Natural Synergies Ltd (NS)

Medium Scale Anaerobic Digestion

An Integrated Energy Business

Report*: DECC*

Phase 3 – 4th Milestone: Redacted Final Report

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LIST OF ABBREVIATIONS

AD	anaerobic digestion
AEMS	automated extraction monitoring system
ASC	advanced suprecritical coal
ATEX	explosive atmospheres (French: Atmospheres Explosives)
BIS	British industrial standards
BO	build and own
CAPEX	capital expenditure
CCGT	combined cycle gas turbine
CCS	carbon capture and storage
CH_4	methane
CHP	combined heat and power
CO	carbon monoxide
CO_2	carbon dioxide
COD	chemical oxygen demand
CR	common reed
DECC	Department of Energy and Climate Change
DEFRA	Department for Environment Food & Rural Affairs
DM	dry matter
DNO	distribution network operator
EA	Environment Agency
EBITDA	earnings before interest, taxes, depreciation and amortization
EPC	engineering, procurement and construction
ESCO	energy service company
EU	European Union
FGD	flue gas desulphurisation
FIT	Feed-in-Tariff
GHG	green house gases
H_2S	hydrogen sulphide
HOTs	head of terms
HRT	hydraulic retention time
IP	intellectual property
IRR	internal rate of return
JV	joint venture
LCA	life cycle analysis
LCOE	levelised cost of energy
LCs	levelised costs
MCC	motor control center
MSW	municipal solid waste
NFU	national farmers union
NEA	North Energy Associates Ltd
NO	nitric oxide
NO_2	nitrogen dioxide

NOx	mono-notrogen oxides NO and NO_2
NPK	nitrogen, phosphorus and potassium
NPV	net present value
NREAP	national renewable action plan
NS	Natural Synergies Ltd
NVZ	nitrate vulnerable zones
O&M	operation and maintenance
O_2	oxygen
ORP	oxydation/reduction potential
PAS	publicly available specification
PLC	programmable logic controller
PM10	particulate matter up to 10 micrometers in size
PPA	power purchase agreement
PV	photovoltaic
R&D	research and development
RHI	renewable heat incentive
ROC	renewable obligation certificate
SBRI	Small Business Research Initiative
SciMed	Scientific & Medical Products Ltd
SHE	safety, health and environment
SMEs	small and medium sized enterprises
SOPs	standard operation procedures
SPV	special purpose vehicle
SR	soft rush
US	ultrasounds
UV	ultraviolet
VFAs	volatile fatty acids
VS	volatile solids

1 SECTION 1 – EXECUTIVE SUMMARY

The Department of Energy and Climate Change (DECC) initiated a Wetland Biomass to Bioenergy, Small Business Research Initiative (SBRI) programme to increase the availability of sustainable UK based biomass feedstock for conversion to bioenergy, as well as addressing the needs and challenges of wetland management. The overall programme was in three distinct staged Phases. Phase 1 of the programme commenced in January 2013 and led to Natural Synergies Ltd (NS) to develop a detailed project plan to visit the wetlands and develop project analysis with regards to developing and establishing a localised energy technology solution that incorporated developing an understanding of wetland management considerations, environmental, planning and permitting requirements. Considerations to the overall mass & energy balance brought NS to the conclusion that anaerobic digestion was one of the potential best available technologies to produce energy from wetland biomass (high water content). Phase 2 of the programme enabled NS to implement the findings of Phase 1 by initiating a detailed design of the engineered anaerobic digestion (AD) bioenergy solution and install the plant at Lilac Farm, which was local to a number of wetland reserves. Initial commissioning steps were also completed. Environmental, planning, permitting and grid connection were also developed and completed for the project. Harvesting of soft rush (Catcott Lows nature reserve) and common reed (Ham Wall nature reserve) were also undertaken, initially using conventional harvesting equipment, followed at a later stage by the utilisation of a PistenBully adapted for wetland use by AB Systems Ltd. Phase 3 of the programme enabled completion of the commissioning phase, followed by full plant trials. Further biomass was harvested using both the newly developed PistenBully and Softrak harvesters.

Trials have led to the findings that conventional biodegradability and conversion to biogas was low and further innovations using cell disruption and biomass homogenisation were successfully incorporated. This has led to the overall conclusion that wetland biomass can be successfully utilised wthin NS's AD plant design, with commercial considerations suggesting co-digestion with higher biomethane potential feedstocks, to increase rates of return and reduce payback periods.

1.1 OBJECTIVES

The overall objectives of the Wetland Biomass to Bioenergy programme has been highlighted above. The objectives of the Phase 3 were as follows

1. To finalise plant commissioning and commence trials on wetland biomass
2. Undertake trials on ensiled mix of approximately 80% soft rush (SR) and 20% common reed (CR)
3. Undertake trials on freshly cut soft rush
4. Determine and optimise biogas conversion efficiencies and biogas composition for 2 and 3 above.

5. Undertake a detailed Green House Gases (GHG) and energy Life Cycle Analysis (LCA) on the utilisation of wetland biomass based on DECC stated counterfactuals
6. Learnings from the overall harvesting/delivery supply chain and its impact on the NS AD technology and wetland management
7. Develop a Process Cost Analysis of the NS AD plant
8. Develop a Business Plan for implementation and investor circulation

1.2 KEY FINDINGS RELEVANT TO THE OBJECTIVES

The NS AD demonstration plant was successfully commissioned and the plant has been operational for over a year with no disruption in biogas production

1 Successful commissioning and operation of the demonstration NS AD plant.

2 AD plant was initially seeded on cow slurry and then operated wholly on wetland biomass

3 AD plant has been producing biogas on wetland biomass (soft rush and mixtures of soft rush/common reed

4 Digester stability has been excellent under thermophilic conditions over a 1 year period.

5 Bioenergy efficiency has been defined as the total energy output from the process, in the form of heat and electricity, which can be used for other purposes (rather than within the process) as a percentage of the total energy input from the biomass source. The preliminary LCA Phase 3 report provides a Bioenergy Efficiency of 27.8%

6 Biogas conversion efficiency on fresh soft rush has been ~40% (based on volatile solids (VS) Conversion)

7 Biogas conversion efficiency using ensiled soft rush/common reed has been ~37% (based on VS conversion)

8 Results had shown that conversion efficiencies were low and innovative steps were utilised by installing cell disruption using ultrasound which has improved biogas yields of fresh soft rush to ~80% (based on VS conversion)

9 Further enhancement step using a homogeniser has been incorporated to further improve biogas yields.

10 Biogas boiler has been in operation and maintaining plant operational temperatures. Excess heat is currently vented using a dump radiator

11 Combined heat and power (CHP) unit supplied was not to UK specifications. This has been corrected and 95% commissioning is complete. Awaiting a final electronic control part.

12 Digestate quality is excellent and Lilac Farm has expressed an interest in utilising and spreading on its farm. Digestate analysis is currently underway.

13 Lessons have been learnt with regards to harvesting and supply of wetland biomass

i) During dry weather conditions, harvesting soft rush using conventional harvesting operation (weather permitting) can produce biomass at the requisite length.

ii) It is well known in the agricultural field industry that the prefer moisture content at the point of harvesting when ensiling grasses is between 67 and 72% (70%) with a size cut of 6 to 9 mm (up to 12 mm max). The length of the harvested biomass is key to ensure that the ensiling process is carried out successfully, minimising the loss of bio-methane potential (BMP) inherent in the wetland biomass. Biomass harvested in long lengths doesn't compact during the ensiling process, which prevents the trapped oxygen from scaping. The trapped oxygen causes fermentation processes to occur. These fermentation processes degrade the biomass. The BMP value of the biomass decreases as the ensiled biomass is degraded by fermentation.

iii) During wet weather conditions, specialised harvesting equipment like the PistenBully and the Softrak with low ground pressure is required to be used to prevent damage of the soil structure. Furthermore, conventional equipment could not been driven under waterlogged soil without risk of sinking or adversely damaging the soil structure.

iv) Harvesting using PistenBully supplied with a Kemper rotary crop header, developed for wetland biomass, needs to be operated at a slow speed (to give sufficient residence time of the harvested biomass within the cutting blade) and with a finer double chop cutting element could lead to delivery of biomass to the plant at the right cut size and has been confirmed by discussions with PistenBully. This is one of the learnings of developing a front end harvester for supplying an AD plant.

v) Initial operation of the Softrak supplied with a Elho double chop forager for harvesting soft rush produced cut size that was not appropriate for supply to an AD plant as the length of the material was exceeding the recommended length for ensiling. This unit (and the PistenBully) were being developed for wetland operation and these learnings need to be incorporated with suitable modifications.

vi) Transportation of harvested biomass can be effectively dealt with using conventional trailers for transport and front loaders for the ensiling operation

vii) Following best industry practice, NS designed the maceration unit to be fed with biomass of a particle size of no more than 60 mm. However, to meet these conditions has presented a challenge when harvesting wetland biomass as the particle size can vary from 12 to 300 mm. The long length material caused problems with the hopper of the maceration unit as the material was bridging preventing a continuous flow of feedstock to the AD process. Therefore, NS was looking at technologies and methods to provide the full scale plant with a homogenised particle size of below 60mm.

viii) An alternative approach to efficient cutting during harvesting is to install an on-site chopping unit for feeding the front end of the AD plant. Trials have been undertaken on a Kuhn unit which can achieve the appropriate cut size but requires additional energy (impact on LCA) and additional plant cost.

ix) Contract for the supply of wetland biomass will include feedstock specification, in terms of tonnages/annum, biomass length, moisture content etc. with suitable leeway given to parameters such as weather, flooding and the priority need of ensuring effective integration into wetland management programmes.

14 A detailed Process Cost Analysis has been undertaken that shows the viability of a 200 kWe pant with returns on internal rate of return (IRR) that would be attractive to investors.

15 Levelised Cost of Energy is £124/MWh which is favourable to similar sized wind and most solar photovoltaic (PV) energy schemes

16 A Business Plan has been developed that shows a wide range of potential applications with definitive potential for use on wetland biomass

17 A series of feedstock supply consideration points resulting from a brainstorm of information from different parties have been drafted. These are a range of issues that might need to be considered by the wetland nature reserves as a basis of discussions for an eventual feedstock supply agreement. One approach could be based on a limited rolling time (1 year), whilst other thoughts are based on a community based energy service company (ESCO).

1.3 EXPLOITATION AND EXPECTED IMPACT

NS has discussed the use and integration of its AD technology with wetland reserve managers and is in the process of pursuing through a draft Contractors Agreement to initiate discussions, which could lead to a finalised supply contract. NS is also in discussions with trusts, farm, agricultural and rural communities, small and medium sized enterprises (SMEs) and large scale food manufacturers, abattoirs, communities and rural businesses. NS is currently completing its DECC funded Wetland Biomass to Bioenergy Project and is now seeking funding to establish a 200kWe AD plant. Rates of return and payback periods are attractive (between 11.6 – 21.9%) and dependent on a range of parameters.

An analysis of potential wetland biomass availability has shown that there could be 3 full scale plants local to the the current site, one of which includes the demonstration site. Further analysis of wetland biomass potential has shown a possible UK potential of 60 NS based AD plants. Furthermore, these plants, because of its scale would fit a distributed energy scheme with local utilisation of both electricity and heat.

