Wetland Biomass to Bioenergy:

Efficient harvesting, processing and conversion of wetland biomass

For Department of Energy & Climate Change

PHASE 1 REPORT

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Date: 29th March 2013

Disclaimer

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EXECUTIVE SUMMARY

This report presents the outcome of research carried out under phase 1 of the Department of Energy and Climate Change's Wetland Biomass to Bioenergy programme. The consortium of partners includes Carbon Compost Company (Lead partner), the University of Sheffield, Loglogic and Crops for Energy.

The partners have developed and tested an end to end bioenergy process. This involved the harvest of wetland biomass using the Softrak harvester, the pyrolisation of rush and grass, reed and willow into charcoal using the Exeter retort and the gasification of samples using the Ultra Superheated Steam (USS) gasifier. During phase 1 each of the component parts of the system have been trialled and shown encouraging results.

The testing of the Softrak harvester was hampered by poor site conditions. A single trial was carried out at Ham Wall Nature Reserve on the 25th March 2013. This was successful and produced two large bales of reed. Five trial burns of the Exeter Retort were carried out at Exminster Marshes and Ham Wall. These took place between 31st January and 15th February 2013. Three types of wetland biomass were tested (rush and grass, willow and reed). Each burn produced some charcoal with a range of 2.5 kg – 40 kg. The conversion rate of fresh reed to charcoal was found to be 5.4 to 1. The conversion efficiency of the Exeter retort varied between 23.4-30.7% using wetland biomass resources. This compares to over 50% for well stocked wood. As the trials involved only partial loads there is potential to improve this with higher quality feedstock and refinements in methodology.

The charcoal produced was transferred to the University of Sheffield's Buxton Laboratory where they were successfully gasified in the USS gasifier. Testing was carried out during February 2013. Good quality syngas was produced and this was used to create electricity. The net calorific values for the charcoals produced were found to be:

- Rush/grass 20.7 MJ/kg
- Reed 23.6 MJ/kg
- Willow 30.9 MJ/kg

The efficiency of electricity production peaked at 35%. The addition of an internal combustion engine to the prototype which would allow the utilisation of heat should enable the conversion process to achieve 65% efficiency.

In phase 2, the project team will aim to further demonstrate the potential for this system. The aim is to produce a harvester and trailer, a larger retort and a 10 kilowatt USS gasifier. Once, the components are built they will be tested at a wetland centre. The current plan is to have a permanent base for the harvester and retort and test the USS gasifier at the Avalon Marshes visitor Centre located on the Somerset Levels.

We envisage that the end to end bioenergy process will involve the following:

- Harvest of 3.2 hectares of reed taking 2-3 days per year
- Production of 23.2 tonnes of feedstock
- 109 burns of the Exeter retort yielding 4.3 tonnes of charcoal
- 10 kW USS gasifier working at a capacity of 33% (2891 hours per year)
- Overall efficiency of 60% and an energy yield of 8,672 kWh/yr of electricity and 8,672 kWh/yr of heat.

The proposed Avalon Marshes Visitor Centre is scheduled to be built over the next 12-16 months. It will be built to Passivhaus standards. Based on a floor area of 670m2 it is expected to have an annual heating demand of 10,050 kWh. As a result the USS gasifier will be an almost perfect fit for providing the heating demand of the centre. Additional benefits include the need for only a very small fuel hopper (as a result of the high calorific value of the fuel), the expected low emissions (as a result of the purity of the charcoal fuel), and the negligible amount of ash produced.

The proposed system will have several environmental benefits. The wetland biomass will be converted to charcoal in situ. This will entail much lower trafficking on the land than alternative management methods. The pyrolisation stage reduces the weight of biomass that needs to be removed from a site by around 80%. The charcoal produced is in small quantities and will be removed from the site in an operative's car or other vehicle. By contrast removing whole bales from a site would require many movements of tractors and trailers.

The proposed system will remove the necessity for burning reed at the wetland site. The life cycle analysis indicates that this would save over 10 tonnes of CO_2 equivalent per hectare of reed harvested. The LCA emissions of the process compare favourably with other bioenergy pathways. The overall fuel carbon intensity of 0.073 kg (CO_2e)/MJ of energy produced is equivalent to 0.020 kg (CO_2e)/kWh. This corresponds to published good practice figures for the production and use of short rotation coppice (SRC) and miscanthus chip and is significantly less than the production and use of straw and pellets.

Initially, the cost of electricity production for the prototype is likely to be high (around £1,500/MWh excluding the costs of harvesting which would need to be done irrespective of the end use).However, if further trials are successful then it should be possible to reduce costs significantly. It is envisaged that the technology will reach commerciality by 2020. At this point it should be possible to produce electricity for £393/MWh (excluding harvesting costs). The cost of combined heat and power generation could be as low as £212/MWh.

These results are in the same ballpark as a 100 kWe combustion system using SRC willow chip and grid electricity produced from tidal technologies. The discounted cash flow analysis suggests that the proposed system could achieve an 8 year payback and a return on investment of 12% based on a Feed in Tariff (FIT) intervention rate of 40p/kWh. This is similar to rates provided in the past to pump prime other immature technologies such as photovoltaics (PV).

It is unlikely that this system will ever be able to compete with large scale grid connected renewables or fossil fuels. As most wetlands are in remote areas, the solution is possibly best suited to providing an off grid energy production system. An economic comparison is made with diesel generation and a renewables system comprising PV, wind and a ground source heat pump (GSHP). The results presented suggest that the wetland biomass to bioenergy solution should provide a realistic and competitive option for off grid heat and power generation by 2020.

This wetland biomass to bioenergy technology could play a significant role in future energy supply. If 20% of the UK's wetland areas were managed this way, this would produce sufficient feedstock for 20,219 small scale combined heat and power (CHP) projects. This would provide an installed capacity of 404 megawatts (MW) and a yearly electricity production of 414 gigawatt hours (GWh) - more than the current generation from wind farms in the SW of England. Furthermore, there are 220 million hectares of inland wetland areas in Eastern Europe so the potential to exploit this system overseas is enormous.

1. FULL SCALE TECHNOLOGY ASSESSMENT

1.1 Detailed description of the end to end process

The project team is aiming to develop an end to end bioenergy process enabling the sustainable and efficient conversion of wetland biomass into electricity and heat. The process involves the harvest and baling of reeds and rushes using the Loglogic Softrak reaper-binder system. The biomass will be stored on site and subsequently pyrolised into charcoal using the Carbon Compost Exeter retort. The charcoal produced will be used as a feedstock in an Ultra-Superheated Steam (USS) gasifier. This machine will gasify the char to produce clean syngas which will be used to generate electricity. We anticipate that this system could be used for small to medium size installations around 10-50 kilowatts (kWe). The process and expected inputs/outputs are shown in Figure 2.

1.1.1 Physical access to the selected site for equipment and movement of material

Ideally, this system will be exploited by Wetland centres across the UK. Such sites will provide all the vehicles with a permanent base and enable transport distances to be minimised. Both the harvester and retort are well suited for use on wetland sites.

Loglogic Softrak Cutter Binder

The Loglogic Softrak was conceived as a result of demand from the conservation and land management sectors, and has been designed to meet the unique requirements encountered in this field of activity. With the use of high strength materials a low weight and rugged strength has been achieved and combined with wide rubber tracks means very low ground pressure.

Figure 1: The Softrak harvester developed by LogLogic.

It is fitted with 600mm wide Bridgestone rubber tracks and able to traverse steep slopes and cross very soft ground or deep snow with ease, causing minimal damage to sensitive environments or highway surfaces. The rubber track has been designed with flexible edges so that it can deflect over obstacles and not cut into soft ground whilst travelling or manoeuvring (unlike rigid track systems) and with floating bogies a smooth ride can be achieved over rough ground. The flexible track also comes into its own when travelling on steep hard ground with wet vegetation, as the outer edges of the track flex upwards it allows the middle 50% of the track to achieve greater penetration and prevent 'tobogganing' which can be a major problem with other types of track systems.

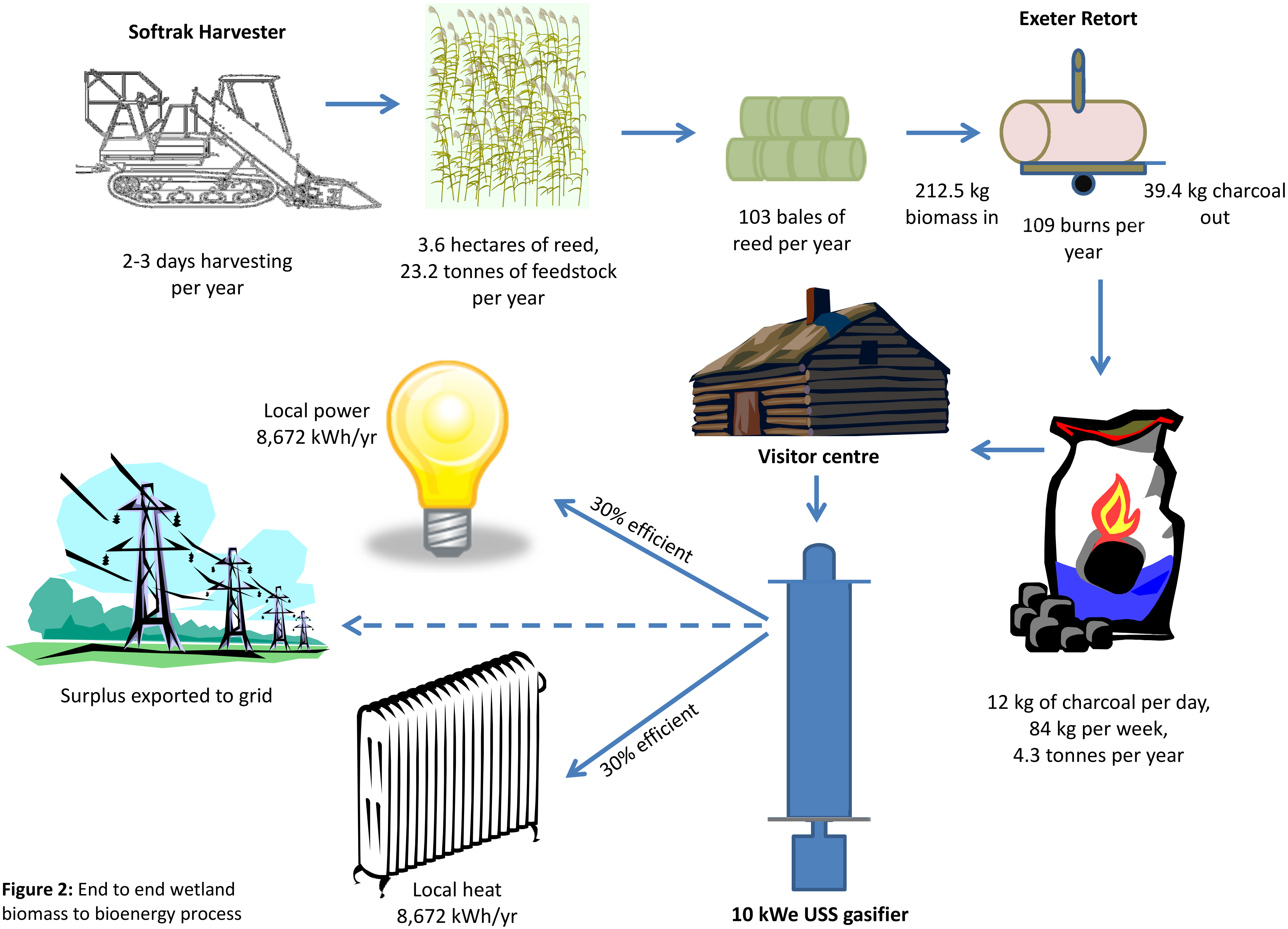

Figure 2: End to end wetland biomass to bioenergy process

The track bodies are constructed in high tensile steel and mounted on transverse cross tubes to allow the track width of the machine to be easily varied for different applications. The system is reliable and requires low maintenance and there is limited down time at the harvest site.

The Softrak harvester has the following specifications

- 600mm Bridgestone rubber track system
- 65hp turbo diesel engine
- Payload 2,500 kg (5 x 1.2m x 2.4m bales)
- Ground pressure (Laden) 4.4psi (400 mm tracks)
- Ground pressure (Laden) 2.9psi (600 mm tracks)
- High torque two speed (13kph/6.5kph) wheel motors
- Working width of 140 cm

Exeter retort

The Exeter retort will be permanently sited in a convenient location with good access. It is trailer mounted and can be towed on and off site with a 4 X 4 vehicle. It is low in weight (1.6 tonnes) and will have very little impact on soil structures.

It is 2.16m wide, 2.18m high, 3.95m long and the ground pressure is approximately 50psi. In damp conditions the load is spread by running large platters of wood under the screw jacks.

1.1.2 Cutting and collection methods.

The Softrak harvester is highly adaptable and can harvest material with from 35mm to 250 mm in height. Depending on conditions the machine can produce approximately 20-25 bundles per minute.

The conveying system comprises a variable speed, hydraulically driven chain conveyer mounted behind the harvesting head, which collects the bundles and conveys them up along the side of the vehicle to the rear platform on the rear of the Softrak. The bundles can then be stacked loose onto the bed or loaded into the baling frame to be formed into a bale 1.2m diameter x 2.4m long comprising approximately 80 bundles. The bale can be tied with sisal or polypropylene twine, plastic or steel strapping or re-usable ratchet straps. A plastic sheet can be incorporated into the bale to improve weather resistance if stored outside. The bales can then be mechanically handled and their size means they can easily be transported by truck if required. A video of the harvester can be viewed by clicking the following link: http://www.youtube.com/watch?v=njwQV7DhkLQ

The Softrak harvester has the following features:

- The Patented BCS binding mechanism on the reaper binder regulates the binding of the cut crop, cutting the twine when the bundle is ready. The diameter of the bundle is easily set, by adjusting the release spring tension.
- The cutter bar can have three types of fingers for various crops; Standard, low cut and anti-clogging (fitted as standard for reed harvesting).
- The hydraulically driven, grease-lubricated drive of the reaper binder is in airtight aluminium housing. Chain and sprockets synchronize the drive components.
- During transit the cutting head can be swung inboard to minimise overall width.

1.1.3 The form in which harvested material is to be collected and transported to the site boundary

The Softrak harvester has an optional powered trailer which can be towed behind the harvester and enables up to five additional bales to be transported. The trailer can either be towed behind the Softrak or if conditions demand then the trailer can be parked adjacent to the harvesting area and the harvester can offload direct onto the trailer.

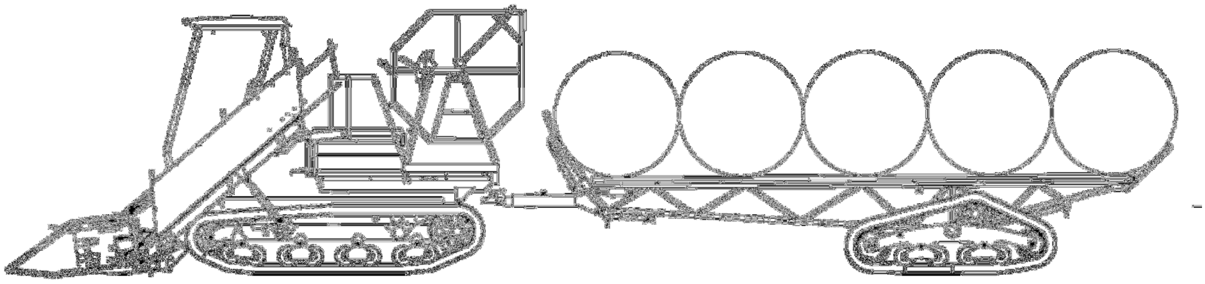

Figure 3: Softrak harvester with optional trailer.

1.1.4 Methods and distances of transportation

The proposed site for a demonstration project in phase 2 will be the Avalon Marshes Centre on the Somerset Levels. There are various wetland sites in close proximity including Ham Wall Nature Reserve, Shapwick Heath and Westhay Heath. The harvester will be kept permanently on site at the centre. The retort will be kept at the centre or other more suitable location if one can be found. All of the reed beds are within a 3 mile radius of the centre.

The basic Softrak can be transported on a standard 3.5 tonnes capacity trailer. The overall weight of a Softrak complete with harvester will be too much for a 3.5 tonne trailer and will need to be transported on a suitable trailer, either a low loader pulled by a truck or a plant type trailer pulled by an agricultural tractor. The alternative is to transport the harvester and Softrak separately; they can be put on the standard 3.5 tonne trailer behind a suitable 4x4 vehicle.

Figure 4: Aerial view showing location of Avalon Marshes centre in relation to nearby wetland areas on the Somerset Levels. Image courtesy of Google Earth.

In total there are 17 hectares of reed beds which will produce ample char for a demonstration project. The amount of wetland biomass required for the project would necessitate as little as two days harvesting a year. Hence, transporting the harvester from the centre to the wetland sites would require a maximum of 12 miles haulage.

The processing of the wetland biomass into char will take place on the site. The conversion rate of raw biomass to char is around 5.4 to 1. This means that less than 20% of the biomass by weight will need to be removed from the site. As such the traffic movements are minimised.

The transportation of char could be done on a daily basis as and when the operator returns to the centre. Each day a 40-50 kg bag would be removed from the site. If we assume that the retort is located 1 mile from the centre and there are 109 burns a year, then in total there would be around 220 miles of haulage. Alternatively, the char could be stockpiled and removed from the site once a week by a site vehicle. This would reduce the number of journeys by a factor of five.

1.1.5 Storage requirements for the harvested / processed material or equipment

Ideally, the harvested feedstock will be stored undercover. This can mean being simply sheeted with a tarpaulin to keep the worst of the weather off. Once the feedstock has been processed the resulting char must be kept dry. This is best achieved in an open sided building with a tarpaulin covering. Storage will be very short term as demand for fuel char will be constant and can be adjusted to suit the supply. A wooden structure measuring 4m X 4m will be sufficient and could be constructed in a suitable location in half a day.

