cost-benefit analysis (Chen, Maraseni, and Yang, 2010). The LCA methodology analyses production systems systemically to account for all direct and indirect inputs and outputs for a specific product and product systems within specified system boundaries. LCA has been applied to a broad range of sectors and is a valuable tool for pinpointing inefficiencies and comparing production methods. The application of LCA to agricultural systems is however relatively complex because, in addition to the main product, there are usually by-products and co-products produced. This requires appropriate partitioning of environmental impacts to each product from the system based on allocation rules. The quality of a LCA analysis will strongly depend on the quality of inventory data. Many of these data are highly variable and difficult to track accurately. This may limit the applications of LCA method. A recent project led by CSIRO is to establish the Australian life cycle inventory (LCI) database for agricultural life cycle assessment (LCA).

6. Energy Uses and Conservation in Agriculture

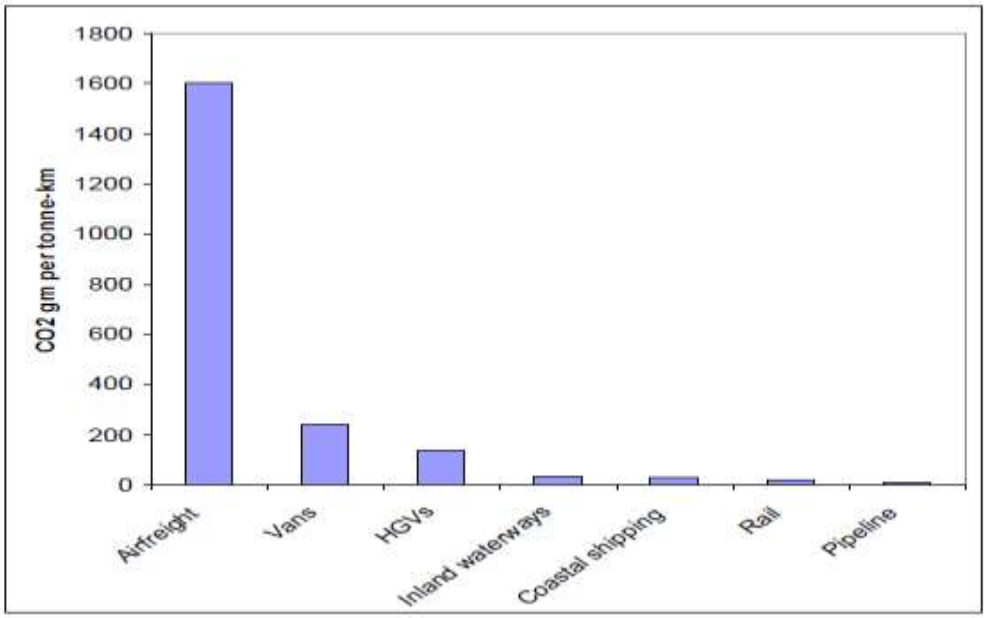
Extensive research has been conducted on both energy use and conservation in agriculture. Table 5 summarizes energy performance data for different cropping systems. Pellizzi et al (1988) found that in Europe, the range of field energy consumption for wheat-like cereals varied from 2.5 GJ/ha to 4.3 GJ/ha. For maize (corn), this was estimated to be between 12.6 GJ/ha to 16.2 GJ/ha. For cotton, a recent study by Chen & Baillie (2009) showed that the direct energy inputs for cotton production in Australia ranged from 3.7 to 15.2 GJ/ha, strongly affected by irrigation practices. Diesel energy inputs ranged from 95 to 365 litres/ha, with most farms using 120 to 180 litres/ha. Dryland cotton was at the lower end of this range. Results by Nelson et al (2009) also indicated that on-site energy use and total energy use for US cotton in 2004 ranged from 1.6 to 7.9 GJ /ha and from 5.5 to 20.5 GJ/ha respectively. Khabbaz (2010) found that in Australia, the life cycle energy consumption and emissions for producing one hectare of cotton from the field to the export shipping port was up to 11.4 GJ.

Table 5 Energy performance data for different cropping systems from published literature

Crops	Total Energy Input [GJ/ha]	Direct Energy Input [GJ/ha]	Indirect Energy Input [GJ/ha]	Researchers	Country
Wheat		2.5 - 4.3		Pellizzi et al (1988)	Europe
Maize		4.7 - 5.0		Pellizzi et al (1988)	Europe
Cotton	49.7	21.1	28.6	Yilmaz et al (2005)	Turkey
Cotton		3.7 - 15.2		Chen & Baillie (2007)	Australia
Cotton	5.5 - 20.5	1.6 - 7.9		Nelson et al. (2009)	USA
Cotton	47-137	11-16	23-125	Khabbaz (2010)	Australia
Sugarcane	148.0	100.6	47.4	Karimi et al (2008)	Iran
Sugarcane	40.7	14.4	26.3	Mendoza & Samson (2002)	Philippine
Sugarcane	64.9	43.5	21.4	Mrini et al. (2001)	Morocco
Rice	64.9			(Pretty, 1995)	USA
Pea	2.5 - 5.4			Gulden & Entz (2005)	Canada
Dairy pasture	18.2	8.2	10.0	Wells (2001)	NZ

It is found that overall, the total energy inputs by a farmer can be significantly influenced by the management and operation methods adopted. Pellizzi et al (1988) showed that with improved management and operation, energy saving of around 12 to 15% of present consumption can be realistically obtained for tractors, 30% for soil tillage, and 10% for harvesting machines. The adoption of minimum tillage may also reduce fuel use by up to 40%, and no-tillage saves up to 75% of fuel. Brown and Elliot (2005) also found that the largest on-farm energy savings are available in motorised systems, especially irrigation pumping. Different modes of transport (Fig.4) also have significant effect (McKinnon, 2007). Pimentel et al (2008) showed that fossil energy use in the US food system could be reduced by about 50% by appropriate technology changes. Using corn production as a model crop, they estimated that total energy in corn production could be reduced by more than 50% with the following changes: (1) using smaller machinery and less fuel; (2) replacing commercial nitrogen applications with legume cover crops and livestock manure; and (3) reducing soil erosion through alternative tillage and conservation techniques.

Figure 4: Variations in CO_2 intensity by different modes of transport (McKinnon, 2007)



7. Australia's coal reserves and resources

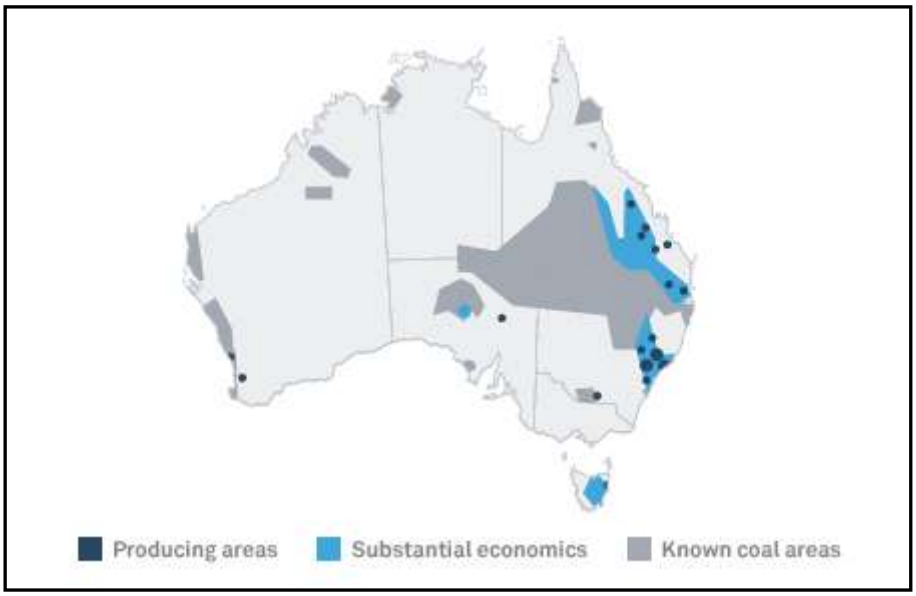
Coal is a combustible rock of organic origin, composed mainly of carbon (50 to 98%), hydrogen (3 to 13%) and oxygen, with lesser amounts of nitrogen, sulphur and other elements.

Coal is abundant in Australia (Fig.5) and considerably less expensive than other energy sources. The life of Australia's coal deposits has been estimated by British Petroleum (BP) to be around 261 years based on consumption increasing with population models, whilst other sources have suggested that it may be as many as 500 years.

Coal in Australia is used to generate electricity and is also exported. 75% of the coal mined in Australia is exported, mostly to eastern Asia. Two forms of coal are mined in Australia, depending on the region: high quality black coal and lower quality brown coal. Black coal is found in Queensland and New South Wales, and is used for both domestic power generation and for export overseas. Black coal was also once exported to other Australian states for power generation and industrial boilers. Brown coal is found in Victoria and South Australia, and is of lower quality due to a higher ash and water content. Today, there are three open cut brown coal mines in Victoria which are used for base load power generation.

In 2009, 78% of the electricity generated was produced from coal, 14% from natural gas, 4.7% from hydro (http://www.world-nuclear.org/info/inf64.html).

Figure 5: Australia's Coal Resources



While providing a secure, affordable and uninterrupted supply of energy, coal is also a major source of Australia's greenhouse gas emissions, contributing up to 37% of total emissions (http://www.newgencoal.com.au/coal-in-australia.aspx). Clean coal technologies are currently under active research, which include various chemical and physical treatments applied pre or post combustion. Among them, Carbon Capture and Storage (CCS) is probably one of the most promising technologies. It involves capture, transportation and long term storage of carbon dioxide and other greenhouse gases in deep geological formations underground. At present, these technologies are still at research and pilot trial stages. Overall, the current CO_2 capture technology is expensive and energy hungry, with a 30-70% cost increase and an estimated 25% additional fuel being required in a coal-fired plant and 15% in a gas plant. Although some people predict that the technology would be available by 2020, others question the feasibility of that time frame. In the future where advanced power plant technologies with carbon capture and sequestration are used, coal could have very similar life cycle GHG emissions with natural gas.

8. Australia's oil reserves and resources

Oil is a fossil fuel that is recovered by drilling wells either on land or from offshore rigs. The world produces about 31 billion barrels per year or 85 million barrels of oil each day (The USA alone consumes some 20 million barrels of oil per day). A barrel is approximately 35 Imperial gallons, 42 U.S. gallons or 159 litres, or roughly equivalent to the volume of liquid held by a standard bathtub. One barrel of oil contains 6.12 GJ of energy. Some oil is used to heat buildings and to generate electricity. The remainder is distilled (cooked) to produce petrol and other by-products. Crude oil (called "petroleum") is easier to get out of the ground than coal. It can flow along pipes, making it cheaper to transport.

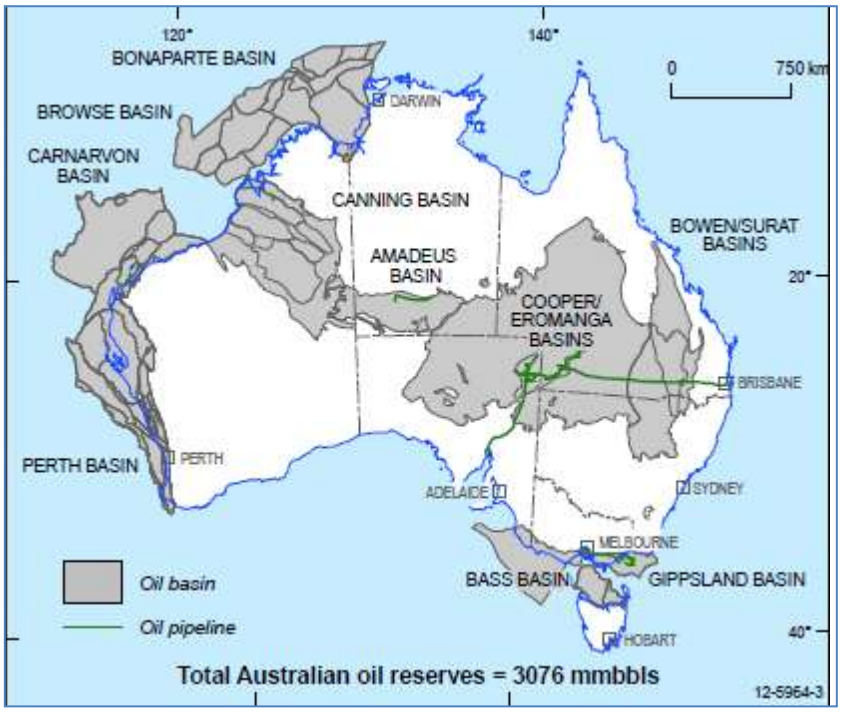
Currently, petrol and diesel accounts for approximately 47% and 34% % respectively of total transport fuel demand in Australia respectively (Table 6). Demand for transport fuel was growing around 12% per annum and reached around 50,000 ML (or approximately over 2,000 L per person)

per year in 2010. The supply of oil in Australia (Figs.6 and 7) is already on the decline and the main fields of Bass Straight will be almost exhausted by 2015. The import requirement for oil at that time is projected to be 500,000 barrels per day, which would put enormous strain on Australia's balance of payments (Fig.7). Alternative transportation fuels to petroleum being researched include biofuels, or fuels derived from coal and natural gas. Research is also being conducted to optimise engine performance as well as particulate trap and other exhaust gas treatments to reduce air pollution.

Table 6: Australia's demand for petroleum-based transport fuels per year in 2003-04 (Commonwealth of Australia, 2005)

Automotive gasoline	47% or 19,962 ML
Automotive diesel	34% or 14,462 ML
Jet Fuel	10% or 4,329 ML
Automotive liquefied petroleum gas (LPG)	6% or 2,547 ML
Others, including lubricants	3% or 1,200 ML

Figure 6: Oil Resources and Infrastructure in Australia (Bureau of Resources and Energy Economics, 2012a). One mmbbl means one million barrels of oil.

