Biomass Feedstock
Innovation
Programme

Phase 1

MiDAS

Feasibility study investigating the integration of geothermal energy to cultivate Spirulina

January 2022

impact solutions

University of Strathclyde

Document Summary

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Prepared by	Idriss Elkettani (Technical Lead) & Nandini Patel (Chemical Engineer)
Approved by	Simon Rathbone (Project Manager)

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Executive Summary

The scope provided by our funding body BEIS is to present an innovative design and project plan that addresses the current barriers to algae feedstock production. This is to aid the UK's scale-up of its biomass supply while also mitigating its greenhouse gas emissions to meet the government's net-zero goals by 2050.

Project MiDAS completed a feasibility study to assess the potential of integrating flooded mines in East Ayrshire, Scotland, with bioreactors. Our Phase 2 plan will build a 5 ton/yr plant to validate the process designed in Phase 2 and provide a launchpad to scale this novel approach to the industrial cultivation of microalgae across the UK. The proposed design is highly scalable, avoids the use of valuable land and could convert brownfield sites in often socially deprived and rural communities into new centres for the industry.

Work carried out in Phase 1 has shown that a mine with water at 22 °C can support the cultivation of microalgae to temperatures of up to 35 C year-round. A new method for appraising mines has been developed, which considers drilling risk and optimal locations within a mine. It was found that geothermal energy can contribute to 40% of the demonstrator energy demand at the chosen site, the Barony. The geothermal integration poses no critical technical barriers to this proposal

MiDAS aims to produce a turn-key solution allowing the UK to tap in 1503 flooded mines in the UK to generate biomass. This presents a considerable opportunity to scale micro-algae production to an industrial scale, decoupling it from other industries that may limit the technology's scale, allowing larger-scale plants to be built (>1000 tonnes). This would bring the production cost down to as low as £1/kg. This advance will have a significant benefit on the UK biomass economy. It will make the growth of microalgae commercially feasible for a wide range of products instead of the niche supplement market it currently supplies.

Project MiDAS is, therefore, the first critical step to providing the blueprint to commercial-scale production of microalgae. This is the key to increasing the UK biomass supply.

