Report

Greenhouse Gas LCA of Ethanol from Whey

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Prepared for

Energy Efficiency and Conservation Authority

Level 8, Vector House
44 The Terrace
Wellington, 6011

42769410

URS

Project Manager:

……………………………
June Gibbons
Environmental Scientist

URS New Zealand Limited

Lambton House, 160 Lambton Quay
Wellington 6011
PO Box 3367, Wellington 6140
New Zealand
T: 64 4 496 3750
F: 64 4 496 3755

Project Director:

……………………………
Vanessa Browne
Principal

Author:

……………………………
June Gibbons
Environmental Scientist

Reviewer:

p.p. ……………………………
Gael Ogilvie
Senior Principal

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Abbreviations

Abbreviation	Description
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
E10	Ethanol blended petrol (10% ethanol)
GHG	Greenhouse gas
GWP	Global Warming Potential
HFC	Hydrofluorocarbons
IAA	Industrial absolute alcohol
LCA	Life cycle analysis
N_2O	Nitrous oxide
PFC	Perfluorocarbons
SEA	Standard ethyl alcohol
URS	URS New Zealand Ltd

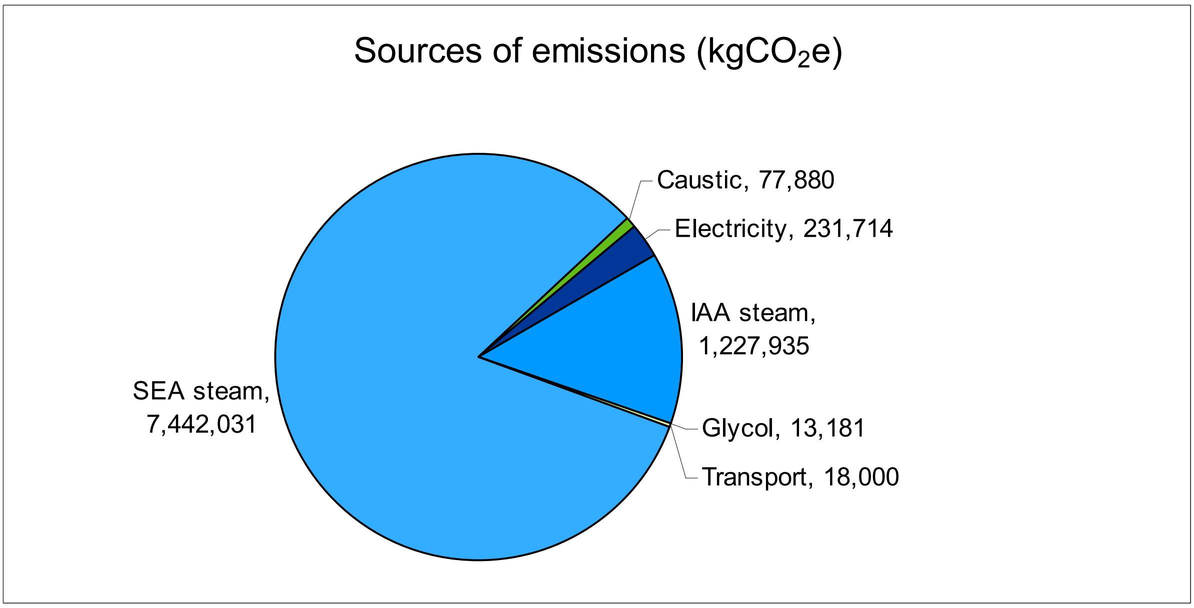
Executive Summary

URS New Zealand (URS) was contracted by the Energy Efficiency and Conservation Authority (EECA) to assist Fonterra with calculating the life cycle Greenhouse Gas (GHG) emissions of ethanol produced from whey.

The calculation generally follows the PAS 2050 standard, but has been modified to remain comparable with other biofuel emission calculations, for example those provided under the United Kingdom Renewable Transport Fuels Obligation (UK RTFO) and previous work undertaken by URS for EECA on biodiesel production in New Zealand.

The evaluation is cradle to gate and is based on ethanol produced at the Reporoa plant in 2008-09. The upstream boundary for this product is the collection point of the ethanol feedstock. This aligns with other biofuels produced from waste feedstock. The downstream boundary is arrival at the blending facility in Mt Maunganui. All inputs and outputs within this boundary were initially accounted for, although some were later excluded on the basis of materiality.

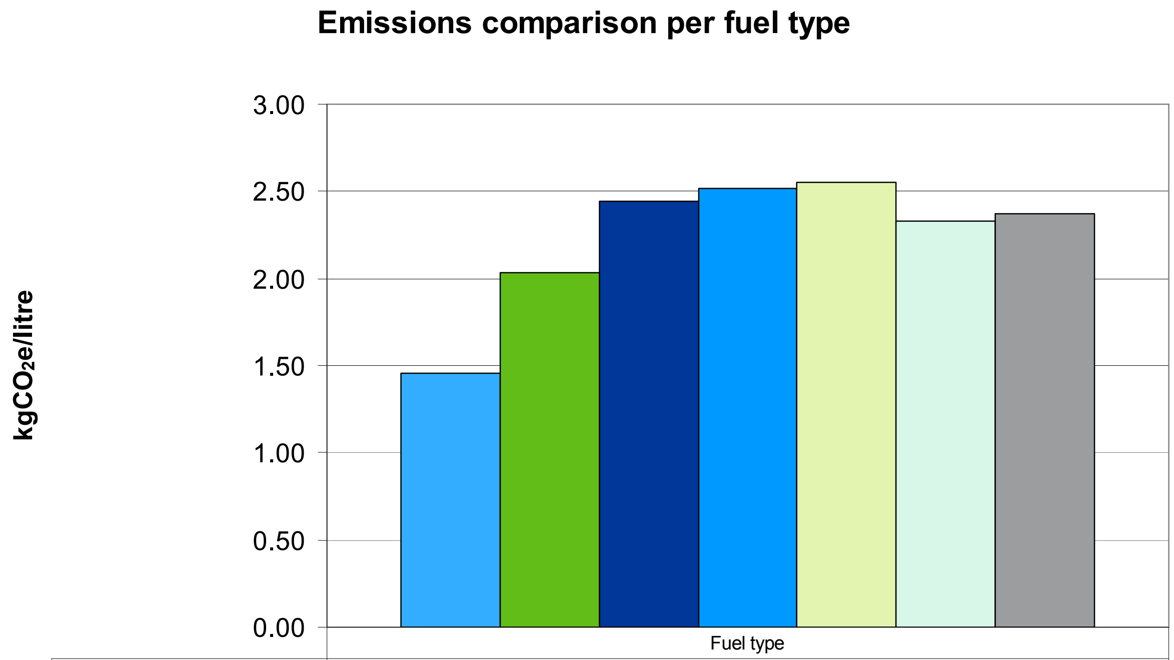
Figure 1 Sources of emissions



	Volume	**Unit**
Total emissions (per year)	9,011,000	kgCO$_2$e
Emissions intensity per litre of IAA output	1.46	kgCO$_2$e/litre IAA
Emissions intensity per MJ of IAA output	0.06	kgCO$_2$e/MJ IAA

Figure 1 summarises the GHG emission results. Steam energy (generated from natural gas combustion) is the single largest source of emissions, while total energy inputs (steam and electricity) together account for 99%% of emissions in ethanol production. Ethanol transport from Reporoa to Mt Maunganui, as well as other chemical inputs, account for less than 1% of total emissions.

Figure 2 Comparison of emission intensity by fuel type



	Fuel type
🟦 Ethanol (IAA)	1.46
🟩 Ethanol adj energy content	2.03
🟦 E10 blend	2.44
🟦 E10 blend adj energy content	2.51
☐ Regular petrol - direct+indirect	2.55
☐ Regular petrol - direct	2.33
⬛ Premium petrol - direct	2.37

Emissions from conventional petrol comprise of two parts: emissions from combustion; and emissions from upstream sources like drilling, transport and refining. Emissions from combustion are larger than those from upstream processes, accounting for approximately 85% of the total.

Figure 2 shows that ethanol has a lower emission intensity than conventional petrol.

