Retro-Analysis of Liquid Bio-Ethanol and Bio-Diesel in New Zealand

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Abstract

This paper uses a new approach of retro-analysis. Typically policy is informed by forward-looking analysis of potential for alternative energy technologies. But historical knowledge of energy and processing requirements and greenhouse effects is more reliable for engineering evaluation of biofuel production systems. This study calculates energy inputs and greenhouse gas emissions for the most efficient biomass feedstocks in New Zealand if the policy had been implemented to maximize liquid biofuel production in the year 2004/2005. The study uses existing processing technologies and agricultural statistics. Bioethanol production is calculated from putrescible wastes and starch crops, and biodiesel production from rapeseed, tallow, wood and waste paper. Each production system is further evaluated using measures of land use, energy input, crop production related to the energy product, plus relative measures of efficiency and renewability. The research findings are that maximum biofuel production in 2004/2005 would have provided only a few per cent of demand, and would not have reduced dependence on foreign imported oil or exposure to fuel price rise. Finally, we conclude that demand management and efficiency are more effective means of meeting policy objectives.

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1. Introduction

Biofuels have gained public interest for more than a decade as potential substitutes for gasoline and diesel fuel petroleum. Projections of future biofuel production have typically shown a positive outlook (Demirbas, 2008). The two main motivations for government support of biofuel development are climate change and transport fuel supply security. Policy in numerous countries has provided support for biofuel production, often from food crops. The results of these policies are currently a matter of discussion, but the policy to support biofuel does not seem to be subject to major policy reconsideration, despite questions of un-anticipated impacts on the agricultural sector, economics of food supply and the environment (Rathmann, et al, 2010).

Our research question is whether retro-analysis could provide more clarity about policy options than forward scenarios. A retro-analysis explores the question, "What if a given policy were successfully in place, causing the desired effect at a particular point in the past?". Rather than developing future scenarios based on assumptions, we could use historical data from the past and calculate the implications of the policy. It is possible that looking in retrospect could provide clarity about policy decisions that future scenarios leave obscured. In this paper, we gathered the complete statistical data for New Zealand agriculture food production and crop wastes for the year 2004/2005. We then calculated the possible biofuel production for a range of biomass feedstocks and waste streams, and the associated reduction in fossil fuel demand as well as the land use and environmental implications.

New Zealand oil consumption was approximately 151,000 barrels per day in 2004, 80% of which was used in the transportation sector (BP, 2005). The

transportation of goods and mobility of citizens was entirely dependent on petroleum-based fuels. The global supply of oil was known to be finite in 2004 (Campbell, 1992), but demand was anticipated to continue to increase continuously through 2030 (IEA, 2004). The concept of peak oil was completely absent from New Zealand government policy documents and parliamentary debate in 2004 (MED, 2007), although a shortfall in supply compared to demand in the world oil supply would cause price increases and negative impacts on New Zealand's petroleum-intensive export and tourism-dominated economy over the next five years (Hirsch et al., 2005). The government was a signatory to the Kyoto Protocol and there was much discussion of reduction of green house gas emissions by substituting renewable energy or hydrogen for fossil fuels. In order to be able to adapt to changes in the available fuel supply, mitigation options must be initiated more than a decade in advance of a fuel supply issue arising (SEF, 2005). Given that there was very little concern of an oil supply price rise or supply constraint within the next decade at that point in time, it could seem reasonable that full utilization of biofuels by 2004 would provide a mitigation measure. Imagining how the past decade would have been different if full development of the country's potential biofuel supply was achieved in 2004, should provide useful insight into the concept that biofuels improve resilience or reduce green house gas emissions.

1.1 Analysis of Biofuel Energy Balance and Impacts

Biomass is often considered as a sustainable feedstock for fuels. An economic analysis for biofuel supply in New Zealand is difficult to assess by applying overseas experience as biofuel production from food crops in other countries is supported by government subsidies (Saunders et al., 2009). Our approach was to focus on technical and energetic analysis. A famous study by Pementel and Patzek

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of Stanford University USA (2005), reports that it takes more energy to make a litre of ethanol than is provided by the fuel. On the other hand, a study by the USDA reported a positive energy return for ethanol from corn of 1.34 which includes credit for energy in by-products and does not include some inputs like irrigation pumping energy which is required in some US locations (Shapouri et al., 2002). It is clear that a general analysis of a hypothetical biofuel production system could have different results, depending on the calculation methodology and consideration of associated processes and inputs.

We previously conducted a study to assess the energy risk to essential transportation activity systems, and found that potential indigenous production of renewable fuels would not mitigate the exposure to oil price or fuel security if world oil supply were to plateau and decline (Dantas et al., 2007). The objective of this work was to provide understanding of the different aspects of support for biofuels in the government's energy policy by carrying out quantitative analysis. The analysis includes possible feedstock sources, research of known production processes, and quantification of the biofuel supply potential for fossil fuel substitution. To obtain consistent results, this study used the basic energy input and output analysis methodology for each feedstock. This simple approach offers a clear and comprehensive picture of the flows of energy and materials through the whole production system and gives an objective basis for comparison. We treat the production system as a sequence of sub-systems that exchange inputs and outputs. This method clearly shows whether more energy is contained in biofuels than the energy used in the production. The percentage of green house gas reduction (%GHG) from substitution of a given biofuel for either gasoline or diesel was calculated using the carbon content of each input component.

We were also interested in how much fossil fuel is used to produce a renewable fuel, as this fossil input would be at the same shortage risk as all other fossil fuelled activities. By using a portion of the biofuel production where appropriate in the processing we can quantify the rate of potential *renewability* of a given biofuel delivered to consumers. We explored two concepts of the renewability, the ratio of renewable to fossil energy inputs, and the percentage of the biofuel output that was produced with renewable energy inputs.