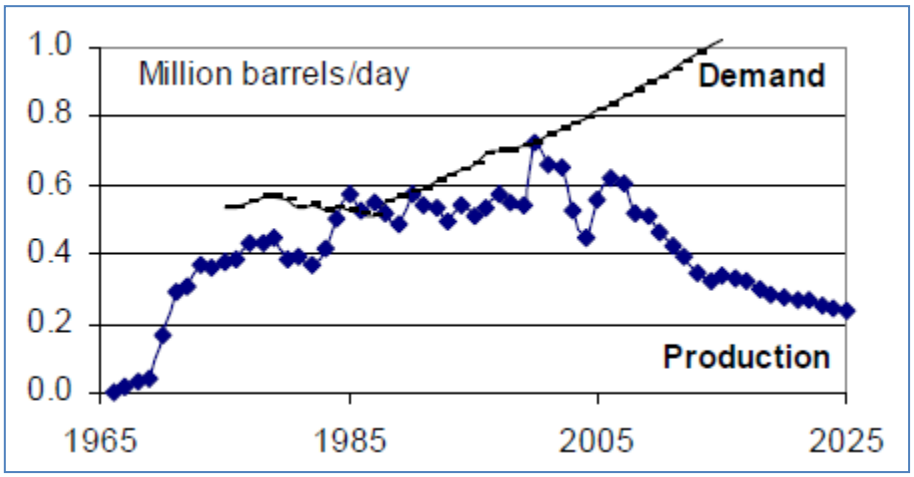


Australia's Energy Security (Oil):

- Year 2000: self-sufficient
- Year 2010: less than 50% self-sufficient (oil import at a cost of $17 billion each year)
- Year 2030: predicted to be less than 20% self-sufficient

Figure 7: Australian crude oil and condensate production and demand to 2004, and forecasts

http://www.aspo-australia.org.au/References/Abstract_Lisbon_Robinson.pdf\



9. Liquid Petroleum Gas (LPG)

LPG is manufactured either during the refining of crude oil, or extracted from oil or gas streams as they emerge from the ground. The value of LPG industry in Australia is currently around $3.5 billion. LPG is composed primarily of propane and butane, while natural gas is composed of the lighter methane and ethane. LPG has a lower energy density than either petrol or fuel-oil. One litre of LPG provides approximately 26 MJ of energy, and one kilogram occupies approximately 2 litres (Table 2). LPG also emits, per GJ, 81% of the CO_2 produced by oil, 70% of that of coal, and less than 50% of that emitted by coal-generated electricity distributed via the grid (Table 3). At the present time, LPG (at around 70 cents per litre) provides a cheaper alternative to petrol (Table 2), but as the oil supplies in Australia run down and LPG has to be imported, the price of LPG could rise to the point where it is unlikely to be much cheaper than petrol. The price of LPG is also about twice that of natural gas in terms of $/GJ energy output (Table 2 and Appendix 1).

LPG may also be injected into diesel fuel. Although there are conversion costs (around $3,000), LPG reduces fuel costs through the lower cost of LPG and the improved combustion efficiency of the mix. Conversion is cost effective for vehicles with large operating hours and irrigation pumps.

10. Australia's natural gas reserves and resources

Australia has limited crude oil but is relatively well endowed with natural gas resources. In 2011, Australia's economic demonstrated resources (EDR) and sub-economic demonstrated resources (SDR) of conventional gas were estimated at 173 000 PJ (Geoscience Australia and Bureau of Resources and Energy Economics, 2012). At current production rates, there is sufficient conventional gas to last another 54 years. The bulk of Australia's gas resources are located long distances from the main eastern Australian markets (Fig.8). These are offshore northwest Western Australia and in the Timor Sea to the north of Australia (Bonaparte Basin). Because of the uneven distribution of gas resources, gas would need to be piped from these fields when the closer smaller eastern fields run down prior to 2020. Natural gas as an energy source has significant environmental benefits over both

coal and oil in terms of lower greenhouse gas and other emissions. This aspect will be of considerable advantage in the further promotion of natural gas use and Australia's energy future.

The natural gas industry has shown remarkable growth—both the domestic and export sectors—over the last few decades and this is projected to continue and will double by 2020 (Fig.9).

Figure 8: Australia's natural gas resources

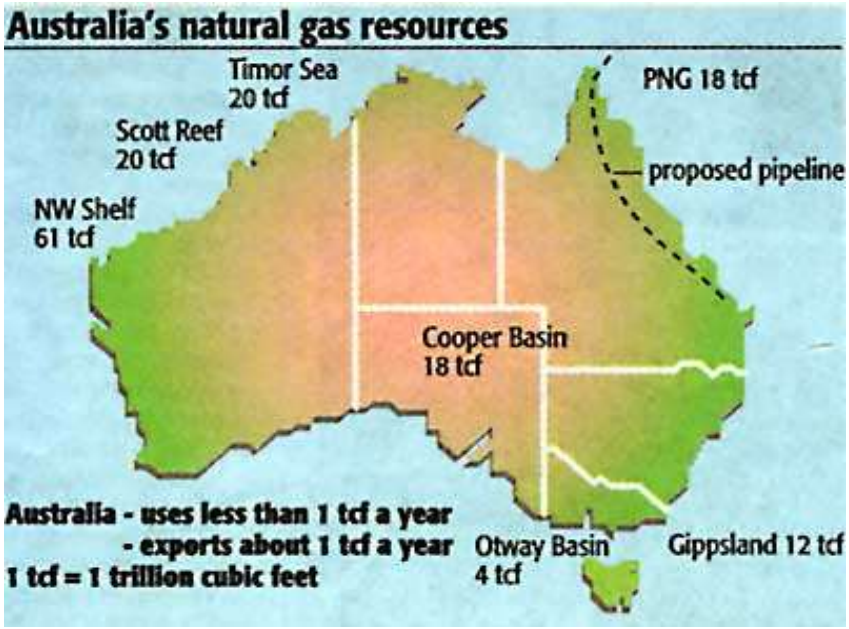
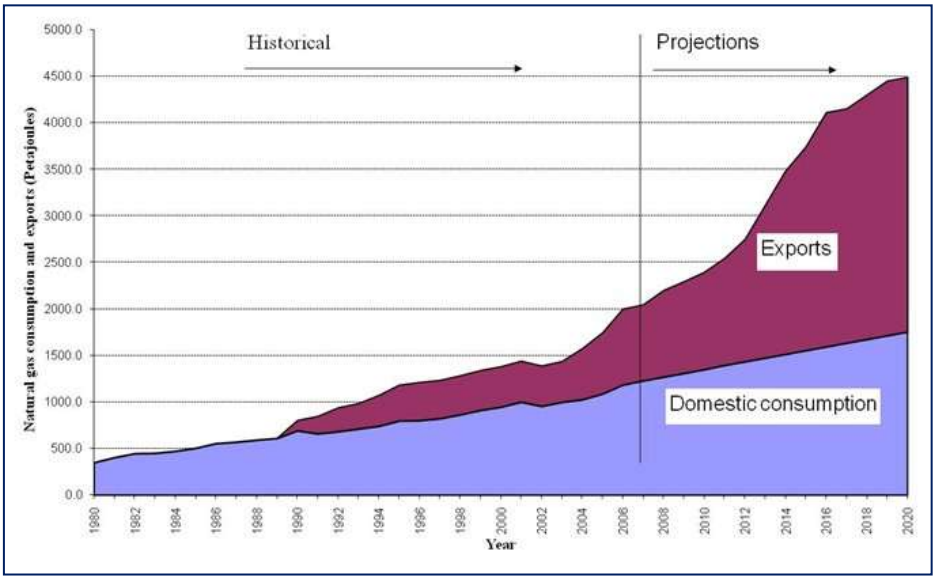


Figure 9: Australia's natural gas consumption and exports
http://www.aph.gov.au/library/pubs/rp/2007-08/08rp25.htm



11. Coal Seam Gas

Coal seam gas is predominantly methane gas stored within coal deposits or seams. Coal seam gas is formed as part of the same natural processes that produced coal over millions of years. It is held in coal by pressure and water. To recover CSG, however, coal extraction is not required.

Figure 10: Increase of coal seam gas production in Australia

http://www.accc.gov.au/content/item.phtml?itemId=904614&nodeId=1c8b084bb65af8b61eebdc959132ca8c&fn=Chapter%208%20%20Upstream%20gas%20markets.pdf

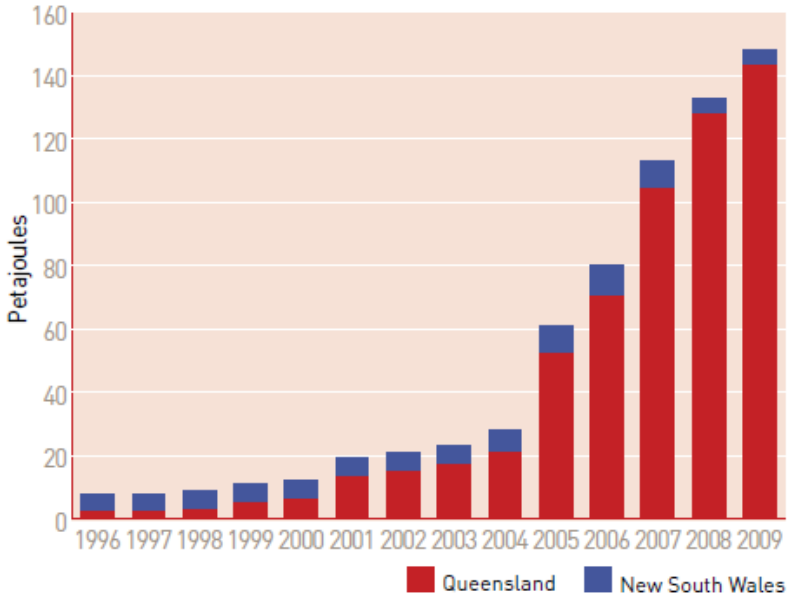
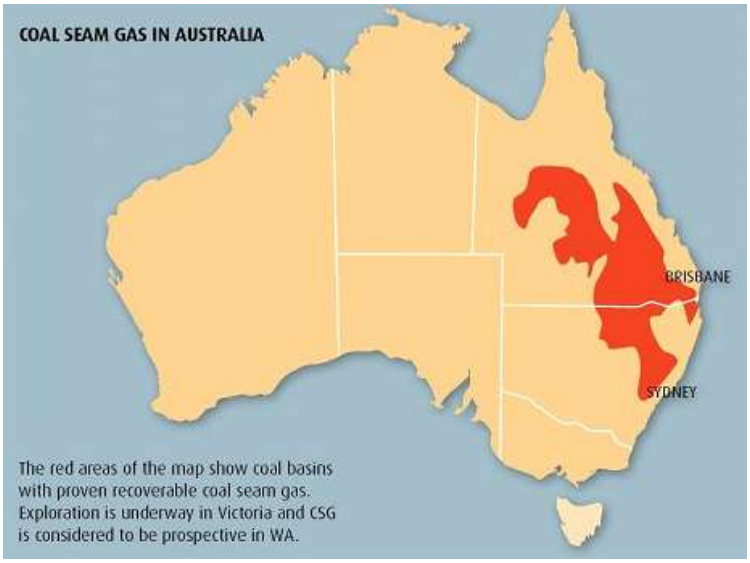


Figure 11: Coal seam gas in Australia

http://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/BN/2011-2012/CoalSeamGas



Just 15 years ago, there was virtually no coal-seam gas extraction in Australia. The rapidly developing coal seam gas (CSG) industry (Fig.10) is now adding to Australia's known economic gas resources. Geoscience Australia indicated that Australia's CSG reserves as at the end of December 2006 was 4,642 PJ. There is enough CSG in eastern Australia to power a city of a million people for 5,000 years. Major CSG basins in Australia are in Queensland (Bowen and Surat) and in NSW (Clarence Moreton, Gloucester, Sydney and Gunnedah) (Fig.11) which are close to Australia's cotton farming regions. The successful development of CSG fields and then liquefying and exporting the gas now contributes to the diversification of gas supply sources and economics, particularly in Queensland. Production in 2004 amounted to some 45 PJ, or about 4.5% of Australia's domestic natural gas consumption. CSG now also supplies 80-90% of the total gas market in Queensland and 35% east coast gas demand. Exports are also currently worth more than $3.2 billion a year (at around $400/t or $10/GJ. This is in comparison with coal export price of $100-150/t). It is forecasted that CSG sales in Australia could triple in the next five years, putting the industry on par with iron ore and coal in terms of export contributions to the economy.

Coal seam gas can be used for the same purposes as the conventional natural gas. CSG may be supplied in two forms. When compressed under high pressures and held in a container, it is called Compressed Natural Gas (CNG).When it is cooled and converted to a liquid for transporting, it is called Liquefied Natural Gas (LNG).

CNG has a lower cost of production and storage as it does not require an expensive cooling process and cryogenic tanks. CNG requires a much larger volume to store the same mass compared to petrol and the uses very high pressures (205 to 275 bar).

In comparison, LNG is produced by cooling CSG in cryogenic tanks. This is expensive but produces a much lower volume. The energy density of LNG is also 2.4 times greater than that of CNG which makes it economical to transport by ships, trains or pipelines. The gas is then converted into CNG before distribution to the end users. LNG has been trialled with some success in road transport, which are constantly on the move. Due to an issue of 'boil-off" – loss of gas when the machine is sitting idle, LNG is unsuitable to agricultural applications where machinery has extended periods of little or no use.