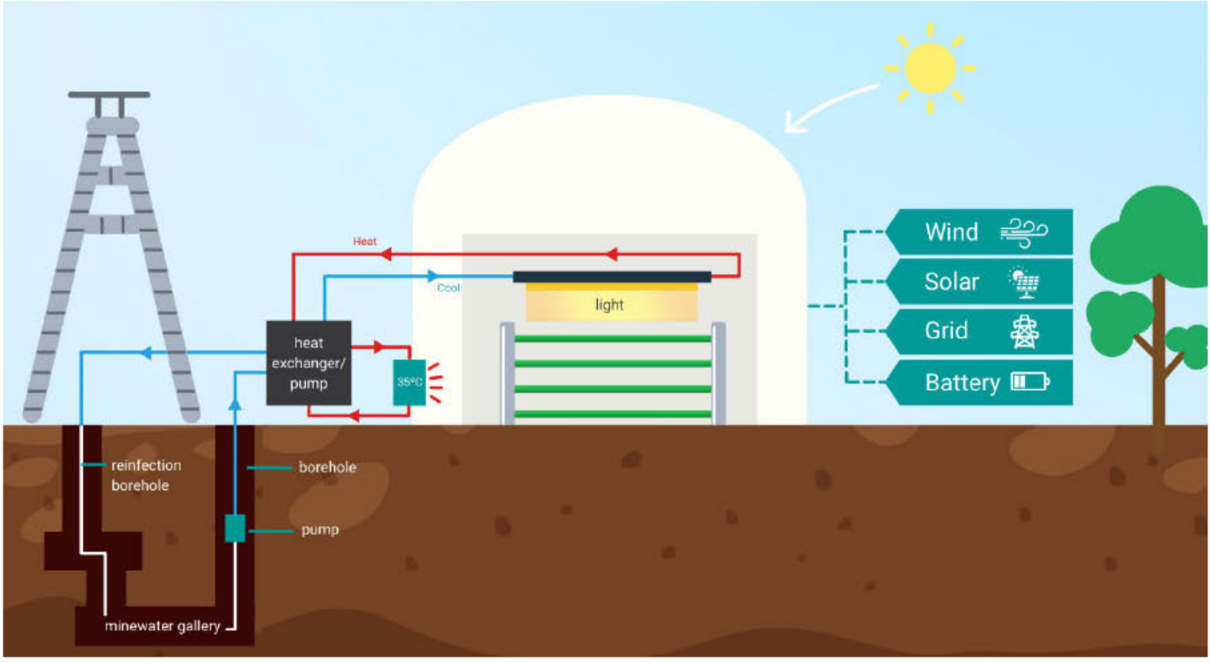

Figure 1: Schematic of innovation proposal

1. Introduction

The greatest challenges facing our generation are climate change caused by global warming and rising emissions. An increased food and fuel demand from a rising world population has led to intensive research to find alternative fuels and methods to produce food without using agricultural land. Algal biomass production is a promising potential to address these problems as it can produce biofuels and bioproducts with low land use. Both the UK and EU have identified the biomass industry as a critical contributor to help to meet the 2050 carbon-neutral targets.

Arthrospira platensis (Spirulina) is the most cultivated microalga worldwide, with production estimated between 3,000-20,000 tons per year and European production contributing to only approximately 142 tons/yr. . Thus, there is an opportunity for the UK to become a leading contributor within this sustainable European market as it currently only has two spirulina production plants in operation.

Spirulina's potential lies with its high nutritional compositions. Not only does it possess a high protein content (60-70%), but it also contains high amounts of essential fatty acids, amino acids, minerals, vitamins (especially B12), antioxidant pigments and polysaccharides. Due to these qualities, it is desirable for several commercial purposes; it can be used either as a nutritional supplement for humans and animals or as a source of active principles in the pharmaceutical and cosmetic industries. As a result,5% of its reported use in Europe is directed towards food supplements. Additionally, a blue photosynthetic pigment can be obtained by extracting pigments, such as phycocyanin.

Spirulina is classified as a photoautotroph microorganism and utilises sunlight to convert CO_2 into carbohydrates and fats via photosynthesis. Consequently, 1 kg of dry weight product requires 1.7kg of CO_2, illustrating its potential to reduce the UK's CO_2 emissions and reach its net-zero goals. Its optimum growth conditions are at 35-38°C (depending on the strain) and alkali conditions (pH 8-10).

Other important growth and composition factors are nutrient availability, light CO_2 supply and reactor choice.

Common methods utilised in industry to reduce production costs are limited to using wastewater as the growing medium and using CO_2 alternatives (e.g., flue gas and air capture system). However, impact solutions have identified a new integration technique of heat energy from flooded mines to meet the energy demand of microalgae cultivation. There are around 1506 closed collieries in the UK with a potential of 13 million MWh/yr of untapped energy. This project is the first to investigate the technical and economic feasibility of using geothermal energy from flood coal mines and presents an opportunity for the UK to be at the forefront of this technology.

Heat transfer to the energy system works by the hot water being upgraded through a heat exchanger coupled to an array of electrically powered heat pumps. The mine water can also be used within a cooling system with no downgrading required.

The project's benefits will go far beyond the integration of mine water with biomass production, with the creation of a model that would allow the coupling of any waste heat source with microalgae production and utilisation of the mine water's thermal resources for alternative uses.

This report presents the key findings of Phase 1 and the plan for Phase 2, including the commercialisation and route to market strategy.

2. Project Scope

The scope provided by our funding body BEIS is to present an innovative design and project plan that addresses the current barriers to algae feedstock production. This is to aid the UK's scale-up of its biomass supply while also mitigating its greenhouse gas emissions to meet the net-zero government goals by 2050.

The partners involved in this project are the University of Strathclyde, assessing the geothermal potential of the possible locations; National pride own the potential two project sites; Coal Authority and East Ayrshire council.

3. Project Objectives

1. Assess the feasibility of using water from disused mines as the primary heat source for algae bioreactors.
2. To design a bioreactor that maximises biomass productivity to similar/above current industrial levels of the microalgae Spirulina.
3. Assess the different process integration opportunities (e.g., air capture system & wastewater treatment) to reduce the production cost
4. To create a project plan for building a demonstrator plant based on the data gathered and process developed in Phase 1.

4. Key stakeholders

The main two stakeholders in this project are BEIS (funding body) and the landowners, National pride. National Pride is a community interest company that repurpose and develop redundant land. Other key stakeholders identified during Phase 1 included Easy Ayrshire Council and the Coal Authority. The coal authority is responsible for decommissioning, repurposing, and maintaining abandoned coal mines.

5. Project constraints

The main project constraints were regarding the key stakeholder objectives. For BEIS, this was ensuring the project ran within a £4 million budget for 3-years. [redacted] Other main project constraints were ensuring the design adhered to the required environmental and pollution controls. The demonstrator was designed based on these constraints, with safety factors included.