The NS AD plant as developed, can also be used as a co-digestion plant utilising wetland biomass together with outputs from rural farm, food and community based schemes. The technology can also be implemented (after proving on varying feedstock) at SME food manufacturing sites. Analysis has shown that the UK has a potential (based on waste/feedstock estimates) of approximately 5000 individual, 200kWe AD plants. If 1500 – 2000 of these plants were commercially viable, the estimated value would be in the region of £1.5 Billion.

2 SECTION 2 – BACKGROUND

2.1 OBJECTIVES

The Wetland Biomass to Bioenergy programme required a number of challenges that needed addressing, with particular emphasis for utilisation in the NS AD plant. The overall objective was the development of a cradle-to-grave approach, i.e. from harvesting on a wetland reserve, to collection, transportation to an operational AD site; ensiling, feeding the primary front end AD plants installed feeding unit followed by processing and conversion of this high ligno-cellulosic biomass to biogas, which could then be converted to useful energy (electricity/heat) and/or higher value chemicals. The solution needed incorporation of this approach, into a sustainable wetland reserve management operation and an implementation of this solution on a commercial footing. Furthermore, the solution proposed needed to prove and demonstrate, using plant data, that the technology solution proposed would offer a significant improvement on current GHG and LCA, based on DECC supplied counterfactuals.

The initial step of harvesting, collection and transportation to site faces difficulties in terms of access to a wetland reserve, minimising damage to soil structure, being very weather dependant, possible only during certain annual time periods that follow wetland reserve management criteria and requiring low ground pressure harvesters (i.e. a tracked vehicle) that can access difficult topography, yet maintain cutting rate and volume collection for delivery to the collection point. The collection point may itself need to be serviced by a tracked vehicle for transport to a delivery point for loading onto trailers for conveyance to site. The cut size is extremely important for a designed plant, as all subsequent plant equipment are sized to incorporate the specified size fraction and is a major challenge when developing the appropriate harvesting solution, as it impacts on both the ensiled quality and retention of BMP potential as well as process equipment operation.

Wetland biomass, e.g. soft rush and common reed are high ligno-cellulosic plant matter. The lignocellulose content increases with plant age and as machine based large scale harvesting is not the norm, then plant matter which could be anywhere between 5 and 15 years may require processing by the AD plant. This puts further constraints on a biomass, that does not have a high BMP potential and requires developing/incorporating suitable innovative technology for enhancing conversion of biomass to biogas.

NS's specific Phase 3 objectives of the programme are detailed below:

1. To finalise plant commissioning and complete trials on wetland biomass
2. Undertake trials on ensiled mix of approximately 80% soft rush and 20% common reed
3. Undertake trials on freshly cut soft rush
4. Determine and optimise biogas conversion efficiencies and biogas composition for 2 and 3 above.
5. Undertake a detailed GHG and energy LCA on the utilisation of wetland biomass based on DECC stated counterfactuals
6. Learnings from the overall harvesting/delivery supply chain and its impact on the NS AD technology and wetland management
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2.2 DETAILED DESCRIPTION OF THE END TO END PROCESS

This section includes a detailed description of the process from harvesting to energy production. Costs for harvesting are detailed in a later section.

2.2.1 HARVESTING TECHNIQUES

As part of the Wetland Biomass to Bioenergy project Natural Synergies had worked together with AB Systems Ltd who were developing harvesting technologies as part of another project also funded by the DECC Wetland Biomass to Bioenergy programme. AB Systems Ltd were working with the PistenBully and Softrak cutting and harvesting systems and details of these systems have been published elsewhere.

One aspect that has been observed with the harvested wetland biomass (soft rush or common reed) has been the nature of the material. This was found to be different depending on the type of equipment that was used during the harvesting operation. To ensure good packing, eliminate excess oxygen, prevent butyric acid accumulation and minimise spoilage losses of the wetland biomass must be cut to a particular size before ensiling. Discussions before harvesting stated that NS required a plant cut size of between 6 mm – 8 mm. This was stated to be achievable by the equipment supplier. However, as this was the first time that the equipment was being used, the actual size was to be determined during the harvesting period.

2.2.1.1 PistenBully

The PistenBully used during harvesting was supplied by PistenBully in Germany and is equipped at the front with a Kemper header. Details of the PistenBully have been provided in a previous NS report. Photographs of the material harvested using the PistenBully are shown below:


Typically the length of the harvested soft rush varied in size from 20 to 30 mm to over 140 mm. The cut size of the common reed was similar.

The cut size that was being achieved was discussed with the manufacturer and equipment supplier. They suggested that what was required was a finer double chop cutting element, (i.e an increase in the number of cutting teeth) and furthermore, the harvesting speed needed to be slowed down to give sufficient residence time of the harvested biomass within the cutting element. The harvesting operation with the PistenBully is a developing and learning process and it is anticipated that future harvesting operations with the correct cutting implement will achieve a smaller cut size that is required for successful ensiling of the harvested biomass.

2.2.1.2 Softrak 120

Softrak 120, is a harvesting equipment that has been recently developed and supplied by Loglogic, a UK company based in Devon. The newly developed Softrak 120 debut trial was cutting soft rush at Catcott Lows Nature Reserve in July 2014.


Two loads of soft rush was cut using the Softrak. After carefully observing the cut size that was being achieved, harvesting operation was discontinued. The cut size of the soft rush that was being achieved by the Softrak was at times well in excess of 300 mm. This excessive particle size would lead to difficulty in future plant operations.

A further observation was made during the ensiling operation (shown below)

It was observed that due to the very long cut length of material that had been supplied, one part of the ensiling operation, which utilises a tractor to drive over the stored material as a means of minimising and driving out air from between the chopped biomass (i.e. compacting), was found to be inefficient with the long lengths acting as a cushion (spring) and preventing compaction. This would lead to poor quality of the ensiled material, leading to a reduction in the energy value of the ensiled biomass.

2.2.2 TRANSPORT AND STORAGE

Transport of the biomass to the storage area is carried out with conventional agricultural equipment.

Figure 1: Conventional agricultural Equipment to collect biomass at the wetland reserve and transported to the AD site location for ensiling

The harvested material collected in the PistenBully bin was transported to a collection point with easy access to a tractor Case MXM155 PRO with a 25 m^3 trailer and loader (360 excavator 110hp, Hitachi GX 135). The harvested material was loaded to the 25m^3 trailer and transported to the silo clamp. A 122hp Terex t250 handler WX04 UVD was used to move the materials to the silo clamp and to compact the materials to remove any trapped air before being covered with two layers of high quality silage plastic sheets.

The first layer consists of a thin, flexible, clear, low permeability Polyethylene film based cover, specially designed to closely follow and cling to the clamp surface, these 'underlay' sheets prevent pockets of trapped air forming to significantly reduce aerobic spoilage on the top and shoulders. Because they provide an effective air seal and create the right anaerobic conditions, they also facilitate a faster, more efficient fermentation process to deliver enhanced silage quality.

The second layer consist of a thick High Density Polyethylene cover, with high resistance to ultraviolet (UV) light and high tear resistance and are easy to handle and recycle, to prevent materials to be in contact with light and air. To keep the pressure in the silo and to keep the cover in position used pneumatics are distributed on the top of the High Density Polyethylene cover.

The effluent produced by the ensiling process will be collected to prevent any seepage to water courses. This effluent will be fed to the AD plant.

For the purpose of the DECC project the existing silo clamp at Lilac Farm, located in Westhay, is being utilised. The dimensions of the silo clamps at Lilac Farm are:

- 100ft x 30ft (30.3m x 9.1m) covered pit with concrete floor and 12ft (3.7m) concrete side panels.

NS's Phase 2 report provides a detail description of the ensiling methodology utilise for storing harvested soft rush, common reed and associated grasses. Figure 2 illustrates photographs of the silo clamp at different stages of construction. The silo clamp has been constructed to store one layer of soft rush, followed by a second layer of common reed placed on top of the soft rush.

Figure 2: Different Stages of the ensiling process

2.2.3 PROCESSING & CONVERSION TECHNOLOGIES

The NS AD plant utilises a number of innovations to achieve high conversion efficiencies at an acceptable equipment capital costs. The design requires feed biomass to be reduced to an appropriate size for pre-treatment to enhance biomass conversion rates and efficiencies.

Initially the wetland biomass is removed from the silage clamp and loaded to the top of the hopper. The hopper feeds the material into a chamber where it is mixed with water/digestate and then first passed through a shredder/macerator and then subsequently through a chopper that reduces the shredded biomass to below 12 mm. The hopper has to be designed to cope with particle size above 10 cm to prevent bridging of the biomass. The size reduced material is then fed into a storage tank.

As required, the material is passed onto a pasteurisation tank which holds the material at 70^{o}C for 1 hour, from where it is fed to the feed buffer tank. Material can also be fed directly from the storage tank to the feed buffer tank by-passing the pasteurisation unit. The feed buffer tank has an ultrasound unit installed in the pipework.

Once the biomass stored in the feed buffer tank has been pre-treated, it is then fed directly into the digester. The digester, which is horizontal in design, is operated under thermophilic conditions. Materials pass along the full length of the digester amd are discharged as required by a pump into the slurry lagoon. Some of the digestate is recycled back to the hopper for use as a dilution media for the incoming fresh material placed in the hopper. Biogas generated within the digester is fed under pressure to the thermal treatment container that houses biogas and back-up oil boilers and the CHP engine. Biogas composition is monitored continuously using a gas analyser and biogas flow is monitored using a mass flowmeter.

Each process item is briefly described below:

2.2.3.1 Pre-Treatment Unit

The pre-treatment unit is critical to the AD process as it ensures a homogeneous feed to optimise bio-methane potential. Therefore, the design of NS AD plant includes three units as part of the pre-treatment system, these are:

- Maceration Unit
- Pasteurisation Unit
- Ultrasounds Unit

The NS AD plant design includes the installation of an odour control system. The main source of odour in the pre-treatment unit will occur during the transfer of the biomass into the maceration hopper. The Pre-treatment unit is skid mounted with no open tanks. The vents of the tanks are connected to a common ventilation duct which has been provided with a passive activated carbon filter. To minimise the parasitic load of the plant, all tanks, digester and pipework have been thermally insulated.

The pre-treatment unit is located on an impermeable surface. Wash waters required for maintaining the pre-treatment unit and any spillages will drain into the underground storage (sealed system) and sent to the AD plant for processing.

The AD process requires a high degree of flexibility in the manner in which feedstock's are processed and the plant is operated to ensure maximum energy output. Operation of the pre-treatment unit involves a number of processes, which are summarised below:

- Maceration Unit

The maceration unit consists on a maceration system that brings the particle size of the feedstock bellow 12mm to maximise the availability of the substrate to the microbial population, enhancing the biogas production.

The maceration unit is operated 3 times a week to prepare feedstock at 12 % dry matter content with a particle size of less than 6 mm, which will be held on the pre-treatment tank.

- Pasteurisation Unit

The macerated material is pumped to the pasteurisation unit. The pasteurisation unit consists of a jacked heated stainless steel tank. The material in the tank is heated above 70 ^{o}C and maintained to this temperature for an hour to comply with publicly available specification (PAS) 110 regulations and to start the hydrolysis of the biomass. The pasteurised material is sent to a buffer tank which is a stainless steel tank where the material is pumped to the final step of the pre-treatment system.

