Abnoba
Algae Solutions

Team 10

Low Carbon Transport Infrastructure in Arran

A report on the feasibility of producing biodiesel derived from algae cultivated in Arran.

Integrated System Design Project

Team 10:

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1. INTRODUCTION

The following is Group 10's final report as required in Integrated Systems Design Project 4. After extensive off-site research, the document outlines the overall feasibility of creating a low carbon transport infrastructure on the Isle of Arran, located within the North Ayrshire council area. The project is in partnership with the Stagecoach Group, in which their current bus network is utilised. The project is set out to ensure Stagecoach meet future restrictions on public road transportation as well as being in keeping with their ethos of being environmentally conscious.

In order to prove the overall feasibility, the document initially covers all technical aspects to show the concept is possible, as well how the project would fit into Arran's existing environment. This is followed by an overview of the various measures carried out to make certain the project abides by the law, maintains a standard of excellence, and is financially stable. The document refers to the provided appendix and is referenced throughout, with careful consideration and measurements taken to ensure their credibility.

2. EXECUTIVE SUMMARY

Abnoba Algae Solutions' mission is to provide a low carbon transport infrastructure on the Island of Arran. To achieve this, the existing bus network is going to be utilised in order to minimise waste and disruption to the local people and businesses in Arran. Algae will be cultivated on the island to create B100 biodiesel which will be directly sold to Stagecoach, who run the bus network on Arran. The entire life cycle of the project will exist on the island, so various measures have been put in place for Abnoba to take a positive place within Arran's community.

Chlorella sp. (algae strain) will be grown in open raceway ponds due to its high oil content, ability to grow in wastewater, and its scalability. An area of 17,084m^2 will be used in order to produce the required 167,078L of fuel per year. Biodiesel will be developed at a carefully selected location within a farmhouse or barn due to the small scale of the project. All by-products will be sold to benefit the island and surrounding areas, covering any costs in transporting them off-site. By using the B100 fuel in the buses, which will undergo various modifications, there will be a 40% reduction in CO_2 emissions.

To create and maintain a standard of excellence Abnoba utilizes a continuous improvement ideology. Various standards have been identified and outlined to ensure the product meets the legal specification of biodiesel, with auditing taking place to ensure these are being followed. Safety issues and regulations are also outlined to guarantee Abnoba complies with the law. As this project initially only has one customer, the marketing focuses on approval from Arran's locals. Arran's community have demonstrated they're interested climate change solutions from undergoing various actions such as a climate strike. In saying that a careful marketing strategy has been developed incorporating local involvement in planning and education. Due to the large amounts of CO_2 algae absorbs the overall infrastructure will be carbon negative, creating a unique marketing opportunity for the islands tourism industry. Production of fuel will cost £4.01 per litre at a 20% profit, but due to subsidies will be sold to Stagecoach at £1.30 per litre. This will create a break-even period of 13.7 years and (due to reducing profit after this period) a project lifespan of 32 years.

3. MARKET ANALYSIS

3.1 SWOT

SWOT analysis has been performed in order to identify the strengths, weaknesses, opportunities and threats the project might face during its lifetime. The outcome is shown in table 1.

Strengths	Weaknesses
• Reduces CO_2 output of Stagecoach buses by 40% • Meet environmental targets • The environmentally friendly connotations of the biodiesel will appeal to Stagecoach and could be attractive to tourists • Works with an already existing bus infrastructure run by Stagecoach • Buses are less reliant on imported diesel, more independent	• Relatively new industry - will need to build reputation • May not be profitable • Limited customer base
Opportunities	**Threats**
• New job opportunities for Arran residents • Potential to supply biodiesel to islanders for their personal use • Potential to sell by-products	• Potential for the people of Arran to reject proposal due to chemical processes and infrastructure if they believe it will affect the environment and tourist industry negatively • Potential production of hazardous materials

Table 1 - SWOT Analysis

3.2 STAGECOACH

Stagecoach have strived to drastically improve their carbon footprint for over a decade now, with biofuels being the foundation. In 2010 they were awarded the Carbon Trust Standard [1] for reducing their carbon emissions by 100,000 tonnes over a five-year period. Then in 2011 they became the first UK bus company to mix its own biofuel in Kilmarnock, Scotland. Powering 100 busses they invested £75,000, proving the concept works. They then used this concept in Lincoln in the East Midlands, resulting in a 40% reduction in emissions [2]. Stagecoach then outlined a plan to invest £11 million in order to meet environmental targets. Their proactive attitude towards climate change makes them a willing partner to this project. Stagecoach are also going to have to abide by new guidelines after Scotland declared a climate emergency in April 2019 [3]. This project aims to future proof their bus network on Arran, ensuring it follows the Climate Change Act – to reduce emissions by 80% - and legislation for Scotland to be net-zero by 2045 [4].

3.3 COMMUNITY

The community within Arran is vital to the success of this project. In recent years Arran's residents have been disapproving of previous projects if there is a direct impact on the local wildlife or scenery. This proposal takes these considerations into account and measures have been outlined to ensure there is no impact on either. On the 19th of September, residents of Arran held a climate conversation in Brodick, to discuss their opinions towards climate change. People expressed the "need for a serious action plan", that "sea levels are a concern" as well as requiring "a sense of urgency" [5]. It was also agreed that "Scotland's carbon neutral target by 2045 was not ambitious enough". On top of this, some of Arran's residents took part in a climate strike on the 14th of February to express their desire to do more to combat climate change [6]. This shows the community on Arran are actively looking for climate change solutions, such as this proposal. Due to people expressing the "need for education, particularly in schools" regarding climate change [5]. The intent is to create awareness of the project within schools and even propose site visits for the local school once the initial stages of the project have been complete. This is not just to educate but to also create a sense of pride throughout the community.

4. TECHNICAL ANALYSIS

Three key technical aspects have been identified. The first section discusses the process of growing the algae and its optimum conditions. The following section outlines the harvesting of the algae and the process of creating B100. Lastly the implications of using B100 are investigated, including emissions and necessary upgrades.

4.1 ALGAE GENERATION

4.1.1 SELECTION OF ALGAE SPECIES

To create the biofuel, algae has been chosen as the raw material due to its exceptional growth rate and its ability to yield 15-300 times more lipid content (oil content) than what crops can produce on average, depending on the algae strain [7]. A table which compares biodiesel from different plant sources can be found in appendix A.1.

The two main types of algae are the macroalgae and microalgae. Macroalgae are multicellular organisms, whereas microalgae are unicellular. Macroalgae is mostly seaweed and marine algae that live near the seabed, as opposed to microalgae which are found in both fresh and marine water. They exist individually, in groups or in chains. They use light as energy and CO_2 to grow photo-autotrophically [8]. Appendix A.2 summaries the photosynthetic reaction for algae and why temperature could decrease the biomass yield. To combat this, the algae will be grown in a controlled environment.

The use of macroalgae for the production of biofuels in this project was discarded due to lack of evidence about the cultivation of macroalgae in the ocean in large scale. Furthermore, the lipid content of macroalgae is lower than in microalgae [7]. The growth of macroalgae would have been very difficult to occur as well as the maintenance of the whole system in the sea.

The *Chlorella sp.* strain has been chosen due to its ability to grow in both fresh and marine water and is said to be easy to be scaled up in an open raceway pond and photobioreactors. It has a lipid content of 10-48 % of dry weight biomass, lipid productivity of 42.1 mg/L/day, volumetric productivity of biomass 0.02-2.5 g/L/day and areal productivity of biomass 1.62-16.47/25 g/m^2/day [8] [9]. *Chlorella sp.* has been repeatedly defined as one of the best feedstock choices for biodiesel production as well as a suitable choice biodiesel production in large cultivation scale [10]. Furthermore, there are a number of studies that focuses on the cultivation of *Chlorella sp.,* aiming for the removal of nutrients from the cultivating medium. Some others focus on the extraction of lipid content from the microalgae to be used for biofuel production [11] [12] [13] [14] .

4.1.2 CULTIVATION MEDIUM

Different strains of *Chlorella* have been cultivated in dissimilar mediums, some of them being wastewater, urea fertilizer medium, and Bold's basal medium [11] [12] [14] [15] [16]. Wastewater seemed to be the most suitable culture medium, due to the high concentration of nutrients and the minimum pre-treatment process that is already done by the council. Furthermore, the use of wastewater is another way of making the process of the production of biofuel as environmentally friendly as possible [8]. Dissolved oxygen, the optical density and the pH will be controlled to help the cultivation of the biomass yield [14] .

4.1.3 HARVESTING METHOD

The chosen method for harvesting the microalgae is flocculation. The use of chemical flocculants could be expensive and lead to environmental risks and water pollution [17] [18]. Therefore, bio-flocculation methods suitable for *Chlorella sp.* were studied. Bio-flocculation with Chitosan as a bio-flocculant, is said to be able to reach 100% efficiency and has already been tested with *Chlorella sp*. [19] [20] [21].

4.1.4 SYSTEM DESCRIPTION

There exist two groups of methods that are used for cultivation: open ponds and photobioreactors (PBRs). PBRs are enclosed, transparent containers that hold water on which floating algae grows. These PBRs are approximately 13 times more efficient [22] in terms of yield/m^2/day than the open pond alternative. However, this increase in efficiency is countered by the increased cost of operation due to the temperature needing to be carefully maintained [22], the O_2 produced needs to be off-gassed as it builds up [22].

Open ponds are exposed directly to the atmosphere and as such do not need to be off gassed as the CO_2 can be taken directly from the air. However, this method requires much more land as the growth area is arranged horizontally, as opposed to vertically as with PBRs.

A list of advantages and disadvantages of open ponds are given below [22] [23]:

Open pond advantages:

- Less expensive to construct
- Can use a variety of materials for construction
- Less energy to operate (compared to PBRs)
- Easy cleaning and maintenance
- Easily absorbs CO_2 from atmosphere – no purified gasses needed
- Scales well

Open pond disadvantages:

- Risk of contamination
- Limited species options
- Lower biomass production
- Subject to atmospheric fluctuations (minimised in a greenhouse)
- Evaporation
- Uneven mixing
- Low area to volume ratio

Because of the cheaper construction, operating costs and the possibility to incorporate carbon sequestration/capture, an open pond design should be used.

4.1.5 EXISTING OPEN POND DESIGN

An open pond system can be a river, lake, sewer line or a pond. For effective cultivation of algae, it is necessary to agitate the water so that each algae cell encounters the maximum amount of light and nutrients. Open ponds can either be made from a plastic sheet placed over a supportive frame, in a hole dug into the ground or from poured concrete. The three most common designs are given below in order of increasing efficiency.

Tanks - Any open, unmixed container of water that algae can grow in.

- In larger tanks algae at the bottom of the tank will not receive any light and will die.
- Nutrient content in the water will not be uniform so algae growth will not be uniform across the tank.

Circular ponds – A circular body of water with a small island in the center that houses a spinning boom arm that stirs the water.

- Similar in appearance to water treatment facilities.
- Requires more energy/ engineering/ materials for stirring the boom arm.
- Circles are an inefficient shape to tile together.

Raceway pond – An extended trench of water that loops back onto itself.

- More space efficient than circular ponds.
- More effective mixing.

All options are graphically outlined within the appendix A.3. Raceway ponds have been chosen for maximum efficiency as well as the utilization of space.