Finally, we recognise that unlike imported oil, renewable biofuels require dedicated use of productive agricultural land. The energy return on land (EROL) was calculated for each of the crop feedstocks. The particular economics of producing biofuel in New Zealand is only known for ethanol from milk whey, as this process is currently carried out by the dairy processing corporation, Fonterra. As the economic feasibility assessment would be highly speculative, even in retrospect, this project focused instead on technical feasibility, energy balance, GHG impacts and renewability.

In general, the results showed a wide variability of energy balance and renewability for different feedstocks. Several biomass resources were identified as possible feedstock for liquid fuels. However, even with all of the most promising biofuels put into production through waste and crop conversion, the amount of fuel and the timing of production were not found to be sufficient to replace a significant fraction of fossil fuel. Thus, even if the New Zealand government had a policy to fully develop biofuels from all viable sources in 2004, the country's economy would not have been insulated from the dramatic rise in world oil price which has occurred since 2006.

2. Methods

Crops and waste streams from government statics in 2004 for all New Zealand agriculture were examined as possible feedstocks for biofuel. The reasoning is that farmers were currently growing crops profitably in certain locations with certain conditions, so these are the resources that would be diverted to biofuels. Quantities of farm inputs, including agrochemicals and fuels for farm machinery, were accounted for as were land requirements. Biofuel processing energy requirements and yields were taken from published commercial and research references. The results were analysed with the conventional Energy Return on Investment (EROI) measure used internationally. In addition three new indexes to assess sustainability were proposed. Green house gas (GHG) balance was calculated for each potential feedstock. The potential of various biofuels to substitute for fossil fuels was examined in the New Zealand context.

Study boundaries include all the processing from agricultural production of feedstock to biofuel manufacture referenced to the energy content (MJ). Local transportation energy was not included as it would depend on particular locations of processing plants and agricultural production, which cannot be known at this point in time. However, we can assume that the existing farm fuel demand would be roughly similar whether the crop was going to the biofuel plant rather than the canned food factory as there are very few cities in New Zealand where processing is done. The transport energy for imported fossil fuel was accounted for in the green house gas analysis. Energy inputs, excluding solar energy, were taken into account in each process step, distinguishing renewable and non-renewable energy.

The characteristics of each feedstock require a specific processing route, and the technologies are currently at different stages of development. Starch feedstock such as maize, wheat, barley, oats and potatoes can be processed via yeast fermentation followed by distillation and molecular sieve. The common esterification process is used for biodiesel production from rapeseed and tallow. Lignocellulosic waste is being investigated for bioethanol production by Saccharification and Co-Fermentation (SSCF) (Wooley et al., 1999; Ballesteros et al., 2004). The Fischer-Trospsch process is used for biodiesel production from wood and paper wastes (Spath and Dayton, 2003). SSCF and Fischer-Tropsch processes for biofuels are currently at the research stage so the results for these fuels should be taken as indicative only.

The biofuel energy flow analysis was considered differently for crop and for waste feedstock. For crops grown specifically for biofuel, energy and embodied energy inputs for farming were included as well as conversion processing. Agricultural inputs include fertilizers (N, P, K), insecticides, herbicides, fungicides, and growth regulators. Farming energy inputs are associated with mechanisation, that is, consumption of fuel by agricultural implements and vehicles for soil preparation, planting, weeding, soil amendment and harvesting. Most crops require some post-harvest processing such as drying, threshing or cool store for fruit to prevent spoilage. For waste feedstock, the agricultural inputs and crop processing energy inputs were not counted in the energy balance because they were already invested to produce the food or fibre product. The conversion from biomass feedstock to liquid fuel product has energy inputs mainly for the fermentation and distillation processes. The energy inputs for processing and conversion were based on published reports for each feedstock.

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Greenhouse gas emissions are accounted for fossil fuels consumed. Gases taken into account are CO_2, N_2O and CH_4. Balances are made for the fuel after ideal combustion as in an engine or boiler. The amount of global GHG emissions during gasoline refining and through combustion is taken as 86.5 g eq CO_2/MJ of gasoline (PWC, 2002). The amount of global GHG emissions during diesel refining and through complete combustion is assumed to be 80 g eq CO_2/MJ of diesel (PWC, 2002). For biofuel, we use a neutral GHG balance between growth and use since CO_2, the main GHG emitted during the combustion step in the engine, had initially been absorbed by the plant from the atmosphere.

3. Biomass Data and Conversion Technology Models

The energy footprint approach for a wide range of possible feedstock crops and waste was conducted using New Zealand data from 2005 agricultural production, and 2004 fertilizer, inputs, and all other farm-related energy consumption. Relevant data from US and European sources was used to model the possible conversion processes.

Fertilisers in various forms are used throughout New Zealand on pasture, crops and orchards. The rate of fertilizer application in New Zealand varies between regions and territorial authorities. This is the direct result of different soil types, geography and land use practices around New Zealand. Among these agrochemical products, lime is the most common fertilizer applied to New Zealand soils. Fertilizers are manufactured by the chemical industry and require a significant amount of non-renewable energy. Given applied rates, fertilizers in New Zealand are an essential input for farming in terms of energy. Data from the New Zealand statistics website (StatsNZ, 2002) was used for agrichemical use. It provides

amounts of fertilizers applied by regions, making no differentiation between each crop. Global values of application rate for each fertilizer and each crop were calculated by taking into account the regional specificity and the crop characteristics. These figures were obtained by taking the average of all regional application rates, weighted by crop area for each crop.