- Ultrasounds (US) Unit

Discussions with a number of ultrasound suppliers have led to a particular unit being chosen for testing and demonstration. Ultrasonication generates alternating high-pressure and low-pressure waves in the exposed liquid. During the low-pressure cycle, the ultrasonic waves create small vacuum bubbles in the liquid that collapse violently during a high-pressure cycle. This phenomenon is termed cavitation. The implosion of the cavitation bubble causes strong hydrodynamic shear-forces. These shear forces disintegrate fibrous, cellulosic materials into fine particles and break the walls of the cell structure releasing more of the intra-cellular material, such as starch or sugar into the liquid. In addition, the cell wall material is being broken into small debris. Ultrasonication makes more of the intra-cellular material e.g. starch as well as the cell wall debris available to the enzymes that convert starch into sugars. It also increases the surface area exposed to the enzymes during liquefaction or saccharification. This increases the speed and yield of conversion processes and increases the bio-availability of the cell constituent, thus increasing the bio-methane potential of the substrate.

This technology requires low energy input and due to its low energy consumption, ultrasounds is a suitable technology for application to small scale anaerobic digestion systems.

2.2.3.2 High Rate Anaerobic Digestion

The pre-treated material is fed to the NS digester following a feeding process control sequence that ensures continuous homogeneous feed to the digester.

The digestion process is maintained in the thermophilic range, with overall operation temperatures of between 47 to 52 ^{o}C with a hydraulic retention time of 15 to 28 days. These two operational parameters maintain the feedstock pasteurised through the digestion process, ensuring the production of a pasteurised digestate that complies with PAS110 regulations.

The digester is insulated to maintain constant and uniform operational temperature along the length of the digester. Moreover, an external heat exchanger provides the heat requirements of the digester to balance energy losses. The heating media is water from the combined heat and power (CHP) engine or biogas boiler at 85 – 90 ^{o}C, which is supplied by the hot water system.

The digester consists of a horizontal stainless steel tank. The digester is mounted on cradles and located on a flat concrete area.

The AD plant is instrumented to maximise plant efficiency without jeopardizing safety. NS has considered potential safety issues throughout the design process of the plant. Therefore, the instruments installed in the NS AD plant will be required for process control and safety operations and this is reflected in the process control philosophy of the plant, hence in the design of the programmable logic controller (PLC) software.

The digester is fitted with a vacuum/ pressure relief valve and emergency vents to prevent excessively high or low pressures, which only occur in the unlikely event of abnormal fault condition. The valves and vents are safety devices and will not operate under normal operation conditions.

Zone classification of the plant requires any equipment within the gas line and in contact with the gas phase to be ATEX (French: ATmospheres Explosives) classified.

The digester unit is placed on an impermeable surface and any spillages from the digester unit will be washed in to the underground storage and sent to the AD plant for processing. In the case of a digester failure the materials will be collected in the open lagoon (impermeable sealed system) and safely disposed through an authorised route. The open lagoon has the capacity to hold the content of the digester.

NS digestion process has been designed to have a high VS conversion factor. Moreover, the pasteurisation unit together with the thermophilic process minimises the risk of pathogens in the digestate. Therefore, through the trials, the digestate was monitored to ensure that it is stable and in compliance with PAS110. Moreover, the nutrient value of the digestate was monitored to assess the environmental benefit to the area when used as a fertiliser. Phase 3, commenced with a retention time of 58 days (plant commissioning) and this was slowly reduced to a retention time of 28 days. During Phase 3 the retention time was initially maintained at 28 days and then slowly reduced during the Oct 2014 – March 2015 period, to the targeted minimum retention time of 15 days. During these trials, the minimum retention time at which the process was stable when treating biomass from a wetland environment was determined. To ensure that the process could be monitored extensive instrumentation of the AD process with on-line analytical equipment and with remote process control system, ensured that the AD plant could be monitored at all times and that historical data was recorded and available for analysis. Moreover, the biogas volume and composition was analysed by an on-line gas analyser to determine the quality of the biogas and estimate emissions from the engine. The gas analyser also gave an indication of the process efficiency and stability.

2.2.3.3 Biogas Unit

The main product of the NS AD plant is biogas which is converted into heat and electricity in a combined heat and power (CHP) engine.

The biogas produced during anaerobic conversion of the biomass is stored on the digester head space and sent to the Biogas Unit.

The biogas unit includes a combined heat and power (CHP) engine, a biogas boiler and a fuel oil boiler.

The parasitic load of the plant has been calculated to be 30% of the heat produced.

As part of safe system operations, both biogas boiler and CHP engine come fitted with flare arrestors installed and are part of the integrated instrumentation schedule.

The fuel oil boiler is only required during commissioning of the digester. The biogas boiler is required during maintenance of the CHP engine. The system has being designed to operate the biogas boiler in case of an emergency breakdown of the engine.

A 20 kWe asynchronous CHP engine has been incorporated as part of the plant design. The biogas boiler has been designed with excess capacity to ensure that it can take the maximum biogas produced in case of an emergency shutdown of the CHP engine.

The engine efficiency is approximately 30%. To improve the energy conversion and recovery in form of heat from the engine, NS is working very close with the engine supplier.

A mass balance on the biogas produced has been carried out to determine the estimated composition and the hydrogen sulfide (H_2S) produced will be approximately 0.05 Nm^3/day when running at maximum capacity. These low levels of H_2S will not be sufficient to produce an odour nuisance in the area.

The biogas unit is skid mounted and has been designed to fit within a twenty foot container. The gas unit comes with its local control panel which is remotely connected to the main plant PLC. The container has been designed with the correct ventilation and instrumentation to prevent any gas accumulation within the container that could create unsafe and toxic gas concentration levels within the container.

2.2.3.4 Digestate

The materials from the digester will be fed to the existing open lagoon, which is an impermeable sealed system, following a feeding sequence to ensure control of biomass removed from the horizontal digester. NS AD process will produce stabilised digestate that complies with PAS110 regulations.

Due to the high conversions of the feedstock into biogas, the produced digestate will be highly stabilised as the biodegradation process will be very slow at this stage, minimising the potential of producing pungent odours that could cause an environment nuisance.

The digestate produced is considered to be a valuable product (fertiliser) from the AD process. The nitrogen, phosphorus and potassium (NPK) value of the digestate depends on the type of feedstock being fed to the digestion process. A fraction of the digestate will be recirculated back to the front end of the plant to provide dilution required to maintain the dry matter content below 12 % in the pre-treatment system and to maintain nutrient levels in the digester. Digestate produced will be used as a soil conditioner/ fertiliser on the farm where the AD plant will be located. Section 4 provides the mass balance around the digestate production. Section 2.2.5 explains in detail the digestate utilisation as a by-product.

2.2.4 PRODUCTION AND TREATMENT OF ANY WASTE MATERIAL

NS's Anaerobic Digestion process has been designed to ensure that no waste is produced as the biogas (main product) will be converted into electricity and heat and the digestate (by-product) will be utilised as a dilution media of the feedstock and as a fertiliser.

The electricity produced will be sold to the grid. Part of the heat will be utilised within the AD plant to provide with the process heat requirements. Avenues to utilise the excess of heat will be evaluated on a project/ site basis. For instance, the heat could be utilised to dry the wetland biomass prior to being briquetted; or it could be utilised in a distributed heat system to provide heat to a small hamlet or any council building; it could be used to provide heat in greenhouses to grow vegetables. Heat utilisation will require careful consideration when designing the full scale plant for a particular site location.

2.2.5 POTENTIAL USE OF BY-PRODUCTS

Anaerobic digestion processes produce a by-product named digestate with an intrinsic fertiliser value. The digestate is formed by excess of AD bacteria and comprises primarily of some undigested biomass, inorganic compounds as well as stones, grit and fibres.

Investigation has been undertaken on the digestate with regards to its potential use as a fertiliser. Table 1 provides information with regards to various parameters on soft rush and common reed

The digestate that has been produced is of a very fine nature and one that can be very easily utilised by conventional farm slurry spreading equipment. A photograph of the digestate showing the extreme fine nature of the digested solids is shown in Figure 3.

Figure 3: Digestate Visual Appearance

Visual and odours inspections have been carried out to assess the quality of the digestate. The quality of the digestate has been shown to a number of visitors and to Lilac Farm, who have all expressed the ease of applying this digestate to land.

Moreover, total solids of the digestate has been monitored to assess its potential to be utilised to dilute the biomass feed. The average total solid concentration of the digestate is not higher than 3%. Therefore, we concluded that the digestate will be a good dilution media preventing the utilisation of water. Moreover, using the digestate to dilute the feed has reduced the amount of digestate sent to the lagoon. We are currently producing 5% digestate (percentage compared to the digester feed). A detailed mass balance is provided in Section 4. The vast reduction in digestate production will facilitate the digestate storage requirements during non-spreadable periods (Nitrate vulnerable zones (NVZs) regulations).

NS has carried out BMP tests on the digestate to assess methane potentially released to atmosphere. The results from the BMP test give single unit values showing that the potential of biogas released by the digestate is very low demonstrating the quality of the digestate. Due to its quality, the digestate produced will be in compliance with PAS110.

Table 1 below shows potential nutrient value of the digestate

Components	Units	Biomass		
		Common reed	Soft rush	
Dry matter	%	40.6	41.9	
VS	%	92.0 - 96.0	92- 96	
Ash	%	2.4 – 2.7	2.0	
Moisture	%	59.4	58.1	
Nitrogen	%	3.4	3.3	
Phosphorous	%	0.03	0.05	
Potassium	%	0.13 – 0.24	0.36	
Zinc	mg/kg	4 - 6	27	
Manganese	mg/kg	41 - 49	235	
Copper	mg/kg	2 - 4	2	

Magnesium	%	0.02 - 0.03	0.07	
Calcium	%	0.01 - 0.08	0.18	
Sodium	%	0.01 - 02	0.14	

Table 1: Preliminary analysis on materials potentially contained in the Digestate

2.3 ENVIRONMENTAL AND REGULATORY REQUIREMENTS

NS has considered the following environment & regulatory requirements on the implementation of a full scale anaerobic digestion plant as a wetland biomass to bioenergy end-to-end process.

- Nature reserves conservation requirements
- Planning permission
- Environmental permits
- Grid connection requirements

2.3.1 NATURE RESERVES CONSERVATION REQUIREMENT

Nature conservation in England has a strong basis in legislation. This has been essential in the lowlands, where the pressures for 'improvement' of land are intense. Legislation has helped sustain some biodiversity value, but only for the designated sites. There is a variety of protective designations that have ensured the safeguard of UK most important sites. To protect these designated areas good management practise needs to be implemented, for instance, management of plant species such as soft rush and common reed or good control of water table. Neglection on the management of these sites causes impoverishment of the biodiversity of these areas.

Therefore, the folowing points could be consider to ensure the biodiversity of these areas:

1. Survey on the nesting periods for the different nature reserves to ensure that no harvesting is carried out during these periods. Understanding the windows of opportunity to carry out the harvesting it is crucial to preserve the biodiversity of a particular site.
2. Important consideration needs to be given to harvesting technology. The technology to be deployed will have to ensure minimal damage to flora and fauna from a wetland environment. Therefore, the use of small scale harvesting technology with low ground pressure will be most favourable. Another important requirement will be ease of manoeuvrability and the ability to reach all types of terrain safely with proven operability within a wetland environment.
3. Measures to reduce the risk of spreading invasive species during harvesting operations:

- Surveys could be carried out on sites to be harvested, to locate populations of invasive plants to design a management plant to prevent further spreading of these species.
- Machinery could be inspected for plant fragments before leaving and entering site.
- Boots could be inspected and washed before leaving and entering sites.
- Clothing could be inspected for plant fragments before leaving and entering sites.