Ethanol from whey also has both combustion and upstream emissions, however since the combustion emissions come from biogenic sources, they are considered to have zero impact. Ethanol from whey emissions are therefore dominated by upstream emissions. Petrol has a higher energy intensity (in MJ per litre) than ethanol; approximately 39% higher. This effect has been accounted for in the energy adjusted figures for ethanol, so that they show the volume of emissions from 1.39 litres of ethanol as this contains the same amount of energy as 1 litre of regular petrol. An energy adjusted comparison is also made for an E10 blend.

Introduction

1.1 Ethanol from whey

The milk processing industry in New Zealand produces large amounts of whey as a by-product of cheese and casein manufacture. Whey can not be directly disposed of due to its high chemical oxygen demand (COD) which creates negative environmental effects in waterways and on land. Different classes of whey are therefore re-processed into other products, for example lactose powders. Alternatively whey must undergo some form of waste treatment before disposal.

Acid wheys can also be fermented to create ethanol. The whey is cooled and then a special yeast is added. The fermentation temperature is a balance between the avoidance of bacteria which grows at high temperatures and maintaining the processing speed. Once fermentation is complete, the yeast is removed and the liquid is distilled and purified into different grades of ethanol. Ethanol can be used for a variety of purposes, including as a transport fuel. Fuel grade ethanol is known as IAA (Industrial Absolute Alcohol).

1.2 Project objectives

URS New Zealand Ltd (URS) was commissioned by the Energy Efficiency and Conservation Authority (EECA) to assist with calculating a life cycle assessment (LCA) of greenhouse gas (GHG) emissions of ethanol from whey produced by Fonterra Co-operative Ltd (Fonterra).

The objectives of this assistance were to:

- Review and provide feedback on the GHG inventory work completed by Fonterra– in particular advising on a technically robust boundary, use of emission factors, and existing calculations.
- Provide feedback on methodologies and any technical issues arising from comparative environmental impact review – in particular the use of either qualitative or quantitative approaches.
- Provide input to the evaluation, calculation and reporting stages of the Fonterra GHG Inventory for Bioethanol production.

URS completed the calculation and reporting as presented in this report, while Fonterra provided input data and some emission factors.

Method

The objective of this assessment is to inform EECA and Fonterra with regard to the embodied carbon emissions in the ethanol produced from whey at the Reporoa plant.

2.1 Standards and guidelines

This greenhouse gas life cycle assessment (GHG LCA) model has been generally calculated in accordance with PAS 2050. The boundary and calculation methods were designed to align with assessments made for other liquid biofuels in New Zealand, as well as a previous GHG LCA report on milk production for Fonterra.

2.2 Scope

All six Kyoto gases were initially considered. However, previous work on the Fonterra processing systems (Lundie et al. 2008) indicates that refrigerants (HFCs and PFCs) are less than 1% and are therefore non-material according to the PAS 2050 standard. SF_6 is not used by Fonterra during processing of whey into ethanol.

The data for the model relates to the 2008-09 financial year (01 July 2008 – 30 June 2009). Data is from the Reporoa plant.

2.3 Functional unit

The functional unit for this model is kilograms of carbon dioxide equivalent emitted for manufacturing one litre of IAA. For comparative purposes, emissions have also been calculated for $kgCO_2e/MJ$ IAA.

2.4 System boundary

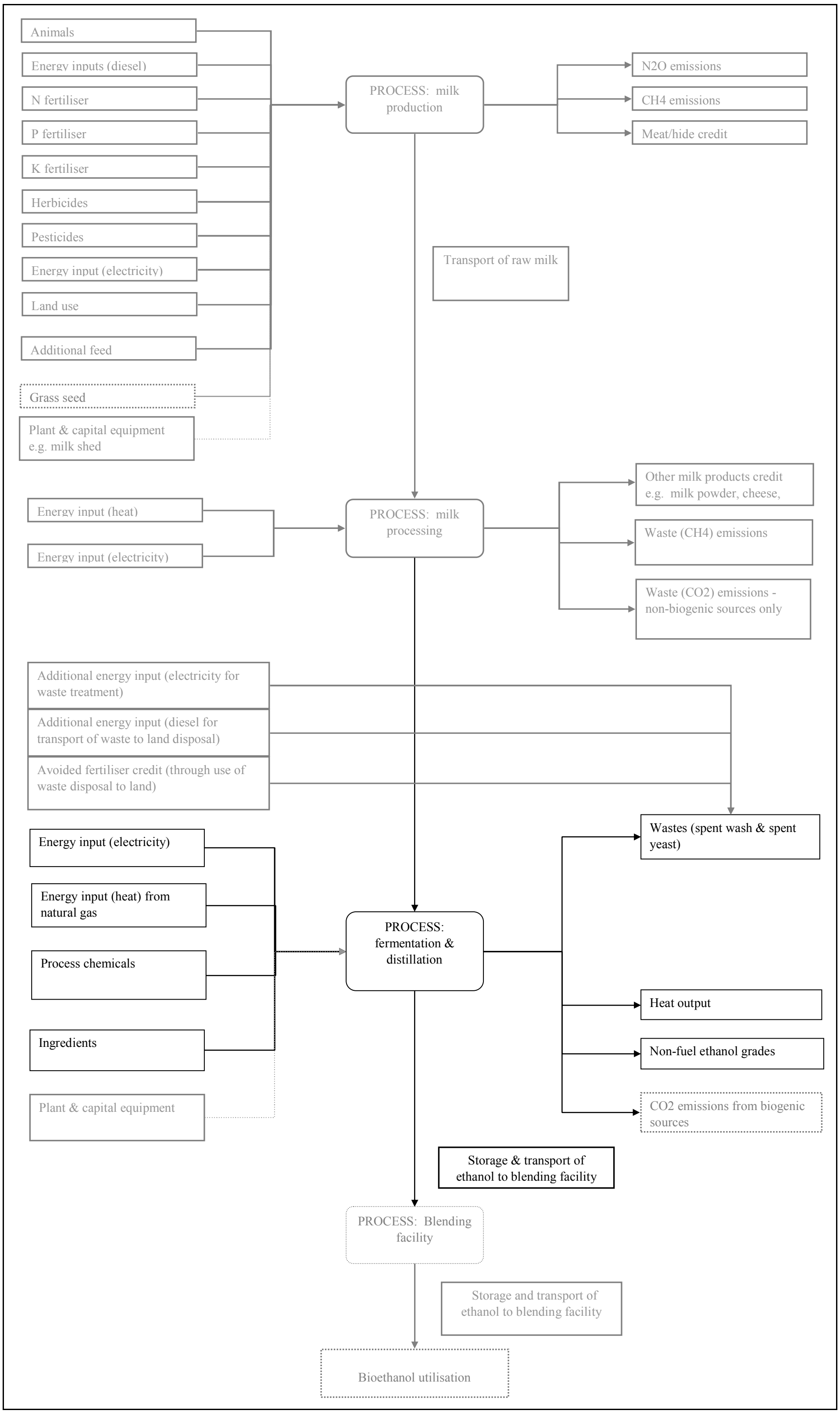
PAS 2050 allows the choice of cradle-to-grave or cradle-to-gate boundaries. Cradle refers to the raw material while gate refers to the end of the manufacturing process (i.e. once the product leaves the gate). Expanding the boundary to the grave includes consumption and disposal of the product.

Similar assessments for New Zealand biodiesel used a cradle-to-gate boundary based on the UK RTFO boundaries (see ORFA 2008). In the case of ‘waste’ feedstocks, the cradle is defined as the collection point of the wastes. This GHG LCA boundary will follow the UK RTFO approach where the upstream boundary is the collection of the feedstock, and the downstream boundary is the blending facility.

Figure 2-1 below shows the process diagram and boundary for this model. The process is listed in the middle column, with inputs on the left and outputs on the right. Greyed items have been excluded from the boundary. There is further explanation of the boundary below **Figure 2-1**.

2 Method

Figure 2-1 Ethanol process boundary



Upstream boundary

Biofuel may be produced using feedstock derived from either purpose-grown crops or from secondary products (i.e. wastes). There are competing arguments regarding whether to include feedstock emissions in biofuel calculations and whether treatment of upstream emissions should vary depending on the type of feedstock (in particular if the feedstock is a waste product or not).