4.1.6 REQUIRED GROWTH

In order to gain an estimate for the required quantities of biofuel required and therefore land required to produce said fuel, it is necessary to determine the total distances travelled by buses on Arran, as depicted in table 2. [24]

Route number	Length of route (km)	Times travelled per week	Total distance travelled (km)
322	17.7	90	1,593
324	38.46	39	1,500
323/321	50.85	133	6,763

Table 2 - Length of Each Bus Route, the Number of Times Each Route is Travelled Per Week, Total Distance Travelled Along Each Router Per Week (Route Lengths Estimated from Google Maps)

There are 3 main bus routes operating on Arran, with 2 buses operating on the same route (routes 323 and 321) [25]. Using this it is possible to calculate the total distance travelled by all routes in a week to be approximately 9,856km. The average fuel consumption of a diesel bus along a normal route is 32.6L/100km [26]. Therefore, 167,078L of fuel will be needed per year. Teresa M. Mata states that a medium lipid content algae such as *Chlorella sp*. can produce oil at a rate of 97,800L/ha/year [9], meaning 1.708 ha, or 17,084m^2 will be required for algae growth.

4.1.7 CO_2 UPTAKE

A diesel bus produces 1.57kg of CO_2 per km travelled [27]. Using the total distance previously calculated the buses on Arran will produce 578.54kg of CO_2 per day. *Chlorella Sp*. is capable of a carbon fixation rate of 0.624g_{co2}/g_{algae}/day [28] in ideal conditions in a column bubble reactor. It is then possible to calculate the mass of algae required to produce the fuel to be 294,057kg. This therefore states that the algae are capable of absorbing 1835kg of CO_2 per day, which is 3.17 times (appendix A.4) the amount produced by the busses, making the overall system carbon negative.

4.2 PROCESSING

4.2.1 TECHNICAL OUTLINE

For bio-oil to be extracted, algae slurry needs to have a moisture content of less than 15% [29]. Therefore, the first stage within the plant will dehydrate the algae slurry generated from processes previously discussed. To achieve this a rotary dryer as seen in figure 1 will be used [30]. The dryer works by rotating the algae at a slight downward angle, allowing the algae to make its way slowly down the dryer while being rotated by the inner ribs inside the dryer. As the algae falls into the ribs it is rotated higher in the dryer. The algae then fall out of the ribs and into the path of an extremely heated air source, drying the algae. The dryer is rotated by a chain and for small loads, up to 1 tonne per hour, it uses 55kWh worth of energy.

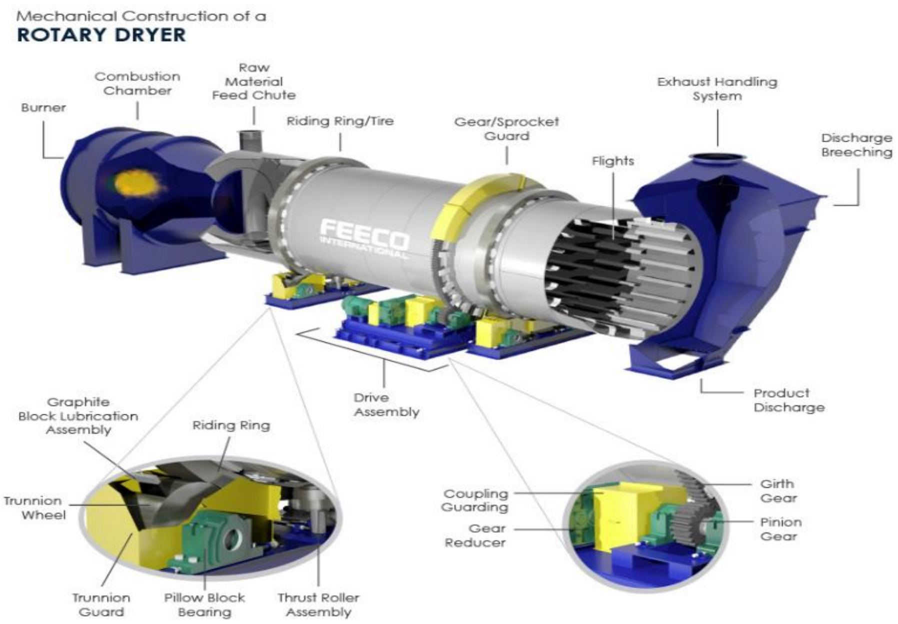

Figure 1 - Feeco Rotary Dryer [30]

The dehydrated algae will then be passed through an oil press which extracts up to 75% of the oil [29]. As the required number of litres per annum is 167,000 a relatively small industrial oil press can be used. A 10L oil press with capacity of producing 100L/h would be suitable for the process and so that the maximum life out of the machine with regular servicing can be ensured. The waste biomass is then rehydrated and mixed with a hexane solvent at a 1:1 ratio. When this occurs the bio-oil floats to the surface and is easily filtered to separate the waste biomass from the bio-oil and solvent allowing 95% of the oil to be extracted [31]. The solvent is then evaporated off as it has a low boiling point of 70°C and can then be reformed to be used again. The resulting excess biomass can be used for agricultural purposes on the island.

The next stage is transesterification. The bio-oil will be mixed with an alcohol (methanol or ethanol) and a catalyst of sodium hydroxide (NaOH). This creates biodiesel and glycerol which will be separated using electrolysis. The resulting glycerol will be sold to cover any transportation costs off site. A small amount will be sold to Arran Aromatics to be used in their soap production [32]. The rest will be transported to Scotland's largest anaerobic digestion plant, operated by SSE, to be used in the generation of electricity located 25 miles away in Barkip [33].

Both methanol and hexane will require a 1000L tank for storage whereas NaOH can be stored in plastic containers [34]. Detail on storage and equipment costs are specified in the financial section of the proposal.

The plant is only required to be big enough to fit the dehydrator, industrial oil press and the storage tanks which will occupy a maximum 100m^2 space. This means the plant will be based within an old farmhouse or barn to ensure the surrounding environment is not disturbed and create a positive impression within the community, as outlined within the market research.

Based on a report conducted by the department of Civil and Environmental Engineering at Mississippi State University, the maximum energy requirements to create 1kg of algae biodiesel is 107.3MJ [35]. The volume required is 167,000L. Based on the average density of biodiesel being 874.7kg/m^3, the annual power consumption is 15.67TJ.

4.2.2 PLANT AND POND LOCATION

Regarding the location of the proposed algae growing ponds and biofuel production plant, there are many factors to be considered. As the natural flora and fauna that can be found on the island appeals to tourists, ensuring that our proposed scheme does not interfere with this is paramount.

While there may not be any national parks within Arran, the Arran Deer Management Group (DMG) has protected areas on the island, these can be broken down to 3 types: National Scenic Area, Sites of Special Scientific Interest, and Special Protection Area [36]. The DMG areas have been collated together and are represented in figure 2 and 3 in white. This area and its proximity must be avoided at all costs. The elevation of the proposed area is also considered, as it must be suitably level to ensure easy access and ease of construction. As can be seen in figure 3, large portions of the unprotected areas seem suitably level, with levels ranging from 16 ft to 1,043 ft [37] (5m to 318m).

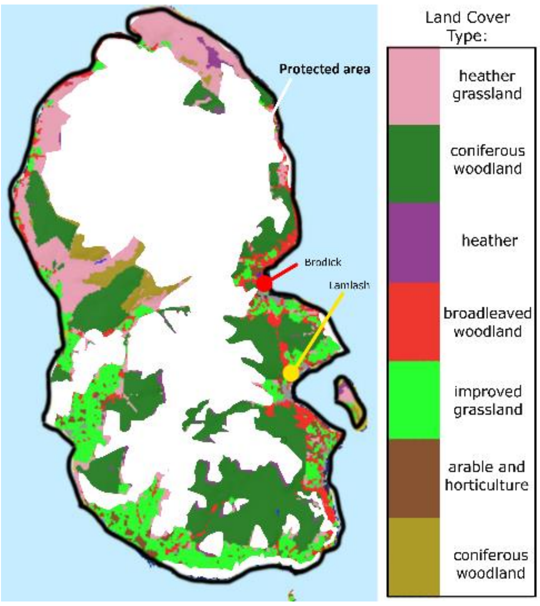

Figure 2 - Map 1: Land Cover

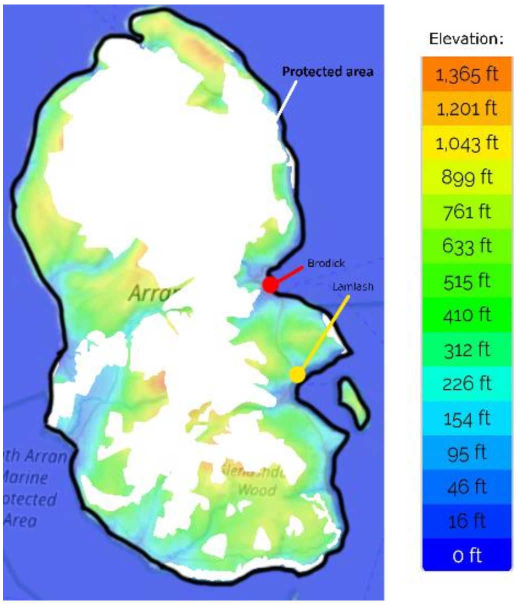

Figure 3 - Map 2: Elevation

The land cover of the island has been quantified and compiled into figure 2, this information alongside satellite images can provide accurate information of the land [38]. Areas of grey and black are residential areas and should be avoided if possible. The Isle of Arran has been categorised as one of the 165 Important Plant Areas in the UK by Plantlife, meaning that it is home to endangered and rare flora [39]. To ensure low interference with the local wild and plant life, heather and heather grass land should be avoided, instead favouring more maintained land, such as the improved grassland.

With this collated information, potential areas have been indicated in figure 4 with red. Proximity to the bus depot is a defining factor in reducing the cost of transporting of the biofuel. The Stagecoach depot is in Brodick, so a plant location in the east of the island is preferred [40]. This could be close to Lamlash, the largest village in Arran with a population of around 1000, potentially supplying a workforce for the plant [41]. There is also the possibility that the people of the island may not wish to see the plant, and so may prefer it to be secluded. Surveys should be carried out in the surrounding areas to determine this and whether the plant will impede on the existing scenery.

With both environmental factors and economic effects considered, there are many potential areas for the plant. In figure 5 there is an example of such, located off the A841 with an area of 100m^2, as calculated in 4.2.1, indicated in blue. It is 3.9km from Lamlash and 1.2km from the Stagecoach depot, in Brodick. It is located on grassland, and it is 1km from the protected area, so will have minimal impact on the surrounding wildlife. It is possible that the proposed location may not be suitable at all, either due to the owner of the land refusing to sell or due to the terrain. The proposed area is expected to change with further local research that could not be completed in these initial stages due to lack of cooperation from the council and the isolated nature of Arran.

Although the initial investment accounts for having to buy the land to store the open race way ponds, there is scope to reduce the initial capital cost by exchanging the use of farmers' land for the waste biomass generated from production process.

Figure 4 - Map 3: Possible Areas

Figure 5- Map 4: Possible Location

4.3 FUEL USE

The final technical aspect that needs to be discussed is how the fuel will be used, what problems it causes and how these can be solved. The bus fleet in Arran consists of 8 Wrightbus Streetlites and 4 Optare Solos, all introduced in 2015 [42]. Both models have either the Euro 5 or the Euro 6 designation, difference between either being lower overall emissions. Both already feature AdBlue injection, though the Euro 6 version features much lower consumption [43].