Section 2.3.3, explains the implications of the location of an AD plant adjacent to a protected site. To obtain a EA permit for an AD located close to a protected site, there are some conditions that needs to be met to ensure that the environment impact is minimal.

2.3.1.1 Protected sites

2.3.1.1.1 Internationally important sites:

Special Areas of Conservation (SACs) are classified under European Union Directive 92/43/EEC known as the ‘Habitats Directive’. This promotes the conservation of important, rare or threatened habitats and species across Europe. It lists 168 natural habitat types for conservation by designation as SACs, and 632 species whose conservation requires designation of their habitat as SACs. Those habitats and species at greatest risk are given ‘priority’ status.

Special Protection Areas (SPAs) are classified under the European Union Directive 79/409/EEC, known as the ‘Birds Directive’, to conserve the habitats of certain migratory or rare birds. Together, SACs and SPAs form a network of protected sites that make up the **Natura 2000** series. The UK Government has made a formal commitment to maintaining these sites in ‘favourable conservation status’.

Ramsar sites are internationally important wetland areas designated under the 1971 Ramsar Convention on ‘Wetlands of International Importance, especially as Waterfowl Habitat’. The Convention defines wise use of wetlands as “the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development”. Wise use can thus be seen as the conservation and sustainable use of wetlands and all the services they provide, for the benefit of people and nature.

2.3.1.1.2 Nationally important sites:

Sites of Special Scientific Interest (SSSIs) are selected by Natural England (government's adviser for the natural environment in England) and protected under the Government’s wildlife legislation, strengthened by the Countryside & Rights of Way Act 2000. They form a nationally important series of the best and rarest examples of our wildlife and geological features.

National Nature Reserves (NNRs) when designated as SSSIs are managed by Natural England, or approved partners, specifically to conserve their wildlife features, and to allow people to experience nature at its best.

2.3.1.1.3 Locally important sites:

Local Nature Reserves (LNRs) are declared by local authorities, in consultation with Natural England, under Section 21 of the National Parks and Access to the Countryside Act, 1949. They are sites with wildlife or geological features that are of special interest locally, which give people opportunities to study, enjoy and have contact with nature.

Sites of Importance for Nature Conservation (SINCs) are identified by local authorities, with the assistance of county Wildlife Trusts, and used to inform planning decisions at the local level. This type of site has been recognised by Government as helping to contribute to the wider delivery of the Biodiversity Action Plan.

2.3.1.2 Wetland Reserves in the Somerset Levels

Discussions with wetland reserves site managers and Sally Mills from the Royal Society for the Protection of Birds (RSPB) has identified the ecological cycles in the different wetland reserves to identify the harvesting periods that minimise environmental impact during harvesting activities. The identified harvesting periods are typically July to September for soft rush and October to January for common reed.

Important consideration has been given to the harvesting technology that could be deployed. The technology to be deployed was chosen to ensure minimal damage to flora and fauna from a wetland environment. Therefore, the use of small scale harvesting technology with low ground pressure was considered to be most favourable. Another important requirement was the ease of manoeuvrability and the ability to reach all types of terrain safely with proven operability within a wetland environment. Site managers had also expressed their preference for the utilisation of tracked vehicles.

Moreover, from the harvesting trials, it has been identified, that a combination of the PistenBully and Loglogic Softrak tracked vehicles will be the best applicable technologies when harvesting wetland biomass. The PistenBully would be utilised when manoeuvrability from the smaller Softrak is not required as the PistenBully will provide the larger biomass volumes required to be harvested, in a reduced period of time. Harvesting using PistenBully supplied with a Kemper rotary crop header, developed for wetland biomass, needs to be operated at a slow speed (to give sufficient residence time of the harvested biomass within the cutting blade) and with a finer double chop cutting element could lead to delivery of biomass to the plant at the right cut size for ensiling. The Kemper rotary crop header operated by the PistenBully is too large to be powered by the smaller Softrak, which can only be operated with headers of similar size to the Elho double chop forager. The Softrak needs to be operated at a slow speed to ensure sufficient residence time of the biomass within the cutting blades.

Visual inspection of the sites was carried out during and after harvesting to assess compaction of the soil. The visual inspections confirmed that utilisation of tracked vehicles had minimal impact on soil compaction and would not present an environment impact to wetland reserves. However, management procedures should be implemented to minimise soil structure disturbances and compaction before harvesting activities can proceed. The two sites where harvesting activities were undertaken are:

- Catcott Lows Nature Reserve: soft rush harvesting was carried out in summer 2013 with conventional agricultural equipment under dry soil conditions and in summer 2014 with PistenBully and Softrak under wet conditions after some grazing had been permitted.

  In Summer 2013, the weather conditions where very dry allowing conventional agricultural equipment to be utilised to carry out the harvesting of the soft rush in Catcott Lows Nature Reserve. The dryness of the soil together with the soft rush growth in summer 2014 could imply minimal impact with regards to soil compaction. Soil compaction tends to occur when heavy equipment repeatedly tracking up and down on muddy wet soils. This compaction can greatly impede the plant’s ability to access nutrients and water as the roots cannot penetrate the soil, causing poor plant growth. However, to confirm no compaction of the soil a visual assessment of the soil through excavation would be preferable.

  The photos below shows visual inspection of the soil and vegetation before and after harvesting in Catcott Lows Nature Reserve.

Figure 4: Catcott Lows Nature Reserve summer 2013 before harvesting with conventional agricultural equipment was carried out. We can see tufts of aged soft rush not been previously harvested.

Figure 5: Catcott Lows Nature Reserve summer 2014 before harvesting with PistenBully and Softrak. We can see the same tufts as in figure 6 with new soft rush grown after last year harvesting. The new growth could be an indication of the low soil damage/ adverse effects.

Figure 6: Harvesting activities with PistenBully. Material was being collected by a tracked vehicle, which was taken to a dumped point. The 360 excavator would then pick the material and transfer it to a trailer pulled by a tractor. This area was located close to the entrance.

Figure 7: Catcott Lows Nature Reserve after harvesting. Monitoring of the same soft rush tufts showed growth from last year harvesting. This growth could be a sign of low compaction

Figure 8: Catcott Lows Nature Reserve collection area showing potential signs of soil compaction. This small area is located close to the entrance. Visual inspection will be carried out to assess vegetation growth after soft rush collection activities

- Ham Wall Nature Reserve: Harvesting 2013 & 2014 with PistenBully and Softrak under wet soil conditions. Annex 1 details the report on Ham Wall Nature Reserve soil assessment after harvesting activities. The report has been provided by Sally Mills (RSPB) and was commissioned by the RSPB. The assessment looks at the quadrat, soil cubes and infiltration overviews.

RSPB reported that ‘the site had been grazed by cattle between last years and this year’s vegetation cutting, and there were minimal signs of poaching in some areas. There were a few areas where the machinery had got stuck last year, but evidence of any damage twelve months on was difficult to determine, especially with the addition of the cattle and obvious footfall from them in some areas. The site was accessed by the Softrak and the PistenBully, with the whole site being cut and the material removed in about a day and a half’.

The Following Photographs visualise the soil conditions after 2013 harvesting period.

Figure 9: Soil Conditions after 2013 harvesting with PistenBully.

2.3.2 PLANNING PERMISSION

NS AD plant and overall system has been designed to consider the provisions required for planning permission.

NS AD plants are designed to minimise environmental impact to air, soil and water course.

During the DECC project, we have identified two major source of potential contamination to *water courses*, that is, the silo clamp leachate and a catastrophic tank failure of the digester. In both cases mitigation measures had been allocated to prevent contamination of water courses.

The leachate from the silo clamp was collected and sent to the front end of the AD plant to be processed. The AD plant, including the digester, was located in a bunded area. Any spillages were collected and sent to the AD plant to be processed. In the unlikely event of a catastrophic tank failure, the contents of the digester will be collected and disposed via a suitable route.

The Digestate was stored in the digestate lagoon which is a sealed system. For the Full Scale plant a covered lagoon would be installed to prevent overfill of the lagoon with rain waters. Bore holes around the lagoon would be monitored to ensure that seepages from the lagoon do not occur.

To mitigate *odour* nuisance, NS has incorporated an odour control system in its design, which consists of a carbon filter unit that collects the vent gases from the pre-treatment unit tanks. Moreover, operation procedures are put in place to maintain the site in good conditions minimising odour sources.

The main source of *noise* is the CHP engine. To mitigate the noise of the engine to acceptable levels, the engine is enclosed in a sound proof enclosure. Moreover, the CHP engine is placed within a container thereby further minimising noise emissions. These two measures, has ensured that noise levels from the CHP engine are reduced to acceptable levels. The maceration system is placed within a shed and will be operated during normal working hours. Therefore, to manage the noise levels even further, standard operation procedures (SOP's) have been put in place, for instance, ensuring that the operation of the maceration system is carried out only at certain times of the day.

The small amount of feedstock and digestate produced in the AD plant implies that the *transport* movement required are not significant. Typically, if we assume 10 Tonne load per movement and a total of say 3750 Tonnes of biomass required per annum, would lead to 375 transport movements of agricultural biomass per annum. This would be focused during harvesting periods as specified by wetland reserves. However, currently either harvested wetland biomass is already being transported from reserves negating any additional impact, or they are left to decompose on the ground resulting in uncontrolled greenhouse gas emissions. The full scale plant will be located adjacent to the silo clamp and the digestate storage tank, therefore, road transport movement would only be required when transporting the biomass from the wetland site to the AD facilities and when the digestate is taken away by the farmer to be spread on his land.

To assess the impact of the AD operations to *air quality* the air quality strategy report for Somerset has been considered. Annex 4 Part 2 of the report provides the current status of air quality for Mendip District Council. The conclusions of the review and assessment process states that it is very unlikely that air quality objectives will be exceeded at any location across the district. The third round of review and assessment started in 2006 were emissions of nitrogen dioxide, particulate matter up to 10 micrometers in size (PM10) and carbon monoxide were analysed at different points. The Updating and Screening Assessment (USA) report concluded that there was no risk of exceeding air quality objectives.

Conversations with the environment officer of Mendip District Council and the environment officer in charge of AD from the Environment Agency, have confirmed that the project will not fall under the Clean Air Act and that the nearest zone regulated by the Clean Air Act was Bristol and furthermore the installation of the small scale AD plant will have little impact on air quality.

Moreover, planning legislation on anaerobic digestion plants estates that on farm AD plants with a foot print of less than 500 m^2 doesn't required planning permission, it only requires notification. Therefore, the NS AD demonstration and full scale plant will only require notification to the planning officer. NS has notified the planning office of the AD Demonstration plant at Lilac Farm.

2.3.3 ENVIRONMENT PERMIT

Wetland biomass harvested and collected from a reserve is considered as waste by the Environment Agency (EA). Use of this material therefore has legal implications in that any demonstration or full scale plant must obtain an environmental permit, exemption or trial consent. Without a permit or an exemption in place, the plant/trials could face prosecution by the EA.

NS AD Full Scale plant complies with T24 exemption – Anaerobic Digestion at Premises used for Agriculture and Burning of Resultant biogas when located on a farm; or T25 exemption – Anaerobic Digestion at Premises not used for Agriculture and Burning of Resultant Biogas if located at a reserve centre such as the Avalon Marshes Centre.

In terms of digestate spreading, the AD activities will comply with the US10 Exemption – Spreading Waste to agricultural Land to confer benefit.