1.1.6 On site processing

The retort will process the wetland biomass into char before it is transported to the Avalon Marshes Centre for utilisation in the gasifier. The pyrolisation process is described below:

- The inner retort is filled with biomass (rush, reed or willow).
- The inner retort doors are closed and sealed to prevent oxygen entering.
- The outer doors are then closed and a fire is lit in the firebox.
- The fire is maintained using scrap wood, reed or willow.
- The temperature in the inner retort is monitored with a digital thermometer attached to a probe mounted in the retort vent.
- As the temperature in the inner retort rises, the moisture from the biomass is driven through the vents as steam.
- When the steam has been removed from the biomass, a flammable gas is produced from the breakdown of the biomass (syngas).
- For approximately 30mins during this time there is a period where the biomass is producing a mixture of syngas and steam. The retort is at its 'dirtiest' state, producing as much smoke as a small bonfire as the steam/gas mixture is vented to atmosphere.
- When most of the moisture has been driven off, the vent caps are put in place and the syngas is forced into the firebox where it ignites and fuels the rest of the process.
- From then on, there is no smoke emitted, just a heat haze from the chimney.
- The temperature is monitored and kept below 500^{o}C using the firebox doors to reduce draught and a butterfly valve situated in the chimney.
- Eventually the all of the syngas is driven off the biomass in the inner retort and the process naturally shuts down and the retort begins to cool. At this stage, the retort can be left.

- The process to this stage takes between 3 to 7 hours depending upon the type, quantity and dryness of the biomass.
- All that remains is pyrolised biomass (charcoal) in the inner retort.
- 99% of the ash from the fire in the firebox will have been consumed during the process.
- The retort is left overnight to cool and the pyrolised biomass can be raked out into a dumpy bag.

Figure 5: The Exeter retort on the Somerset Levels during phase 1 of the project.

During phase 1 of the project we have successfully proved that wetland biomass (reed, rush/grass and willow) can be converted into high quality charcoal. In total, five trial burns were conducted as detailed below.

Table 1: Dates and locations of phase 1 retort trials

Burn	Location	Date	Biomass material tested	Amount of char produced (kg)	Biomass to charcoal conversion rate
1	Exminster Marshes	31/01/13	Rush and grass	2.5	6 : 1
2	Exminster Marshes	01/02/13	Rush and grass	6	6 : 1
3	Exminster Marshes	04/02/13	Seasoned willow	40	4.2 : 1
4	Somerset Levels	14/02/13	Fresh reed	8	5.4 : 1
5	Somerset Levels	15/02/13	Fresh reed	11.5	5.4 : 1

Please note: The retort was not completely filled for any of these burns.
A video of burn 3 can be downloaded from youtube:
http://www.youtube.com/watch?v=Rs7sqfjx0Rg

Figure 6: Clockwise from top left: Rush/grass char; Reed char; willow char

1.1.7 Utilisation of energy from processed material
The char will be converted into electricity and heat using the ultra-superheated steam (USS) gasifier developed by the University of Sheffield.

Gasification is the conversion of biomass (or coal) to a fuel-gas (known as syngas which consists mainly of carbon monoxide and hydrogen) in the presence of reactive gaseous atmospheres. The by-products of this process include condensable liquids, tars, and the residual solid material. Gasification is thus distinct from other forms of energy conversion such as pyrolysis or carbonisation, which occur in inert-gas atmospheres, or liquefaction, which occurs in liquid medium.

Conventional gasifiers operate typically in the range of 800-900^{o}C with the heat energy required by the endothermic gas producing reactions supplied by the partial combustion of fuel e.g. coal/biomass with air or oxygen. By contrast the USS gasifier uses a much higher temperature (typically over 1600^{o}C) and a mixture of steam and CO_2. The USS is generated as a 'flame' by simply burning a gaseous fuel in low-grade steam to which a small amount of oxygen has been added to create a form of 'synthetic' air.

The attraction of steam-only gasification is that it produces a syngas that has almost no N_2 and CO_2 because there is no combustion taking place in the reaction zone. In theory this should also lead to a higher syngas yield as all the carbon in the biomass fuel material is available for gasification (none is expended in combustion). Also, the high temperatures prevent the condensation of tar by cracking high molecular weight compounds, which is one of the major problems in gasification.

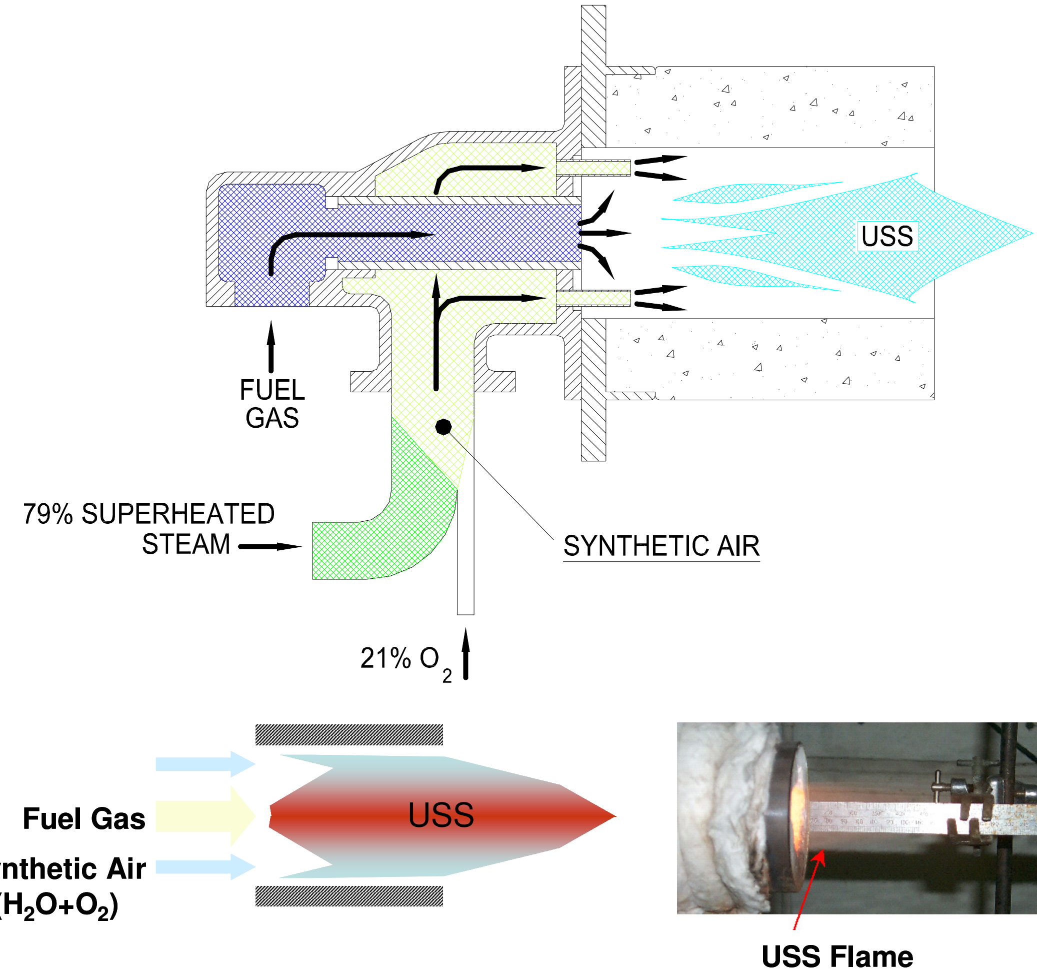

Figure 7: Ultra Superheated Steam (USS)

As part of phase 1 of the project we have also proved that each of the charcoal samples produced by Carbon Compost could be successfully gasified in the USS gasifier to produce electricity. The current rig has a theoretical energy output of 76.4kW. Based on 7.5 hours of use per day 81 kg of charcoal would be required. Results of the gasification tests can be viewed in Section 1.3.3.

The aim in phase 2 is to produce a 10 kW demonstration facility to be sited at the RSPB's Avalon Marshes visitor centre and provide all of the centres electricity and heat requirement. Surplus electricity could be exported to the grid or sold to other local businesses as part of a private wire agreement. We anticipate that the gasifier will have a capacity factor of 33% (2,891 hours/year). Based on this, we expect to require 4.3 tonnes of charcoal per year (see section 1.3). This would mean that the gasifier will have a typical throughput of 1.5 kg per hour. Based on a usage of 7.5 hours per day the fuel store would require 78 kg of charcoal per week.

Prior to being introduced into the gasifier the char will need to be ground to a powder using a simple grinder and sieve assembly. Assuming a bulk density for charcoal powder of 220 kg/m^3 then the hopper would need to be less than a cubic meter in size to accommodate a week's fuel. The conceived system will therefore have a much lower footprint than most biomass boilers which typically require 40-50 m^3 fuel stores.

1.1.8 Projected energy yields

Table 2 below shows the calorific values for the char samples measured by the University of Sheffield. The willow sample was found to be similar in energy content to higher quality house coal. As one would expect the reed and rush/grass chars had lower calorific values. Nevertheless, these are very encouraging results as the energy density is significantly higher than typical biomass sources such as wood chips, pellets and miscanthus straw.

Table 2: Calorific values and energy density of char samples compared to fossil fuels and biomass. *Figures from the Biomass Energy Centre website

Sample	Moisture content (%)	Calorific value		
		Gross (MJ/kg)	Net (MJ/kg)	kWh/tonne
Rush/Grass char	3.7	21.52	20.72	5,756
Willow char	2.7	31.77	30.91	8,586
Reed char	3.8	24.48	23.55	6,542
House coal*	?	?	27-31	7,500-8,600
Anthracite*	?	?	33	9,200
Wood chips*	30	?	12.5	3,500
Wood pellets*	<10	?	17	4,800
Miscanthus bale*	25	?	13	3,600

1.1.9 Production and treatment of any waste material / bi-products

There is only a very limited amount of waste associated with the process. Some baling twine is used but organic substitutes made of sisal are available which could be pyrolised in the retort. The sealing rope needs replacement after every 10 burns.

Neither the pyrolisation or gasification processes lead to any significant ash production. This is a clear advantage of this system compared to a simple combustion system. Herbaceous biomass resources tend to be high is ash and have a low ash melting point[1]. In addition they tend to have higher chlorine and sulphur contents. This makes these fuels very difficult to use in conventional boilers. In addition, the operations and maintenance costs are much higher due to the need for frequent ash disposal and cleaning of heat exchangers. Also, boilers tend to be higher in price due to the need for bigger and more expensive step grate systems, flue gas recirculation kits, stainless steel combustion units (to combat corrosion) and larger ash boxes. Typically, boilers using herbaceous biomass tend to have a shorter lifespan than those using woodchip although the corrosive nature of the fuel can be somewhat reduced by the addition of lime or other additives. Hence, if minerals are removed during the pyrolisation stage then this is a real benefit.

The ash issue is of particular importance with rush as this material is harvested in summer. The ash content can almost double in summer. However, with our system there will be no reduction in fuel quality as a result of summer harvesting. The only negative issue concerning the lack of ash is that it removes the opportunity to reapply this to local farmland as a fertiliser.

[1] Reed as bio-energy: opportunities to use it in boiler-houses and as biogas source. Seminar by Ülo Kask Tallinn University of Technology. March 2011. http://www.cofreen.eu/images/stories/presentations/2011-03-11/Ulo%20Kask%2011.3.2011%20Reed%20Seminar%20Tuorla.pdf

1.1.10 Potential use of bi-products

It is possible that during the pilot stage that additional biomass could be processed into char and mixed with compost to enhance its fertility and produce biochar. This could be sold at RSPB visitor centres. The Somerset Levels is one of the major UK sources of peat. The biochar produced could be processed into an organic, peat free alternative.

1.1.11 Any inputs required by the process

The retort requires around 30-50kg of dry wood to start the process. Currently there are plenty of free sources of wood that can be used. As these biomass resources become scarcer it should be possible to harvest the required wood sustainably from the wetlands sites. This will have a small cost implication (man hours, petrol for chainsaw etc.).

A very small amount of propane gas is typically used to start the operation of the USS gasifier. However, it would be possible to recycle some syngas produced by the USS gasification process. This would entirely remove any fossil fuel input from the process.

1.1.12 Any re-cycling aspects

All working components of our system are fully recyclable so the end of life disposal is not a problem. Certain items, such as the trailer the retort is mounted on, can be expected to have a longer life than the retort it is supplied with. Therefore when a retort eventually needs replacing its trailer can be used again after light servicing.

1.1.13 Losses, inefficiencies and emissions

There are some energy losses during the pyrolisation stage, mostly heat loss from the firebox. Some heat goes up the flue and more is lost through radiation from the retorts outer metal casing. This is kept to a minimum as a result of very efficient insulation. It is unfortunately not possible to harvest this waste heat in a practical way.

Some feedstock will produce more syngas than is required to maintain the pyrolisation process. It should be feasible to bleed off excess gas, scrub it and store it for use in internal combustion engines. However, at this scale it is unlikely to be cost effective.

Emissions are dealt with in section 1.5.

1.1.14 Predicted bioenergy conversion efficiencies

The trials carried out by Carbon Compost suggest a wetland biomass to charcoal ratio of 5.4 to 1. The retort has a maximum capacity of 1.7 cubic metres so the maximum biomass that can be processed at any one time is 212.5 kg based on a bale density of 125 kg/m^3. Loose willow sticks have a lower bulk density than the other forms of wetland biomass. The conversion efficiencies for the three feedstocks are outlined below.

Our results suggest that the conversion efficiency of the Exeter Retort varies between 23.4-30.7% using the wetland biomass resources. It can achieve much higher efficiencies (over 50%) when using well stacked solid wood.

The USS gasifier operates with an overall efficiency of approximately 30% due to its small scale.

Table 3: Wetland biomass conversion efficiency using the Exeter Retort

Sample	Amount of wood required (kg)	Energy contained within wood (MJ)	Amount of wetland biomass (kg)	Energy contained within wetland biomass (MJ)	Total energy of input biomass	Amount of charcoal (kg)	Energy contained within charcoal (MJ)	**Conversion efficiency %**
Rush/Grass	35	514.5	212.5	2,975	3,489	39.4	815.6	**23.4**
Willow	35	514.5	170	2,656.3	3,170.8	31.5	973.1	**30.7**
Reed	35	514.5	212.5	2,975	3,489	39.4	927.9	**26.6**

Assumptions

- Bulk density of input fuels
- Rush and reed bales – 125 kg/m^3
- Willow sticks – 100kg/m^3
- Net calorific values of input biomass
  - Wood for starting the process 14.7 MJ/kg
  - Rush/grass at 20% MC - 14 MJ/kg
  - Willow at 30% MC - 12.5 MJ/kg
  - Reed at 20% MC - 14 MJ/kg
- Net calorific values of charcoal
  - Rush/Grass char at 3.7% MC - 20.72 MJ/kg
  - Willow char at 2.7% MC - 30.91 MJ/kg
  - Reed char at 3.8% MC - 23.55 MJ/kg

1.1.15 Measures to improve efficiency

There are a number of ways where efficiency savings could be made. As further harvesters are built it should be possible to make refinements and increase the bale output per day by up to 20%. In phase 2 Carbon Compost will be aiming to increase the size of the retort from 1.7 m^3 to 4 m^3. This will enable greater throughput and save on consumables. Also, through increased bale density and familiarity with wetland biomass resources we anticipate that it should be possible to reduce the biomass conversion from 5.4 to 1 to 4.5 to 1.

Our estimates for replacement parts of the retort are based on previous experience with stem and branch wood. This is much heavier than the wetland biomass and burns at high temperatures leading to greater wear and tear and more frequent servicing. Reed by contrast produces less gas and has a lower burn temperature. The two trial burns had peak temperatures around 480oC and did not need controlling. We are therefore hopeful that the lifetime of the retort will be extended when using these feedstocks.

The efficiency of the USS gasifier will be increased in phase 2 by the addition of an internal combustion. This will enable heat as well as electricity to be used. We believe that an overall efficiency of 65% is achievable with electricity generation at 35%. The addition of an internal combustion engine will enable around 30% of the heat to be recovered from exhaust gas and cooling.

1.2 Regulatory requirements

Prior to any harvesting activities we will always liaise closely with the reserve manager and adhere to their instructions and recommendations. The reserve manager is with take into account several factors before agreeing to a work plan such as:

- Weather (colder temperatures can delay onset of breeding season)
- Status of site (for instance is it a SSSI?)
- Bird breeding seasons. These vary according to weather, breed of bird and geography. For instance if Bitterns are present then the off season would be from mid Jan to the end of July. For other species the offseason could be shortened by a month or two to allow cutting into March.
- Rotation. The site manager will determine the frequency and areas of cutting on a particular site to provide the habitat they need.

In the last year there have been huge issues with flooding on the Somerset Levels with some areas being flooded for the last 3 to 4 months and even 12 months in one particular area. Such extreme weather will dictate any work programme.

Depending on the site and the wishes of the reserve manager we will provide risk and method statement for all works – both harvesting and processing with the retort. We will ensure that all harvester operatives and volunteers using the retort are familiar with relevant health and safety training and provided with relevant personal protective equipment.

The consortium will liaise with Sedgemoor District Council and Somerset County Council early in Phase 2 to make them aware of our project and seek any permits required. Also, the consortium will consult with the Environment Agency in order to satisfy any restrictions or requirements of working in close proximity to watercourses and Natural England, the RSPB and the Somerset Wildlife Trust in relation to our harvesting and processing activities in the designated areas at the following sites:

- Ham Wall (RSPB Reserve)
- Ashcott Corner
- Shapwick Heath (Natural England Reserve)
- Westhay Heath (Somerset Wildlife Trust reserve)

There are two regulatory requirements that the retort must comply with. The first concerns the trailer. This has to meet current VOSA requirements for roadworthiness. Each trailer is manufactured to meet these requirements and is issued with an Individual Vehicle Approval prior to delivery. Most retorts delivered with a trailer are likely to be moved from point to point on site only and therefore may not need VOSA approval, but ensuring each retort has approval increases the flexibility and usefulness of the unit. At sites such as Ham Wall in Somerset going from point to point around the reserve does mean using public highways and it is desirable for the retort operator to be able to move the machine without concern that the trailer is road legal. At the moment each individual trailer goes through an approval process but consideration will be given to gaining vehicle type approval if demand makes this economical.

The second regulatory requirement concerns the operation of the retort in areas where there are restrictions on the amount of smoke produced. As the machine is intended to be operated in remote areas such restrictions are extremely unlikely to prevent operations. Smoke restricted areas tend to be around large residential areas well away from the wetland sites, but each retort operator should check to ensure that using a retort will not contravene any smoke limiting regulations in the area of operation. Because the retort produces no solid or liquid wastes operation near watercourses presents no problems. Any ash remaining in the firebox is contained during retort operation and is not disturbed during loading and unloading operations. If it is necessary to empty the firebox of ash this can be done away from the burn site to eliminate any possibility of the slight pollution risk this operation can pose.

During retort operation the machine emits as much smoke as a small bonfire for about an hour, after which no visible smoke is ejected. Although detailed measurements have yet to be carried out analysis is not expected to show significant levels of airborne pollution across the operating spectrum. We can find no regulations affecting the operation of a retort on SSSIs or SPAs.

The retort requires no CE marks as it has no external power inputs and does not produce electricity nor operate under pressure. We have already been in contact with the CE licensing authority and checked that this information is correct.