4.3.1 INTERNAL COMBUSTION ENGINE

The chemical reactions that occur during diesel combustion yield carbon dioxide (CO_2) and nitrogen oxide (NO_X), shown in appendix A.5. The exhaust flows through a variety of post-processing stages, figure 6, before being finally exhausted.

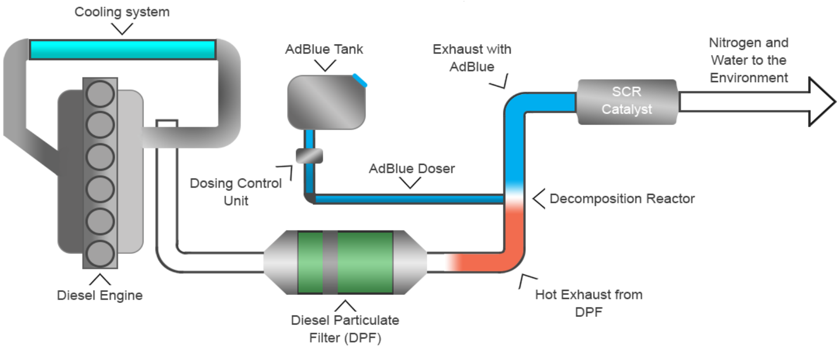

Figure 6 - Exhaust Layout of Internal Combustion Engine [98]

4.3.2 POST-PROCESSING

The diesel particle filter (DPF) is made of a series of honeycomb filters [44] which catch particulate matter such as soot in order to reduce emissions and comply with governmental regulations. To prevent it from clogging and to extend its life cycle it undergoes a process called regeneration, where the soot particles are burned up to ash and then exhausted.

AdBlue (32.7% urea and 67.5% deionised water [45]) is then injected into the exhaust between the DPF and the catalytic converter, as shown in figure 6. AdBlue reacts with the NO_X, creating two harmless substances, nitrogen and water. The chemical reaction between the exhaust and AdBlue is as follows:

$$6NO + 4NH_3 \rightarrow 5N_2 + 6H_2O \quad [46]$$

4.3.3 COMPATIBILITY

Busses are generally more suited to use B100 fuel compared to regular car engines as they are more robust due to the sheer number of kilometres they have to endure. In saying that, pure biodiesel still introduces unique issues with conventional diesel engines. Research conducted into the use of high-level biodiesel blends shows that engines are required to undergo modifications in order for the fuel to be sustainable. Therefore, Stagecoach's existing busses will undergo the following modifications.

DIESEL PARTICLE FILTER

When B100 is introduced to an engine, it creates a solvent effect, i.e. dissolves remaining substances from the previous fuel, which effectively cleans the fuel system. During the transition period from conventional diesel to biodiesel, filters are susceptible to clogging as the new biodiesel washes out the debris from previous diesel that has accumulated on the walls of the tank [47]. The debris then gathers in the filter, which ultimately renders it inactive. To combat this, after the bus has ran on the initial tanks of biodiesel the filter will be cleaned. To ensure no diesel mixes with the B100 the fuel tank can also be cleaned before introducing B100 to the system [47].

HOSES, GASKETS & SEALS

Due to the nature of biofuel, biocompatible parts are required in engines that are managing biodiesel. B100 softens and degrades rubber compounds, causing leakage and subsequent fuel spills as the parts erode [48]. Any nitrile, polypropylene, polyvinyl, and tygon materials that come in to contact with the fuel must be replaced. To prevent this, rubber parts namely hoses, gaskets and seals will be replaced with suitable biocompatible materials in the bus.

OIL CHANGES

The solvent effect of B100 also has an impact on the oil changes [47]. The oil system in the bus is drained faster and as a result, requires to be changed more frequently at approximately half the distance compared to when conventional diesel is used.

4.3.5 IMPLICATIONS

POWER OUTPUT & DRIVING DYNAMICS

Regular diesel has an average energy density of about 42.5MJ/kg while B100 biodiesel only has around 37.2MJ/kg [49]. This equates to approximately 20% lower energy density and therefore power output, assuming the combustion process remains the same. This figure might seem significant, however engine power outputs with diesel and biodiesel are irrelevant as the user will subconsciously over press the gas pedal to obtain the same driving experience [50] as if they were driving on diesel. Furthermore, pressing the pedal completely occurs very rarely, hence making the loss in power output associated with switching from diesel to biodiesel less noticeable.

B100 EMISSIONS

Researchers generally agree that B100 generally offers much lower emissions than regular diesel, as outlined in table 3.

Emission	**Particulate Matter (PM)**	**Sulphur (S)**	**Carbon Monoxide (CO)**	**Hydro-carbons (HC)**	**Carbon Dioxide (CO_2)**	**Nitrogen Oxides (NO_X)**
Change	-50%	-100%	-50%	-50-75%	-40%	+10%

Table 3 - Emissions Change [49] [50]

To reduce the increased NO_X emissions associated with using B100 the current buses would have higher AdBlue consumption. Therefore, tanks would either have to be larger than normal or would need to be refilled more often because more AdBlue would be required to neutralise a larger amount of NO_X. Since the increased NO_x can be neutralised, table 3 clearly shows there will be significant improvement throughout all emissions. The reduction in carbon dioxide is the same amount Stagecoach achieved using a similar system in Lincoln. Since the biofuel will power stagecoach for almost 10,000km a week, the system will save approximately 330 tonnes of CO_2 as seen in appendix A.6.

4.3.5 FUEL STORAGE AND STABILITY

Properties of biodiesel also present storage issues due its susceptibility of gelling in cold temperatures and stability.

COLD TEMPERATURE ADDITIVES

The pour and cloud point of any fuel signifies the temperature ranges at which a fuel can operate. The cloud point is the temperature at which solid crystals can be observed when the fuel is cooled which can result in the filters clogging or drop to the bottom of the tank. The flow point is more severe as this is the temperature at which the crystals gel and ceases to flow.

Biodiesel measure cloud and pour points at much higher temperatures compared to conventional diesel. This trend is shown in figure 7, as the higher concentrated blend of biodiesel used, the cloud point increases. B100 is significantly higher than compared to B20 and poses a risk in cold temperatures.

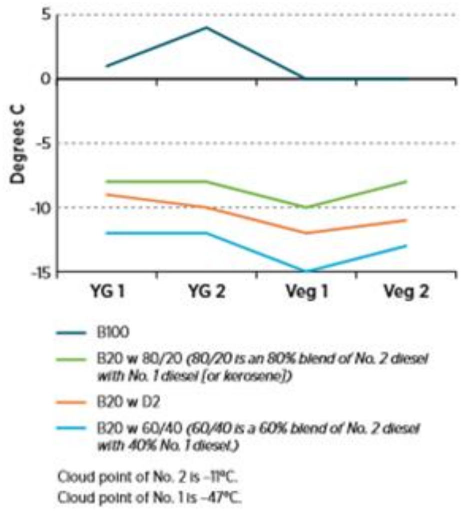

Figure 7 - Cloud Points of Various Blends of Biodiesel [48]

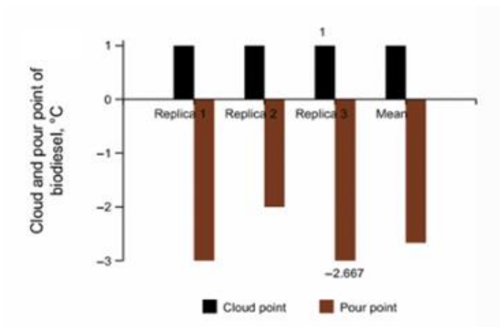

Figure 8 - Cloud and Pour Points of Biodiesel Produced from Algae [51]

The guidelines provided by Alternative Fuels Data Centre on storing B100 biodiesel advise that fuel should be stored at temperatures at least 2.5°C to 5°C higher than the cloud point. Cloud point of B100 can vary dependant on the source of the fuel. A research article [51] testing the properties of biodiesel produced from algae recorded a cloud point of 1°C and an average pour point of -2.67°C, illustrated in figure 8. During winter, the temperatures in Arran vary with an average low of 1°C and average high of 6°C [52]. As the cloud point of biodiesel produced from algae is 1°C, the biodiesel is planned to be treated with cold weather additives in order to adhere to the recommended storage guidelines. The biodiesel additive is a Chemiphase product, ColdBoost 590. The product contains winter additives which prevents gelling and clouding at low temperatures. It achieves through modifying the wax crystals and lowering the cloud and pour point of the biodiesel fuel [53]. The product also contains performance enhancing additives which improve the miles per gallon and increase the cetane rating of the biodiesel. The mixing process of the ColdBoost 590 additive and the Biodiesel must be conducted at a minimum of 6°C (5°C above cloud point).

The estimated volume of biodiesel required to be produced to fuel the buses annually is 167,000L. 200L of ColdBoost additive can treat 50,000L of biodiesel. This volume will be able to treat the biodiesel during the winter months when gelling is likely to occur.

Problems also arise when storing B100 biodiesel fuel. B100 has poor oxidization stability which means it cannot be stored any longer than four months unless treated with synthetic antioxidants. Synthetic antioxidants will prolong the period before which oxidation occurs [54]. At two months the biodiesel being stored will need to be tested for oxidation stability every 2 weeks to ensure the fuel is still effective. To avoid additional costs in buying synthetic antioxidants, during early stages of the project, biodiesel production will match demand for the fuel and therefore storage will not exceed 4 months.

5. QUALITY

5.1 PURPOSE

High standards must be maintained to ensure the product meets quality requirements. Quality assurance is therefore incorporated throughout the project to create and maintain a high level of operation. This will ensure the project is safe, non-wasteful and creates a positive force within Arran's community.

5.2 STANDARDS

The quality management role is fundamental in creating and maintaining a high-quality product. All design and technical operations will follow an established set of standards. The sustainable criteria for the production of biofuel is set by the European Committee for Standardization. An outline of the relevant standards that the project works towards is shown in appendix B.1.

The quality management imposes these standards onto the project, and ensures any new standards are being followed. All personnel involved in either a managerial or operational capacity will be required to understand the most recent standards. This will be achieved through informing new workers of the quality system and training individuals to the correct standard before deemed able to work effectively and safely. A quality system will be created to keep track of management and employer’s training records.

Pure biodiesel (B100) specification is also set by the European Committee for Standardization. The fuel must meet the EN 14214 standards before use. The table in appendix B.2 defines the specifications set for pure biodiesel.

5.3 QUALITY SYSTEM

The quality system will be at the centre of the project once it has been launched and will be subject to internal and external audits, so it is pivotal it is managed correctly. The system will consist of the following:

- Quality manual
- All relevant standards filed and kept readily available for team members to view
- Training records
- Calibration certificates of machinery and equipment
- An outline of test procedures to ensure fuel is within spec.
- Risk register of processes
- Audit log

5.3.1 RISK REGISTER

To assist in the quality objective, a risk assessment (see appendix B.3) was undertaken to highlight and identify areas of the project where things may go wrong. A risk register is put in place to prove to the investors and Stagecoach, that the project is viable and to outline the necessary costs and steps required to ensure that the project is successful.