Unlike LNG, CNG is a suitable fuel for tractors, trucks and irrigation engines. Research is being conducted to develop the optimum conversion technology for diesel engine to use these gases. Essentially, there are two available technologies to convert conventional diesel engines to natural gas engine: 1) a dual system where diesel fuel still operates as a pilot fuel. This technology is cheap, easy, and it can return to 100% diesel fuel with less modification. 2) Mono-gas, which requires major conversion to the engine. A new fuel injection system will need to be installed with a spark. Ignition system also requires major work, and the compression ratio needs to be increased to maintain the original power output. Advantages of this technology are reduced engine weight, lower emissions and the reduced fuel costs. It is also identified that a key research question is the appropriate design of CNG storage and on-vehicle tanks for agricultural operations.

It was also reported that the conversion of an engine to CNG could be costly (around $2,000 for engine modifications and $2,000 for a new fuel tank). This means it will need to run 50,000 to 100,000 km to recover the capital cost. Professionally qualified commercial suppliers are able to design a system that avoids engines occasionally de-rating and backfiring and maintains engine reliability. For irrigation pumps, the payback period is estimated to be about 1-2 years using CNG and

4 years using LNG (Yusaf et al, 2010). It was also estimated that for dryland framers in Australia adopting no-till or minimum till, between 2.3 and 4.2 years would be required to pay back the conversion to CNG, and 15 to 27 years when LNG is used (Yusaf et al, 2010). The conversion cost for LNG would be around $6,000.

CSG is extracted by pumping up water from the coal seam, which reduces the pressure and allows the gas to be released. There are concerns over the impact of coal seam gas mines on water supplies and possible impacts on crop lands. It is argued that if not properly managed, the dissolved salts may permanently ruin good farming land and water aquifers, making it useless for agriculture or pastoral production. It is toxic to aquatic life if spilled into creeks or rivers. Research is being carried out to manage these issues. Individual gas wells usually have a life of about 15 years.

12. Summary of energy industry and available resources in Australia

According to Bureau of Resources and Energy Economics (2012), Australia is currently the world's ninth largest energy producer, accounting for around 2.5 per cent of world energy production and 5 per cent of world energy exports. In 2009-10, net energy exports accounted for 68 per cent of domestic energy production, while domestic consumption accounted for the remaining 32 per cent.

In 2009/10, coal accounted for 37 per cent of Australia's total primary energy supply, followed by oil (35 per cent), gas (23 per cent) and renewable energy sources (5 per cent). Energy consumption increased at an average annual rate of 1.8 per cent over the ten years from 1999/2000 to 2009/10.

Table 7: Australia's economic demonstrated resources, 31 December 2010 (Bureau of Resources and Energy Economics, 2012)

Sources	Types	Energy available (PJ)	Share of World (%)	Resources Available for Production (years)
Coal	Black coal Lignite	1 255 470 384 6895	10.3 8.6	128 517
Petroleum	Oil Condensate LPG	5 685 12413 4 063	0.2 N/A N/A	9 38 38
Gas	Conventional gas Coal seam gas	113 373 35055	1.6 N/A	66 175
Uranium		648 480	33.0	134

13. Renewable Energy

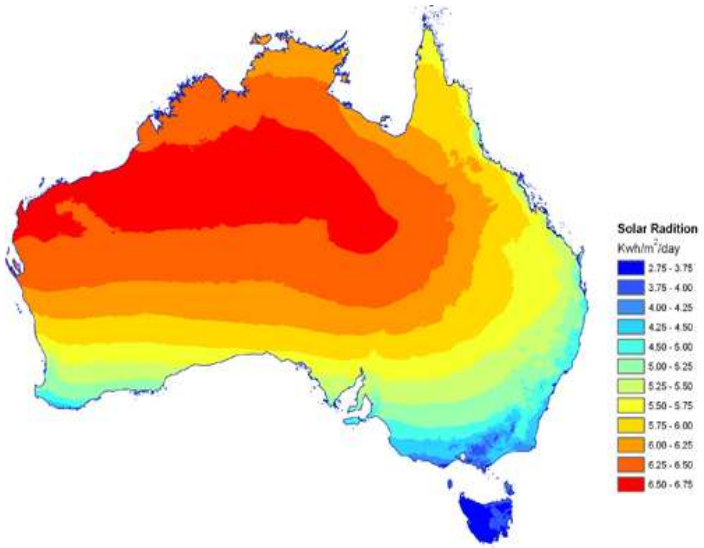
At present, renewables contribute around 5 to 7% to Australian electricity generation. This is dominated by hydroelectricity, bagasse (sugar cane waste), wood and wood waste, which together accounts for 85% of renewable energy production. Wind energy, solar energy and biofuels (which include landfill and sewage gas) accounts for the remainder of Australia's renewable energy production. Most solar energy is used for residential water heating and accounts for 1.8% of final energy consumption in the residential sector. In 2008/09, renewable energy production increased by 6%. In August 2009, the Australian Government passed legislation requiring electricity retailers to source, and hence generators to produce, 20% of Australia's power from renewable sources by 2020 – signalling a potential major expansion in renewable energy industry in the country.

14. Solar energy

The fact that Australian refer to their land as "the sunburnt country" aptly describes the strength of Australia's solar energy resources (Fig.12). It was estimated that solar radiation reaches the earth's surface at a maximum flux density of about 1.0 kWh/m^2 in a wavelength band between 0.3 and 2.5 mm. For inhabited areas, this flux varies from about 3 to 30 MJ (0.83 to 8.3 kWh/m^2) per day, depending on place, time, and weather. To power all of Australia's energy needs would require only 0.3% of the land surface to be devoted to solar power generation.

Figure 12: The potential for solar power generation in Australia

http://www.geni.org/globalenergy/library/renewable-energy-resources/world/oceania/solar-oceania/solar-australia.shtml



There are essentially two methods of harnessing the energy from solar radiation from the sun: solar photovoltaic (PV) and solar thermal (Fig.13).

The basic building block of PV technology is the solar "cell". Commercial photovoltaic efficiency typically ranges from 10% to 13%. Amorphous modules have the lowest price, yet their lifetime is short and their efficiency is up to 8% only. Today, research is also enabling progress toward achieving 20% to 25% efficiency. Research is also being conducted to make better use of the full spectrum of

sunlight to generate electricity, and making solar cells from plentiful, cheap and non-toxic elements.

Figure 13: Solar energy applications
http://adl.brs.gov.au/data/warehouse/pe_aera_d9aae_002/aeraCh_10.pdf

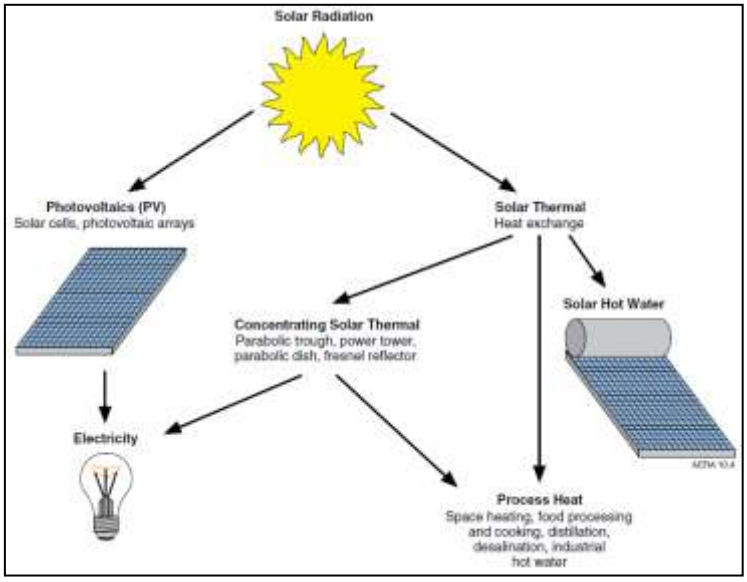
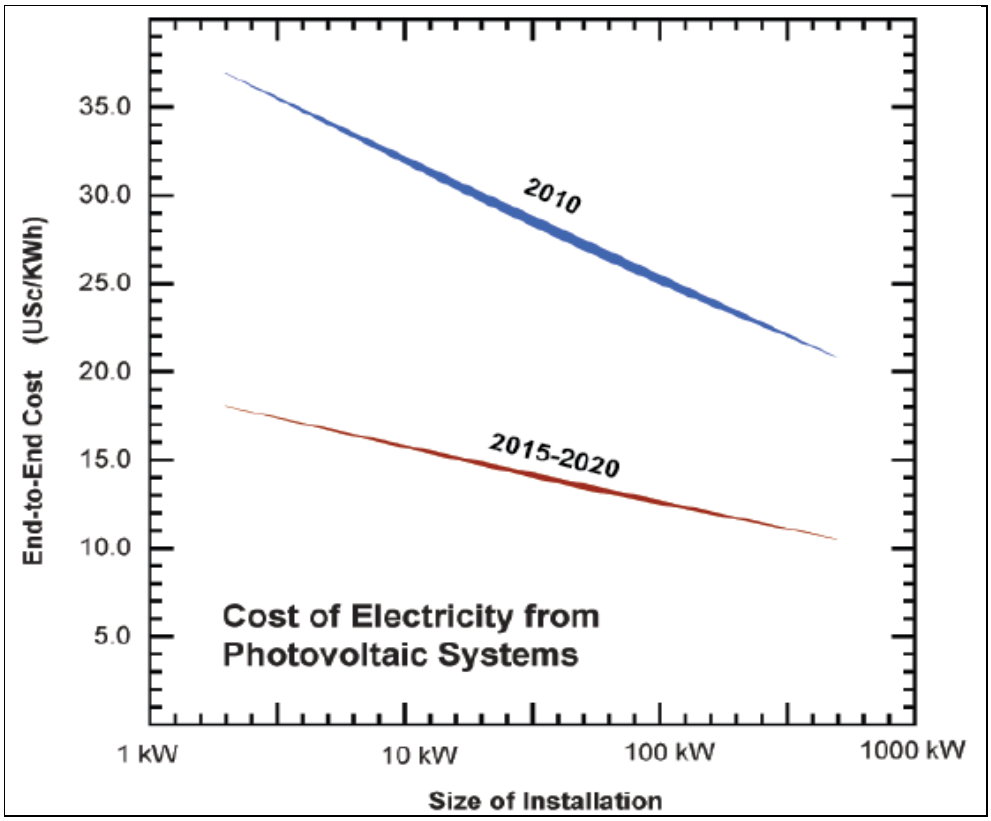


Figure 14: The whole of lifetime costs of energy production from photovoltaic systems as a function of size of the installed system.
http://www.science.org.au/reports/documents/AusRenewableEnergyFuture.pdf



Depending on feed-in tariffs, photovoltaics currently require between 4 and 10 years to recoup their investment and 2 to 3 years to recoup the energy used in their manufacture. Current costs are around $0.20 to 0.30/kWh, but with the new technologies currently under development, generation costs are expected to fall by 50% by 2015 (Fig.14). It was also predicted that over the next 20 years, distributed solar will revolutionise the industry and will do to grid power what cell phones have done to fixed-line telephony over the past 20 years. http://www.theaustralian.com.au/business/opinion/we-are-missing-the-boat-on-clean-energy/story-e6frg9if-1226396021478

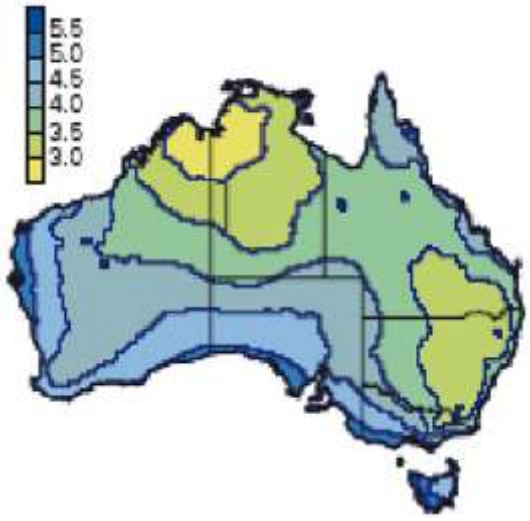
While still a small contributor, solar (thermal) electricity experienced the strongest growth in 2008/09, increasing by 40%. Solar hot water also increased strongly, with a 27% increase from 6.5 PJ in 2007/08 to 8.2 PJ in 2008/09.

15. Wind Power

Wind is created by the unequal heating of the Earth's surface by the sun. Wind turbines convert the kinetic energy in wind into mechanical power that runs a generator to produce clean electricity. These blades are aerodynamically designed to capture the maximum energy from the wind. The wind turns the blades, which spin a shaft connected to a generator that makes electricity.

The economies of scale have permitted wind power to reduce the cost of delivered power by more than 80% over the last 20 years (now as low as 5 cents per kWh). Currently, large wind turbines are cheaper than any other renewable energy source, and under the Mandatory Renewable Energy Target (MRET) they could compete head-to-head with coal-fired electricity generation at current costs. Medium and small wind turbines have an important place in Australia's renewable energy future. At present, small turbines have an installed cost per unit of power output similar to that of photovoltaic arrays, but about three times higher than large wind farms. It is thus necessary to have feed-in tariffs that include wind energy to encourage the uptake of small turbines for individual houses, and medium turbines for community and business power schemes. Storage could be a key factor for wind that produces a lot of excess energy at night and to help shift solar into serving late afternoon and early evening peaks. Because of the active research on storage technologies in the wind industry, storage costs are likely to fall significantly. Other researches focus on the optimisation of blade designs and the method to achieve good energy extraction at low wind speeds.