6. Phase 1 Findings

6.1 Geothermal Potential

Two sites were identified as potential sites for the demonstrator. [redacted] Both sites are now cleared. Both collieries were mined using longwall mining of worked panels. The mines were accessed by shafts, linked by arterial roadways.

The University of Strathclyde undertook a comprehensive sub-surface assessment of the two possible collieries to install a mine water geothermal energy scheme to provide heating and cooling for the growth of algae biomass.

The essential activity in Phase 1 was the digitalisation of the coal authorities mine plans for both sites using QGIS. [redacted].

Consideration of worked panel area, worked panel depth and surface constraints leads us to propose several target areas at each site that have the highest chance of accessing a large enough volume of worked area to supply the requirement of the algae plant. Deciding which site to target requires joint consideration of surface impacts as well as subsurface risk.

The key findings for both sites are summarised below:

6.1.1 [redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]

6.1.2 Barony

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

[redacted]

Figure 2: Map of Barony site, showing the total longwall panel area that could be assessed by intersecting the stacked coal workings. Five prospective locations (A to E) for a vertical borehole within the site boundary are presented

All five areas provide access to the mineworking's, but to establish which of these sites is optimal requires consideration of the surface distribution of the site including the development plans, planning consents, and consultation with neighbours. Priotisation is made on the basis that 1) accessing a larger panel is best, ignoring connections between panels, 2) the closer to a roadway, the more likely and open void, 3) the deeper seams will be slightly warmer

6.1.4 Potential Target areas at [redacted]

There are six areas where worked seams underly the [redacted] red line boundary. None of these represent stacked seams. Additionally, there are two areas where a high concentration of well-mapped roadways will provide access to a wide network.

- [redacted]
- [redacted]

6.1.5 Comparison of Sites

[redacted]

[redacted]

Table 1: Comparison of drilling risk and resource uncertainty at the two collieries

	Drilling misses mines/roadway	Mitigation	Drilled Panel or roadway is not connected to the wider network	Mitigation
Barony: Panel	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Several uncertainties remain, which cannot be addressed by legacy data alone and require exploration boreholes, thermal modelling & pump tests. This work will occur in Phase 2.

6.2 Location

The Barony was chosen as the proposed site for Phase 2. Pre-planning application has been submitted and accepted for the Barony Eco-Wellness centre, [redacted] By sitting within the eco-wellness centre, infrastructure for utilities will be taken care of by National Pride. They will also have their own wastewater treatment centre, which we can feed into. This all reduces the cost of the project.

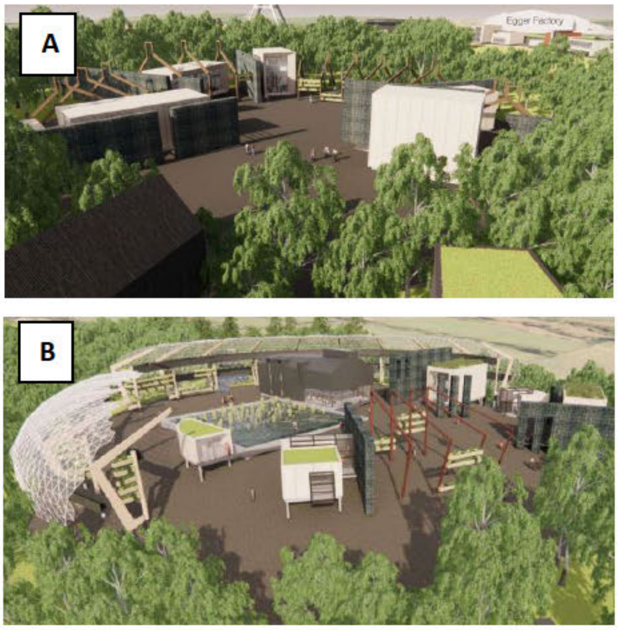

Figure 3: Barony Site location for Demonstrator

While [redacted] provides a slightly better heating ability, more data and information regarding the mines from past engineers are available for Barony. There site preference of Barony is due to having more subsurface data and a better set of workings. In addition, it offers better risk mitigation due to uncertainties regarding seals and compartments in the mines, which will not be fully realised until drilling.

Both sites are surrounded by dairy and poultry farms, offering opportunities for wastewater integration to replace Spirulina's culture medium. Contact with these farms falls within Phase 2 stakeholder engagement plan.

6.3 Spirulina Cultivation

The cultivation process comprises three stages; the cultivation stage where the algae is grown, the harvesting stage where this algae solution is removed, and a drying stage, where dry spirulina biomass is obtained via removing the excess culture medium.