Each risk was assessed using the following criteria: the probability of occurrence and consequence of occurrence. The probability and consequence were ranked on a scale from 1-5 (1 = low risk, 5 = high risk). An appropriate response was then planned in order to reduce the risk level. The consequence of a risk was rarely reduced after mitigation measures were put in place. The main objective was to reduce the likelihood of that risk occurring to a satisfactory level.

The management and the team were able to identify and prioritise high-level risks, as to establish a response to reduce the risk level. The assessment covered all aspects of the process, with each technical section being considered, and the health and safety risks associated with it. The highest risks were primarily associated with serious injury or death to workers, and the cancellation of the project from Stagecoach, if funding was cut. The impact of poor group dynamics and the local influence on the project was also considered.

5.3.2 TESTING

Testing is present throughout the process and is essential in delivering an in-specification and high-quality product to the customer. A table detailing the various test procedures that will be carried out at different stages of the project is shown in appendix B.4.

5.3.3 SAFETY

A health & safety officer and facilities engineer will be appointed due to the high level of risk when working with fuel and chemicals. Both jobs will be based onsite, overseeing daily proceedings. The health & safety officer will ensure all workers have been issued the correct Personal Protective

Equipment (PPE) and are being worn onsite. They will also keep a log of all incidents and continuously review jobs to ensure they are being carried out as safely as possible, and there is no breach of the health & safety at work act. The facilities engineer will test the fire alarms daily, visually inspect the site and storage facilities, ensure the plant is safe and secure, and most importantly ensure the plant meets government regulations and environmental, health and security standards.

5.3.4 AUDITS

Audits will take place to ensure the quality of the product and working processes. Internal audits will work within the organisation to help improve risk management and ensure operations are effective. The audits will investigate the production stage of the fuel, which determines if the product meets the correct standards and regulations. Internal audits will be carried out quarterly. This will involve ensuring the correct test methods have been put in place and are being carried out effectively. Identifying new risks and how to reduce the impact of these risks will also be documented. Feedback from each audit report will be discussed in monthly reviews and how to implement new test procedures. The overall safety of the site is also examined to ensure the project meets environmental laws and health & safety regulations. Ensuring all workers have been trained and any equipment and machinery that is being used has had regular maintenance checks and up to date calibration certificates.

The organisation will also be subject to external audits. European regulatory bodies will visit the plant and ensure the correct measures are taken in following the relative fuel production standards. The frequency of audits is set by the regulatory bodies.

5.4 CONTINUOUS IMPROVEMENT

Following the launch of the project, focus will shift towards reviewing and maintaining high standards. This will be achieved by adopting an attitude that evolves around continuous improvement.

5.4.1 MONTHLY REVIEW

A full site monthly meeting will take place to enforce the standards the project is looking to achieve. All site personnel are invited to discuss each process to help identify possible areas of improvement. The meeting will follow the structure shown in the appendix B.5. Meetings will occur monthly to ensure any new ideas and changes to the process can be implemented before being reviewed. Appendix B.5 also outlines the continuous improvement ideology that will be enforced. Team meetings are essential to this process, to ensure that proper planning and reviews are taken place.

The continuous monitoring of processes allows the project to evolve around the changing environment. Working towards maintaining high standards will result in a high quality product for the duration of the project.

6. COMPLIANCE

In this section, safety issues and regulations are discussed based on the Renewable Transport Fuel Operation (RTFO), the Small-Scale Manufacture of Biodiesel of Scottish Environment Protection Agency (SEPA) and the Health and Safety in Biomass Systems Design and Operation Guide by the Combustion Engineering Association (CEA).

6.1 RISKS AND MITIGATION

Different mitigation measures would be applied to the project to prevent and reduce the severity and occurrence of any harmful action in the plant. The mitigations listed below are highlighted in the Biofuel from Algae by the House of Parliament, Parliamentary Office of Science and Technology and from the Health and Safety in Biomass Systems by CEA. The Pollution Prevention and Control Regulations are applicable where the emissions to air, water and land, and other environmental effects are considered. An important legal requirement that the company should follow is the Health and Safety at Work Act 1974, which is the primary health and safety legislation in the UK related to the staff and visitors. Risk assessment in appendix B.3 highlights a more detailed and specific analysis of risks.

The team needs the consent of following Environmental Permitting Regulation 2010 (EPR). Environmental risks include:

- The risk of water contamination should be treated with care.
- Cultivation conditions could affect the regulation of fuel production.
- Should show that the use of wastewater and algae is not classified as a waste product and is the same as using non-wastewater [55].

The design of the plant, the delivery of the fuel and the biofuel storage should meet the following requirements stated by CEA:

Plant Design:

- The designer should ensure that the operational and maintenance instructions of the manufacturers are appropriate and relevant or are specified for an application.
- The designer should be working with others to ensure the safe design of the plant.
- A risk assessment is a legal requirement for all the working activities.
- Must have a formal health and safety evaluation for the design.
- Reduce fuel storage risks by building restricted areas above the ground.
- If daily inspections are done at a high level, suggest a way to be able to work at a lower level if possible or use permanent access and inspection platform if necessary.

Delivery of the fuel:

- Delivery vehicles should have hard standing for safe parking.
- Barriers can be used to assign access to the areas of fuel reception and storage for the avoidance of injuries.

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- Risk assessment should highlight the risks of the delivery process. For example, specify the time of the receiving deliveries, if the presence of pedestrians will be allowed and if other vehicles will be involved in this.

Biofuel storage:

- Avoid having heavy and large lids for the aversion of accidents.
- The filling system should steadily load the container to avoid spillages and turbulence flow.
- The Confined Spaces Regulations 1997, the Work at Height Regulations 2005, and the Supply of Machinery (Safety) Regulations 2008 should be taken into account in the design of the fuel storage.
- Follow the Building Regulation AD J 2010 for building safety. For example, the installation of carbon monoxide monitors [56].

6.2 PERMISSIONS AND CERTIFICATIONS

Companies which supply less than 450,000L annually can register for Renewable Transport Fuel Certificates (RTFCs) but they must open an account with the Administrator. A penalty of maximum £50,000 or 10% of the annual income will be assigned to companies who fail to do so. Also, the company will use the RTFO Operating System (ROS) for the submission of the volume of fuel supplied and its sustainability. ROS is used to calculate the supplier's obligation to record the issuing RTFCs. RTFO states sustainability criteria of biofuels. Owners are awarded one RTFC per litre of biofuel supplied. Fuels from wastes are eligible for double the RTFCs per litre [57].

According to SEPA, for a company to be assumed as a small-scale manufacturer the following must be conducted:

- The company should register as a waste carrier since wastewater will be used for the cultivation of algae.
- Specific requirements about the exemption, like the storage limit and record keeping should be followed.
- Follow the requirements of oil storage and care.
- Confirm that waste products are disposed properly.

All waste management activities should be carried out without endangering human health and without using procedures that can harm the environment. These are the 'relevant objectives':

- Risk to water, plants, animals, soil and air.
- Being irritated through noise and odours.
- Disturb the countryside or places of special interest.

A company that produces less than 200 tonnes annually does not need a Pollution Prevention and Control (PPC) permit or a Waste Management License (WML). This means that the company will be registered for exemption from the waste management licensing [58].

Due to rarity of biodiesel production from algae, there are no specific legislations for the approval of the use of algae as the source of oil. Animal and Plant Health Agency (APHA) is responsible for the approvals given for the use of animal fat and animal oil for the production of biodiesel. The legislations applied for the use of animal by-products (ABPs) could be used as an indication on the permission that the company will need. For the site to get approved or registered for using ABPs it needs to be registered with APHA. To be approved, there is an application form consisting of different requirements that have to be completed. Some of them are the identification of risk areas, the plan to control these risks, what happens in case of contamination, how to deal with faults, and how the staff is trained to be able to work on the site. APHA also refers to the hygiene of the site, the safety of staff and equipment used, keeping records and disposal of waste [59] [60].

By the production and use of biodiesel, the CO_2 from the atmosphere is not directly reduced. However, the production method of biodiesel is a way of reducing CO_2 emissions. The emissions of carbon dioxide from the whole procedure should be calculated [55]. This should include:

- The building of the plants
- The effect of land use
- The use of energy during algae cultivation
- The production of biodiesel
- Transport of fuel
- Use of fuel

In order to comply with the law while storing the chemicals involved in the production process, the plant will need a PPC permit. This is required when producing more than 500L a year. The plant will also have to comply with the Water Environmental Regulations, such as the Urban Wastewater Treatment Directive, which keeps the aquatic environment from being damaged by urban wastewater and industrial discharges [61]. Methanol and hexane are flammable and therefore the Health and Safety Executive (HSE) on Storage of Flammable Liquids in Containers should be followed for the safe storage of flammable chemicals [62].

6.3 MEETING REGULATIONS AND SOCIAL ACCEPTABILITY

Research was conducted so that the most suitable procedures, methods and components for the project are used. As mentioned in the risk assessment section, the risk against human health and the environment are low. The main greenhouse emission is the CO_2 from the use of the vehicles. Due to the use of wastewater and algae, there might be an odour at the plant. There will be some noise in the area throughout the process of the construction of the plant, where it will be noticeable. The residences affected by the noise, living close to the land will be monthly informed about the progress of the construction and the finishing day. Regarding both the noise and the odours from the plant, the SEPA guidance on both will be met [63] [64].

The area will be decorated with plants so that it could be more attractive to visitors. The by-products will be repurposed to minimise the waste. A meeting with the council will be scheduled with the residents of the island to announce the building of the plant in collaboration with Stagecoach. Prior to this, the company will send information brochures (see appendix C.1) that will highlight the main purpose and aims of the project. The benefits of this project and how the islanders will be affected by this will be added. The possible areas for construction will be highlighted. Furthermore, an approach on how this would help in the CO_2 emissions could be summarised in a brief and understandable way.

7. MARKETING

7.1 PRODUCT

The biodiesel product is produced from algae cultivated on Arran and is sold to Stagecoach to power their bus fleet. The by-products of the biodiesel process can potentially be sold to local businesses. The low CO_2 emissions from using the biofuel helps the UK reach their carbon targets [65], which gives incentive for Stagecoach to use this in place of diesel. This environmentally orientated proposal also provides the possibility of using this to Arran's benefit, particularly in the case of tourism. Due to the chemical processes required in the plant, it is important that positive marketing is maintained to ensure that it is not detrimental to the island's image.

7.2 PLACE

Ideally, the raceway ponds will be placed across Arran on pieces of farmland. In exchange for using their land, the farmers will be supplied with left-over biomass as fertilizer. The proposed area on the east of the island will contain the plant, where the biodiesel will be processed. The location of this is nearby the Stagecoach depot in Brodick, where the biodiesel will be delivered and distributed to the buses.

7.3 PRICE

The cost of the biodiesel is more than the price of standard diesel, this will be reduced to match the standard diesel price using external funding. It is possible that the proposal could obtain a grant or a loan, examples of possible funding sources includes: Innovate UK, the Department for Transport, and Green Investment Group [66] [67] [68]. The by-products of the biofuel process may also provide an additional revenue stream. After the infrastructure is established on the island, the biofuel could be offered to residents of the island at a discounted rate for their own use.