Figure 15: The potential for wind power generation in Australia



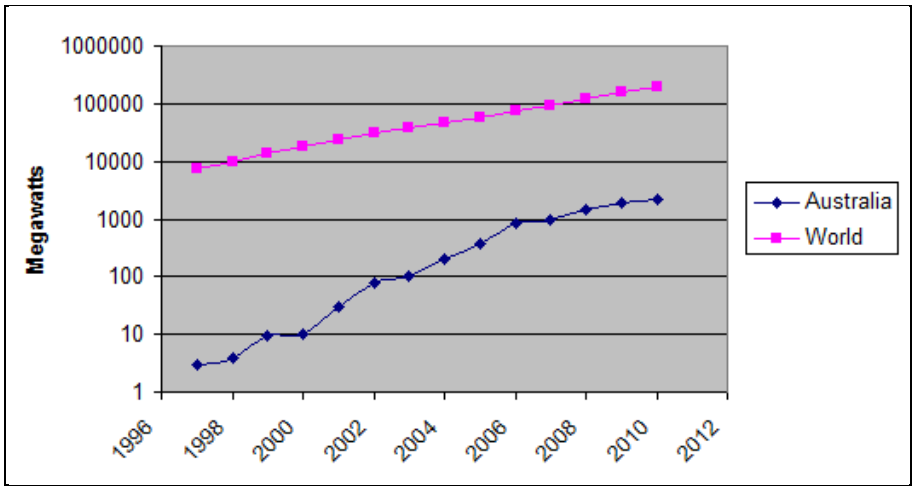
Tapping wind energy through wind turbines can be the most cost-effective renewable energy technology, apart from hydro-electric generation (Appendix 2). Wind turbines also require less than 3 to 6 months to recoup the energy used in their manufacture. It has been shown that the life cycle carbon dioxide emission of wind power can be as low as 9 g CO_2 /kWh (2.5 kg CO_2/GJ), in comparison with 160-178 g CO_2 /kWh for decentralised PV systems and 446 g CO_2 /kWh and 955 g CO_2 /kWh for natural gas and coal respectively (Appendix 2).

Wind farms are now a familiar aspect of the environment. Because the power output scales approximately as the cube of the wind speed, existing wind farms in Australia are concentrated along the windy southern littoral districts (Fig. 15). Generally, the site will need to have average annual wind speed of at least 4.5 to 5 m/s.

As fossil fuels are anticipated to incorporate their environmental costs with the introduction of an emissions trading scheme, the competitive position of wind turbines should continue to strengthen (Fig.16). Subject to amenity and aesthetic considerations, there are significant opportunities for small- and medium-sized turbines to be installed in urban and semi-urban areas such as sporting fields, parks, shopping centre car parks and industrial areas. It was recently predicted by the Bureau of Resources and Energy Economics (BREE, 2012b) that solar and onshore wind production could produce some of the lowest electricity generation costs in Australia by 2030.

As of June 2009, Australia has approximately 1,700 MW of wind power either in operation or nearing completion.

Figure 16: Installed wind power capacity – The world and Australia
http://ramblingsdc.net/Australia/WindPower.html



Although it could be slightly more expensive for most suburban and rural settings and applications, a solar power system is usually the best choice for the following reasons:

- Has no moving parts
- Has better reliability and a 25 year warranty
- Requires less monitoring
- Does not require expensive maintenance
- Provides more predictable energy output
- Better value for money in sites with average wind speeds less than 5m/s
- Is less conspicuous than a wind turbine
- Is totally silent in operation
- Allows for quicker installation with less cable required
- Is less susceptible to lightning damage
- Is less susceptible to high wind damage
- Requires less space in most cases as the panels can be installed on a roof
- Is particularly suitable for remote locations where diesel generators may be very costly

An online renewable energy calculator (Chen et al, 2011) has been developed at the National Centre for Engineering in Agriculture (NCEA), University of Southern Queensland (USQ), to provide an indication of potential for solar or wind systems to replace purchased electricity and feed electricity into the grid. The calculator can select the appropriate size of solar or wind turbine system and provide a simple cost benefit analysis based on available information of expected energy demand, renewable energy to be generated, electricity costs and system capital and operating costs.

16. BioEnergy

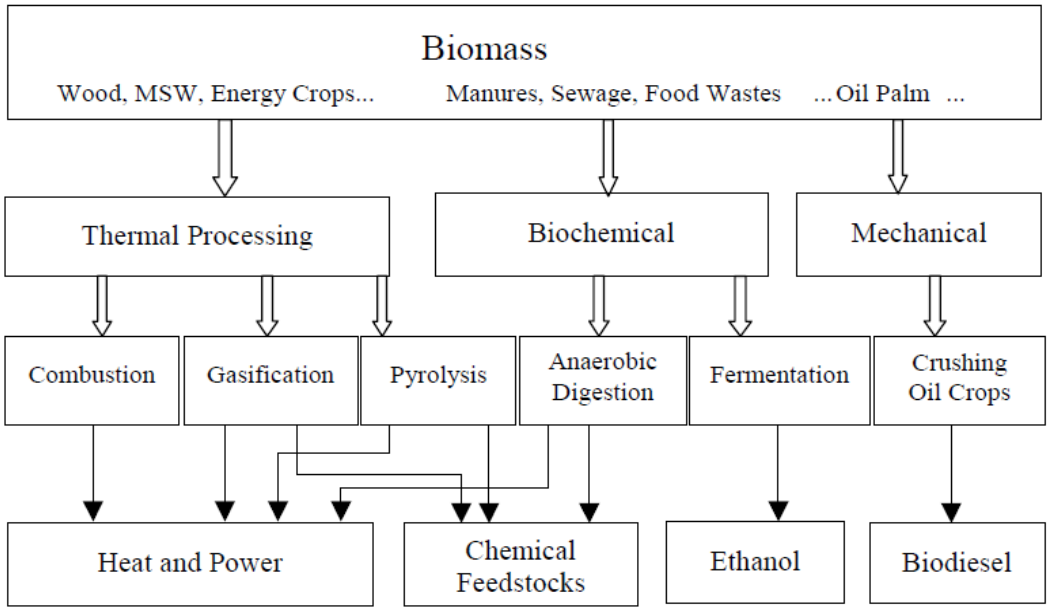
Bioenergy uses biomass to generate either heat, electricity or transport fuels (Fig.17). Biomass is a very versatile resource and refers to organic matter, derived in recent times, directly or indirectly, from plants. It includes a wide variety of materials, from forestry and agricultural residues, to organic waste by-products from various industries, purpose grown energy crops, human sewage and animal manures, to woody weeds and municipal green waste. Bioenergy can be regarded as a form of solar energy, as photosynthesis combines atmospheric carbon dioxide with water in the presence of sunlight to form the biomass, while also producing oxygen.

The straw/grain ratio for cotton was reported to range from 0.95 to 2.0 (Lal, 2005; Girard and Fallot, 2006). However, due to very high cotton yield, this number may be more likely to be around 1.0 in Australia. It was also reported that in 2012, with a national cotton crop of close to five million bales, the ginning process is likely to produce almost 1.3m tonnes of seed. This gives a cottonseed cotton lint ratio of around 1.2.
http://sl.farmonline.com.au/news/nationalrural/cotton/general/chineseled-boom-for-cotton-seed-exports/2598673.aspx

Increasingly, agriculture is also now being looked to as a source of energy. Bioenergy crops, or agricultural products, which can be converted to solid or liquid fuel can offer a lower carbon emitting

source of energy (Table 3). Owing to the concern over global warming, unstable diesel fuel prices in the world market and a limited supply in the future, many farmers have been looking for alternative fuels or growing their own. Ethanol and bio-diesel are two of the alternatives. To achieve best outcomes, there are many factors to be taken into account for each bioenergy resource, such as moisture content, resource location and distribution, and type of conversion process.

Figure 17: Bioenergy conversion routes (Schuck, 2007)



Currently, the majority of Australia's bioenergy use is sourced from bagasse (sugar cane waste) and some wood waste, which represents 92% of bioenergy use for direct heat and electricity generation. Biogas represents 6% of bioenergy use and the remaining 2% are biofuels for transport fuel. The most widely utilised biofuel in Australia is the use of ethanol blended petrol and biodiesel which is available Australia wide. Bioenergy use in Australia is projected to increase by 2.2% per year to 340 PJ in 2029/30.

16.1 Direct combustion

This technique accounts for about 90% of modern bioelectricity. It is very similar to coal-fired power stations: burning biomass to raise steam, which drives a turbine or steam engine, driving an alternator. Biomass can be added to the feed stock of conventional coal-fired stations with little modification, leading directly to a reduction in the greenhouse gas footprint of these stations.

Australia has about 808 MW of electricity generation capacity in total from biomass sources. Growth in this sector, together with wind power, is expected to account for most of Australia's increase in electricity generation from renewable sources to 2030. Bagasse, a by-product of sugar production, has been used in Queensland and northern NSW for 50 years for commercial power generation, supplying power to the mills themselves and exporting a contribution of about 1% of Australia's electrical generation. Small amounts of energy are also produced by burning wood waste at some timber mills. Over the last decade, several sugar mills have replaced their electricity production systems with much

higher efficiency systems to enable them to export more to capitalise on electricity production income.

For cotton ginning, it has been previously found (Ismail et al, 2011) that gas usage per bale for drying ranged between 0.029-0.154 GJ/bale with the average being 0.1GJ/bale. With a heat content (energy value) of 10-15 MJ/kg and assuming that the range of straw/grain ratio for cotton is 0.95-2.0 (Girard and Fallot, 2006), it can be shown that 10% of the cotton stalk straw biomass would be sufficient to meet the drying energy need of ginning operation. Alternatively, the amount of energy can also be provided by the gin trash which is readily available at the ginning sites, avoiding the current reliance on LPG or natural gas. It was noted (Allison, 2012) that the technology to produce a hot air stream is neither complex nor overly capital intensive and hence risk that exists with employing this approach is minimal. It was suggested that the suitability of cotton gin trash to the feed systems associated with the hot air generation systems be further investigated.

16.2 Biofuel

Because the energy density of biofuel is typically 3 to 4 times higher than that of biomass, biofuel has a lower transportation cost and is often produced as a consumer fuel. The most widely utilised biofuels in Australia are ethanol blended petrol and biodiesel, which are available Australia wide.

Biofuels are renewable fuels and although still subject to debate, can reduce CO_2 emissions from transport by up to 30% to 50% compared to traditional fossil fuels. Thus, biofuel has the potential to assume an important portfolio in future energy for agriculture.

Fermentation to produce ethanol

Ethanol is one of the key alternatives being introduced around the world to reduce reliance on fossil fuels. The process to produce ethanol (C_2H_5OH) for use as a transport fuel or a fuel additive is alcoholic fermentation. The energy content of ethanol ranges from 21 to 23 MJ/L. This is relatively low when compared to 38.6 MJ/L of diesel. By adding vegetable oils, the viscosity can be altered to ensure that it runs better in conventional engines.

Generally, the agricultural raw materials for bioethanol can be classified into three categories: first-generation sugar-containing feedstocks (e.g. sugar cane, sugar beet, sweet sorghum and fruits), starch materials (e.g. corn, wheat, triticale, rice, potatoes, cassava, Jerusalem artichoke, sweet potatoes and barley), and second-generation lignocellulosic materials (e.g. wood, straw, grasses, cotton stalks and trashes).

The bulk of ethanol produced in Australia is from waste starch (grains based) or sugarcane (molasses) (Fig.18 and Table 8). Current practice in Australia is to blend 10% ethanol with petroleum based petrol as a fuel extender and octane enhancer. Other countries have a much higher level of ethanol blend, up to 100% in some cases. In 2012, 306 ML of ethanol was consumed in Australia, with around 90% of that being used in petrol/ethanol blends. World fuel ethanol production (Fig.19) will reach 63 billion litres by 2012. This is a growth rate of 5% per annum. Around world 40% of ethanol was sourced from sugar (mainly Brazil), 40% from corn (mainly US) with the remainder sourced from other countries (Fig.19). It is claimed that ethanol in the US and Brazil would have occurred without government support.