PAS 2050 states that all GHG emissions should be included from all raw materials, and defines raw materials to also include secondary products. The only justifiable way to exclude an input is via immateriality (<1% of total emissions). Accordingly, from a technical perspective, upstream emissions from whey should remain within the process boundary. Some of the inputs included in whey production are highly likely to be immaterial relative to ethanol production and can therefore be excluded, for example grass seed. The treatment of inputs from secondary products or recycled products is likely to be reviewed in future versions of PAS 2050.

However, the upstream boundary for biofuels sourced from secondary products, typically starts at the collection point of the waste product (ORFA 2008). This is justified by both economic allocation arguments and a pragmatic approach. That is, the upstream process is concerned with producing the primary product, not the waste (i.e. the milk production process is not undertaken in order to create whey) and it is often difficult for the biofuel producer to obtain information on the upstream processes creating their feedstock.

Tallow, used cooking oil and whey are all considered waste feedstock. The upstream boundary for this GHG LCA was chosen to ensure comparability with international biofuel GHG LCA studies and therefore it excludes the emissions associated with creating whey.

The upstream boundary for waste feedstocks is however an area of ongoing debate within the international biofuel community and emerging standards may mean that the boundary for this model should be changed in the future. A bolt-on module to this model could be developed to account for upstream emissions if required. Some of the data from the Lundie et al, 2008 study could be used by Fonterra for this purpose.

Plant & capital

Emissions embodied in plant and machinery were excluded from the boundary according to PAS 2050.

Production & utilisation of wastes

The ethanol fermentation process creates two outputs which are considered wastes, wastewater and fusel oil. The volume of these wastes was calculated, however any additional inputs required to treat and dispose of these wastes were not included in the boundary.

The wastewater from ethanol production is mixed with other wastes from the Reporoa factory, and then disposed of to land as a fertiliser. Fusel oil output is very small.

In the future, the boundary could be expanded to include emissions from waste treatment and disposal. This could include a credit for avoided on-farm synthetic fertiliser use.

Emissions from biogenic sources

Emissions of CO_2 which are from biogenic sources are considered to have a GWP of 0 according to PAS 2050 (see s.7.9.4 of PAS 2050, 2008). This means that any CO_2 released from ethanol fermentation, as well as the CO_2 from ethanol combustion is considered to have no net emissions.

Downstream boundary

The downstream boundary of this GHG LCA is the point where the ethanol arrives at the Mt Maunganui blending facility. Emissions from blending, as well as from ethanol combustion are therefore excluded from the boundary.

This boundary differs slightly from earlier comparable biodiesel production models created by URS for EECA. The biodiesel boundary currently ends with production of biodiesel and does not include transport to a blending facility. This is because no biodiesel was being commercially blended at the time of model development.

Emissions from the blending facility, fuel distribution and fuel combustion are excluded in accordance with both PAS 2050 (cradle-to-gate) and the ORFA 2008 guidance. The volume of emissions from blending ethanol into E10 and distributing the fuel are unknown. Emissions from the ethanol fraction of combusting E10 are considered to be zero.

2.5 Life cycle inventory data

Data was collected on all inputs and outputs identified in the boundary. A Workings spreadsheet is included in the excel model which provides details on all background calculations required to derive data for the model. This worksheet is included as part of **Appendix A**.

2.5.1 Inputs – SEA ethanol

The base material used to manufacture ethanol is called Standard Ethyl Alcohol (SEA). SEA contains approximately 95% alcohol. The SEA is purified to produce the desired grade of ethanol (i.e. IAA) using a number of columns; rectifier, anhydrous and extractive distillation. Input SEA volumes were derived from the actual IAA output by dividing the output by 0.9. This is because it requires approximately 1.1 times the volume of SEA to make IAA.

2.5.2 Inputs – energy

Actual electricity used for the fermentation process was known. An assumption was made that all grades of output ethanol required an equivalent quantity of electricity, and that electricity ratio was then apportioned to each grade based on the relative volume of output.

Heat is required for processing, and it is delivered in the form of steam. The volume of steam was calculated based on steam budgets. It is estimated that it requires 6.0 tonnes of steam to make 1000 litres of SEA from whey, and an additional 1.1 tonnes of steam to make 1000 litres of IAA. Comparison of budget figures for all ethanol output grades against actual figures for the fermentation process show that the budget figures are conservative and likely to slightly overestimate requirements.

2.5.3 Inputs – ingredients

A variety of ingredients, clean-in-place (CIP) chemicals and cooling tower (CT) chemicals were identified. Similarly to electricity, actual ingredient and chemical volumes were known for the whole process. Using the assumption that each grade of ethanol output required an equivalent quantity of input, ingredients and chemicals were apportioned to each grade based on number of litres output. Volumes of ingredients and chemicals were generally low, ranging from 225 litres of Drewbrom-one-L to 74,300 litres of Caustic.

Ingredients and chemical inputs are unlikely to be material emission sources unless the embodied emissions in each input is relatively high. To make an example, “Antifoam - Dist. (SEA)” is the next largest input and a little less than 9,000 litres is used per year. If, hypothetically, the emission factor were 2.5 (which is similar to that of another process chemical glycol), then overall emissions would be increased by 0.3%. The emission factor would need to be at least 8.75 to make a 1% difference in overall emissions. On this basis, only glycol and caustic use were included in the model and all other ingredients, CIP and CT chemicals were excluded.

2.5.4 Outputs – fuel grade ethanol (IAA)

The fuel-grade ethanol produced is called Industrial Absolute Alcohol (IAA). A number of other ethanol grades are also produced in smaller quantities (e.g. XNS, NS and HGAA). Actual volumes of each ethanol grade were recorded.

2.5.5 Outputs – waste

The process creates two other forms of output in addition to the various grades of ethanol: fusel oil and wastewater.

Fusel oil is a waste alcohol with more than two carbon atoms. Small quantities are produced during fermentation. Depending on the season (shoulder or peak) the average production is different, due to the different volume of SEA running through the plant. Average volumes for the shoulder and peak seasons were calculated, and then a weighted volume was used.

The volume of wastewater produced annually at Reporoa from ethanol processes is known. Wastewater output is for the whole system, and is therefore allocated to the different system outputs. This is done by physical allocation. Total wastewater volume (m^3) is related to SEA input (kL), this ratio (32.6 L/L) is then used to allocate wastewater to the output grades of ethanol.

2.6 Emission factors

Emission factors for the model were obtained from a variety of sources. They are explained in detail and referenced in the model and summarised below:

- Ministry for the Environment 2008 for electricity and diesel.
- Barber 2008 for the natural gas required to create steam. Fonterra provided data on steam boiler efficiency and the energy content of the steam and URS applied a full life cycle emission factor to the input natural gas. The emission factor is based on Gross Calorific Value which may slightly overestimate emissions.
- PE International Gabi database for caustic soda and glycol.

Emission factors were chosen for their robustness and conservativeness.

2.7 Allocation

The system boundary and method of inventory data calculation already excludes most co-products. For example, emissions associated with production of other ethanol grades are already excluded by deriving inventory data that only relates to IAA ethanol.

Waste volume data was collected (i.e. waste water and fusel oil), but no emissions were allocated to the waste. All emissions in the model were therefore allocated to IAA ethanol.

Results

The table below shows the total emissions and emissions intensity to produce fuel-grade ethanol at Reporoa in 2008-09.

Table 3-1 Results summary

Inputs	**Volume**	**Unit**
Total emissions from process (per year)	8,993,000	$kgCO_2e$
Total emissions from transport (per year)	18,000	$kgCO_2e$
Total emissions (per year)	9,011,000	$kgCO_2e$
Outputs	**Volume**	**Unit**
Fuel grade ethanol quantity (IAA) output (per year)	6,174,000	litres
Emissions intensity per litre of IAA output	1.46	$kgCO_2e$/litre IAA
Emissions intensity per MJ of IAA output	0.06	$kgCO_2e$/MJ IAA

Figure 3-1 shows that most emissions come from the fermentation process. Less than 1% occurs as a result of transporting the IAA to the Mt Maunganui blending facility.

