ENERGY HARVESTING FROM WASTE COFFEE GROUNDS IN THE FORM OF BIOFUEL

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Statement of Candidate

I, Laura Filia, declare that this report, submitted as part of the requirement for the award of Bachelor of Engineering in the Department of Mechanical Engineering, Macquarie University, is entirely my own work unless otherwise referenced or acknowledged. This document has not been submitted for qualification or assessment at any academic institution.

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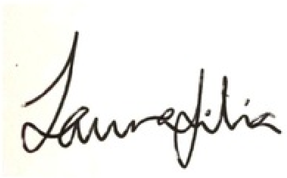

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Abstract

The development of alternative and renewable energy resources is demanded by our community to ensure current and future energy demands of Australia can be met. Biofuel is a viable renewable energy option, which could be produced on a large scale to cope with significant transport and consumer needs. However, cost effective and efficient feedstocks to produce biofuel are limited. Spent coffee grounds (SCG) are a newly investigated feedstock potential for biofuel creation. SCG is highly abundant, has a significant oil yield and can be collected and utilised instead of being placed in landfill. These properties make SCG a favourable feedstock for biofuel and ultimately could be a significant part of the answer to ongoing energy demands. Environmentally, biofuel emits up to 85% less greenhouse gases to the atmosphere than traditional fossil fuels and through the utilisation of SCG as a biofuel feedstock, it will also help to reduce the amount of waste discarded as landfill.

Within this report, results show that as a biofuel feedstock, SCG has a 2.5-year pay-back period before becoming highly profitable. When considering Global Warming Potential combined with electricity demand, the evidence reveals SCG has the lowest value compared to other leading biofuel feedstock competitors. Thus, through research and data analysis such as a life cycle cost analysis and an economic viability analysis, SCG as a feedstock for biofuel in Australia is found to be feasible and viable.

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List of Abbreviations and Acronyms

Abbreviation or Acronym	Meaning
SCG	Spent Coffee Grounds
ML/yr	Mega litres per year
Mt/ha/year	Metric tonne per hectare per year
c/L	Cents per litre
bbl	Barrel of oil
PJ	Petajoule
RET	Renewable Energy Target
LRET	Large-scale Renewable Energy Target
SRES	Small-scale Renewable Energy Scheme
STC	Small-scale Technology Certificates
GHG	Greenhouse Gas
ILUC	Indirect Land Use Change
t	Tonne
$AU/year	Australian dollars per year
CO_2	Carbon Dioxide
USD	United States Dollars
TOE	Tonne of Oil Equivalent
GWh	Giga-Watt hours
°C/min	Degrees Celsius per minute
MC	Moisture Content
FC	Fixed Carbon
VM	Volatile Matter
HHV	Higher Heating Value
wt/%	Wet weight percentage
FTIR	Fourier Transform Infrared Spectroscopic
FFA	Free Fatty Acid
SFE	Supercritical Fluid Extraction
MJ	Mega joules
K	Degrees Kelvin
TGA	Thermo gravimetric Analysis
DTG	Differential Thermo gravimetric Analysis
KOH	Potassium Hydroxide
I_2	Iodine
SO_2	Sulfur Dioxide
$PO^{3}{}_{-4}$	Phosphate
LCA	Lifecycle Assessment
EVA	Economic Viability Analysis
CML2016	Impact Assessment Method
ODP	Ozone Depletion Potential
AP	Acidification Potential
EP	Eutrophication Potential

1. Introduction

In modern society, Australians rely upon many energy powered devices and technologies to get through day-to-day life. From turning off the alarm clock in the morning, to catching the train to work and then pressing the button on the coffee machine for a morning coffee. Energy demands in Australia are continuously rising with no sights of slowing down[1]. Whilst Australia is a world leader in energy production, these energy demands will not always be able to be met, as there are limited fossil fuel resources left [2]. Thus, there is a demand for feasible and viable renewable energy options.

Biofuel is a renewable energy fuel that has been derived from materials such as waste plant and animal matter [3]. This renewable fuel can be used as a substitute for petrol and diesel, which can then be used to create electricity or many other purposes. Biofuel is used on only a small scale in Australia due to limited feedstock options and high production costs[4]. Alternate feedstock's such as spent coffee grounds (SCG) must therefore be investigated to increase the efficiency and cost effectiveness of biofuel, providing an energy solution to the current and future energy crisis's[5]. Biofuel has a positive environmental impact when compared to fossil fuels, with carbon emissions from biofuel being up to 85% less than traditional energy sources. Utilising feedstocks such as SCG will also help aid in decreasing the amount of waste placed in landfill [6].

SCG is the waste product from coffee drink and product creation. SCG has a significant oil content, which can be used through conversion processes to create biofuel for a potentially effective and efficient cost [7]. SCG is abundant within Australia and is generally disposed to landfill, with only 7% being recycled [8].

This report provides the outcomes of further investigation into the feasibility of spent coffee grounds as a biofuel feedstock for Australia through lifecycle cost analysis, economic viability analysis and data analysis. Therefore providing the basis for an efficient, cost-effective and viable renewable energy source to aid Australia's energy crisis.

1.1 Project Goals

An objective of this research is to explore the use of coffee ground as a viable, alternative and low cost source of biodiesel. To accomplish this, an extensive study of coffee grounds properties, environmental impact and cost analysis must be conducted. This study aims to address current biofuel feedstock issues such as:

- High biofuel production costs
- Low biofuel production efficiencies
- Availability of feedstock
- Environmental impact of feedstocks

These issues will be explored through an extensive literature review, a lifecycle cost analysis and an economic viability analysis. Through addressing these key attributes of spent coffee grounds as a biofuel feedstock, the feasibility of this alternative biofuel source will be established.

1. 2 Motivation for Thesis

Energy demands in Australia have never been higher and with limited traditional fossil fuel energy sources remaining, an alternative and feasible renewable energy source must be found. Biofuel is currently used on only a very small scale within Australia, however, biofuel has an enormous potential to be a solution to energy demands in Australia if a feasible biofuel feedstock was sourced and developed.

Currently, biofuel conversion techniques lack efficiency and cost effectiveness. Through the research conducted and documented within this report, a low cost and feasible feedstock for biofuel will be presented, therefore motivating and promoting biofuel as a more attractive option to governments and companies.

1.3 Project Plan

To ensure all aspects of spent coffee grounds as a biofuel feedstock is explored, specific data must be understood. These include but are not limited to:

- What is biofuel?
- Current biofuel feedstocks and their costs and limitations
- Current demand for energy in Australia
- Renewable Energy Targets in Australia
- Amount of spent coffee waste generated in Australia
- Environmental impact of SCG
- Biofuel properties of SCG such as oil yield
- Conversion techniques of SCG oil to biofuel
    - Are these techniques efficient and cost effective?
    - Which technique is superior for Australia
    - Cost of technology and process to complete this conversion
- How much biofuel can be generated from SCG

From this data, different analysis's can be conducted to examine the cost efficiency of SCG as a biofuel feedstock. These include:

- An economic viability analysis of SCG as a feedstock
- A lifecycle cost analysis of SCG as a biofuel feedstock

The data collected and subsequent analysis from these steps will present the feasibility and viability of spent coffee grounds as a biofuel feedstock in Australia. This data will then be used to produce two journal articles that will be submitted for publication and titled as:

1. A comprehensive review of the 2nd generation biodiesel production from waste coffee ground; and

2. Utilization of waste coffee ground to produce alternative low cost biodiesel in Australia: Thermal performance and combustion characteristics.

These published results and findings of research seeks to encourage further research, funding and implementation of coffee grounds as a feedstock of biodiesel in Australia

2. Background and Related Work

2.1 Biofuel

Biofuels are liquid fuels that have been derived from materials such as waste plant and animal matter. The two main types of biofuel currently produced in Australia are bioethanol and biodiesel. Bioethanol is used as a replacement for petrol and biodiesel is used as a replacement for diesel [3]. The processes for the manufacturing of biofuel can be seen in Figure 2.1. Fats, oils, starches, sugars and plant materials are converted to biofuel products by chemical, biological or thermochemical methods. Biofuel products developed through this process include biodiesel, ethanol, methane, hydrocarbons and natural fats. Different conversion techniques are used depending on biomass type and desired output [9]. Research is continuing to improve the efficiency and cost effectiveness of these processes.

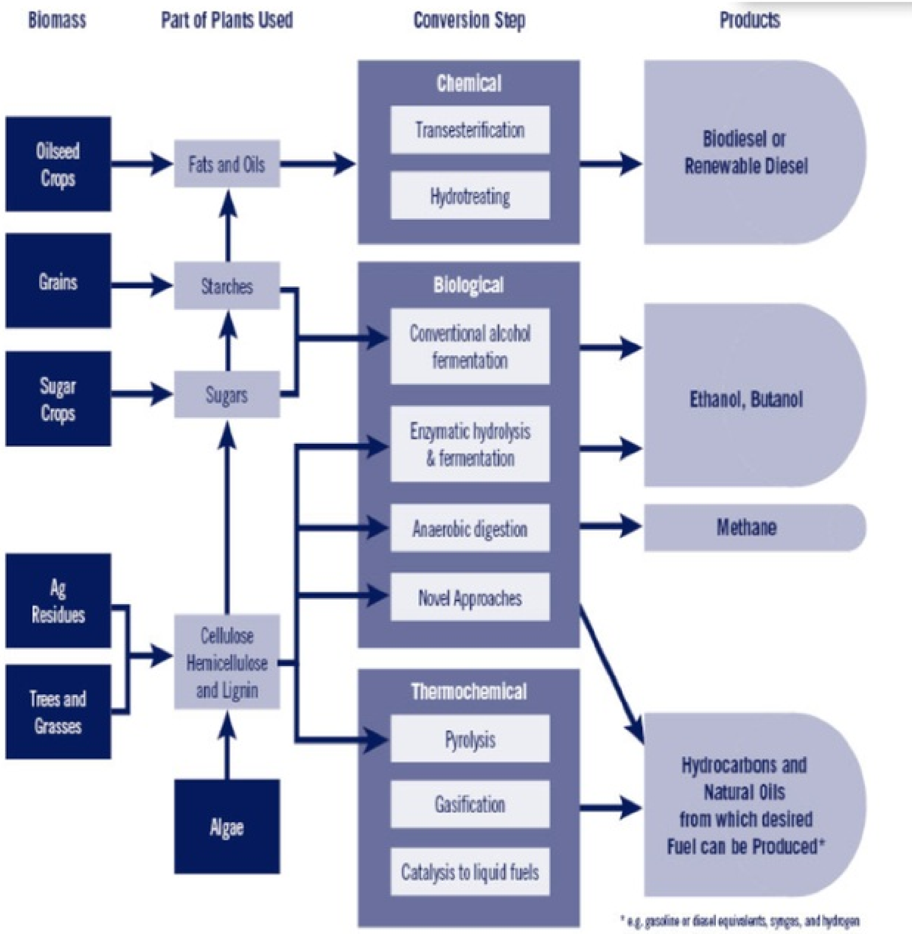


Figure 2.1- Method of Biofuel Creation [9]

Biofuels represent a significant growth opportunity for Australia as a cleaner renewable alternative and has an important role to play in displacing fossil fuels which Australia is currently dependant on.

2.1.1 Biodiesel

Globally, the production and use of biodiesel has seen a quantum jump in the recent past due to benefits associated with its ability to mitigate Greenhouse Gas emissions (GHG)[10]. Energy sources such as fossil fuels have adverse environmental impacts that have been studied and documented. These adverse effects to the environment have resulted in a push for more eco-friendly energy sources such as biofuel. With just over a decade of commercial-scale production, the biodiesel market has substantially grown around the world. An example of this is in the U.S with a significant increase of biodiesel production; from 95 million litres in the early 2000s, to 10.5 billion litres in 2016 [4].

In Australia the rise of biodiesel use has not been as significant when compared to other developed countries. Many biodiesel production companies have closed or are unable to produce a cost effective amount of biodiesel to make a real impact on Australian energy supplies, refer Table 2.1 [3]. Most current biodiesel plants in Australia utilise used cooking oil as the feedstock for their biodiesel creation.

Table 2.1- Biodiesel Plant locations and status in Australia [3].

Biodiesel Plant	Location	Owner	Total Installed Capacity (ML/yr)	Feedstock	Status (As of 01.06.15)
ARfuels Barnawartha	Victoria	Australian Renewable Fuels	60	Tallow, Used Cooking oil	In production
ARfuels Largs Bay	South Australia	Australian Renewable Fuels	45	Tallow, Used Cooking oil	Mothballed
ARfuels Picton	Western Australia	Australian Renewable Fuels	45	Tallow, Used Cooking oil	Mothballed
ASHOIL	Western Australia	Asburton Aboriginal Corporation	Unknown	Used Cooking oil	In production
Biodiesel Industries	New South Wales	Biodiesel Industries Australia	20	Used cooking oil, vegetable oil	In production

Ecofuels Australia	Victoria	Ecofuels Australia PTY Ltd	1.5	Canola oil	In production
EcoTech BioDiesel	Queenslan-d	Gull Group	30	Tallow, Used Cooking Oil	In production
Macquarie Oil	Tasmania	Maquarie Oil Co	15	Poppy seed oil and Waste Vegetable Oil	In production
Neutral Fuels	Victoria	Neutral Fuels PTY Ltd	Unknown	Used Cooking Oil	Closed
Smorgon Fuels-BioMax Plant	Victoria	Smorgon Fuels PTY Ltd	15	Tallow and Canola Oil	Closed
Territory Biofuels	Northern Territory	Territory Biofuels Ltd	140	Palm Oil, Used cooking oil	Closed

With further advances in research into biodiesel, this alternative, renewable energy source could be a solution to ongoing energy demands in Australia.

Advantages of producing and using bio-diesel include:

- Foreign oil imports reduced;
- Current installed distribution networks can still be used; and
- Current engine technologies can still be used without modification.
- Reduced CO_2 emissions
- Waste being utilised rather than placed in landfill

The use of renewable sources for the biofuel industry will also help to increase not only job generation and incomes, but also promote energy self-sufficiency in rural areas [5].

Biodiesel can also be used in existing diesel engines without modifications if strict technical fuel quality and engine performance specifications have been met. The use of biodiesel in engines is covered by all major engine manufactures' warranties [4].

Different qualities and varieties of biofuel can be created globally depending on the type of feedstock used to produce the fuel. Some current feedstocks lack cost efficiency or are not environmentally friendly. Biofuel feedstocks play a significant role into the efficiency and viability of biofuel and are a key element in achieving an environmentally friendly energy source.

2.1.2 Biofuel Feedstock's

Biofuel (biodiesel and bioethanol) feedstocks are the plant or animal matter, which is used to create biofuel. These feedstocks vary depending on many different factors and play a vital role in the feasibility of biofuel use.

2.1.2.1 Global Feedstock's

Current common biofuel feedstocks used around the world can be broken into distinct categories seen in Table 2.2. Different feedstocks possess varying properties (see Table 2.3). These properties have a direct influence on the quantity and popularity of the feedstocks used, which can be seen in Table 2.4.

Table 2.2: Current common global biofuel feedstock

Feedstock Category	Feedstock	Reference
Non-edible vegetable oil	Tobacco, linseed, algae, cotton seed, jatropha, rapeseed	[5] [11] [12] [13]
Edible vegetable oil	Palm oil, corn oil, soya	[5] [11] [14]
Animal fats	Beef tallow, pork lard, yellow grease	[3] [5] [11] [15]
Waste materials	Cooking oil, frying oil	[3] [5] [11] [14] [15] [16] [17]
Lignocellulosic Biomass	Maize, sorghum, switchgrass and miscanthus	[18] [19] [20] [21]
Starch	Wheat, barley, oat, triticale grain, corn starch	[22] [23] [24]
Sucrose	Sugarcane sugar, C-molasses	[22] [25] [26]
Planted Forest Waste	Sawdust, bark chips and shavings	[27] [28] [29]
Plant Matter	Algae	[23] [12] [30]

The above feedstocks are generally used due to their elevated availability and high oil yielding properties, however the cost for these feedstocks can be particularly high and are not always from environmentally friendly sources, thus making biofuel not the most attractive option for many [31] [32]. A greater understanding of the oil yielding properties of common feedstock options can be seen in Table 2.3.

Table 2.3: Biofuel feedstock property comparison [12] [33] [34] [15]

Feedstock Category	Oil Source	Biomass (Mt/ha/year)	Oil/Fat Content (% dry mass)	Biofuels (Mt/ha/yr)
Non-edible vegetable oil	Jatropha	7.5-10	30-50	2.2-5.3
	Rapeseed	3	40	1.2
Edible vegetable oil	Palm Oil	19	20	3.7
	Soya	1-2.5	20	1.2-0.5
Plant Matter	Algae	50-150	20-50	10-75
	Corn	3	35	2.8
Animal Fats	Beef Tallow	0.15	90	2.1
Waste Material	Used Cooking Oil	-	99	99% of biomass with correct process
Starch	Wheat Barley	0.81	19	1.3
Sucrose	Sugar Cane	50	20-30	3.5

Globally, countries utilize different feedstocks due to varying resource availability and demand. For example, in Argentina soybean is the preferred raw material for biodiesel production due to its low cost, whilst in China this feedstock is not accepted as a source for biofuel due to the high demand of soybean oil for traditional Chinese food [5]. An example of the widespread feedstock options for different countries can be seen in Table 2.4.

Table 2.4: Top 10 Biofuel production countries and feedstocks used [35] [36] [37].

Country/Continent	Biofuel Production (TOE)	Main Feedstock Utilized	
		Bioethanol	Biodiesel
U.S	25,350,000	Corn	Soybean
Brazil	15,570,000	Sugar Cane	Palm Oil
Germany	2,930,000	Wheat	Rapeseed
France	2,300,000	Sugar Cane	Soybean
Argentina	1,700,000	Corn	Soybean
China	1,400,000	Starch	Palm oil
Spain	1,170,000	Grain	Rapeseed
Canada	995,000	Wheat	Canola
Italy	670,000	Corn	Rapeseed
Thailand	650,000	Molasses	Palm Oil
Australia	31,000	Sugar Cane	Cooking Oil

Palm oil is currently one of the largest suppliers of biofuel feedstock, it has the lowest production cost (USD 0.53/L) and is produced in countries throughout the tropics including Malaysia, Indonesia, Thailand and Columbia [11]. However many oppose the use of this biofuel source due to the significant detrimental impact palm oil plants have on the environment. Corn, soybeans and sugar cane are also large competitors within the biofuel feedstock market. However due to requiring extremely large amounts of land, equipment and money for growth and harvesting, they are still not the most attractive biofuel feedstock option. For biofuel to be a viable alternative energy option, it must have a low production cost with a high production rate.

An alternative feedstock option of Spent Coffee Grounds (SCG) will be examined to determine if SCG is feasible for large-scale biofuel production in Australia. For this option to be successful SCG as a feedstock must have a low production cost, have large continuous available quantities and be environmentally friendly [38].

2.1.2.2 Currently used Industrial Feedstocks

Table 2.5: Current biofuel feedstock in Australian industries

Feedstock Category	Feedstock	Example of feedstock utilized	Quantity Used (%)	Reference
Waste Material	SCG	Nestles factory in Gympie, QLD used a biomass boiler to convert SCG into usable energy. However this feedstock is currently only used on a very small scale.	2	[6] [16] [3] [38]
	Used cooking oil	Used in varying biodiesel production facilities around Australia.	35	[3] [14] [17]
Cellulosic Plant Material	Switchgrass, miscanthus, poplar	Companies use this type of feedstock to create biofuel as the production of this feedstock does not complete with food/feed production in a direct way.	2	[29] [21] [3] [19] [39] [21] [12]
Plant based material	Sawdust, bark and wood shavings	Nestle company in Gympie, uses a mixture of feedstocks such as shavings to generate biofuel.	5	[27] [3] [28] [40]
Oil Plants	Palm Oil	Oil plants are industrially utilized to produce biofuel due to their extremely high oil content, which will therefore produce a greater amount of biofuel, making them more cost effective. However, they can have negative environmental effects due to large land usage.	20	[29] [13] [3] [41]
	Jatropha		5	[14] [3] [42] [41]
Animal Fats	Tallow	Animal fats and waste products are used in biodiesel productions facilities around Australia.	30	[3, 5] [11] [23]

Note: Remaining 1% made up from feedstocks used on miniscule scale.

Different industries will use varying feedstock's depending on the outputting product they require. Generally the more cost effective a feedstock is, the more likely it will be to be utilized. An example of this is a small Nestle factory in Queensland, produces large amount of spent coffee grounds from the manufacturing of coffee products.

As this feedstock is free and readily available, the company utilizes it as an energy source to run the factory. A biomass boiler enabled the company to increase the amount of energy extracted and as a result, approximately 70 per cent of the energy used at the factory is now from a renewable source. Since the installation of the boiler in 2009, CO_2 emissions have reduced 31 per cent and the amount of coffee grounds disposed into landfill and compositing has fallen 80 percent [6].

Current feedstocks used in Australia are heavily based upon which source is most available. Different areas within Australia use varying feedstocks which somewhat reflects the culture of that area.

For example in the Green Triangle of Australia (6 million hectares of land in South Australia and western Victoria), the most prominent feedstock is forest waste such as sawdust and bark [27]. However, as Sydney is a much more industrialized and commercialized area therefore used cooking oil has higher availability as a feedstock [3]. The extent of Australian biofuel feedstock availability for plant-based material can be seen in the Figure 2.2.