6.3.1 Cultivation Stage

Microalgae are grown using photobioreactors, divided into two main groups: open and closed systems. Closed systems such as artificial ponds, tanks, and raceways are in direct contact with the environment resulting in a high contamination risk and low biomass productivities. They have a low associated CAPEX/OPEX and are used mainly in warmer countries that capitalise on free lighting and heating from the environment.

Due to the colder UK climate, a closed system was chosen. Closed systems such as tubular, bubble, flat-plate and biofilm designs are enclosed illuminated vessels. The conditions in a closed PBR are strictly controlled, allowing the manipulation of operating conditions. Their advantages over open systems are that they minimise contamination risk, provide better control over vital variables (CO2, temp, pH, light), prevent water evaporation, and are more flexible to different strains. And have high biomass productivities. Multiple reactor choices were investigated during phase 1, summarising the different options shown in Table 2.

Table 2: Assessment of different types of Photobioreactor

	Pros	Cons
Tubular	• Modular design • Well established and reliable tech • Versatile to other strains • Modular design & easily scaled • High purity • High process control	• Large footprint • High energy requirement • High CAPEX and OPEX • Large water requirement
Flat Plate	• High photosynthetic efficiency • Versatile to other strains • Modular design • Lower water consumption	• Scale-up issues due to many components • Prone to biofouling • Process control difficulties • High CAPEX and OPEX
Bubble	• Low land requirement • Easy sterilisation • Low O2 accumulation • Good for biogas processing	• High foaming/fouling risk • Scale-up limited • High maintenance cost
PSBR	• Substantial reduction in liquid volume by several orders of magnitude • High final biomass density achieved • Versatile to use of many different strains	• Non-homogenous growth process • Novel design • Industrial scale-up not proven • High-risk design

A tubular photobioreactor was identified as the best reactor choice for this project. Of the closed system designs, a tubular reactor is the preferred industrial option to cultivate Spirulina with size and capacity increasing yearly. It is a well-established design with strict process control. It has also been successfully integrated with both flue gas and wastewater. Thus, the risk associated with this design choice is low. Furthermore, it offers versatility to using different strains with it the technology used commercially at a scale up to 10x of our demonstrator.

Tubular photobioreactors consist of transparent tubes in a horizontal or vertical arrangement. The culture medium is circulated with an air pump or airlift system. While circulating, the culture medium broth is exposed to light (natural or artificial) and air/CO_2 to facilitate microalgae growth and prevent pH changes. A degasser unit is connected to the tubes where microalgae harvesting occurs.

[redacted], a leading tubular photobioreactor, was identified and chosen as our supplier for Phase 2. They are a UK based manufacturer of the Phyco-range of photobioreactors with more than 30 years of experience designing, constructing, and deploying algal photobioreactors. To date, they have deployed over 290 systems ranging in the scale from 5L-400,000L, demonstrating the technical confidence in delivering this demonstrator on Phase 2. As a UK based sub-contractor, this project supports UK businesses jobs.

[redacted]

Figure 4 [redacted] *which will be used in the Demonstrator*

Additionally, a UK based contractor removes the risk of delivery delays due to Brexit/COVID and mitigate the economic risk of unforeseen export taxes.

6.3.2 Harvesting and Drying stage

These two stages aim to obtain a final spirulina product of moisture content of 5wt%. Firstly, output from the reactor needs to be harvested. Harvesting will occur semi-continuously for the tubular design. Harvesting will occur once a day for a cycle lasting 6 hours. Due to the large size of the spirulina filaments, a vibrating mesh will be used for this section. From this stage, the Spirulina will be dried using a spray dryer. The role of the dryer in the process is to reduce the moisture content of the spirulina slurry to form a powder ready to be packaged. This ensures that the product can be stored for extended periods and makes it more efficient to transport as less of the packed volume is water.

6.4 Energy Modelling

The energy systems team developed a high-resolution integrated thermal and solar model at the University of Strathclyde. Their aim was to provide process information for demand and provide a decarbonisation assessment and strategy/assessments.

Detailed hourly time step thermal demand models incorporating material specifications, were developed for two potential reactor enclosure concepts; A transparent polytunnel to allow an ambient lighting contribution and a passive house insulated system to limit heat loss. The advantage of the insulated building is that there is no heat demand as it is satisfied via lighting gains and limited cooling demand as the minewater is used directly. This thermal model was integrated with a solar illuminance model to determine the required process lighting power and associated heat gains.