We do not envisage any biosecurity issues.

1.3 Detailed mass and energy balances of the proposed process

1.3.1 Simple overview of biomass to bioenergy process
We are basing our biomass requirements on a 10 kW gasifier, used for 8 hours a day and having an efficiency of 30%. The capacity factor is 2,920/8,760 hours = 33%.

Hence, the gasifier will produce 10 kW x (8,760 hours x 0.33) x 0.30 = 8,762 kWh of electricity per year

The output of the gasifier when using charcoal is 30% efficient therefore the amount of energy that the fuel needs to be capable of supplying in theory is equal to 10 x 8,760 x 0.33 = 28,908 kWh.

If we assume an average gross calorific value of 25 MJ/Kg and avg. MC of 3.4% then the net calorific value = 24.15 MJ/Kg. This is equal to 6,714 kWh/tonne so 28,908 ÷ 6,714 = an annual fuel requirement of 4.3 tonnes of char. Based on a 5.4 to 1 charcoal production rate this would mean that 23.2 tonnes of feedstock would be required.

Reed is the most likely feedstock for the system. Assuming reed has an average yield of 5.5 odt/ha and a moisture content of 15% then a 10 kW gasifier would require just 3.6 hectares of wetlands.

Based on a retort having a capacity to process 212.5 kg at a time it would need 109 burns a year. Therefore, the processing of reed into charcoal could be achieved with a single retort

The biomass required for the project could be harvested in 1.5-3 days.

If we assume a harvest schedule for reeds of 60 days per year (1st Nov – 31st Jan allowing for the holiday period and non- activity due to inclement weather) then one harvester could potentially harvest enough reeds for 20 -30 gasifier projects.

However, there is only 17 hectares of reed in the SW so this resource could be the feedstock for four projects and would require 12 days harvesting a year.

1.3.2 Detailed description of the pyrolisation process
This is described in section 1.1.6. A process flow diagram is shown below.

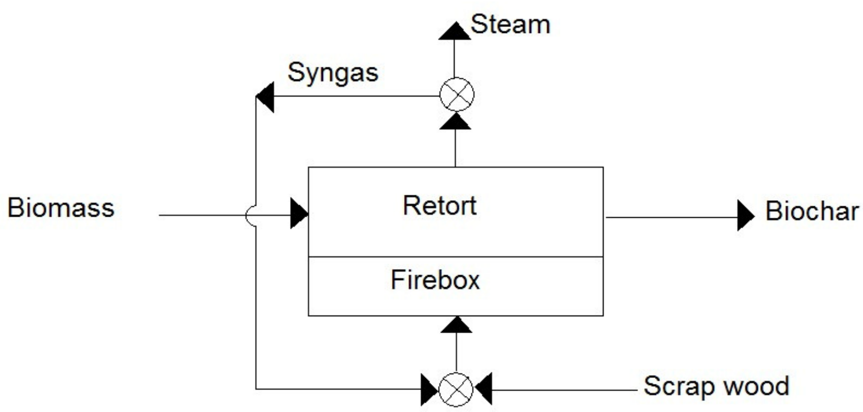

Figure 8: Exeter retort process flow diagram

1.3.3 Detailed description of the gasification process

Ultra Superheated Steam (USS) is steam at flame temperatures (typically above 1600K for gaseous fuel combustion at stoichiometric conditions). It can be generated in any conventional burner that fires a gaseous fuel such as methane or propane. The oxidiser in the combustion reaction is a mixture of oxygen and steam in lieu of air, with the components proportioned similar to air, i.e. approximately 79% steam and 21% oxygen by volume. This mixture is referred to as synthetic air . The products of the fuel-gas and synthetic air combustion are the USS. For stoichiometric combustion, the USS consists of about 90% steam and 10% carbon dioxide. The USS flame is colourless.

Figure 9 presents our previous calculation results for equilibrium adiabatic flame temperatures for propane, methane and hydrogen vs. synthetic air combustion at varying oxygen contents (Swithenbank, Shabangu et al, 2004). Real flame temperatures are however not as high as the adiabatic flame temperatures. The flame temperature is a critical variable in determining the heat transfer from the USS to the load, which is the fuel particles undergoing gasification.

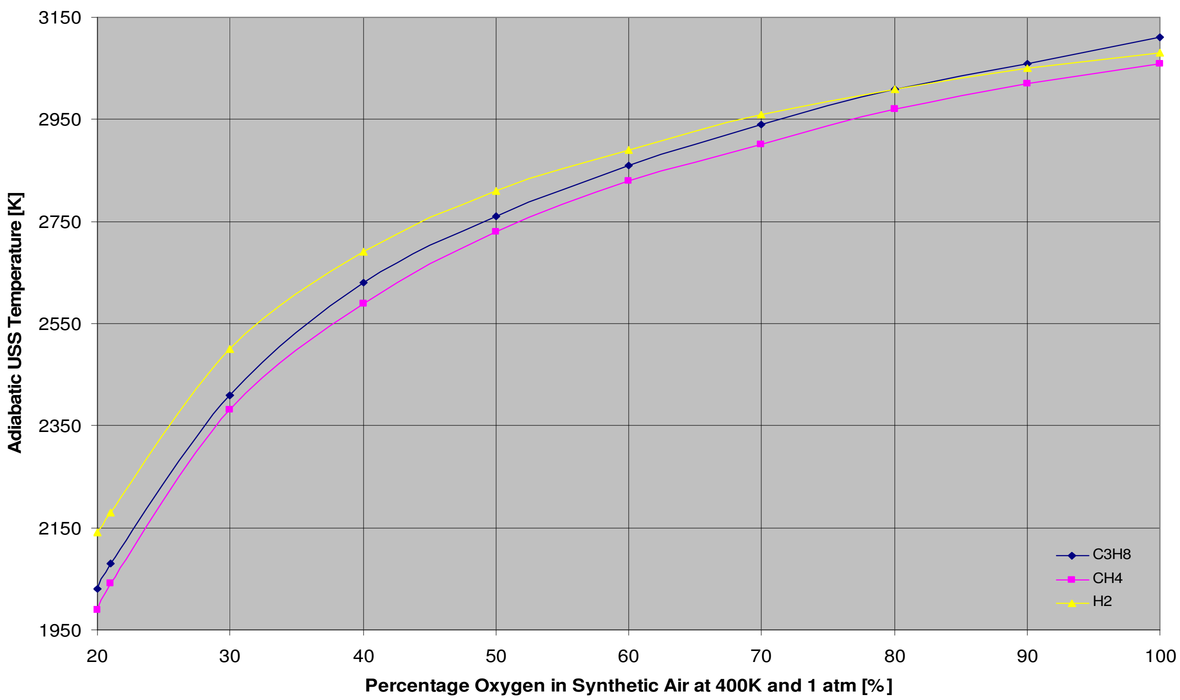

Figure 9: Flame temperatures for propane, methane and hydrogen vs. synthetic air combustion at varying oxygen contents.

For example, the overall reaction of the USS from the synthetic air of 40% O_2 and 60% H_2O mixture can be represented as:

$$C_3H_8 + 12.5\ (0.4O_2+0.6\ H_2O) \rightarrow 3CO_2 + 11.5H_2O$$

Such high temperatures of USS not only provide the heat for endothermic reactions, but also prevent the condensation of tar by cracking high molecular weight compounds, which is one of the major problems in gasification. The low-grade steam can be acquired from various sources e.g. process cooling, and local industry.

- *Main reactions of USS gasification*:
  a) Partial combustion
  $C + ½ O_2 \leftrightarrow CO$ ΔH = -123.1 kJ/mol

  b) Combustion
  $C + O_2 \leftrightarrow CO_2$ ΔH = -405.9 kJ/mol

  c) Gasification with Carbon Dioxide (Boudouard reaction)
  $C + CO_2 \leftrightarrow 2CO$ ΔH = +159.7 kJ/mol

  d) Gasification with Steam (Water-Gas reaction)
  $C + H_2O \leftrightarrow CO + H_2$ Δ+118.9 kJ/mol

  e) Gasification with Hydrogen (Hydrogasification)
  $C + 2H_2 \leftrightarrow CH_4$ ΔH = -87.4 kJ/mol

In USS gasification, the USS generation can be considered to be complete before gasification takes place. This means that no oxygen enters the gasification zone, and so there are no *Reactions (a)* and *(b)* to provide the heat energy needed for the endothermic reactions *(c)* and *(d).* The heat energy is provided by the USS in an allothermic process. With treatment, the syngas can be recycled as the start-up fuel for the USS generation

The USS gasifier is composed of two distinct parts; the USS generator (a burner) and the gasification chamber. The burner selected for the generation of USS and subsequent USS gasification is a dual-fuel burner. Its design capacities are a maximum air flow of 0.0322 m^3/s (1935 l/min) and a maximum heat output of 120 kW (410 000 Btu/h). This burner is used because, being manufactured for dual fuel operation it could be easily adapted for the USS gasification by replacing the liquid fuel pipe with one suitable for the supply of granular material for the gasification of solids, or by just using the burner as supplied for the gasification of biomass liquid or slurry material.

The gasification chamber is composed of a mild steel shell, lined with 50 mm thick fused alumina-based castable refractory with high abrasion resistance. Its maximum service temperature is about 2100K. The internal dimensions of the gasification chamber are 1250 mm height and 285 mm diameter. The gasifier is designed to have a catch pot at the bottom to collect ash or slag. The USS gasification is performed using methane as the gaseous fuel for the generation of USS and propane was used to fire the pilot burner.

The USS gasifier has an entrained flow configuration, and uses ultra-superheated steam to gasify the fuel. The ultra-superheated steam is generated as a ‘flame’ by simply burning a gaseous fuel in low-grade steam to which a small amount of oxygen has been added to create a form of ‘synthetic’ air. The char powder is introduced into the root of the flame to form the entrained flow reactor. A gas sampling line is connected at the bottom of the gasifier, and collects the syngas sample into a sampling bottle (see Figures 10, 11 and 12).

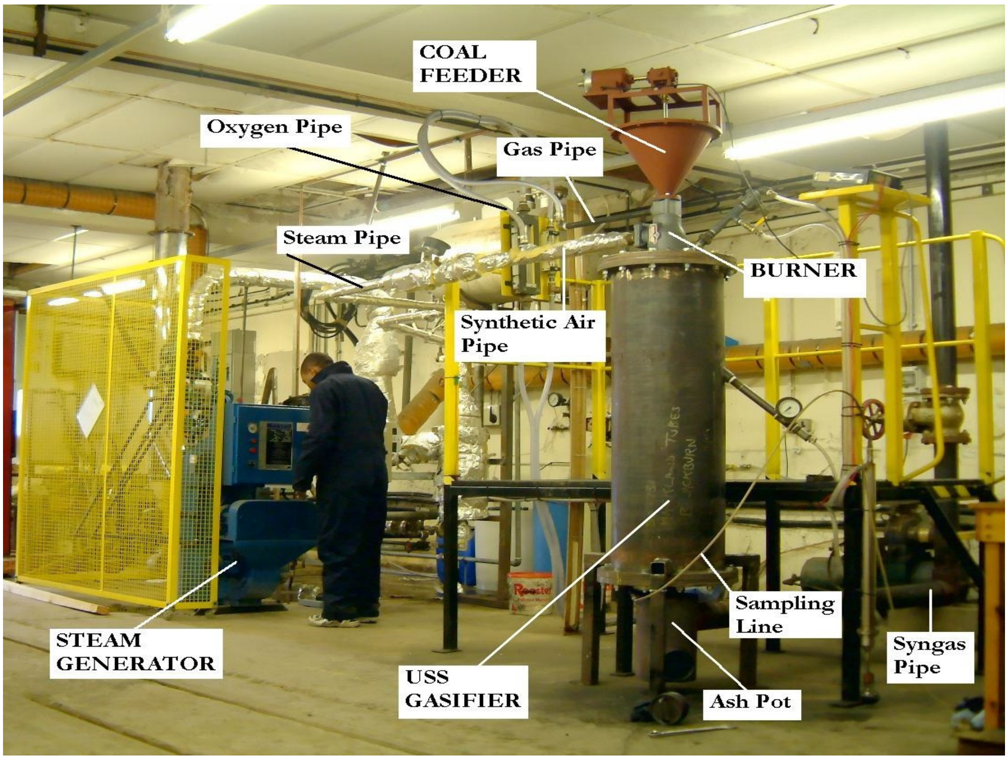

Figure 10: Ultra superheated steam gasifier at Sheffield University Buxton Lab

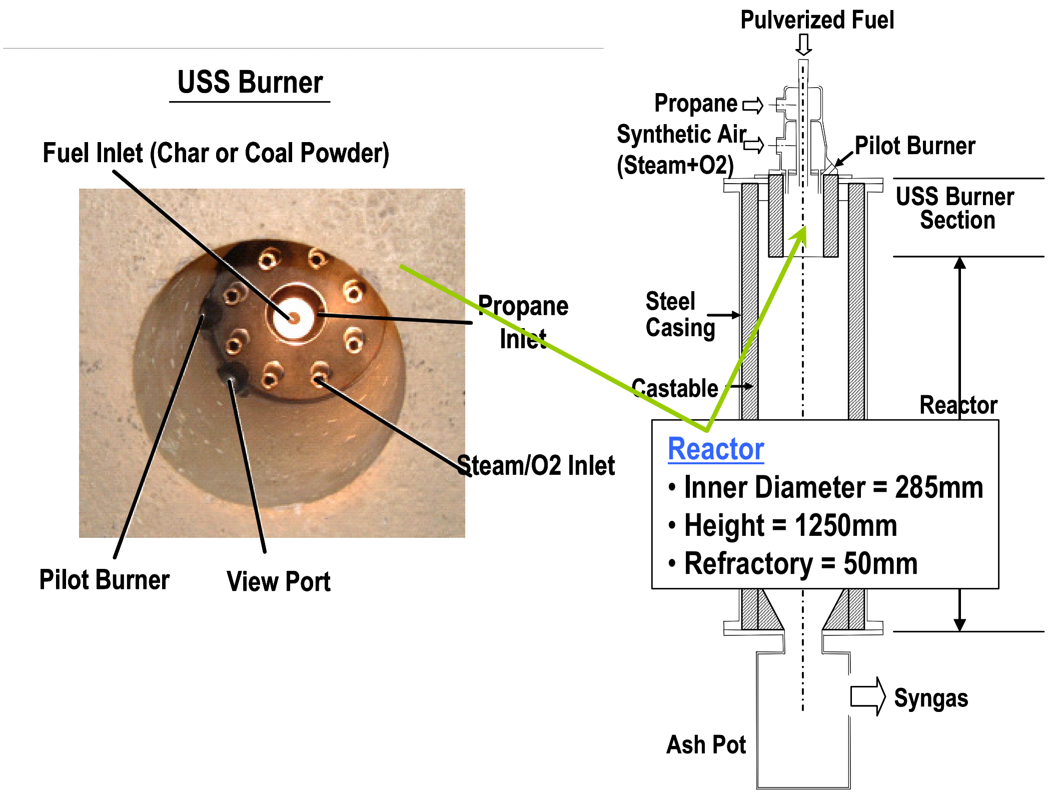

Figure 11: Schematic of the USS gasifier.

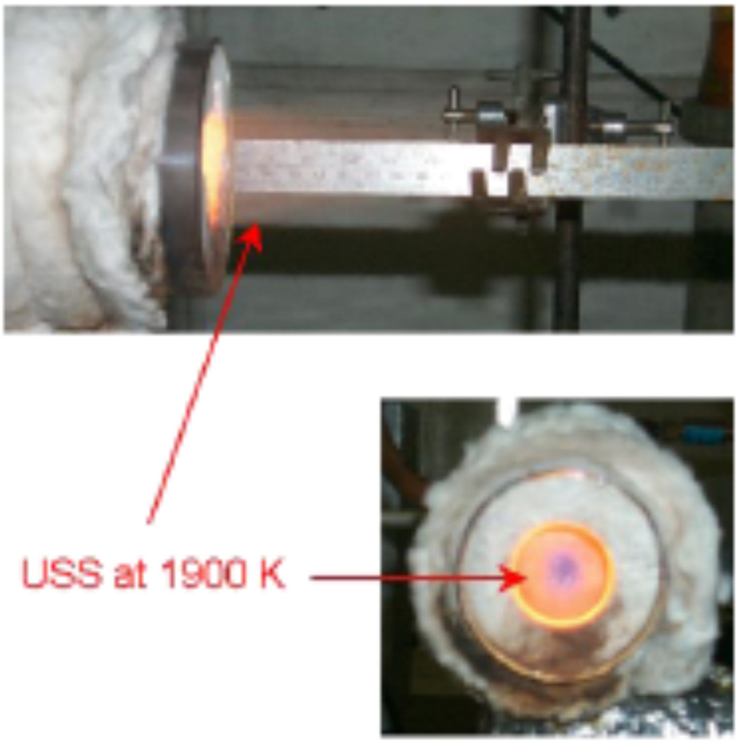

Figure 12: Tunnel burner operating on USS and Illustrating flame transparency.