Figure 3-1 IAA emission profile

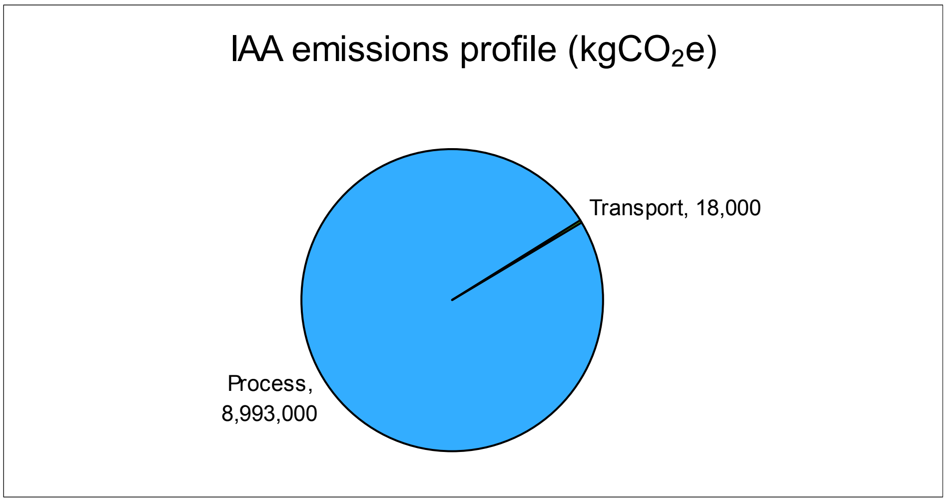
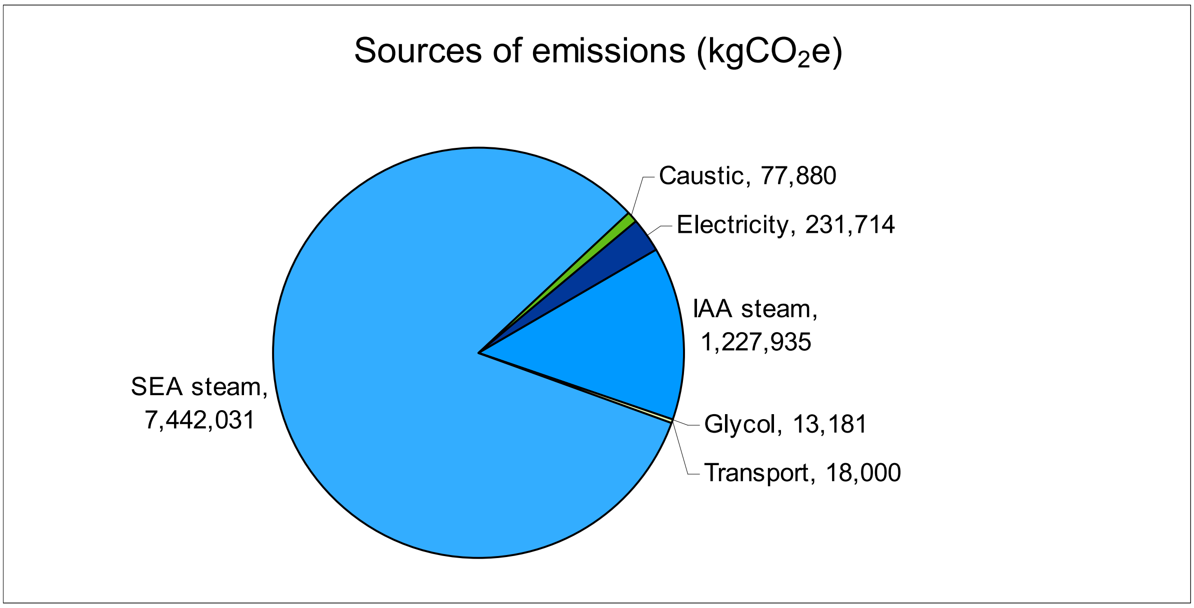


Figure 3-2 shows that the largest emission source is from steam (82% for SEA process plus 14% for IAA process) followed by electricity (3%). Together, energy inputs account for 99% of emissions. Ingredients and chemicals are very small contributors (1.0% for caustic and 0.2% for glycol). Transport is extremely small (0.2%).

Figure 3-2 Sources of emissions



Discussion

4.1 Emission intensity of conventional petrol

Table 4-1 below shows the results of two separate studies into conventional fuel emission factors in New Zealand. Net calorific values (lower heating value) were used to convert emission factors between litres and MJ of fuel. This is a more conservative approach than gross calorific values (higher heating value).

Table 4-1 Fossil petrol emission factors

Comparisons against fossil petrol	**Emissions per litre**		**Emissions per MJ**	
MfE 2009 petrol - default - Emissions from combustion only - 2008 calendar year - Unit not converted to MJ as unknown octane composition of fuel, however it is likely to be an 80:20 mixture of regular: premium petrol.	2.34	$kgCO_2e$/ litre petrol		
MfE 2009 petrol - regular (91 octane) - Emissions from combustion only - 2008 calendar year. - Unit converted from litres to MJ using MED 2009 Energy File (for 2008 calendar year) - net calorific value 32.65 MJ/l for regular petrol	2.33	$kgCO_2e$/ litre petrol	0.071	$kgCO_2e$/ MJ petrol
MfE 2009 petrol - premium (95 octane) - Emissions from combustion only - 2008 calendar year. - Unit converted from litres to MJ using MED 2009 Energy File (for 2008 calendar year) - net calorific value 33.01 MJ/l for premium petrol	2.37	$kgCO_2e$/ litre petrol	0.072	$kgCO_2e$/ MJ petrol
Barber, 2008 petrol - regular - Conservative emission factor. - Life cycle approach includes emissions from foreign extraction, NZ refineries and domestic transportation (primary and secondary energy) as well as combustion. - Based on 2006 data - Volume based emissions converted from Barber's energy based calculations (MJ to litres) by URS using net calorific value from the 2006 calendar year MED Energy Data File Liquid Fuels Properties (32.56MJ/litre)	2.55	$kgCO_2e$/ litre petrol	0.078	$kgCO_2e$/ MJ petrol

The Ministry for the Environment 2009 figures are a direct emission factor only, which means they only include combustion of the fuel and do not include any upstream emission sources such as drilling, transport or refining the fuel. The emission factors are sourced from the Ministry of Economic Development's New Zealand Energy Greenhouse Gas Report 1990-2008. The MfE emission factors were provided in $kgCO_2e$/ litre petrol and have been converted to $kgCO_2e$/ MJ by URS to allow comparison with other fuels.

The Barber 2008 figure includes both combustion and upstream emissions, which means that it includes emissions from drilling, transportation and refining. Barber 2008 assumes that upstream emissions for petrol are the same as those which he calculated for diesel. The figures are based on total New Zealand fuel statistics as provided by the Ministry of Economic Development; a top down approach to LCA.

The Barber 2008 figures are more comparable to the GHG LCA undertaken for this project, than the MfE figures because they account for both combustion and upstream emissions. The major difference between Barber and this ethanol evaluation, is that this project boundary does not include any emissions from blending the ethanol into E10 blend fuel, or from distribution around New Zealand. It is unknown how significant these emission sources may be. This evaluation also excludes ethanol combustion from its boundary, however as noted earlier, combustion emissions from ethanol are effectively zero as they originate from biogenic sources.

4.2 Comparison of ethanol against conventional petrol

Table 4-2 shows a variety of emission comparisons between ethanol and conventional petrol. The figures are shown graphically in **Figure 4-1**. **Table 4-3** shows the differences between fuels as a percentage. Please use some caution in interpreting these comparisons as the studies used slightly different boundaries and different calculation approaches. They are, however, an indicative guide and are as robust as is currently publicly available.