Pesticide, herbicide and fungicide use in New Zealand have been surveyed by the Ministry of Agriculture and Forestry (Holland and Rahman, 1999). In this field, it is important to have up-dated data, because these products can require, like fertilizers, large amounts of energy to manufacture them. The energy required and GHG emissions for manufacturing the agrochemicals come from international green house gas LCA analysis by the Food and Agriculture Organization of the United Nations (FAOSTAT, 2006). Fossil fuel inputs for farming were taken from a range of references for corn (Shapouri, 2001), wheat and rapeseed (PWC, 2002), and for corn, potatoes, barley and oats (CNCPP, 2006).

Crop yields for New Zealand in 2005, which are the result of the 2004 inputs, in tonnes per unit land area and the land area in production for each crop were taken from MAF data (Holland and Rahman, 1999). All data concerning farming crops given in a per-tonne basis were converted to a per-hectare basis using the current yield in New Zealand (FAOSTAT, 2006). All data concerning tallow for biodiesel conversion come from commercial production in New Zealand as reported by Judd in a report for the Energy Efficiency and Conservation Authority (EECA) (Judd, 2002a; Judd, 2002b).

Nearly 30,000 MJ of wood waste is currently used in New Zealand in the wood and pulp production industry for process heat and power generation. In addition, waste wood chips, logs and bark are used for boiler fuel and domestic heating (StatsNZ, 2007). We don't know how much, if any, of the current uses for wood

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waste would be diverted to liquid fuel production, so have used wood waste availability as surveyed by Judd (2002a).

Energy required for converting a biomass feedstock into a biofuel was taken from an international report for all crops used for bioethanol production (S&T, 2004). The Energy required for industrial conversion process for rapeseed comes from the FAOSTAT report (2006). Energy inputs for SSCF and Fischer-Tropsch process were sourced from Emert and Katzen (1981) and Judd (2002a) respectively. The agricultural waste stream in New Zealand was evaluated for production of methane biogas from anaerobic digestion, which would then be a feedstock for the F-T liquid fuel process (Thiele, 2005). Bioethanol production from enzymatic processes was taken from an American study (Emert and Katzen, 1981). GHG emissions and primary energy required for all conventional fuels (natural gas, oil, coal) come from the United Nations analysis (PWC, 2002). The transportation step from the oil fields in the exporter countries to the refinery in New Zealand was taken into account.

4. Analysis

It is well understood that if costs outweigh benefits, then the development is not profitable, but can be possible with financial subsidies. In the case of biofuel development, the most obvious cost-benefit relationship is between the energy investment in production and the energy product. This is expressed as the EROI as shown in Eq. 1 below. We propose three other cost-benefit analyses to explore the different motivations for biofuel development.

4.1 Energy Returned On Investment (EROI):

$$EROI = \frac{Net\ Biofuel\ Product\ Energy\ \text{[MJ]}}{Primary\ Input\ Energy\ \text{[MJ]}} \tag{1}$$

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EROI measures the ratio of the net renewable energy product to the total primary energy inputs, irrespective of whether they are renewable and non-renewable. If the *EROI* is greater than one, then the process can produce more energy than it requires. Solar energy is excluded from the input primary energy.

4.2 Fossil Energy Fraction (B/F):

$$B/F = \frac{Biofuel\ Product\ Energy\ _{[MJ]}}{Primary\ Fossil\ Energy\ _{[MJ]}} \qquad (2)$$

The fossil energy fraction, *B/F,* is the ratio of the energy in the biofuel product to the fossil fuel inputs. If *B/F* is less than one, then more fossil energy has been invested than has been gained in biofuel. The production of biofuel is unproductive in this case as resources are used for no gain. If *B/F* is greater than one, the conversion process consumes less fossil energy than the biofuel produced and there has been an energetic gain on the fossil investment. However, one should realize that this does not mean that atmospheric carbon emissions have necessarily been reduced as the fossil fuel has been burned, releasing fossil CO_2 in the process. With a *B/F* near unity, there is clearly no benefit to pursuing biofuel production, with respect to carbon emissions, as the same carbon would be released by using the fossil fuel for transport as for making then using the biofuel.

4.3 Renewability (Re*n*):

$$\mathrm{Re}n = \frac{Renewable\ Product - Fossil\ Input}{Renewable\ Product}\ \% \qquad (3)$$

The renewability examines the fossil investment compared to the biofuel production. A biofuel may be considered renewable to some degree if Re*n* is positive. In a process relying entirely on fossil input energy, with an EROI near

one, the process would have Re*n* near 0% and the biofuel produced is not renewable. In this case, the biofuel is not a fossil energy substitute. By definition, non-renewable energy sources have negative values of Re*n*, with increasing negative values as life cycle energy efficiency decreases. For example if a fuel shows a Re*n* of –22%, it means that non-renewable energy required to produce this fuel is 22% greater than its final energy content. On the other hand, if organic agriculture and non-fossil energy, such as wood chip fuel for process heat were used, then the Re*n* could be quite large and the biofuel would be more renewable. Note that for a biofuel to be truly renewable, there would have to be no fossil inputs. This would be a Re*n* of 100%.

4.4 Energy Returned On Land (*EROL*):

$$EROL = \frac{Biofuel\ Product\ Energy - Fossil\ Energy}{Production\ Land\ Area} [\text{MJ/ha}] \qquad (4)$$

The *EROL* highlights the net energy, defined by the difference between biofuel energy and non-renewable energy required in production, on a hectare-basis, taking into account the yield of each crop. This indicator is useful for considering how much land is required for biofuel production.

5. Results

Bioethanol from crops, bioethanol from wastes, and biodiesel are discussed separately in section 5.1, 5.2 and 5.3. Then, in section 5.4, a number of scenarios are considered, and a comparison with current fuel consumption is provided. Results were obtained by an interactive Matlab programme which was developed to allow exploration of any number of combinations of agricultural choices and waste use. The Matlab programme calculates the following values:

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- The biofuel production for the portion of feedstock converted

- The non-renewable energy required

- All policy indicators defined in Section 4

- GHG emissions (g/MJ biofuel).