Figure 18: Map of Ethanol Plants in Australia (Biofuels Association of Australia, 2012)
http://www.biofuelsassociation.com.au/index.php?option=com_content&view=article&id=74&Itemid=91

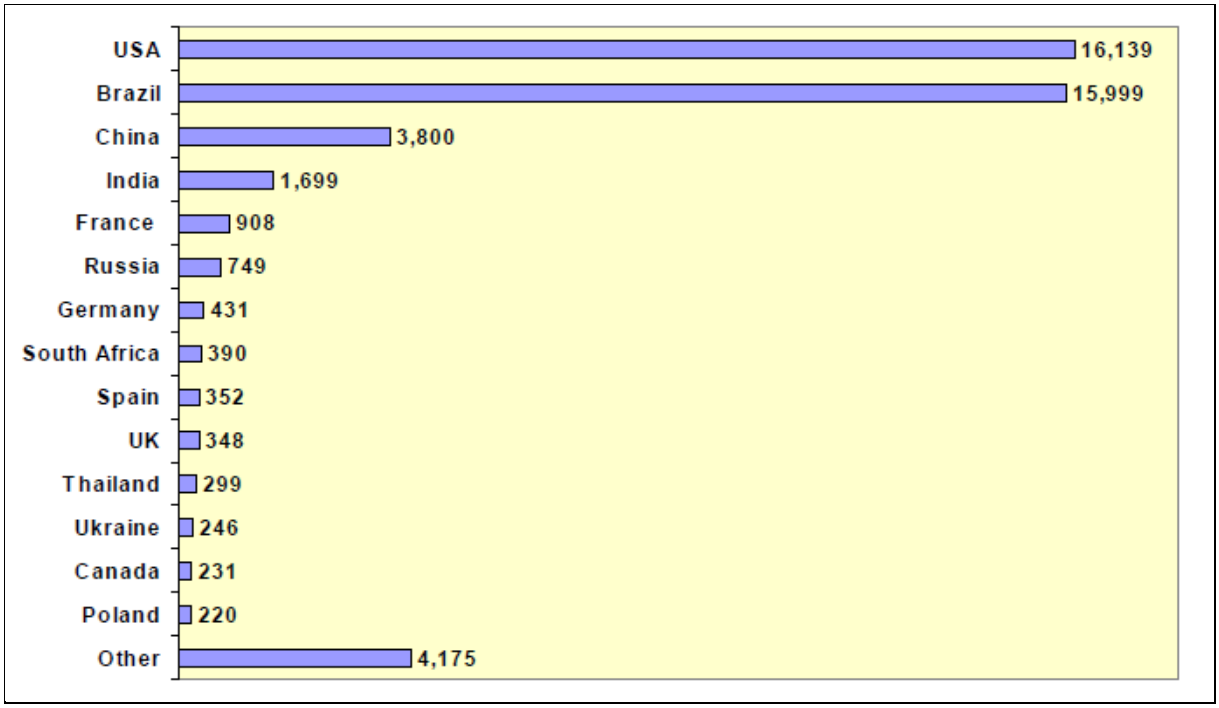
Table 8: Ethanol Plants in Australia (Biofuels Association of Australia, 2012)

Plant	State	Capacity (ML)	Feedstock
Sarina Distillery (Mackay)	QLD	60	Molasses (by-product from sugarcane)
Dalby Bio-Refinery	QLD	80	Sorghum grain – consuming some 200,000 tonnes of sorghum a year
Manildra Ethanol Plant	NSW	300	Starch (by-product from flour milling)

Depending on the starch content, 1 tonne of grain can produce 360 to 420 litres of ethanol, or 1000 to 1500 litres of ethanol per ha for an average 3 to 4 t/ha sorghum yield. In comparison, one person would directly consume, on average, only 100-200 kg of grain per year. Using cotton stalk waste as the feedstock, and assuming the industrial process yield in the distillery as 80% of the theoretical yield based on cotton stalks chemical composition, the cotton stalk ethanol yield may be around 180 kg (225 kL)/tonne of dry feedstock (Pappis and Petrou, 2011) .

Taking a full life cycle analysis approach from sugar production to delivery of the ethanol to the end customer, it is found that bioethanol has an extremely good energy ratio delivering 7.6 units of energy (9.3 prior to shipping) for every unit of input for Brazilian sugarcane. This energy ratio is projected to improve to 9.9 by 2020 (11.6 prior to shipping - Macedo et al., 2008). In comparison, the cotton stalks ethanol system has a relatively poor environmental performance (especially regarding the land use impact category) because of its low production yield in ethanol (as a consequence of cotton stalks' low concentration in cellulose) and its low raw material production yield (1 to 2 t/ha).

Figure 19: World ethanol production in 2005 [million litres]
http://www.landcorp.com.au/_document/Ord-Land-Release/DAFWA-Sugar-Production-Potential-Kimberley_pi1.pdf



Ethanol plants have a high plant capital cost. The wet cereal ethanol co-product has also a limited storage time of 3 to 5 days. Research has thus been undertaken to develop methods of increasing the storage time with limited success.

Research is being actively conducted to identify, select and breed specific crop varieties tailored for energy and biofuel production, including the native plant species (Ashwath, 2010). Recent US research is looking at inserting a specific gene to keep the perennial grass in its juvenile form — a plant that doesn't flower, doesn't produce seeds, and doesn't have a dormant growth phase, so that the sugars making up the plant starch are more readily available for conversion into cellulosic ethanol http://www.centralvalleybusinesstimes.com/stories/001/?ID=21830.

Biodiesel

Biodiesel is a liquid fuel made from processing of tallow (animal fat) or vegetable oil in a process called “esterification”. Overall, biodiesel production is a simple process of removing glycerates from vegetable oil and only needs a cheap source of feedstock. This can be done on a small scale on the farm http://www.bebioenergy.com/documents/BallaratUniversity.pdf to provide fuel for diesel-powered farm machinery. By comparison, ethanol involves a fermenting process and is more expensive to set up a processing plant.

Figure 20: Predicted wholesale ethanol price in Australia [cents/litre]
http://www.landcorp.com.au/_document/Ord-Land-Release/DAFWA-Sugar-Production-Potential-Kimberley_pi1.pdf

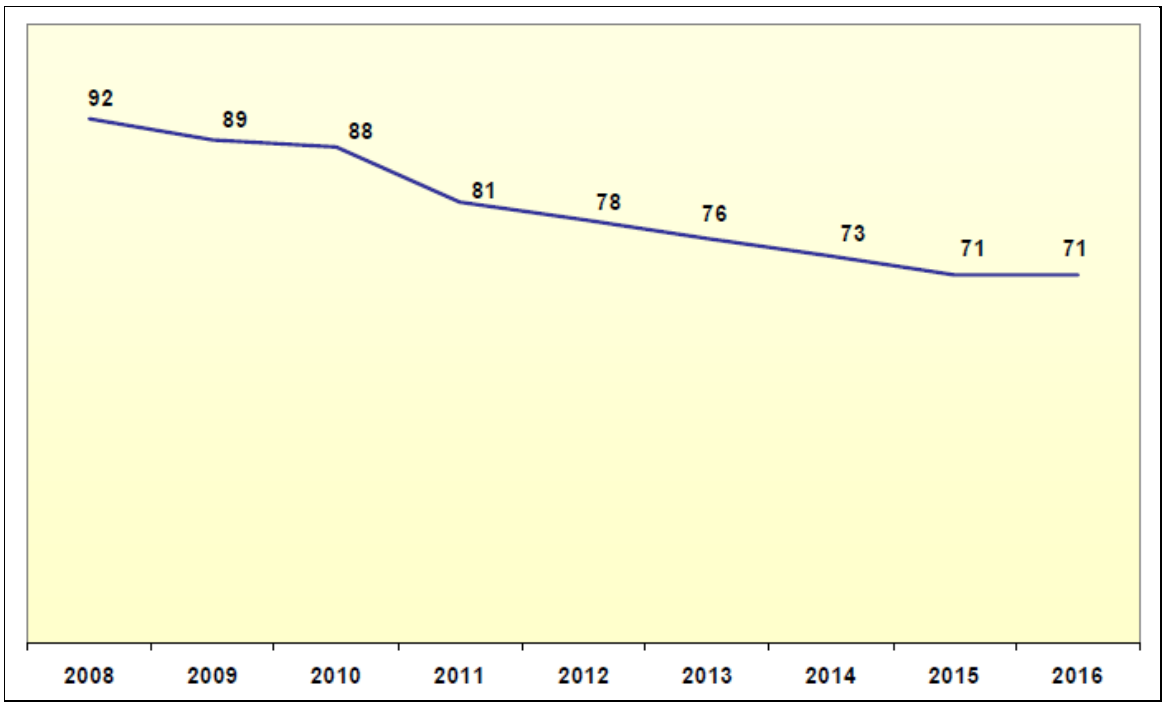


Table 9 shows the estimated input costs for biodiesel production from Canola, assuming $375 per tonne canola price and $250 per tonne meal price (Whittington, 2006). The cost of capital will vary widely depending on what existing infrastructure can be used and how much biodiesel is produced. In comparison, the price of cottonseed varies between $180-250 per tonne. The assumed transport cost from oil plant to cotton farm may also be reduced.

Table 9: Input costs ($/L) for biodiesel production from Canola (Whittington, 2006)

Plant capital cost	0.27
Canola	0.57
Crushing cost	0.22
Transport	0.12
Methanol and caustic	0.20
Electricity	0.02
Labour	0.03
Total input costs	1.43

Biodiesel is renewable and can be used as a fuel in diesel engines either as biodiesel (processed vegetable oil, as above) or as straight oil that has been filtered. The energy content of biodiesel is approximately 36.2 MJ/L. Biodiesel fuel can be made from new or used vegetable oils and animal fats (from livestock by-products). Typical vegetable oils include canola, sunflower and soybeans (Table 10). The oil content of cottonseed is 19% (Girard and Fallot, 2006) while this is 40% for Canola.

Table 10: Biofuel yields per ha [L/ha and GJ/ha] (Girard and Fallot, 2006)

Generation	Biofuel	L/ha	GJ/ha
First	Sunflower biodiesel	1,000	35
	Soybean biodiesel	500 - 700	17 - 25
	Canola biodiesel	1,200	42
	Wheat ethanol	2,500	53
	Maize ethanol	3,100	65
	Sugar beet ethanol	5,500	116
	Sugar cane ethanol	5,300 – 6,500	110 - 140
Second	FT biodiesel eucalyptus plantation	13,500 – 18,000	470 – 620
	Methanol eucalyptus plantation	49,500 – 66,000	770 – 1,030
	DME eucalyptus plantation	45,000 – 60,000	850 – 1,130

Assuming an average annual production of 2 million bales of cotton, Australia will produce some 500,000 tonnes of cottonseed as a by-product (Queensland Cotton 07 3250 3323). This will produce up to 100 ML of cottonseed biodiesel, or up to about 3 times of cotton direct on-farm fuel demand assuming 150L diesel use per ha (Chen and Baillie, 2009). The estimated around 500 L per ha cotton biodiesel yield potential (100 ML for 0.2 m ha cotton plantation) is also roughly consistent with the estimations of Baffes (2010) and Girard and Fallot (2006). Tests have also indicated that the use of cottonseed biodiesel in internal combustion engines give comparable performance to conventional diesel (Leenus Jesu Martin et al, 2011; Al-lwayzy, et al, 2011)

Although biodiesel has better combustion efficiency, there are a number of issues that will influence the future production and utilization of biodiesel. These include the need to meet the usual costs and technical specifications, such as performance at low temperature, fuel quality standards, and decrease in power and torque generated by biodiesels (Hansen and He, 2010). Others may include carbon deposits formation, fuel filter clogging and engine wear etc. Higher costs of maintenance may thusbe likely.

For diesel engines, there are two main approaches to the use of bio-diesel:

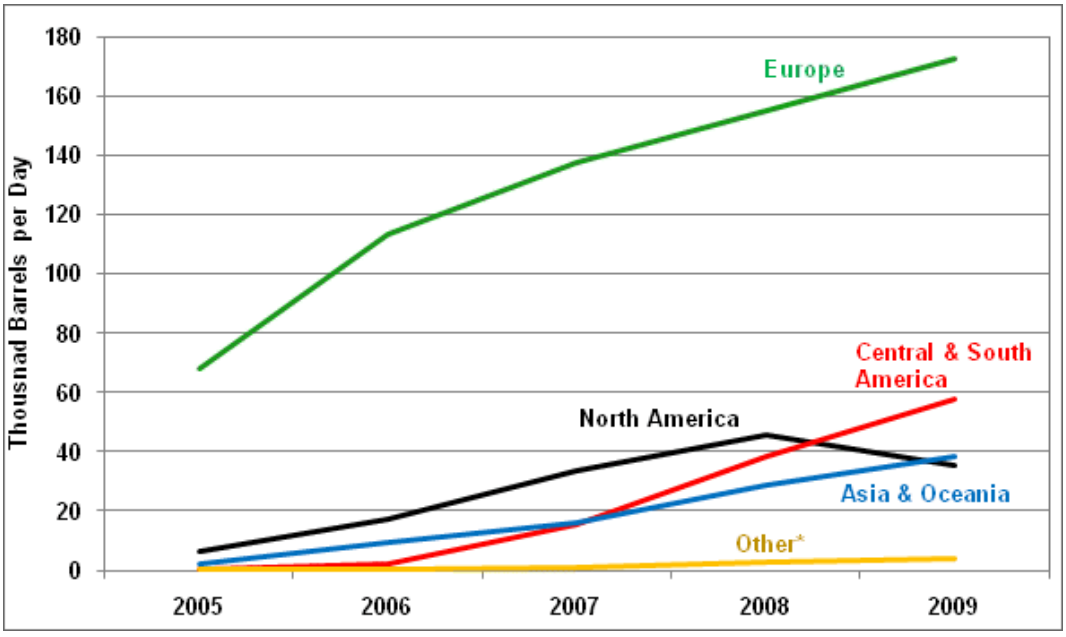
- The first approach is to test the properties of fuel, and if necessary modify the fuel to run in the vehicle so that bio-diesel can be used as a straight replacement for diesel.
- The second approach is to modify the fuel delivery system. With this option, a second fuel tank and other modifications to machinery may be necessary.

It was claimed that biodiesel blends of 20% or less should not change the engine performance in a noticeable way. This has included the cottonseed oil (Leenus Jesu Martin et al, 2011). Blends of up to 5% biodiesel in conventional diesel are permissible in Australia without any labelling changes or notification to the consumer.

Like ethanol, food versus fuel balance is also an important issue when using food crops for the production of biodiesel. Excessive uses of food for fuel could either decrease the food supply around the world, or it increase deforestation to provide more farmland, both of which are undesirable. It was said that filling one tank of biodiesel could use 1 year's food for poor people. It was also estimated that biofuel production needed to replace just 10% of fossil fuels in transport in the US, Canada and the European Union could require between 30 and 70% of existing crop areas. The co-products from the production of biodiesel, canola and soybean meals have been used in Australian pig and poultry diets for many years.

Alternative sources of second-generation feed stocks for biodiesel, for example, from ''industrialized'' sources such as algae oil or agricultural wastes are being actively researched. It is predicted that the technology for the second generation biofuels may take another 10 years to become viable to compete with "cheap" mineral oil.