[redacted]

The model formed the basis to investigate the different methods to decarbonise the process and the costs associated with this task. The key findings of this model were:

- Energy demand for cooling and heating is feasible to be met by mine water, with geothermal energy contributing to [redacted] of the required energy demand of the demonstrator
- Full decarbonisation of the process is achievable by integrating renewable energy such as wind, solar and battery storage.
- The passive house enclosure requires higher lighting power
- Passive house enclosure had a lower peak demand [redacted] and had more stable demand as compared to polytunnel whose peak lighting period is dictated by daytime, coinciding with peak grid demand periods
- Running the reactors on opposing lighting schedules reduces thermal demand by [redacted] reduces peak loads and infrastructure capacities.

[redacted]

Within Phase 2 this analysis will be continued, with the model continuously refined to provide the best energy model to support the building and commissioning of the first commercial plant.

7. Demonstrator Proposal

Output	Parameters	5 ton/yr.
Reactor	[redacted]	[redacted]
	[redacted]	[redacted]
	[redacted]	[redacted]
	[redacted]	[redacted]
	[redacted]	[redacted]
	[redacted]	
	[redacted]	[redacted]
	[redacted]	[redacted]

Table 3: Key Design Outcomes for demonstrator

CAPEX	£M
Major Purchased Equipment	1,048,300
Geothermal Extraction	285,000
Site clearance and Preparation	250,000
Engineering Contractors	252,054
Total	1,835,354

Table 5: CAPEX Costs

OPEX	£M
Variable OPEX	[redacted]
Fixed OPEX	[redacted]
Total OPEX	656,068

Table 6: OPEX Costs

8. Project Cost

BEIS has set a project budget of £4 million. Impact evaluated the economic feasibility of both a 5 ton/yr and 10 ton/yr demonstrator. [redacted] **Therefore a 5 ton/yr demonstrator will be implemented in Phase 2.** All Capex estimates are at a feasibility level in Table 5, with OPEX costs shown in Table 5. A CAPEX of £1,835,354 and OPEX of £656,068 was calculated for a 5 ton/yr. Demonstrator with a production cost of £131/kg. It should be noted this could be reduced to £99/kg if R&D costs were excluded. All Capex costs include installation fees.

Geothermal energy contributes to meeting [redacted] of the energy demand required for [redacted]

[redacted]

Figure 5: Geothermal impact on the total energy demand of the Demonstrator

9. Integration Opportunities

The main difficulty associated with industrial scale-up is ensuring production costs are competitively low (<£5/kg). Integrating alternative sources for carbon and nutrient supply is essential to bringing down the high production costs associated with closed cultivation systems. For example, the high costs associated with the culture medium and nutrient supply can be reduced through the bioremediation of wastewater streams. Also, through CO_2 from industrial flue gas or an air capture system. Economic advantages of these integration opportunities are:

1. Reducing/negating growing medium costs, which can contribute [redacted] of the OPEX of the process. Provides "free feed."
2. Revenues from by-products can be made from these processes
3. Avoided costs for companies not having to build new/elaborate Wastewater treatment units

Integrating wastewater into the design utilises hazardous waste material and provides an economic incentive for farmers and algae cultivators. This will be investigated during the phase 2 demonstrator.
While CO_2 integration is promising, a few barriers still exist. When coupling with flue gas, correct selection, and modification of such strain to the specific flue gas environment, it requires the algae cultivation system to be nearby.

Using an air capture system, which directly captures carbon from the air, is an emerging technology that could revolutionise the microalgae industry. This is an extremely interesting integration option and would eliminate all CO_2 operating costs. In addition, this would protect the project running over cost from inflation and supply shortages and unforeseen events such as pandemics. However, currently, as this option was identified late on in Phase 1, a smaller output unit could not be quoted. This ultimately led to this option not being budgeted due to the high cost.

10. Renewable Integration

Work was carried out using the energy model system to investigate decarbonising the process by analysing potential renewable generation and storage contributions.

The scenarios analysed were baseline case (geothermal and grid), baseload case (where renewables and storage are designed to provide baseload demand with zero grid exports), Net Zero case (based on the overall balance of grid importing and exporting) and Excess case (Where grid importing is <2% of overall demand).

From Figure 6, decarbonisation of the process is achievable via electrification of thermal energy generation coupled with co-located renewable generation and storage. The barrier to applying this to the demonstrator in Phase 2 was CAPEX investment ranging from between £400,000-£900,000 for the scenarios.