Permitted activities must not be carried out within 500 metres of a International site, Ramsar site or a Site of Special Scientific Interest (SSSI) (excluding any SSSI designated solely for geological features). The permitted activities must not be carried out within a specified Air Quality Management Area (AQMA). The activities must be outside groundwater Source Protection Zone 1. Gas engine stacks between 3 metres and 7 metres in height have to be located 200 metres from any building used by the public including dwelling houses in cases where they do not have an effective stack height of 3 metres as defined by the rules.

All storage and treatment of waste solids, liquids and sludges shall also not be within:

- 10 metres of any watercourse

- 50 metres from any spring or well, or from any borehole not used to supply water for domestic or food production purposes, and
- 50 metres from any well, spring or from any borehole used for the supply of water for human consumption. This must include private water supplies.

These standard rules do not allow any emission into surface waters or groundwater except clean water from roofs and parts of the site not used for waste activity including storage of wastes. However, under the emissions of substances not controlled by emission limits rule, biogas condensate, treated digestate and waste waters may be discharged to a sewer subject to a consent issued by the local water company.

2.3.4 GRID CONNECTION

The approval by the disribution network operator (DNO) for grid connection of a 100 to 200 kWe AD plant doesn't present a barrier on the projects development. However, it is important to locate the AD plant on a site within close proximity to a transformer. If grid connection is not available close to the AD plant, the cost associated with the installation could be such that it can put the project development at risk.

Opus Energy has been appointed as the Power Purchase organisation. A Power Purchase Agreement (PPA) contract is required to ensure that NS can sell the electricity produced by the CHP engine and that it can claim Feed in Tariffs and Heat Incentives.

3 SECTION 3 – TRIALS & DEMONSTRATION

This report gives a description with the trials and demonstration carried out during Phase 3 of the Wetland Biomass to Bioenergy Project.

3.1 OBJECTIVES/ PLANS

NS has undertaken several trials during the Phase 3 demonstration period. The objective of the trials has been to maximise the biogas production from the wetland biomass used during the course of the trials, i.e. from soft rush and common reed. The trials carried out have been the following:

- Enzymes addition.
- Ultrasounds (US) application.

Enzymes & ultrasounds was applied to a feed composed of soft rush

Ultrasound was applied to a feed composed of approximately 20% common reed and 80% soft rush.

The following sections provide a detailed description of the trials that has been undertaken by NS.

3.2 SOFT RUSH – ENZYMES & US

3.3 INTRODUCTION

Lignin content needs to be considered when AD is selected as a bioenergy conversion process of wetland biomass in particular common reed and soft rush. Lignin is the second most abundant biopolymer in nature. The complex structure of lignocellulose prevents the economical use of plant polysaccharides or the potential use of lignin derivatives as feedstock on the production of bioenergy or ruminant feed.

The main components of lignocellulosic biomass, such as cereal straw, sugarcane bagasse and grass are cellulose and hemicellulose in close association with lignin. Cellulose and Hemicellulose are hydrophilic and Lignin is hydrophobic. These lignocellulosic materials are mostly insoluble in water and in organic solvents due to the hydrogen bonds between polysaccharides and adhesion of lignin to the polysaccharides.

Lignocellulosic biomass needs to be pre-treated physically, chemically or biologically to make available the plant content for microbial biodegradation in the production of bio-fuels such as biogas.

NS development to breakdown lignocellulosic biomass consists of the application of technologies that requires low energy input and that have a low environmental impact.

3.4 ENZYMES

3.4.1 HYPOTHESIS

Lignocellulose in plant cell wall is composed of cellulose (~45%), hemicellulose (~25%) and lignin (~ 1-35%). Cellulose is a linear polymer of glucose with β-1,4 glycosidic bonds. It has extensive hydrogen bonding that hold the molecule in a crystalline structure making it inaccessible to hydrolytic enzymes. Hemicellulose is also linked by β-1,4 linkages with different side groups such a sugars, sugar acids and acetyl esters which prevent the molecule from forming a homogenous crystalline structure. Lignin is an aromatic macromolecule made of Phenylpropanoid units in a condensed structure with more than 12 types of chemical linkages. The insoluble property of lignin makes it resistant to most forms of biodegradation.

However, research and development of novel enzymes have been carried in the animal feed and bioethanol industries to enhance the digestibility of lignocellulose contained in plant matter. For instance, the use of Xylanase, name given to a class of enzymes which degrade the linear polysaccharide beta-1,4-xylan into xylose, thus breaking down hemicellulose which is a major component of the cell wall of plants. These novel enzymes have been developed as an animal feed supplement to help with the digestion of cellulose, hemicellulose and lignocellulose materials. The enzymatic breakdown of these materials will release sugars, sugar acids and acetyl esters hence the bioenergy value.

3.4.2 METHODOLOGY AND ASSESSMENT

The potential increase of bioenergy will be monitored during the enzymatic addition at different stages of the ensiling and pre-treatment process. The results will be introduced in a model to assess the potential impact on Bio-methane generation which will be validated during the trials.

The results will provide information on the type of enzymes to be utilised and the period of contact with biomass required, before being diluted with water. However, these results will have to be validated on the demonstration plant by assessing the increase in biomethane composition in the biogas produced.

3.5 ENZYMATIC TREATMENT RESULTS

Phase 2 report provided preliminary trials results, to assess the best enzyme to be applied for soft rush (harvested in July 2013) and common reed (harvested in October 2013). The results determined the best enzyme/enzymes culture together with the time of contact required between the enzymes and the biomass to biodegrade the lignocellulose compounds. Samples of soft rush & common reed were macerated and mixed with enzymes to perform two different reactions, that is:

The first reaction consisted of a solution of water and Enzyme A

The second reaction consisted of a solution of water and Enzyme B

In both cases, the performance reaction showed that the trials were not successful when samples of soft rush & common reed were in contact with Enzyme A.

The results were very different when samples of soft rush & common reed were in contact with Enzyme B. The trials with soft rush were not successful. However, when common reed was in contact with Enzyme B culture the results shows a sugar release of 33µmol/g after an hour of being in contact. However, after six hours the sugar release decreased to 7µmol/g.

Biomethane Potential (BMP) tests were carried out to determine the potential BMP increase after enzymatic addition by comparing results before and after addition of the identified enzymes. The BMP results were inconclusive due to the challenge in preparing a representative consistence sample of biomass to carry out several BMP tests. Development work is being carried out to assess a suitable sample preparation methodology that will provide a representative consistence sample to carry out BMP tests.

The main challenge of the enzymatic pre-treatment is the application of the enzymes to the biomass. The enzymes are perishable when submitted to thermophilic temperatures and secondly and more importantly, they need to be applied on to the dried biomass before being diluted to maximise the mass transfer/ reaction between the biomass and the enzymatic culture.

Therefore, the ensiled material was the best point for potential application of the enzymes, before being sent to the maceration unit. The preferred moisture content at the point of harvesting when ensiling grasses is between 67 and 72% (70%) with a size cut of ¼" to 3/8" (up to maximum of ½ an inch). Therefore, the demonstration plant was designed to receive harvested wetland materials below ½ an inch. However, harvesting wetland biomass to the optimum specifications has proven to be a major challenge. The particle size of harvested materials varies from 1 inch to above 12 inches, making difficult to successfully apply the enzymes to the existing ensiled material.

3.5.1 WAY FORWARD

The design modifications introduced for the full scale plant will provide a potential solution to apply the enzymatic culture successfully. NS is assessing feeding systems that cuts and mixes the biomass to a homogeneous particle size before it is sent to the maceration unit to further reduce the particle size below 6 mm. The enzymatic culture could be added and homogeneously mixed and left for a period of time before being sent to the maceration system.

Plans are underway for trials to be performed on the full scale plant with enzymatic biodegradation of the lignocellulose compounds.

3.6 ULTRASOUNDS

3.6.1 HYPOTHESIS

Ultrasound is a mechanical acoustic wave with a frequency that can range from 10 Hz to 20MHz. It imparts high energy to the feedstock (biomass/water solution) by cavitation and secondary effects. In a typical dynamic process of cavitational bubbles, numerous microbubbles are generated that grow and undergo radial motion as acoustic energy propagates through the liquid medium. This microbubbles grow to a maximum of about 4-300 µm in diameter, and can be stable or transient. With low acoustic intensity, the radius of the microbubbles periodically and repetitively expand and shrink (radial oscillation) within several acoustic cycles. When acoustic energy has sufficient intensity, some microbubbles become unstable within one or two cycles, collapsing and creating special physical and chemical effects, enhancing thermochemical/ biochemical reactions or treatment.

The unsymmetrical collapse of bubbles produces micro-jets at high speed toward the solid wall cell surface. The instantaneous collapse of bubbles also produces strong shockwaves. This violent movement of fluid toward or away from the cavitational bubbles is defined as micro-convection, which intensifies the transport of fluids and solid particles and results in forces that can cause emulsification or dispersion depending on the conditions, while the strong shockwaves and micro-jets generate strong shear forces that are able to scatter liquid into tiny drops or crush solid particles into powder.

The chemical effect of ultrasonic energy comes from the local hotspots produced by cavitation. At the moment of bubble collapse, a huge amount of energy is released that cannot be immediately transferred to the surroundings. As a result, local hotspots are developed that have extremely high temperatures (~5000 °C), high pressures (~50 Mpa) and high rates of heating and cooling in the bubbles ($>10^9$ °C/s). The extremely high temperature and pressure can destroy the crystalline state of solid materials, cause solids to melt or fuse solid particles when they collide with each other.

Ultrasound technology gives a pre-treatment solution that provides high energy input to destroy lignocelluloses (hotspots), but remain at relatively mild conditions and low energy intensities such as room temperature, short treatment time and neutral pH values of solution preventing the denaturalisation of vitamins, proteins, organic compounds and other inner cell compounds required to enhance the production of biogas.

This technology has been successfully used for microbial cell lysis in sewage sludge to produce biogas. However, the novel application of this technology on high lignocellulose content plant matter requires further development to assess the best operation conditions of the ultrasound technology when applied to wetland biomass.

3.6.2 METHODOLOGY AND ASSESSMENT

The ultrasound (US) unit utilised during the trials consisted of:

- Industrial Ultrasonic Processor consisting of transducer and generator, with adjustable amplitude from 20 to 100%.
- Block Sonotrode connected with the transducer or booster for transferring the oscillations to the medium to be sonified.
- Flow Cell jacketed reactor
- Booster to increase (or decrease) the amplitude at the sonotrode.

The methodology followed on the US trials consisted in two steps:

- Step 1: Quantification of the biogas flow rate and composition before pre-treatment with US Unit
- Step 2: Quantification of the biogas flow rate and composition during pre-treatment with US Unit.

Both steps were carried out under the same operational parameters.

The digestion of soft rush before pre-treatment with US unit provides the basis of the trials to enable assessment of the improvement in biogas production and composition when the biomass is sonified.

3.7 ULTRASOUND RESULTS & DISCUSSION

The use of the US unit as a pre-treatment technology has improved the biomethane concentration in the biogas by 18.86% and the biogas production by 50%.

The ultrasound process was utilised (Phase 3 – Milestone 3 & 4) to provide enhancement and overall benefits to the anaerobic digestion process, hence the production and quality of the biogas.

3.8 DISCUSSIONS AND CONCLUSIONS

The Wetland Biomass to Bioenergy project comprises the end-to-end process from harvesting to energy generation.