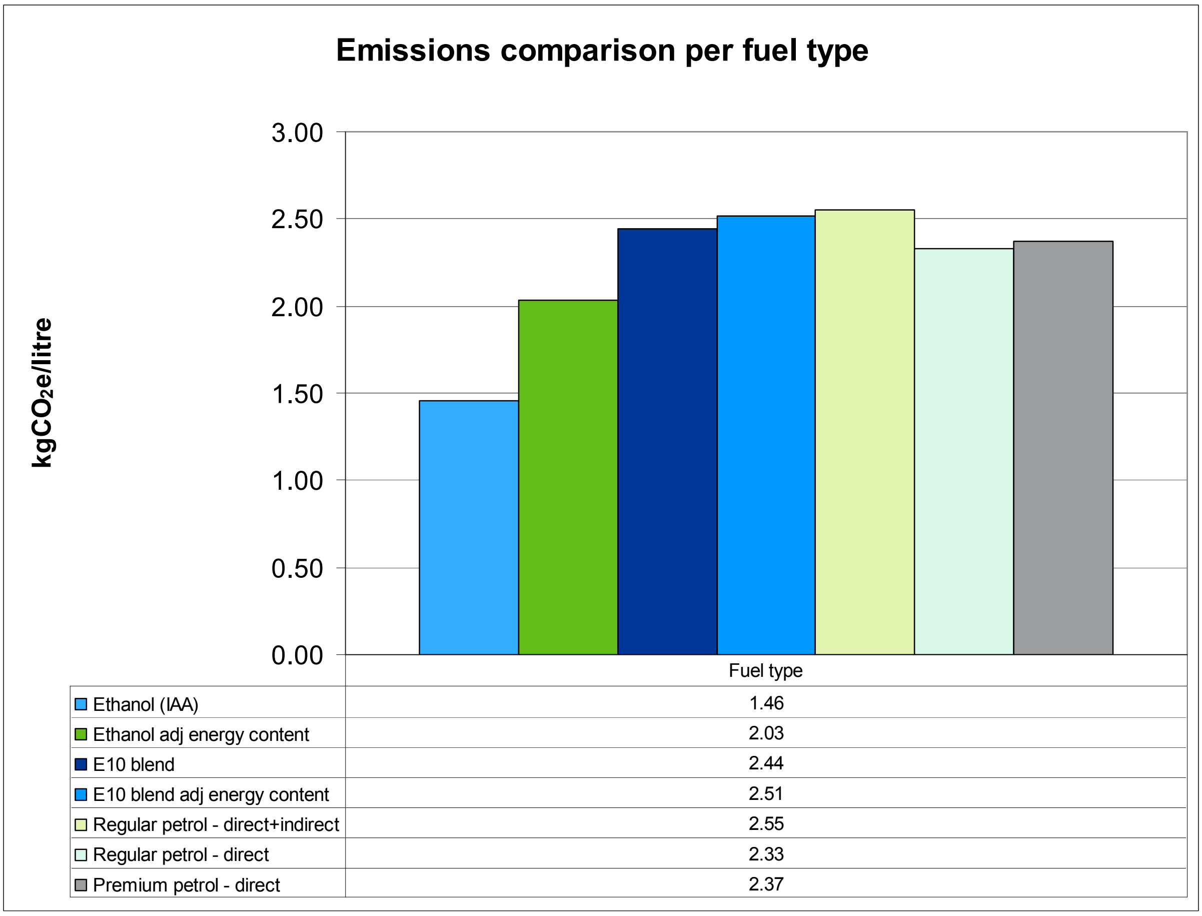
Table 4-2 Comparison of emission intensities between fuels

Comparisons against fossil petrol	**Emission factor**	**Unit**
Emissions from blended bioethanol (E10) - E10 blends refer to 10% ethanol and 90% petrol, calculated by volume. - Uses Barber 2008, regular petrol emission factor (includes indirect emissions)	2.44	kgCO_2e/ litre E10 blend
	0.08	kgCO_2e/ MJ E10 blend
Emissions from blended bioethanol (E10) adjusted for energy content - E10 blends refer to 10% ethanol and 90% petrol, calculated by volume. - The E10 blend is 31.73MJ/litre (10% @ 23.46MJ/litre; 90% @ 32.65MJ/litre). This is 2.9% less energy than regular petrol. - The E10 blend is therefore increased by 2.9% (in litres) to account for the slightly lower energy content. This has been done to preserve an accurate volume based comparison.	2.51	kgCO_2e/ litre regular petrol equivalent
Pure ethanol adjusted for energy content - IAA ethanol is 23.46MJ/litre and regular petrol is 32.65MJ/litre. This is 39% more energy than ethanol. - The ethanol volume is therefore increased by this ratio to account for its lower energy content. This has been done to preserve an accurate volume based comparison.	2.03	kgCO_2e/ litre regular petrol equivalent

As discussed above, emissions from conventional petrol consist of both combustion and upstream emissions. The Barber 2008 study estimates that combustion emissions are approximately 85% of total emissions, while upstream emissions account for about 15%. Emissions associated with ethanol used as a fuel are upstream emissions only. This is because the CO_2 released during combustion is from biogenic sources and is therefore considered to have a GWP of 0.

Figure 4-1 shows that ethanol from whey produces fewer emissions per litre than conventional fossil petrol in New Zealand. The magnitude of this difference varies depending on the conventional petrol emission factor used. Conventional petrol has a higher energy intensity (in MJ per litre) than ethanol, approximately 39% higher. This effect has been accounted for in the energy adjusted figures, so that it shows the volume of emissions from 1.39 litres of ethanol, which contains the same volume of energy as 1 litre of regular petrol. This comparison is also made for an E10 blend (where the difference is 2.9%).

Figure 4-1 Comparison of ethanol and petrol emission intensity (kgCO_2e per litre)



	Fuel type
🟦 Ethanol (IAA)	1.46
🟩 Ethanol adj energy content	2.03
🟦 E10 blend	2.44
🟦 E10 blend adj energy content	2.51
🟨 Regular petrol - direct+indirect	2.55
⬜ Regular petrol - direct	2.33
⬛ Premium petrol - direct	2.37

Table 4-3 below shows that emissions from ethanol are lower than emissions from regular petrol. Emissions per litre show the greatest reduction, however because ethanol has a lower energy intensity than petrol, the reduction is not as large when considered from an energy perspective. The first row compares ethanol against regular petrol. Combusting one litre of ethanol causes 43% fewer emissions than combusting one litre of petrol. However, because ethanol has a lower energy intensity than petrol, this drops to a 21% reduction when compared by energy content. Similarly, emissions per litre of E10 are 4% less than emissions of regular petrol, but the difference is only 2% less when compared by energy intensity. This comparison does not consider any other changes to engine fuel consumption rates related to any other properties of the fuel.

Table 4-3 Relative emission reductions between ethanol and fossil petrol

Comparisons against fossil petrol	**Percent difference** (per litre)	**Percent difference** (per MJ)
Comparison between ethanol and regular petrol - The regular petrol emission intensity come from Barber 2008 and includes both combustion and upstream emissions.	-43%	-21%
Comparison between E10 blend and regular petrol - The E10 blend uses 10% ethanol and 90% regular petrol (by volume). - The regular petrol emission intensity come from Barber 2008 and includes both combustion and upstream emissions.	-4%	-2%

4.3 Sources of uncertainty in results

The data was obtained from only one year and from one ethanol plant which makes the data likely to be internally consistent. However it is unknown how these figures may vary between plants, between years, or between seasons. For example, a major emission source is steam and this is directly affected by boiler efficiency which varies from year to year. Much of the data was derived from actual data and underlying assumptions. These are assumed to be correct, however the authors have not independently verified the data.

A number of ingredients and chemical inputs were excluded from the boundary on the basis of immateriality. While this is likely to be correct, it is possible that one or more input may in fact be material. This would be the case if the emission factor for that input is particularly high. Potentially, if all other ingredients and chemical inputs had high emission factors, then these combined inputs could be a material source of emissions.

Emission factors change over time. In particular, the emission intensity of electricity in New Zealand alters annually due to changes in the proportion of renewable electricity generation used each year. It is recommended to review emission factors periodically to ensure they remain current. Steam heat is the single largest source of emissions in this process. If the emission intensity of the steam changed, for example by utilising bioenergy sources or by converting to a coal boiler, then this will affect the emission intensity of the ethanol.

There can be considerable uncertainty comparing different LCA studies. This is because studies often choose different boundaries, different emission factors, or are based on limited data sets. Any comparison of results, for example between this evaluation and those undertaken for fossil fuels, should only be made after examining the relative boundaries and assumptions of the studies.

Glossary

Greenhouse gases (GHG)

Greenhouse gases (GHG) are gases that influence the way in which the Earth's atmosphere traps heat. Increasing levels of GHG in the atmosphere are causing the phenomenon of climate change, leading to adverse effects on the world's environment, and subsequent social and economic impacts.