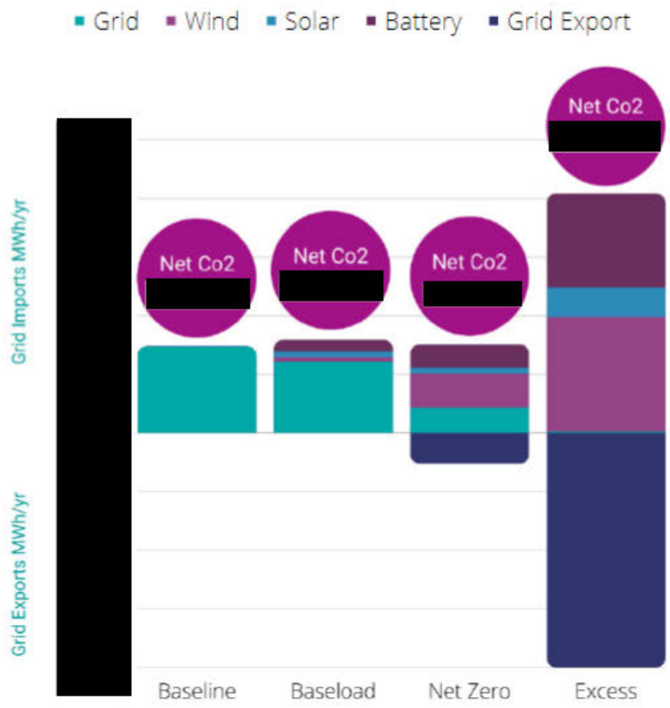

Figure 6: Assessment of different de-carbonisation strategies

This analysis illustrates the technical feasibility of decarbonising the process and will be a basis for data validation in Phase 2. In addition, it provides a solid foundation for further research during commercialisation and roll-out post Phase 2.

11. LCA

The carbon emissions associated with the production of spirulina was assessed and compared to the emissions of comparable products. It was found that the emissions produced from cultivating spirulina at this particular location have the potential to be reduced by [redacted] directly as a result of integrating geothermal energy into the process.

Figure 7, shows a graph comparing the emissions of the demonstrator in instances where energy demand is met entirely from the grid, met from the grid and geothermal (demonstrator) and met using geothermal and on-site renewable generation. Note that it doesn't include other inputs such as choice of growing medium.

As geothermal energy provides the process [redacted] of the overall energy input, it also means that emissions [redacted] than if this process was run entirely relying on the National Grid. Although a similar outcome can be achieved if the demonstrator was run on a mixture of on-site renewable and the grid, our work in Phase 1 shows that geothermal energy is reliable year-round and requires a much lower CAPEX investment.

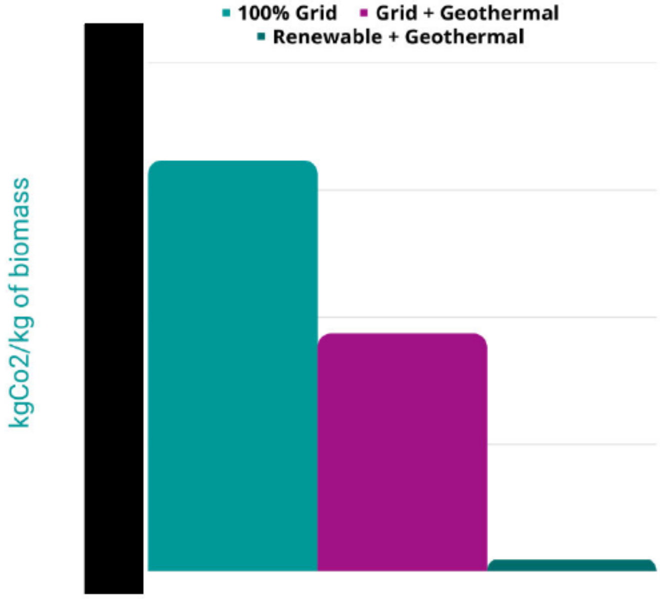

Figure 7: CO2 emissions associated with different energy sources fir cultivating 1kg of spirulina

The biomass itself has the potential to decarbonise a range of sectors such as polymer production and human feed. The figures specific to the demonstrator are based off initial calculations carried out at the University of Strathclyde and aren't reflective of the emissions from a commercial scale plant. It is anticipated that through substituting inputs such as energy from the grid and standard growing medium with more sustainable alternative such as wastewater and renewable energy, it has the potential to reduce the emissions produced by various industries such as agriculture, hydrogen generation and waste management. These opportunities will be explored further in Phase 2 as it prepares Impact to forge links with partners working towards achieving net-zero.