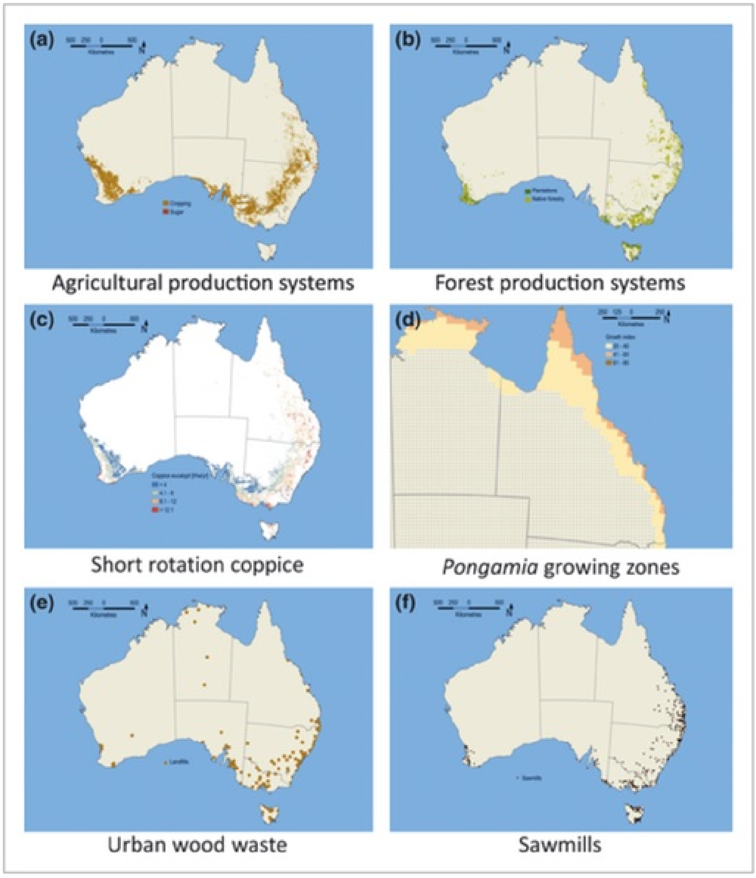


Figure 2.2- Resource location and land areas for growing feedstocks [22].

Varying feedstocks have different production costs due capital cost, operating cost, feedstock cost and co-product revenue. Majority of costs are produced from purchasing feedstock, this can be seen in Figure 2.3. These costs significantly impact on the use of the feedstock for biofuel. Waste oil has a low production cost and hence is the most used feedstock for biodiesel in Australia [3].

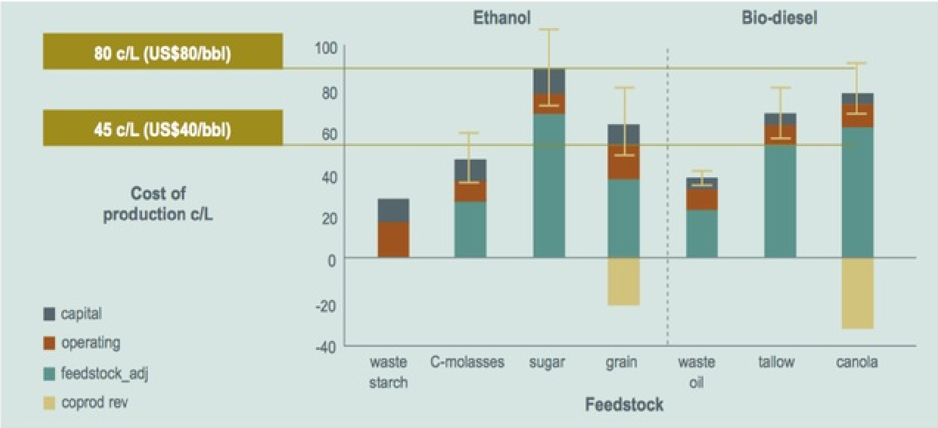


Figure 2.3- Indicative production costs in Australia, showing capital cost, operating costs and feedstock costs. Co-product revenues are show as a negative cost [43].

2.1.2.3 Future Potential Feedstock's

Continual development into future feedstock possibilities is crucial to increase the feasibility of biofuel as an alternative energy source. This development will help to find or improve feedstocks to make biofuel creation even more cost effective. Table 2.6 shows varying feedstocks, which are being developed or improved to enhance favourable biofuel creation properties.

Table 2.6: Future Potential Feedstocks for Biofuel

Feedstock Category	Feedstock	Reference
Cellulosic Plant based	Corn stover- high in abundance and common waste product non-utilised for other applications	[29] [21]
	Napiergrass- Easily grown and maintained, and it disease resistant.	[40] [19] [21]
Plant waste	Thielavia terrestris (Funghi strain)- having a highly active enzyme, this feedstock is able to accelerate the biofuel production process.	[39] [19] [14]
	Spent Coffee Grounds (SCG)- SCG are widely available and have high oil yielding properties.	[32, 38] [14] [44] [11] [45] [32]
	Citrus fruit peels- high in abundance and utilisation of waste could aid in mitigating Greenhouse Gas emissions.	[46] [47]
Starch products	Beer broth- chemical characteristics of this feedstock are almost identical to that of ethanol, through the use of microbes beer broth can be upgraded into a useable fuel.	[24] [48] [49]
Plant matter	Camelina- this feedstock is a fast growing plant, which has very low maintenance and growing requirements. It also produces a high oil yield. Camelina also has a very positive environmental footprint.	[30] [29] [49] [50] [51]
	Pennycress- this feedstock has very high oil content and is considered a weed.	[20] [30] [5]
	Crambe- Drought tolerant and has a higher economic efficiency than soybeans.	[30] [29] [5]

2.1.3 Energy Demand in Australia

Australia is a strong competitor globally in energy production and consumption. In terms of consumption, Australia uses a wide variety of energy types such as electricity and fuels. Electricity is mainly generated using coal, with the small help of renewable sources such as hydropower, wind, solar and bioenergy, as depicted in Figure 2.4 [52]. Bioenergy makes up only 1% of the total electricity consumption in Australia, leaving much room for improvement.

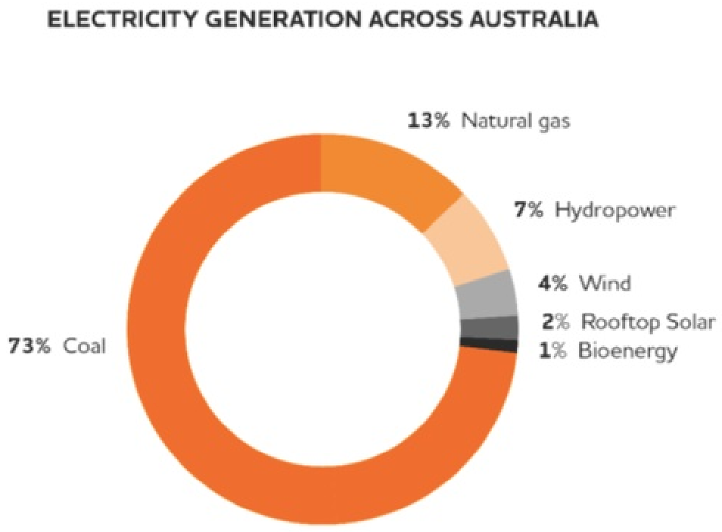


Figure 2.4- Sources of electricity generation in Australia [52].

The sectors within Australia that use the most energy are the manufacturing sector and the transport sector. In the transport sector, Australia consumed 5885 Petajoules of energy over the 2012-13 period [1].

Fossil fuels (coal, oil and gas) dominated Australia's primary energy production, with 94% of total energy consumed in Australia derived from fossil fuels. The remaining 6% was derived from renewable energy sources such as wind, solar, geothermal, hydro, wave, tidal and bioenergy.

Australia's total transport energy consumption can be broken into categories shown in Figure 2.5.

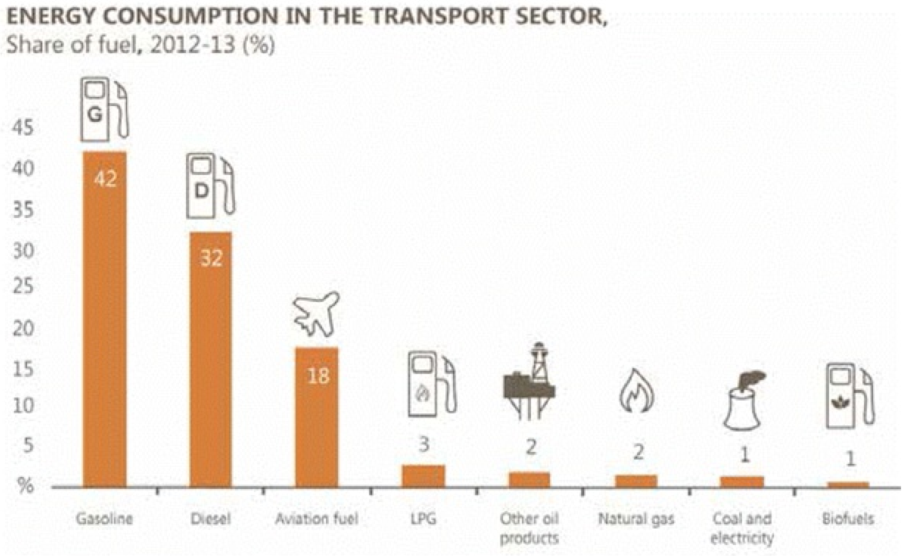


Figure 2.5- Energy Consumption by Transport Sector in Australia 2012-13 [1].

Diesel is 32% of Australia's total energy consumption in the transport section and only 1% of energy consumption is made up of biofuels. Australia's demand for petrol and diesel has risen steadily over recent decades, largely due to the increasing transport sector demand [1].

Energy consumption in Australia is growing at a fast rate, with some Australian states predicted to increase energy consumption by 60% by 2050[2]. Predictions for future energy demands in Australia can be seen in Table 2.7. States with the highest predicted energy growth include Queensland and the Northern Territory.

Table 2.7: Current and Projected energy consumption in Australia[2].

State/ Territory	2014-15 (PJ)	2034-35 (PJ)	2049-50 (PJ)	Average Annual Growth 2014-15 to 2049-50 (%)	Total Growth from 2014-15 to 2049-50 (%)
New South Wales	1540	1869	2051	0.8	36
Victoria	1310	1488	1677	0.7	31.5
Queensland	1447	2136	2445	1.5	67.5
South Australia	363	382	384	0.2	9
Western Australia	1038	1384	1526	1.1	49.5
Tasmania	121	125	134	0.3	13.5
Northern Territory	197	277	324	1.4	63
Average Total				0.86	38.5

Current and future diesel demands will be difficult to maintain and therefore a cost effective alternative becomes more attractive. In 2014, BP completed a study, which found there is only enough petroleum diesels to last until 2057 [5]. As a result of the forecast diesel demands versus availability, it becomes imperative that an alternative diesel energy supply be developed.

2.1.4 Renewable Energy Targets in Australia

Renewable energy is energy that is collected from renewable sources. Many countries and organisations are working towards using more renewable energy sources instead of traditionally used fossil fuels to minimise negative environmental impact and be more cost efficient. Currently in Australia, renewable energy only makes up a small portion of energy consumed, as depicted in Figure 2.6.

Figure 2.6- Australian sectors Energy Consumption [53].

In Australia, government policies (related to energy) have been implemented to increase the amount of renewable energy that Australia generates and consumes. Policy responsibilities (related to energy) are distributed across different government levels. Much of Australia's energy policy is advanced and implemented through cooperation between the Australian national, state and territory governments. Australia's national energy policy objective is to aid in delivering reliable, secure, clean and competitively priced energy to consumers [54].

National policies implemented by the Australian Government include the Clean Energy Future Plan, legislated in late 2011. The Australian Government implemented reforms help transition the economy to a clean energy economy. Whilst there have been amendments made to this policy since its debut in 2011, a key factor in this policy is the Renewable Energy Target (RET) [54].

The RET scheme is designed to deliver on the Australian Government commitment that at least 20 per cent of Australia's electricity will come from renewable sources by 2020. Initially this target was to ensure 41,000 GWh of renewably sourced energy was generated by 2020, but was reduced to 33,000 GWh in 2015 [55]. The RET places on entities that purchase electricity (mainly electricity retailers), a legal obligation to provide a specific number of renewable energy certificates to the Clean Energy Regulator each year. Each certificate represents one megawatt-hour of additional renewable energy for compliance purposes [54].

RET has operated as two parts [55]:

1. Large-scale Renewable Energy Target (LRET)
2. Small- scale Renewable Energy Scheme (SRES)

The LRET provides a financial incentive for the construction or development of renewable energy power stations. It also includes legislated annual targets, which will require significant investment in new renewable energy generation capacity in the near future.

The SRET provides a financial incentive for households, small businesses and community groups to implement small-scale renewable energy systems. This is accomplished by legislating demand for Small-scale technology certificates (STCs). STCs are created for systems at the time of installation; according to amount of renewable energy they are expected to produce in the future.

Further development into renewable sources such as biofuels is demanded to achieve the Renewable Energy Target set by the Australian Government.

In South Australia, there have been issues with renewable energy production from wind and solar sources. The state government has been forced to make an expensive $550 million dollar contract with gas companies to provide a solution for the energy crisis [56]. The state government owned fast start gas-fired power station would provide energy when the renewable energy supply market is unable to keep up with consumer demands. This energy solution is quite expensive and still requires for the South Australian government to continually purchase gas from gas companies, causing on going costs. A viable renewable source such as biofuel would be a more effective solution for this problem as once the plant is built; the feedstock for this source would be much cheaper and cost effective than purchasing gas. A cost effective and readily available feedstock such SCG would also make biofuel a much more feasible solution to South Australia's energy crisis.

2.1.5 Environmental Impact of Biofuel

All energy sources have an environmental impact. Traditionally used fossil fuels have quite a detrimental environmental effect, renewable energy sources specifically biofuel, provide a much cleaner, eco-friendly energy source. Use of biodiesel can reduce carbon emissions by 85% compared to mineral diesel [3]. The environmental benefits of biodiesel have been widely documented. Reductions in greenhouse gas emissions resulting from the use of biodiesel are closely aligned with the Australian Governments "Direct Action" approach to climate change. Reductions in Greenhouse Gas (GHG) emissions through the use of biofuels can be seen in Figure 2.7.

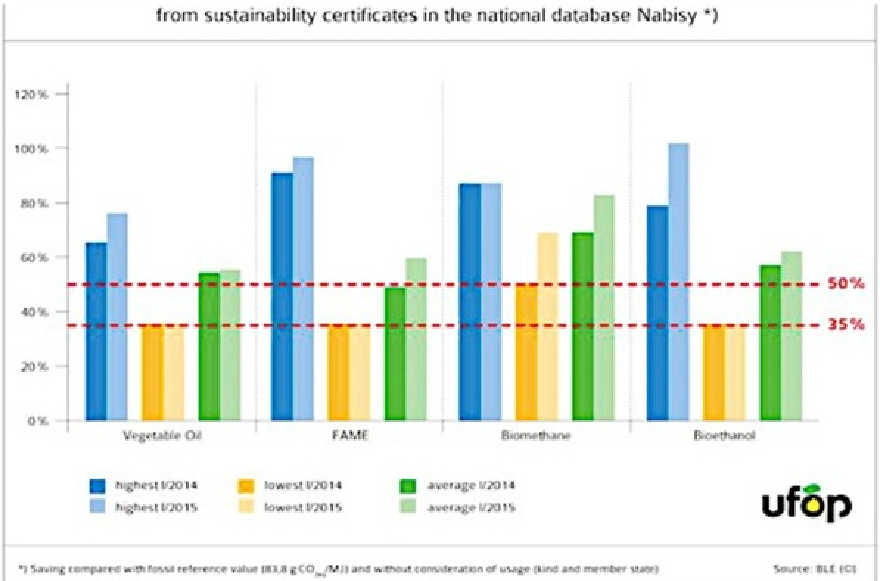


Figure 2.7- GHG emission reductions through the use of biofuels instead of fossil fuels [57].

Figure 2.8 depicts GHG emissions of different biofuel feedstock's with also added Indirect Land Use Change (ILUC) emissions, showing that only particular feedstock options produce lower GHG emissions than fossil fuels [58].

Note that as the feedstock of Spent Coffee grounds will be waste taken from consumers and companies, it will not have to be grown purely for biofuel feedstock purposes and therefore should have no ILUC emissions associated with it, producing a very efficient and low emitting biofuel feedstock option.

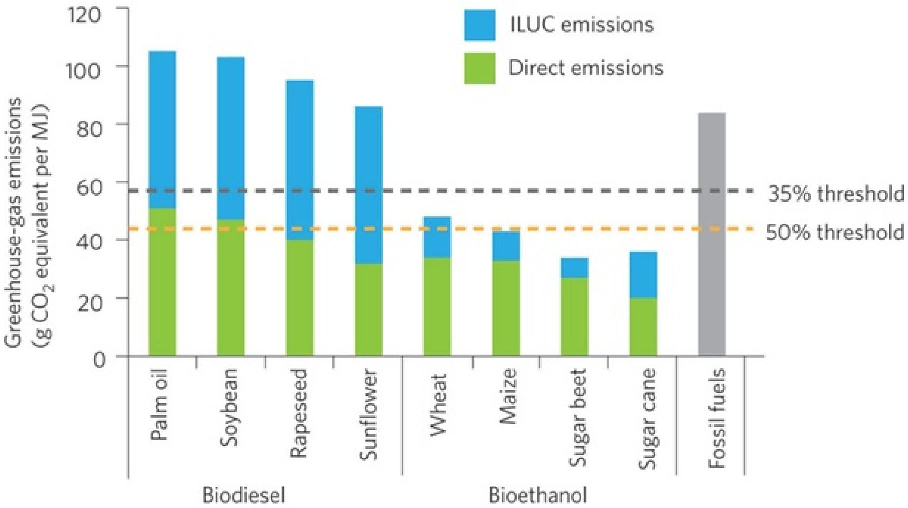


Figure 2.8- Greenhouse gas emissions of different biodiesel feedstocks [58].

Biodiesel blends also have a positive impact on air quality due to the reduced pollutant gas emission relative to fossil fuels. Diesel particulate emissions are a rising concern, as they continue to increase in emission amount and are classified as a Group 1 carcinogen by the International Agency for Research on Cancer. Air quality, particularly in and around major cities, ports, tunnels and airports can be improved with small changes to the fuels used, and an increased uptake of biofuels may have a positive impact on health outcomes and reduce national and state health budget costs [3].

Biodiesel also enables waste produce that would be traditionally put into landfill, to be used for energy production. As seen in Figure 2.9, Australian states and territories still place significantly larger amounts of waste into landfill than recycle. This amount of waste being placed in landfill also continues to rise, as seen in Figure 2.10.

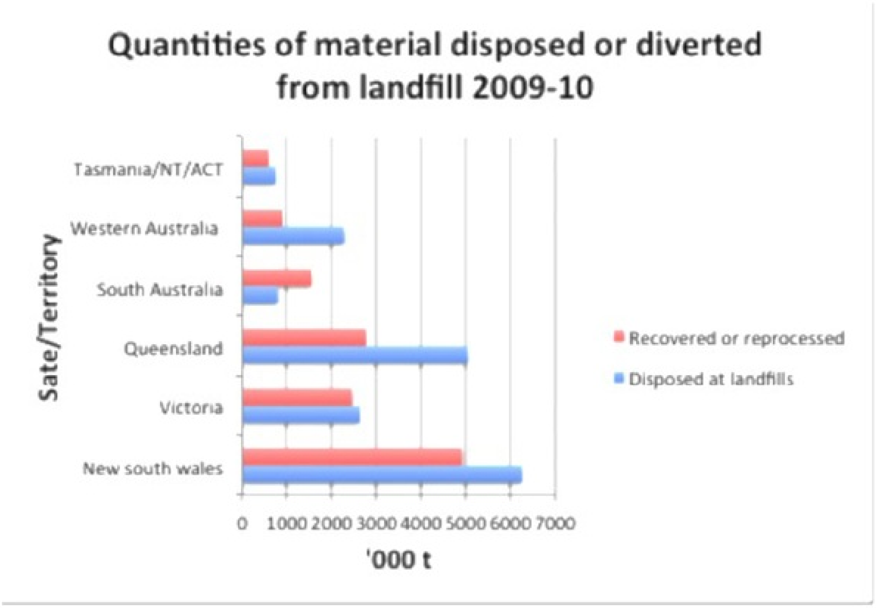


Figure 2.9- Quantity of waste placed or diverted to landfill in Australia [59].

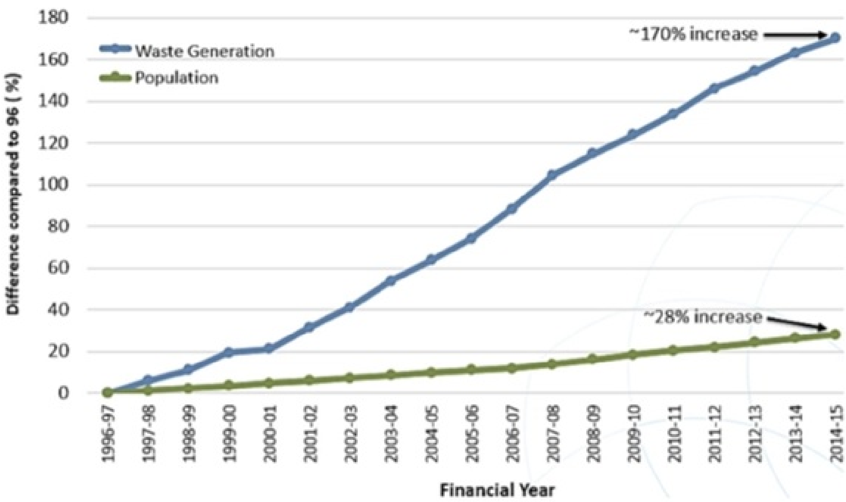


Figure 2.10- Waste generation increasing over time in Australia [60].