The harvesting development and demonstrations to provide wetland biomass to an AD plant has been carried out by AB Systems Ltd. The utilisation of tracked vehicles such as the PistenBully and Softrak were the preferred vehicles for use during harvesting. The Softrak will be utilised in those areas where no straight access by the bigger PistenBully is available. A precision chop harvester head would be preferable in ensuring the smallest cut size possible as the length of the biomass is a limiting factor for successful ensiling.

NS has implemented changes and new ancillary equipment from the original design to ensure that a higher degree of flexibility (both plant and operational) were incorporated when receiving/utilising wetland biomass.

Moreover, the introduced equipment has improved the anaerobic degradation of high lignocellulose content in common reed and of the soft rush to a lesser degree.

The utilisation of the digestate as dilution media has reduced the amount of digestate produced minimising the storage requirements. NVZs regulations prevent fertiliser spreading for a period of four to six months. The storage of six months of digestate requires foot print and CAPEX, therefore reduction on the amount of digestate requiring storage, is reflected in the foot print area of the plant and the CAPEX required for a covered lagoon or digestate tank.

3.9 LESSONS LEARNED/ FUTURE IMPLICATIONS

Harvesting of the biomass is one of the most critical steps in the overall end-to-end process. The appropriate harvesting equipment and procedures needs to be put in place and implicitly followed by the harvesting operators to prevent compaction of the soil thereby having an adverse environmental impact on the wetland reserve. It is important that the wetland managers implement procedures to assess the best soil conditions prior to allow harvesting of the wetland reserve. In the same way, harvesting periods needs to be identified for each reserve to ensure that no damage to fauna occurs during harvesting.

On the other hand, harvesting activities needs to be carefully undertaken to ensure that the harvested biomass quality is sufficient to ensure successful storage of the biomass to prevent losses in the biomethane potential of the feedstock to the AD plant.

Therefore, further development in harvesting technologies and biomass storage needs to be carried out to improve the quality of the feedstock delivered to the anaerobic digestion plant minimising any environment plant to the wetland flora or fauna.

The bottleneck of the AD plant is the maceration unit. Going forward on the implementation of the full scale plant, a different hopper will be implemented. The feeder/hopper design integrates the solid feeder with the shredder. The material at the outlet of the unit will have a reduced particle size giving flexibility to the material that the AD plant can receive. Dilution of the feed will be added before the pump, providing the correct dry matter content is ensured so that the feed can be pumped. Moreover, the design of the hopper prevents bridging of the material inside the hopper.

Co-digestion of the wetland biomass with a high nutrient feedstock such as cow slurry will be advisable to maximise the biogas production.

As a process of continuous improvement, NS will keep assessing new technologies in other industry fields to maximise the biogas quality and production when digesting wetland biomass.

4 SECTION 4 – TECHNICAL ANALYSIS

This Report has compiled data required to carry out an LCA on the soft rush & common reeds utilized in the production of biogas in NS's Anaerobic Demonstration Plant. The LCA was carried out by North Energy Associates Ltd (NEA).

The report contains two sections: Section 1 – soft rush harvested in July 2013; Section 2 – common reed harvested in October 2013

4.1 SOFT RUSH

Phase 3 Interim LCA was carried out by North Energy Associates Ltd (NEA) in October 2014. The data provided to NEA consisted of performance data of the stabilised digester. However, two variations have been introduced on the process when treating soft rush, these are:

- Ultrasounds (US) unit.
- Digestate utilisation to dilute the biomass

Further trials with soft rush were carried out. However, due to the decomposition of the ensiled material the biogas production decreased dramatically. Once the digester was stabilised with the poor quality feed, trials were carryied out to optimise the digester hydraulic retention time. Due to the robust process the increase in the flow rate, hence organic load, did not affect biogas production.

NS considers this case as non-representative of a commercial plant, were the storage of the wetland biomass will prevent decomposition leading to loss of biogas potential.

4.1.1 HARVESTING – SUMMER 2014

Soft rush summer 2014 harvesting data was compiled after soft rush summer harvesting at Catcott Lows natural reserve. This data has been provided to North Energy Associates Ltd (NEA). Further Data has been collected from NEA by liasing directly with AB Systems Ltd. Conclusions from harvesting data are compiled in NEA report, which is included in Annex 8.

Dates: 29th & 30th of July

Harvested Material: New soft rush growth after 2013 harvesting

Distance: 3.6 miles each way

- ***Weighbridge:***

Vehicle: T6070 New Holland 150 hp

Weight of vehicle including trailer: 11980 kg

Net Weight (kg): 2780; 3000; 3140; 3520; 3600; 3240; 3460; 3240; 3660; 3600; 3760; 3730

Total Net Weight: 40,730 kg

Vehicle: FENDT 718 150 hp

Weight of vehicle including trailer: 12000 kg

Net Weight (kg): 2700; 3380; 3340; 3420; 2860; 3180; 3440; 3700; 3720; 3960; 4000; 3860; 4520

Total Net Weight: 46,080 kg

Total Material Harvested: 86,810 kg

- ***Total Diesel Consumption:***

Vehicle: T6070 New Holland 150 hp - Total Diesel Consumption: 70 litres

Vehicle: FENDT 718 150 hp – 7 litres per load x 13 loads = Total Diesel Consumption of 91 litres

Telehandler: Total Diesel Consumption 30 Litres

Vehicle: FENDT 718 150 hp used to roll the silo – Total Diesel consumption of 60 litres

- ***Trailer: Richard Western SF12 LX***

Silage Capacity: 27.77 m^3

Tare Weight: 3510 kg

4.2 COMMON REED

Common reed trials have been carried out with an approximate composition of 20% common reed & 80% soft rush.

The trials were carried out under the same operational parameters as the soft rush. However, a decrease in the biogas production rate was evident in a few days to levels, were the biogas boiler could no longer produce the required heat to the process.

Further particle reduction has proven to increase biogas production of the common reed + soft rush. Therefore, the data for the common reed LCA is provided below.

4.2.1 HARVESTING

The data required for the LCA of the soft rush & common reed needs to be taken from the harvesting activities carried out in July/October 2013. The data has been made available directly to NEA by AB Systems Ltd to carry out the LCA.

4.2.2 BIOMETHANE POTENTIAL

Biomethane potential tests were carried out to assess a potential correlation between the BMP values and the operational values when processing soft rush by itself and SR/CR to a composition of 80/20.

Parameters	Soft Rush	Common Reed
BMP Tests		
External CH4%	52	51.9
External Nm3/T	224.4	215.1
Internal CH4%	N/A	N/A
Internal Nm3/T	198	180

Table 2: BMP Results carried out in soft rush & common reeds Samples taken during summer 2013 harvesting operations

The BMP values are very similar to SR & CR. However, it has been proven that when digesting CR at a particle size of 6mm the biogas production decreases to critical levels. The introduction of the homogeniser brings the biogas production to healthy levels similar to those of soft rush (poor quality) after US. However, considerations need to be taken with regardto the increased power demand.

4.3 COST ANALYSIS

A detailed cost analysis has been carried out for a full scale 200 kWe NS AD plant. The analysis uses standard discounted cash flow analysis. Sensitivity to various parameters such as electricity and feedstock price, interest rate, electricity price fluctuation has also been determined. Levelised cost of electricity has also been calculated. The impact/reliance of renewable incentives has also been evaluated. A major impact of the analysis has shown that due to decreases in the Feed in Tariff (FIT) incentive rates for sub 250 kWe AD plants, the commercial size of the NS AD plant has had to be increased from 100 to between 150 – 200 kWe for commercial viability.

4.3.1 DISCOUNTED CASH FLOW ANALYSIS OF A 200 KWE NS AD PLANT

A detailed discounted cash flow analysis has been detailed in Annex 6. The analysis is based on estimates of plant capital costs and based on discussions and budget costs and estimates of full scale plant installation costs. Revenues are based from the sale of electricity and heat and renewable energy incentives, i.e. Feed in Tariff (FIT) and the Renewable Heat Incentive (RHI). A detailed estimate has been made on operating costs which includes, labour, consumables, cost (positive/negative) of feedstock, maintenance, site lease/rent, spare parts etc. Parasitic costs, for plant electric/heat consumption has also been taken into account.

Project installation costs, grid connection and planning and permitting costs have also been considered.

Plant costs are based on mechanical equipment (tanks, pipework, valves etc.); instrumentation (control valves, level gauges, thermocouples, flow meters etc.); electrical equipment which includes cabling for power and for instrumentation; control systems that include software and hardware (motor control center (MCC), invertors, transformers, power back-up), thermal plant (boiler and CHP) and containers to house thermal plant and control system.

Plant depreciation has been calculated over a period of up to 20 years. Finance has been calculated utilising a mixture of debt and lease finance, with repayment periods over a 10 and 5 year period respectively. Interest repayment rate has been set at 8%. Sales and cost inflation has also been included in the model.

Analysis has used the following values:

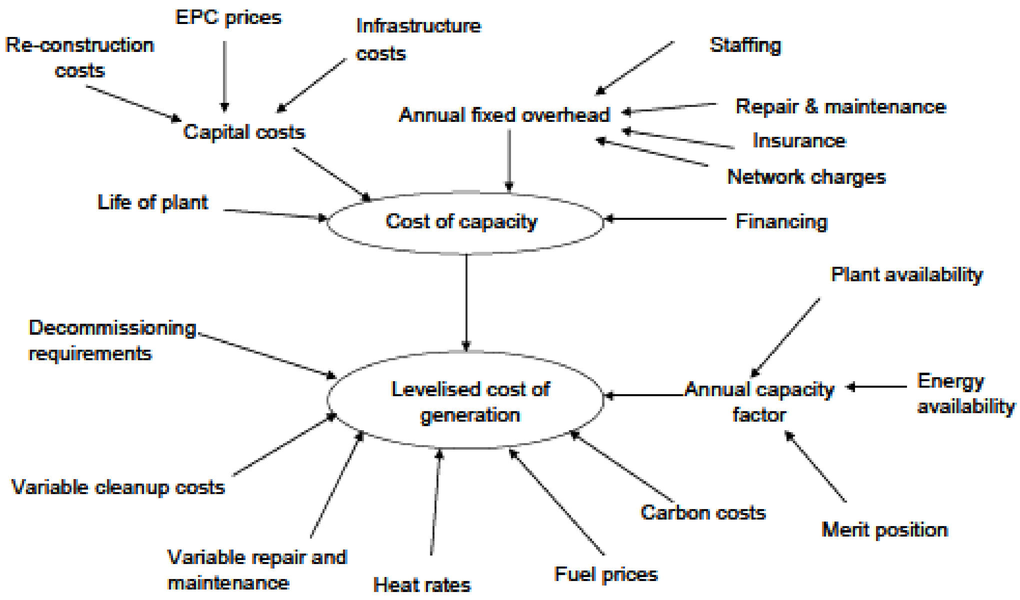
Total Project costs	£1,400,000
(Assuming 50% of the plant Capex is based on Lease finance)	
Interest Rate	8%
Capital Payback Term	10 years
Lease Finance period	5 years
Discount Rate for NPV(1)	10%
Electricity Price Inflation	5%
Labour Cost Inflation	2.5%
Maintenance Cost	6% of Total Project Cost.
Operator	£15625 (1 person x 0.5)
Spares	£2000 (this is in addition to maintenance costs)
Digestate Fertiliser	No income assumed. (Minimum £5/T based on NPK values)

(1)Net present value (NPV)

Outputs of the model are included in the business plan and shown as a sensitivity analysis.