5.1 Bioethanol production from crops

The first biofuel examined was ethanol from food crops. Crops with suitable sugar and starch content grown in New Zealand include corn, wheat, oats and potatoes. Sugar cane is not a possible crop in New Zealand. Table 1 summarizes the different values for bioethanol production from crops.

Table 1: Indicators for bioethanol production from crops

Feedstock	*EROI*	*B/F*	Re*n*	*EROL* $\frac{10^3 MJ}{ha \cdot year}$	GHG emissions $\frac{gCO_2}{MJethanol}$	% GHG reduction compared with gasoline
Corn	1.56	1.68	0.40	29.26	37.77	56.34
Wheat	1.22	1.28	0.22	10.56	44.91	48.08
Barley	1.09	1.15	0.13	6.45	56.16	35.08
Oats	0.92	0.97	-0.04	-0.88	74.17	14.25
Potatoes	1.13	1.20	0.17	13.71	42.32	51.08

All starch crops, except oats, have fossil energy fraction *EROI* and *B/F*, greater than 1. The most efficient crops for biofuel production are corn and wheat with values of *EROI* of 1.56 and 1.22 respectively. For reference, this compares to EROI of gasoline fuel from petroleum of at least 10, even for the most energy intensive conventional oil fields (Dale et al, 2011). For corn, *EROI* is high in relation with other figures from international reports. Shapouri (2001) gives a value of *EROI* = 1.24 is given for corn ethanol in the USA. The difference is due to the hypotheses made (taking into account the means of transportation, the distribution step, different allocation choices, and current data). For example, authors use a value of

corn yield that amounts 7.7 t/ha whereas the 2004 New Zealand corn yield was 10.8 t/ha.

The fossil energy fraction, *B/F* that takes into account only non-renewable energies used in the process, was found to be 1.68 and 1.28 for corn and wheat respectively. This indicates energy efficient bioethanol production from corn and wheat in New Zealand is possible on the basis of energy inputs, but neglecting water and other issues. For corn and wheat, Re*n* was 0.40 and 0.22 respectively. For corn and wheat, GHG emissions amount to a reduction of 56% and 48% respectively over burning petrol. Potato crops can be also considered an efficient feedstock for bioethanol production, with a Re*n* of 17% and a reduction of GHG emissions of 51%. Other starch crops, namely barley and oats have lower ratios *B/F* and *EROI*, with Re*n* of -0.04 for oats. A GHG emission reduction of 14% in relation to gasoline use is the sole positive aspect for the oat crop. Oats and barley have low renewable energy return on fossil investment. Therefore, it would be pointless to attempt biofuel production from these grains in New Zealand, even if the could be grown at low economic cost.

EROL is high for crops with significant yield, e.g. *EROL* = 29,200 MJ/ha/year for a corn yield of 10.8 t/ha. This means that 29,200 MJ of net energy per hectare of crop cultivated can be produced per year. Potato crops have lower *EROI* and *B/F* than wheat and have an *EROL* of 13,710 MJ/ha/year. It is the high yield for potatoes (44.2 t/ha) that accounts for this value.

Energy balances show that industrial biofuel production processes require a range of primary energy input as a fraction of biofuel energy produced from 60% (for potatoes) to 85% (for corn). Agricultural inputs range from 5% (corn) to 19% (oats). Primary fuel energy for farming ranges from 10% (corn) to 30% (potatoes). The greatest energy input requirement for bioethanol is processing energy,

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primarily distillation. Sustainable practices for farming could be focused on minimising fertilizer use, as it requires a great amount of manufacturing energy. The use of more efficient machinery for farming can also decrease the fossil fuel investment.

GHG emissions follow the same patterns for each crop as the energy intensity. The industrial conversion process, including fermentation and distillation, contributes to a range from 57% (oats) to 81% (corn) of GHG emissions. N_2O emitted during nitrogen fertilizer application is not negligible with a range from 3% (wheat) to 25% (oats). GHG emissions due to fossil fuel use for farming ranges from 1% (cereal crops) to 8% (potatoes). The conversion processes and N_2O emitted are responsible, on average, for 72% and 13% of GHG emissions, respectively, in the bioethanol production operation. Fossil fuel use for farming is not the main contributor to GHG emissions, fertilizer is.