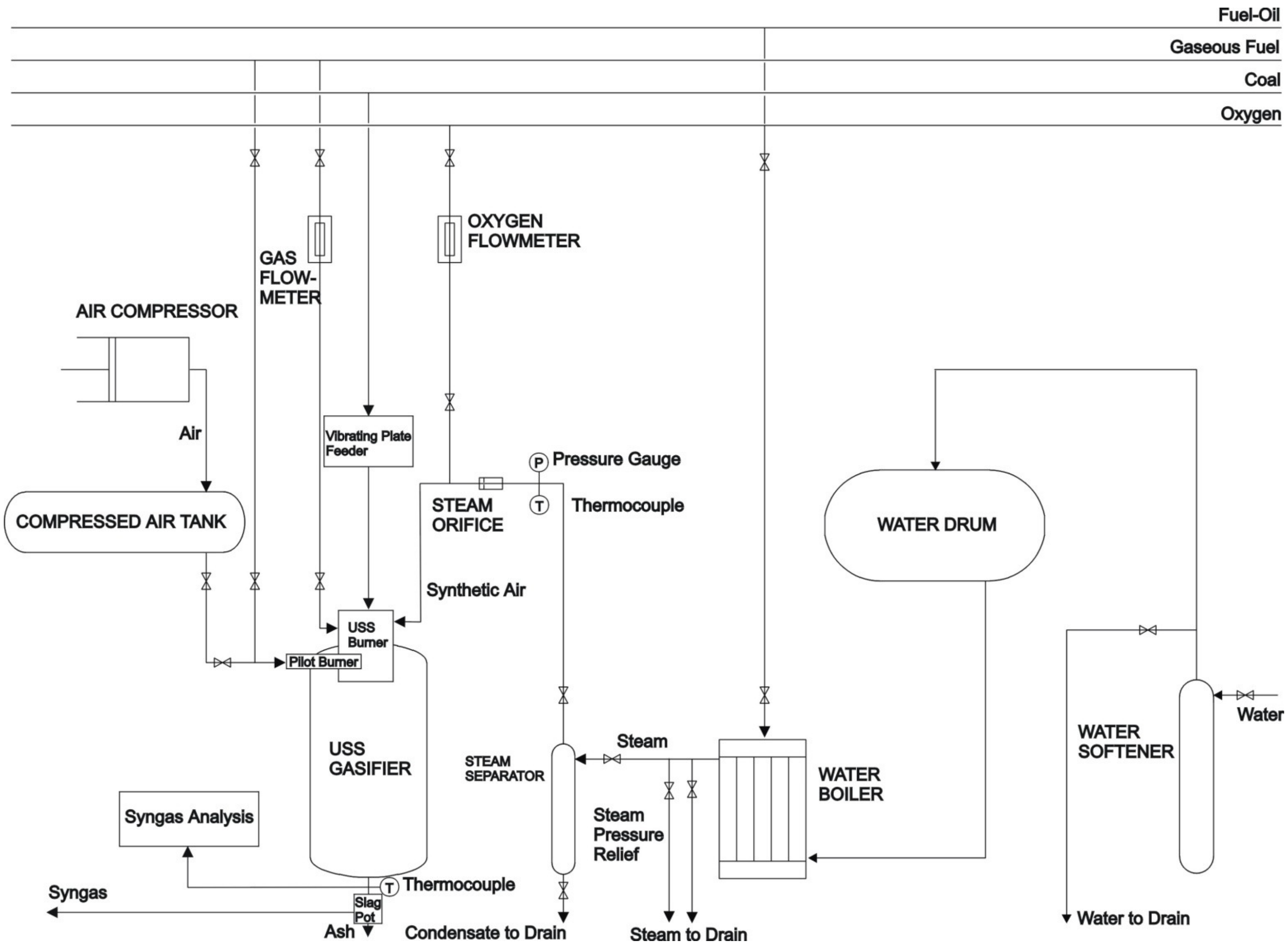

Figure 13: USS Gasifier Flow Diagram

Analytical Tests:

Methodologies: Laboratory proximate and ultimate analyses were carried out prior to gasification tests. The carbon and hydrogen content of the biomass char samples and the proximate analysis were carried out according to the ASTM (American Society of Testing Material) analytical method. The analyses were carried out in the analytical laboratory of the Department of Chemical and Biological Engineering, University of Sheffield. The proximate analysis determines the moisture evolved at 105°C, volatile matter (VM) released on heating to 925°C in a closed crucible, ash residue on combustion at 800°C and the fixed carbon (FC). The results are expressed in weight %. The ultimate analysis gives the carbon, hydrogen and nitrogen composition present in the sample expressed as weight %. The calorific value determinations are made using adiabatic calorimeter method as described by British Standard 1016 Part 5.

The analytical results obtained for three wetland biomass char samples are shown below:

Table 4: Proximate Analysis Results

	Rush/Grass Char Sample	Willow Char Sample	Reed Char Sample
Moisture	3.7	2.65	3.8
Volatile matter	12.05	5.1	6.4
Fixed carbon	60.95	89.35	72.2
Ash	23.3	2.9	17.6

Table 5: Ultimate Analysis Results

Element	Rush/Grass Char Sample	Willow Char Sample	Reed Char Sample
Carbon	56.1	81.8	69.7
Hydrogen	2.1	1.7	1.0
Nitrogen	1.9	1.1	1.2

Table 6: Gross Calorific Values (CV) Results

	Calorific value (MJ/kg)
Rush/Grass Char Sample	21.52
Willow Char Sample	31.77
Reed Char Sample	24.48

Gasification Tests

For these tests USS was produced from the reaction of propane with the synthetic air having approximately 40% oxygen and 60% steam, which would give a mixture of 21% CO_2 and 79% H_2O after complete reaction. The feed duration was determined from the change of the temperature measured at the top of the ash pot. The temperature was about 1,037°C for USS. The overall feed rate of the char powder samples was ~ 3 g sec^{-1}.

The syngas samples were collected in sampling bags for further analysis using a gas chromatograph (Varian Analytical Instruments, CP-3800 GC). Helium is used as a carrier gas and the types of detectors employed in the measurement are the Flame Ionization Detector(FID) and the Thermal Conductivity Detector(TCD).

Table 7: Typical Gas composition of USS.

Type	**USS**
Synthetic air composition	40% O_2, 60% steam
Propane flow rate	~ 1.1 g/s
Steam flow rate	~ 5 g/s
Oxygen flow rate	~ 7 g/s
USS composition	~21% CO_2, ~79% H_2O

Table 8: Experimental conditions for the wetland biomass char gasification tests

Test Case		**Test 1**	**Test 2**	**Test 3**
Fuel	Feed material	Rush char	Willow char	Reed char
	Particle size (approx)	100µm	100µm	100µm
	Feed rate	~3.1 g/s	~3.1 g/s	~3.2 g/s
USS	Type	USS	USS	USS

Syngas Composition and Solid Residue

No ash residues were produced in the catch pot during the USS gasification of wetland biomass char samples. The tiny ash particles were carried out with the syngas.

Figure 14: Tiny ash particles are carried out with the syngas

The measured temperature at the outlet of gasifier during the feasibility tests was approx 1090 C. Based on our previous research and the feasibility gasification tests, the syngas produced from gasification tests consists of approx 32%-37% vol% of H_2, 24 to 27 vol% CO, 0.2 to 0.5 CH_4 and approximately 36% CO_2.

It should be noted that all the CO_2 in the syngas (approx 36% vol) comes from the reaction of propane (initial stage of USS process). This fossil based CO2 could be removed from the overall process if some of the syngas generated from gasification process is recycled/reused to generate USS (instead of propane)!

Energy and Mass Balances

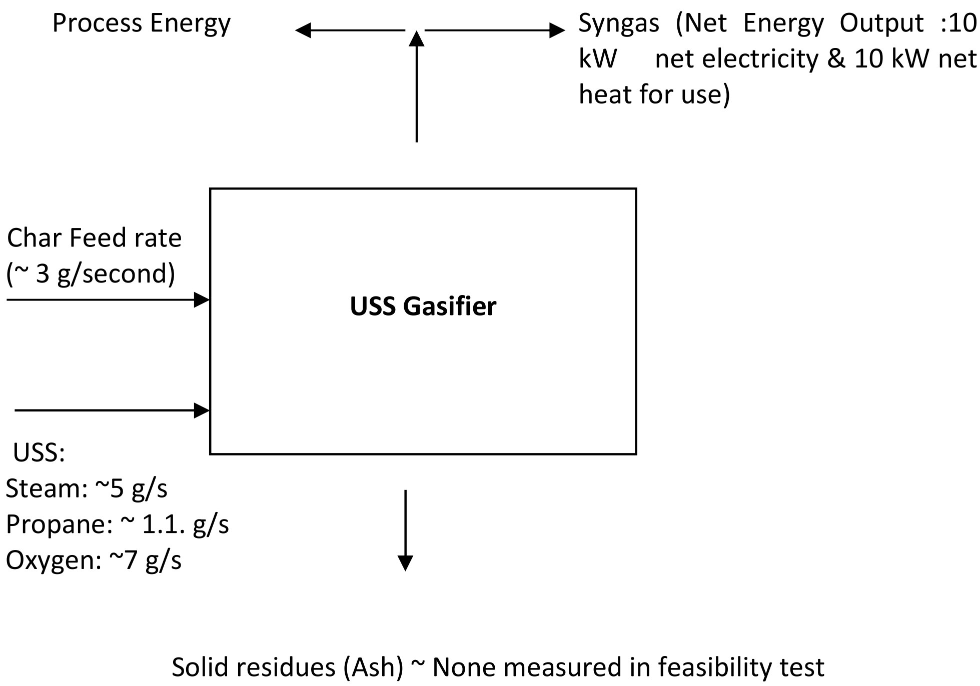

Figure 15: Energy and mass balances for the USS gasifier.

The feeding rate of the gasifier is approx 180 - 200 g/min. The original char samples were crushed/pulverised using a grinder and a ball mill in order to prepare char samples with an average particle size of approximately 100 μm. No measured solid residue was produced from the USS gasification process.

Char feed rate: ~ 3 g/s

3 x 60 x 60 = 10,800 g/hr (~11 kg/hr)

Average wetland biomass char calorific value ~25 MJ/kg (3 samples with ~ 21, 24, 31 MJ CVs – see Table 6)

Estimated Output per Hour:

Total Energy Generated : 11 kg/hr x 25 MJ/kg = 275 MJ

275 MJ is equal to 275,000 kJ / (60 x 60) s = 76.38 kW (maximum theoretical energy output)

Estimated overall USS/IC Engine system efficiency is 65%, i.e. 35% (electricity) and 30% (heat)

Therefore:

Maximum output from USS/IC engine = ~ 26.73 kW (electrical output) and ~22.91 kW (heat output)

Process Energy

Approximately 1 kW of electrical energy is required to run the pumps/other associated equipment connected to the USS gasifier/IC engine. Approximately 10 kW of electrical energy is required to generate steam for use in the USS process.

Carbon Conversion

Conversion efficiency is usually represented by carbon conversion, which is the ratio of carbon output in the syngas to total carbon in the fuel feed. The carbon output can be calculated from the measured flow rate and carbon content of syngas (Hara, 2002; Lee, 1996; Lv, 2004). Although the flow rate measurement was not available in the USS gasifier, it is possible to estimate an approximate figure of the carbon conversion using the measured gas concentration and properties of input materials.

Firstly, it is necessary to assume the change in the elemental composition of the fuel during conversion. It can be assumed that all the H and O components are converted regardless of carbon conversion. Then, the overall gasification reaction for the fuel ($C_xH_yO_z$) can be represented as:

$f\,(\phi\, C_x + H_y + O_z) + r_1\, C_3H_8 + r_2\, O_2 + r_3\, H_2O \rightarrow c_1CO + c_2CO_2 + c_3H_2 + c_4CH_4 + c_5C_nH_m + c_6H_2O$ (R1)

where ϕ is the carbon conversion. The coefficients for the reactants (f, r_1, r_2 and r_3) are determined from the flow rate of each material. r_3 incorporates the moisture from the fuel and the steam in the synthetic air.

For the overall reaction (R2), the mass balance of each atom becomes:

Mass balance of C atom:

$$f x\phi + 3r_1 = c_1 + c_2 + c_4 + nc_5 \qquad \text{(Eq.1)}$$

Mass balance of H atom:

$$f y + 8r_1 + 2r_3 = 2c_3 + 4c_4 + mc_5 + 2c_6 \qquad \text{(Eq.2)}$$

Mass balance of O atom:

$$f z + 2r_2 + r_3 = c_1 + 2c_2 + c_6 \qquad \text{(Eq.3)}$$

The above three equations have three unknowns, ϕ, c_6 and c_1. Once c_1 is determined, c_2, c_3, c_4 and $c5$ are calculated from the dry syngas composition, which can be expressed as:

$$c_i / s = g_i \qquad \text{(Eq.4)}$$

where $s = \sum_{i=1}^{5} c_i$ and g_i is the measured mole fraction of species i (i=1 to 5) in the dry syngas.

(Eq.1) can be rewritten for ϕ:

$$\phi = \frac{sC_{sum} - 3r_1}{fx} \qquad \text{(Eq.5)}$$

where $C_{sum} = g_1 + g_2 + g_4 + ng_5$

The equation for s can be acquired by substituting (Eq.4) into (Eq.1)-(Eq.3).

$$s = \frac{4r_2 - 8r_1 - fy + 2fz}{-H_{sum} + 2O_{sum}} \qquad \text{(Eq.6)}$$

where $H_{sum} = 2c_3 + 4c_4 + mc_5$ and $O_{sum} = c_1 + 2c_2$

It can be easily checked that the above method is correct for pure carbon. For validation, this method was previously applied to the experimental results for biomass (pine sawdust, $C_1H_{1.68}O_{0.61}$) air-steam gasification in a fluidised bed reported in the literature (Hara, 2002). For various air-steam mixtures that give measured carbon conversion efficiencies of 65%-90%, the above method provides satisfactory result with an error of ±7%. It over-predicts at higher efficiencies (+5% for 90%) and under-predicts at lower efficiencies (-7% for 68%).
Since the char samples in this feasibility study have a very high carbon content, the error is expected to be smaller than in the above result.

Table 9 presents the estimated carbon conversion for the wetland biomass char samples. The values vary between 43% to 51% for the char samples.

Table 9: Estimated carbon conversion for the test cases

Test Case	Test 1 (Rush)	Test 2 (Willow)	Test 3 (Reed)
Carbon Conversion, ϕ (%)	43.3	51.1	46.0

Based on the above method, it is also possible to compare the total flow rates of H_2O and CO_2 in the syngas to those expected from the USS without the fuel. When expressed by the coefficients in (R2), these two ratios become:

$$\mathrm{H_2O_{syngas}/H_2O_{USS}} = c_6 / (4r_1 + r_3)$$
$$\mathrm{CO_{2,syngas}/CO_{2,USS}} = c_2 / 3r_1$$

The ratio for H_2O was around 90% for the char, which means that about 10% of the steam in the USS decomposes into H_2. The ratio for CO_2 is less than 100% for the char gasification, which means that all the CO_2 in the syngas comes from the reaction of propane.

It should be noted that the complete conversion can be achieved by recycling unconverted carbon or by increasing the scale of the gasifier to industrial scale thus increasing the residence time in the reactor.

1.4 Carbon and energy life cycle assessment (LCA)

The life cycle analysis for the wetland biomass to bioenergy system is outlined below.

Biomass harvested and energy produced

3.6 hectares of reed harvested
Yield of reed = 5.5 odt/ha = 6.47 tonnes/ha @ 15% MC
Total amount of wetland biomass harvested per year = 23.3 tonnes
Total charcoal produced = 4.32 tonnes
Avg. energy content of charcoal = 24.15 MJ/Kg (or 6,714 kWh/tonne)
Total energy contained in 4.32 tonnes of reed charcoal = 104,328 MJ (or 28,908 kWh)
Useful energy based on 60% efficiency (30% heat & 30% electricity) = **62,596.8 MJ** (or 17,344.8 kWh)

Moving the Softrak harvester from the Wetland Centre

Transported on a trailer by a 4 wheel drive diesel vehicle (e.g. Land Rover Discovery)
Fuel economy = 20 miles per gallon[2] or 4.4 miles per litre
1 gallon = 4.546 litres
Maximum haulage of harvester for single project = 12 miles
Therefore, total diesel used = 12 ÷ 4.4 = 2.72 litres
Utilisation of 1 litre of diesel emits 2.6676 kg CO_2e[3]
Therefore, moving the harvester will emit 7.28 kg of CO_2e/yr
As 3.6 hectares are harvested = 7.28 ÷ 3.6 = **2.02 kg of CO_2e/ha**
The emissions from moving the harvester for each MJ of produced energy =7.28 ÷ 62,597 **= 0.000116 kg (CO_2e)/MJ**

Harvesting of wetlands using the Softrak

1 hectare of reed harvesting requires 15 litres of diesel
3.6 hectares requires 54 litres of diesel
Utilisation of 1 litre of diesel emits 2.6676 kg CO_2e
Therefore, harvesting 1 hectare will emit **40.01 kg of CO_2e/ha**
The harvesting of 3.6 hectares of wetland will emit 144.05 kg of CO_2e/yr
The emissions from harvesting for each MJ of produced energy = 144.05 ÷ 62,597 **= 0.002301 kg (CO_2e)/MJ**

Moving the retort from the Wetland Centre

Transported on a trailer by a 4 wheel drive diesel vehicle (e.g. Land Rover Discovery)
Fuel economy = 20 miles per gallon or 4.4 miles per litre
1 gallon = 4.546 litres
Maximum haulage of harvester each year = 12 miles
Therefore, total diesel used = 12 ÷ 4.4 = 2.72 litres
Utilisation of 1 litre of diesel emits 2.6676 kg CO_2e
Therefore, moving the harvester will emit 7.28 kg of CO_2e/yr
As 3.6 hectares are harvested this = 7.28 ÷ 3.6 = **2.02 kg of CO_2e/ha**
The emissions from moving the harvester for each MJ of produced energy =7.28 ÷ 62,597 **= 0.000116 kg (CO_2e)/MJ**

[2] http://www.fuelly.com/car/land%20rover/discovery/2004
[3] Carbon Trust conversion factors 2011 update. http://www.carbontrust.com/media/18223/ctl153_conversion_factors.pdf

Processing the wetland biomass into charcoal

Emissions from a traditional ring kiln range from 0.77-1.63 kg (CO_2e)/kg of charcoal produced[4]
CO_2 emissions from a retort are 50% less than a traditional ring kiln[5]
We assume that the Exeter retort will have 50% less emissions than the average ring kiln.
This equals 0.6 kg (CO_2e) per kg of charcoal produced
Conversion rate of reed to charcoal = 5.4 to 1
One hectare of reed = 6.47 tonnes of raw biomass which yields 1.2 tonnes of charcoal
3.6 hectares = 23.2 tonnes of raw biomass which yields 4.3 tonnes of charcoal

Each burn requires 35 kg of dry wood to start the process
Calorific value of air dry wood at 20% MC = 14.7 MJ/kg[6]
109 burns of the retort each year requires 3,815 kg of wood
Energy content of 3,815 kg of wood = 56,080.5 MJ
Approximate life cycle CO_2 emissions from wood = 0.002 kg/MJ[5]
Therefore, annual emissions from wood burning = 112.16 kg (CO_2e)/yr
Annual emissions from retort = 4300 kg x 0.6 = 2,580 kg (CO_2e)/yr
Total emissions from retort including start up fire = 2,692.16 kg (CO_2e)/yr
As 3.6 hectares are harvested this = 2692.16 ÷ 3.6 = **747.82 kg of CO_2e/ha**
The emissions from the retort for each MJ of produced energy =2,692.16 ÷ 62,597 **= 0.043008 kg (CO_2e)/MJ**

Moving the charcoal from the retort back to the Wetlands Centre

Maximum 115 journeys
Average journey roundtrip distance = 2miles
Annual mileage = 230 miles
Transported by 3 year old small diesel car (e.g. Ford Focus estate)
Fuel economy = 50 miles per gallon or 11 miles per litre
1 gallon = 4.546 litres
Total diesel used = 230 ÷ 11 = 20.91 litres
Utilisation of 1 litre of diesel emits 2.6676 kg CO_2e
Therefore, transporting the charcoal will emit 55.78 kg of CO_2e/yr
As 3.6 hectares are harvested = 55.78 ÷ 3.6 = **15.49 kg of CO_2e/ha**
The emissions from transporting the charcoal for each MJ of produced energy =55.78 ÷ 62,597 **= 0.0008914 kg (CO_2e)/MJ**

Basifying the charcoal in the USS Gasifier

Reed charcoal is 69.7% carbon
1 kg of hard coal with a carbon content of 75% will produce around 3.89 kg of CO_2e
Basifying biomass instead of burning coal leads to a net GHG reduction of around 90%[7]

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[4] Emissions of greenhouse gases and other airborne pollutants from charcoal making in Kenya and Brazil. David M. PenniseKirk R. SmithJacob P. KithinjiMaria Emilia RezendeTulio Jardim RaadJunfeng ZhangChengwei Fan. 2001. Journal of Geophysical Research: Atmospheres Vol 106 Issue D20. http://ehs.sph.berkeley.edu/krsmith/publications/2006%20pubs/JGR_Pennise1.pdf

[5] Charcoal production with reduced emissions. P.J. (Patrick) Reumerman and B. (Bart) Frederiks. 2002. 12th European Conference on Biomass for Energy, Industry and Climate Protection. Amsterdam. http://www.cleanfuels.nl/Projects%20&%20publications/Charcoal%20Production%20with%20Reduced%20Emissions%20(paper).pdf

[6] Biomass Energy Centre http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,20041&_dad=portal&_schema=PORTAL

[7] Life cycle analysis of net greenhouse gas flux for bioenergy cropping systems. Paul R Adler, Stephen J Del Grosso, and William J Parton. Ecological Applications, 17 (3), 2007, pp. 675–691. Ecological Society of America http://www.tamu.edu/faculty/tpd8/BICH407/EcoAppcostbenefit.pdf

Based on this assumption, gasifying 1 kg of charcoal will release 0.389 kg of CO_2e
Total emissions from 4,320 kg of charcoal = 1,680.5 kg (CO_2e)/yr
As 3.6 hectares are harvested this = 1,680.5 ÷ 3.6 = **466.81 kg of CO_2e/ha**
The emissions from the gasifier for each MJ of produced energy =1,680.5 ÷ 62,597 = **0.026846 kg (CO_2e)/MJ**

1.4.1 LCA Summary

The LCA for the wetland biomass to bioenergy system is summarised below. The pyrolisation and gasification stages are the two most carbon intensive activities during the chain.