4.3.2 LEVELISED COST OF ENERGY

A preliminary analysis of the cost of energy has been undertaken. Levelised Costs of Energy (LCOE) generation is an accepted methodology for comparing cost effectiveness of power generation technologies and shown in the diagram below.



The Levelised cost of electricity is a constant unit price (£/MWh) for comparing the costs of power plants that have different technologies, use different fuels, have different capital expenditure paths, differing annual costs (such as operating, maintenance, taxes, carbon prices), different net outputs, and different economic lives.

Industry figures and LCs, for AD plant costs (£/MWh installed) for medium/large scale farm/food waste AD plants (~ 1MWe) is ~ £4M - £7M, rising rapidly for decreasing plant size. NS project Capex expenditure for a 100kWe system is estimated at ~ £850k. LCs estimates for 100kWe & 150kWe are £140/MWh & £110MWh respectively and £78/MJ & £61/MJ respectively utilising FITs and RHI (50% heat utilisation).

	LC's (£/MWh)
Advanced conversion technologies	121.8 – 45.5
Dedicated biomass	126.0 – 143.0
Standard large scale AD	109.8 – 132.4
Standard small scale AD	122 0 – 194.0

This is in comparison to typical LCOE of developed fossil fuel systems of

GAS CCGT[(3)]	73 0 - 76
Coal ASC[(4)] FGD[(5)] with 300MW CCS[(6)]	112.0 – 121.0 (2025)

[(3)]Combined cycle gas turbine (CCGT); [(4)]Advanced supercritical coal (ASC); [(5)]Flue gas desulphurisation (FGD); [(6)]Carbon capture storage (CCS)

The above figures show that based on a LCOE, the energy system based on a combined cycle gas turbine is the benchmark, against which all renewable energies technologies being developed should aim towards.

There are various ways of calculating LCOE. The following approach has been used:

Initial cost - P	£1,400,000
Operation and maintenance – M	£73,000
Loan payments with interest - I	£203,830

Discount rate - R 10.00%
Energy output - E 1524240 kWh/year
Degradation rate - d 0.05%
System lifetime - T 20 years
The following equation is used to calculated the LCOE

$$LCOE = \sum_{t=0}^{T} \frac{P_{t+M_t+I_t}}{(1+r)^t} \div \sum_{t=0}^{T} \frac{E_t(1-d)^t}{(1+r)^t}$$

The result of the calculation shows that the LCOE cost of the NS AD plant based on present costs is £124/MWh.

As plants are produced and a regular supply chain is established, we anticipate that further refinements and process efficiency gains would reduce the LCOE to below £120/MWh

4.3.3 RATE OF RETURN ON INVESTMENT

The internal rate of return on investment (IRR) has been calculated for a range of scenarios.

The rate of interest used for borrowing capital and for lease finance does impact on the IRR. As interest rate increases, its primary impact is on IRR and on projects cumulative cash flow. As interest rate is increased from 3% to 8%, IRR decreases from 21.9 to 18.4 %.

A major impact on IRR, is that of any purchase costs of feedstock. If feedstock price cost is increased from £5/T to £30/T, IRR decreases from 18.2 % to 11.6%. However, if a positive feedstock price of £10/T was received, then IRR increases to 21.8%

The price of electricity has a major impact on IRR. As electricity price is increased from 5.7 p/kWh to 8.5 p/kWh, IRR increases from 17.2% to 20.6%.

The NS AD technology, although at the much smaller end of the overall AD plant size market sector, has a return on investment that would be favourably looked at by investors. However, both FIT's and RHI are essential in enabling the plant to be commercially acceptable to any investor project finance.

The above analysis shows the impact of some of the variables that could impact favourably or negatively on an NS project based on its AD technology. Other scenarios will require calculation on specific projects depending on feedstock.

4.3.4 COMPARISON WITH OTHER RENEWABLE TECHNOLOGIES, E.G. WIND/SOLAR

It is difficult at this stage to compare the NS AD technology with either wind or solar based renewable technologies as both wind and solar are not capable of supplying continuous power production as it is based on a discontinuous energy source.

LCOE of onshore wind is in the region of ~£90/MWh, whereas offshore wind is in the region of £130/MWh. However, these are for large scale installations on what is an established technology.

LCOE of solar PV greater than 50 kWe has been estimated. These range from £165 – 306/MWh with the best locations in the SW of England.

5 SECTION 5 – BUSINESS PLAN

5.1 INTRODUCTION

NS has discussed the use and integration of its AD technology with wetland reserve managers, trusts, farm, agricultural and rural communities, SME and large scale food manufacturers, abattoirs, communities and rural businesses. NS is currently completed its DECC funded Wetland Biomass to Bioenergy Project and is now seeking funding to establish a 200kWe AD plant. Rates of return and payback periods are attractive and dependent on available feedstock.

NS has integrated well established technologies together with its own pre-processing and digester technology to enable the creation of a potential zero waste AD operation. This is based on a modularized and skid-mounted AD plant (~150 - 200 kWe) using horizontal digesters. The build and technology model developed by NS overcomes the major hurdles in AD plant development in the UK.

The Wetland Biomass to Bioenergy project has enabled NS to develop their technology. A 20 kWe sized complete AD installation has been established, which includes, feed system, pre-treatment unit, digester, boiler/CHP container, control/operational container. The unit is operational. NS aims to grow its activities such that it has developed and will provide technical services to established plants.

5.2 NATURAL SYNERGIES VISION

Natural Synergies (NS) aims to provide integrated AD technology aimed at the sub 200kWe market.

NS's unique selling point (USP) is to establish an anaerobic digestion business that is economically viable at ~150 – 200 kWe AD plant; securing feedstock supply by locating plant alongside production source; minimising the difficulties for achieving planning and permitting; modularised system that could attract lease finance; good quality digestate for localised use/sale

NS aims to achieve this based on technology development by successfully completing a DECC funded Wetland Biomass to Bioenergy SBRI competition; installing small-scale AD facilities adjacent to businesses in the chosen markets of wetland reserves, agricultural, food, industrial, brewing and distilling; rural and community locations thereby securing feedstocks; increasing plant reliability due to identifiable, traceable and known feedstock.

This will lead to removing barriers by utilising; on-site palnning; on-site permitting; on-site grid connection and by removing/ reducing the need for transporting feedstock. NS will establish competitively priced renewable energy (heat/power) based on sustainable feedstock from selected rural, agricultural, industrial and community markets. NS business plan shows that an attractive business could be developed with a 10 year NPV of ~ £11 million.

5.3 STRATEGIC OBJECTIVES

The strategic objectives of this venture are to provide biomass waste producers, (wetland reserves, agricultural facilities, rural communities, food manufacturers, and waste recyclers) with a proven, disruptive, economically viable, small scale, modularised AD technology that overcomes the impediments of planning, grid-connection, transport and permitting. Provide NS with the opportunity to improve effectiveness by collaborating with partners who can bring essential skills in adjacent technologies, finance, land and waste management delivering early cash flows and minimising risk.

Currently NS has assembled all necessary supply chain technology providers and other partners to enable delivery of a small-scale plant for a range of potential clients. NS requires investor support, to develop into an independent AD technology project developer and supplier.

5.4 CURRENT ORGANISATION

NS is currently managed by its two founders Faisal Salam and Victoria Melchor. As the business is stablished and developed, NS will continually review its management structure and resourcing requirements. At the appropriate time NS will employ a project engineer and a commissioning engineer/ engineering manager to ensure smooth delivery of the first special purpose vehicles (SPVs). NS will contractually provide technical services for each plant.

5.5 ANAEROBIC DIGESTION OPPORTUNITY

5.5.1 SUMMARY OF THE MARKET OPPORTUNITY FOR ANAEROBIC DIGESTION

A number of market drivers are combining to create the opportunity for rapid NS‘s market sector AD exploitation. AD plants are attractive to:

- Wetland reserve managers as part of their overall wetland management plans are harvesting plant species such as soft rush, common reed and other plant biomass on an annual controlled basis. These types of biomass can effectively be utilised for providing a sustainable biomass feedstock to bio-energy conversion processes, generating renewable heat and electricity (such as NS AD process). Furthermore, this can be integrated into a community wide renewable energy scheme which utilises biomass from a number of sources enabling continuity of feedstock supply and regenerating rural enterprises.

- Many farmers are now looking to utilise slurries (potentially combined with grass and maize silage) in AD plants to provide part of their own heat and electricity requirements. This can be further enhanced with the addition of biomass feedstock from wetland reserves. In addition the digestate that is left following digestion is a clean and high quality fertilizer that can be safely reused as part of the fertiliser input for the growing of the silage.

- Rural/ Agricultural based food processing facilities can use their own organic wastes in closed loop systems so wastes can be used to generate heat and power for consumption on the site. They are therefore looking for integrated waste-to-energy solutions that provide some or all of their own energy needs and reducing their carbon footprint.

Meeting the UK's renewable targets will be aided by a rapid growth in 'green' locally produced distributed energy schemes.

5.5.2 SUPPLIERS AND CUSTOMERS

Sector specific stakeholder aspirations include:

- Wetland reserve organisations are seeking an outlet for their biomass cut during the course of the year as part of their wetland management programme. Biomass suitable for the NS AD plant could be made available from reedbed, wet grassland, lowland fen and upland acid grassland.

- There are aims to stablish 1,000 farm-based anaerobic digestion plants and some larger waste-linked farm based anaerobic digestion facilities.

- NS's modularised localised AD facility could be attractive to smaller brewing, distilling and food industries. These industries are also facing higher energy costs and require waste to energy solutions.

Green energy is increasingly attractive as community, crowd-funded based localised schemes which fit the NS model.

An estimate has been made on product hence NS AD potential

i) Food waste - viable feed stock 13 million tonnes

ii) Agricultural – animal waste and biomass

iii) Waste - source segregated/commercial & industrial ~ 35 million tonnes

iv) Distillery/Brewing – whisky and brewery industries ~ 3 million tonnes

Based on feedstock potential, the Total Potential Number of Plants is estimated at around 5000 (@ 200 kWe output) with an estimated value of between £5 - 6 Billion

5.5.3 WETLAND BIOMASS RESOURCE

The Wetland Biomass to Bioenergy project has enabled NS to identify a new sustainable biomass resource that has previously been unaccounted for use in anaerobic digestion plants.

Current available wetland biomass could be significantly increased, if a commercial outlet and use was made available for the cut biomass. The UK based sustainable biomass stock available for renewable energy utilisation could be significantly increased with wetland biomass produced from the management of the nature reserves.

A detailed UK wide market study needs to be undertaken to differentiate between resource availability and site based commercial viability. However, if we assume that 20% of this total can be utilised for NS based AD plant, then a conservative estimate of plant numbers would total in excess of 60.

If we focus on wetland based resource, agricultural and food waste, a limited number of segregated waste and agricultural sites then conservative estimate for the number of potential sites would reduce to between 1500 – 2000 plants with an estimated value approaching £1.5 Billion.

NS's aims at establishing in excess of ~50 plants in 10 years are prudent. A greater number of plants could be developed with the required gearing.

5.6 FINANCE

A number of discussions have been held with investor and business angels that have a strong interest in investing in small rural and community based renewable schemes.

The first group of investors are looking for proven technologies that require greater confidence than NS is currently able to provide and consider project costs greater than £3 million.

There are other UK investors who are considering near market ready innovative small-scale renewable technologies.

- NS has been approached by, and has entered into discussions with, a number of companies to discuss the options for collaboration and direct financing of project opportunities.
- NS is also discussing opportunities with community and rural investors that are interested in the sub 200 kWe market.

