An environmental assessment of the production of biodiesel from waste oil : two case studies

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Abstract: The UK transport sector is currently responsible for 30% of UK CO_2 emissions. Therefore, the use of biofuels is explored. As the CO_2 released when energy is generated from biomass is generally balanced by that absorbed during the fuel's production it is often regarded as a 'carbon neutral' process. However, there are impacts associated with bioenergy production, including, for example, the growth and transportation of feedstock. One way to overcome these is to use a waste oil feedstock. Whilst there will not be enough waste oil to meet all our fuel demands, some firms in the UK have started to use their waste catering oil for transport. Collection and conversion is often done on a small scale and a number of methods are used for the processes. Therefore, the associated environmental impacts are variable. The environmental impact of the production and use of biodiesel from waste oil based on two case studies has been assessed. The impacts associated with the use of fossil fuels and climate change gas production is lower than that of the production of conventional fossil fuel diesel. The biggest impact within the process is associated with the use of methanol and the waste oil collection.

Keywords: *Biofuels, environmental life cycle assessment, waste oil.*

1. Introduction

Climate change and energy security have become major concerns in recent times and many countries have agreed, under the Kyoto Protocol, to reduce emissions of greenhouse gases. One of the ways in which this is being done is through the pursuit of bio-energy. As the carbon dioxide (CO2) released when energy is generated from biomass is generally balanced by that absorbed during the fuel's production it is often regarded as a 'carbon neutral' process [1]. However, there are impacts associated with various stages of bio-energy production, including, for example, the boiler production and transportation of feedstock.

Bio-energy is unique amongst renewable energy in that it is not immediately dependant on the weather (unlike, for example, wind and solar). However, it is also unusual in that it requires a feedstock of often bulky materials which can limit its capacity and the geographical extent of its supply chain [2]. The production of this feedstock can also be associated with environmental consequences, with some citing rising food prices and land use conflict as an unwelcome side effect of its use. This is due to the land required to grow specialist biomass crops such as miscanthus or oilseed crops. One way to overcome the issues associated with "land squeeze" is to use waste oil to produce bio-fuels. This study examines two such systems. Both use waste oil to produce bio-diesel. One system works on a fairly small scale, and the other on a larger scale. Life Cycle Assessments (LCA) of the systems have been undertaken in order to examine their environmental costs and benefits.

LCA is an environmental management tool which examines the environmental burden of a product or system over its entire life, from production, through use and on to disposal or recycling. The energy and materials used, pollutants or wastes released into the environment as a consequence of a product or activity are quantified over the whole-life cycle from "cradle-to-grave". Two case studies were selected and a truncated LCA was undertaken. Data for the collection of the waste oil and its conversion into biodiesel were determined and analysed. Impacts associated with the previous life of the oil were not considered; nor were impacts associated with the biodiesel's use in vehicles after conversion. These data are then examined with regard to a number of environmental impacts. The embodied energy and greenhouse gas emissions are calculated for both systems and are compared with the production of biodiesel from virgin rapeseed oil and the energy output when used.

2. Methodology

The methodology of LCA has been standardised via Society of Environmental Toxicology and Chemistry (SETAC) guidelines subsequently codified in ISO Standards [3&4]. There are four main stages in the LCA process: Goal Definition, Inventory, Impact Assessment and Improvement Assessment and Interpretation. These are described below;