Figures 1 and 2 show flow diagrams for bioethanol production from corn and wheat respectively. These representations allow a quick comparison of different processes. For example, wheat requires 4-times more input for farming than corn. Therefore, its renewability is lower than corn. In addition, the industrial conversion process for wheat requires 11% more energy than corn and the losses are 30% greater than for the corn biofuel process. The whole process for corn is thus more efficient than the one for wheat.
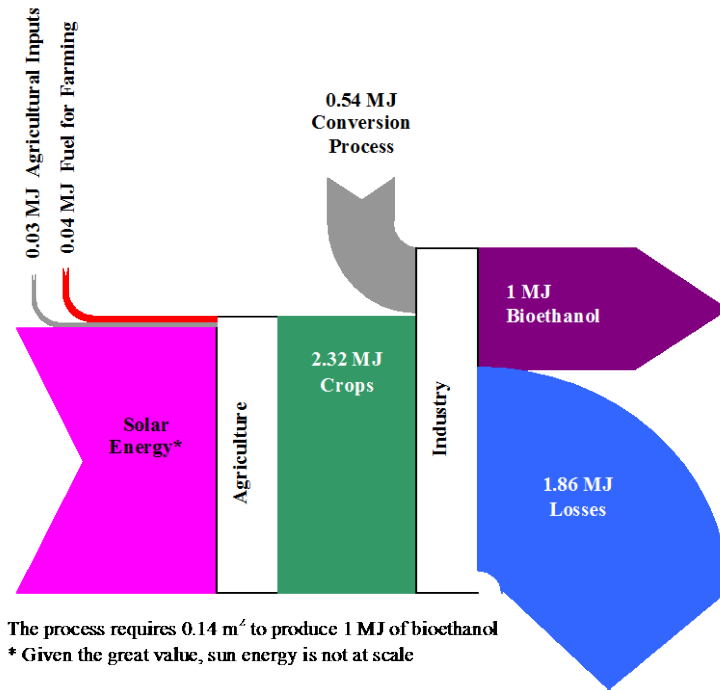
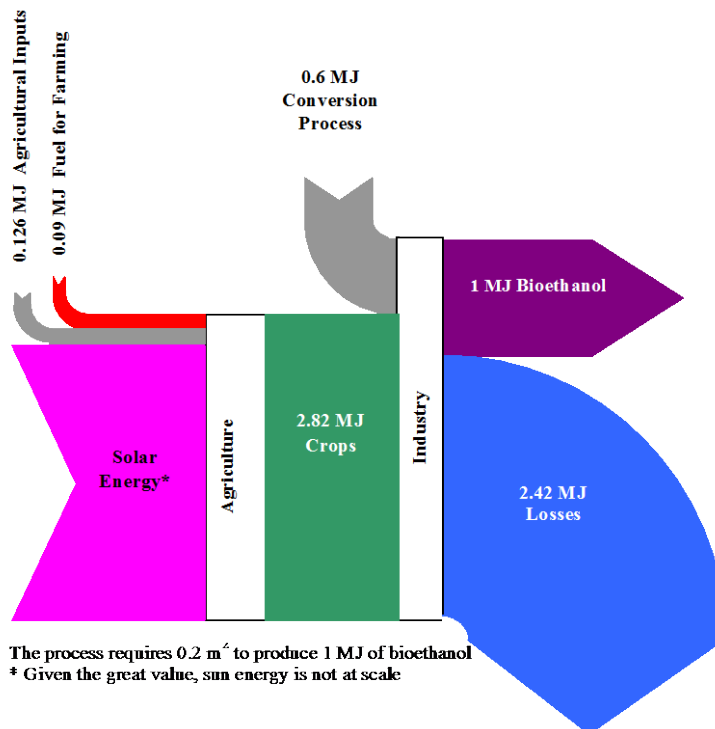Figure 1: Bioethanol production from corn per year

Figure 2: Bioethanol production from wheat per year

5.2 Results for bioethanol production from wastes

Wood waste has traditionally been used for energy in New Zealand. Whey, a byproduct of milk processing is currently converted into ethanol. We also examined waste from Kiwi fruit processing. Table 2 summarizes the different indicators calculated for each waste feedstock.

Table 2: Indicators for bioethanol production from putrescible wastes.

Feedstock	EROI	B/F	Ren	GHG emissions $\frac{gCO_2}{MJethanol}$	% GHG reduction in comparison with gasoline use
Paper Waste	2.15	3.45	0.71	20.5	76.3
Straw	3.36	5.64	0.82	12.2	85.9
Kiwi waste	0.56	1.79	0.44	39.6	54.2
Whey	0.75	2.32	0.57	39.6	54.2
Wood waste	1.92	3.06	0.67	23.2	73.2

Waste with low water content, paper and straw, have the best *EROI* as they do not require de-watering energy input. With Ren of 71% for paper and 82% for straw, they appear to be candidates for bioethanol production if the technical feasibility at a large scale of the SSCF process could have been deployed in 2004. Values of Ren are higher than for crops since only energy required for the process is taken into account, reasoning that inputs for the non-waste portion of the crop does not contribute to the biofuel product. Whey and wood waste have Ren of 57% and 67% respectively, and their use could provide reduction of GHG emissions of 54% for whey and 73% for wood waste. Kiwi fruit waste has a less favorable Ren of 44% due to high drying energy input, and GHG emission reduction of 54%. High lignocellulosic content feedstock offers the best opportunities for future bioethanol production. For waste feedstock, *EROL* has not been calculated because the land productivity is for the primary food product.

Figures 3 and 4 show representative flow diagrams for bioethanol production from straw and wood waste respectively. Although the processes can be considered efficient from an energetic point of view, losses during processing are significant. They are greater than those for fossil fuel refining. On the other hand, waste straw or wood must be handled, transported and disposed of, which may represent an *avoided* energy input if the waste is used for fuel.

High lignocellulosic content improves the renewability of the process but all the renewable energetic potential of the feedstock has not been exploited by the conversion process. This may have fewer consequences since it does not affect the depletion of non-renewable resources.
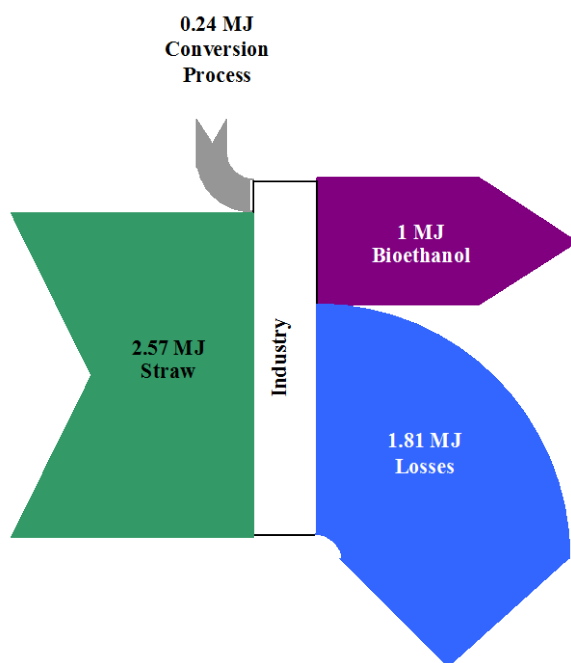