The Kyoto Protocol[1] addresses six GHG: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6).

Carbon footprint

A carbon footprint is an assessment of the GHG emitted by a particular organisation, project, product or service, typically expressed for a 12 month period. A carbon footprint includes assessment of the six GHG addressed under the Kyoto Protocol, and can include other GHG if desired. A carbon footprint describes GHG emissions in carbon dioxide equivalents (CO_2e); that is, the global warming potential of the gas relative to CO_2.

Global warming potential

The global warming potential is an assessment of the warming potential of a particular GHG compared to carbon dioxide. For example, methane (CH_4) has 21 times the global warming potential of CO_2; therefore 1 tonne of methane would be expressed as 21 tonnes of CO_2e.

Emission factor

An emission factor converts a specific quantity (e.g. a litre of diesel) to a measure of the GHG (e.g. CO_2) that would be emitted by the emission source (e.g. combustion of diesel in vehicles) in kg or tonnes. When the GHG is not CO_2, the emission factor also includes a conversion of the GHG to a CO_2e. A range of emission factors exist, both in New Zealand and internationally.

Embodied emission

An 'embodied' emission refers to an emission of GHG that result from the production and transportation of a product and is therefore embodied in the product. For example, embodied emissions in a tonne of steel would include any fuel or energy (or other process causing emissions of GHG) resulting from the extraction and processing of materials, manufacture and transport of the item to the point of use.

Ethanol

Ethanol in this report refers to ethanol from whey as produced by Fonterra at the Reporoa plant unless stated otherwise.

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[1] The Kyoto Protocol is a legally binding international agreement aimed at slowing, and eventually stopping, global warming. New Zealand ratified the Kyoto Protocol in December 2002.

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Office of the Renewable Fuels Agency (ORFA) 2008. *Carbon and sustainability reporting within the renewable transport fuel obligation – technical guidance part two carbon reporting – Default values and fuel chains*. Office of the Renewable Fuels Agency, London

Limitations

URS New Zealand Limited (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Energy Efficiency and Conservation Authority and only those third parties who have been authorised in writing by URS to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the Proposal dated 26 March 2009.

The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to URS was false.

This report was prepared between 26 March and 26 November 2009 and is based on the conditions encountered and information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

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Appendix A Emission model

Last updated:26/11/09

Data description (Reporoa Process only)	**Data**	**Unit of data**	**Source of data** (who at Fonterra maintains this data)	**Reference year** (what year does this data relate to? E.g. 2007/08 financial year)	**Data quality Actual (A) Derived (D) Estimate (E)**	**Emission factor (kgCO_2e/ unit)**	**Emissions kgCO_2**
Fermentation & distillation - inputs							
Ingredient - SEA	equals IAA produced / 0.90			FY09			
Energy input - electricity	included in IAA production electricity consumption below		Michelle Phillips	FY09	D		
Energy input - natural gas	n/a						
Energy input - Steam	41,160	T	Michelle Phillips	FY09	D	181	7,442,031
Process chemical - Antifoam - Ferm. (SEA)	4,604	L	Michelle Phillips	FY09	D		
Process chemical - Antifoam - Dist. (SEA)	8,853	L	Michelle Phillips	FY09	D		
Process chemical - Caustic (SEA)	74,294	L	Michelle Phillips	FY09	D	1.05	77,880
Process chemical - Sulphamic (SEA)	2,014	kg	Michelle Phillips	FY09	D		
Cooling Tower Chemical - Amersperse 3001	3,071	L	Michelle Phillips	FY09	D		
Cooling Tower Chemical - Drewbrom-one-L	253	L	Michelle Phillips	FY09	D		
Cooling Tower Chemical - Enviroplus 2430	1,075	L	Michelle Phillips	FY09	D		
Cooling Tower Chemical - Sulphuric Acid	202	L	Michelle Phillips	FY09	D		
Output (but input to the IAA process) - SEA produced	6,860	kL	Michelle Phillips	FY09	D		
Additional Requirements to Convert SEA to IAA							
Energy input - electricity	1,404,329	kWh	Michelle Phillips	FY09	D	0.165	231,714
Energy input - Steam	6,791	T	Michelle Phillips	FY09	D	181	1,227,935
Process chemical - Glycol (IAA)	5,536	L	Michelle Phillips	FY09	D	2.38	13,181
Process chemical - Amersperse 3001 (CT) (1/2 SEA, 1/4,	3,412	L	Michelle Phillips	FY09	D		
Process chemical - Drewbrom-one-L (CT) (1/2 SEA, 1/4, IAA/HGAA, 1/4 XNS/NS)	281	L	Michelle Phillips	FY09	D		
Process chemical - Enviroplus 2430 (CT) (1/2 SEA, 1/4, IAA/HGAA, 1/4 XNS/NS)	1,194	L	Michelle Phillips	FY09	D		
Process chemical - Sulphuric Acid (CT) (1/2 SEA, 1/4, IAA/HGAA, 1/4 XNS/NS)	225	L	Michelle Phillips	FY09	D		
Emissions (kgCO_2e) SUM of Inputs							**8,992,742**

Total emissions (kgCO_2e)

Fermentation & distillation - outputs					
Fuel grade ethanol quantity (IAA)	**6,174,000**	**L**	Michelle Phillips		A
Waste water removed from fermented beer - spray irrigated on farms	223,455,000	L	Michelle Phillips		D
Output - Fusel Oil	16,000	L	Michelle Phillips		D

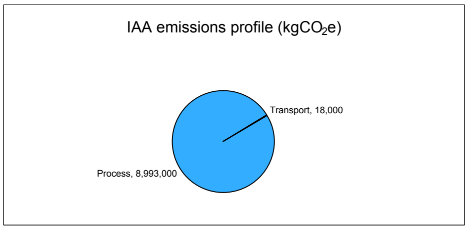
Transport to blending facility							
Diesel consumed to transport ethanol from Reporoa to Mt Manganui blending facility	0.001	litres diesel/L IAA			E	2.68	**18,000**

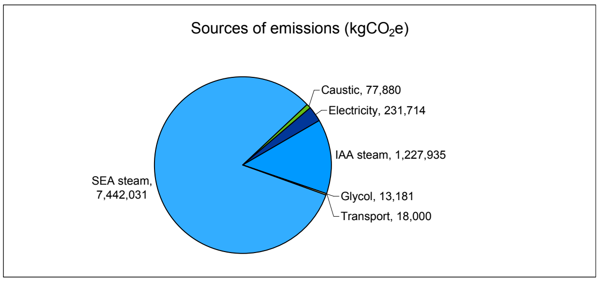
Summary

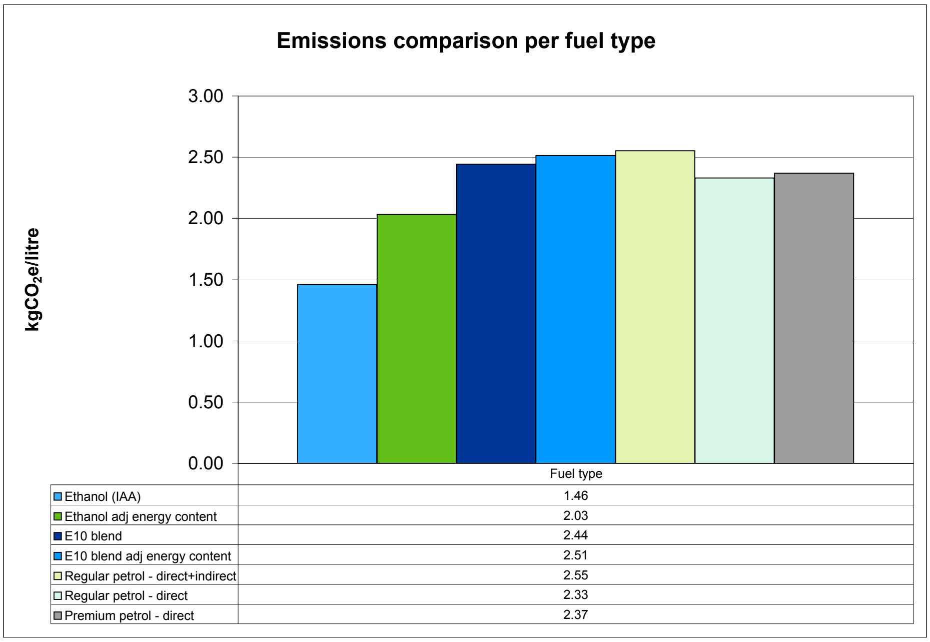
Inputs

Total emissions from process (per year	8,993,000	kgCO$_2$e
Total emissions from transport (per year	18,000	kgCO$_2$e
Total emissions (per year	9,011,000	kgCO$_2$e
Fuel grade ethanol quantity (IAA) output (per year)	6,174,000	litres
Emissions intensity per litre of IAA outpu	**1.46**	kgCO$_2$e/litre IAA
Emissions intensity per MJ of IAA outpu	**0.06**	kgCO$_2$e/MJ IAA