Some Australian states have their individual policies enforced to minimise environmental impact of current energy sources. The Victorian state government has put into effect a zero-waste policy directive in which all wastes, regardless of quantity, should be diverted from landfill [61]. Biodiesel would assist this policy by taking many different animal and plant waste traditionally placed into landfill to be used for energy production. In particular, spent coffee grounds, which are regularly placed in the bin, could be utilized for energy purposes.

2.1.6 Summary

Table 2.8: Biofuel Summary

Component	Claim	Reference
Biofuel	Biofuels are liquid fuels that have been derived from materials such as waste plant and animal matter. The two main types of biofuel currently produced in Australia are bioethanol and biodiesel.	[3] [4] [62]
Biodiesel	Biodiesel is used as a replacement for diesel. Biodiesel production is slowly rising in Australia but still in juvenile stages.	[3] [4] [62] [63]
Biofuel Feedstocks	Most common biofuel feedstocks are non-edible vegetable oil, edible vegetable oil, animal fats and waste materials. To make biofuel a more attractive option to consumers, a cost effective and environmentally friendly feedstock must be identified.	[5, 22, 29] [21] [49]
Energy Demand in Australia	Australia is a word leader in energy production and consumption. Renewable energy makes up a very small percentage of Australian energy consumption. Future diesel demands will not be able to be met and therefore an alternative solution must be found.	[1] [2, 52] [53] [64]
Australian Renewable Energy Target	Legislation to ensure 20 per cent of all generated electricity in Australia comes from renewable sources by 2020. Financial incentives in place to make the change from traditional fossil fuels to renewable sources more attractive.	[54] [55]
Environmental Impact of Biodiesel	Biodiesel use compared to mineral diesel use has an 85 per cent lower carbon emission. Biodiesel use also can help improve air quality and decrease waste placed in landfill.	[3] [61] [57] [58]

2.2 Spent Coffee Grounds

Spent Coffee Grounds (SCG) are the waste product of ground coffee production. The availability of SCG must be examined to ensure there is a sufficient amount of feedstock to produce an acceptable amount of biofuel [44]. An investigation of the environmental/financial impact SCG has on Australia will also be conducted to aid in the feasibility analysis of energy harvesting coffee waste in the form of biofuel.

2.2.1 Biofuel Generation from SCG

2.2.1.1 Oil Compounds in SCG

The oil content of SCG has a significant impact on the feasibility of SCG as a feedstock for biodiesel as the amount of oil able to be extracted directly influences the amount of biofuel able to be created. If SCG has very low oil content, the amount of biodiesel to be created would be quite low and therefore not feasible or economically viable. The oil content and oil deriving compounds found in SCG can be seen in Table 2.9.

Table 2.9- Identification of compounds found in bio-oil extracted from SCG [38].

Compound Name	**Formula**	**Compound Area (%)**	
		10°C/min Heating Rate	60°C/min Heating Rate
Methylphenol	C_7H_8O	2.43	3.09
Catechol	$C_6H_6O_2$	2.31	2.84
Palmitic Acid	$C_{16}H_{32}O_2$	13.90	13.14
Linoleic Acid	$C_{18}H_{32}O_2$	25.59	28.67
Eicosanoic Acid	$C_{20}H_{40}O_2$	2.53	3.36
Ethoxyethyl Acetate	$C_6H_{12}O_3$	2.15	3.52
Furan-2-ylmethanol	$C_5H_6O_2$	2.36	3.28
Phenol	C_6H_6O	1.43	1.86

When SCG samples are first collected, the sample has several characteristics such as moisture content (MC), ash content (Ash), fixed carbon (FC) and volatile matter (VM). These all affect the amount of oil able to be extracted from the sample. The distribution of these components for a SCG sample can be seen in Table 2.10, the high heating value (HHV) of the samples can also be seen in this table. These characteristics also aid in the understanding of specifically where the oil content of SCG is found and the amount of oil available. The ultimate analysis of this sample also shows the chemical breakdown of a dry SCG sample.

Table 2.10- Proximate and ultimate analysis of SCG [38].

Proximate Analysis (wt%)				Ultimate Analysis (wt%)					HHV (MJ/kg)
MC	Ash	VM	FC	C	H	N	O	S	23.2
8.1	1.7	82.0	16.3	54.5	7.1	2.4	34.2	0.1	

Fourier Transform Infrared Spectroscopic (FTIR) analysis is also used to identify functional oil and compound groups in SCG samples. As seen in Figure 2.11, FTIR shows the presence of methyl, methylene and useable oils at varying wave bands (wavenumbers) in SCG samples. These results are from a FTIR analysis which was performed at Macquarie University in the Environmental and Science Laboratory.

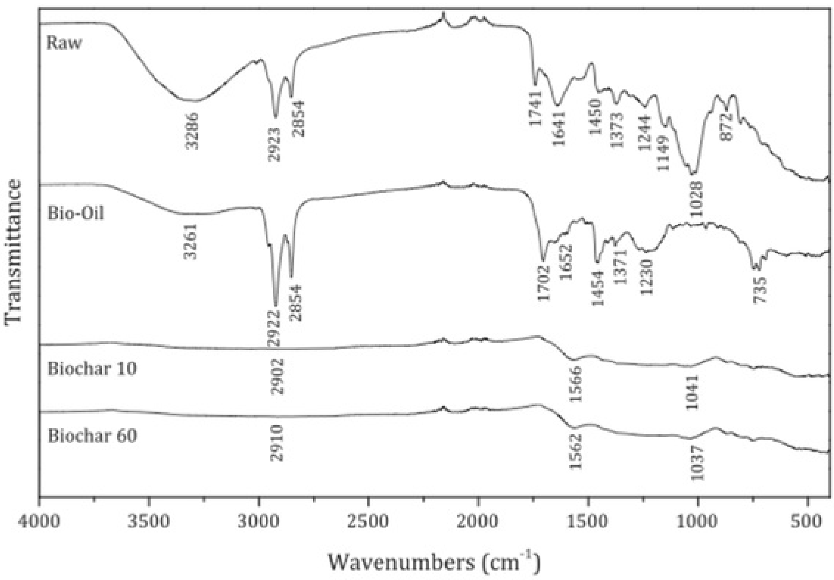


Fig. 1. FTIR spectra of spent coffee grounds and its subsequent pyrolysis products.

Figure 2.11 – FTIR spectra of SCG and its subsequent pyrolysis products [38].

Functional oil groups in SCG are found at a higher level in bio-oil and raw samples. Thus showing that the organic (biological or raw) matter that is in SCG produces a high level of useable oil for biodiesel creation.

Oil extracted from SCG can also be characterised in terms of fatty acid composition and basic parameters such as acid, iodine, saponification and ester values as seen in Table 2.12. Coffee oil characterisation can be seen in Table 2.11. Dominating fatty acids found in SCG samples were linoleic acid (43.7%), palmitic acid (35.7%), and oleic acid (9.4%)[65]. Coffee oil has a relatively high acid value (7.1kg Potassium Hydroxide per gram of coffee oil), thus indicating a large amount (approximately 3.6%) of free fatty acids (FFA). This provides a significant amount of oil (free fatty acids) to be used for biofuel creation.

Table 2.11- Composition of fatty acids (oil compounds) extracted from SCG [65].

Fatty Acid	Content (%)
Palmitic Acid	35.7
Stearic Acid	7.1
Oleic Acid	9.4
Linoleic Acid	43.7
Arachidic Acid	2.2
Linolenic Acid	1.1
Behenic Acid	0.4
Eikosenoic Acid	0.3

Table 2.12- Basic parameters of oil extracted from SCG [65].

Oil Parameter	Value
Saponification Value	166.1
Acid Value	7.1
Iodine Value	70.3
Ester Value	158.9

2.2.1.3 Specific Coffee Varieties Oil Content

Coffee comes in a variety of types and these types produce an assortment of oil characteristics based on their chemical and physical structures. Due to this variance, different coffee varieties have altered oil extraction efficiencies. Chemical characteristics of two varying coffee types can be seen in Table 2.13. From this data, it can be seen that Coffee Arabica produces more coffee oil than Coffee Canephora. Thus, providing evidence that Arabica SCG is a better biofuel feedstock option than Canephora, as more oil is produced for an equivalent amount of waste [66].

Table 2.13- Chemical composition of coffee varieties: Coffee Arabica and Coffee Canephora [66].

Compound Category	Specific Compound	Concentration (gram/100 grams)	
		Coffee Arabica	Coffee Canephora
Carbohydrates/fibre	Sucrose	4.2	1.6
	Reducing Sugars	0.3	0.3
	Polysaccarides	31-33	37
	Lignin	3.0	3.0
	Pectins	2.0	2.0
Nitrogenous Compounds	Protein	7.5-10	7.5-10
	Free Amino acids	ND	ND
	Caffeine	1.1-1.3	2.4-2.5
	Trigonelline	1.2-0.2	0.7-0.3
	Nictonic Acid	0.016-0.026	0.014-0.025
Lipids	Coffee oil	17.0	11.0
	Ditrpene esters	0.9	0.2
Minerals		4.5	4.7
Acids and Esters	Chlorogenic Acids	1.9-2.5	3.3-3.8
	Alaphatic Acid	1.6	1.6
	Quinic Acid	0.8	1.0
Melanoidins		25	25

2.2.1.2 Oil Extraction Techniques

There are different oil extraction techniques used globally. Detailed below are the most common techniques.

Soxhlet Extraction

Soxhlet extraction is a very popular oil extraction technique. It is most commonly completed with n-hexane as the extracting solvent at the solvent normal boiling point. The extraction runs until the feedstock is completely exhausted of oil. The n-hexane is then evaporated from the extracted oil in a rotary evaporator [67]. This extraction type yields 18.3% on a dry weight base ($\%g_{oil}/100g_{dry\ spent\ coffee}$).

Supercritical Fluid Extraction (SFE)

SFE is an emerging extraction technique. It eliminates organic solvent polluting the mixture and reduced the cost of post-processing solvent pollution elimination. Carbon dioxide is the most widely used solvent for SFE as it is widely available, safe and cost effective [68]. The low critical temperature of carbon dioxide also allows for thermo labile substances to be extracted without degradation, including extracting essential oils from plants and waste material such as coffee waste. SFE extraction equipment can be seen in Figure 2.12 [67].

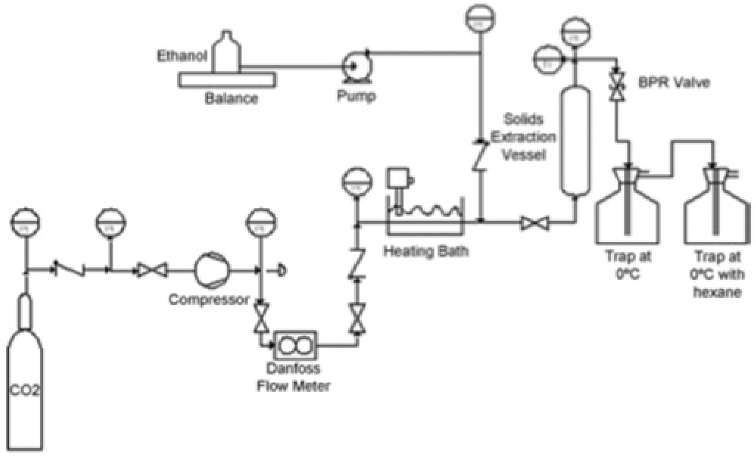


Figure 2.12- High pressure apparatus for SFE of SCG [67].

Carbon dioxide is taken from a cylinder; it is then compressed to a desired extraction compressor. The fluid is then heated to a desired temperature by moving through a high pressure tubing coil (immersed in a heating bath). Supercritical carbon dioxide then flows at a desired pressure and temperature through a densely occupied space of SCG. To minimise entrainment effects, the SCG space is put between porous, metallic plates and any unfilled space is stuffed with cotton. The extractor is heated using a heating jacket. The substances extracted from the apparatus were collected and then passed through a series of traps to ensure all compounds were recovered.

Less Used Oil Extraction Techniques

There is numerous oil extraction techniques used globally, some are more popular than others due to their beneficial economic properties, some techniques however are not as popular due to not being cost effective or environmentally friendly or highly efficient. Example of less popular extraction techniques can be seen in Table 2.14.

Table 2.14-Less Used Oil Extraction techniques

Extraction Technique	Summary of Technique	Reference
Ultra-sound assisted oil extraction	Feedstock is immersed in hexane, in a constant specific temperature, whilst sonication is performed on the sample. The oil is then transferred to a rotary evaporator and finally an oven drier to remove any hexane that might be still present.	[69]
Cold Press Extraction	This technique is not very popular, nor efficient or effective.	[70]
Two-phase solvent extraction	Methanol and other solutions are added to biofuel feedstock sample, the solution is then separated to access the created biofuel.	[71]

2.2.1 Oil to Biodiesel Conversion

Varying biodiesel conversion techniques are used globally based on cost, efficiency of the technique, feedstock type and socio-environmental factors. This section will investigate the different oil to biodiesel conversion techniques, including existing techniques, common techniques and future possible technique advancements. These techniques will then be compared and contrasted to assist in identifying the superior conversion technique to create biofuel specifically in Australia.

2.2.2.1 Biodiesel production techniques

Currently, there are many existing biodiesel production techniques. An overview of these techniques can be seen in Table 2.15.

Table 2.15- Existing Oil to Biofuel Conversion techniques used globally

Conversion Technique	Summary of Technique	Reference
Pyrolysis	Thermochemical conversion that can produce many biofuel products.	[72] [73]
Enzymatic Catalysts	Chemical reaction using enzyme catalyst and heat to produce biofuel.	[70]
Trans esterification	Chemical mixture conversion technique.	[74]
Two-step Acid-catalysed esterification and alkali-catalysed trans esterification	Two-step approach, employs both an acid and alkali catalyst to produce a chain chemical reaction, resulting in biofuel.	[70]
Ultra-sound assisted esterification	Chemical mixture consisting of bio-oil, alcoholic solution and acidic compound are placed in an ultrasonic bath, where the esterification reaction occurs.	[69]
Hydrothermal Liquefaction	Biofuel feedstock is liquefied in hot-compressed water to produce crude biofuel.	[75]
Subcritical Water Extraction	Feedstock sample is placed in water extraction vessel. The extracts are then separated by centrifuge to attain biofuel compounds.	[76]

2.2.2.1.1 Most common techniques

Pyrolysis

Pyrolysis is a highly developed thermochemical conversion technique that can produce bio-char, bio-oil and biogas [72]. This process utilises thermal decomposition of biomass in the absence of oxygen to produce final biofuel products. The quality and characteristics of pyrolytic products are determined by controlling the heating rates with a 95.5% fuel-to-feed efficiency [73].

Pyrolysis liquid bio-oils are produced by heating samples of SCG (feedstock can vary) from room temperature to a specific temperature with a constant heating rate. This process takes place in an inert argon insulated environment. Glass wool is also placed at one end of the reactor tube to trap any condensable volatile material. Once the pyrolysis process is completed, the trapped biofuel in the glass wool is dissolved used a dichloromethane solvent [38]. An example of the apparatus required and used for this process can be seen in Figure 2.13.

Pyrolysis temperature has a direct effect on bio-oil yield and quality. This can be seen in Table 2.16. From this table it can be seen that the greatest amount of biofuel is created at 823K. As the solid reside, water residue and density are collectively highest. The highest yield of bio-oil is not the same as the temperature for the highest HHV (higher heating value) [77].

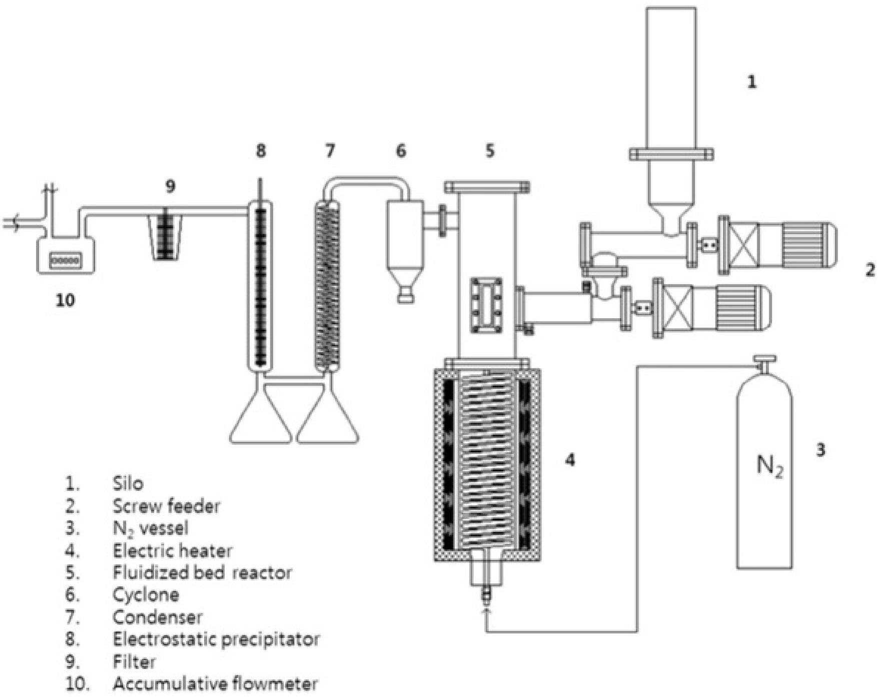


Figure 2.13- Pyrolysis conversion technique apparatus set-up example [77].

Table 2.16- Physical and chemical analysis of bio-oil produced from coffee grounds through pyrolysis at varying temperatures[77].

Reaction Temperature (K)	HHV (MJ/kg)	Water content (wt.%)	Solid Residue (wt.%)	pH	Ash (wt.%)
673	12.04	28.88	0.07	2.9	0.12
723	23.19	23.96	0.1	3.1	0.08
773	22.46	29.82	0.06	3.2	0.19
823	20.38	31.11	0.25	3.1	0.17
873	20.03	32.93	0.13	3.5	0.06

Pyrolysis of SCG can also have environmental impacts such as the production of non-condensable gases. The yields of gases can be seen in Figure 2.14 and 2.15. The figures illustrate the effect of reaction temperature increases to the amount of gas increases. CO_2 is a major component and CO is the second greatest gas product in the non-condensable gases. The yields of combustible hydrocarbon gases and H_2 are very low[77].

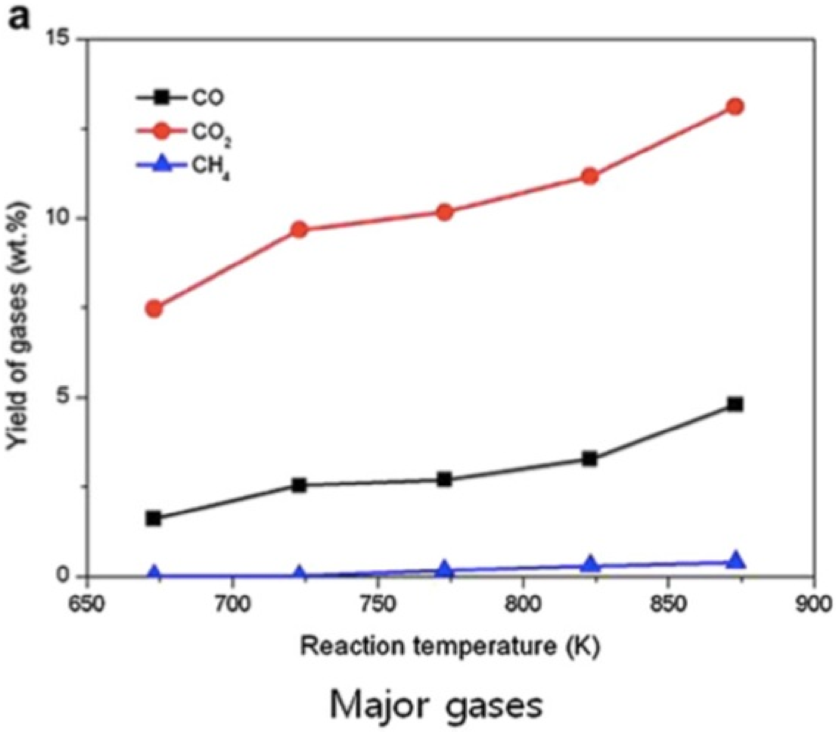


Figure 2.14- Yields of major non-condensable gases from pyrolysis conversion of SCG [77].