Figure 21: World biodiesel production by region and selected countries, 2005-2009
http://www1.eere.energy.gov/vehiclesandfuels/facts/2011_fotw662.html



The life cycle energy balance of biodiesel production from canola under typical Western Australian (WA) agricultural practices has been analysed (Rustandi and Wu. 2009), which considers all direct and indirect energy consumptions during canola seed cultivation, canola seed oil extraction and transesterification for biodiesel production. By-products, including agricultural residue (canola straw), canola seed meal and glycerol are also considered in different scenarios. It is shown that the net energy returns for biodiesel production from canola in WA may be negative. Only marginal energy return is achieved even when energy in by-products is considered. The key reason for this is because of the relatively low yield of grain crops and the extra nitrous oxide (N_2O) being emitted due to the applications of synthetic nitrogen fertilizers in producing these crops. N_2O is a greenhouse gas with a Global Warming Potential (GWP) approximately 300 times that of carbon dioxide (CO_2), so a small amount could make a huge difference. In addition, making nitrogen fertilisers also consume considerable energy (1 kg of nitrogen fertilisers use the energy equivalent to 1.5 to 2 litres of diesel fuel to make it).

To replace 15% of diesel consumption in WA by canola-based biodiesel, it is estimated that over 0.8 million hectares of agricultural land is required - double the current total land for oilseed production in WA. Therefore, it is concluded that biodiesel production from canola in WA may not be sustainable and its wide implementation can significantly compete with food production.

Figure 22: Biodiesel production facilities in Australia

http://www.biofuelsassociation.com.au/index.php?option=com_content&view=article&id=59&Itemid=67

Table 11: Biodiesel Plants in Australia (Biofuels Association of Australia, 2012)

Biodiesel Plant	State	Capacity [ML]	Feedstock	Status
Smorgon Fuels - BioMax Plant	VIC	15 to 100	Tallow, canola oil, dryland juncea (oilseed crop)	In production
Biodiesel Producers Limited	VIC	60	Tallow, used cooking oil	In production
Australian Renewable Fuels Largs Bay	SA	45	Tallow, used cooking oil	In production
Australian Renewable Fuels Picton Plant	WA	45	Tallow, used cooking oil	In production
Biodiesel Industries Australia	NSW	20	Used cooking oil, vegetable oil	In production
Vopak	NT	130	Palm oil	Not in production
Eco-Tech Biodiesel	QLD	30	Tallow, used cooking oil	Not in production
National Biofuels Plant	NSW	300	Soya	Potential

Biodiesel is commercially available in Australia and is predominantly blended with petroleum diesel at a rate of 20% or less. Currently, there are seven biodiesel plants in Australia with a combined capacity of over 240ML/year and one potential renewable diesel plant. However, only four or five of these plants are operating so the actual production of biodiesel is around 50-100 ML/year (or around 2-5 L per person per year), which is less than 1/3 of the amount of ethanol produced. Currently, demand for biofuels makes up just 1 per cent of total fuels demand. The aviation industry in particular is very interested in biofuels and has trialled the use of jet fuel made from waste oil.

Biogas

Biogas is a combustible gas derived from decomposing biological waste in the absence of oxygen. Biogas normally consists of 50% to 60% methane. It is currently captured from landfill sites, sewage treatment plants, livestock feedlots and agricultural wastes. The typical conditions required are biomass combined with water in a lagoon or containment vessel, with the combined solution being maintained between 16°C and 60°C. Recent research (Isci and Demirers, 2007) shows that the average amount of biogas generated from 1 kg of three different cotton wastes (cotton stalks, cotton seed hull and cotton oil cake) is 76 ml, which indicates that 13 kg of cotton waste is needed to produce $1m^3$ (39 MJ or 0.67 kg) of pure methane. Based on these results, the annual methane production of Australia via digester bioconversion of the estimated 0.4 million tonnes of cotton stalk waste (for 2 million bales of cotton) may be calculated as 30 million m^3, containing 12 PJ of primary energy or equivalent to 300 ML of diesel energy. Alternatively, this amount of gas has the potential to generate some 1500 million kWh of electricity each year. Research is also being conducted to investigate the use of biogas as fuel for combustion engines. Particular issues here include adding other high energy fuels to improve combustion speed. The desirability of converting cotton stalks into methane gas is to be debated, as the former is currently ploughed back as mulch to improve soil organic matter.

17. Hydro Power

Hydropower is a well proven and advanced technology, with more than a century of experience. Modern power plants provide extremely efficient energy conversion.

Small-scale micro hydro power is both an efficient and reliable form of energy, most of the time. However, there are certain disadvantages that should be considered. These include that hydropower is only suitable for sites with large volumes of flowing water. Considerable capital investment is required, especially for large schemes. It is crucial to have a grasp of the potential energy benefits as well as the limitations of hydro technology.

The amount of electricity generated from a system also depends not only on its capacity (size of turbine and generator) but also on the amount of water available. In times of drought, water to hydroelectricity systems is limited and they have a reduced electricity output. Overall, Australia is a dry continent and has limited hydro-electric resources. Much of the best large-scale hydro sites have already been developed, although opportunities remain for small-scale hydro projects utilising existing infrastructure.

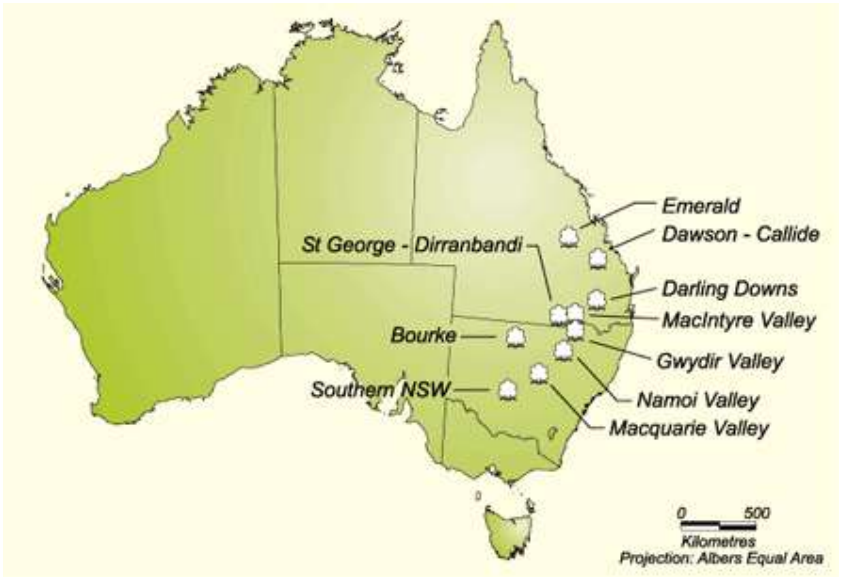
18. Specific applicability of alternate energy sources in cotton production regions

18.1 Cotton growing regions of Australia

Australian Natural Resources Atlas (Fig. 23) has broadly divided Australian cotton production areas into 3 regions: Northern Region (Emerald and Dawson-Callide districts), Central Border Region (Macintyre Valley, Darling Downs, St George-Dirranbandi, Namoi Valley and Gwydir Valley districts), and Southern Inland Region (Macquarie Valley, Bourke and Southern NSW districts).

Figure 23: Cotton growing areas of Australia

http://www.anra.gov.au/topics/agriculture/cotton/index.html



In Australia, cotton is farmed mainly in New South Wales and Queensland. On average, 500,000 ha of cotton are planted annually, yielding 1 to 4 million bales of cotton per year. Currently, Australia yields an average 1,907 kg (8.4 cotton bales) per hectare. This figure is almost two and a half times the world average of 747 kg/ha. Around 80% of Australian cotton is irrigated (Cotton Australia, 2010 http://cottonaustralia.com.au/cotton-library/fact-sheets/cotton-fact-file-water).

18.2 Availability of alternative energy resources in the cotton growing regions

Australia has the highest average solar radiation per square metre of any continent in the world. From the comparison of Fig. 12 with Fig.23, it can be seen that although solar energy resources are the greatest in the northwest and centre of Australia, the cotton farming regions are also highly suitable for solar electricity generation.

Table 12: Key alternative energy source suitability table

	Northern Region	Central Border Region	Southern Inland Region
Solar	High	High	High
Wind	Low	Low	Low
Ethanol	High	High	High
Biodiesel	High	High	High
CNG	Excellent	High	Fair
LPG	Widely available	Widely available	Widely available

Wind power is an alternative and renewable electrical energy source suitable to areas of Australia with average wind speeds above 5 m/s. However, from the comparison of Fig.15 with Fig.23, it can be seen that Australia's wind energy resources are located mainly in the southern parts of the continent. It appears that most of the cotton farming regions have a lower average wind speed of around 3m/s and may not be suitable for the development of large scale wind farms.

Australia's potential bioenergy resources are also large and diverse. There are under-utilised resources in crop residues, forest residues and waste streams. In the cotton farming regions, there are significant potential of locally produced crops and crop wastes (cottonseed for biodiesel, cotton stalk for ethanol and biogas or direction combustion, sugar bagasse for combustion, corn and sorghum for ethanol production).

As found above, although the oil content of cottonseed is relatively low at 19%, it is estimated that it has the potential to produce up to 100 ML of cottonseed biodiesel per year or 500 L per ha, or up to about 3 times of cotton direct on-farm fuel demand. The annual ethanol and methane biogas production via fermentation or digester bioconversion of cotton stalk waste is also calculated as up to 40 ML ethanol or 15 million m^3 methane biogas, containing 6 PJ of primary energy. The drying energy demand of cotton ginning operation can also be largely provided by the combustion energy of gin trash which is readily available at the ginning sites, avoiding the current reliance on LPG or natural gas.

Table 13: Potential use of cotton waste and by-products

	Potential available energy	Potential contribution to direct on-farm energy demand	Potential contribution to life cycle primary energy demand
Biodiesel from cottonseed	500 L/ha	1.5-5 times (average may be around 3 times)	20-45% (average may be 30-35%)
Ethanol or methane biogas produced from cotton stalks and other by-products	500 L/ha ethanol or alternatively 300 m^3 or 200 kg/ha methane biogas		10-20%
Energy from direct combustion of gin trash for cotton drying	200-300 MJ/bale or 2-3 GJ/ha or $50-75/ha to replace LPG, or $25-35/ha to replace natural gas	1-3 times of cotton drying energy need, depending on moisture removal (average may be around 3 times)	2-5%

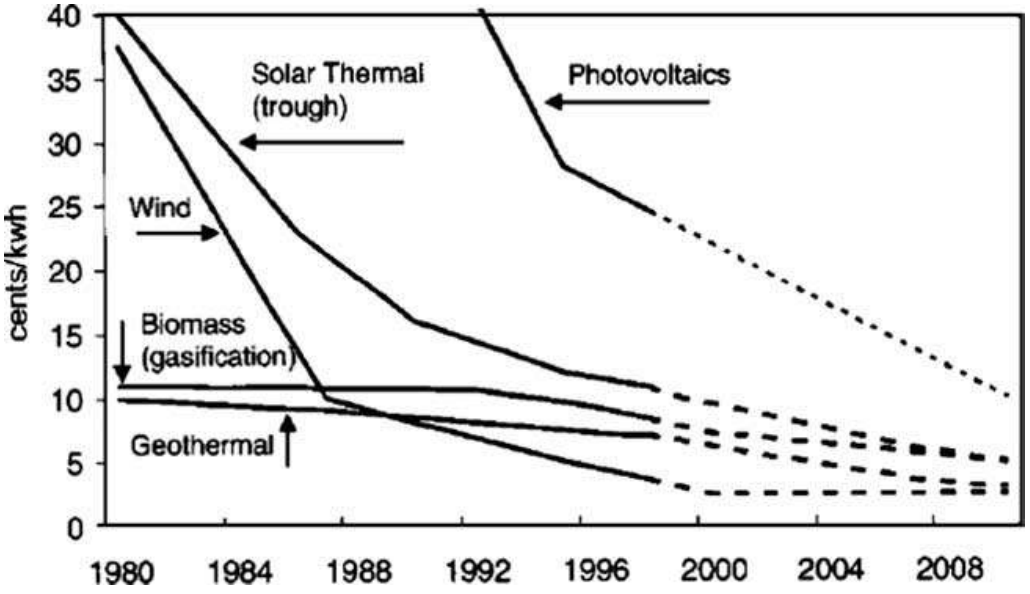
18.3 Key project considerations

Where the opportunities are appropriate, renewable energy such as solar, wind and bio-fuel can be integrated into the farming operations to save energy costs and reduce greenhouse gas emissions. Examples of specific applications (USAID, 2009; Chel and Kaushik, 2011; Chen and Maraseni, 2012) include solar crop drying, solar space and water heating and using biomass for heating purpose and electricity generation. Other applications include off-grid electric fences, lighting, irrigation, livestock water supply, wastewater treatment pond aeration, communication and remote equipment operation and others. Fig.24 shows the estimated costs for various electricity generation technologies. Overall, renewable energy at present may not be viable to serve in large scale as a primary energy source. In many cases, additional government support and financial incentives would be required to compete with more polluting fossil fuels. However, because of the increasing concern over the greenhouse gas emissions and declining reserves of fossil fuel, use of renewable energy is on the rapid rise globally. This will lead to further reduction in their prices.

In addition to the cost of production, other factors may also influence the viability of alternative energy. For example, the wind is not always predictable (Kitaneh et al, 2012). This increases the supply capacity risk and may require supplementary capacity from alternative sources. Noise is another factor. Subject to turbine design, a wind generator may make a constant, low, "swooshing" noise day and night and it has been required in Victoria that large wind turbines should not be built within 2 km of an existing homes. In comparison, solar power can be used where there is no easy way to get electricity or to a remote place. It has also better reliability and a 25 year warranty, and is totally silent in operation. The infrastructure necessary for large scale projects would however require a large amount of capital. For example, producers of renewable and bioenergy do not always have the capability of supplying power generated into the electricity grid. If a site is generating over 100kW of

electricity, it will need to negotiate access with the owner of the electricity infrastructure and also negotiate a feed in tariff. The location of power generation, which can often be remote, may be in an area with little capacity to accept the energy generated.