- **Goal definition** is the stage in which the scope of the project is outlined. Here the study boundaries are established and the environmental issues that will be considered are identified.
- The **inventory** is where the bulk of the data collection is performed. This can be done via literature searches, practical data gathering or through the use of software. Most commonly, a combination of the three is adopted.
- **Impact assessment** is where the actual effects on the chosen environmental issues are assessed. This stage is further subdivided into three (or four) elements: classification, characterisation, (normalisation) and valuation.
  - **Classification** is where the data in the inventory are assigned to the environmental impact categories. In each class there will be several different emission types, all of which will have differing effects in terms of the impact category in question.
  - A **characterisation** step is therefore undertaken to enable these emissions to be directly compared and added together. This step yields a list of environmental impact categories to which a single number can be allocated.
  - These impact categories are very difficult to compare in terms of relative impact and so the **valuation** step is employed so that their relative contributions can be weighted. This is subjective and difficult to undertake and many studies omit this step from their assessment. The LCA ISO standards state that it should not be used in any comparative or decision making study.
    - Instead of, or as well as, **valuation** many people employ **normalisation** as an intermediate step. Normalisation allows a degree of comparison between data types by determining the relative contribution of the calculated damage to the total damage caused by a reference system. Within this research the LCA impact assessment method, EI99 was used. It is a damage-oriented method, which considers, by means of damage factors, the effects of the emitted or used substances in three damage categories: human health, ecosystem quality, and resources (both fossil and mineral). Within this report the data have been normalised with respect to the average emissions or damage within Europe. In order to give a more comprehendible number this is then divided by the amount of people within Europe. Because the normalisation step compares the emissions or damage generated by a particular system with those generated at a European or global level the result of a normalisation step are dimensionless. Within this paper the normalisation method proposed and used in the methodology Eco-Indicator 99 has been followed [5]
- **Improvement assessment** is the final phase of an LCA in which areas for potential improvement are identified and implemented.

LCA requires all the energy inputs, raw materials inputs, emissions to air, soil and water, and waste to be examined at every stage of the life of the product or system. It is a simple, elegant idea, but it can become convoluted in practice [6].

3. The Case Studies

Two case studies have been examined and produced; these have both followed on from previously funded research [7&8]. Details about the composition, use and performance of the systems, together with information about feedstock sourcing, were obtained from the case study companies. This was done through a combination of visits, emails, phone conversations and augmentation of the data gathered from the previous case studies [8].

Data for the production of the materials used to produce the systems were calculated using generic life cycle inventory data. Where possible the EcoInvent database [9] was used. Where data required some geographical amendments (for example, changing to the UK electricity mix) this was done. Some estimation was made in the material composition of the systems, but generally there was detailed information about their size, weights, and composition. In general it was assumed that virgin materials, for example steel and rubber, were used in the production of the systems. However, where specific alternative information was available, for example the large tanks in the case studies had been reclaimed and were being reused, this was modelled accordingly and not all of the environmental impacts associated with the production of these units were allocated to this life cycle.

The first case study is based on a small company based in the south west of England, UK. Used cooking oil is collected from pubs, hotels, restaurants and schools in the local area; some is also delivered by customers who purchase their biodiesel. Where collected, a flat bed truck which runs on their own product is used. They make 220,000 litres per year, using a system that they have built and designed themselves. The company sells the biodiesel on site.

The second case study is a larger business with the capacity to produce 1,000 litres per hour, utilising automated control systems as far as possible. The processing site is also in the south west of England, UK, and the system was purchased from a UK manufacturer. The company purchases their oil from national oil collectors. The oil is delivered in 30,000 litre loads and is brought in by the company's own oil tanker which collects the oil from the collectors. After the biodiesel has been produced, the tanker is used to haul the biodiesel out of the plant, which means that the tanker avoids empty journeys. The tanker runs on 100% biodiesel. Much of the biodiesel is sold to haulage companies; some is sold on site to local customers. The company produces approximately 3 million litres a year. The processes followed for both case studies are shown in Figure 1.

4. Results

4.1. System Production

Within both case studies, much of the equipment has been hand made or assembled and so, whilst these case studies are a good example of local businesses, the results from this may not be indicative as an average of the whole industry. Some parts of the equipment have been re-used, for example the large holding tank was originally an old printers' ink tank. It is possible that this is due to cost, but also that those involved with making a product such as biodiesel are interested in the re-use of products for their environmental benefits. Therefore, whilst the re-use of materials does in some way make each system unique; it is possible that many companies will use re-cycled and re-used materials.