Comparisons against fossil petrol	**Emissions per litre (volume)**	**Unit**	**Emissions per MJ (energy)**	**Unit**
Fossil Petrol emission factors				
MfE emission factor for petrol - default Direct emissions only (i.e. from combustion) for 2008 calendar year - Unit not converted to MJ as unknown octane composition of fuel	2.34	kgCO$_2$e/litre petrol		
MfE emission factor for petrol - regular (91 octane) Direct emissions only (i.e. from combustion) for 2008 calendar year - Unit converted from litres to MJ using MED 2009 Energy File (for 2008 calendar year) - net calorific value 32.65 MJ/l for regular petrol	2.33	kgCO$_2$e/litre petrol	0.071	kgCO$_2$e/MJ petrol
MfE emission factor for petrol - premium (95 octane) Direct emissions only (i.e. from combustion) for 2008 calendar year - Unit converted from litres to MJ using MED 2009 Energy File (for 2008 calendar year) - net calorific value 33.01 MJ/l for premium petrol	2.37	kgCO$_2$e/litre petrol	0.072	kgCO$_2$e/MJ petrol
Barber, 2008 Petrol - regular - Conservative emission factor. - Life cycle approach including emissions from foreign extraction, NZ refineries and domestic transportation (primary and secondary energy). - Based on 2006 data - Volume based emissions converted from Barber's energy based calculations by URS using net calorific value from the 2006 calendar year MED Energy Data File Liquid Fuels Properties (32.56MJ/litre)	2.55	kgCO$_2$e/litre petrol	0.078	kgCO$_2$e/MJ petrol
Comparison calculations				
Emissions from blended bioethanol (E10) - E10 blends refer to 10% ethanol and 90% petrol, calculated by volume. - Uses Barber 2008, regular petrol emission factor (includes indirect emissions)	2.44	kgCO$_2$e/litre E10 blend	0.08	kgCO$_2$e/MJ E10 blend
Emissions from blended bioethanol (E10) adjusted for energy content - E10 blends refer to 10% ethanol and 90% petrol, calculated by volume. - The E10 blend is 31.73MJ/litre (10% @ 23.46MJ/litre; 90% @ 32.65MJ/litre). This is 2.9% less energy than regular petrol. - The E10 blend is therefore increased by 2.9% (in litres) to account for the slightly lower energy content. This has been done to preserve the volume based comparison.	2.51	kgCO$_2$e/litre regular petrol equivalent		
Pure ethanol adjusted for energy content - IAA ethanol is 23.46MJ/litre and regular petrol is 32.65MJ/litre. This is 39% more energy than ethanol. - The ethanol volume is therefore increased by this ratio to account for its lower energy content. This has been done to preserve the volume based comparison.	2.03	kgCO$_2$e/litre regular petrol equivalent		
Percent comparison				
Comparison between ethanol and regular petrol - The regular petrol emission intensity come from Barber 2008 and includes both combustion and upstream emissions.	-43%	Percent difference (per litre)	-21%	Percent difference (per MJ)
Comparison between E10 blend and regular petrol - The E10 blend uses 10% ethanol (by volume) and 90% regular petrol. - The regular petrol emission intensity come from Barber 2008 and includes both combustion and upstream emissions.	-4%	Percent difference (per litre)	-2%	Percent difference (per MJ)







	Fuel type
Ethanol (IAA)	1.46
Ethanol adj energy content	2.03
E10 blend	2.44
E10 blend adj energy content	2.51
Regular petrol - direct+indirect	2.55
Regular petrol - direct	2.33
Premium petrol - direct	2.37

BUDGET	ACTUAL	COMMENTS	CALCULATED VOLUME PER GRADE

To produce IAA at Reporoa, the following inputs are needed: Steam, Electricity, SEA, Other Ingredients (Glycol/Antifoams), CIP Chemicals, and Cooling Tower (CT) Chemicals. The outputs from the process are the Fuel Grade IAA, Fusel Oil (from the SEA production process), and water (that is removed from the whey in the SEA production process). Below are production volumes (both budget FY09 and actual FY09) for ethanol, and the calculations to show the volumes of the inputs and outputs of the process. Refer to the comments for each section for assumptions relevant to each input/output.

Volume

Budget: Grade	kL	Actual: Grade	kL
SEA	0	SEA	405
XNS	630	XNS	1,396
NS	1,800	NS	151
IAA	4,348	IAA	6,174
HGAA	150	HGAA	71
Redistill	1,120	Redistill	559
Total:	8,048		8,756

Comments: Budget volumes of ethanol, planned to manufacture at Reporoa (Source: Reporoa Budget Workbook F2009). Actual Volumes produced as at 17.06.2009 (Source: Reporoa Daily Summary F09) These Budget and Actual Volumes are used to calculate the usages of electricity/steam/chemicals/ingredients below.

	kL	
SEA (to produce IAA	6,860	SEA figure based on IAA figure below (=6174/0.9)
IAA:	6,174	IAA figure is based on actual output (K13).

Steam

Budget: Grade	T/kill	T	Actual: T/kill	T
SEA	6	0		
XNS	11.3	7,119		
NS	8.95	16,110		
IAA	7.1	30,871		
HGAA	12.82	1,923		
Redistill	4	4,480		
Total:	50.17	60,503		62,320

Comments: Budget T/kL sourced from Reporoa Budget Workbook F2009 document. Overall Actual figured sourced from Reporoa daily Summary document (as at 17.06.2009).

Logic used:
Based on budget t/kL usage, if we took the actual ethanol volume produced, and multiplied this by the budget t/kL we would see a total steam figure of 66536 Tonnes. The Actual steam figure is 62320 Tonnes, so we would be overstating our steam usage. As per to the right, we have decided to use our budget steam usage of 1.1 for IAA and 6.0 for the SEA used to make the IAA.

	T	T/kL
SEA:	41,160	6
IAA:	6,791.4	1.1

Electricity

Budget: Grade	kWh/kL	kWh	Actual: kWh/kL	kWh
SEA	240	0	227	92,050
XNS	240	151,200	227	317,549
NS	240	432,000	227	34,256
IAA	240	1,043,520	227	1,404,329
HGAA	240	36,000	227	16,204
Redistill	240	268,800	227	127,164
Total:		1,931,520	227	1,991,552

Comments: Budget kWh/kL sourced from Reporoa Budget Workbook F2009 document. Overall Actual figured sourced from Reporoa daily Summary document (as at 17.06.2009). Assumption is that kWh/kL usage is consistent across the grades, as budgeted, and this equals 227kWH/kL (i.e. total kWh used / Total Production).

	kWh	kWh/kL
SEA:	1,560,365.8	227
IAA:	1,404,329.2	227

Ingredients

Budget: Type	L/kL	L	Actual: L/kL	L
Ethylene Glycol	1	4,498	0.90	5,600
Dist. Antifoam	1	9,091	1.29	12,000
Ferm. Antifoam	0.55	5,000	0.67	6,240

Comments: Budget L/kL sourced from Reporoa Budget Workbook F2009 document. Overall actual figures sourced from Reporoa Daily Summary document (as at 17.06.2009). Note that Glycol is used for IAA and HGAA, and the Antifoams are used for SEA only.