Table 10: LCA for the wetland biomass to bioenergy process.

Activity	Fuel carbon intensity kg (CO_2e) /MJ of energy produced	% contribution to the chain
Transport of machinery	0.000232	0.3
Harvesting of reed	0.002301	3.2
Processing into charcoal	0.043008	58.7
Transport of charcoal	0.000891	1.2
Energy production	0.026846	36.6
Total	**0.073278**	**100**

The LCA of carbon and energy emissions of 0.073 kg (CO_2e)/MJ of energy produced is equivalent to 0.020 kg (CO_2e)/kWh. This corresponds well to other bioenergy LCA figures presented below.

Table 11: Greenhouse gas emissions from producing different biomass fuels[8].

Feedstock	Range of emissions (kg CO_2/kWh)	Good practice (kg CO_2/kWh)
SRC chips	0.010-0.040	0.020
Miscanthus chips	0.012-0.052	0.020
UK sourced woodchips	0.010-0.025	0.015
Straw	0.050-0.105	0.075
SRC Pellets	0.030-0.140	0.100
Miscanthus pellets	0.035-0.130	0.065

[8] Biomass – Carbon Sink or Carbon Sinner. AEA Technology for the Environment Agency. April 2009. www.environment-agency.gov.uk/static/documents/Biomass__carbon_sink_or_carbon_sinner_summary_report.pdf

We have not considered the manufacture of machinery in the above table. According to figures on the Biomass Energy Centre website for LCA of wood chips including the manufacture of a biomass boiler would be expected to be around 0.003 kg (CO_2e) /MJ of energy produced. So, if all three components of the system (Softrak harvester, Exeter retort and USS gasifier) have similar fuel carbon intensities then this would only add 0.009 kg (CO_2e) /MJ to the LCA. This would account for 11% of the overall emissions. There is no waste product produced as part of the process so this was not considered in the LCA.

We will gain a better understanding of the LCA for this process in phase 2 of the project and provide a final definitive report on this topic in phase 3. We are confident that the system will achieve the figures presented. The Exeter retort is a very clean technology and it is quite possible that this will result in lower CO_2e emissions than we predict.

1.4.2 LCA Counterfactuals

The wetland biomass to bioenergy system has been compared to two LCA reference systems (counterfactuals) outlined below which indicate the current state of play for wetland management practices.

i. A reed bed (dominated by common reed) that is cut manually through brushcutters and pedestrian mowers, raked and burned by hand.

Details of machinery used:

Brushcutter - FS 450 / 2.1kw.
1 tank of petrol / oil mix will last 40 minutes cutting
1 tank of petrol / oil mix will hold 0.67 litres.
Purchase Cost of machine £874

Pedestrian Mower - Aebi HC 44 / 8.2kw
1 tank of petrol will last for 1.6 hours cutting
1 tank of petrol will hold 6 litres and so use 3.7litres/h
Purchase Cost of machine £9,000

2.5% cost of the machine goes into maintenance each year

Time taken to cut 1 hectare of reed

- Brushcutter operation = 4 hours to cut edges and inaccessible spots
- Pedestrian mower operation = 35hours cutting
- Raking up and burning = 199.5hours

All machinery and labour is transported to site using a 4 x 4 vehicle and trailer over a distance of a 10 mile round trip.

Brushcutting

4 hours using the brushcutter = 6 tanks of petrol/pil
6 tanks x 0.67litres = 4.02 litres of petrol/oil

Utilisation of 1 litre of petrol emits 2.3117 kg CO_2e[9]

4 hours of brushcutting emits 4.02 x 2.3117 = 9.29 kg CO_2e

Mowing

35 hours of using the pedestrian mower uses 35 x 3.7 litres = 129.5 litres of petrol

4 hours of mowing emits 129.5 x 2.3117 = 299.37 kg CO_2e

Burning of reed

Reed bed yield = 5.5 odt/ha or 6.47 tonnes at 15% MC

The elemental composition of dry reed suggests a carbon content of 47%[10]

Based on the atomic weight of carbon and the molecular weight of CO_2 12 tonnes of C emits 44 tonnes of CO_2

Amount of carbon in 6.47 tonnes of reed = 6.47 x 0.47 = 3.04 tonnes of C

Burning 6.47 tonnes of reed therefore release (44÷12) x 3.04 = 11.15 tonnes of CO_2e or 11,150 kg CO_2e.

Transportation

Transportation of machinery and operatives by a 4 wheel drive diesel vehicle (e.g. Land Rover Discovery)

Fuel economy = 20 miles per gallon or 4.4 miles per litre

1 gallon = 4.546 litres

Maximum haulage for a single project = 10 miles

Therefore, total diesel used = 10 ÷ 4.4 = 2.27 litres

Utilisation of 1 litre of diesel emits 2.6676 kg CO_2e

Therefore, moving the vehicle will emit 6.06 kg of CO_2e

The total emissions from this counterfactual are presented below.

Table 12: LCA counterfactual for management of a reed bed.

Activity	**Fuel carbon intensity (kg of CO_2e/ha)**
Brushcutting	9.29
Mowing	299.37
Burning	11,150
Transportation	6.06
Total LC emissions	**11,464.72**

[9] Carbon Trust conversion factors 2011 update. http://www.carbontrust.com/media/18223/ctl153_conversion_factors.pdf

[10] Seminar "Reed for Bio-energy and Construction". Reed as bio-energy: opportunities to use it in boiler-houses and as biogas source. Ülo Kask, Tallinn University of Technology. 11.03.2011 http://www.roostik.ee/ettekanded/Ulo%20Kask_11.3.2011_Reed_Seminar_Tuorla.pdf

ii. **A wet grassland with 70% soft rush, which is cut, baled for hay and passed to farmers as poor feed / animal bedding, whose farm is located within a 20 mile radius.**

Details of machinery used:

Tractor – John Deere 6930 - 150hp

Purchase Cost £70,000

All other machinery used, e.g. mower, baler etc. is conventional farm machinery.
2.5% cost of the machine goes into maintenance each year

To cut 1 hectare of wet grassland

Full crop - 8.5 large round bales taken off per ha
Cutting - 28 litres of diesel an hour, cutting 4.5ha an hour - 6.2 litres per ha
Rowing - 20 litres of diesel an hour and would row 10ha in an hour – 2 litres per ha
Turning - 20 litres of diesel an hour and would turn 10ha in an hour - 2 litres per ha
Baling - Tractor under full load use 30 litres of diesel an hour to produce 40 bales per hour – 0.75 litres per bale at 8.5 bales per ha = 6.4 litres per ha
Taking off site where loaded on to a trailer - 25 litres of diesel an hour and 30 bales moved in an hour - 1 litre per bale x 8.5 bales = 8.5 litres per ha

Harvesting

Total litres of diesel used per ha = 25.1 litres per ha

Utilisation of 1 litre of diesel emits 2.6676 kg CO_2e[11]

Cutting 1 hectare of grassland therefore releases 25.1 x 2.6676 = 66.95 kg (CO_2e)

Transportation

Tractor travels (with each attachment and trailer) to site involving a 10 mile round trip.
Tractor and trailer which carries 20 round bales is used to transport to a farm which is located within a 20 mile radius

Fuel economy of tractor and trailer = 7.5miles per gallon or 1.7 miles per litre

1 gallon = 4.546 litres

Maximum haulage of tractor and trailer for single project = 50 miles

Therefore, total diesel used = 50 ÷ 1.7 = 29.41 litres

Therefore, moving tractor and trailer will emit 29.41 x 2.6676 = 78.46 kg (CO_2e)

The total emissions from this counterfactual are presented below.

[11] Carbon Trust conversion factors 2011 update.
http://www.carbontrust.com/media/18223/ctl153_conversion_factors.pdf

Table 13: LCA counterfactual for management of a wet grassland with rush.

Activity	Fuel carbon intensity (kg of CO_2e/ha)
Cutting, rowing, turning & baling	66.95
Transportation	78.46
Total LC emissions	**145.4 kg**

1.4.3 Comparison of the three management systems

The wetland biomass to bioenergy system compares favourably with both current management practices. The summary of activities and their fuel carbon intensity per hectare are summarised in Table 14 below and a comparison of all three systems is shown in Table 15.

Table 14: LCA counterfactual for wetland biomass to bioenergy system.

Activity	Fuel carbon intensity (kg of CO_2e/ha)
Transport of machinery	4.04
Harvesting of reed	40.01
Processing into charcoal	747.82
Transport of charcoal	15.49
Energy production	466.81
Total	**1,274.17**

Table 15: Comparison of wetland biomass to bioenergy system with current management practices.

Habitat	Management method	Fuel carbon intensity (kg of CO_2e/ha)
Reed bed	Cut manually, raked and burned by hand	11,465
Wet grassland and rush	Cut, baled for hay as poor feed / animal bedding	145
Reed bed	Pyrolisation and gasification to produce electricity and heat	1,274

The wetland biomass to bioenergy system reduces CO_2 emissions by a factor of 10 compared to burning reed on site. This equates to a saving of 10.19 tonnes of CO_2e for each hectare of reed harvested. This is highly significant considering the area of reed in Europe (see section 1.7.4). In

Estonia alone there are 24,000 hectares of reed beds[12]. If 20% of these were harvested using this process then 48,912 tonnes of CO_2e could be saved per year There is potential that clean burn charcoal production will in future be rewarded with carbon credits[13]. This would bring in additional revenue to schemes adopting this approach.

[12] Seminar "Reed for Bio-energy and Construction". Reed as bio-energy: opportunities to use it in boiler-houses and as biogas source. Ülo Kask, Tallinn University of Technology. 11.03.2011 http://www.roostik.ee/ettekanded/Ulo%20Kask_11.3.2011_Reed_Seminar_Tuorla.pdf

[13] Approved consolidated baseline and monitoring methodology ACM0021. Reduction of emissions from charcoal production by improved kiln design and/or abatement of methane" http://cdm.unfccc.int/filestorage/U/J/B/UJBDVFYLQKSEWCM73XG14Z692TRHO0/EB47_repan06_ACM0001_ver11.pdf?t=S2d8bWtkYmd0fDCTywQjTgNho44R-j70Kdwr

1.5 Emissions

Producing charcoal from retorts has several key advantages over traditional ring kiln methods. They are more efficient, cleaner, produce fewer emissions and a higher grade of charcoal without contaminants. Retorts use an external heat source to start the process and recycle the syngas that is generated. The process can be likened to cooking biomass in a gas oven and therefore there is much greater control throughout the process.

Figure 16: Traditional ring kilns are much more polluting and visually intrusive than the Exeter Retort.

The pyrolisation of biomass results in the following products:

- charcoal
- non-condensable gases (carbon monoxide (CO), carbon dioxide (CO_2), methane, and ethane)
- pyroacids (primarily acetic acid and methanol)
- tars and heavy oils
- water

All except the charcoal are emitted to the atmosphere. CO_2 and water vapour are the largest components as most of the volatile organic compounds (VOC) and CO undergo complete combustion before leaving the retort. This is highly significant as methane is 20 times more potent as a greenhouse gas than CO_2. Although, uncombusted tars may solidify to form particulates (PM) and pyroacids may form aerosol emissions, it is estimated that the utilsation of the syngas through "after burning" reduce emissions of PM, CO, and VOC by at least 80%[14,15].

1.5.1 Measures to counteract emissions

The retort was carefully designed and computer modelled to ensure that it burns off harmful particles and emissions by ducting the hot gases back into the retort. Measuring the emissions of the retort is not a simple activity as there are so many variables (feedstock, moisture content, pyrolysis

[14] Emission Factor Documentation for AP-42. Section 10.7 Charcoal. Final Report For U. S. Environmental Protection Agency Office of Air Quality Planning and Standards. Emission Factor and Inventory Group. September 1995 http://www.epa.gov/ttnchie1/ap42/ch10/bgdocs/b10s07.pdf

[15] The environmental Implications of emissions from charcoal production. Bioregional. 1995. http://www.bioregional.co.uk/files/publications/EmissionsCharcoal_1995.pdf

temperature). Measurements will be required from both the firebox and the retort chamber and these are likely to vary greatly according to the type of fuel used to start the process and the length of time exothermic energy is applied.

Measurements from the retort chamber will also vary greatly with the size, density and nature of the feedstock. This means that any measurements taken will be a snapshot of the emissions being produced by whatever fuel and feedstock was being used on the day. Even measurements taken over a period of time with different feedstocks and fuels will give only a very broad indication of likely emissions as each burn is different due to the number of variables involved.

Beyond capturing excess syngas there are no other methods currently employed for reducing emissions. However, we intend to thoroughly test the retort for emissions from the pyrolisation of wetland biomass in Phases 2 and 3 of the project. We will also explore the practical and economic implications of incorporating additional abatement components such as ceramic filters, electrostatic precipitators, cyclone technology and flue gas recirculation[16]. Any possible solution for reducing the emissions needs to ensure that airflow is maintained thereby facilitating quick combustion.

1.5.2 Evidence that all emission types have been considered

The smoke that issues from the retort during the early stages of pyrolisation may attract attention and cause concern to members of the public passing by. As stated above, the vast majority of dangerous emissions are recycled during the process. However, there will be some local increase in levels of CO and VOCs caused by the pyrolisation of reed but we are assured that these pollutants are less important than NOx and particulates. We consulted Robert Stewart of Defra's smoke control team. He stated that:

> *"CO is generally of interest for safety of the user and efficiency and because it is an indicator of combustion efficiency. In air quality terms it is not likely to be an issue as thresholds are comparatively high and background levels are low so an individual appliance is unlikely to impact significantly on ambient concentrations of CO. By comparison, for NO_2 and PM10/PM2.5 (i.e. particulates) the 'headroom' for additional emissions can be very small."*

Hence, although the CO levels will be slightly higher when pyrolising wetland biomass the level should not significantly affect air quality. In any case, the largest source of CO is from road transport[17] particularly vehicles travelling at low speeds on urban or minor roads[18].

1.5.3 Consultation with local councils regarding site-specific air quality requirements

During phase 2 we will liaise closely with Sedgemoor District Council regarding air quality. The Ham Wall site is not in a Smoke Control Zone nor in an Air Quality Management Area (AQMA) for benzene, PM_{10}, NO_2 or SO_2[19]. Sedgemoor DC previously had an AQMA for SO_2 but this was revoked back in 2005[20]. We do not perceive there being any issues when using this process in either rural or urban locations. In each case, the wetland biomass will be processed *in situ* so the majority of emissions will be produced at the wetland site and therefore cause little disruption to the general

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16 http://www.combustiontechnology.co.za/training/oxides_of_nitrogen.htm

17 The Air Quality Strategy for England, Scotland, Wales and Northern Ireland Vol 1. DEFRA 2007. www.defra.gov.uk/publications/files/pb12654-air-quality-strategy-vol1-070712.pdf

18 The Air Quality Strategy for England, Scotland, Wales and Northern Ireland Vol 2. DEFRA 2007. www.defra.gov.uk/publications/files/pb12670-air-quality-strategy-vol2-070712.pdf

19 http://aqma.defra.gov.uk/aqma/maps.php

20 http://aqma.defra.gov.uk/aqma/list.php

public. The charcoal fuel going into the gasifier, by contrast is likely to lead to little in the way of smoke emissions. More people will be working or visiting the Wetlands Centre but we envisage that there will be no reduction in their local air quality. If this is the case, this would mean that the gasifier should also be suitable for urban locations such as the local towns of Glastonbury and Wells. The testing of emissions in phase 2 and 3 will indicate whether the gasifier produces more, the same or an improved spectrum of emissions compared to alternative biomass systems with wetland biomass feedstock.

1.5.4 The long term impact of burning these feedstocks and measures /adaptions that can be made to counteract such impact

Although the retort technology produces significantly fewer emissions than a traditional ring kiln it is still imperative that the operatives are aware of health and safety issues and wear appropriate personal protection clothing (PPE). The most important part of the process for user safety is the opening of the retort after a burn as there is a small chance that they will be exposed to CO and particulates. Masks and goggles should also be mandatory when emptying the retort and filing the hopper with charcoal to guard against dust inhalation and getting debris in the eyes.