12. Roll out Potential

The UK is home to 1503 flooded mines with an estimated total of 13 million MWh/yr geothermal potential. These closed collieries are often built on brownfield sites in areas in economic decline. Project MiDAS offers the utilisation of this untapped energy source on land that is disused. Phase 2 is paramount to the successful development of this biomass scale-up procedure, as is the first step before expanding this technology to the rest of the country. The number of available collieries and available land thus pose no critical barrier to the Project MiDAS' potential post Phase 2.

Figure 8: Location of AD plants U.K

Geothermal energy will be the primary route in Phase 2 and for the first stages of our commercial plan. However, the plan to develop a full turn-key solution coupled with any industrial process with spare heat capacity is a focus within Phase 2. Technical assessment to ensure the demonstrator and all models are not dependent on geothermal integration will be considered. Additionally, the modular design of the photobioreactors allows the technology to be tailored to the specific environment and industrial requirements. This places no limits on the potential supply of Spirulina, with the possible industrial integrations limitless.

The integration of wastewater and CO_2 is paramount to reducing the production cost. Figure 8 demonstrates a large number of plants available in the UK. The wastewater supply offers no limitation to expanding this process to the rest of the UK, located near all closed collieries. The addition of an air capture system allows for the system to be deployed anywhere. The key barrier associated with this system is the high CAPEX and novelty of the technology. However, this technology is ever-expanding, which we forecast to reduce costs and increase in scale as technology advances.

13. Scale-Up Potential

Currently, high production costs limit the commercial opportunities and supply of biomass production within the U.K

During phase 1, the scale-up viability of the process was assessed. **As a result, a commercially competitive production cost of [redacted] occurs at the commercial output of [redacted] when all integration options are imposed.** This demonstrates that this project overcomes the key commercial barriers in the UK microalgae industry.

Assessing the production cost to greater detail will occur in Phase 2 during the techno-economic assessment, with this analysis continually refined throughout.

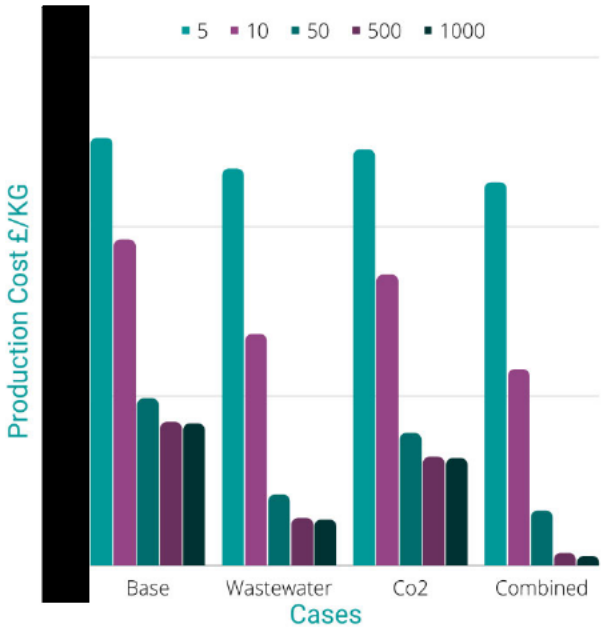

Figure 9: Production cost for different outputs (5-1000ton/yr.) for different cases

14. Commercialisation

[redacted]

[redacted]

[redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]

[redacted]

15. [redacted]

[redacted]

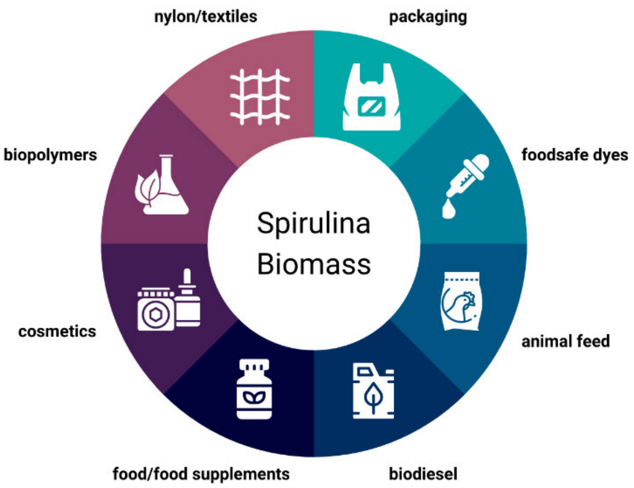

Figure 11: Spirulina Market

[redacted]

[redacted]

16. Phase 2 Plan

[redacted]

A milestone/stage¬gate approach will be taken with a go/no¬go assessment made at the end of key WP to determine if the project can proceed, with progress monitored via a steering group (SG) made of the key contractors and stakeholder partners. The SG has responsibility for strategic and technical direction, including 2nd level plans; project monitoring of progress against costs and KPIs, management of risk register; commercial exploitation plans. Day to day managing will lie with the WP leaders. Reporting lines with BEIS will be kept open with regular monthly update meetings on project progress. Impact utilise PRINCE2 project management practices and have experienced project managers on the team to ensure successful delivery.