The NS business model utilises locally arising biomass (e.g. wetland biomass) and wastes combined with slurries and manures to produce locally required power and heat. By adopting this approach the "food versus fuel" argument is avoided and the clients get the linked benefits of lower power costs, lower effluent treatment costs and lower carbon dioxide emissions. In addition the NS model links with organisations that can provide some of the waste and also use some of the heat and power produced. This closed loop approach creates higher and more consistent financial returns.

The UK current energy production from biogas is estimated at 4500 GWh with a national renewable energy action plan (NREAP) target for 2020 of 20,046 GWh. This is a growth factor of 4.5 as compared with German growth factor rate of 2.1; equivalent to 175 (2MWe) or 1400 (100kWe) AD plants per annum. When compared to the potential barriers, perceived or otherwise that exists in developing a 500kWe + site in the UK, this growth factor could be quite ambitious to implement. However, the AD plant, as developed by NS, could form a vital part in meeting this implementation programme

The resulting business platform will be used to establish its commercially effective, integrated small scale, competitive and market leading small scale AD market technology.

5.7 CUSTOMERS AND MARKETS

5.7.1 WETLAND RESERVE ORGANISATIONS

These organisations are established not-for-profit entities that maintain and manage wetlands, by incorporating a well-structured and defined harvesting programme, which is particular to specific habitats and species. Currently biomass (e.g. soft rush, common reed, Glyceria etc.) are harvested at certain specific months during the year. Discussions with reserve managers, has confirmed that harvesting of soft rush could commence in some areas from the 14^{th} of July to the middle/end of September and in some reserves in October. Typical harvesting period for common reed is from November to the end of January. These harvesting periods are very dependent on weather conditions. An immediate implication of these restricted periods for harvesting is that there will be a requirement for ensiling harvested biomass. Discussions have been on-going with the RSPB (through Sally Mills), whose role in the DECC Wetland Biomass to Bioenergy project was funded by DECC and who has been instrumental in disseminating information of the trial progress to DECC and the wider nature reserves community.

A series of feedstock supply consideration points resulting from a brainstorm of information from different parties have been drafted. These are a range of issues that might need to be considered by the wetland nature reserves as a basis of discussions for an eventual feedstock supply agreement. One approach could be based on a limited rolling time (1 year), whilst other thoughts are based on a community based energy service company (ESCO), with a local, centralised ensiled silage storage depot, fed by participating supply members. This organisation could contract directly with NS to ensure continuity of supply.

5.7.2 FARMS

NS has been in discussions with a number of farms with regards to establishing and extending the next stage of the NS AD development. These sites can incorporate the use of wetland biomass together with other agricultural based feedstock as well as food waste. They have also mentioned investment in an SPV, as a partner to NS. These sites have been visited and current considerations with regards to planning, permitting and grid connection are being evaluated.

A number of potential farm based AD plants utilising maize/grass silage are being approached. Presentation to a group of prospective farmers/site owners has been given. It is envisaged that this will lead to a pre-feasibility study before commencement to a full plant build and would provide a full detailed individual negotiation with the identified farmer leading to a plant build.

5.7.3 FOOD MANUFACTURERS

Following the establishment of the DECC based NS working AD plant, visits are being organised. A more detailed presentation is given to senior managers. These companies had been contacted during the DECC project and have been awaiting development of a working demonstration unit.

5.8 OPERATIONS & FINANCE

5.8.1 OPERATIONS

NS will hold technical services contract for each SPV. NS will also seek opportunities to provide technical services for other plants to generate additional revenues.

An AD plant is reliable once it is commissioned and provided it only accepts feedstock within defined parameters. This is the principle advantage of an on-site plant as it prevents the need of continuously identifying and checking daily receipt of feedstock from various sources. The main day-to-day operation of the plant will be able to be monitored remotely using telemetry.

NS will train and validate the maintenance provider, in association with the relevant technology partners.

For Build and Own (BO) projects, NS will provide specialist technical support to the sub-contracted O&M provider who will be responsible for each plant and who will also provide advice on safe day to day operation of each plant. These operators (potentially sub-contracted) but may well be employees of the host site, will be fully trained and regularly reassessed by the NS and the O&M provider. In addition, all the AD plants constructed will be highly instrumented and will be monitored remotely at the NS headquarters and also by the control rooms of the O&M sub-contractors and by the site operators. This 24 hr monitoring will allow problems to be identified early and action to be taken to alleviate any problems.

Planned visits will be made by NS's team of engineers (sub-contractors) to ensure

i) Standard operation procedures (SOPs) are adhered to and

ii) Carry out any preventive maintenance to ensure design performance is achieved and to highlight areas for improved performance.

Operating experience elsewhere shows that the only substantial major expenditure to be expected at an SPV will be the replacement of major components of the gas engine approximately half way through the 20 year life of the plant.

Safety, health and environment (SHE) issues are relevant on two levels:

- The design and construction of the AD plants.
- The safety of the plants in use.

NS will draw on its safety, health and environment (SHE) systems, behaviours and management experience. This approach will be adopted and further developed to create a strong SHE culture that is directly relevant to the requirements of this business.

Despite the fact that AD plants produce and store methane they are generally safe as long as they are designed and built to a high standard of safety. To this end NS has developed a process to manage the SHE impact of all the plants it will develop. This process combines the project management process with the requirements of UK legislation together with good health and safety practice. The approach will be documented. Members of the NS team have designed, installed, commissioned and operated many process plants similar to AD plants.

Commercial AD plants will have to comply with the relevant legislative and regulatory requirements. NS has carried out work to identify the existing and developing requirements and standards for the UK market. However, there will be specific requirements for other markets.

The combination of sound design and modular construction combined with the process industry approach of NS's means that the plants that NS builds will be intrinsically safe. This will be augmented by rigorous training, monitoring systems and the development of a strong safety culture right across the organisation that will ensure that plant operations are undertaken to the highest possible standards.

5.8.2 FINANCIAL INFORMATION

NS has aimed at minimising the financial support required in its initial phases. However, working capital is required to cover start-up costs. It is likely that further funds will be required from other sources as the business develops, especially if Build Own SPV's are incorporated into the business model. It is assumed, funds will only be drawn down as required and that once a strong project pipeline is in place the business will be profitable. As previously outlined NS will receive fees for the services it provides to the SPVs on a plant by plant basis.

Managing Director and Technical Director salaries have been included in the start-up costs. This cost will be minimised as NS receives fees from technical services and consultancy work. Salary package that includes pension, private health and car allowance will be incorporated when the project is self-financing.

As each plant will be potentially different in feedstock (gate fee) it is not possible to demonstrate the actual returns that NS will receive. However, it is possible to demonstrate the principles that will be applied to an individual SPV.

Total Project Cost ~ £1,400k		Current Interest Case	High Interest Case	Low Interest Case	Low Electricity Price	High Electricity Price	Low Gate Fee Cost £-5/T	High Gate Fee Cost £-30/T	Low Gate Fee Income £10
Interest Rate	%	8	10	3	8	8	8	8	8
Number of Years **50% Capex Lease Finance**	Years Years	10 5	10 5	10 5	10 5	10 5	10 5	10 5	10 5
Electricity Price	p/kW$_h$	7.5	7.5	7.5	5.7	8.5	7.5	7.5	7.5
Feedstock Price	£/t	0	0	0	0	0	- 5	- 30	**+10**
EBITDA - Year 6 **EBITDA - Year 10** **EBITDA - Year 20** **IRR (10 Year)**	£k/yr £k £k %	412 516 11,236 19.4	412 516 11,236 18.4	412 516 11,237 21.9	378 475 10,344 17.2	431 540 11,732 20.6	394 497 10,831 18.2	302 397 8,805 11.6	449 526 12,047 21.8
Cumulative Cashflow (Yr 6) **Cumulative Cashflow (Yr 10)**	£k £k	898 2089	841 2005	1031 2285	760 1836	975 2231	819 1175	367 1270	1056 2362

Table 3: ***Sensitivity Analysis of Return.***

5.9 FINANCIAL PROJECTIONS ASSUMPTIONS

NS financial summary assumes that 50 plants with a total asset value of ~£37m are constructed over the 10 year period. It is assumed that NS receives income from:

- Fee of 20% on Capex of plant
- Technical Services Fee of 3% of sale

Under this base case scenario the financial highlights are as follows:

- NS requires development capital of £550k over a 2 year period
- Operating cash flow becomes positive in year 2.5 and grows to over £6 million p.a. in Year 10
- Cumulative cash flow becomes positive by year 3 and is in excess of £23 million in Year 10
- 10 year NPV of over £11M
- Value at Year 5 with a profit multiplier of 5, is in excess of £8 million

5.10 ASSUMPTIONS

The major assumptions on which the projections are based are included in the following sections

5.10.1 CORE COSTS

Core costs over a 2 year period (salaries including National Insurance).

Managing Director	150,000
Technical Director	150,000
Commercial/Finance Assistant	31,250
2 man office	12,300
Telephone and IT:	7,650
Travel & Subsistence	21,500
Central Services (Patents etc.)	21,500
Marketing	26,500
Total core business costs Over 2 years	**£420,700**

5.10.2 SPV DEVELOPMENT COSTS

This will vary depending on farm or food based locations and furthermore, from BO to direct sales. However we can estimate that SPV Project Development costs are estimated to range from £50k - £130k for each SPV.

5.11 FUTURE INVESTMENT REQUIREMENTS

The current funding will take the company through to profitability. No significant future investment is planned but, depending upon the pace of growth, management may decide that further funding is warranted in order to capitalise on an increased SPV deal flow.

5.12 EXIT PLANNING

It is envisaged that the most likely exit will be through a trade sale probably between Years 5 - 10.

Potential purchasers include:

- Other AD Technology Suppliers that would see NS as completing part of their technology portfolio.

- Energy generators, particularly those keen to ensure an appropriate ‘green’ component to their portfolio.
- Waste companies

No efforts have yet been made to identify or pursue these as it is deemed to be too early in the business life cycle.

5.13 RISK MANAGEMENT

NS proposes to manage its risks by:

Using proven technologies from reliable suppliers.

Establishing structured technical services to ensure that the plant is operated according to established operation and safety procedures as defined in management system

Introducing process enhancements only when proven at pilot scale – and then only under clearly defined protocols.

Securing long-term, fixed price contracts, for all waste feedstocks and a significant proportion of all saleable products (electricity, water, fertiliser, etc.).

This approach should generate cash flows that are sufficiently reliable to enable their securitisation if appropriate.

5.14 INVESTMENT CASE

Natural Synergies is an attractive investment for a number of reasons:

It is a development stage company with a substantially proven business model

The market is growing rapidly as a result of increasing government policy initiatives in renewables

The company is operating in an attractive market with high margins and rapid growth where NS has the potential to take a dominant technology position through being best-in-class

NS has a strong proprietary position

The company does not need to raise further investment before exit

A trade sale of NS at a multiple of 5x earnings, i.e. £6m after 5 years, is likely to satisfy a discriminating investor.

5.15 SUMMARY OF NS REQUIREMENTS

NS requires development capital of £550k over a 2 year period

In Return NS will generate:

- Operating cashflow becomes positive before year 3 and grows to over £6 million p.a. in Year 10

- 10 year NPV of over £11M
- Value at Year 5 with a profit multiplier of 5, is in excess of £8 million
- Cumulative cash flow becomes positive in year 3 and is in excess of £23 million in Year 10