7.4 PEOPLE

For the success of this proposal, it is paramount that it is seen in a positive light by both tourists and the community of Arran. If public opinion of the proposed plant is negative, this may compromise the planning of the project. Informing the whole island, not just the surrounding villages, and allowing them to voice their concerns can ensure that there is no discontent. Conforming to EU standards and regulations will ensure that the public is safe and that the company running the plant is held accountable.

7.5 PROMOTION

As the biodiesel will be sold directly to Stagecoach, there is little need to directly advertise to them, however it is important to make our biodiesel more appealing than other sources. Stagecoach has worked with Argent Energy to supply biodiesel for their buses, their biodiesel is derived from industrial by-products, and so they are a direct competitor [69]. The selling point of our fuel is it is made from algae grown on Arran, so it has potential to create local jobs and will not be imported onto the island like diesel, meaning that it is more independent.

The proposed logo and name of the project is shown below, its inspiration comes from the *Chlorella Sp.* cell structure and the name is in reference to the Celtic Goddess of the forest, Abnoba.

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Figure 9 - Proposed Logo

It is important for the biodiesel to be advertised to the community of Arran and tourists. There is potential for Arran to be marketed as the island with a carbon negative transport system, and so could potentially attract more tourists and provide incentive for them to use the buses. This can be done with advertising on the buses themselves as well as online, such as through social media and the setting up of our own website. This will make information on the project accessible to the public. The targeted tourism advertising is likely to be more effective during the summer season.

As seen in section 3.3, the residents of Arran are concerned about the climate. This proposal can show the people of Arran that their concerns have been heard, and that they are at the forefront of sustainability in Scotland. To specifically reach the residents, advertising in the local paper "The Arran Banner" and delivering brochures to every house will create positive awareness towards the project. An example of what the brochure would look like can be found in appendix C.1. There is the potential of working alongside Visit Scotland as they offer free listings on their website to businesses in Scotland, reaching larger audience [70]. Compared to the cost of making the biodiesel, the marketing costs are expected to be low.

8. FINANCIAL

8.1 CAPITAL EXPENSES (CAPEX)

8.1.1 ALGAE GENERATION

The required amount of fuel was calculated previously in section 4.1.6 to be 167,078L, to achieve this, a total pond area of 17,084m^2 is required. It is estimated that the cost of construction of an open raceway pond is approximately £25,025/acre [71] or £6.18/m^2. This estimation includes the construction of the concrete pond, the paddle wheel, and associated piping required. Therefore, the total cost for construction of the ponds can be calculated to be £105,642.

In addition to the construction of the ponds, certain measurement tools are required for purchase such as a pH meter at £231.74 [72], a spectrophotometer at £1,100 [73] and a dissolved oxygen meter at £206.67 [74] totaling £1,538.41. Ideally raceway ponds would be placed on farms across the island but the worst-case scenario has been considered, therefore, £1,071,632.7 has been made available [75].

8.1.2 PROCESSING

The initial expenditure of the biofuel plant is as follows. The costs of the machines themselves make up almost 75% of the cost. The land and building costs are £69,000 [75] and £22,000 [76] respectively. Four storage tanks will be required for the storage of methanol and hexane which will total £2,000 [77]. Finally, the two machines required are an oil press and a rotary drier, costing £231,000 [78] and £39,000 [79] respectively.

8.1.3 FUEL USE

As stated previously, some modifications will be required to be made to the buses. However, these modifications will be the responsibility of Stagecoach and as such have been ignored. In addition, these costs are negligible compared to all other costs and could be ignored even if they were to be included.

8.2 OPERATING EXPENSES (OPEX)

8.2.1 ALGAE GENERATION

The operational costs of an algae farm were estimated to be £3,742/acre [71] or £0.92/m^2. This estimated cost includes power consumption, labour, and required chemicals (flocculant etc). Using the total area estimated in section 4.1.6 a total value of £15,717 can be estimated as the yearly running cost of the algae farms.

8.2.2 PROCESSING

The operating costs for processing the algae are again the largest for the project. Totalling £533,446, the breakdown is as follows. The required chemicals of methanol, hexane, and sodium hydroxide will cost £110,220 [80], £1,546 [81], and £500 [82] respectively per annuum. Electrical consumption of the plant will cost approximately £286,210 [83] annually. This is a very large cost that has significant impact on the cost of the whole project, as such this would be the most beneficial cost to attempt to reduce. Finally, the total cost of wages for operational staff is £135,000 [84], this includes four technicians to ensure the smooth running of the plant.

8.2.3 FUEL USE

The running costs of the buses would be the responsibility of Stagecoach and therefore have not been considered. Furthermore, they're assumed to be negligible.

8.2.4 MAINTENANCE COSTS

Maintenance costs were taken to be 2.5% of the capital costs of each component. This means that £2,679.50 and £6,800 will be required for generation of algae and production of fuel respectively.

8.3 FUEL GRANTS AND SUBSIDIES

A resource the project can use is the availability of two grants which can subsidise the cost of fuel. Both grants were issued by the Department of Transport in February 2019. The first grant pledged £48 million for the funding of 263 ultra-low emission buses [85]. If Abnoba was to receive the equivalent funding for the 12 buses on Arran. Abnoba would receive £2.19 million. The second grant available is to assist in the production of biofuels. Two projects of a similar size to Abnoba received £6.5 million to provide green fuel for heavy vehicles in 2019 [86]. Abnoba meets the requirements for this grant creating a total £8.69 million of available funding for the project.

The economy on Arran would also be positively impacted by the launch of the project. The idea of a carbon negative public transport infrastructure is in the best interest to the council. The environmental benefits would draw in more tourists and appeal to the locals on the island. Therefore, there is scope for the local council to back the project financially.

8.4 COST PER LITRE

The cost per litre of fuel was determined by analysis of the total operating costs. Generation of algae totalled £18,396.50, and production of fuel totalled £540,246 showing that the production of fuel is the most expensive part of the project. Combining these two values give an annual operational cost of £558,642.50. Dividing the operational costs by the number of litres produced per year results in a price of the fuel (at 0% profit) of £3.34/L. Abnoba intends to make a 20% profit on fuel sold, this would create a price of £4.01 per litre. As this price would not compete within the current market, measures have been put in place to reduce the price for the consumer.

As the economy of Arran would benefit so much from a carbon negative public transport infrastructure it has been predicted that it is in the best interests of Arran council if they were to subsidize the cost of the fuel by 20%. This would reduce the price of the fuel from £4.01 to £3.21 per litre. With the selling price to Stagecoach set at £1.30 per litre the price deficit is £1.91 per litre. The deficit would be covered by potential grants. After 13.7 years the capital cost will have been recuperated. At this point the cost per litre will drop to £3.34 per litre (0% profit) and with the 20% Arran subsidy the deficit will be reduced to £1.37 per litre. With the estimated income for grants set at £8.69 million the funding lifetime for the project is 32 years.

The calculations involved in determining the figures in the CAPEX and OPEX sections can be reviewed under appendix D.1.

8.5 BREAK-EVEN POINT

Figure 10 shows the number of years it will take for the project to earn back the initial capital cost put into the project. From the graph it is shown that at 20% profit the capital cost will be earned back after 13.7 years. After this time the profit margin will be cut to 0%.

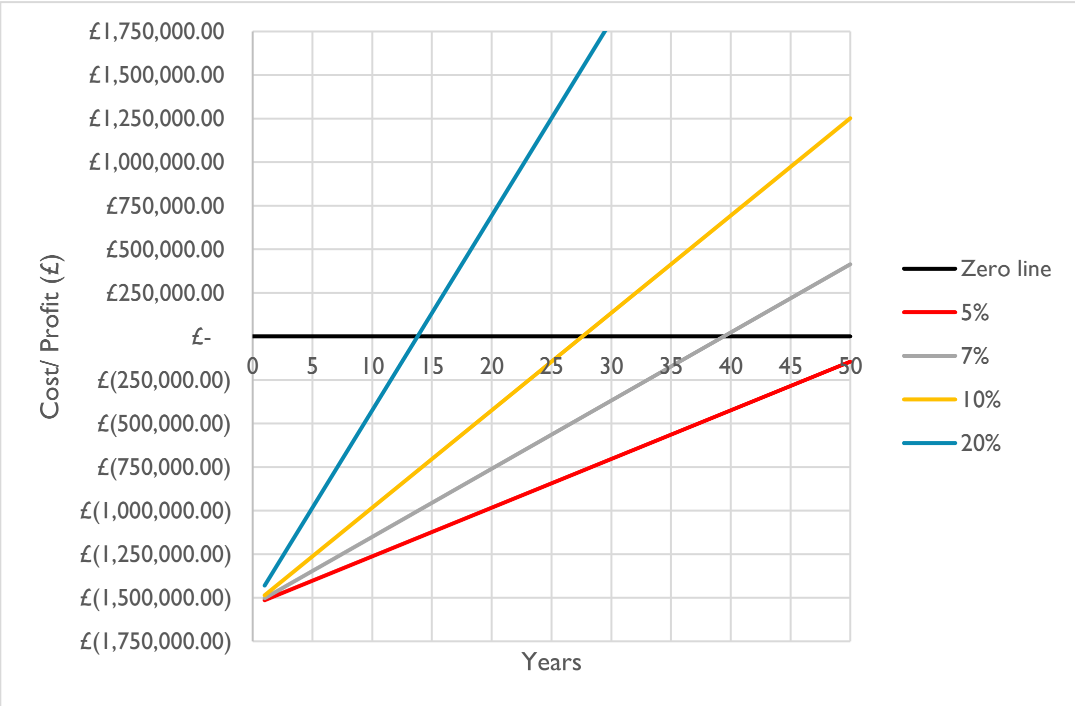

Figure 10 – Break-even Analysis Graph

8.6 SENSITIVITY ANALYSIS

Due to assumptions and simplifications made, the given fuel cost per litre will only be an estimate that will change with variations in the financial parameters such as OPEX and electricity cost. Therefore, it is necessary to perform a sensitivity analysis to determine how the fuel cost per litre will vary with parameter variation. Financial parameters are likely to vary with time due to dips and rises in their respective markets, as such this analysis makes it possible to see what parameters will have the greatest impact with the smallest percentage variation. Because the fuel cost per litre was calculated solely on OPEX parameters, CAPEX has not been included in this analysis.