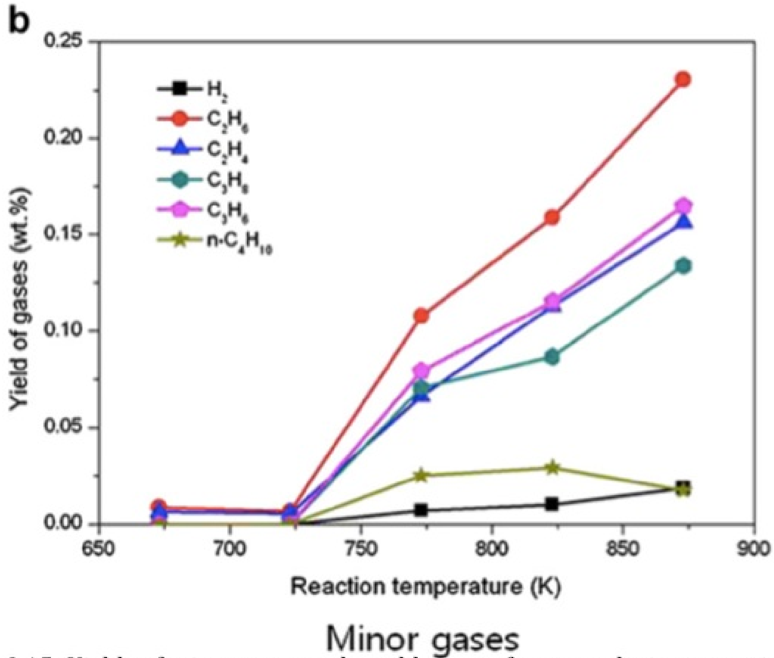


Figure 2.15- Yields of minor non-condensable gases from pyrolysis conversion of SCG[77].

Enzymatic Catalysis

This method requires coffee oil to be preheated in a water bath to a desired temperature before any reaction takes place. A specific amount of a specific type of enzymatic catalyst is pre-soaked overnight, and then placed in the solution. This process is a solvent-free system. The reaction then occurs in a shaker bath at specific temperature for 72 hours [70]. Figure 2.16 shows peaks of free and bound glycerol indicating the completeness of the biodiesel production process [70].

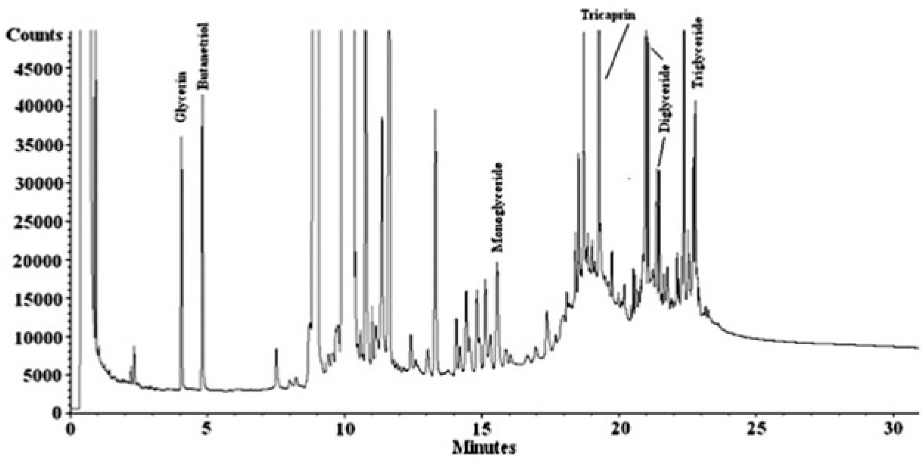


Figure 2.16- Gas chromatography of biodiesel created from coffee oil by an enzyme-catalysed approach [70].

Trans esterification

This process employs the use of methanol, chloroform and an acid catalyst to be combined with a specific feedstock [74]. This mixture is then placed in a heating bath at a specific heating range for a specific time. Varying the amounts of material and conditions, which the process is completed at, alters the final products produced. After the mixture has reacted, the mixture is cooled and neutralized. Phases are then separated using a centrifugal process and biofuel products are collected [74].

Two- Step Acid Catalysed Esterification and Alkali Catalysed Trans esterification

This method employs a two-step approach to generate the greatest amount of biofuel from spent coffee ground oil. Coffee oil and acid-methanol solution is first preheated on a hot plate to a desired reaction temperature. The two solutions then reacted, following this reaction; the solution is poured into a separation funnel and was allowed to settle for two hours. After this time, layers in the solution are created, with the lower (oil phase) layer being moved on to the next stage of the process[70].

The lower layer is then preheated to a desired reaction temperature, methanol-caustic solution is then added to the esterified coffee oil. The trans esterification process is then completed on a heated plate with constant stirred. Following this reaction, the solution is poured through a separatory funnel and allowed to settle overnight[70].

2.2.2.1.2 Future technique advancements

Pyrolysis Future Advancements

Varying heating rates in the pyrolysis process has a significant impact on the quality and properties of the products produced. Research conducted supports evidence that specific heating rates provide a more successful and efficient process at that producing biofuel from SCG. The evolution and production of biofuel from SCG at two distinctive and different heating rates can be seen in Figures 2.17, 2.18, 2.19, 2.20 and 2.21 below.

Where TGA is the Thermo gravimetric Analysis and DTG is Differential Thermo gravimetric curves. These analyses were completed to analyse the mass loss of the SCG during heating.

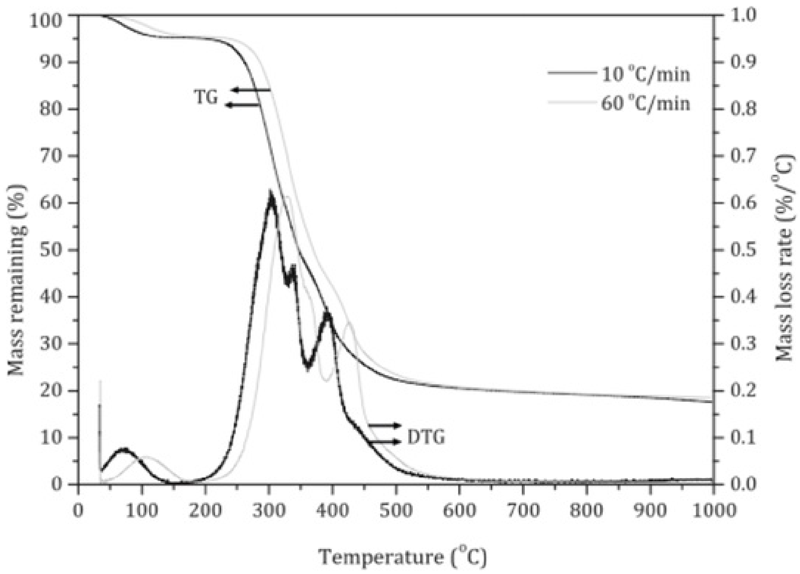


Figure 2.17- TGA and DTG curves for SCG decomposition at heating rates of 10 and 60 °C/minute [38].

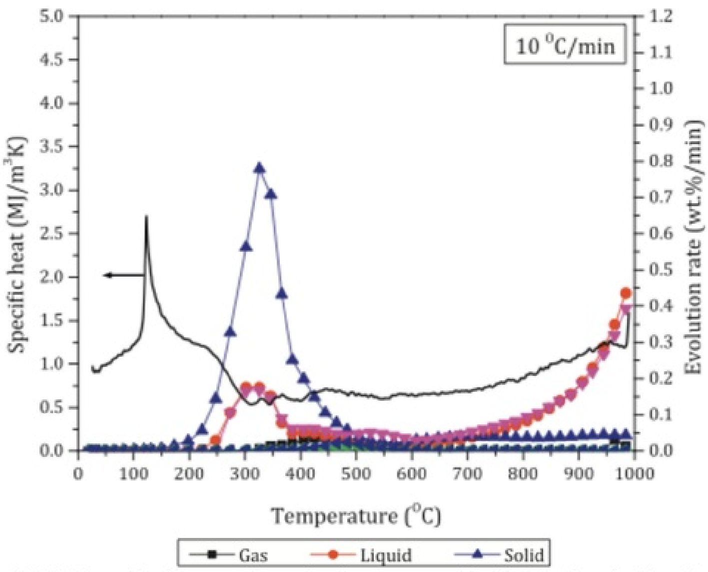


Figure 2.18- Specific heat and evolution rates of individual volatiles from coffee ground pyrolysis with the temperature at heating rates of 10 and 60 °C/minute [38].

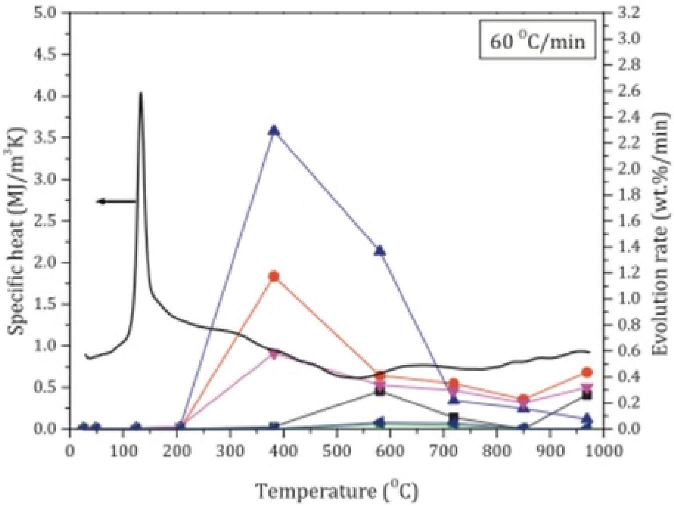


Figure 2.19- Specific heat and evolution rates of individual volatiles from coffee ground pyrolysis with the temperature at heating rates of 10 and 60 °C/minute [38].

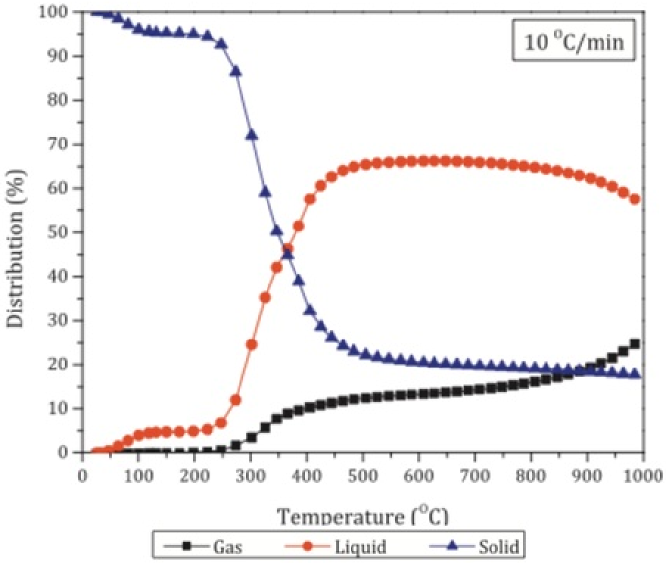


Figure 2.20- Distribution of gas, liquid and solid products from pyrolysis of SCG at heating rates of 10 and 60 °C/minute [38].

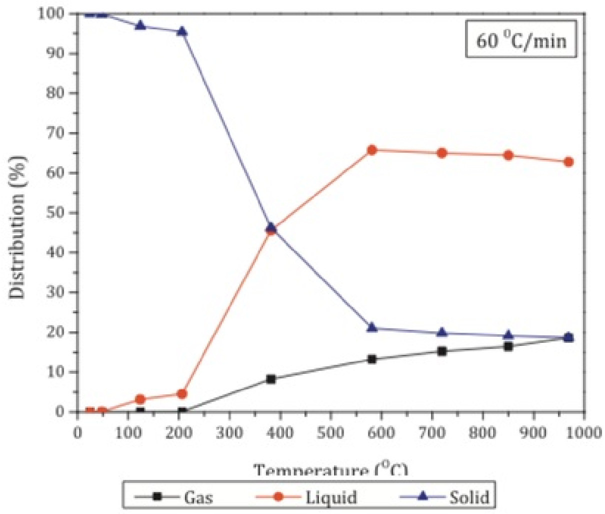


Figure 2.21- Distribution of gas, liquid and solid products from pyrolysis of SCG at heating rates of 10 and 60 °C/minute [38].

From these figures and data, it can be derived that there is little difference in the process stages in the curves at both heating rates, however at the higher heating rate, the thermal properties of the sample does change and improve. Positive effects of a higher heating rate include improving the quality of bio-oil in terms of elemental composition. This makes the higher heating rate more attractive and beneficial to the pyrolysis process. This research should be implemented to all pyrolysis processes to increase efficiency and productivity of process.

2.2.2 Availability of SCG

2.2.3.1 In Australia

In Australia, 16.3 million coffees are consumed on an average day. [8]. This results in 6 billion cups of coffee being consumed annually. Approximately two-thirds of this coffee is made from instant coffee powder, with the remaining third from ground coffee [78]. This portion of ground coffee based drinks, produces 75,000 tonnes of spent coffee grounds (SCG) every year [79].

Whilst coffee intake has slightly decreased over the past 10 years from 10.5 cups a week to 9.2 cups a week, coffee consumption is still significantly high [8]. There is also still a steady increase of Australians alternating from instant powder coffee to ground coffee, with a 6% drop of individuals buying instant coffee powder between 2010 and 2015 [8],[80]. An example on the closing gap between instant coffee powder and ground coffee can be seen in Figure 2.22, and supports the concept that ground coffee production and SCG are slowly increasing in Australia. Arabica coffee beans are the most widely used type of coffee bean in Australia [45].

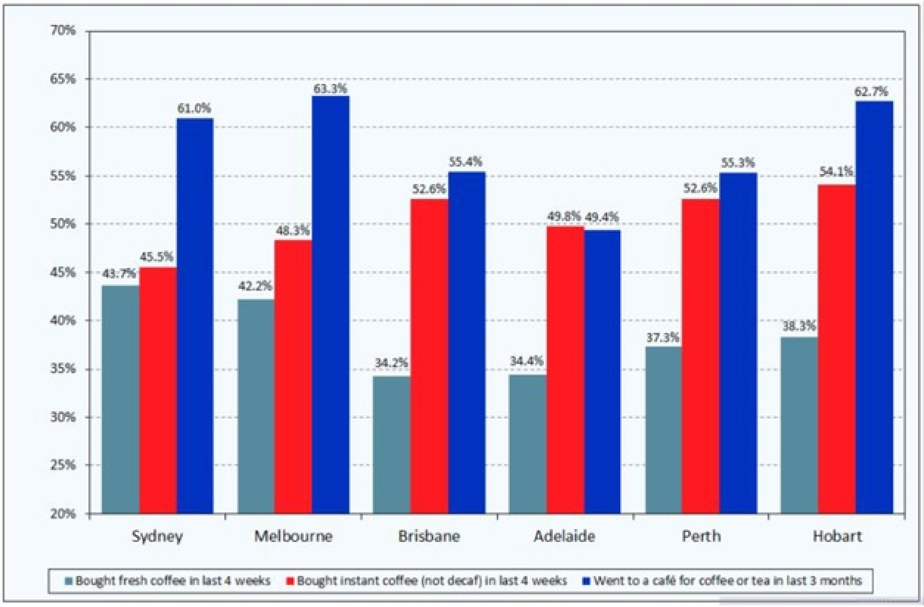
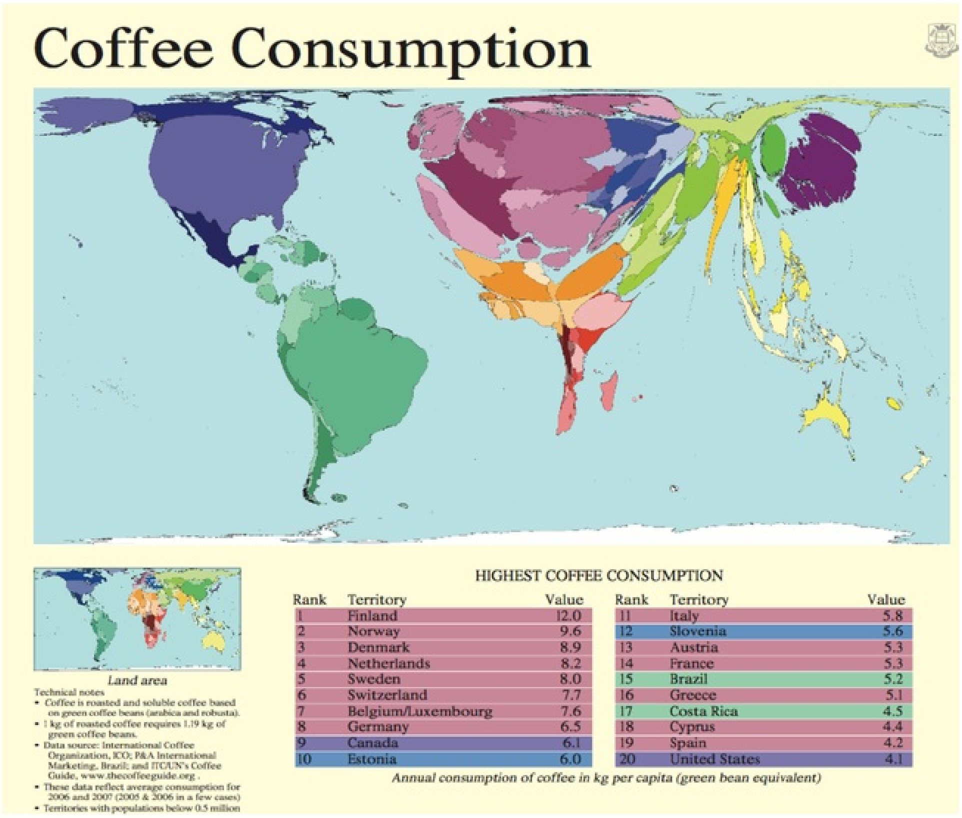


Figure 2.22 - Graph showing the closing gap between instant coffee powder and ground coffee consumption [80].

The quantity of ground coffee based cafes has also increased over the past 5 years and individuals' owning a private ground coffee maker in their home has risen from 28% (in 2009) to 36% (in 2013). Thus, providing evidence that Australia currently produces the largest amount of SCG it ever has, with no sights of slowing down [8].

2.2.2.2 Globally

On a world scale, Australia is ranked roughly 40th in coffee consumption [81]. Globally, around 8 million tonnes of coffee is produced per year, 45-50% of this results in spent coffee grounds [82],[83]. Global coffee production has increased by approximately 17% between 2000 and 2012 and continues to rise [84]. World ranking leaders for coffee consumption come from predominantly European origin, consuming roughly 8-10kg per capita per year of coffee shown in Figure 2.23 [81].



Rank	Territory	Value	Rank	Territory	Value
1	Finland	12.0	11	Italy	5.8
2	Norway	9.6	12	Slovenia	5.6
3	Denmark	8.9	13	Austria	5.3
4	Netherlands	8.2	14	France	5.3
5	Sweden	8.0	15	Brazil	5.2
6	Switzerland	7.7	16	Greece	5.1
7	Belgium/Luxembourg	7.6	17	Costa Rica	4.5
8	Germany	6.5	18	Cyprus	4.4
9	Canada	6.1	19	Spain	4.2
10	Estonia	6.0	20	United States	4.1

Figure 2.23- Global Coffee consumption [81] .

2.2.2.3 Macquarie University Study

A study was conducted within Macquarie University to gain an accurate representation of the amount of SCG produced daily by cafes. Café owners from 5 different cafes within Macquarie University completed a survey (depicted in Figure 2.24), which provided the following information in Table 2.17. Each coffee creates roughly 50g of wet coffee waste, found from weighing coffee waste per shot in various cafes.

Table 2.17: Survey Information: Representation of the amount of coffee waste generated in Australia daily by cafes.

Café	**Number of Coffees Sold Daily**	**Amount of SCG Produced Daily (Wet-kg)**	**Disposal Method of SCG**	
			Recycle	**Landfill**
1	300	15		Yes
2	500	25		Yes
3	350	17.5		Yes
4	600	30		Yes
5	400	20		Yes
Average	430	21.5		
Total = 14,400*0.5* Average	3,096,000	150,500		

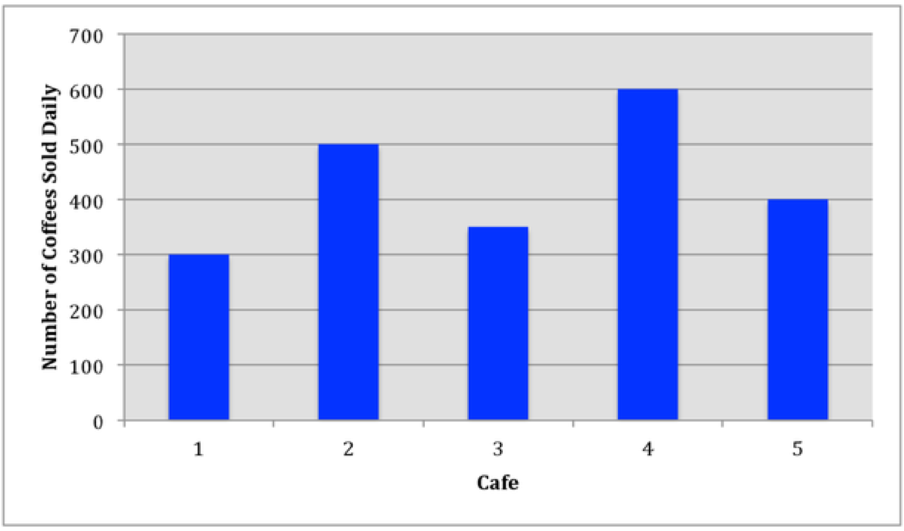


Figure 2.24- Number of Coffees sold daily at 5 different cafes in Macquarie University.