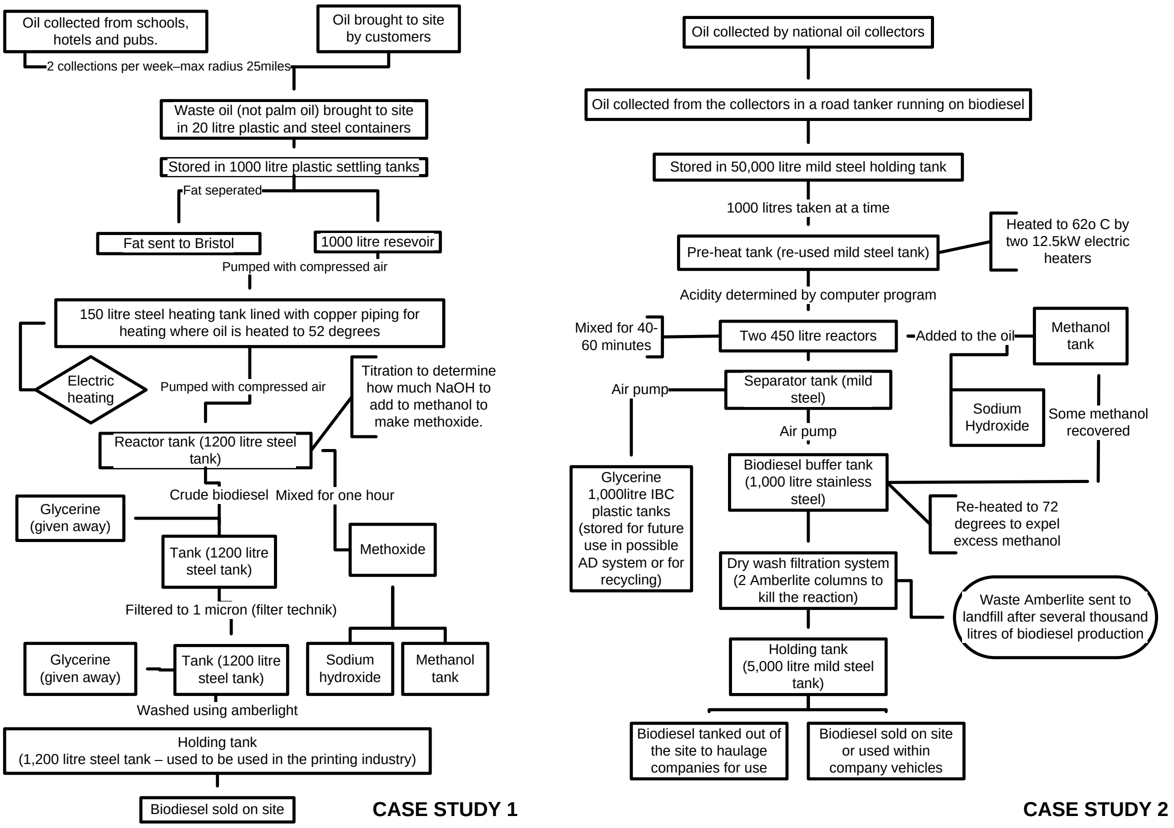

Figure 1. Waste oil collection and biodiesel production processes.

A fair way to determine the allocation of environmental burden to a re-used product is difficult. If a product is used once then all of the burdens must be attributed to that one use. If it is certain that the product will be recycled then any benefit associated with the recycling, eg any reduction in the amount of virgin material used, can be attributed to the product during the recycling stage. However, where there is no knowledge of the full life cycle of a product, for example, how many times it will be used and for what period of time, it is more difficult to attribute environmental burdens to its different life cycle stages. However, it is known that many of the tanks used have been bought second hand and so have therefore had a previous life. This previous life should be allocated some of the burdens. It is not acceptable to attach none of the environmental burdens to the second use of the system, as there is clearly a good second hand market for these tanks. Therefore, it is proposed that half of the environmental impacts associated with the production of these re-used tanks are attributed to this system.