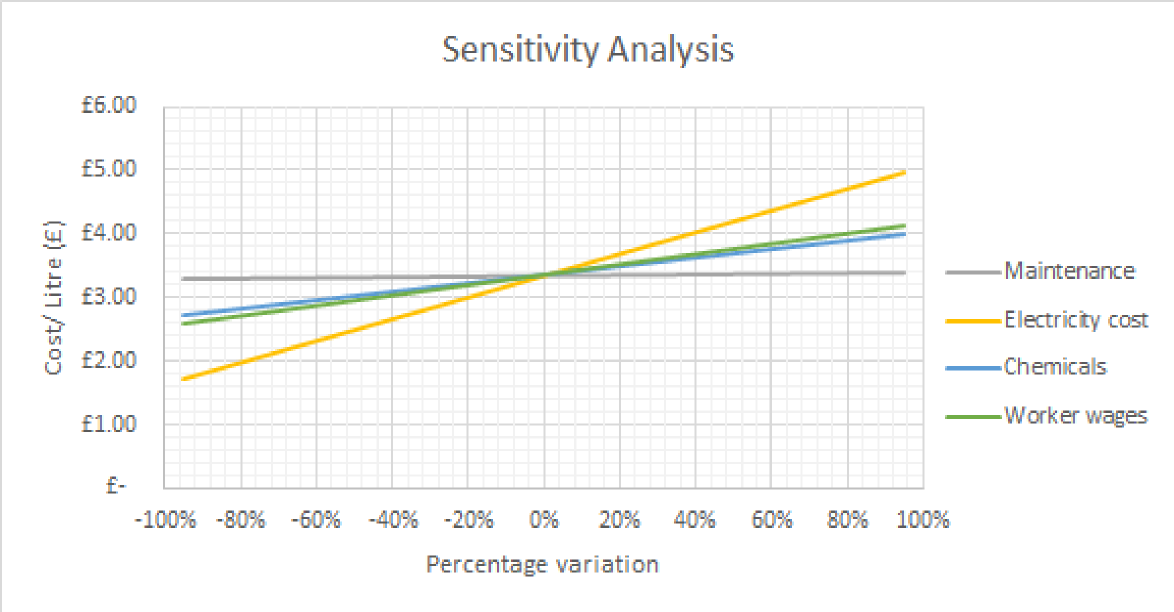

Figure 11 - Sensitivity Analysis Graph

From figure 11 above it is possible to see that variation in the electricity cost has the greatest impact in the fuel cost per litre. This confirms that the most effective way to reduce the cost of the fuel would be to seek a method of reducing power consumption. However, it also illustrates that an increase in electricity costs or use will quickly increase the price of fuel. It is also possible to see that the cost of required chemicals and worker wages will have a similar impact on fuel cost. Worker wages could not be significantly changed in order to stay competitive, however chemical costs could be potentially reduced by producing or sourcing them more locally. Finally, the maintenance costs make up a negligible portion of the OPEX and as such varying this cost has little impact on the fuel cost.

8.7 INTERNAL RATE OF RETURN

To find the internal rate of return (IRR), Abnoba had to decide on a given profit margin and an estimated life span on the project that would yield a similar price per litre to regular diesel. Using a span of 32 years and profit margin the internal rate of return has been computed to be 17% using the formula specified in appendix D.2. The current discount rate is 8.8% [87] meaning the project would be worth investing in since it’s lower than the IRR.

9. CONCLUSION

By harnessing the exceptional oil content of algae, Abnoba can provide the people of Arran a transport infrastructure that positively impacts the local environment. This is something the people want as they are currently demanding action, due to concerns regarding climate change. Although this process creates a price per litre that cannot compete within the current market, this can be combated by harnessing grants and local funding, creating a project lifespan of over thirty years. The project benefits extend beyond the environmental impact as there is a strong focus on education and communal pride. The project is not only an example of how to minimise waste when installing a new low carbon transport infrastructure, but also as an example of how remote locations will be able to adapt within the current climate emergency. With the external proposed help, Abnoba can be a success and bring about climate solutions the world currently craves.

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Abnoba Algae Solutions

APPENDICES

APPENDIX A: TECHNICAL ANALYSIS

Appendix A.1: Crops Vs Algae Biodiesel [88]

Plant source	Biodiesel (L/ha/year)	Area to produce global oil demand (hectares × 10^6)	Area required as percent global land mass	Area as percent global arable land
Cotton	325	15,002	100.7	756.9
Soybean	446	10,932	73.4	551.6
Mustard seed	572	8,524	57.2	430.1
Sunflower	952	5,121	34.4	258.4
Rapeseed/canola	1,190	4,097	27.5	206.7
Jatropha	1,892	2,577	17.3	130 (0[a])
Oil palm	5,950	819	5.5	41.3
Algae (10 g m^{-2} day^{-1} at 30% TAG)	12,000	406	2.7	20.5 (0[a])
Algae (50 g m^{-2} day^{-1} at 50% TAG)	98,500	49	0.3	2.5 (0[a])

Table A.1. Difference of biodiesel between crops and algae.

Appendix A.2: Photosynthetic reaction of algae [89]

The sketch below shows the photosynthetic reaction of algae. The reaction is divided into two phases, the light and the dark reaction. The light reaction can take place in milliseconds, but the dark reaction can take from seconds to hours to complete. Changes in temperature could lead to this large gap in time between the two reactions which could decrease the biomass yield. In the light-dependent reaction, light is taken up by algae breaking water to oxygen(O2) and using the hydrogen and an electron into the formation of reduced coenzyme nicotinamide adenine dinucleotide phosphate (NADPH). Furthermore, ATP is formed which is used in combination with carbon dioxide (CO2) in the formation of carbohydrates.

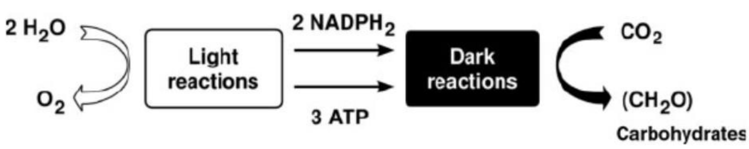


Figure A.2. Algae reaction

Appendix A.3: Different Open Pond Designs [90] [22]

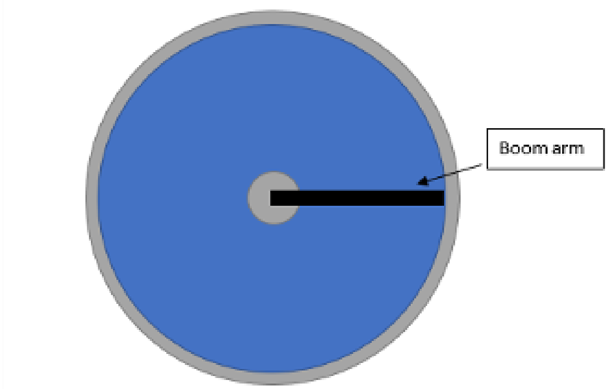


Figure A.3a. Example of Circular Open Pond

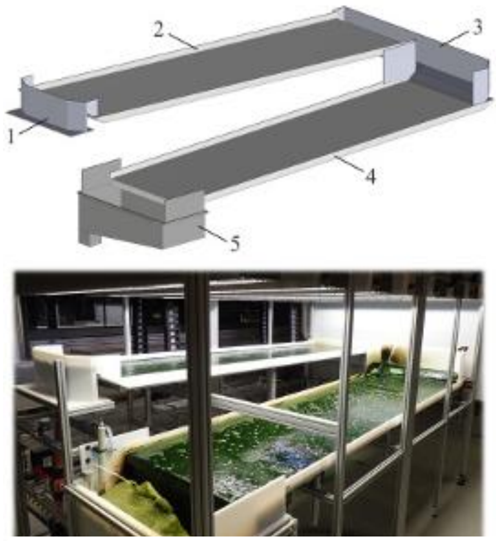


Figure A3b. Example of a Thin Layer Cascade System

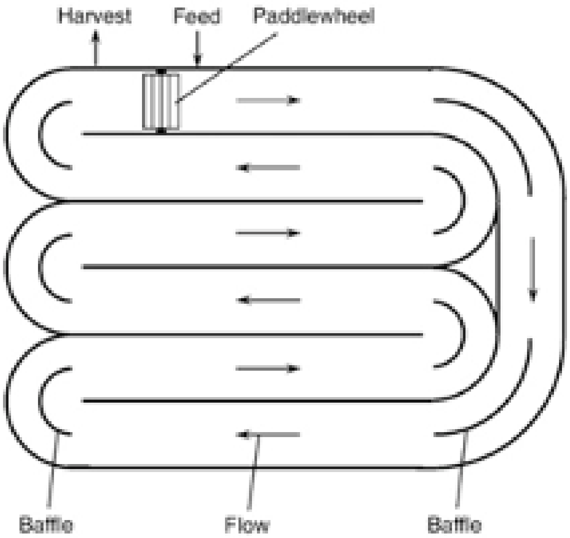


Figure A.3c. Example of an Open Raceway Pond

Appendix A.4: Calculations [91]

Distance travelled: 9,856km

CO_2 per km: 1.57kg

$$CO_2\ Produced\ per\ day = CO_2\ per\ km\ \times km\ travelled = 1.57\ \times 9856 =\ 578.54\text{kg}$$

Fuel needed per year: 167,078L

Biodiesel density: 874.7kg/m^3

$$Mass\ of\ fuel = Volume\ of\ fuel\ \times Biofuel\ density = 874.7 * 167.078 = 147{,}029\ kg$$

1:1 conversion from lipids to fuel

Percentage lipid content: 50%

Mass of algae: 294,057kg

CO2 fixation rate: 0.624 g_{CO2}/g_{algae}/day

$$Mass\ of\ CO_2\ sequestered = CO_2\ fixation\ rate\ \times 1\%\ \times Total\ mass\ of\ algae$$
$$= 0.624\ \times 1\% \times 294{,}057{,}000 = 1835kg$$

Number of times CO_2 absorbed

$$Number\ of\ times\ CO_2\ is\ absorbed =\ CO_2\ produced\ \div\ CO_2\ sequestered = 578.54\ \div 1835$$
$$= 3.17$$

Appendix A.5: Diesel combustion chemical equation [92]

$$4\ C_{12}H_{23} + 71\ O_2 \rightarrow 48\ CO_2 + 46\ H_2O$$

Appendix A.6: Carbon saved calculation

$$(1.57kg/km * 10000km) * 52weeks * 0.4 = 326{,}560kg$$

APPENDIX B: QUALITY

Appendix B.1: Biodiesel production criteria standards [93]

ID	Name	Application	Standardization Group
EN 16214-1:2012	Sustainability criteria for the production of biofuels and bioliquids for energy applications - Principles, criteria, indicators and verifiers - Part 1: Terminology	This standard defines all technical terminology used by personal within this project. This will ensure clarity.	European Committee for Standardization
CEN/TS 16214-2:2014	Sustainability criteria for the production of biofuels and bioliquids for energy applications - Principles, criteria, indicators and verifiers - Part 2: Conformity assessment including chain of custody and mass balance	This standard will be used to ensure that the biofuel produced fulfils the sustainability criteria defined in the Renewable Energy Directive.	European Committee for Standardization
EN 16214-3:2012	Sustainability criteria for the production of biofuels and bioliquids for energy applications - Principles, criteria, indicators and verifiers - Part 3: Biodiversity and environmental aspects related to nature protection purposes	This standard will be followed to in keep with the environmental awareness of the project and will be applied during the biofuel production process.	European Committee for Standardization
EN 16214-4:2013	Sustainability criteria for the production of biofuels and bioliquids for energy applications - Principles, criteria, indicators and verifiers - Part 4: Calculation methods of the greenhouse gas emission balance using a life cycle analysis approach	This standard will be used to clearly state any greenhouse gas emissions resulting from the production process. This will allow for a reliable estimate to be made for the projects overall environmental benefits.	European Committee for Standardization
EC 1907/ 2006	Regulation of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals	This standard will be used to ensure the quality of the chemicals used in the biofuel production process.	European Commission

EN 590	Specification for Automotive Diesel Fuel	This standard will be followed throughout the entire lifecycle of the project to ensure the fuel produced is at a high enough standard to sell in Europe.	European Committee for Standardization

Table B.1. Biodiesel production criteria standards

Appendix B.2: Biodiesel properties standards [94]