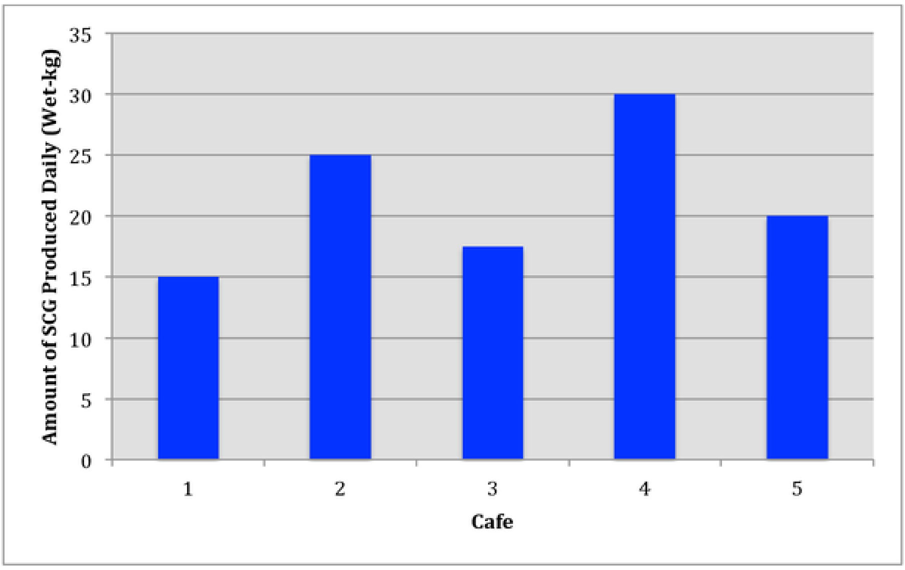


Figure 2.25- Amount of SCG produced daily by 5 cafes in Macquarie University.

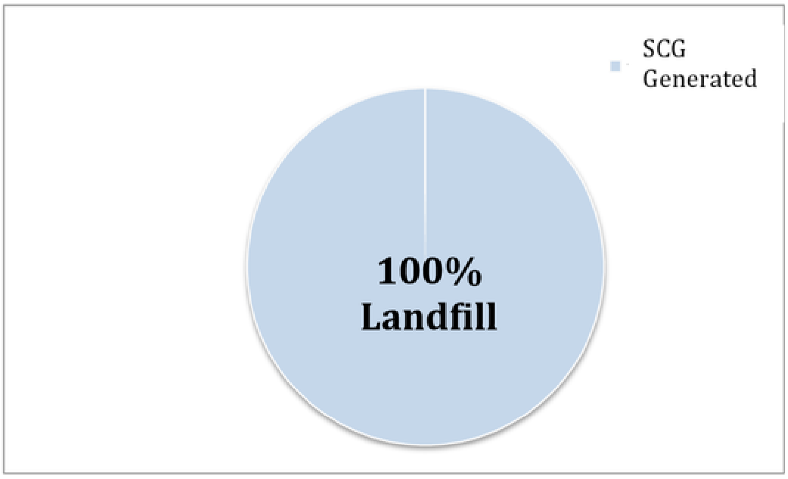


Figure 2.26- SCG Disposal Methods of 5 cafes in Macquarie University.

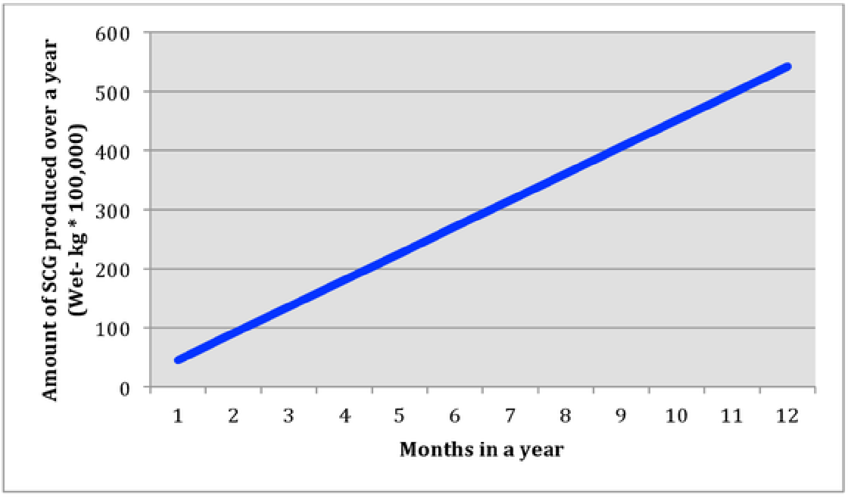


Figure 2.27- Average amount of SCG produced over a year for all cafes in Australia.

From Table 2.17 and Figure 2.24, 2.25, 2.26 and 2.27, it can be seen that a significant amount of spent coffee grounds is produced and that most of this waste is deposited into landfill. In 2016, there were roughly 14,400 cafes in Australia. This excludes the market giants such as Gloria Jeans and Starbucks [85]. In understanding that not every café within Australia would have equivalent work capacities, it can be assumed that not all cafes produce identical amount of spent coffee grounds. Therefore when analysing the amount of SCG produced the total amount of SCG produced daily is found by multiplying the average number of cups of coffee by the number of cafes in Australia (14 400) by 0.5 (to allow for varying service amount per café).

The total amount of SCG produced uniquely by cafes in Australia can be estimated (based on information gathered from the survey) to be 150,500 kilograms/day, which accumulates to 40,000 tonnes per year. This is consistent with finding of 2.2.3.1 whereby total SCG produced by cafes, market giants and consumers is 75,000 tonnes. Hence a significant amount of SCG is readily available.

A Survey on Coffee Consumption

By Laura Filia

Café Name:

Number of coffees sold daily:

Please rank the following coffee types from 1-5.
1 = Most Popular 5 = Least Popular

And indicate the number of coffee shots placed in a single cup of coffee for that coffee type.

Coffee Type	Rank	Number of Coffee Shots per Coffee
Latte		
Flat White		
Espresso		
Cappuccino		
Long Black		

How do you dispose of café spent coffee grounds?

Throw in the bin

Recycle – if so how? ____

Other ____

Thankyou for participating in this study!

Figure 2.28- Survey issued to café owners to gather accurate data on the amount of SCG produced by cafes.

2.2.3 Environmental Impact of non-utilised SCG

Within Australian cafes, 93% of SCG produced is placed in landfill, with only 7% being recycled. A survey completed by Planet Ark showed that from 921 Sydney cafes alone, 3000 tonnes of SCG is placed in landfill annually [79]. The 7% currently being recycled is generally used for gardening or composting purposes. Particular larger companies such as Nestle recycle their SCG to utilise for energy requirements [6]. However, many companies and most cafes and individuals dispose of their SCG into the rubbish bin, producing an 0.14 kg CO_{2e} per kilogram of green coffee, emission to the atmosphere [86].

2.2.4 Summary

Table 2.18: Summary table of Spent Coffee Grounds

Component	Claim	Reference
Spent Coffee Ground (SCG)	Spent Coffee Ground is waste product of ground coffee production. SCG contains large amounts of organic compounds such as fatty acids, amino acids, polyphenols, minerals and polysaccharides.	[44] [80] [85] [87]
Coffee Consumption Rate	Decrease in coffee consumption but still significantly large amount of SCG available for utilisation.	[8] [80] [83] [88] [89]
Available Amount of SCG	In Australia alone, 75,000 tonnes of SCG is produced each year.	[79] [85] [89] [90]
Oil Content of SCG	Oil yields from SCG can vary from technique to technique. The technique, which produces the highest oil yield, is soxhlet extraction.	[71] [75]
Oil to Biodiesel Conversion Techniques	Oil to biodiesel conversion of SCG can enable high or low oil to biodiesel efficiency. This result is determined by the conversion technique. Common conversion techniques are pyrolysis and trans esterification.	[72] [73] [44] [74]
Environmental Impact of SCG	In Australia, 93% of SCG produced is placed in landfill, with only 7% being recycled.	[79] [45] [91] [90]
	Industry giants such as Nestle utilise SCG for energy purposes. Majority of SCG from the Nestle coffee factory in Gympie, Queensland is used as an energy source to run the factory. Many factories however, do not utilize their SCG, causing a negative environmental impact.	[6] [79]
	SCG had emissions of 0.14 kg CO_{2e} per kilogram of green coffee. This emission is an accumulation of the effect disposal and storage of SCG has on the environment.	[86] [84] [91] [87]

2.3 Background and Related Work Summary

2.3.1 Biofuel

Biofuels are liquid fuels that have been derived from materials such as waste plant and animal matter. The two main types of biofuel currently produced in Australia are bioethanol and biodiesel. Bioethanol is used as a replacement for petrol and biodiesel is used as a replacement for diesel [3]. Fats, oils, starches, sugars and plant materials are converted to biofuel products by chemical, biological or thermochemical methods. Different biofuel conversion techniques are used depending on biomass type and desired output [9].

Biofuels are high in demand due to rising energy needs and a need for an environmental friendly energy supply. New biofuel feedstock options such as spent coffee grounds, must also be investigated to increase the feasibility of biofuel as an energy alternative. Current biofuel feedstocks include tallow, palm oil, soybean oil and corn.

In Australia, there are Renewable Energy Targets (RET), which provide financial incentives to consumers to use renewable energy. The use of this energy is aimed at minimising negative environmental impacts. Biodiesel use compared to mineral diesel use has an 85 per cent lower carbon emission. Biodiesel use also can help improve air quality and decrease waste placed in landfill.

2.3.2 Spent Coffee Grounds

Spent Coffee Grounds (SCG) are the waste product of ground coffee production. In Australia alone, 75,000 tonnes of SCG is produced each year. This amount of SCG can produce a significantly large amount of bio-oil [44]. Oil to biodiesel conversion of SCG can vary in efficiency. This efficiency is determined by the conversion technique. Common conversion techniques are pyrolysis and trans esterification [72] [73] .

In Australia, 93% of SCG produced is placed in landfill, with only 7% being recycled. Industry giants such as Nestle utilise SCG for energy purposes. Many factories however, do not utilize their SCG, causing a negative environmental impact. SCG has emissions of 0.14 kg CO_{2e} per kilogram of green coffee. This emission is an accumulation of the effect disposal and storage of SCG has on the environment [86] [84] [91] [87].

Compared to other biofuel feedstock options, SCG has a significantly smaller environmental impact. SCG as a feedstock will not have a significant negative environmental impacts that other feedstocks have, such as Indirect Land Use Change, as SCG will not be grown purely for biofuel purposes [91].The use of SCG will also aid in minimising the amount of waste being placed in landfill and help decrease negative environmental impacts.

3 Prospects in Australia

The amount of energy and biofuel able to be created by the available SCG in Australia, directly impacts the feasibility and likelihood of SCG being used as a biofuel feedstock. In this section, the amount of biofuel able to be produced from available SCG in Australia will be investigated.

3.1 Amount of Oil

From the survey-collected results, it is understood that collectively, cafes in Australia produce 150,500 kg of wet spent coffee grounds each day.

To convert coffee from wet to dry weight, we use the simple calculation [92]:

$$Dry\ weight = 0.5 * Wet\ weight$$
$$Dry\ weight\ Coffee\ generated\ in\ Australia = 0.5 * 150{,}500 = 75{,}250\ kg/\text{day}$$

Using Soxhlet oil extraction technique, this extraction type yields 18.3% of oil on a dry weight base ($\%g_{oil}/100g_{dry\ spent\ coffee}$) [67]. The following calculation can then be used to find the amount of oil able to be extracted [93].

$$Extracted\ Oil = 0.183 * Dry\ Coffee\ weight$$
$$Extracted\ Oil = 0.183 * 75{,}250 = 13{,}770.75\ kg\ of\ oil$$
$$Extracted\ Oil\ from\ Australian\ SCG = 15{,}560\ Litres/day$$

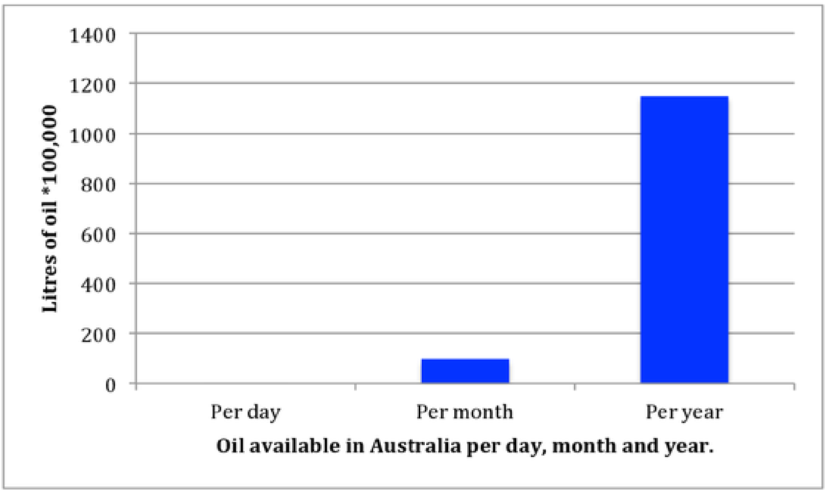


Figure 3.1- Amount of oil available to be extracted from SCG in Australia per day, per month and per year.

3.2 Amount of Energy

From the amount dry coffee waste generated in Australia, the amount of energy in the form of biofuel can be found, through the conversion process pyrolysis. Using the conversion technique pyrolysis, it is understood that the HHV (High Heating Value) of SCG at 723K is 23.19 MJ/kg [77].

Therefore the amount of energy able to be created from the amount of SCG produced in Australia everyday can be easily calculated using the following formula.

$$Amount\ of\ energy = 23.19 * Kilograms\ of dry\ coffee$$
$$Amount\ of\ energy = 23.19 * 13{,}770.75$$
$$Amount\ of\ energy\ available\ from\ SCG\ in\ Australia = 319{,}343.69\ MJ/day$$

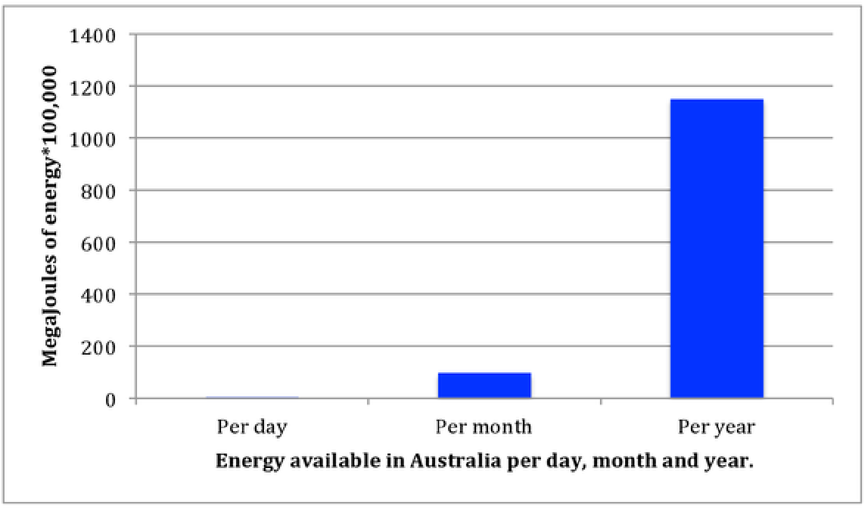


Figure 3.2- Amount of energy available to be extracted from SCG in Australia per day, per month and per year.

In summary, there is a large enough amount of energy able to be created from available SCG in Australia, to make the process feasible and viable. The amount of generated biofuel would also be able to cope with a significant percentage of Australia's energy needs, reducing Australia's dependence on fossil fuels.

4 Oil Conversion Technique Comparison

Different oil to biofuel conversion techniques will be compared and contrasted in this section. This will enable a superior conversion method to be selected to aid in increasing feasibility and economic viability of using SCG as a feedstock for biofuel.

The two most popular oil to biofuel conversion techniques which will be discussed are:

1. Pyrolysis
2. Trans esterification

The main factors, which will determine which conversion technique is superior for use in Australia and for SCG feedstock include:

1. Cost
2. Biofuel Yield
3. Environmental Impact

4.1 Cost

Cost is one of the most significant factors in determining which conversion technique will enable SCG to be a feasible, large-scale biofuel feedstock in Australia. A low cost technique will attract more companies and consumers to use this more eco-friendly energy source.

Cost of a conversion technique can be simplified by breaking it into two main components:

- Equipment
- Personnel

Equipment not only includes the purchasing of equipment, but the cost of maintenance, energy requirements, disposal and storage.

Personnel, also does not just include the paying of workers, but also training and equipping of employees which is considered for every occupation. These cost breakdowns can be seen in the following sections, tables and figures. The cost of purchasing SCG and transportation was not taken into account for this comparison, as it would be identical for each process.

4.1.1 Pyrolysis

Table 4.1: Pyrolysis Production Stage Equipment list and associated costs [94] [95] [96].

Pyrolysis Production		
Item	**Amount**	**Unit**
Pyrolysis Oil Yield	10,000	Tonnes/year
Operation Time	8000	Hours/year
Operation Life	20	Years
Depreciation	0	%
Raw material feed ratio	2.4	Tonne raw material/tonne of oil
Biochar yield ratio	0.5	Tone biochar/tonne oil
Pyrolysis Oil Density	1.2	Tonne/m^3
Equipment	1,200,000	$AU
Personnel Costs	800,000	AU$/year
Maintenance Costs	150,000	AU$/year
Insurance and taxes	1,900,000	AU$/year
Overhead	70,000	AU$/year
Power Consumption	233	kW
	1,864,000	kWh
	372,000	AU$/year
Total Cost	4,492,000	AU$/year

4.1.2 Trans esterification

Table 4.2- Tran esterification Production Stage Costs [97].

Trans esterification Production			
Category	**Item**	**Amount**	**Unit**
Biodiesel Oil Yield	-	50,000	Tonnes/year
Storage Equipment	Biodiesel Storage Tank	500,000	AU$
	Crude glycerol storage tank	33,000	AU$
Process Equipment	Methanol Storage Tank	36,000	AU$
	Potassium Hydroxide tank	37,500	AU$
	Reactor	225,000	AU$
	Filter Press	466,500	AU$
	Distillation Tower	180,000	AU$
	Biodiesel Evaporator	50,000	AU$
	Fatty acid storage tank	15,000	AU$
	Pumps	93,000	AU$
	Additional process equipment	649,500	AU$

Utility Equipment	Steam generation	104,000	AU$
	Instrument Air	25,000	AU$
	Electrical distribution system	100,000	AU$
Installation	-	2,000,000	AU$
Utility Cost	Electricity	0.19	AU$/kWh
		513,000	AU$/year
	Process Water	0.08	AU$/$m^3$
		433,000	AU$/year
Labour Cost	Engineers	156,000	AU$/year
	Supervisors	237,200	AU$/year
	Administration	123,000	AU$/year
	Labourer	190,000	AU$/year
Total Cost		6,166,700	AU$/year

4.1.4 Summary

Table 4.3: Total cost comparison of different techniques [94] [95].

Cost Item	Pyrolysis	Trans esterification
Total Equipment Cost (AU$)	1,200,00	2,285,500
Total Labour Cost (AU$)	800,000	706,000
Additional Cost (AU$)	2,492,000	3,175,200
Total Cost (AU$)	4,492,000	6,166,700

4.2 Biofuel Yield

The amount of biofuel able to be extracted or created from SCG is significantly important when selecting a superior conversion technique, as the amount of biofuel created will directly decrease the overall cost of the process. For example, if a process is quite expensive but produces a significantly large amount of biofuel, this biofuel can be sold and overall have a positive net value. A cheaper process, which only yields a small amount of biofuel, might not be economically beneficial.

To determine how much biofuel each process yields, specific experimental cases will be studied, which dealt specifically which SCG as the biofuel feedstock, thus increasing relevancy of this comparison.

4.2.1 Pyrolysis

When SCG is placed in a pyro lytic process, it produces varying compounds, as seen in Table 4.4. The gross amount of energy (or Higher Heating Value (HHV)) produced through pyrolysis for SCG specifically can be found in Table 4.5.

Table 4.4- Biofuel Compounds created from SCG through pyrolysis [38].

Compound Name	Formula	Compound Area (%)	
		10°C/min Heating Rate	60°C/min Heating Rate
Methylphenol	C_7H_8O	2.43	3.09
Catechol	$C_6H_6O_2$	2.31	2.84
Palmitic Acid	$C_{16}H_{32}O_2$	13.90	13.14
Linoleic Acid	$C_{18}H_{32}O_2$	25.59	28.67
Eicosanoic Acid	$C_{20}H_{40}O_2$	2.53	3.36
Ethoxyethyl Acetate	$C_6H_{12}O_3$	2.15	3.52
Furan-2-ylmethanol	$C_5H_6O_2$	2.36	3.28
Phenol	C_6H_6O	1.43	1.86

The High Heating Value (HHV) of biofuel products created using pyrolysis, when combined, is significantly high at 63.17 MJ/kg.

Table 4.5- Analysis of SCG Pyro lytic products [38].

Products	MC	Ash	HHV (MJ/kg)
Bio-oil	68.9	0.01	21.23
Bio-char	6.6	6.1	31.1
Biogas	-	-	14.84

MC= Moisture Content %

4.2.2 Trans esterification

Trans esterification produces biofuel oil with varying characteristics, as seen in Table 4.6. The High Heating Value (HHV) of biofuel, when extracted using trans esterification, is quite high at 40.8 MJ/kg.

Table 4.6- Bio oil yield using trans esterification [98] [99].