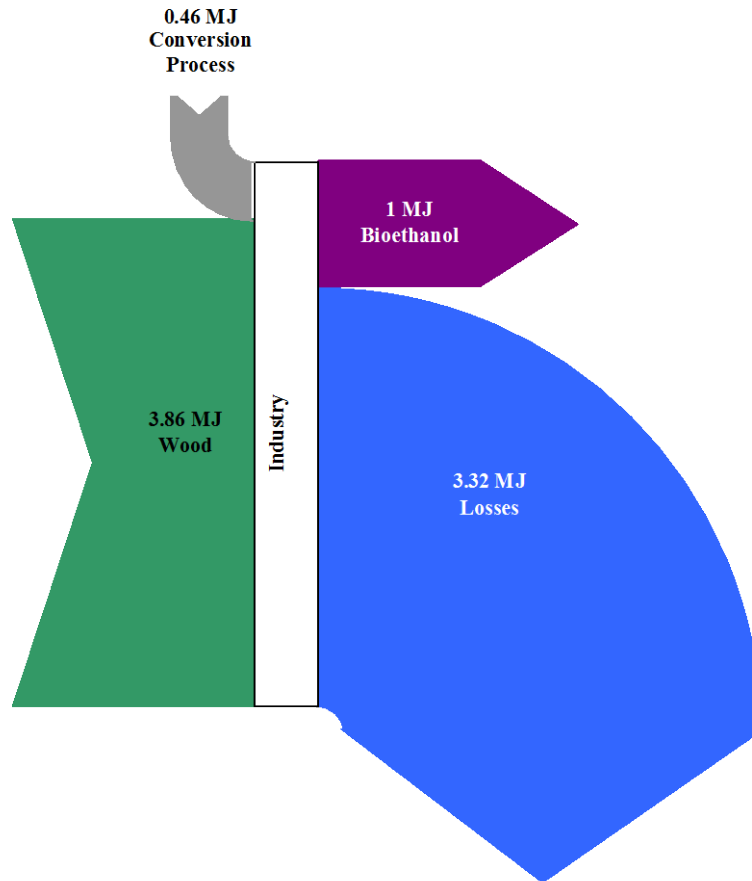Figure 3: Annual straw bioethanol production.

Figure 4: Annual wood waste bioethanol production.

5.3 Results for biodiesel production

Tallow and rapeseed are well known feedstocks for biodiesel that are currently produced in New Zealand. Again, wood waste is a known energy resource in New Zealand, and this analysis used international research into gasification and F-T processing to bio-diesel. Table 3 summarizes the different indicators for each biodiesel feedstock.

Energy ratios *EROI* and *B/F* are greater for biodiesel processes than bioethanol production. Results concerning rapeseed, currently used mainly in Europe for biodiesel production, confirm the role that this crop can play as a transport fuel. When energy required for farming is taken into account, the rapeseed Re*n* is 53%. Waste resources considered have a good potential with a Re*n* of 72%

for tallow and 86% for wood and paper. Concerning GHG emissions, we find a reduction of 85% and 82% for tallow and rapeseed respectively and 89% for wood waste and paper.

Table 3: Indicators for biodiesel production

Feedstock	EROI	B/F	Ren	GHG emissions $\frac{gCO_2}{MJ biodiesel}$	% GHG reduction in comparison with diesel
Tallow	3.58	3.60	0.72	12.1	84.9
Rapeseed	2.13	2.14	0.53	14.4	82.0
Wood	7.21	7.28	0.86	8.9	88.8
Paper	7.21	7.28	0.86	8.9	88.8

5.4 Retro-Analysis Scenarios

Two scenarios for retro-analysis of the most promising biomass feedstocks and processes were studied. The most promising crops for biofuel production in New Zealand are corn, wheat, barley and potatoes. For both scenarios we assume that all current land area of each crop and all current available waste feedstock are used for biofuel processing. Although this hypothesis is unrealistic, it can be relevant to study an upper-limit case as a reference. The results are compared to 2004 New Zealand consumption of petrol, 113×10^9 MJ, and diesel, 102.5×10^9 MJ (Dang, 2005). In the first scenario, all paper and wood waste feedstock were be used for biodiesel conversion, and in the second scenario the lignocellulose resources were used for bioethanol conversion. It should be noted that other solid fuels, most likely coal, would need to be used to replace the wood waste currently used for boilers and power generation.

Table 4 gives the maximum bioethanol production that could have been realised in 2004/2005 if all of the food production for these crops had been diverted

to ethanol production. The largest crop yield was barley, but due to the lower ethanol yield, the net energy production is lower than for corn. Frozen sweet corn is a major export product for New Zealand with markets in over 30 countries, and about 75% of the crop (25,000 tonnes) exported earning $50 million NZD (HortNZ, 2010).

It is interesting to look at the impact on the national balance of payments for 2004. The energy density of petrol (gasoline) is 36 MJ/liter, so the net corn ethanol energy would have replaced 13 million liters of petrol. The price of petrol rose sharply from $1.00/lit in 2003 to $1.50/lit in 2005, with the 2004 average price at $1.15/lit, of which $0.52 was taxes and levies. The avoided cost of imported finished unleaded petrol in 2004 which would have been provided by corn ethanol would have amounted to around $8.2 million NZD. The lost export earnings due to production of ethanol from corn would have been $50 million NZD, thus causing a negative $41.8 million NZD impact on the balance of payments. The agricultural industry would have needed a very large subsidy in order to go into the domestic biofuel business instead of the export food business.