Any SO_2, NOx, CH_4 or pyroacids released from the flue of the retort are believed to be in small enough quantities to have little or no effect on an operative's health. Common sense will need to be exercised – for instance avoiding direct inhalation of emissions from the flue. Full exposure to the emission stream could cause breathing difficulties and watering of eyes.

We will endeavour to site the retort away from nearby trees so that they are not exposed to any long term, low level SO_2 and acetic acid emissions. One must bear in mind that this process is very localised and small scale so will not lead to acid deposition in nearby towns and cities.

In order for the USS gasifier/IC engine system to be eligible for payments through the Feed in Tariff and Renewable Heat Incentive Schemes it will be necessary to prove that the technology can meet new emission limits of 30 grams per gigajoule (g/GJ) for particulates and 150 g/GJ for NOx. As the charcoal feedstock used will be almost pure carbon the emissions from this aspect of the process are likely to be well below the specified limits. This would not be the case for briquettes or pellets produced from reed or rush. Such herbaceous materials will have similar issues to miscanthus grass which is likely to require abatement equipment for particulates and possibly NOx. In a separate piece of work for South Somerset District Council, Crops for Energy discovered that only two of the six "miscanthus compliant" boilers available in the south west have achieved the emissions limits in independent tests[21]. A quote for adding a ceramic filter to the flue system of a 200 kW Hargassner boiler was £17,000.

Furthermore, reed or rush pellets and briquettes are likely to cause much harsher wear and tear to any boiler in which they are used due to the high ash content, low ash melting point and corrosive nature of the fuel (See section 1.1.9). The USS gasifier is likely to have a much longer lifetime than a conventional boiler using these fuels as almost all of the ash forming inorganic contaminants and corrosive compounds are burnt off during pyrolisation leaving a very pure carbon rich charcoal.

The independent testing of a boiler is likely to be relatively expensive costing £5,000-£10,000 each time a boiler is tested with a different fuel. This however, will be crucial to the exploitation of the commercial unit and this will be factored into the phase 3 budget.

[21] Potential for biomass boiler projects using locally sourced energy crops. Crops for Energy for South Somerset District Council. February 2013.

1.6 Process cost analysis

Detailed analysis of turnkey costs for producing electricity and heat from wetland biomass using our proposed process are outlined in Appendices I and II. We have produced a pre-competitive scenario based on current kit prices and a more commercial 2020 scenario based on increased efficiencies and reductions in production and processing costs. In each case, we have included an energy cost in £/MWh both including and excluding harvesting costs. However, as harvesting would take place as part of conservation management of wetland areas irrespective of the biomass being used for energy generation we are satisfied that these costs can be discounted.

Table 16 below outlines some of the key information in both these scenarios. The pre-competitive scenario presents a very high cost of electricity generation from our system. By 2020 we believe that with refinements and economies of scale we should be able to bring down the electricity generation costs to £393/MWh – a reduction of 73%. The addition of an internal combustion engine will enable the heat to be utilised (i.e. combined heat and power or CHP). This will bring down the overall cost of total energy production (heat and electricity) to £212/MWh.

Table 16: Summary of inputs and costs of energy generation from the retort/USS gasification system.

		Pre-competitive 2013 scenario	**Commercial 2020 scenario**
Amount of reed required (tonnes/yr)		23.2	47
Wetland area required (ha)		3.6	7.3
Amount of char required		4.3	10.4
Conversion rate of biomass : char		5.4 to 1	4.5 to 1
Size or retort (m^3)		1.7	4
Number of burns per year		109	94
Size of gasifier (kWe)		10	20
Electricity produced (MWh/yr)		8.672	20.24
Heat produced (MWh/yr)		/	17.35
Cost of electricity generation (£/MWh)	With harvesting	£ 1585.71	£ 474.37
	W/o harvesting	**£ 1449.65**	**£ 393.03**
Cost of CHP generation (£/MWh)	With harvesting	/	£ 255.43
	W/o harvesting	/	**£ 211.63**

Please note: we have not included a cost for grid connection as this can be site specific. In certain circumstances it will be too expensive for this to be an option. See section 1.6.2 c.

1.6.1 Discounted cash flow analysis

Table 17 below presents a cash flow analysis for our wetland biomass to bioenergy system. We have used the production and generation costs of the commercial scenario for 2020 along with current prices for replacement fossil fuel energy. In order for our system to be a worthwhile investment it would need subsidies from the Feed in Tariff (FITs) and the Renewable Heat Incentive. In the analysis below we have set the FIT intervention rate at 40p/kWh and assumed that the renewable heat produced would receive 8.5p/kWh (allowing for Retail Price Index rise in April 2013).

Based on these and the other assumptions (listed below) our system would pay back in 8 years and achieve a return on investment (ROI) of 12.2%. We feel that the assumed subsidies are fair and in line with previous pump priming measures offered through the FITs scheme (e.g. the FIT rate for solar photovoltaics was 41.3p/kWh for installations prior to 31st March 2012).

Table 17: Discounted cash flow analysis for the retort/USS gasification system.

Year	Costs	Revenue	Interest	Balance
1	£ 51,033.27	£ 11,036.69	£ -	-£ 39,996.58
2	£ 4,010.27	£ 11,698.89	-£ 1,999.83	-£ 34,307.79
3	£ 6,875.88	£ 12,400.82	-£ 1,715.39	-£ 30,498.24
4	£ 8,630.94	£ 13,144.87	-£ 1,524.91	-£ 27,509.21
5	£ 4,776.29	£ 13,933.56	-£ 1,375.46	-£ 19,727.40
6	£ 7,687.87	£ 14,769.58	-£ 986.37	-£ 13,632.06
7	£ 5,366.64	£ 15,655.75	-£ 681.60	-£ 4,024.55
8	£ 9,813.64	£ 16,595.10	-£ 201.23	£ 2,555.69
9	£ 8,654.96	£ 17,590.80	£ 63.89	£ 11,555.43
10	£ 6,391.76	£ 18,646.25	£ 288.89	£ 24,098.81
11	£ 6,775.26	£ 19,765.03	£ 602.47	£ 37,691.05
12	£ 13,931.78	£ 20,950.93	£ 942.28	£ 45,652.48
13	£ 7,612.68	£ 22,207.99	£ 1,141.31	£ 61,389.09
14	£ 8,069.44	£ 23,540.46	£ 1,534.73	£ 78,394.84
15	£ 11,178.61	£ 24,952.89	£ 1,959.87	£ 94,128.99
16	£ 13,191.83	£ 26,450.07	£ 2,353.22	£ 109,740.46
17	£ 9,610.84	£ 28,037.07	£ 2,743.51	£ 130,910.20
18	£ 12,812.49	£ 29,719.29	£ 3,272.76	£ 151,089.77
19	£ 10,798.74	£ 31,502.45	£ 3,777.24	£ 175,570.73
20	£ 11,446.66	£ 33,392.60	£ 4,389.27	£ 201,905.94

Pay back	8 years
Return on investment	12.16

Assumptions

- 2020 commercial set up costs = £47,250
- Oil and mains electric replaced with CHP from USS gasifier
- Does not include harvesting costs
- Operation and maintenance costs = 3% of capital costs
- Replacement retort chamber (£2,625.00) replaced after 225 burns - years 3, 6, 9, 12, 15, 18)
- Replacement retort outer (£4,125.00) replaced after 340 burns - years 4, 8, 12, 16)
- Electricity offset = 20,236 kWh/yr
- Oil heating offset = 17,345kWh/yr
- Savings compared to fossil fuel (1st year) = £1,732.88
- Feed in Tariff intervention rate set at 40p/kWh
- FITs income (1st Year) = £8,094.40
- RHI tier 1 tariff = 8.5p/kWh
- RHI income (1st year) = £1,209.41
- Interest rates for positive bank balances = 2.50%
- Interest rates for negative bank balances = 5.00%
- Reference fuel cost inflation rate = 6.00%
- RPI inflation rate = 4.80%

- Annual maintenance cost inflation rate = 2.70%
- Annual fuel production price increase = 2.70%

Table 18 shows the effect of the FIT rate on the pay back and ROI. Our view is that 40p/kWh would be the minimum rate in order for this to be a sound investment.

Table 18: Effect of the FIT intervention rate on the simple payback and return on investment.

Hypothetical FIT intervention rate (p/kWh)	Payback (years)	Return on Investment (%)
15	/	/
20	18	3.60
25	14	5.74
30	11	7.88
35	11	10.02
40	8	12.46
45	7	14.31
50	6	16.45

1.6.2 Comparison with alternative forms of energy production

a) Grid electricity

DECC have recently produced estimated costs for different electricity producing technologies. These are detailed in Table 19 and Figure 17 below. It can be seen that during the pre-competitive phase our solution is a very expensive form of electricity production. However, by 2020 the technology will be much more competitive with generation costs achieving similar figures to other more expensive forms of renewable energy such as tidal energy.

b) Small scale biomass generation using energy crops

We have also compared our predicted costs for a commercial system with the estimated costs of running a 100 kW combustion generator fed with dried short rotation coppice (SRC) willow chips. As the Energy Crops Scheme is coming to an end[22] and there is as yet no information on a successor scheme we have omitted the 50% grant for establishment costs. If we include the wetland biomass harvesting costs, our solution has a slightly higher cost of electricity production (£ 474/MWh versus £ 410/MWh). However, if the harvesting is discounted then our solution is slightly more competitive than the SRC fed combustion plant. This is partly due to the much greater efficiency of the USS gasifier (35% versus 20%) but also as a result of negligible transport costs.

It is also important to note that small scale biomass CHP systems using energy crops and low grade wood waste have a very chequered history. Several projects have floundered and Talbott's have removed their flagship 100 kWe Biogenerator from the marketplace. Many problems resulted from the fact that low value (and therefore poor quality) wood chip was required to make the system financially viable. By contrast, in our initial tests we have demonstrated the simplicity and functionality of our retort and gasification technology. By creating a premium fuel through the pyrolysis stage we remove one of the biggest hurdles encountered by small scale biomass generation and CHP.

[22] Energy Crops Scheme closes to new application in August 2013. As long as a site is approved for planting by December 31st 2013 then the crop may be established in the spring of 2014 or 2015.

Table 19: Estimated levelised cost ranges for electricity technologies[23,24]

Technology	Electricity generation cost (£/MWh)	
	2010	2020
Combined Cycle Gas Turbine	76-79	87-91
Landfill gas	39-50	39-50
Sewage gas	57-122	55-115
Large hydro > 5 MW	42-74	42-75
Small hydro < 5 MW	67-215	68-218
Offshore wind	149-191	102-176
Onshore wind	75-127	71-122
Dedicated biomass	127-165	120-156
Biomass co-firing	94-110	93-110
Biomass CHP	210-250	185-220
Biomass conversion	106-128	106-127
AD < 5MW	75-194	70-173
Solar PV	202-380	136-250
Geothermal	132-341	77-184
Wave	/	208-266
Tidal stream	/	162-262
Tidal barrage	/	206-340

Another distinct advantage of wetland biomass over woody energy crops is that the material is already growing and requires harvesting every year. Farmers have been very slow to embrace the planting of SRC willow and miscanthus. Currently, there are only around 10,000 hectares of perennial energy crops planted in England under the Energy Crops Scheme[25].

In 2000 there were around 738,000 hectares of wetlands in the UK. If 20% of this area was harvested and utilised using our solution this would yield 413 gigawatt hours (GWh) of electricity per year. This would be the same amount produced from 50,400 ha of SRC willow. Energy crops are typically grown on grade 3 land that is suitable for arable food production. So by utilising 147,600 hectares of wetland for energy production this would reduce the amount of farmland required for energy crops. 50,400 hectares of land would be enough to produce around 340,200 tonnes of wheat[26]. This would yield enough grain to bake 756,000,000 loaves of bread a year[27]! This is not an argument for food versus fuel (as we need both) but more of a justification for using our land resources as effectively as possible.

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[23] Review of the generation costs and deployment potential of renewable electricity technologies in the UK. Study Report REP001 Final Updated October 2011. Arup for DECC. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/42843/3237-cons-ro-banding-arup-report.pdf

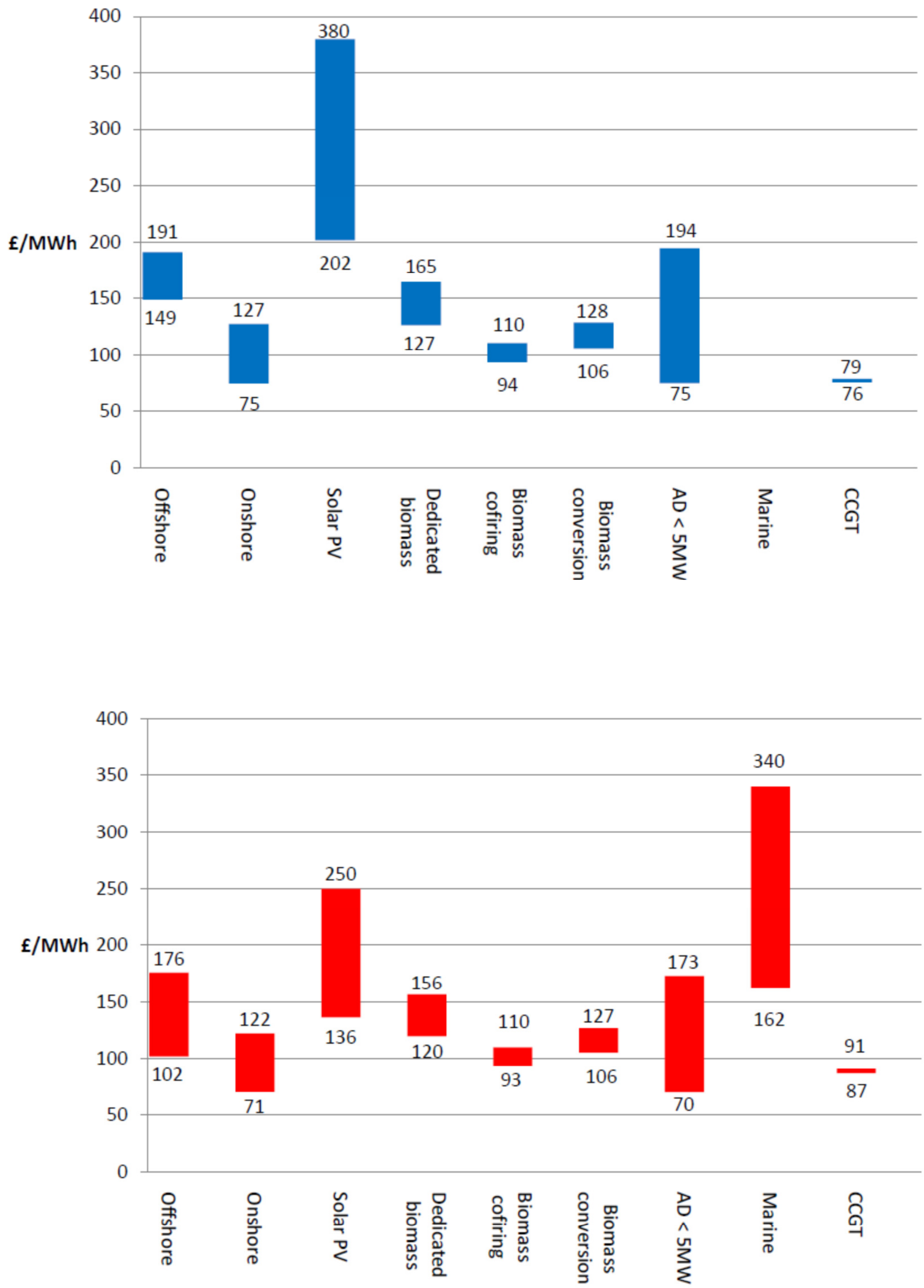
[24] Electricity generation costs. DECC October 2012. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65713/6883-electricity-generation-costs.pdf

[25] Domestic Energy Crops: Potential and Constraints Review. NNFCC for DECC. April 2012.

[26] John Nix Farm Management Pocketbook. 43rd edition. 2013. Page 5. Low winter wheat yields of 6.75 tonnes/ha.

[27] Crops for Energy blog. Food versus Fuel – Do us a favour! http://www.crops4energy.co.uk/food-vs-fuel-do-us-favour

Figure 17: Graphs showing levelised costs for electricity technologies in 2010 (top) and 2020 (bottom). Extracted from the UK Renewable Energy Road Map[28].



[28] UK Renewable Energy Road Map. DECC July 2011. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48128/2167-uk-renewable-energy-roadmap.pdf

Table 20: Comparison of energy generation costs using SRC and wetland biomass.

		Short rotation coppice	Wetland biomass	Notes
Feedstock	Biomass type	Willow chips	Reed bales	
	Amount of raw feedstock required (odt/yr)	85.2	40	
	Moisture content at harvest	55%	15%	
	Amount of processed feedstock required (odt/yr)	85.2	10.4	
	Moisture content when used	20%	3%	
	Land required (ha)	10.7	7.3	
Biomass utilisation	Technology	Combustion	Pyrolisation & gasification	
	Size (kW)	100	20	
	Cost (£/kW)	4,000	3,600	Indicative current price for 100 kWe combustion system; Commercial 2020 scenario for USS gasifier.
	Hours of operation/year	4,380	2,891	
	Load factor	0.5	0.33	
	Electrical efficiency	0.2	0.35	
	Annual generation (MWh)	**87.6**	**20.2**	
Annualised costs	Crop production	£ 1,453	£ -	No establishment grant considered. Costs spread over 22 years
	Harvesting and extraction	£ 1,864	£ 1,646	Costs spread over 22 years (7 harvests) for SRC. 10 years for reed biomass.
	Biomass conversion	£ -	£ 5,103	Costs of retort and labour spread over 10 years
	Transport	£ 852	£ -	£10/odt for local transport. Negligible for charcoal removal – done as part of incidental travel by retort operative.
	Drying and storage	£ 1,549	£ -	£10/tonne to bring MC below 20%
	Biomass utilisation	£ 30,182	£ 2,850	Capital cost spread over 22 years. Annual cost includes O&M at 3% of capital.
	Total	**£ 35,900**	**£ 9,599**	
Production costs	Cost of electricity generation £/MWh)	**£ 410**	**£ 474**	
	Cost of electricity generation (pence/kWh)	0.41	0.47	
Land use	MWH produced per hectare of land required	8.2	2.8	

c) Off grid energy solutions

In many ways, our solution is best suited to providing an off grid energy production system as most wetlands are in remote areas. This is particularly the case in other countries such as the Russian Federation, Estonia, Latvia and Finland.