Parameter	Value	Unit
Moisture	0.114	%
HHV	40.8	MJ/kg
Acid Value	9.9	mg KOH/g SCG
Iodine value	47.6	g I_2/100g SCG

4.3 Environmental Impact

Being environmentally friendly when creating fuel is not only a preference in current society, but also a legal obligation. In many states there are environmental clauses and acts, which must be followed to ensure a reputable, legal and environmentally friendly energy production system. Global Warming Effect is a direct measurement of the amount of carbon dioxide released into the atmosphere, per metre cubed of oil. This measurement enables simple comparison between different conversion techniques, and their direct impact on the environment.

4.3.1 Pyrolysis

Pyrolysis uses a variety of equipment and techniques to achieve the final result of biofuel. These equipment and processes have a most significant environmental impact in the form of global warming effect, acidification and eutrophication.

4.3.1.1 Global Warming Potential

Pyrolysis has an 140-kg/CO_2/m^3-pyrolysis oil Global Warming Potential in the production stage [94]. This is primarily derived from equipment electricity consumed in the pyrolysis oil production stage. Detail into Global Warming and other significant environmental potentials of pyrolysis, can be seen in Table 4.7 and Figure 4.1 and 4.2.

Table 4.7- Environmental Impact Evaluation for Biomass Pyrolysis[94].

Potential	Unit	Production Stage
Global Warming	kg/CO_2/m^3 pyrolysis oil	139.4
Acidification	kg SO_2/m^3 pyrolysis oil	0.13
Eutrophication	Kg $PO^{3-}{}_4$/m^3 pyrolysis oil	0.054

Figure 4.1 and 4.2 also depicts the environmental impacts of pyrolysis oil in comparison to traditional fossil-fuel oil.

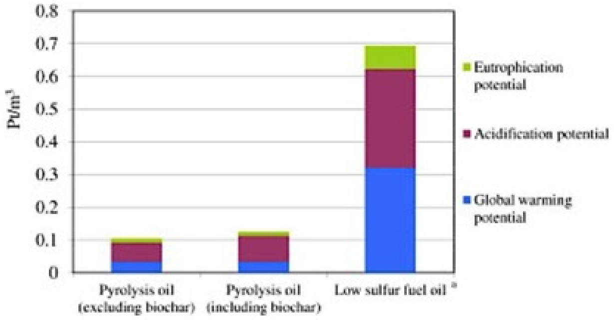


Figure 4.1- Environmental Impact Potentials for Pyrolysis process, compared to traditional fuel oil [94].

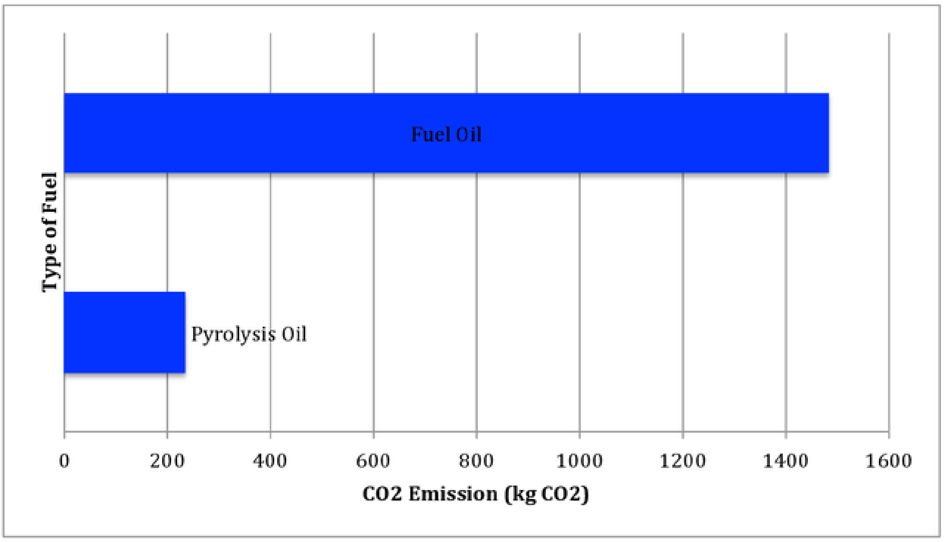


Figure 4.2- Comparison of environmental impacts between pyrolysis and traditional fossil fuel oil. Pt is potential [94].

4.3.1.2 Energy Required by Process

The energy required by the pyrolysis process is 233 kW per hour of usage [94]. This is one of the largest environmental impacts the process has.

4.3.2 Trans esterification

The trans esterification technique has environmental impacts during the production stage. This is heavily due to the power required during the process, and the large machinery used. Specific environmental impacts can be seen in the following Tables and Figures.

4.3.2.1 Global Warming Potential

Trans esterification produces a Global Warming Potential during the production stage. This effect is a direct measure of the impact this conversion technique has on the environmental. The extent of this impact can be seen in Table 4.8

Table 4.8- Environmental Impact Potentials for trans esterification[100]

Potential	Unit	Production Stage
Global Warming	kg CO_2/m^3 pyrolysis oil	147.82
Acidification	kg SO_2/m^3 pyrolysis oil	1.04
Eutrophication	kg $PO^{3-}{}_4/m^3$ pyrolysis oil	0.05

4.3.2.2 Energy Required by Process

The trans esterification process uses a total of 416 kW per hour during the processing and biodiesel creation stages. This is heavily due to the large amount of equipment required by the process and has a significant impact on the environmental effect of trans esterification.

4.4 Summary

A summary of the comparison factors between pyrolysis and trans esterification can be seen in Table 4.9. The energy required by each process can also be seen in Figure 4.3.

Table 4.9- Summary highlighting main comparison factors of Pyrolysis and Trans esterification [38] [94] [95][95] [98] [99] [100].

		Conversion Technique	
		Pyrolysis	**Trans esterification**
Comparison Factor	**Cost (AU$)**	4,492,000	6,166,700
	Biofuel Yield (HHV)	65.17	40.8
	Environmental Impact (GWP)	139.4	147.82

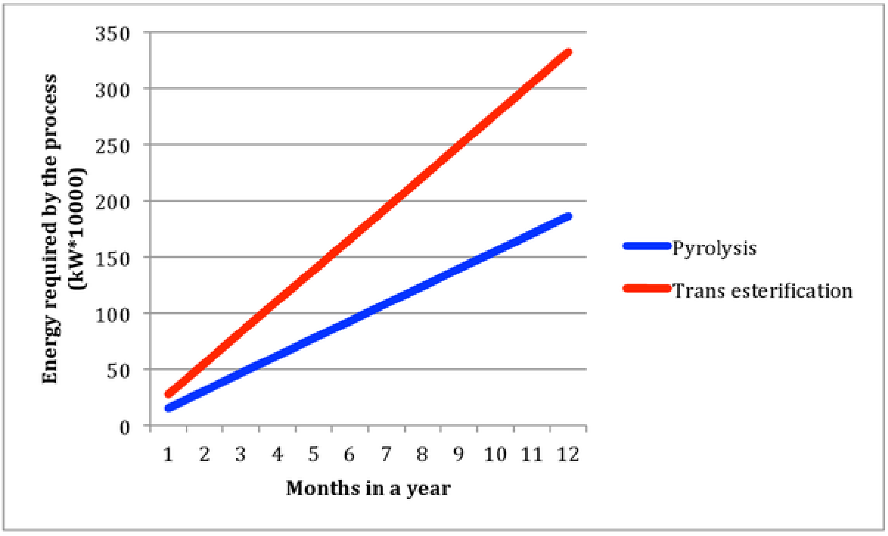


Figure 4.3- Energy required by pyrolysis and trans esterification process over a year, with assumed 8000 hours of operation per year.

In comparison, the pyrolysis conversion technique is cheaper, produces more energy per kg of SCG and has a lower environmental impact. Therefore the pyrolysis process is the process considered when determining the feasibility and viability of SCG as a biofuel feedstock.

5 Economic Viability Analysis (EVA)

The economic repercussions and net cost of using SCG as a feedstock for biofuel, has a significant impact on its' feasibility. An economic viability analysis (EVA) will therefore be performed on SCG as a biofuel feedstock to show the economical benefits or limitations of SCG as a biofuel feedstock.

An EVA is an analysis to ensure a concept or idea is economically feasible and will generate enough revenue to sustain costs associated with producing, selling and operating and the returns are acceptable to the provider[101]. Some projects or products do not have to be profitable to economically viable. For SCG as biofuel feedstock to be economically viable, it must have a profitable process within an acceptable and realistic time frame.

5.1 Currently Used Analysis Methods

There are many different methods and equations used to complete an EVA. These methods and equations will be compared and contrasted to allow for an enhanced method to be created which will ensure all significant aspects of the economic profile of the feedstock is considered.

5.1.1 Melo Approach

The approach taken by Melo was used in a similar context to which the current EVA which will be conducted. Melo's approach is based upon on the methodology of Turton et al[102]. It establishes the cost of manufacturing (COM) as a function of investment cost (FCI), labour cost (COL), utility cost (CUT), waste treatment cost (CWT) and raw material cost (CRM), using the below relation [67]:

$$COM = 0.304FCI + 2.73COL + 1.23(CUT + CWT + CRM) \quad (1)$$

Through research, a market value for biofuel can be obtained and the feasibility of the process can be obtained.

Positives of Melo Approach:
- Accounts for multiple factors relevant to SCG particular case
- Simple approach reducing risk of error
- Methodology based upon reliable and repeatedly used method
- Used previously on similar case to current case.

Negatives of Melo Appreach:
- Does not account for transportation
- Coefficients of factors are not specific to SCG case

5.1.2 Holderman Approach

Holdermans approach, is a highly mathematically based approach [103]. This approach has been used widely for different applications. A high level of detail and knowledge is required to use this approach.

$$K_0 = -I_0 + \sum_{t=1}^{n} \frac{(1 - t \propto)G_1(1+\beta)^t T_1 - OM_t}{(1+i)^t} + \frac{L}{(1+i)^n} \qquad (2)$$

$$I_0 = \sum_{t=1}^{n} \frac{(1 - t \propto)G_1(1+\beta)^t T_1/(1+i)^t}{1 + \gamma \sum_{t=1}^{n} 1/(1+i)\hat{}t} \qquad (3)$$

Table 5.1- Parameter explanation for Holdermans approach

Parameter	Explanation
K_0	Net present value (R$)
I_0	Investment (R$)
$\propto$	Annual efficiency loss (%)
G_1	Generation of the PV system in the first year of operation (kWh/a)
β	Annual electricity tariff charge rate (%)
T_1	Electricity tariff (R$/kWh)
$OM_t(y; I_0)$	Annual operation and maintenance cost (R$)
L	Liquidation proceeds (R$)
γ	Annual share of O&M costs depending on I_0 (%)
i	Discount rate (%)
n	Minimal system life time (a)
t	Year (a)

Positives of Holderman Approach:

- Extremely detailed
- Accounts for main factors in SCG to biofuel process

Negatives of Holderman Approach:

- Highly mathematical and complex, allowing easy errors
- Many factors which could vary with the current level of information for current SCG case.

5.1.3 Coelho Approach

This approach is based on simple cost-benefit analysis, with considerations of various costs such as: initial, operating, maintenance, labour and maintenance [101].

- Initial (new equipment purchase, lab space, administrative costs), operating, maintenance and all estimated labour costs were quantified per piece of equipment.
- Operation and maintenance costs were determines based on energy consumed by the equipment. Labour costs include management, local supervision, equipment operators and non-specialised workers.
- Benefits were measured by the ability to sell final products and recycle any equipment.
- Fixed costs including equipment and equipment replacing

All of these factors are then added together and plotted on a graph to show the average net cost and payback period of the project.

Positives of Coelho Approach

- Qualitatively detailed
- Accounts for many key factors in SCG for biofuel process
- Could be easily applied to current SCG case
- Includes personnel costs and ability to recycle products for return costs.

Negatives of Coelho Approach

- Does not provide a mathematical correlation between all factors

5.2 SCG based Biofuel Approach

To a complete an accurate economic viability analysis for SCG as a feedstock for biofuel, a new approach must be created to encompass all significant aspects of the process. This approach will be a combination of Melo and Coelho approach, highlighting the mathematical correlation in Melo's approach, and the detailed qualitative analysis of Coelho's approach.

Table 5.2- Factors used in EVA formula

Factor	Description	Fixed or Variable Cost	Unit
CEQ	Initial Equipment Purchase Cost	Fixed	AU$/year
CLU	Land Use Cost	Variable	AU$/year
COM	Cost of manufacturing	Variable	AU$/year
COL	Labour Cost	Variable	AU$/year
CUT	Utility/Operation Cost	Variable	AU$/year
CWT	Waste Treatment Cost	Variable	AU$/year
CRM	Raw Material Cost	Variable	AU$/year
CTR	Transportation Cost	Variable	AU$/year
CIT	Insurance and Taxes Cost	Fixed	AU$/year
REN	Revenue generated by selling biofuel	Variable	AU$/year

The following equation is an equation generated specifically for the biofuel process, weighting has been placed accordingly on factors with higher and lower importance.

$$COM = CEQ + CIT + CLU + 2.4(COL + CUT) + 0.5(CWT + CRM + CTR) - 1.3REN \qquad (4)$$

The coefficients seen in Equation 4, come from the break down on the importance of the individual factors within the biofuel process. Utility and labour cost are extremely important and hence are weighted much higher than waste treatment, raw material and transportation cost. Revenue generated also has a higher weighting due to several revenue production avenues available for the process.

5.3 EVA: SCG as a feedstock for Biofuel

Using the factors in Table 5.2, 5.3 and Equation 4 an economic viability analysis for SCG as a feedstock for biofuel can be created. Cost for the different factors were found through research and calculation.

Table 5.3: Cost Factors of SCG to Biofuel Process

Factor	Description	Cost	Unit	Reference
CEQ	Initial Equipment Purchase Cost	1,200,000	AU$	[94] [95]
CLU	Land Use Cost ($3000 per week)	156,000	AU$/year	[104]
COL	Labour Cost	800,000	AU$/year	[94] [95]
CUT	Utility/Operation Cost	592,000	AU$/year	[94] [95]
CWT	Waste Treatment Cost- Including waste disposal in landfill cost	300,000	AU$/year	[105] [94] [95]
CRM	Raw Material Cost	0	AU$/year	[94] [95]
CTR	Transportation Cost – Including fuel truck and driver.	267,350	AU$/year	[106] [94] [95]
CIT	Insurance and Taxes Cost	1,900,000	AU$/year	[94] [95]
REN	Revenue generated by selling generated biofuel - ($0.8/litre of fuel)	8,000,000	AU$/year	[107] [108]
COM	Cost of manufacturing	-3,349,320	AU$/year	

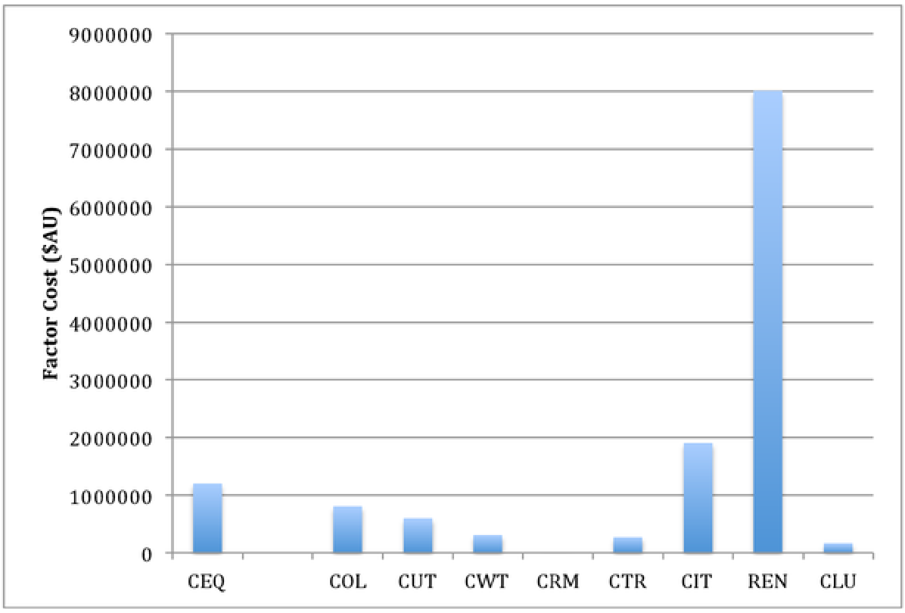


Figure 5.1- Cost Factors of SCG to Biofuel Process

As seen in Table 5.3 and Figure 5., revenue generated by the creation of biofuel from SCG allows the process to be profitable in its' first year. A negative cost of manufacturing shows the process is profitable. Main costs are related to tax and initial equipment costs. This model shows SCG as a biofuel feedstock to be extremely viable. If a factory were to be purchased for 5 million dollars, rather than rented, the payback period would be roughly 2.5 years before cost-revenue break even would occur and the process would become profitable, as seen n Figure 5.2.

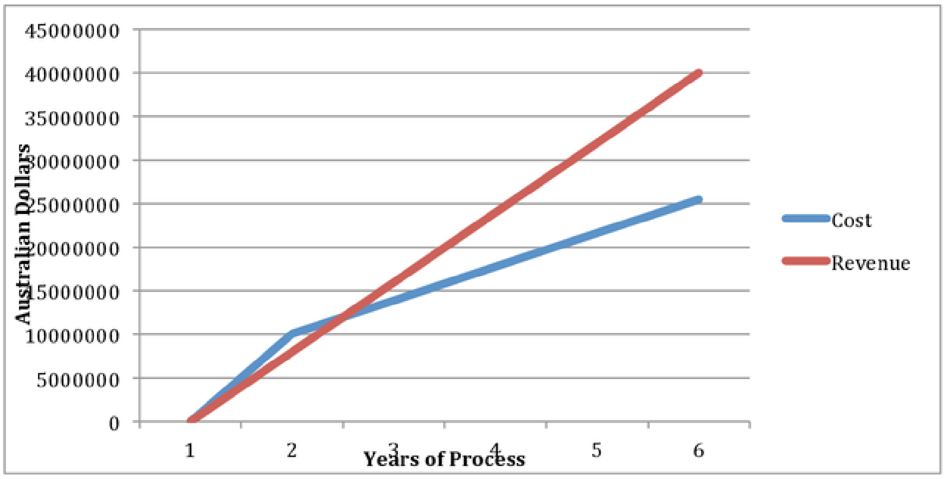


Figure 5.2- Break-even analysis of SCG as a biofuel feedstock, when factory is purchased rather than rented.

From the above figures and tables, it can be seen that biofuel created from SCG is an economically viable option. With profit occurring within the first year of practice if the factory is rented, or within the first 3 years if the factory is purchased, this is an extremely beneficial and attractive biofuel option. Even if worst case scenarios were to be carried out, with lower amounts of SCG available and higher factor costs, the process would still be profitable after an acceptable amount of years. Thus, this analysis provides proof that SCG as a biofuel feedstock is economically viable.

6 Lifecycle Assessment

A Lifecycle Assessment (LCA) of SCG as a feedstock option for biofuel must be completed to confirm that biofuel, specifically created with SCG is superior or second-class to competing fuel sources.

A Life Cycle Assessment was completed for the biofuel life cycle (using SCG as a feedstock) using GaBi software. Using this software, boundaries, conditions and significant processes were outlined which resulted in an understanding of the environmental impact of the process. The results displayed below arrive from the LCA report generated from software analysis. The full report can be seen in Appendices B.

6.1 LCA Setup

6.1.1 Goal

The goal of the creation and application of the GaBi i-report is to provide a life cycle assessment to compile and evaluate the inputs, outputs and the impacts of a system during its lifetime. Inputs are understood to be the resources required and outputs are emissions to different compartments such as air, water and soil.

This LCA helps to identify environmental hot spots and use this information to help improve the environmental performance at every stage of the systems life cycle. This LCA report will help to identify the feasibility of using spent coffee grounds (SCG).

6.1.2 Boundaries

This SCG to biofuel system has boundaries, which account for the amount of SCG available, energy required to enable the process and end of lifecycle effects. This report focuses on the SCG to biofuel process, end of life cycle effects and transportation through the entire process. The efforts necessary for the processing of the biofuel are calculated and adjusted automatically. The mode of transportation and distance for the raw materials of the biofuel is specified and the environmental impacts associated with these are calculated automatically.

6.1.3 Scenarios

Three scenarios have been constructed to display different environmental impacts for SCG as a form of biofuel when particular boundaries and factors are changed.

1. ***Scenario 1***: is based on current conditions, which represents the typical SCG to biofuel to end of life process, with all factors typical to current research. This includes current SCG availability, current process efficiency and energy requirements.

2. ***Scenario 2***: is based on worst-case conditions, which represents the SCG to biofuel to end of life process with maximum electricity and hexane requirements.
3. ***Scenario 3***: is based on minimum hexane requirements.