Figure 2 shows the normalised data for the production of both systems. This includes all the components within the system. In case study 1 there are in total six 1000 litre plastic tanks, one 150 litre steel tank, four 1,200 litre steel tanks, one 25,000 litre steel tank and one 100 litre plastic tank. The production of the larger tanks (unsurprisingly) has the biggest impact. Within the second case study the predominant impacts are shown to be attributed to fossil fuel use, mineral depletion and the production of respiratory inorganics (Figure 2). Similarly to the first case study these are due to the production of steel, which is one of the largest material components of the system. Note the differing scales on the y axis – whilst case study two system production has a larger production impact it is a larger system that can produce more fuel, therefore at this stage the figures should not be compared against each other in terms of scale, but they do show where differences in production impact occur.

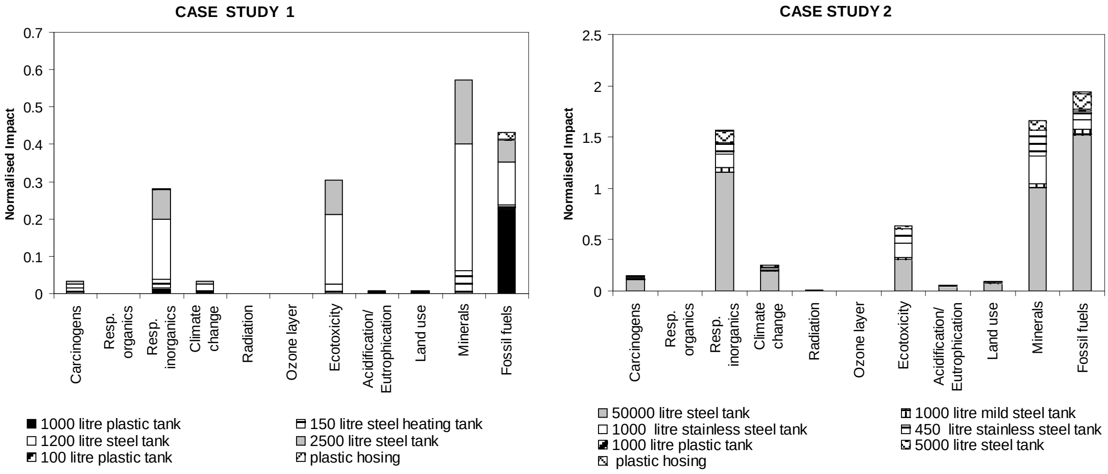

Figure 2. Normalised data for the production of the two systems; this shows the entire production systems and is not a comparison based on the final functional unit.

4.2. Production of the biodiesel

In order to determine the impact of the production of the fuel the production of the system, the use of electricity and any other consumables – such as the washing and filtering system and the collection of the oil etc, must also be examined. Specific data for the trade marked washing and filtering system used in case study 1 were not available and so this has been estimated using a generic ionic resin (of which the trade marked system is one). With used oil, there is a variation in the conversion rate from approximately 98% - 60% if the oil supplied is bad.

For the first case study, once the oil has been collected or delivered it is stored in an Intermediate Bulk Container (IBC) in the yard. From there it is pumped to a 150 litre heating tank in the building, where the oil is heated to 52ºC by electricity. It is then pumped to a reactor tank where a titration test determines the necessary quantities of methanol and sodium hydroxide needed to create a complete reaction process. The chemicals are mixed in a small methoxide tank and passed into the reactor tank. The reaction takes about one hour after which the liquid is pumped to a holding tank, which used to be a printers' ink tank. The glycerine settles to the bottom overnight and is then pumped to 150 litre tanks outside. The biodiesel then passes through a 1 micron filter to a further holding tank during which most of the particulates are removed. Further filtration then takes place via a resin filter system. The biodiesel is then stored in a final tank from which it is dispensed to customers through a metered pump. The glycerine made as a by-product of the process is given away (Figure 1).