Property	Units	lower limit	upper limit	Test-Method
Ester content	% (m/m)	96.5	-	EN 14103
Density at 15°C	kg/m^3	860	900	EN ISO 3675 / EN ISO 12185 / EN12185.
Viscosity at 40°C	mm^2/s	3.5	5.0	EN ISO 3104 / EN 14105
Flash point	°C	> 101	-	EN ISO 2719 / EN ISO 3679.
Sulfur content	mg/kg	-	10	- EN ISO 20846 / EN ISO 20884.
Cetane number	-	51,0	-	EN ISO 5165
Sulfated ash content	% (m/m)	-	0,02	ISO 3987
Water content	mg/kg	-	500	EN ISO 12937
Total contamination	mg/kg	-	24	EN 12662
Copper band corrosion (3 hours at 50 °C)	rating	Class 1	Class 1	EN ISO 2160
Oxidation stability, 110°C	hours	8[1]	-	EN 14112
Acid value	mg KOH/g	-	0,5	EN 14104
Iodine value	-	-	120	EN 14111
Linolenic Acid Methylester	% (m/m)	-	12	EN 14103
Polyunsaturated (>= 4 Double bonds) Methylester	% (m/m)	-	1	EN 14103
Methanol content	% (m/m)	-	0,2	EN 14110
Monoglyceride content	% (m/m)	-	0,7	EN 14105
Diglyceride content	% (m/m)	-	0,2	EN 14105
Triglyceride content	% (m/m)	-	0,2	EN 14105
Free Glycerine	% (m/m)	-	0,02	EN 14105 / EN 14106

Total Glycerine	% (m/m)	-	0,25	EN 14105
Group I metals (Na+K)	mg/kg	-	5	EN 14108 / EN 14109 / EN 14538
Group II metals (Ca+Mg)	mg/kg	-	5	EN 14538
Phosphorus content	mg/kg	-	4	EN14107

Table B.2. Biodiesel properties standards

Appendix B.3: Risk Register

ID	Description	Owner	Cause	Effect	Probability	Consequence	Response	Adjusted Probability	Adjusted Consequence
1	Group Dynamics								
1.1	Short term absence	Team Members	Health/ Bereavement	Short delay in progress	5	2	Keeping up to date log books and using good communication protocols	2	2
1.2	Long term absence	Team Members	Health/ Bereavement	Long delay in progress	2	4	Keeping a detailed log book of personal work	1	4
1.3	Group disagreement	Project Director	Ineffective team work	Poor communication within the team	2	4	Ensuring all team members can access all documents and information regarding the project	1	4
1.4	Irregular Meetings	Project Director	Poor planning	Poor understanding of overall progress	3	4	Create an assigned time for everyone to meet in person once a week	1	3
1.5	Members not completing assigned work	Team Members	Obstructions	Gaps in groups knowledge	2	4	Asana is used to keep track of individuals tasks	2	4
1.6	Lack of team work	Project Director	Poor planning	Incoherent solution	2	4	Regular meetings in teams and sub teams	1	3
1.7	Poor Communication	Project Director	No assigned protocol	Lack of team work	3	2	Use Microsoft Teams for regular communication	1	2
2	Local Influence								
2.1	Opposition to Project's technology	Marketing Manager	Lack of information regarding project	Poor relationships with locals of Arran	4	3	Host information evenings with the locals to educate the locals on the benefits of the technology to the environment and the economy	2	3
2.2	Resistance to new buildings	Marketing Manager	Poor marketing, and bad design	Poor relationships with locals of Arran, and protests	4	3	Design plant that fits with the landscape and minimise noise pollution	2	3

2.3	Resistance to construction of plant	Marketing Manager	Poor marketing, and bad design	Poor relationships with locals of Arran, and protests, possible rejection of planning permission	3	5	Inform locals of the environmental benefits of Biofuel	2	3
2.4	Resistance to a running plant on the island	Marketing Manager	Lack of communication with locals	Poor relationships with locals of Arran, and protests	4	3	Minimise disruption caused by plant and inform locals of the advantages to the economy and generation of jobs	2	3
3	Generation of Algae								
3.1	Plant Location	Design Manager	Unstable Terrain and soil	Plant has to be moved, complete halt in project and further planning permission to be granted	4	5	Land assessment survey conducted before construction	1	5
3.2	Insufficient growth of Algae	Production Manager	Incorrect algae yield, and poor growth conditions	Biofuel production delay	3	4	Test algae yields and species in the same climate and conditions on Arran before initiation of project.	1	4
3.3	Too High moisture content of Algae	Production Manager	Rotational dryer malfunction	Algae batch can't be used to produce Biofuel	3	4	Regular maintenance checks of machine, install sensors to detect correct rotation and speed of water	2	4
3.4	Failure at Transesterification stage	Production Manager	Incorrect chemical mix	No production of Biodiesel or insufficient energy content of Biofuel	3	3	Train workers and provide clear instructions on the mixing process	2	3
3.5	Theft/Vandalism on farm site	Design Manager	Easily accessible farm	Stolen equipment and delay in growth of algae	3	5	Lock all equipment in secure shelter, set up perimeter fence, and install CCTV	1	5
4	Biofuel production								
4.1	Lack of fuel being produced	Production Manager	Poor management and communication with stagecoach	Biofuel production failing to meet fuel demand	3	5	Analyse fuel consumption weekly and host regular meetings between stage coach and plant management	1	5
4.2	Biofuel eroding storage tanks, containers and tools	Design Manager	Materials not being biocompatible	Damaged storage tanks, containers and tools	3	3	Contact manufacturer and ensure materials are biocompatible	1	3
4.3	Fire Hazard of fuel	Design/Production Manager	Flammable materials not being stored away correctly or electric faults	Death and Storage facility destroyed	4	5	Regular maintenance checks of sight and storage, and thorough design of storage facilities to reduce fire risk	2	5
4.4	Biodiesel poor oxidation stability	Production Manager	Fuel stored for longer than 4	Biofuel oxidation rendering fuel void	3	4	Test oxidation stability every two weeks after two months, and store	1	4

			months and exposed to oxygen				biofuel in oxygen tight containers		
4.5	Theft/Vandalism at plant	Design Manager	Easily accessible plant	Stolen equipment,	3	5	Lock all equipment in secure shelter, set up perimeter fence, and install CCTV	1	5
5	Use of Biofuel								
5.1	Clogging of Diesel particulate filter	Design Manager	Deposits from previous diesel use clogs filter	Renders filter inactive and Bus is not road legal	5	4	Clean bus tanks before administrating biofuel and replace filters regularly during introductory stage	2	4
5.2	Biofuel gelling in cold temperatures	Production Manager	Crystals forming in biofuel when exposed to cold temperatures	Biofuel becomes unusable	3	4	Schedule administration of cold temperature additives in winter months before transportation to fuel sight	2	4
5.3	Non-biocompatible bus parts eroding in contact with fuel	Design Manager	Bus part materials not being biocompatible	Damaged bus parts and fuel spillages	4	4	Check each bus spec and service history of bus to ensure materials are biocompatible	1	4
5.4	Failure to use fuel back log	Production Manager	poor management and record of fuel	Fuel oxidises and becomes unusable	4	4	Keep logs of biofuel containers and date of fuel production	1	4
6	Health and Safety								
6.1	Chemical exposure to workers	Quality/Production manager	No PPE equipment worn, and poor training	Worker injured and law suit	4	5	Train workers on handling chemicals and provide/ensure PPE equipment worn on-site	1	5
6.2	Carbon monoxide poisoning	Quality/Production manager	Faulty machinery	Death of workers	3	5	Install Carbon monoxide monitors and regular maintenance checks on machinery	1	5
6.3	Injured workers through use of equipment	Quality/Production manager	No PPE equipment worn, and poor training	Worker injured and equipment broken	4	5	Fully Train workers on use of equipment, have supervisor onsite, and provide PPE equipment to be worn	2	5
7	Funding								
7.1	Stagecoach cancel funding	Finance Manager	Stagecoach are unhappy with workings of project	Project is cancelled	3	5	prove that the concept is viable and keep in constant communication with stagecoach regarding there satisfaction.	2	5
7.2	Failure to obtain government grants	Finance Manager	Not meeting criteria for funding	Project is cancelled	2	5	Keep up to date with government regulations regarding environmental grants	1	5
7.3	Run out of funds	Finance Manager	Not following financial plan	Project is cancelled	4	5	Create a financial plan and follow it	2	5

							throughout the life time of the project		
8	Time								
8.1	Delay in completion of Algae growth site	Contractor	Poor planning and lack of resources.	No Algae production, and whole project is delayed	3	4	Thorough planning of site involving contractors and project team, and land assessment to be carried out.	2	4
8.2	Delay in completion of plant and storage facilities	Contractor	Poor planning and lack of resources	Biodiesel unable to be generated, no place to store Biodiesel and stagecoach left unhappy	2	4	Thorough planning of plant, and growth of algae stage only initiated once storage facilities have been constructed	1	4
9	Regulations and Law								
9.1	Not adhering to European standards for biodiesel	Quality manager	Poor quality system and lack of testing procedures in place	Halt in production and selling of Biodiesel, lose contract with stage coach	3	5	Create an effective quality system, and recruit a quality team to ensure standards are being adhered to	1	5
9.2	Not adhering to Environmental and Health and safety laws	Complianc e/ Qualty manager	Poor planning from compliance and design manager.	Organisation subject to legal action, and project cancellation	3	5	Compliance manager conduct thorough research and constant communication with design team.	1	5
10	Weather								
10. 1	Flooding of site and plant	Contractor	Poor drainage system and construction	Damaged equipment and machinery in plant. Fuel leakage	3	5	Install better drainage systems on site and construct water tight storage systems.	1	5
10. 2	Road conditions	Contractor	Icy/snowy roads	Workers unable to travel to plant, delay in fuel transport to fuel stations	2	3	Ensure roads are treated, keep in contact with council and stage coach during bad weather	1	3
10. 3	Cold temperatures	Project Director	Cold Temperature s	Algae farm water freezing, fuel oxidizing	2	4	Protect farm from elements, install heating system at water and stroage facilities	1	4

Appendix B.4: Test table

Test Description	Test Objective	Frequency
Oxidization test	To determine if the fuel has oxidized	Every 2 weeks after 2 months of storage
Cloud and pour point test	To determine if cold additives have been correctly added to the fuel	Before every fuel delivery to stagecoach site (during winter)
Calibration tests	Calibrate all equipment and machinery	Before the renewal end date of the current calibration certificate
Contamination test	To determine if algae arriving at plant has been contaminated.	Random batch will be tested each month.