6.2 Life Cycle Illustrations

6.2.1 Life Cycle of Biofuel created from SCG

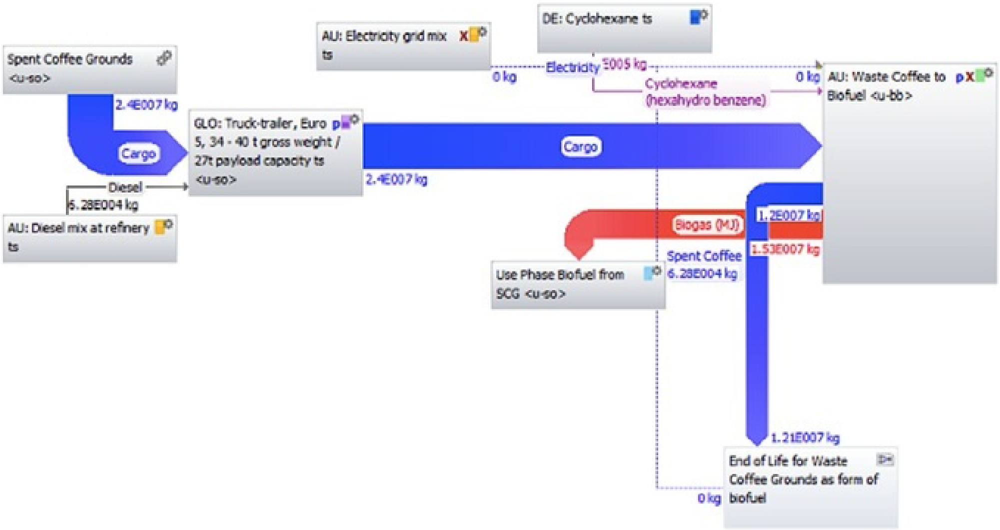


Figure 6.1- Life Cycle of Biofuel using SCG as a feedstock, for 1 year of operation with mass flow quantities.
Note: Electricity grid mix and End of Life processes show 0kg flow rate, as at these points, no mass is transferred, only energy.

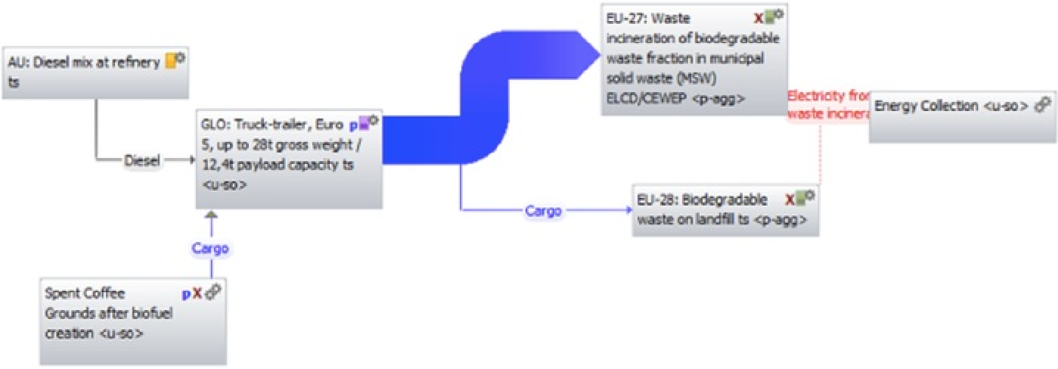
Life Cycle Processes in Detail

In this process, all elements of the SCG to biofuel conversion is taken into account. This includes:

- Electricity required to power the machinery for the reaction - Amount of hours the machinery is on
- Volume of solvent (hexane) required to complete the process (varied in different scenarios)
- Equipment required for oil extraction and biofuel process - Amount of SCG delivered and required by the process
- Mass volume of waste coffee grounds after the process - Amount of energy produced by the process
- Amount of heat produced by the process
- Method of biofuel transportation/ type of vehicle used/distance travelled.
- Method of waste coffee ground transportation

6.2.2 End of Life Phase

Figure 6.2- End of Life phase processes



End of Life Phase in Detail

The End of Life phase takes into account the processes and requirements of the system after the SCG to biofuel process has taken place. This includes the transportation and disposal of waste material. Considered elements in the End of Life phase include:

- Transportation of waste material to selected location
- Distance vehicle must travel
- Type of travel
- Disposal method
    - Incineration
    - Landfill
- Energy created and collected from disposal methods
    - Energy from gas produced by landfill
    - Heat energy created from incineration
- Use of energy created and collected

6.3 Life Cycle Assessment Results

Through the use of GaBi software, LCA results were generated. These results show the energy and environmental impacts of using SCG as a biofuel feedstock. These results will be used later in the section to compare the studied feedstock with competing feedstocks and fuel sources. All results depicted in this section, show the energy and environmental impact of the entire SCG to biofuel to end of life process for 100 years of production.

6.3.1 Energy Resources

Table 6.1 presents the demand on energy resources for the different scenarios. The fields are a green colour when an alternative has a value that is 10% lower than the base scenario (Scenario 1). The red colour fields indicate the scenario has at least a 10% higher value than the base scenario.

Table 6.1-Energy demands of different scenarios for SCG to biofuel system for 100 years of production.

	Scenario 1	**Scenario 2**	**Scenario 3**
Primary Energy [MJ]	212,686,142	252,330,547	176,366,333
Primary energy demand from renewable and non-renewable resources (gross value) [MJ]	55,240,363	65,533,474	45,806,887
Primary energy demand from renewable and non-renewable resources (net value) [MJ]	50,470,971	59,875,360	41,855,062

6.3.2 Primary Energy Demand

Figure 6.3 shows the primary energy demand according to the CML2016 assessment methodology for each of the production phases according to their relative contribution. Results are displayed for the three scenarios.

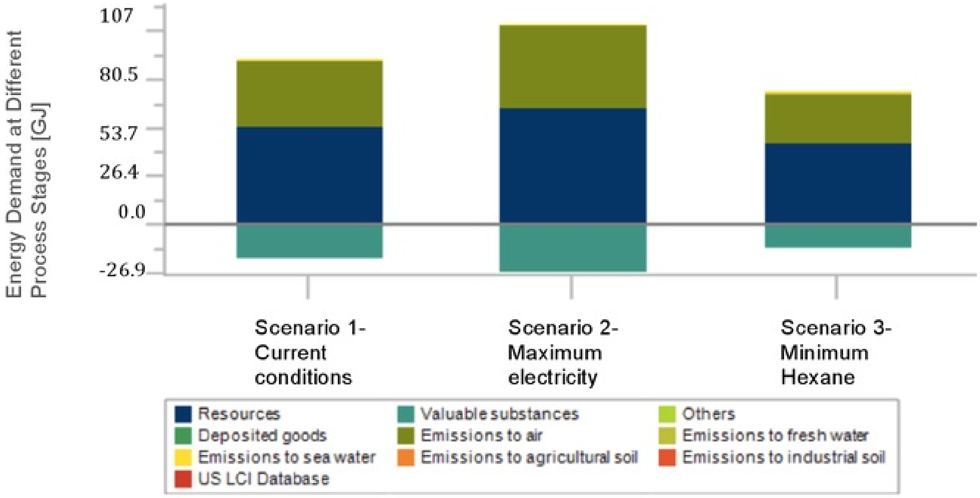


Figure 6.3 - Energy demands of SCG to biofuel process for different scenarios. Note: Negative values in graph are found from energy created in the system.

6.3.3 Global Warming Potential

Figure 6.4 shows the Global Warming Potential (GWP) results according to the CML2016 assessment methodology. Results are displayed for the three scenarios. It shows the GWP for 100 years of biofuel production from SCG. A breakdown of the contributors to the GWP for biofuel production from SCG can be seen in Figure 6.5.

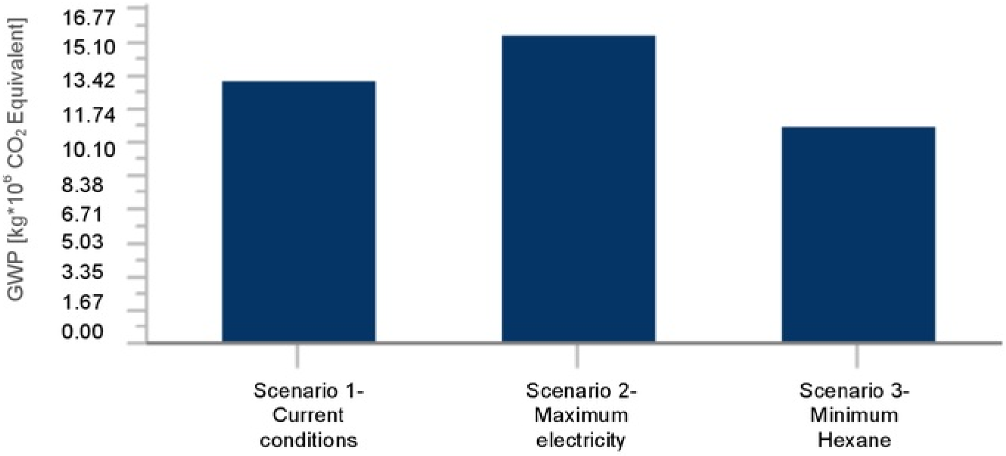


Figure 6.4- GWP for 100 years of biofuel creation from SCG for different scenarios.

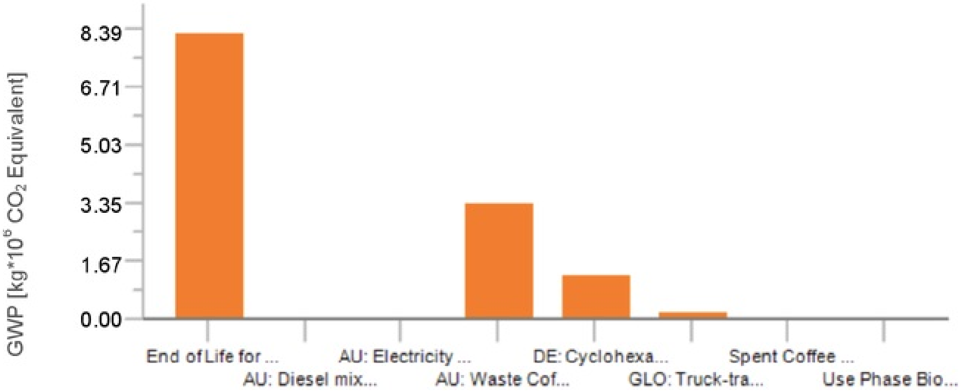


Figure 6.5- Contributors to GWP for SCG to biofuel life cycle and end of life cycle.

6.3.4 Other Environmental Impacts

This section shows a selection of impact assessment results according to the CML2016 methodology. Table 6.2 depicts other impacts the SCG to biofuel to end of life cycle has on the environment. Table 6.2 is highlighted red when the values within the cells are more than 10% greater than the Base scenario (benchmark). Likewise, those cells that contain values that are 10% less than the Base scenario values are highlighted green. Further detail of other environmental impacts can be seen in Figure 6.6-6.8.

Table 6.2- Results for other selected environmental impacts

	Scenario 1	**Scenario 2**	**Scenario 3**
CML2016- Acidification Potential (AP) [kg SO_2 Equivalent]	7,757	9,564	6,080
CML2016- Eutrophication Potential (EP) [kg Phosphate Equivalent]	1,397	1,732	1,090
CML2016- Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equivalent]	0.04	0.05	0.03
CML2016- Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equivalent]	379	449	265

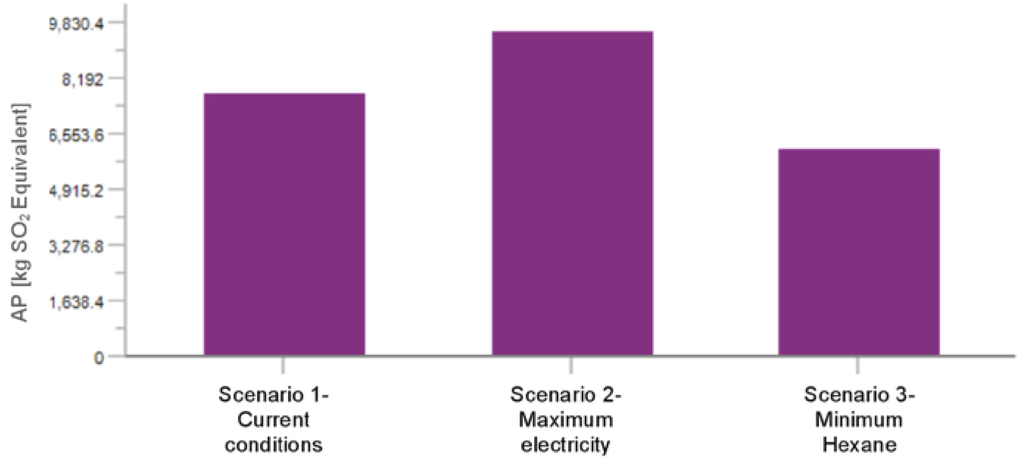


Figure 6.6 – Acidification Potential for different scenarios for SCG to biofuel system

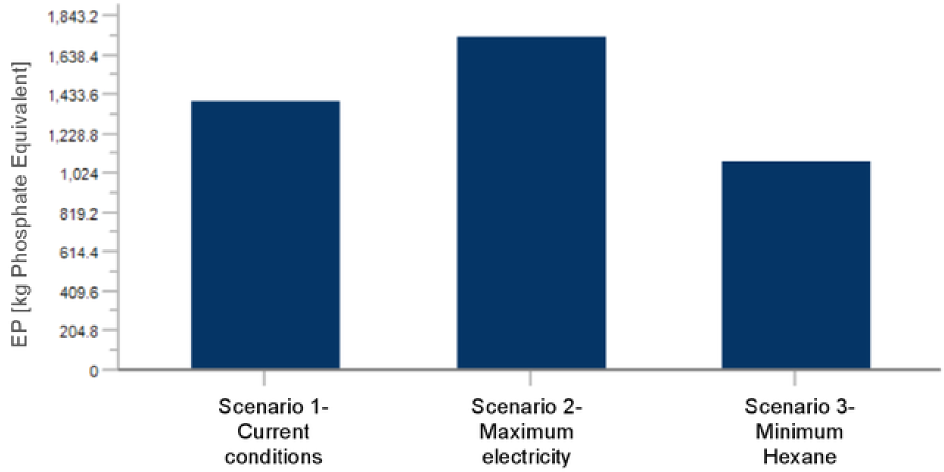


Figure 6.7- Eutrophication Potential for different scenarios for SCG to biofuel process.

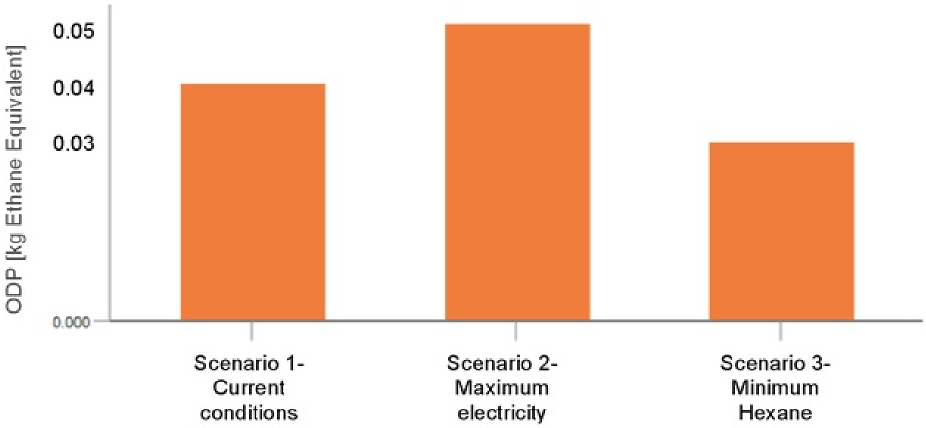


Figure 6.8 – Ozone Layer Depletion Potential (ODP) for SCG to biofuel process.

6.3.5 Summary of LCA

In conclusion, it is clearly demonstrated that Scenario 3 has the smallest environmental impact and therefore the SCG to biofuel to end phase system should aim to replicate Scenario 3 conditions. Scenario 1, which is based on current available data still also produced low environmental impacts and therefore a positive LCA. Scenario 2 however, produced greater negative environmental impacts in almost every category and therefore this system should not be replicated.

Significant environmental impacts were seen through factors such as:

- Global Warming Potential
- Acidification Potential
- Eutrophication Potential
- Ozone Depletion Potential
- Total energy use

These results can be used to determine the feasibility of SCG as a feedstock for biofuel and can allow for comparison of SCG with other feedstock options. For Scenario 1, which is based on current available resources and processes, the negative environmental impact was quite low. Any comparisons made, will be compared to Scenario 1 as it is the current available scenario, with processes and feedstock quantity which is available.

6.4 Comparison with other Feedstock and Fuel

To aid in determining the feasibility of SCG as a biofuel feedstock, comparisons must be made between SCG and other feedstocks used for biofuel and traditional fuel sources. An effective comparison technique is the comparison between the GWP and energy required of different feedstocks for biofuel and fossil fuels. The GWP accounts for all elements and processes within varying techniques and is a reliable measurement of the environmental impact of the different techniques. A lower GWP is highly favourable and aids in increasing the feasibility of the biofuel process.

The energy demand of the system also plays a large role in the feasibility of the process, as lower energy needs results in lower costs and demands. A comparison of different feedstock options for biofuel and traditional fuels can be seen in Table 6.3, Figure 6.9 and Figure 6.10 The values seen in Table 6.3 are for the entire process of fuel creation.

Table 6.3- Comparison of environmental energy impacts of varying feedstocks of biofuel and alternative fuel sources [109] [110] [111] [112] [113]

Biofuel Feedstock Comparison		
Feedstock	**Energy Required [MJ]**	**GWP [kg CO_2 Equivalent] per MJ produced**
SCG	**0.0986**	**0.041**
Corn	0.2898	0.025
Soybean	0.5240	0.062
Alternative Fuel Sources Comparison		
Fuel Source	**Energy Required [MJ]**	**GWP [kg CO_2 Equivalent] per MJ produced**
SCG Biofuel	**0.0986**	**0.041**
Brown Coal	-	0.900
Diesel Oil	-	0.699

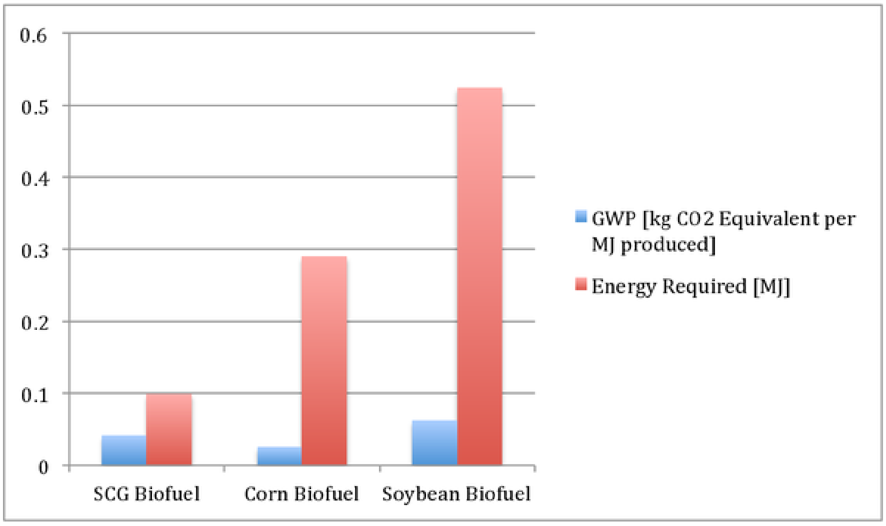


Figure 6.9- Comparison of GWP and Energy required between varying biofuel feedstocks.

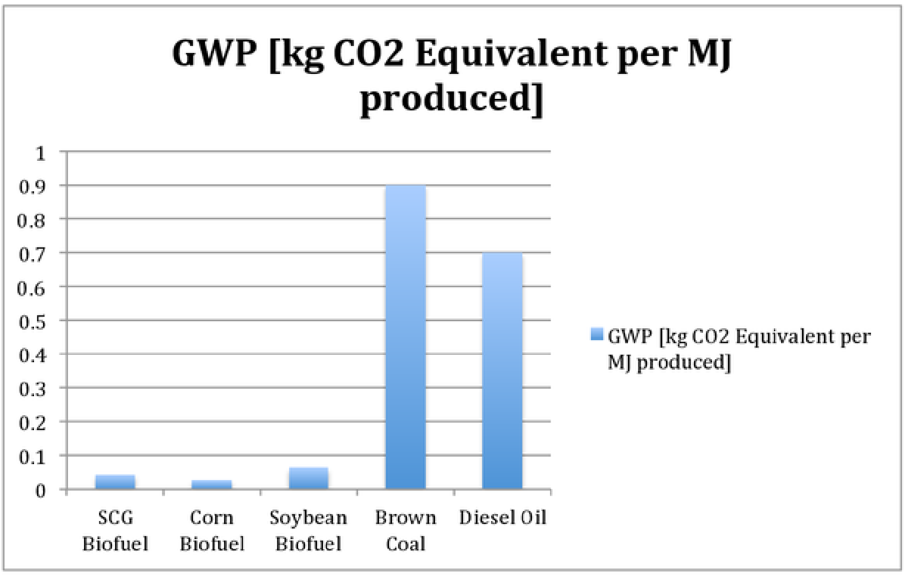


Figure 6.10- Comparison of GWP for varying biofuel feedstocks and traditional energy sources.

From the results, it can be seen that SCG based biofuel has the lowest GWP compared to other sources and the second lowest energy required. Thus making SCG based biofuel the most attractive fuel option.

7 Conclusion

This report investigated the feasibility of SCG as a biofuel feedstock in Australia. The objective of this research was to explore the use of coffee ground as a viable, alternative and low cost source of biodiesel. To accomplish this, an extensive study of coffee grounds properties, environmental impact and cost analysis was conducted through research, lifecycle cost analysis, economic viability analysis and data analysis. This study addressed current biofuel feedstock issues such as:

- High biofuel production costs
- Low biofuel production efficiencies
- Availability of feedstock
- Environmental impact of feedstocks

Results obtained through this analysis provide proof that SCG for a biofuel feedstock in Australia is:

- Economically viable – with a short payback period and high net revenue within an acceptable period of time.
- Environmentally effective- having a much lower negative environmental impact and energy requirement than other feedstock options and fuel sources.
- Cost and productivity efficient- producing a high amount of energy from the available SCG in Australia for a viable cost, with revenue creating profit from early in the process.