In the second case study the oil delivered by the tanker is pumped into a 50,000 litre holding tank. From this, 1000 litres at a time are pumped into a pre-heat tank. This heats the oil to 62^{o}C using two 12.5kW electric heaters. To this is added methanol and methalate (the control systems automatically add the specified amounts) and the oil is then mixed for between forty and sixty minutes (Figure 1).

From the reactor tanks, the liquid is pumped into a separator tank where most of the glycerine falls to the bottom as the liquid flows continuously over flow plates. This means that there are no filters that need to be changed periodically in this stage of the process. The glycerine is pumped out of the bottom of the tank and currently is stored for possible future use in anaerobic digestion systems or other forms of recycling. This potential use has not been modeled here, as it held no commercial value to the companies. The biodiesel still contains some methanol and glycerine, and the next stage involves heating the liquid to 72°C in a buffer tank. The methanol evaporates at 68°C and by then re-condensing the vapour in the exhaust pipe, some of the methanol is captured and then re-cycled.

Glycerine causes problems if it is found within biodiesel and the reaction can continue after this stage, so in order to stop the reaction the liquid is then pumped through a washing and filtration process. The filters are the same as in the first case study and contain a polymeric resin that absorbs sodium and fats and attracts glycerol to the outside of the polymer beads. The system can filter 14 litres per minute and the columns can process 300,000 litres of biodiesel before they need to be emptied. The waste is inert and is sent to landfill.

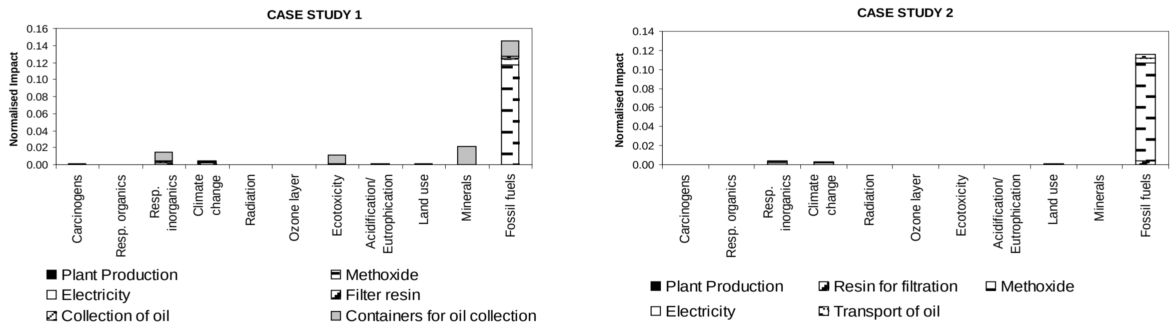

Figure 3. Normalised data for the production of 1000 litres of biodiesel using the two systems

Figure 3 shows the normalised data for the production of 1000 litres of biodiesel. Both plants are assumed to have a working life of ten years. In both cases the use of fossil fuels is the largest impact; predominantly associated with the production of methoxide, this finding is consistent with other publications in this area, for example Morais et al [10]. This is because methanol is made from either natural or coal gas. Methanol can be produced from a number of sources, and so it might be possible to reduce the impact of the methoxide by purchasing methanol that has not been made from fossil fuels. Another option would be to recover some of the methanol. This is done in case study 2; resulting in a slightly lower impact (see again the differing values on the y axis). Within case study 1 the use of the small steel and plastic collection containers also has a visible impact. These containers have been re-used, and so only half of their production impact has been allocated to them. The remaining impact is considered to be attributable to their first life.

4.3. Disposal of the Systems

No disposal options have been modelled for the plants as it is not possible to determine how they will be disposed of at this time. If the plant were to be recycled and any benefits were associated with this at the end of its life, the impact of the plant production would be reduced. However, as the plant production has a relatively small impact in the life cycle impacts, this would not have as significant effect as any change in the production methods of the methanol or a change in the collection system.