16.1 KPI

KPIs will be used and progress against them will be monitored on a regular basis.
The KPIs can be split into 5 categories:

- KPI 1 – Land Preparation and Site Permits
- KPI 2 – Demonstrator Operation and Production of Biomass
- KPI 3 – Biomass Output Check
- KPI 4 – Market Viability and Process Economics
- KPI 5 – Model Viability

KPI 1 measures the progress made with regards to preparing the land, ensuring utilities are fitted and that the relevant permits have been obtained for the operation of the demonstrator.
KPI 2 looks at the production of biomass and will assess the operation based off the models derived in Phase 1.
KPI 3 will assess the daily output from the demonstrator and analyse the samples to ensure they meet standards relevant to their application. Biomass characteristics such as protein and final water content and amino acid composition will be carried out in-house.
KPI 4 aims to track the OPEX for the demonstrator to refine estimates for a commercial plant producing 50 tonnes. It will use data gathered from sensors around the greenhouse to assess where the process can be optimised
KPI 5 will validate the models developed during Phase 1 using data from the demonstrator to ensure that it is reproducible to a commercial scale. Data from other mines will be gathered during this stage to identify other potential sites

16.2 [redacted]

Phase 2 will contribute to the biotechnology sector and the bioeconomy by opening up opportunities to use microalgae in sectors previously not considered economically viable.

A key innovation area [redacted]

During Phase 2, one WP is dedicated to developing [redacted]

An additional WP will [redacted]

16.3 Stakeholder Engagement

Engagement with all the relevant stakeholders is imperative to the project's success throughout the next phase. Impact solutions have already received letters of support from multiple stakeholders close to the project; Coal Mine Authority, National Pride, East Ayrshire Council and [redacted] Fostering relationships with key stakeholders in phase 2 will provide the basis of the necessary support required for commercialisation post Phase 2.

In Phase 2, engagement with other stakeholders will support the business development of this technology. Contact with farmers will occur to assess the feasibility of wastewater integration at both the Barony and [redacted] Relent bodies will be contacted to investigate the potential of AD plant integration not just within Scotland but also in the UK. Additionally, through Impacts' extensive petrochemical and plastic network, engagement with the relevant industries will occur to formalise a successful route to market for spirulina biomass.

16.4 Permits and Consents

Work was undertaken to identify the relevant consents and permits required to build and operate the demonstrator. The planning permission required concerns the project's mining aspect, i.e., geothermal energy. Planning permission is required if drilling is below 200m. In addition, a subsurface permit and site permit will need to be obtained from the Coal Authority, which generally takes approx. 2-3 months. Engagement with the coal authority and East Ayrshire council throughout Phase 1 has ensured all necessary permits have been identified and factored into Phase 2.

Regarding wastewater disposal, it is assumed that the growing medium is below the heavy metal content that requires a SEPA permit. Additionally, as we are disposing of less the 1m3 a day, no special SEPA permit is required. This will be reviewed in Phase 2.

16.5 Risks and Risk Management

Impact recognises the need for an on-going, comprehensive risk mitigation and management process which forms part of the project management WP An FMEA (Failure Mode-and-Effect-Analysis) table will be used to monitor progress against the project milestones and identify areas of risk to sub-contractors in order that action can be taken.

Some of the key risks and mitigations are described below:

Technical Risks

[redacted]

Commercial Risks

[redacted]

[redacted]

16.6 Dissemination

Dissemination of results to the broader audience is fundamental to our Phase 2 objectives and the overall plan of increasing biomass supply and reducing GHG emissions. Key activities include presentations at algae and geothermal conferences, publication of research papers, promotion of the project and technology on Impact Solution website and all social media platforms. The fundamental aim of Phase 2 is to create a modelling system/ scale-up procedure. This will form the blueprint to rolling out this technology to the rest of the UK Engagement with the coal mine authority will help disseminate the critical learnings from Phase 2 across their network, ensuring the relevant people/projects are reached.

17. Appendix

Gantt Chart

[redacted]