Figure 24: The electricity costs by different renewable sources (Bull, 2001)



Biodiesel is not quite suitable for use in the winter of cold regions in Western NSW and Queensland. CNG may require machinery modifications. Bioenergy is also dependent on a wide range of factors such as feedstock prices, seasonal availability and the relative value of biomass for the production of other commodities.

18.4 Indirect tariff and policy issues and carbon tax implications

There are a number of financial incentives available to assist farmers in the uptake of renewable energy sources. Feed-in-tariffs (FiT) have been introduced by a number of states to increase the amount of solar PV power generated. The New South Wales State (Labor) Government originally announced details of the state's feed in tariff incentive on June 23, 2009. On November 9 2009, it made a further decision to switch from a net feed in tariff to the gross model which is a much more generous arrangement. http://www.energymatters.com.au/government-rebates/feedintariff.php. However, on May 13, 2011, after the election, the new NSW Government (Liberal-National coalition) announced the NSW Solar Bonus Scheme was closed to new applications. Western Australia also saw their Solar Feed-in Tariff incentive programs eliminated completely after Liberal Party took office in 2008.

The Queensland Government Solar Bonus Scheme commenced on 1 July 2008. However, the new Queensland LNP Government after the March 2012 election has announced that from midnight on July 9, 2012, the generous 44 cents/kilowatt scheme will be reduced 8 cents/kilowatt hour to new installations. Existing Solar Bonus Scheme participants will continue to receive 44 cents/kilowatt hour feed-in tariff.

At the Federal Government level, the Mandatory Renewable Energy Target (MRET)which was introduced in 2001 aims to ensure that renewable energy obtains a 20% share of total electricity supply in Australia by 2020. The MRET requires wholesale purchasers of electricity to purchase Renewable Energy Certificates (RECs) equivalent to 1MWh of electricity generation from a certified renewable energy source. These sources include wind, hydro, landfill gas and geothermal, as well as solar PV and solar thermal, providing a stimulus and additional revenue for these technologies. Currently RECs trade around $26 to $40 each. The scheme will last until 2030, although there is recently a debate if it is a cost-effective way to reduce the greenhouse gas emissions.

Overall, the optimism of green energy companies has somehow dimmed since the carbon tax legislation was passed in 2011, amid political uncertainty and growing concern over the forthcoming review of the 20 per cent by 2020 renewable energy target. The Victorian government has recently scrapped its target of a 20 per cent cut to greenhouse gas emissions by 2020 which has already impacted on the local renewable industry. The oversupply of renewable energy certificates has also held electricity retailers back from new investment. The tight finance conditions worldwide were particularly squeezing for the renewable industry and the customers.

The carbon price is unlikely to have much of an impact on generation choice until it reaches a level of about $50 a tonne, and on current scenarios that seems unlikely for a decade at least. So the fortunes of clean energy technologies, particularly those in emerging technologies, will lie mostly in schemes such as the Renewable Energy Target, financing through the Clean Energy Finance Corporation, and grants from the Australian Renewable Energy Agency. The schemes are however also subject to uncertainty. http://www.theaustralian.com.au/business/opinion/carbon-price-means-good-news-and-bad-for-industry/story-e6frg9if-1226404835074

For biofuels, a production grant of 38.143 cents per litre for bio-diesel and 7.6 cents per litre for ethanol, equal to the excise duty rate (fuel tax), is also currently available to domestic producers of biofuels. This scheme has recently been extended “indefinitely”.

19. Current and future large projects of alternate energy sources in the cotton regions

Although not directly related to cotton farming, the following two large-scale solar projects in/near the cotton farming regions is also worth of mentioning:

- The Moree Solar Farm, a 150MW photovoltaic panel farm, costing $923 million, in northern NSW backed jointly by Pacific Hydro and Spanish firm Fotowatio Renewable Ventures. The Moree Solar Farm could be one of the world's largest solar generation facilities, supplying enough energy to power 45,000 homes. Construction was set to begin in the second half of 2012, with a completion date set for 2015. However, delay may be expected, due to funding issues after BP announcing its intent to withdraw from the project and pull its funding.
- Solar Dawn, to be built near Chinchilla in South West Queensland, costing $1.5 billion, and potentially being one of the biggest solar power stations in the world, has not been able to meet a June 30, 2012 financial deadline, following the withdrawal of $75 million state government’s support. The 250 MW Solar Dawn uses the advanced solar thermal technology, also known as concentrating solar power, where sunlight is focused with lenses or mirrors and tracking systems to create a high-intensity heat source to create steam and drive turbines to generate

electricity. While more expensive than PV technology, this method has the advantage that its energy can be stored and dispatched when needed.

20. Conclusion

Agriculture requires energy as an important input to production. In Australia, to produce 1 bale of cotton, up to 300 L of fuel equivalent of primary energy may be consumed and 900 kg of greenhouse gases emitted. With the rising energy costs and increasing concern over greenhouse gas (GHG) emissions and pressure on clean production, farm energy efficiency and conservation is becoming increasingly important.

There are two main ways in which energy costs can be managed. The first is to look at energy efficiency on farms. It has been shown that the total energy inputs can be significantly influenced by the management and operation methods adopted. By appropriate technology changes in production and processing, fossil energy use in the current agricultural system could be significantly reduced. For example, 20 to 30 % of fuel may be "easily" saved by improving the engine operations and pumping systems. Zero-tillage and controlled traffic also use much less energy (10 to 15%) than farms with conventional tillage. Furthermore, the cost of nitrogen fertiliser is a reflection of world energy prices. Maximising the efficiency of fertilisers and the use of legumes (to produce nitrogen) will come into play with rising energy prices.

The second way to manage energy costs is to consider alternative fuels. The supply of oil in Australia is already on the decline and Australia is becoming increasingly dependent on imported oil and petroleum products. The main volume alternative is natural gas which is abundant in Australia and can be used for both electricity generation and other purposes. Natural gas as an important current and future energy source has significant environmental benefits over both coal and oil in terms of lower greenhouse gas and other emissions. When sourced from local gas supplies, the cost of compressed natural gas (CNG) could be as low as 30% of the cost of diesel, and 50% of the cost of LNG. Some machinery modifications may be necessary and current research is being focused on the conversion technology for diesel engine to use these energy sources, particularly the design of vehicle fuel and tank systems.

Renewable energy is another important direction for further research. Research and use of renewable energy is on the rapid rise globally. Wind energy has experienced strong growth over recent years and now represents 1.5% of total electricity generation in Australia. Solar energy is being used increasingly as an energy source for pumping water for live stock, but it appears to be too expensive at present to provide energy for larger pump stations or electricity for other farming operations.

Despite of the current arguments, the long-term future for renewable energy is definitely positive since the prices of fossil fuels will continue to rise as the resources are depleted while the prices of renewable energy will continue to decrease as technology improves. For example, the electricity price in Australia has been increasing at a rate of 10 to 20% per annum in the last couples of years, while the price of solar PV has been steadily decreasing at a rate of 10 to 40% per annum in the same period of time.

Agriculture can also contribute to energy security, farming incomes and carbon sequestration through production of biofuels and bioenergy. Australia has a large agriculture sector and this presents excellent opportunities for the development of bioenergy resources. It may also allow the farmers be

transformed from pure energy consumers into "prosumers". One of the major barriers to implementation of alternative and biomass energy in Australia has been the relatively low cost of fossil fuels, specifically coal. There are also other barriers to uptake: capital expenditure is sometimes required to replace existing boilers, and boiler management is likely to be more time consuming (depending on the fuel source). Development of an efficient harvesting and transport technology of the bulky biomass can also be a challenge. Production of biofuels is dependent on the quantity and geographic location of the biomass. In addition, bioenergy resources need to deal with issues of sustainability if they are sourced from food crops. Alternative sources of second-generation feed stocks for biodiesel from ‘‘industrialized’’ sources such as algae oil or agricultural wastes such as cotton stalk and ginning trashes are being actively researched. Further research is also required on the methods of on-farm production, collection, storage, conversion, and use of this significant resource.

Specific applicability of alternate energy sources in different cotton production regions has been evaluated in this report, including the indirect tariff and policy issues and carbon tax implications. It has been found that in the cotton growing regions, the preferred alternative energy sources may be solar and bioenergy, rather than wind energy. The viability of alternative energy may be subject to uncertainty in the government policies.

Although the oil content of cottonseed is relatively low at 19%, it is estimated that it has the potential to produce up to 100 ML of cottonseed biodiesel per year or 500 L per ha or up to about 3 times of cotton direct on-farm fuel demand. The annual ethanol and methane biogas production via fermentation or digester bioconversion of cotton stalk waste is also calculated as up to 80 ML ethanol or 30 million m^3 methane biogas, containing 12 PJ of primary energy. The drying energy demand of cotton ginning operation can also be largely provided by the combustion energy of gin trash which is readily available at the ginning sites, avoiding the current reliance on LPG or natural gas.

There are already a good number of successful examples of application of alternative energy sources in the cotton industry, including the use of biodiesel and LPG for water pumping operations (http://www.bennettclayton.com.au). To use these alternative fuels, some machinery modifications may be necessary. Current research is focused on the conversion technology for diesel engine to use these energy sources, particularly the design of vehicle fuel and tank systems. Some research shows that biodiesel blends of 20% or less would not change the engine performance in a noticeable way. It has also been found that research and practical on-farm demonstrations are essential for the success of these technologies and will be needed to further assess viability of the use in agriculture and clarify the technical issues raised.

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Glossary:

- **Biodiesel.** Biodegradable transportation fuel for use in diesel engines that is produced from biomass (organically derived vegetable oils or animal fats). The oil or fat is reacted with alcohol to produce a fuel that can be used on its own or mixed with petro-diesel.
- **Biofuels.** Liquid fuels, such as ethanol and biodiesel, made from biomass. These fuels can be used in their pure form or blended with petrol or petro-diesel. First generation biofuels are based on fermentation and distillation of ethanol from sugar and starch crops or chemical conversion of vegetable oils and animal fats to produce biodiesel. First generation technologies are proven and are currently used at a commercial scale. Second generation biofuels use biochemical or thermochemical processes to convert lignocellulosic material (non-edible fibrous or woody portions of plants) and algae to biofuels. Second generation technologies and biomass feed stocks are in the research, development and demonstration (RD&D) stage. Third generation biofuels are in research and development (R&D) and comprise integrated biorefineries for producing biofuels, electricity generation and bioproducts.
- **Biogas.** A combustible gas derived from decomposing biological waste, including digester gas. Biogas normally consists of 50% to 60% methane. It is currently captured from landfill sites, sewage treatment plants, livestock feedlots and agricultural wastes.
- **Coal.** A hydrocarbon-based fossil fuel composed of the remains of land plants which have been transformed into a solid mass of carbon, hydrogen and oxygen through the heat and pressure resulting from burial. Coal is found in seams that can be extracted either by surface or underground mining.
- **Coal seam gas (CSG).** Natural gas extracted from underground coal seams. CSG can be processed as LNG and CNG. The Coal Seam Gas industry has the potential to offer substantial economic and other benefits to Australia. However, if not adequately managed and regulated, it also risks having significant adverse impacts on adjacent surface and groundwater systems.
- **Compressed Natural Gas (CNG).** Natural gas that has been compressed under high pressures and held in a container; expands when released for use as a fuel. CNG is also a cleaner alternative to other fuels such as petrol and diesel.
- **Crude oil.** Complex liquid mixture of hydrocarbons, with small amounts of S, O, N impurities. Crude oil can be refined to produce heating oils, gasoline, diesel, jet fuels, lubricants, asphalt, ethane, propane, butane and many other products.
- **Diesel.** A petroleum-based fuel used in engines ignited by compression rather than spark. Diesel fuels are heavier and produce higher emissions than petrol. They also provide more power per unit of volume.
- **Digester gas.** Biogas that is produced using a digester which is an airtight vessel or enclosure in which bacteria decomposes biomass in water to produce biogas.
- **Electricity.** Electric current generated by (mostly) coal-fired power stations and used as a power source.
- **Emissions.** The release or discharge of gases or particulate matter into the air or water.

- **Energy crops.** Crops grown specifically for their fuel value. These include food crops such as corn and sugarcane and non-food crops such as poplar trees and switch grass. Currently, energy crops under development in the U.S. include short-rotation woody crops, which are fast-growing hardwood trees harvested in five to eight years, and herbaceous energy crops, such as perennial grasses that can be harvested annually after reaching full productivity in two to three years.
- **Energy source.** Any substance that supplies heat or power (e.g. petroleum, natural gas, coal, renewable energy and electricity).
- **Ethanol.** An alcohol compound with the chemical formula C_2H_5OH formed during sugar fermentation by yeast. Also known as grain alcohol. Blends of 90% unleaded petrol and 10% fuel ethanol are commonly referred to as E10.
- **Fossil fuel.** Fuels produced by the decomposition of deeply buried organic matter from plants & animals
- **Gigajoule (GJ).** A unit of measurement of energy consumption. A gigajoule is equal to one billion joules. At the current market condition, 1 GJ of energy would typically cost around $10 to $40. The corresponding greenhouse gas emissions range from zero (using 100% renewable energy) to around 78 kg CO_2/GJ (using diesel fuel).
- **Liquefied Natural Gas (LNG).** Natural gas which has been cooled to its boiling point of minus 161ºC at which it liquefies, reducing its volume to one 600^{th}. Exports are currently worth more than $3.2 billion a year and it is forecasted that LNG sales in Australia could triple in the next five years, putting the industry on par with iron ore and coal in terms of export contributions to the economy.
- **Liquefied Petroleum Gas (LPG).** LPG is usually derived from fossil fuel sources, being manufactured during the refining of crude oil, or extracted from oil or gas streams as they emerge from the ground.
- **Mandatory Renewable Energy Target (MRET).** A target level of renewable energy to be produced and used. Usually expressed as a percentage of total electricity usage, e.g. 20% by 2020.
- **Methane** is a colourless, flammable, nontoxic gas with the chemical formula CH_4.This gas is created by anaerobic decomposition of organic compounds. Wetlands, livestock and energy are the main sources of methane emissions to the atmosphere, where it acts as a greenhouse gas. Methane is also a major component of natural gas. It is mainly extracted from geological deposits for fuel and industrial uses.
- **Natural gas.** Underground deposits of gases consisting of 50% to 90 % methane (CH_4) and small amounts of heavier gaseous hydrocarbon compounds such as propane (C_3H_4) and butane (C_4H_{10}). As a fuel, natural gas is convenient and efficient. It is currently used primarily for heat. It is also used to produce electricity, in some cases using gas fired turbines, in others to fire steam boilers.
- **Petajoule (PJ).** A unit of measurement of energy consumption. One petajoule is equal to one million gigajoules, or 10^{15} joules. One petajoule is also the heat energy content of about 43 000 tonnes of black coal or 29 million litres of petrol.
- **Petrol.** A fuel refined from oil that is used in internal combustion engines.