Table 4. Retro-potential bioethanol production from the best crops in 2004.

Scenario 1	Bioethanol energy ($\times 10^6$ MJ)	Fossil energy input ($\times 10^6$ MJ)	Net energy ($\times 10^6$ MJ)
Corn	1170	701	469
Wheat	1907	1495	412
Barley	2565	2242	323
Potatoes	930	775	155
Total	6572	5213	1359
		% of 2004 petrol consumption	1.2%

Table 5 gives the ethanol production from the best agricultural wastes. The combined ethanol production from food crops and agriculture wastes would have provided less than 4% of the petrol demand for the year. Table 6 gives the biodiesel production in the first scenario where all of the good food and oil crops for producing biodiesel plus the waste wood and waste paper are processed to biodiesel. These resources amount to just over 8% of the diesel consumption in 2004.

Table 5. Bioethanol production from best agricultural waste in 2004.

Scenario 1	Bioethanol energy ($\times 10^6$ MJ)	Fossil energy input ($\times 10^6$ MJ)	Net energy ($\times 10^6$ MJ)
Straw	3054	541	2513
Kiwi	26	15	11
Whey	342	192	150
Total	3422	748	2674
		% of 2004 petrol consumption	2.4%

Table 6. Biodiesel production per year (Scenario 1)

Scenario 1	Biodiesel energy ($\times 10^6$ MJ)	Fossil energy input ($\times 10^6$ MJ)	Net energy ($\times 10^6$ MJ)
Tallow	4267	1184	3083
Rapeseed	74	35	39
Wood	6185	849	5336
Paper	3	0.4	2.6
Total	10529	2068	8461
		% of 2004 diesel consumption	8.3%

The second scenario maximizes ethanol production by using the waste wood and paper together with the other wastes and food crops. Table 7 gives the waste and wood ethanol production, which amounts to 8.6% of New Zealand's 2004 petrol demand. Together with the 1.2% from food crops, the maximum ethanol

scenario would still not quite provide 10% of petrol demand. Of course, using the wood waste for ethanol rather than diesel would reduce the biodiesel production as shown tin Table 8 which totals the biodiesel from the rapeseed (canola) crop and the rendered fat from meat processing. The biodiesel production in the second scenario would provide 3.1% of the country's diesel demand.

Table 7. Bioethanol production from waste per year (Scenario 2).

Scenario 2	Bioethanol energy ($\times10^6$ MJ)	Fossil energy input ($\times10^6$ MJ)	Net energy ($\times10^6$ MJ)
Paper	2353	683	1670
Straw	3054	541	2513
Kiwi	26	14.7	11
Whey	342	192	150
Wood	8044	2631	5413
Total	13819	4062	9757
		% of 2004 petrol consumption	8.6%

Table 8. Biodiesel production per year (Scenario 2).

Scenario 2	Biodiesel energy ($\times10^6$ MJ)	Fossil energy input ($\times10^6$ MJ)	Net energy ($\times10^6$ MJ)
Tallow	4267	1184	3083
Rapeseed	74	35	39
Total	4341	1219	3122
		% of 2004 diesel consumption	3.1%

6. Discussion

Biofuel production could be possible for certain feedstock sources in New Zealand. The retro-analysis gives a good understanding of why, despite high public and policy interest, biofuels have not become a major fuel through market forces. The export value of the best ethanol feedstock, corn, was more than three times greater than the domestic value of the transport fuel product. In 2008 the Labour

government instituted a biofuel obligation for the country's one refinery to source and blend an increasing percentage to 2.5% ethanol into the petrol supply by 2012. An election in the same year brought in a National party government, which eliminated the biofuel obligation as one of the first policy actions. The National government discussed the possibility of a tax incentive for producers of biodiesel. However at the end of 2012 no subsidy scheme has been enacted for biodiesel, although the sale of biodiesel is exempt from the excise tax which is 50.5 cents per litre on the 2012 petrol pump price of $2.20 per litre. The state owned enterprise, Solid Energy, has built a biodiesel plant which uses oilseed rape grown in the South Island. The company estimates that there is sufficient production of the crop to produce 4 million liters of biodiesel per year.[1]   Using an energy density of 35 MJ/lit, this would represent about 0.1×10^6 MJ, a much smaller quantity than our retro-analysis for 2004 using all of the canola oil crop.

The main policy driver for biofuel in New Zealand remains reduction of CO_2 emissions from transport. New Zealand does not have the historical policy driver of becoming free from "dependence on foreign oil" as has been the case in the USA since the 1973 OPEC oil embargo.[2] This retro-study showed that GHG emissions are reduced to some degree in relation to using conventional fossil fuel as long as the *EROI* is substantially greater than one. However, it must be emphasized that none of the biofuel systems studied has a renewability of 100%. This means that the biofuel production, whatever the process, requires some fossil fuel inputs.

The retro-analysis method in this paper sheds light on the future possibility of biofuel use in New Zealand. The year chosen for the analysis was 2004, just as the price of oil on the world market was beginning a price move from the range of $30

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[1] http://www.biodiesel-nz.co.nz   Accessed Dec 1012
[2] U.S. President Richard Nixon announced Project Independence on Nov 7, 1973.

per barrel to a record high price of \$145.29 on July 3, 2008 on the NYMEX exchange. The global atmospheric CO_2 concentration grew by 2.29% in 2003, and by 1.56% in 2004. The Mona Loa monitoring station reported the CO_2 concentration of 377.5 ppm in 2004, while in October 2012 the reading was 391.0 ppm (NOAA, 2012). The idea is that if we can get a realistic picture of the possible realizable benefits which would have been provided by aggressive biofuel policy in the past, it could provide some perspective for the potential costs and benefits of biofuel development in the future.