	To determine if the water algae is growing in is fresh and of correct pH	Continuous
Water content test	To determine if the algae has the correct water content once coming out of rotary dryer	After each process
Chemical purity tests	To determine if chemicals e.g methanol have the correct purity	Random batch will be tested every month.
Oil content test	To determine if the maximum amount of oil has been extracted after algae has been pressed	After each process
3-27 Conversion Test	To determine if the fuel has completed the conversion from oil to biodiesel and has the correct chemical properties	After each process
Emissions tests	To test the biodiesel emissions	At release of first 5 batches, then once a month during the first year of initial product release

Table B.4. Test table

Appendix B.5: Continuous Improvement Process

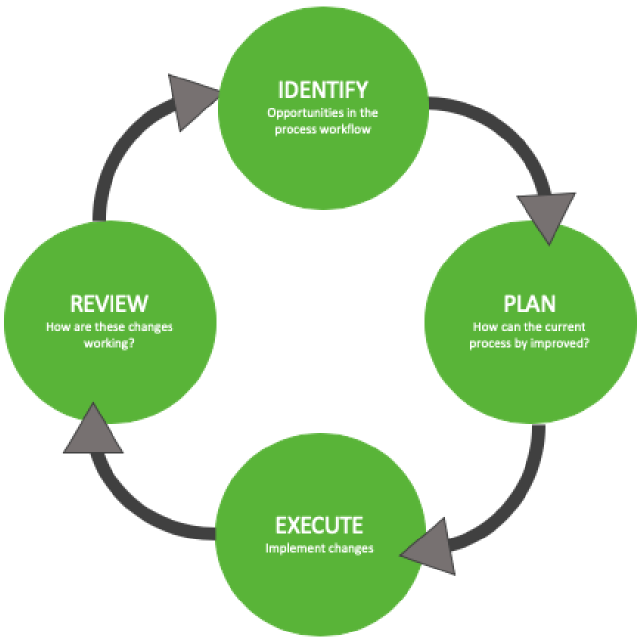


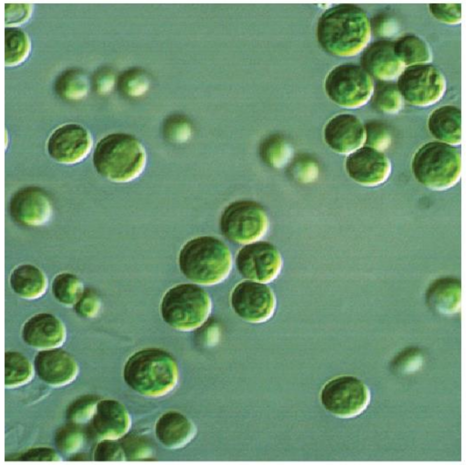
Figure B.5. Showing the continuous Improvement Process

APPENDIX C: MARKETING

Appendix C.1: Brochure

Abnoba
Algae Solutions

An algae biofuel processing plant is being developed in Arran. As a home owner on the island, here is some key information you may be interested in.



What is it?

By using an algae derived biodiesel, the Stagecoach buses can reduce their carbon emissions by 50%. This biodiesel is made with algae grown on the island in specialised ponds, which removes carbon from the atmosphere.

Stagecoach

Where is it?

The proposed loaction of the plant is located off the A841 with an area of 100m². It is 3.9km miles from Lamlash and 1.2km miles from the Stagecoach Depot, in Brodick.

Have your say

We believe it is important to keep in touch with the community of Arran as we develop our infrastructure.

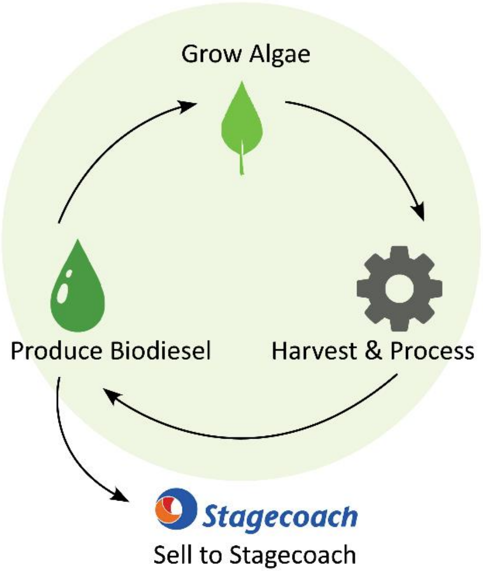
More information and our FAQ can be found at:
www.abnoba-algae.co.uk

Information about Stagecoach can be found at:
www.stagecoach.com

Any queries can be directed to:
help@abnoba-algae.co.uk

How does it work?

The biofuel manufacturing process can be broken down into 3 stages:



Is it safe?

Abnoba Algae Solutions complies with European standards (specific standards can be found on our website). We are also designing our plant in line with regulations discussed in the Small Scale Manufacture of Biodiesel of Scottish Environment Protection Agency.

The location of the plant was took into account the relevant protected areas specified by the Arran Deer Management Group. The plant is 1km away from the nearest protected location.

How will it affect me?

Other than the A841 being a bit busier than usual, the proposed algae biodiesel plant should not dramatically impact your day to day life.
This new infrastructure will offer the people of Arran and tourists a low carbon option of travel.

There may be job opportunities to work on building and running the algae biodiesel plant.

In the future, the biodiesel may be available to public to purchase for personal use.

More information and our FAQ can be found at:
www.abnoba-algae.co.uk

APPENDIX D: FINANCE

Appendix D.1: Table of cost breakdown

Expense		Cost breakdown	
Algae generation	CAPEX	Construction	Price per acre: £25,025 Converted to price per m^2: £6.18 Total area required: 17,083.64 m^2 $Total\ cost\ of\ construction$ $= Total\ area\ required$ $\times Price\ per\ m^2$ $= 17{,}084\ \times 6.18$ $= £105{,}641.61$
		Land	Price for 1100 m^2 = £69,000 $Assumed\ price\ per\ m^2 = \frac{£69{,}000}{1100\ m^2} = £62.72$ Total area required: 17,083.64 m^2 $Total\ cost\ of\ land$ $=\ Price\ per\ m^2$ $\times Total\ area\ required$ $= 62.72\ \times\ 17{,}083.64$ $= £1{,}071{,}610.15$
		Total	Total CAPEX = $Cost\ of\ construction +\ Cost\ of\ Land + Cost\ of\ PH\ meter + Cost\ of\ spectrophotometer + Cost\ of\ dissovled\ oxygen\ meter =\ 105{,}641.61 + 1{,}071{,}610.15 + 231.74 + 1{,}100 + 206.67 = £1{,}178{,}790.17$
	OPEX	Operation	Price per acre: £3,742.20 Converted to price per m^2: £0.92 Total area required: 17,083.64 m^2 $Total\ cost\ of\ operation$ $= Total\ area\ required$ $\times Price\ per\ m^2$ $= 17{,}084\ \times 0.92$ $= £15{,}797.48$
		Maintenance	$Total\ cost\ of\ maintenance = 2.5\%\ of\ (Cost\ of\ construction + Cost\ of\ PH\ meter + Cost\ of\ spectrophotometer + Cost\ of\ dissovled\ oxygen\ meter) = 0.025\ \times (105{,}641{,}61 + 231.74 + 1{,}100 + 206.67)$ = £2,679.50
		Total	$TOTAL\ OPEX = Cost\ of\ operation$ $+ Cost\ of\ maintenance$ $= 15{,}797.48 + 2{,}679.50 = £18{,}476.98$
Processing	CAPEX	Construction	An automated “self-build” calculator was used to approximate the cost of a building that would be used. = £22,000
		Land	A plot costing £69,000 for 1100m^2 is to be used.

		Total	$TOTAL\ CAPEX = Cost\ of\ construction + Cost\ of\ Land + Cost\ of\ oil\ press + Cost\ of\ rotary\ Dryr + Cost\ of\ sotrage\ tanks = 69{,}000 + 22{,}000 + 231{,}000 + 39{,}000 + 2{,}000 = £363{,}000$
	OPEX	Methanol	Volume required per year: 501,000L Cost per litre: £0.22 $Total\ cost\ per\ year = Volume\ required \times Cost\ per\ litre = 501{,}000 \times 0.22 = £110{,}220$
		Hexane	Volume required per year: 1000L Cost per kg: £2.34 Converted to cost per L (rounded): £1.52 $Total\ cost\ per\ year = Volume\ required \times Cost\ per\ litre = 1000 \times 1.516 = £1516$
		Sodium Hydroxide	Mass required per year: 1000kg Cost per kg: £0.50 $Total\ cost\ per\ year = Mass\ required \times Cost\ per\ kg = 1000 \times 0.50 = £500$
		Electricity	Average Energy consumption per kg of biodiesel produced form algae= 107.3MJ/kg. Biodiesel density = 874.7 kg/m^3 Mass of biodiesel produced every year = volume X density multiplied by 167078 litres = 146,143kg energy consumption = mass multiplied by 107.3MJ/kg = 15,681,157MJ per annum. Divide by 365 divide by 24 * 1000 = 1,790,086kwh. Average price per kwh = 15.99 pence = £286,210
		Technician wages	4 technicians paid £33,750 Total = £135,000
		Maintenance	$Total\ cost\ of maintenance = 2.5\%\ of\ (cost\ of\ oil\ press + cost\ of\ rotary\ dryer + cost\ of\ storage\ tanks) = 0.025\ X\ (231{,}000 + 39{,}000 + 2{,}000) = £6{,}800$

		Total	$Total\ cost\ of\ OPEX = cost\ of\ methanol + cost\ of\ hexane + cost\ of\ sodium\ hydroxide + cost\ of\ electricity + cost\ of\ technician\ wages + cost\ of\ maintenance = 110{,}220 + 1{,}516 + 500 + 286210 + 135{,}000 + 6{,}800 = £540{,}246$
Total	Total	CAPEX	Total CAPEX = Algae generation CAPEX + Processing CAPEX = £1,178,790.17 + £363,000 = £1,541,790.17
		OPEX	Total OPEX = Algae generation OPEX + processing OPEX = £18,476.98 + £540,246.00 = £558,722.98

Subsidization plan	Cost per litre 0% profit = Running cost / volume of biodiesel in litres $\frac{558{,}722.98}{167078} = £3.34\ per\ litre.$
	Cost per litre 20% profit = Cost per litre 0% profit * 1.2 = $3.34\ X\ 1.2 = 4.01$
	Cost per litre 20% profit, subsidized 20% = Cost per litre 20% profit * 0.8 = $4.01\ X\ 0.8 = £3.21$
	Number of years to cover CAPEX = CAPEX/Number of litres X profit margin $\frac{1{,}541{,}790.17}{167078\ X\ (4.01-3.34)} = 13.8\ years$ = 14 years
	Deficit at 20% profit = Cost per litre 20% profit, subsidized 20% - price of sale = 3.21 – 1.3 = £1.91
	Total cost of deficit at 20% profit = Deficit at 20% profit X volume of biodiesel X number of years = $1.91\ X\ 167078$ X 14 = £4,467,665.72
	Grant money left after 14 years = Total grant - Total cost of deficit at 20% profit = $8{,}690{,}000 - 4{,}467{,}665.72 = £4{,}222{,}334.28$
	Cost per litre at 0% profit, subsidized 20% = Cost per litre at 0% profit * 0.8 = £2.67
	Deficit at 0% profit = Cost per litre at 0% profit, subsidized 20% - price of sale = 2.67 – 1.30 = £1.37
	Total cost of deficit at 0% profit per year = Deficit at 0% profit X volume of biodiesel = $1.37\ X\ 167{,}078 = £228{,}896$
	Lifetime at 0% profit = Grant money left after 14 years/ Total cost of deficit at 0% profit per year = 4,222,334.28/228,896 = 18.4 years = 18 years
	Total funding lifetime = Number of years to cover CAPEX + Lifetime at 0% profit = 32 years

Appendix D.2: Internal Rate of Return Formula

$$0 = \sum_{t=1}^{T} \frac{C_t}{(1 + IRR)^t} - C_0$$

where t is the number of time periods, IRR the internal rate of return, C_t the net income and C_0 the initial investment costs