- **Photovoltaic.** A system that converts direct sunlight to electricity using semi-conductor materials.
- **Renewable energy.** Naturally occurring energy sources that are continually replenished. Examples of renewable energy are wind, solar and water.
- **Solar energy.** The radiant energy of the sun, which can be converted into other forms of energy, such as heat or electricity.
- **Solar thermal collector.** A device designed to receive solar radiation and convert it into thermal energy. Normally, a solar thermal collector includes a frame, glazing, and an absorber, together with the appropriate insulation. The heat collected by the solar thermal collector may be used immediately or stored for later use.
- **Wind energy.** Energy present in wind motion that can be converted to mechanical energy for driving pumps, mills, and electric power generators. Wind pushes against sails, vanes, or blades radiating from a central rotating shaft.
- **Wind turbines.** Converts the wind's kinetic energy into mechanical power that a generator, in turn, converts into electricity.

Appendix 1: Characteristics of possible alternative energy sources for cotton farming in Australia

Energy Type	Description	Main advantages	Main disadvantages	Estimated costs	Potential for the cotton industry
(Grid) Electricity	Electric current used as a power source. In Australia, grid-supplied electricity is mostly generated from fossil fuels (mostly the lower quality brown coal, particularly in Victoria).	• High-grade energy • Clean and very convenient for use on site	• Relatively expensive • May not available everywhere • Use of 1 kWh electricity in Australia emits around 1 kg CO_2 (244 kg CO_2–e/GJ) • Grid electricity is responsible for emitting around 40% of Australia's total greenhouse gases.	• $40/GJ (15c/kWh) • Off-peak electricity may costs only 1/3 of the peak electricity cost • Typically, network costs may make up between 40 to 50% of a power bill.	• Electricity price is likely to rise significantly in the next couple of years
Coal	Coal is composed primarily of carbon along with variable quantities of other elements. Coal is formed from dead plant matters.	• Abundant in Australia • Provide 40% of energy and 76% of all electricity in Australia • Considerably less expensive than other energy sources	• Lower quality brown coal has high air pollution • Emission is 93.1 kg CO_2–e/GJ for brown coal and 88.4 kg CO_2–e/GJ for black coal, equivalent to around 3 times of the weight of coal itself.	• $10/GJ	• Some power stations are being converted into gas-fired • Coal gasification and clean coal technologies are being actively researched and developed to allow for high-efficiency, low-emission energy generation.
Petroleum oil	Petroleum is used mostly for producing fuel oil and petrol, both important "primary energy" sources.	• Relatively abundant. • Easily transportable, high energy density. • Oil has become the world's most important source of energy • Reliable and well known for users	• High air pollution - emission is 69 CO_2–e/GJ or 2.35~2.7 kg CO_2–e per litre for petrol or diesel • A significant proportion has to be imported to Australia	• $40/GJ for petrol • $40/GJ for diesel • Farmers may be able to claim the excise duty (38 cents per litre) to reduce the fuel costs.	• Australia is becoming increasingly dependent on expensive imported oil and petroleum products • Research is being focused on the technology for exhaust gas treatment.
LPG	Liquefied petroleum gas (LPG) is a product of petroleum gases, principally propane and butane, produced at refineries and natural gas processing plants. Stored under pressure to keep it in a liquid state. Also known as autogas.	• High octane rating enables LPG mix better with air and burn more completely, generating less carbon. • Can be mixed with petrol or diesel	• Lower energy density than petrol and fuel-oil • Converting a vehicle to LPG can be quite expensive • Emission is 60 kg CO_2–e/GJ or 1.54 kg CO_2–e/litre LPG. This is 30% lower than petrol.	• $27/GJ • The price is twice that of natural gas	• In the future, LPG may have to be imported, and the price will rise.

Energy Type	Description	Main advantages	Main disadvantages	Estimated costs	Potential for the cotton industry
Natural gas	Consist of 50 to 90 % methane (CH_4) and small amounts of heavier gases. Natural gas is commercially extracted from oil fields and natural gas fields.	• Abundant in Australia. • Reserve equal to 125 years' supply at 2002 consumption level. • Relatively cheap • Low greenhouse gas emissions	• Not a renewable energy resource • Constructing and managing gas pipelines is capital intensive. • Emission is 51 kg CO_2–e/GJ or only 55% of coal	• $13/GJ (or about 1/3 of petrol, diesel or electricity).	• It is currently used primarily for heat • It is also used to produce electricity and in some cases to fire gas turbines and steam boilers. • It can be fired up at short notice to meet peak demand (eg, to make up the shortfall by solar or wind power).
Coal Seam Gas (CSG), and CNG or LNG	CSG is a methane based natural gas regularly found in the porous structure of coal deposits. When compressed under high pressures and held in a container, it is called Compressed Natural Gas (CNG). When it is cooled and converted to a liquid form for transporting, it is called Liquefied Natural Gas (LNG)	• Very large reserves in Australia	• Concerns over the impact on water supplies and possible impacts on crop lands. • Emission is similar to that of natural gas (51 kg CO_2–e/GJ)	• $10/GJ for CNG • $20/GJ for LNG	• CNG has a lower cost of production and storage compared to LNG • LNG is principally used for transporting natural gas to markets, where it is re-gasified and distributed as pipeline natural gas. • Conversion technology to use these gases is being further optimised.
Solar Photo Voltaic	Solar power is produced by collecting sunlight and converting it into electricity, using solar panels. Solar panels are large flat panels made up of many individual solar cells. It is most often used in remote locations, although it is becoming more popular in urban areas as well.	• Renewable and clean with little emission • A very reliable system (no moving parts) • Particularly suitable for remote locations where diesel generators may cost 50c/kWh (0.26L/kWh)	• Still relatively expensive compared with fossil energy • Produces power intermittently • Performance is location-dependent • Only suitable for low power requirement applications	• $24-97/GJ (8.5c to 35c/kWh)	• Very competitive for remote, rural locations where connection to the grid is difficult or expensive • With the new technologies currently under development, prices will further reduce in the near future.
Solar thermal energy	This technology harnesses solar energy for thermal energy (heat) and then possibly for electricity. Solar thermal collectors are classified as low, medium, or high-temperature collectors. Low-temperature collectors are flat plates generally used to heat swimming pools. Medium-temperature collectors are also usually flat plates but are used for heating water or air for residential and commercial use. High-temperature collectors concentrate sunlight using mirrors or lenses and are generally used for electric power production.	• STE technology is much more efficient than photovoltaics. • Solar to electric conversion by high-temperature STE technology can achieve efficiencies of up to 30% • The efficiency of a solar collector depends on factors such as ambient temperature and fluid temperature. It usually ranges between 40 to 60%.	• Still relatively expensive compared with fossil energy • Produces power intermittently • Performance is location-dependent	• $90-108/GJ (25c to 30c/kWh for electricity generation)	• Solar Dawn project, planned to be built near Chinchilla in South West Queensland, and costing $1.2 billion, will use this technology for electricity generation.

Energy Type	Description	Main advantages	Main disadvantages	Estimated costs	Potential for the cotton industry
Wind Power	Wind power is produced by using wind generators to harness the kinetic energy of wind.	• Renewable with little emission	• The main barriers for adoption are: location, capital cost, amenity and aesthetic considerations and noise. • Maintenance could be an issue for remote areas. • The wind is not always predictable. This increases the supply capacity risk and may require supplementary capacity from alternative sources.	• $20/GJ ($70/MWh) • Requires less than 3 to 6 months to recoup the energy used in their manufacture. • Currently, large wind turbines are cheaper than other renewable energy sources	• Gaining worldwide popularity as a large scale energy source, although it still only provides around one percent of global energy consumption. • Wind speed may not be high enough in cotton growing regions of Australia • Storage technologies and optimisation of blade designs are being actively researched to improve reliability and efficiency
Biomass	Biomass as an energy source involves two different methods: burning vegetative material and burning biogas (methane) produced by the breakdown of organic matter.	• Renewable with very low emission (1.28 kg CO_2–e/GJ) • Biomass may be available in a large quantity locally	• Difficult to compete the low cost of fossil fuels, specifically coal. • Need to develop an efficient harvesting and transport technology • Could be location dependent	• $8-15 /GJ for wood or sugarcane bagasse (cane stalks)	• Crop residue could be an important source of biomass from agriculture. • Australia's cotton industry has the potential to produce up to 15 million m^3 of methane gas, containing 6 PJ of primary energy
Ethanol	Ethanol is made by fermenting and then distilling starch and sugar crops such as maize (corn), sorghum, potatoes, wheat, sugarcane, fruit and vegetable waste. The addition of ethanol increases the oxygen content in petroleum. Ethanol also raises the octane rating of fuel. 1 tonne of sorghum grain can produce 360 to 420 litres of ethanol. 1 tonne of cotton stalk can produce 180 litres of ethanol.	• Renewable • Lower in carbon emissions • Can be used to replace expensive imported oil • Creates jobs in the regional areas • Little to no modification for petrol engines	• 30% lower energy content than conventional fuel on a per liter basis • High plant capital cost • Concern over food versus fuel balance • Emission of E100 is 3.4 kg CO_2–e/GJ.	• $32-36/GJ (70-80c/L) • Can potentially compete other fossil fuels without government support	• Blends of 90% unleaded petrol and 10% fuel ethanol are commonly referred to as E10. • E10 has 3% less energy content than petrol • E10 mandate for several states in Australia

Energy Type	Description	Main advantages	Main disadvantages	Estimated costs	Potential for the cotton industry
Bio-diesel	Biodiesel is a versatile, clean-burning fuel made from renewable, biodegradable sources. It can be used as a diesel (B100) or as a blend with normal diesel, normally at 20% (B20) in diesel engines. Biodiesel can be made from almost any vegetable oil or animal fat, through a process that is neither difficult nor prohibitively expensive. The oil content of cottonseed is 19% and 40% for Canola.	• Relatively easy to manufacture • Can be made at home • Renewable • Lower in carbon emissions • Can be used to replace expensive imported oil • Create jobs in the regional areas	• 5-10% lower energy content than conventional diesel on a per litre basis • Poor cold weather performance • Fuel stability concerns • Concern over food versus fuel balance • Emission of B100 is 3.4 kg CO_2–e/GJ.	• $25-41/GJ ($0.90 – 1.50 $/L depending on feedstocks.)	• An important fuel option to meet future energy demand • Biodiesel production is growing rapidly, and some farmers are already producing their own fuel. • Australia has the potential to produce up to 100 ML of cottonseed biodiesel per year or up to about 3 times of cotton production fuel demand. • Second or third generation feed stocks from algae oil or agricultural wastes such as cotton stalks are being actively researched.
Hydro Power	The water stored in the dam is released through pipes that run through turbines that turn generating dynamos. The force of the water is very strong, so large and powerful generators can be used.	• Renewable • No carbon emissions • Capacity can be quickly increased or decreased as demand changes.	• Require a suitable site • Require a large capital investment (~$3m for 1 MW capacity) • Reduced capacity in times of drought.	• $20/GJ ($72/MWh)	• Much of the best large-scale hydro sites have already been developed in Australia, although opportunities remain for small-scale hydro projects utilising existing infrastructure.
Geothermal	Geothermal energy sources originate from thermal energy trapped beneath and within the solid crust of the Earth. There are two forms of geothermal energy resources in Australia – geothermal aquifer and geothermal "hot fractured rock".	• Little emission Geothermal energy for electricity generation is cheap where it is easily accessible.	• Tends to be in places that are volcanically active.	• $14-16.5/GJ ($50-$60 /MWh)	• With the full exploitation of opportunities, it may be possible that geothermal energy can supply 5% of global electricity by 2020.

Appendix 2: Life cycle carbon dioxide emissions of various energy sources and technologies [grams of CO_2-e per kWh] (Schuck, 2007)

Technology	g CO_2-e / kWh
Coal best practice	955
Natural gas in combined cycle plant	446
Onshore wind	9
Hydro – existing large	32
Hydro – small scale	5
Decentralised photovoltaic (PV) retrofit	160
Decentralised PV new houses	178
Bioenergy – poultry littler - gasification	8
Bioenergy – poultry litter - steam cycle	10
Bioenergy – straw – steam cycle	13
Bioenergy – straw - pyrolysis	11
Bioenergy – energy crop gasification	14
Bioenergy – forestry residue - steam cycle	29
Bioenergy - forestry residue - gasification	24
Bioenergy – animal slurry anaerobic digestion	31
Landfill gas	49
Sewage gas	4

Appendix 3: Energy costs and emissions for various energy sources