From this research, evidence promotes SCG as a biofuel feedstock to be a feasible and economical viable process. Therefore providing the basis for an efficient, cost-effective and viable renewable energy source to aid Australia's energy crisis.

8 Recommendations for Future Work

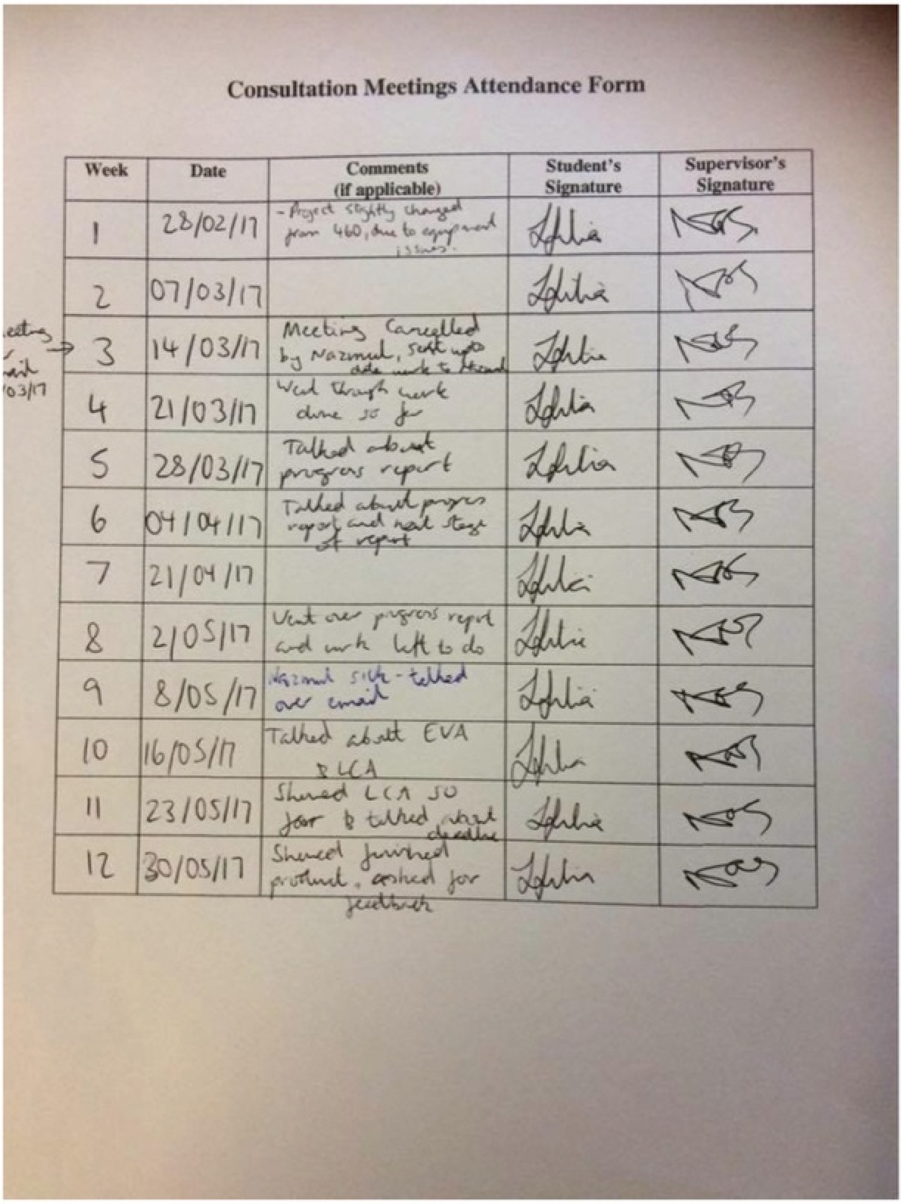
To further increase the efficiency, cost effectiveness and viability of SCG as a biofuel feedstock in Australia, several area and components of the process could be improved through research and analysis. The most significant factors for future improvement include:

- Oil Extraction Process
- Hexane Requirement
- Biofuel Creation Process
- Experimentation and publication

Further research into the oil extraction process, to increase the amount of oil able to be extracted from the SCG would increase the biofuel yield and efficiency of the process. Research into minimising the amount of hexane required within the feedstock to biofuel process should also be conducted, as the environmental impact of hexane is a significant contributor to the negative environmental impact of the process. Within the biofuel creation process, further research should be completed to improve the production efficiency and overall biofuel yield, increasing the attractiveness and likelihood of biofuel being used on a larger scale.

Finally, further experimentation and publication of SCG as a biofuel feedstock should be completed to increase the awareness of the feasible biofuel feedstock and motivate larger companies, organisations and government sectors to utilise the wasted feedstock.

9 Appendix A- Consultation Attendance Form



Consultation Meetings Attendance Form

Week	Date	Comments (if applicable)	Student's Signature	Supervisor's Signature
1	28/02/17	- Project slightly changed from 460, due to equipment issues.	[illegible]	[illegible]
2	07/03/17		[illegible]	[illegible]
3	14/03/17	Meeting Cancelled by Nazmul, sent up to date work to [illegible]	[illegible]	[illegible]
4	21/03/17	Went through work done so far	[illegible]	[illegible]
5	28/03/17	Talked about progress report	[illegible]	[illegible]
6	04/04/17	Talked about progress report and next stage of report	[illegible]	[illegible]
7	21/04/17		[illegible]	[illegible]
8	2/05/17	Went over progress report and work left to do	[illegible]	[illegible]
9	8/05/17	Nazmul sick - talked over email	[illegible]	[illegible]
10	16/05/17	Talked about EVA & LCA	[illegible]	[illegible]
11	23/05/17	Showed LCA so far & talked about deadline	[illegible]	[illegible]
12	30/05/17	Showed finished product, asked for feedback	[illegible]	[illegible]

10 Appendix B- Life Cycle Report

Waste Coffee Grounds in the Form of Biofuel

24th May 2017

Laura Filia

PE INTERNATIONAL
EXPERTS IN SUSTAINABILITY

24.05.17 I SCG in the form of Biofuel

1 Introduction

This report will outline the Lifecycle Assesment (LCA) of spent coffee grounds (SCG) as a feedstock option for biofuel. In this report, boundaries, conditions and signifcant processes will be outlines which will result in an understanding of the environmental impact of the process.

2 Goal and system boundaries

This section outlines the goal of the GaBi i-report. The underlying system boundaries for this example will also be explained and briefly described.

2.1 Goal

The goal of the creation and application of this GaBi i-report is to provide a life cycle assesment to compile and evaluate the input and outputs and the impacts of a system during its lifetime. Inputs are understood to be the resources required and outputs are emissions to diferent compartments such as air, water and soil. This LCA helps to identify environmental hot spots and use this information to help improve the environmental performance at every stage of the systems life cycle. This LCA report will help to identify the feasibility of using spent coffee grounds (SCG).

2.2 System boundaries

The GaBi 5 plans in the next topic illustrate the system set-up on which the process of SCG to biofuelare based. This system has boundaries which account for the amount of SCG available, energy required to enable the process and end of lifecycle effects. This report focuses on the SCG to biofuel process, end of life cycle effects and transportation through the entire process. Here different transportation distances, mass of hexane needed for the process and the amount of SCG available can be adjusted. The efforts necessary for the processing of the biofuel are calculated and adjusted automatically. The mode of transportation and distance for the raw materials of the biouel can be specified by the user and the environmental impacts associated with these are calculated automatically.

2.3 Scenarios

Three scenarios have been constructed to display different environemental impacts for SCG as a form of biofuel when particular boundaries and factors are changed. Benchmark is the first scenario which represents the typical SCG to biofuel to end of life process, with all factors typical to current research. Option 1 is the second scenario which represents the SCG to biofuel to end of life process with maximum electricity and hexane requirements. Option 2, the final scenario represents the system with the lowest hexane requirement.

3 Illustration of SCG to Biofuel Life Cycle

3.1 Entire Life Cycle

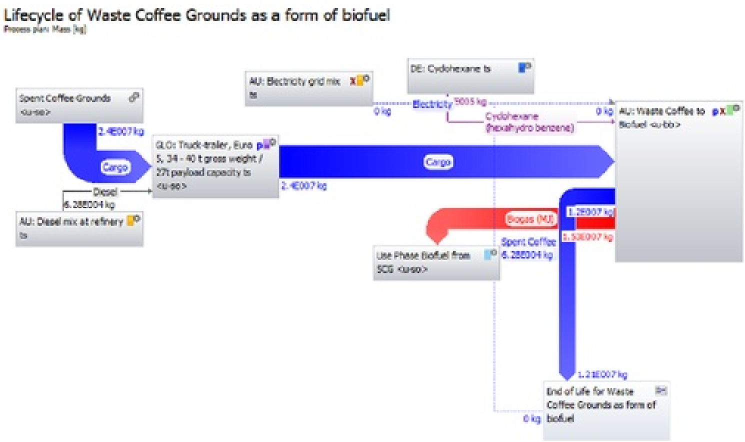


Figure 1. Life Cycle of SCG as a form of biofuel, for 1 year of operation with mass flow quantities.

3.1.1 Life Cycle Processes In Detail

Waste Coffee to Biofuel

In this process, all elements of the waste coffee ground to biofuel conversion is taken into account. This includes:

- Electricity required to power the machinery for the reaction
- Amount of hours the machinery is on
- Volume of solvent (hexane) required to complete the process (varied in different scenarios)
- Equipment required for oil extraction and biofuel process
- Amount of SCG delivered and required by the process
- Mass volume of waste coffee grounds after the process
- Amount of energy produced by the process
- Amount of heat produced by the process
- Method of biofuel transportation
- Method of waste coffee ground transportation
- Type of vehicle used
- Distance vehicle must travel (varied in different scenarios)

End of life processes are defined in Section 3.2.1.

3.2 End of Life Phase

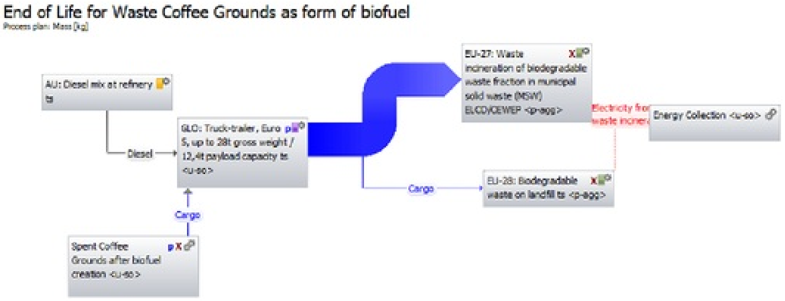


Figure 2. End of Life Phase processes

3.2.1 End of Life Phase in Detail

The End of Life phase takes into account the processes and requirements of the system after the SCG to biofuel process has taken place.This includes the transportation and disposal of waste material. Considered elements in the End of Life phase include:

- Transportation of waste material to selected location
- Distance vehicle must travel
- Type of travel
- Disposal method
    - Incineration
    - Landfill
- Energy created and collected from disposal methods
    - Energy from gas produced by landfill
    - Heat energy created from incineration
- Use of energy created and collected

4 Selected Inventory Results

4.1 Energy Resources

Table 1 presents the demand on energy resources for the different scenarios. The fields arecoloured green whenan laternatives has a value that is 10% lower than the base scenario (benchmark). Red coloured fields indiciate the scenario has at least a 10% higher value than the base scenario.

	Benchmark	Option 1	Option 2
Primary energy	212,686,142.95	252,330,547.62	176,366,333.08
Primary energy demand from ren. and non ren. resources (gross cal. value) [MJ]	55,240,363.15	65,533,474.42	45,806,887.59
Primary energy from non renewable resources (net cal. value) [MJ]	50,470,971.96	59,875,360.05	41,855,062.32

Table 1.Energy demands of different scenarios for SCG to biofuel system.

5 Environmental Impact Assesement

5.1 Global Warming Potential

This chart shows the Global Warming Potential results according to the CML2016 assesment methodolgy. Results are displayed for the three scenarios.

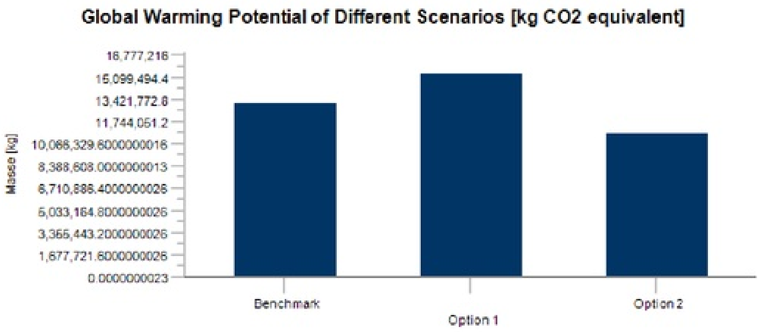


Figure 3. GWP for 100 years for biofuel creation from SCG for different scenarios.

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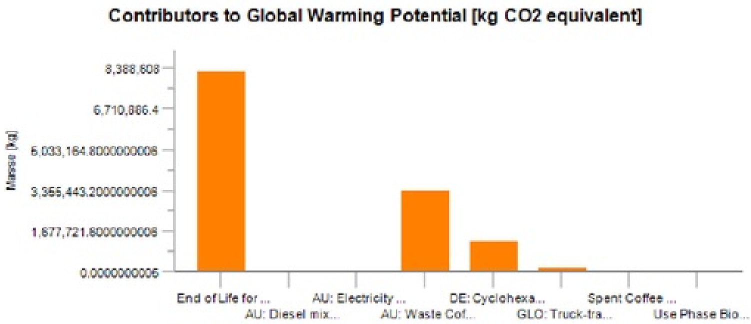

Figure 4. GWP of specific processes within SCG to Biofuel Process for benchmark scenario.

5.2 Other Selected Impact Categories

This section shows a slection of impact assesment results according to the CML2016 methodology. This tabe is setup to highlight the cells red when the valus within are moe than 10% greater than the Base scenario (benchmark). Likewise, those cells that contain values that are 10% less than the Base scenaio values are highlighted green.

Table 2: Results for other selected impact categories

	Benchmark	Option 1	Option 2
CML2001 - Jan. 2016, Acidification Potential (AP) [kg SO2-Equiv.]	7,757.97	9,584.41	8,080.66
CML2001 - Jan. 2016, Eutrophication Potential (EP) [kg Phosphate-Equiv.]	1,397.26	1,732.14	1,090.21
CML2001 - Jan. 2016, Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	0.04	0.05	0.03
CML2001 - Jan. 2016, Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	379.53	449.97	265.93

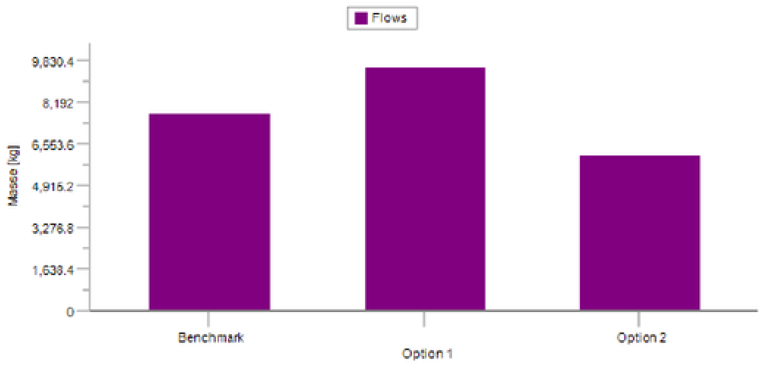

Figure 5. Acidification Potential for different scenarios for SCG to biofuel system.

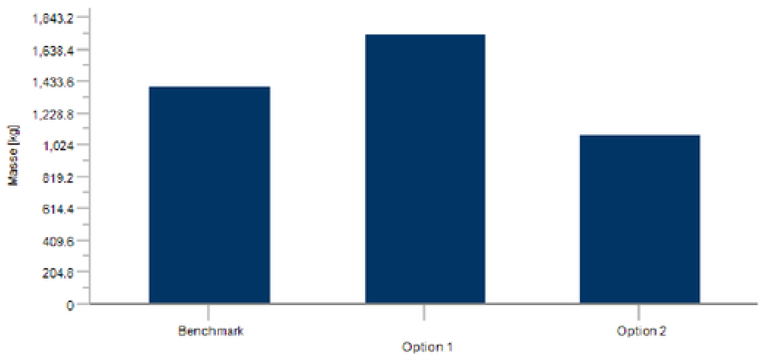

Figure 6. Eutrophication Potential for different scenarios for SCG to Biofuel process.

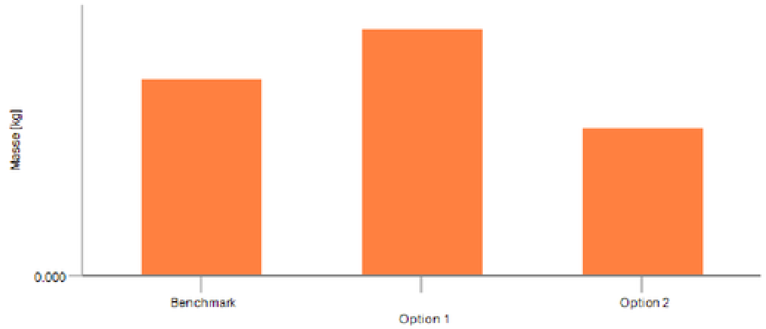

Figure 7. Ozone Depletion Potential of different scenarios for SCG to Biofuel system.

5.3 Primary Energy Demand

This chart shows the primary energy demand according to the CML2016 assesment methodology for each of the production phases according to thei relative contribution. Results are displayed for the three scenarios.

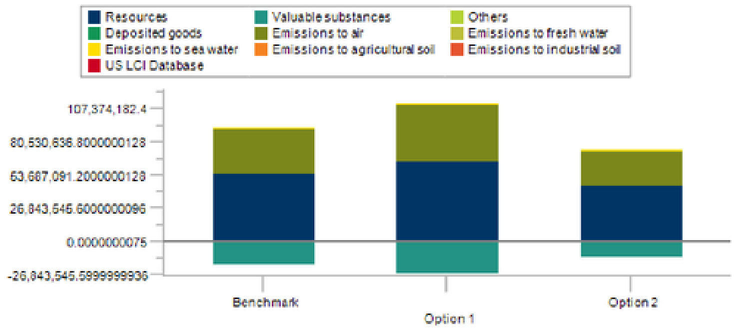

Figure 8 . Energy demands of SCG to biofuel process for different scenarios.

24.05.17 I SCG in the form of Biofuel

6 Conclusion

In conclusion, it is clearly demonstrated that Option 2 scenario has the smallest environmental impact and therefore the SCG to biofuel to end phase system should aim to replicate Option 2 conditions. The benchmark scenario, based on real life data still also produced low environmental impacts and therefore a positive LCA. Option 1 however, produces greater environmental ipacts in almost every category and therefore this system should not be replicated.

Significant environmental impacts were seen through factors such as:

- Global Warming Potential
- Acidification Potential
- Eutrophication Potential
- Ozone Depletion Potenial
- Total energy use

These results can be used to determine the feasibility of SCG as a feedstock for biofuel and can allow for comparison of SCG with other feedstock options.

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Sustainability awareness is the road to long-term corporate operation and a vibrant environment. PE INTERNATIONAL has been steadily guiding companies all over the world along this road since 1991. Today, PE INTERNATIONAL is the international market leader in strategic consultancy, software solutions and extensive services in the field of sustainability.

PE INTERNATIONAL provides conscientious companies with cutting-edge tools, in-depth knowledge and an unparalleled spectrum of experience in making both corporate operations and products more sustainable. Applied methods include implementing management systems, developing sustainability indicators, life cycle assessment (LCA), carbon footprint, design for environment (DfE) and environmental product declarations (EPD), technology benchmarking, or eco-efficiency analysis, emissions management, clean development mechanism projects and strategic CSR consulting.

Over 1500 companies and institutes worldwide put their trust in PE INTERNATIONAL's consultancy and software, including market and branch leaders such as Alcan, Allianz, Bayer, Daimler, Deutsche Post DHL, Rockwool, Siemens, Toyota, ThyssenKrupp and Volkswagen.

Consulting

Life Cycle Assessment	Life Cycle Engineering
Design for Environment	Carbon Footprinting
Environmental Risk Management	Environmental Communications

Software Sales & Support

- GaBi Software: An all-in-one platform for modeling complex product systems from a Life Cycle Perspective. Users can build product models, balance emissions and material inputs, and create interactive reports like this one! GaBi is packaged and sold to meet a broad range of client needs; we look forwards to working with you to identify the most suitable solution to meet your firm's software needs.
- SoFi Software: The most affordable and flexible software platform for enterprise-wide environmental management. With four product lines and customized deployments to meet your organization's reporting structure, SoFi can be tailored to meet all your sustainability needs, from Environmental Health & Safety to Emissions Management.

Database Supply & Data Warehouse

- The GaBi database is regularly updated with information derived from industry sources and published literature, creating a solid foundation for assessing your materials, products, services and processes. The database is typically sold in "professional", "lean", and "extension" packages. We also provide cost-effective "data-on-demand" to meet your specific data needs.

11 Appendix C- References

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