The use of the USS gasifier with an internal combustion engine will provide combined heat and power and is non-intermittent meaning that residents of any building can benefit from the heat and electricity when they need it. By contrast, other forms of renewable energy are less predictable and would require some form of back up and means of storage (e.g. batteries). We have compared our 20 kWe gasifier with two alternatives for off grid generation – firstly a diesel generator and secondly a renewable energy solution combining photovoltaics (PV), wind and a ground source heat pump (GSHP). A summary of this analysis is presented below and the detailed financial analysis of these options (including the assumptions made) can be found in Appendices III, IV and V.

Table 21: Comparison of the Exeter retort/USS gasification system with other off grid options.

<table>
<tr><th></th><th colspan="2">Diesel generator</th><th colspan="2">Exeter retort/
USS Gasifier</th><th>PV/Wind/
GSHP</th></tr>
<tr><td>Scenario</td><td>2013</td><td>2020</td><td>2013</td><td>2020</td><td>2013</td></tr>
<tr><td rowspan="3">Capacity</td><td rowspan="3" colspan="2">10 kVa</td><td rowspan="3">10 kWe</td><td rowspan="3">20 kWe</td><td>PV 8.8 kW peak</td></tr>
<tr><td>Wind 6 kW</td></tr>
<tr><td>GSHP 25 kW</td></tr>
<tr><td rowspan="2">Electricity produced (MWh/yr)</td><td rowspan="2">10.9</td><td rowspan="2">10.9</td><td rowspan="2">8.672</td><td rowspan="2">20.24</td><td>PV 7.68</td></tr>
<tr><td>Wind 9.09</td></tr>
<tr><td>Heat produced</td><td>/</td><td>/</td><td>/</td><td>17.35</td><td>38.25</td></tr>
<tr><td>Capital costs</td><td>£8754</td><td>£10,271</td><td>£85,000</td><td>£47,250</td><td>£75,238</td></tr>
<tr><td>Annual costs of electricity generation</td><td>£12,110</td><td>£17,267</td><td>£13,751</td><td>£9,599</td><td>£9,338</td></tr>
<tr><td>Cost of electricity generation (£/MWh)</td><td>£1,111</td><td>£1,584</td><td>£1,450</td><td>£393</td><td>£361</td></tr>
<tr><td>Cost of total heat and power production (£/MWh)</td><td>/</td><td>/</td><td>/</td><td>£211</td><td>£241</td></tr>
</table>

During the pre-competitive stage the cost of electricity generation from the retort/gasifier combination is very high even when compared to the diesel generator. However, by 2020 the gasifier could produce electricity and heat for a similar cost to the PV, wind and GSHP combination whilst the cost of diesel generation would be four times as much. A large proportion of the electricity produced by the latter combination will be required to provide power for the heat pump. By contrast the heat produced by the gasifier is much less than that produced by the GSHP. This shortfall could be dealt with by using surplus power for supplementary electric heating.

Hence, by 2020 our solution should provide a realistic and competitive option for off grid heat and power generation.

1.7 Exploitation

1.7.1 Protection and any use of IP during the project
Carbon Compost Company already has a patent application at an advanced stage on certain aspects of the retort. It would be very difficult for another manufacturer to produce a machine that functions in a similar way without infringing the patent or using a gas delivery method that will result in the same efficiency as our machine enjoys. This patent was applied for several months before the start of this project.

1.7.2 Agreements with the land managers etc.
During phase 1 of the project Carbon Compost have already used the retort worked on the RSPB managed wetland sites at Exminster Marshes and Ham Wall. Both were arranged via Sally Mills the RSPB's Reserves Bioenergy Project Manager. Following this we liaised directly with staff at the respective sites. We met the H & S requirements and found suitable locations for the retort at both sites. We intend to build upon such relationships during phase 2.

1.7.3 Negotiations and agreements with end users of the bioenergy
In the early development of this technology the custodians of the wetland sites will also be the end users. As stated above we are already in dialogue with Sally Mills, who is very keen to demonstrate the system at the Avalon Marshes Wetland Centre on the Somerset Levels. As this activity increases we will be aiming to sell the system to third parties.

1.7.4 Commercialisation plans and market potential
The Exeter Retort has already found a market amongst charcoal makers and biochar manufacturers. The larger developed machine will be also have applications in other markets, although optimised for wetland biomass fuels. Carbon Compost Company intend to market the entire ensemble required for this project if agreements can be reached and we can establish there is a market for the process, although each component is marketable in standalone form anyway. Development after phase 2 will continue with the Exeter Retort in incremental steps that build on the knowledge and experience gained by using the prototype and production machines under differing conditions and with different feedstocks.

In 2000, there were 157 wetland sites covering 738,000 hectares in the UK[29]. If 20% of this area was utilised using our proposed solution this would provide a market for 950,301 tonnes of wetland biomass[30]. Based on a requirement of 47 tonnes of raw feedstock for a commercial 20 kWe USS gasifier this would provide enough biomass for 20,219 projects in the UK alone. This would provide an installed capacity of 404 MW and a yearly electricity production of 414 GWh. This is more than the current generation from wind farms in the SW of England (394 GWh in 2012)[31].

Initially we will be aiming for our wetland biomass to bioenergy system to be adopted by the many wetland sites in the UK with visitor centres. For instance, the Wildfowl and Wetlands Trust and RSPB have 18 wetland reserves in the UK. Each of these has offices, shops and restaurants.

There are 220 million hectares of inland wetland areas in Eastern Europe[32] so the potential to exploit this biomass to bioenergy system is enormous. Figure 18 shows areas of wetland in Western Europe.

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[29] Ramsar sites in England. A Policy statement. http://www.ramsar.org/cda/en/ramsar-documents-list-uk-launches/main/ramsar/1-31-218%5E21178_4000_0__
[30] 147,600 multiplied by 6.4 tonnes/ha @ 15% moisture content.
[31] Renewable Energy Progress Report. South West 2012 Annual Survey. Regen SW
[32] Review of wetland inventory information in Eastern Europe. N Stevenson & S Frazier. 1998. www.wetlands.org/rsis/wkbase/growi/report_easterneurope.doc

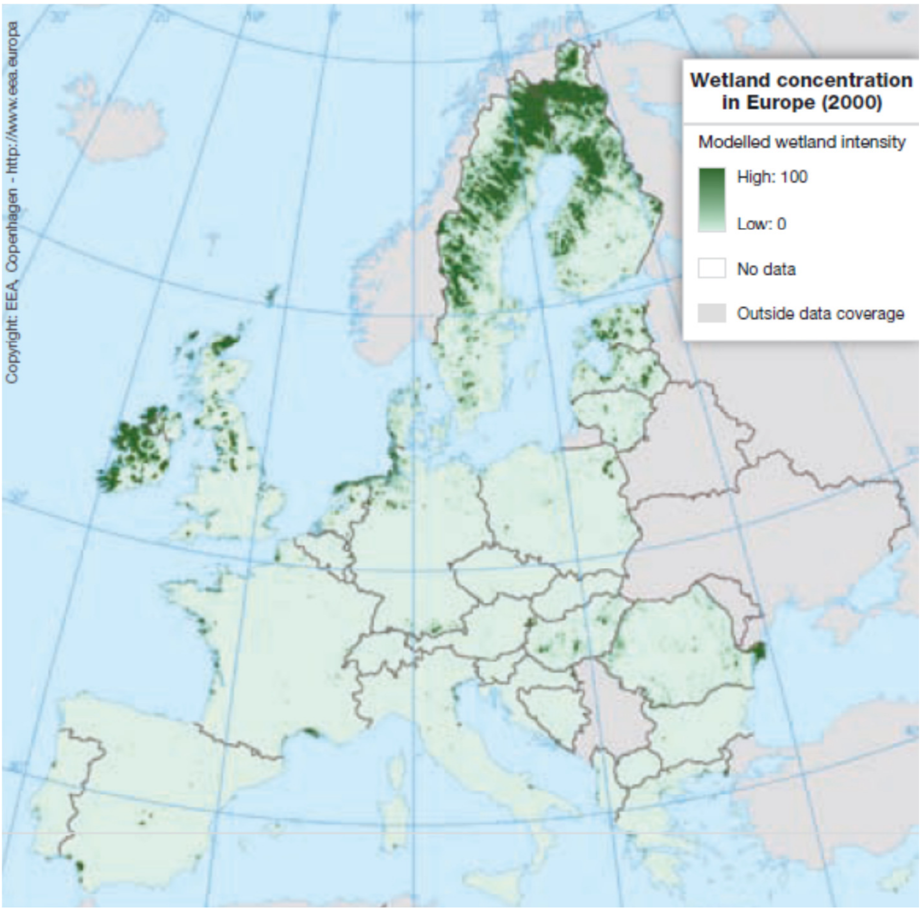


Figure 18: Wetland areas in Europe. Extracted from: Life and Europe's Wetlands[33].

Apart from the UK there are significant areas in Ireland, Finland, Denmark, Holland, Sweden, Estonia, Latvia, Lithuania, Germany, Poland, Hungary and Romania.

1.7.5 Scalability and adaptability to different land types, including networks of remote sites
The Exeter Retort is trailer mounted and can be adapted to any land type as long as a suitable towing vehicle is used. It has a light footprint and its mass can be spread further by use of the screw jacks fitted as standard. For this reason remote sites pose no problems for the pyrolisation stage of our project. As long as a 4 X 4 or a tractor can access the site, so can the retort. It is our intention to build a larger machine to the make best use of the feedstock available to us during phase 2. We see no significant difficulties doing this without compromising the advantages the standard machine has.

The USS gasifier is particularly well adapted for producing heat and electricity to buildings in remote sites. Section 1.6.2 c suggests that this system could be a competitive off grid renewable energy system.

[33] Life and Europe's Wetlands: Restoring a vital Ecosystem. European Commission 2007. http://ec.europa.eu/environment/life/publications/lifepublications/lifefocus/documents/wetlands.pdf

2. PROJECT PLANS FOR PHASE 2, PHASE 3 DEVELOPMENT & TRIALS

2.1 Project plan

The ultimate aim is to provide a closed loop biomass to bioenergy life cycle within a close proximity of the wetland area. In phase 2 we will work towards the siting of a 10-20 kWe prototype USS gasifier to provide combined heat and power to a visitor attraction on an actively managed wetlands site. The University of Sheffield will design, manufacture, test and commission a gasification unit at their Buxton Lab. Once the unit has been thoroughly tested and is fully functional it will be transported to the site of choice for further testing as part of phase 3.

Carbon Compost Company will continue to develop their retort. The objective will be to increase the size of the machine so that throughput and charcoal yields can be maximized and operator time can be streamlined. Trials will also be carried out on other woody materials in conjunction with reed and rush biomass in order to perfect the proportion of ingredients necessary to produce the best yield and quality of charcoal from the system.

Loglogic will investigate the potential of developing machinery for baling willow/alder brash or processing thicker material (>25mm) into suitable small logs for processing in the retort.

Crops for Energy will liaise closely with site owners and lead on the feasibility of integrating the USS gasifier into an existing building or new build. C4E willow also collate information from the consortium and present a project report detailing the development of the various technologies and the advanced trials that build on those we c=have carried out in phase 1.

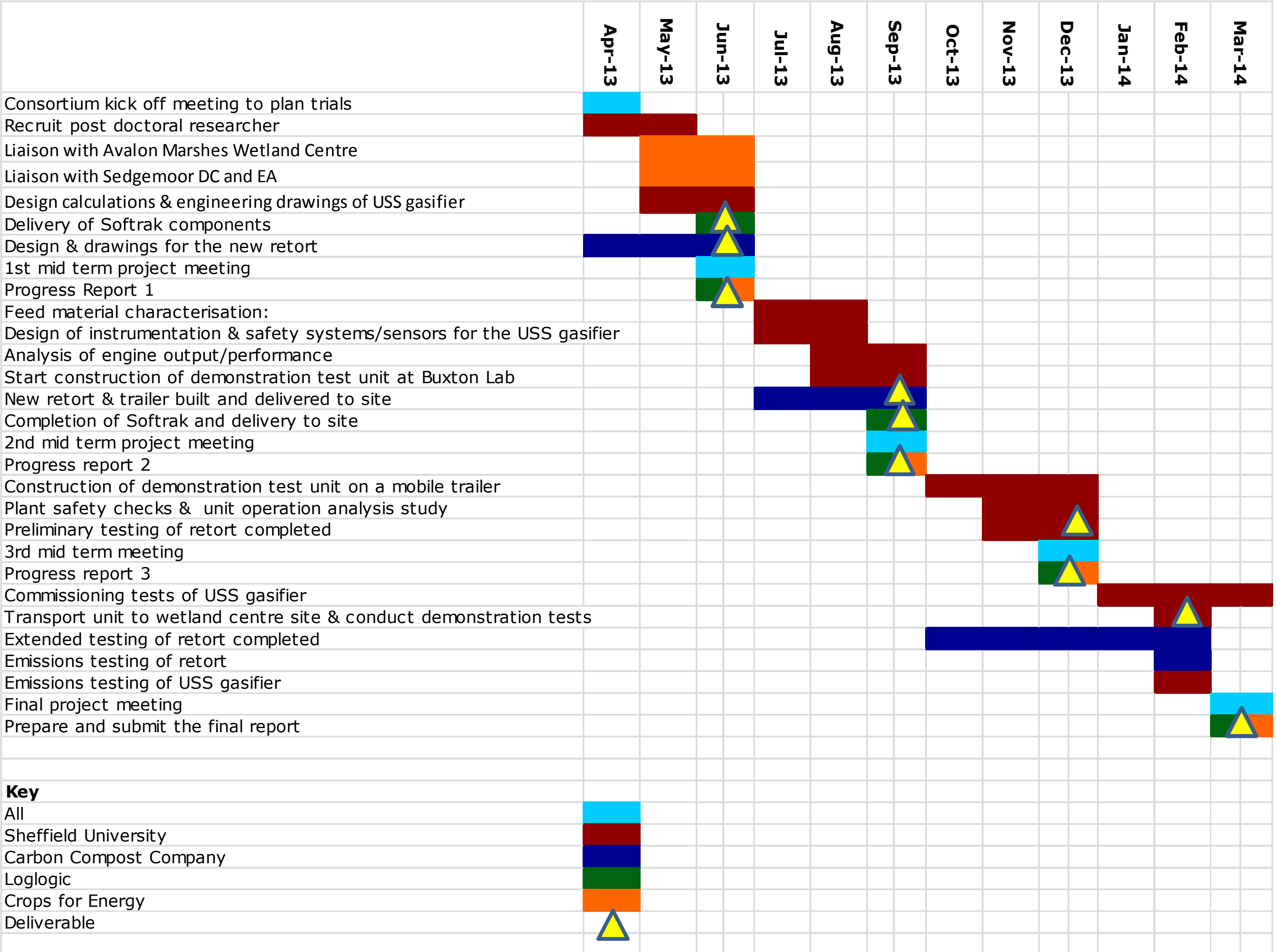
In phase 3 of the project we will be looking to add final tweaks to the harvesting, processing and conversion technologies. Further demonstration trials will be conducted at a wetland site and exploitation plans will be developed showing a realistic route to market.

The tasks for phase 2 are outline below and in a Gantt chart (Figure 19). Deliverables are in bold and indicated with a red arrow on the Gantt chart.

Months 1 to 3:

- Advertise/recruit a suitable postdoctoral researcher to work on the project (UoS)
- Liaison with Avalon Marshes Wetland Centre and partner organisations to discuss site work and testing the gasifier (C4E)
- Liaison with Sedgemoor District Council and Environment Agency regarding any regulatory permits required (C4E)
- Carry out design calculations/prepare engineering drawings for demonstration test Unit i.e. sizing, capacity and design of feeder, USS gasifier, gas clean up system (particle removal) and IC engine (UoS)
- **Delivery of Softrak components (tracks, motors, engines) (LL)**
- **Complete design, drawing and production plan for the new retort and trailer (CC)**
- **Prepare Progress Report 1 and meet with partners to discuss results (UoS & C4E)**

Figure 19: Gantt chart showing activities and deliverables.



Months 3 to 6:

- Feed material characterisation: Calorific value, particle size determination, ultimate and proximate analysis (UoS)
- Design of the associated instrumentation and safety systems/sensors for the demonstration unit (UoS)
- Analysis of engine output/performance (UoS)
- Start construction of demonstration test unit at Buxton Lab (UoS)
- **New retort and trailer built and delivered to site (CC)**
- **Completion of Softrak and delivery to site (LL)**
- **Prepare progress report 2 and meet with partners to discuss results (UoS & C4E)**

Months 6 to 9:

- Construction of demonstration test unit at Buxton Lab on a mobile trailer unit (UoS)
- Plant safety checks and unit operation analysis study (UoS)
- **Preliminary testing of retort completed (CC)**
- **Prepare progress report 3 and meet with partners to discuss results (UoS & C4E)**

Months 9 to 12:

- Harvesting of 3.6 hectares of reed (LL)
- Commissioning tests at Buxton lab using demonstration unit (months 9 and 10) (UoS)
- **Transport demonstration test unit to wetland visitor centre site and conduct demonstration tests at the site using wetland biomass (months 11 and 12) (UoS)**
- Extended testing of retort completed (CC)
- Emissions testing of retort (CC)
- Emissions testing of USS gasifier (UoS)
- **Prepare and submit the final report and meet with partners to discuss results (UoS & C4E)**

2.1.1 Site to be used for demonstration purposes

The intention is to demonstrate the wetland biomass to bioenergy system at the proposed Avalon Marshes Visitor Centre. Facilities will include a café and a shop and teaching areas. This will be located on the grounds of a former cafe and garden centre site at Shapwick Road, Westhay on the Somerset Levels.

The proposal for the site is in an advanced stage - final plans (Appendix VI) were drafted following a consultation with the general public in the summer of 2012. We will liaise with the partner organisations (Natural England, Royal Society for the Protection of Birds, Somerset County Council, Somerset Wildlife Trust, Hawk and Owl Trust) involved in the running of the centre to investigate the potential to test the USS gasifier on the site. The test facility will be mounted on a mobile trailer so will not disrupt the layout of the building in any way. The Avalon Marshes attracts more than 70,000 visitors each year[34] so this present an exceptional way of disseminating this project to other conservation bodies and the general public.

The building will be built in two phases. Phase one and two will be constructed at the same time. The maximum floor area of the site is 670 m^2 of which 235m^2 is first floor, the rest ground floor. Phase Three will be approximately 250m^2. The heating requirements of the building have not been modelled for this study but are likely to be relatively low as the intention is to build it to Passivhaus standards, making the most of natural light and ventilation, and insulating to very high standards.

The Passivhaus standard[35] suggests that the:

- Specific heating demand of a building should be ≤ 15kWh/m^2/yr or the
- Specific heating load should be less than ≤ 10W/m^2

Based on a floor area of 670m^2 this would mean that the Avalon Marshes Centre will have:

- an annual heating demand of 10,050 kWh and
- a specific heat load of 6.7 kW.