4.4. Energy and Green House Gas Emissions Analysis

There is little point producing biodiesel if it uses more energy in its production that it can produce when it is in use. Therefore the embodied energy of the biodiesel has been calculated. This has been calculated using the same processes and boundaries shown in the previous parts of the paper and includes the energy required to produce the systems, collect the waste oil and process it into biodiesel. In order to produce one litre of biodiesel with the first case study process approximately 11 MJ of energy are required, and for the second case study the figure is slightly lower at 8MJ. The difference between the two systems is predominantly due to the different scales of the systems and the way in which the oil is collected. By comparison, the energy content of diesel is approximately 38MJ/litre and the energy content of biodiesel is approximately 37MJ/litre [1]. Published ranges of embodied energy of bio-diesel from rapeseed varies; but is approximately 15MJ/L [11] to 30MJ/L [1&6]. Therefore, the production of the biodiesel from waste oil requires significantly less energy than that from rapeseed, and also provides much more energy than it requires in its production.

The total greenhouse gas emissions (GHG) have been calculated for both systems using IPCC 100 year time horizon data. The production of one litre of biodiesel generates 343g and 228g CO_{2eq} from case studies one and two respectively. Much of the GHG result from the use of the methanol and also from the collection of waste oil process. Compared to published literature these results are high. Alternatives suggest values from 87g/litre [12] to 343g/litre [11]. The differences primarily occur due to differing boundaries and allocation procedures. For example, in many cases the glycerine is used, therefore some of the burden can be and is attributed to that. As the glycerine was not used in either of these cases no burden was allocated to it. Also, the boundaries selected here do not attribute any impact to the initial production of the oil before it becomes waste. However, there are also differences that can be attributed to the producers examined; larger, more commercial producers may produce biodiesel more efficiently.

5. Discussion and Concluding Remarks

A significant impact in both of the biodiesel production systems is the use of methanol. This is due to the methanol production process which uses natural gas or coal gas. An alternative method for its production is through the gasification of a range of renewable biomass materials, such as wood and black liquor from pulp and paper mills. However, this is not as common as its production from fossil fuels. One way in which both companies could reduce their impact would be to source methanol produced from these more renewable sources.

Both systems use materials and parts that have been used before. This brings some interesting issues associated with how the burdens should be divided between the product's current use and any previous or future uses. Within any life cycle system, if an individual component is to be used two or three times then each use would be allocated half or a third of its environmental burden. However, these products have been used in completely different situations and how the burden is allocated for this is more difficult. It is unrealistic to say that the second use should have all of the burdens, as it has already fulfilled one function elsewhere. However, the second use cannot be ignored and be said to have no burden as the product clearly has a market value and therefore has been sold. It is not known whether the product has had one or two previous lives, or if it will be further used after being used in these systems. Therefore, the burden has been divided by two in order to simulate two lives for these products. As the impact of these products is small during the life time of the system, this is not a significant issue.

However, this does raise inconsistencies with the way in which the oil has been treated and modeled. Within this system the oil used has been treated as a waste. That means that no environmental burdens have been allocated to it for its production or transport to the place of its original use. Within this study the boundaries have been set at the point where the oil becomes no longer useful to its owner and is collected by the waste carrier. Often this oil is free of monetary cost to the collector, who then adds value to it by collecting it and delivering it in bulk to a second user. Previously much of this oil would have found itself as waste. Sometimes energy might have been recovered from it, sometimes not. As a waste product, it is acceptable to decide that all the production impacts are associated with the first use.

However, if this becomes a commercial product, is this method still acceptable? At this point within an LCA these issues become more philosophical than scientific. The impacts still happen, so one is only then deciding to whom or what the impact is attributed. The allocation of such burdens is an area of ongoing research within the life cycle community.

In order to improve the two systems in question less methanol use, or methanol produced from renewable sources, would improve the environmental performance of the biodiesel. In addition, a more efficient collection system would improve the process. For any further studies using the data produced, the issues associated with the system boundaries and environmental burden allocation must be noted.

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