			L	L/kL
Glycol	**SEA:**	n/a		
	IAA:		5,536	0.90
Dist. Antifoam	**SEA:**		8,853	1.29
	IAA:	n/a		
Ferm. Antifoam	**SEA:**		4,604	0.67
	IAA:	n/a		

CIP Chemicals

Budget: Type	L/kL	L	Actual: L/kL	L
Caustic	12.00	109,088	10.83	100,700
Sulphamic Acid	0.25	2,273	0.29	2,730

Comments: Budget L/kL sourced from Reporoa Budget Workbook F2009 document. Overall actual figures sourced from Reporoa Daily Summary document (as at 17.06.2009). Note that CIP chemicals are used for SEA only.

			L	L/kL
Caustic	**SEA:**		74,294	10.83
	IAA:	n/a		
Sulphamic Acid	**SEA:**		2,014	0.29
	IAA:	n/a		

CT Chemicals

Budget: Type	L/kL	L	Actual: L/kL	L
Amersperse 3001	0.31	5,000	0.50	8,500
Drewbrom-one-L			0.04	700
Enviroplus 2430	0.09	1,500	0.17	2,975
Sulphuric Acid	0.04	700	0.03	560

Comments: Budget L/kL sourced from Reporoa Budget Workbook F2009 document. Overall actual figures for each chemical sourced from Reporoa Daily Summary document (as at 17.06.2009).

		L	L/kL
Amersperse 3001	**SEA:**	3,071	0.50
	IAA:	3,412	0.50
Drewbrom-one-L	**SEA:**	253	0.04
	IAA:	281	0.04
Enviroplus 2430	**SEA:**	1,075	0.17
	IAA:	1,194	0.17
Sulphuric Acid	**SEA:**	202	0.03
	IAA:	225	0.03

Waste

Estimate:

Fusel Oil
802.13 cm^2

		L/hr	L (SEA per hr)	L Fusel/L SEA	Ave (L of fusel / L of SEA)
Shoulder:	3 cm/hr	2.41	900	0.0027	0.0024
Peak:	7 cm/hr	5.61	2500	0.0022	

Actual:

Water (removed from the fermented whey)

Total Season Output 302,879 m^3

32.57 L of wastewater produced / L of SEA

Comments: Fusel Oil is a by-product of the SEA production process. It runs off into a cylindrical tank which has a base area of 802.13cm2 (100.4cm circumference.). Depending on the season (shoulder or peak) the average collection (in cm) is different, due to the different volume running through the plant. We have assumed an average of 3cm of fusel per hour in the shoulder season (with production of 900L of SEA), and 7cm per hour during the peak (with 2500L of SEA produced). Taking a weighted average of these, the L of fusel produced per L of SEA produced is 0.0024. This number multiplied by the total production figure for the SEA used to make IAA equals the total figure.

Comments: Wastewater output is for whole system, and must therefore be allocated to the different system outputs. This is done by physical allocation. Total wastewater (m3) is related to SEA input (kL), this ratio (32.6l/l) is then used to allocate to the outputs. Fonterra pay a contractor to cart the water removed from the fermented whey away, and he in turn charges farmers to spread it. This is done within a 30km radius from the site.

		m^3	L/L output
Fusel Oil	**SEA**	16	0.002
Waste Water	**SEA**	223,455	32.57

Fuel

nce from Reporoa to BST Mt Maunganui is	80 km
Fuel efficiency is	2.3 km/L
	34.78 L/load
Load size is	32300 L's
	0.0011 L/L

The trip is 99 times out of 100 a back haul – tanker has discharged south of Reporoa and thus we would be paying the diesel for it to return to base – There would be some diversion involved and more diesel consumed as the truck will be loaded rather than empty – using half the kilometres would be a very generous allowance to cover this – say 40 km's or 17.4 litres of diesel per delivery. Assuming 34l per load is therefore a likely overestimate.

		Per Load	L diesel /L IAA
Diesel	**IAA**		0.001

	Cell ref	Grade	kL	%	Multiplier	Value for I90 cell
Wastewater cross-c	K10	SEA	405	4.62%		
JG 17/08/09	K11	XNS	1,396	15.94%	0.8	1,745
	K12	NS	151	1.72%	0.85	177
	K13	IAA	6,174	70.51%	0.9	6,860
	K14	HGAA	71	0.81%	1	71
	K15	Redistill	559	6.39%		
		SUM	8,756	100.00%		

9,258 kL SEA (input for all ethanol grades)
32.71 kL wastewater/m3 SEA
32.71 L wastewater/l SEA

Multiplier is used to account for how much SEA is required to make each output grade of ethanol produced that year.

Ethanol energy

Energy content of Reporoa ethanol

23.4 MJ /litre ethanol (100% ethanol)

23.6 MJ /litre ethanol (100% ethanol)

If ethanol purity is 99.85%, then
23.36 MJ /litre ethanol (99.85% ethanol)
23.56 MJ /litre ethanol (99.85% ethanol)

Average energy
23.46 MJ /litre ethanol (99.85% ethanol)

"Please be advised that the MJ/litre rating for Ethanol is reported as being between 23.4 and 23.6 MJ/litre for 100% Ethanol. Our product 99.85%. " - Email from Peter Motion, 11/09/09
- Assume that these figures are net calorific value (lower heating value)

Energy content of Reporoa Ethanol	23.46 MJ/litre IAA

Emission factor	Unit	Explanation
Steam		
181	kgCO_2e/tonne steam	Steam is generated from natural gas at Reporoa. An email from Fonterra (25/11/09) notes that the energy required to create 1 tonne of steam is approximately 2.96GJ natural gas. URS have converted this to emissions using the natural gas LCA emission factor from Barber 2008. URS suspects that the Barber figure is based on Gross Calorific values (HHV) because his figures are based on the MED Energy GHG Report which uses GCV. Using GCV may slightly overestimate emissions, however URS were unable to recalculate the emission factor to Net Calorific Value. Barber, A. (2008) NZ Fuel and Electricity – Total Primary Energy Use, Carbon Dioxide and GHG Emission Factors. Report prepared by AgriLINK NZ Ltd.
Electricity		
0.165	kgCO_2e/kWh	MfE, 2008. Guidance for voluntary, corporate greenhouse gas reporting; data and methods for the 2007 calendar year. Ref: ME904 Direct emissions only based on national electricity profile for that year. Does not include indirect emissions such as transmission losses This emission factor is consistent with the URS report to EECA on biodiesel emissions
Diesel		
2.68	kgCO_2e/litre	MfE, 2008. Guidance for voluntary, corporate greenhouse gas reporting; data and methods for the 2007 calendar year. Ref: ME904 Diesel used for transport (Direct emissions only i.e. combustion) This emission factor is consistent with the URS report to EECA on biodiesel emissions
Caustic		
1.52	kgCO_2e/kg	Fonterra caustic is supplied from Orica and comes from Korea or USA. Lillian Sherman email 04/09/09 Emission factor is from German source (PE International - GaBi database) - Jim Barnett email 04/09/09
1.05	kgCO_2e/litre	The specific gravity of caustic is 1.45 and glycol is 1.115, so if you multiply the volume in litres by these numbers you will get the kilograms". Lillian Sherman email 04/09/09
Glycol		
2.65	kgCO_2e/kg	Fonterra glycol is supplied by Orica and comes from China. Lillian Sherman email 04/09/09 Monoethylene Glycol is used - Lillian Sherman email 07/09/09 Emission factor is from German source Ethylene glycol (via O2/Methane) from PE International (GaBi) - Jim Barnett email 04/09/09
2.38	kgCO_2e/litre	The specific gravity of caustic is 1.45 and glycol is 1.115, so if you multiply the volume in litres by these numbers you will get the kilograms". Lillian Sherman email 04/09/09
0.93	kgCO_2e/litre	Another potential emission factor is from a Dutch source Ethylene glycol (from ethene and oxygen via EO) from PE International (GaBi database) - Jim Barnett email 04/09/09. The German emission factor is used as it produces a more conservative result. The difference between emission factors is large (157%) but does not significantly affect the overall ethanol emissions intensity (0.1% change due to emission factor choice).

URS New Zealand Limited
Lambton House, 160 Lambton Quay
Wellington 6011
PO Box 3367, Wellington 6140
New Zealand
T: 64 4 496 3750
F: 64 4 496 3755

www.urscorp.co.nz