When we consider current consumption of fossil fuel, we can see that even the unrealistic case of use of 100% of all crop and waste stocks still amounts to a low contribution to addressing the serious issues of high transport fuel demand, high transport fuel cost, and growing GHG emissions. The two scenarios, taking into account the whole capacity available of each feedstock, show that the possibility of a substitution of biofuels for fossil fuels is not realistic.

The fact that potential biofuel production is small does not mean that industrial development will not occur. Economic development of energy resources is possible for smaller resources if the economics and technology are applicable. Indeed if a new oil field in New Zealand were discovered that could supply 1% of New Zealand oil supply, it might be developed depending on a range of factors, and the producers could make a profit if production costs were not too high. Our analysis does not consider the wider issues of viability of a business venture to convert some biomass resource into liquid fuel. Rather our analysis sheds light on some of the claims commonly associated with biofuel which influence policy direction. Firstly, biofuel does not reduce market dependence on imported oil, nor does it increase resilience to oil shocks for *B/F* values around unity as is the case for corn. As long as the production of the feedstock is fossil energy intensive, the

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whole biofuel supply chain is exposed to import fuel disruptions and price shocks. Secondly, bio-derived liquid fuel is not a 100% renewable fuel unless the Ren value is 100%, which would not currently be the case for any of the possible fuels studied. Thirdly, biofuel is not carbon-neutral or GHG-free as long as excess nitrogen fertilizer and fossil fuel is used in the agriculture and processing.

Finally, consider that the Ministry for Economic Development (MED) estimates that a 7% petrol and diesel fuel demand reduction can be achieved by correct vehicle tire pressure, reduced highway travel speed and carpooling (Colegrave te al., 2004). The reduced carbon emissions from fuel demand reduction would not require consumption of fossil fuel to achieve. Demand reduction would require minimal land use, very small capital investment in production plant, and no loss of export earnings from food crops. We also have some questions about the logistics of harvesting, storage, processing and dispensing of agriculturally-derived biofuels in a small country like New Zealand. Crops are harvested, and processing wastes accumulated around one time of the year, while demand is continuous. We anticipate there would be additional costs and resources needed to store the biomass feedstocks without letting them ferment until they are needed for processing. Alternatively, if the biofuel plant were made large enough to process the feedstocks all at one time, that would leave plant idle and probably result in serious cost issues. There appear to be a range of lower-cost, more effective demand-side alternatives to deal with reduced imported oil supply or reduce GHG emissions. However, new policy communication capability will need to be developed in order for presidents or prim ministers to call for demand side management with the same fervor that they call for development of biofuels. One suggestion we have for future work in this area is to change the perception of demand side management from one of austerity and economic decline into one of transition and adaptation driven by

freedom and prosperity. Ours is not the first study to conclude that it is not even remotely possible to "substitute" renewable or alternative energy resources or technology platforms to meet the established fossil fuel energy demand. The future work which is usually suggested by authors is that more research is needed to improve the alternative energy technology. We propose that it is obvious that what is needed is demand reduction. What is not so obvious is that this demand reduction needs innovation on an even broader scale that alternative energy. The innovations needed are technical but are also social and market-based. Thus we propose a new field of engineering which we have termed *Transition Engineering* which will deliver the changes in the embedded fossil fuel systems to meet the most urgent targets of fossil fuel use reduction and climate change mitigation. Development of the engineering measurement, analysis and design tools for Transition Engineering is the focus of our current and future work to inform and support energy policy.

7. Conclusions

The motivation for this research project was to evaluate the potential role of indigenous biofuel production as an adaptive measure for reducing green house gas emissions or reducing exposure to risk of shortages of imported fossil fuel. The approach was to collect agricultural data on possible biofuel feedstock sources grown in New Zealand at a particular date in the past, then to model the candidate production processes for each material using real data. International sources were used for process modelling.

The standard energy balance indicator, *EROI*, was calculated for each feedstock-process route combination. We proposed two new indicators of the renewability of the fuel product by considering the fossil fuel input. We also

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calculated an energy return on land use, *EROL,* for New Zealand crop data. Finally, we calculated the cumulative total of biofuel production capacity if all of the feedstock resources were converted to biofuel production. We did not consider economic viability or water use.

We can conclude from this study that biofuel from high *EROI* feedstock using proven conversion processes is possible in New Zealand. The analysis showed that food crops such as corn, wheat and potatoes could be used now to make ethanol, and that tallow and rapeseed could be used to manufacture biodiesel. More speculative processes include wood, paper and straw for ethanol and wood and paper for biodiesel production. The *EROI* was less than one for oats and barley, which would preclude these crops as candidate biofuel sources. The biofuel supply chain with the highest *EROI* is, not surprisingly, the rapeseed biodiesel using current production methods used in Europe and elsewhere.

From the renewability analysis we conclude that production of biofuel should not be considered to produce wholly renewable or sustainable fuels. Given the fossil fuel inputs as a fraction of biofuel product, we conclude that producing indigenous biofuel does *not* reduce New Zealand's dependency on imported fossil fuels. The farming and biofuel production process would be exposed to the same risk of disruption from imported fuel shortages as all other transport activities. Looking at the greenhouse gas analysis, biofuels should not be considered as carbon-neutral unless the processing energy is all from non-fossil resources. This implies that more research and development work would be needed to develop fossil-free biofuels if they are to be considered for carbon credits or other incentives

In the future, research, devoted to the whole transportation system, including demand management and improved efficiency would appear to have potential for great benefit. Importing one unit of fossil fuel to produce 1.3 units of

ethanol or 2.3 units of biodiesel does not reduce GHG emissions as cost effectively and sustainably as reducing the demand for one unit of fossil fuel directly though better transport system design.

8. Acknowledgements

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