A 10 kWe prototype gasifier would therefore be ideally suited to providing this heat demand. Based on a 33% capacity factor and heat production being 30% efficient the gasifier would produce 8,672 kWh/yr. Hence, we would only need to increase the capacity factor to 40% in order to meet this need.

Following the successful testing of the facility the Wetland Centre may wish to provide the permanent base for the gasifier. We anticipate that the unit will work well and fulfil other requirements by being relatively compact with a small fuel hopper and having low emissions. Most biomass boilers fail as a result of problems with fuel specification (e.g. incorrect particle size and moisture content). With our system we are creating a premium, carbon rich fuel with a very low moisture content. As a result, once the gasifier has been rigorously tested it should be efficient, reliable and easy to maintain.

2.1.2 Habitat types to be harvested

Reed, willow and perhaps rush will be harvested from the network of local wetlands that are all within a 3 mile radius of the Avalon Marshes Visitor Centre.

Table 22: Sites on the Somerset Levels from which we intend to harvest wetland biomass.

Site	Ownership / management responsibility	Habitat type	Current annual harvest area (hectares)	Estimated annual yield (odt/yr)	Time of harvest
Ham Wall	RSPB	Reed bed	8	44	Winter
			2	11	Summer
Shapwick Heath	Natural England	Reed bed	6	33	Winter
		Rank grassland	3	?	Summer
Westhay Moor / Heath	Somerset Wildlife Trust	Reed bed	3	16	Winter
		Fen	12	?	Summer
		Grassland	40	?	Summer

[34] New Visitor Centre Planned for the Avalon Marshes http://www.somersetwildlife.org/article37.html
[35] Passivhaus primer: Introduction. An aid to understanding the key principles of the Passivhaus Standard BRE. http://www.passivhaus.org.uk/filelibrary/Primers/KN4430_Passivhaus_Primer_WEB.pdf

Notes

- Yield is measured in oven dry tonnes (ODT) as moisture contents will vary widely.
- ODT for hayfields and fen not currently known
- ODT stated for reed assumes that reed returning 5.5 tonne / ha
- Values given are for a typical year although this can vary due to seasonal conditions and access issues

There is ample reed to supply the Exeter Retort /USS gasifier system. Additional burns could be produced and processed into biochar which could be sold in the visitor centre shops.

In the early stages of the project we will continue to trial the retort using existing sources of wetland biomass:

- Ham Wall
    - We will use the reed bales that will have been cut by Loglogic as part of their harvesting demonstration
- Exminster Marshes
    - There are sufficient round bales of rush mixed with grass already harvested.
    - There is sufficient willow cut and stored for at least one demonstration.

2.1.3 Access requirements

The harvester and retort are compact facilities so we do not envisage there being any significant access issues.

The trailer and towing vehicle will need to be able to get to the working site but still on a hard standing with a suitable turning area. If this is an issue then the Softrak can be driven on the road (If suitably licensed) to get to the site.

Most access gates in the countryside are of standard widths. The minimum sized economy gate is around 2.44m wide. The overall width of the Softrak and harvester in transport mode is 2.83m. The Softrak alone has a working width of 1.4 m so will have no access issues when unloaded. The current retort is 2.1m wide so this should also have unbridled access to most locations. The scaled up retort has a proposed working width of 2.5m so it might not be possible to get into some fields.

Processed charcoal will be removed from the site in a small vehicle. We will carefully choose a site that minimises the distance that baled material needs to be transported as well as providing a firm base for the retort and allows regular trafficking from the operative's vehicle.

As the managers of the visitor centre are also the custodians of the wetland sites we see no unforeseen issues regarding access to locked gates. We will negotiate with the partner organisations to gain permission to carry copies of keys for specific sites during the harvest season. Ultimately, volunteers will be carrying out charcoal production. A system will need to be adopted where they sign out keys and return them each day.

2.1.4 Time of year for harvesting

We will take advice from partner organisations on the best time to harvest reed, rush and willow. It is possible that unseasonal weather will mean an influx of migrant birds or other wildlife into the wetland areas at unusual times of the year. We understand that conservation of the wetland areas is paramount and we will not put the requirement for feedstock above the preservation of species and key habitats.

As a general rule we will assume that most reed and willow will be harvested in winter between 1st November and the 31st January. There may be opportunity for harvesting rush and grass during summer between the periods of 1st August to 1st October. However, as reed and willow are the most preferred feedstocks and there is sufficient material at the three local sites we do not envisage needing to harvest rush in the summer.

2.1.5 Composition of material to be harvested

Reed and rush/grass will be harvested and stored in round bales. Willow branches will be cut with either traditional tools (billhooks, bow saws, loppers) or with chainsaws depending on the skill set of the voluntary labour available. Willow branches will be stored in heaps and due to large amount of air space between branches should dry down to 30% in 3-6 months with limited loss of dry matter.

2.1.6 Methods and expected timescale of harvesting

Reed will be harvested using the Softrak cutter/baler. The harvesting window is 90 days between November and the end of January. There are 19 hectares of reed in the immediate surround of the Wetland Centre. The harvester has a work rate of 1.5-2.5 ha per day. If the entire area of reed was harvested then the Softrak would be required for 6-10 days during this period. We predict that only 23.2 tonnes of material will be required to produce enough charcoal for the 10 kW gasifier. This would mean a maximum of three days of harvester time specifically for fuel production.

We hope that weather conditions will be suitable to allow the harvesting to be completed within this window of opportunity. If weather conditions are unfavourable (e.g. the autumn/winter of 2012/13) then the system will have to make do with other wetland biomass resources.

A 10 kWe Gasifier will require 30 tonnes of raw rush/grass feedstock. Assuming a yield of 1.4 odt/ha for sparse rush and a moisture content of 25% this would entail harvesting 16 hectares. According the LCA counterfactuals obtained from Sally Mills It should be possible to cut, row, turn and bale 4.5 hectares of rush in three hours. Hence, it should be possible to produce enough rush from just two days of harvesting. This would be done with a 150 HP tractor and conventional mower attachment and baler.

Willow will be harvested using traditional hand tools or chainsaw anytime during winter. It is not possible to quantify the time required to produce a particular volume from manual harvesting as volunteer operatives will vary in fitness and speed of operation. A skilled chainsaw operator should be able to harvest 1-2m^3 in woodland and 0.5-1m^3 in coppice. In a wetland situation it is probably sensible to assume a low work rate of about 0.5 m^3. If willow was to be used exclusively for charcoal production then 14 tonnes would be required. Based on a mass density of 520 kg/m^3 at 20% MC this would mean a volume of 27 m^3. This would require 54 hours of operative time to harvest and stack. There is ample willow feedstock that could be accessed from pollarded willows planted along the rhynes and other watercourses on the Somerset Levels. It is unlikely that willow will be the main constituent of the feedstock.

2.1.7 Methods and expected timescale for the removal of harvested material

The reed can be pyrolised as soon as it is cut and the resulting biochar can be collected and removed the next day.

2.1.8 Amount of material to be harvested and size of area required

See section 2.1.6 above.

2.1.9 Storage requirements

Storage areas are summarised in table 23 below.

Table 23: Onsite storage requirements for wetland biomass.

Feedstock	Amount required (tonnes)	Storage medium	Bulk density (kg/m^3)	Volume required (m^3)
Reed	23.2	Bale	125	186
Rush/grass	30	Bale	125	240
Willow	14	Heap of branch wood	100	140

The harvested material can be left on site ready for processing by the retort. As the material can be processed immediately, storage can be kept to a minimum.

2.2 Cost Breakdown

The overall budget for phase 2 is presented below.

We have reduced the budget by £8,002 as a result of the risk-benefit sharing approach to SBRI.

The work programmes have changed slightly since the application was made for phase 1 support. The allocation for two of the partners has been slightly reduced whilst Carbon Compost has had an increase in respect of the additional work required to test the retort.

2.2.1 Justification of Resources (Sheffield University):

Staffing:

- **Staff: Directly Incurred Costs**

The phase 2 of DECC Wetland Biomass Project demands high quality personnel with expertise in design and operation of biomass gasification/power generation. Funding is requested for one postdoctoral research associate (full time over a period of 12 months) to undertake design, construction and operation of the mobile demonstration test unit as well as the associated theoretical work. Funding is also requested for one part-time technician (Mike O'Meara) over the period of 12 months to manufacture/construct/operate the main experimental rigs and to assist with the operation of these rigs over the project period.

- **Staff: Directly Allocated**

Professors Sharifi will manage the project at Sheffield University and both Professors Swithenbank and Sharifi will contribute technically to the project i.e. design and associated calculations, technical supervision of project, project outputs etc.

Travel and Subsistence:

- Daily car journeys to Sheffield University's Buxton research laboratory/site where the experimental rigs will be based and preliminary experimental tests will be conducted.
- Transportation of mobile demonstration unit from Buxton Lab to Somerset (one of UK's sites) for demonstration trials (hiring relevant motorway transportation)
- Overnight accommodation, travel and subsistences costs for 3 staff from Sheffield University (one researcher and two technicians) for 4 weeks while running demonstration trials at Somerset site

Other Directly Incurred Costs

- **Consumables**

Funding is requested at Sheffield to construct and operate the mobile demonstration unit. The main items include feeder, gasifier, emission removal unit (particle removal), IC Engine for this research study. Other consumables include: the experimental raw materials and chemicals, pressure swing oxygen unit, steam generator, data logging hardware and software, water pumps, electrical heated steam lines, gas cylinders, analytical consumables, safety material for experiments, various valves and gauges, glassware, electrical consumables, calibration gases, gas pumps, ducting, thermocouples, heating elements, instrumentation, water gauges, tubing, metal pipe work, personal safety protection equipment, sampling probes, etc.

Table 24: Phase 2 budget.

Activity		Unit cost	Quantity	Sub total	VAT	Total cost
Labour costs						
Carbon Compost	Robin Rawle	£350.00	7.15	£2,502.50	£500.50	£3,003.00
	Geoff Self	£350.00	7.15	£2,502.50	£500.50	£3,003.00
Loglogic	Marcus Frankpitt	£480.00		£0.00	£0.00	£0.00
Crops for Energy	Kevin Lindegaard	£500.00	20.00	£10,000.00	£2,000.00	£12,000.00
University of Sheffield	Vida Sharifi	£600.00	1.65	£982.00	£0.00	£982.00
	Michael O'Meara	£600.00	32.00	£19,216.00	£0.00	£19,216.00
	Jim Swithernbank	£600.00	5.80	£3,500.00	£0.00	£3,500.00
	Postdoctoral Researcher	£389.00	108.00	£42,057.00	£0.00	£42,057.00
Materials costs						
Harvester				£97,000.00	£19,400.00	£116,400.00
Retort				£20,000.00	£4,000.00	£24,000.00
Gasifier				£66,500.00	£0.00	£66,500.00
Sub Contract costs				£0.00	£0.00	£0.00
Travel & Subsistence Costs	University of Sheffield			£6,500.00	£0.00	£6,500.00
	Carbon Compost			£215.00	£43.00	£258.00
	Crops for Energy			£100.00	£20.00	£120.00
Indirect Costs	University of Sheffield (Overheads)			£33,343.00	£0.00	£33,343.00
Other Costs	University of Sheffield (Estates Costs)			£12,580.00	£0.00	£12,580.00
	Emissions testing of retort at UoS			£1,500.00	£0.00	£1,500.00
	Emissions testing of USS gasifier at RHI certificated test centre			£5,000.00	£1,000.00	£6,000.00
Phase 2 total				**£323,498.00**	**£27,464.00**	**£350,962.00**

2.2 Invoicing plan
Our invoicing plan is set out below.

Table 25: Invoicing schedule.

Partner	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Total
Carbon Compost	£6,064.50	£18,064.50	£3,067.50	£4,567.50	£31,764.00
LogLogic	£46,800.00	£69,600.00	£0.00	£0.00	£116,400.00
University of Sheffield	£46,169.50	£46,169.50	£46,169.50	£52,169.50	£190,678.00
Crops for Energy	£3,030.00	£3,030.00	£3,030.00	£3,030.00	£12,120.00
Total	**£102,064.00**	**£136,864.00**	**£52,267.00**	**£59,767.00**	**£350,962.00**

2.3 Deliverables

2.3.1 Phase 2 deliverables

Months 1 to 3:

- Delivery of Softrak components (tracks, motors, engines) (LL)
- Complete design, drawing and production plan for the new retort and trailer (CC)
- Prepare Progress Report 1 and meet with partners to discuss results (UoS & C4E)

Months 3 to 6:

- New retort and trailer built and delivered to site (CC)
- Completion of Softrak and delivery to site (LL)
- Prepare progress report 2 and meet with partners to discuss results (UoS & C4E)

Months 6 to 9:

- Preliminary testing of retort completed (CC)
- Prepare progress report 3 and meet with partners to discuss results (UoS & C4E)

Months 9 to 12:

- Transport demonstration test unit to wetland visitor centre site and conduct demonstration tests at the site using wetland biomass (months 11 and 12) (UoS)
- Prepare and submit the final report (UoS & C4E)

2.3.2 Phase 3 deliverables

In phase 3 of the project we will be looking to add final tweaks to the harvesting, processing and conversion technologies. Deliverables from phase 3 include:

- Continued on-site demonstrations of the technology at one or more wetland sites (CC & UoS)
- Development of exploitation plan (CC, UoS & C4E)
- Production of a finalised LCA using the trial data (C4E)
- Prepare and submit an extended report detailing the output of these further trials, and refinements made to the system (UoS & C4E)

2.4 Key Risks and Mitigation

The key risks involved in the project and our mitigation strategy is outlined in the table below.

Table 26: Key risks and mitigation strategies

Risk type	Specific part of the process	Specific issue	Impact on the project (high, medium, low)	Likelihood of occurrence (high, medium low)	Mitigating action
Technical	Retort	Scaled up retort doesn't work	Medium	Low	The projected retort builds on a wealth of operational and engineering experience gained from using the smaller version.
	Softrak	Poor quality raw wetland feedstock	Medium	Medium	The quality of the cut reed is very dependent on the previous management of the site and on-going weather conditions. It is difficult to cut dry reed if it is raining hard. If the reed has not been managed for several years then the build-up of litter (dead leaves, grass etc.) could cause problems with the cutter binder as the base of the bundle becomes enlarged due to the additional litter collected, this also makes it more difficult to form a good bale. However machine has been trialled in these less than ideal conditions and found to perform well. Once harvested then the reed beds will improve in subsequent years. If reed is cut wet then the bales can be stacked on dry land (or ideally on something like pallets to allow air to circulate) and covered with a tarpaulin, they will then air dry down to an acceptable level. This is also the same method for storing excess material.
	Retort / Gasifier	Poor quality charcoal produced	High	Low	There is a risk of contamination if incorrect feedstock is used, especially chromated copper arsenate (CCA) treated wood. Care must be taken to process only untreated materials. Risk of external contamination is very low, the most obvious being water absorption. Char should be unloaded and taken to a dry area as soon as possible.
	USS Gasifier	Prototype fails to work	High	Low	Unlikely due to wealth of experience built up during development of the current system. There is ample expertise and budget to make sure this does not happen.

	Softrak	Technical failure	Medium	Low	Softrak cutter binder is a well proven, standard commercial machine with a ready availability of spares held by Loglogic. Trained engineers are available if required. Softrak has a 12 months warranty.
Programme	Retort/ USS Gasifier	Production deadlines are missed	High	Low	In each case we will build on the large pool of experience already gained. It is intended to develop the units early on in the programme to make sure we have plenty of time to prove it and make suitable changes should they be required.
	USS Gasifier	Failure to recruit post-doctoral researcher	Low	Low	In the event that a suitable candidate cannot be recruited or there is a delay in the candidate's start date UoS will use an existing member of technical staff (David Palmer) to do the work. This would not affect the budget in any way.
	Softrak	Production deadlines are missed	Low	Medium	There is some risk due to late receipt of equipment delaying production of the Softrak and cutter binder. Delivery is normally 5-6 months for this type of equipment. It may be possible for use to be made of existing equipment owned by the RSPB on the Somerset levels to provide material for trials.
	Retort	Failure to get enough volunteers on board	Low	Low	This should not be an issue as it is planned that the machine will require operating only two days a week. This is really a question for the operator rather than the vendor.
Environmental	Retort	Emissions from the retort causing a nuisance	Low	Medium	The machine will be sited well away from the public during normal operations and as it produces little smoke complaints are unlikely. A burn was carried out at Exminster Marshes in Devon adjacent to the RSPB offices and close to a road and footpath and other industrial units. No complaints were received during the three days we operated there. We intend to test the retort for emissions in the latter stages of phase 2.
	Retort	Damage by flooding when sited on the Somerset Levels	High	Low	Flood should not be an issue because if you can harvest then the area you'd be moving the retort to is unlikely to be flooded. If it does look like the weather is going to take a turn for the worse the machine could be moved even when hot to higher ground, although this is best avoided.
	USS Gasifier		High	Low	The gasification unit is placed on a trailer so flooding will not damage the unit. It can be moved in advance of serious flooding events.

	Softrak	Noise and air pollution causing a nuisance	Low	Low	The Softrak has standard exhaust and sound levels typical for this type of equipment. Diesel engine is of approved emission level. Harvesting reed with the cutter binder require little power so noise and exhaust levels are low. This type of equipment is regularly operated on these sites with no significant complaints from the general public.
	Softrak	Damage by flooding when sited on the Somerset Levels	Low	Low	Flooding: Machine stored in area not prone to flooding. Softrak can wade up to 600mm. Flooding more an issue in terms of lost production. Can be mitigated by diversity of sites or if necessary storing of cut material in secure location for use when harvester unable to work due to weather, flooding or other unforeseen circumstances.
Permissions/ regulatory requirements	Retort	/	Low	Low	The retort has no regulatory requirements to meet as far as manufacture and operation is concerned aside from the usual H&S considerations and operations in low smoke zones. The latter will have no effect as the machine will be sited at remote locations well away from designated zones. Permissions to use the machine on site for the demonstration will be granted by the RSPB, and Carbon Compost Company will comply with the requirements they specify to gain permission.
	USS Gasifier	Failure to meet RHI emissions thresholds	High	Low	The unit contains a gas clean up system (particle removal) so there will be few emissions into the atmosphere. Also the charcoal is very pure so unlikely to contain a high content of particulates of NOx. We intend to test the USS Gasifier for emissions at an RHI accredited test house during phase 3.
Budget/ resource	Retort	Budgetary issues	Low	Low	The prototype larger machine is the cheapest component of this project and although build and development will run to well into five figures the resource is available to cope with this. Stage payments will be arranged for phase 2 to ensure good cash flow.
Safety	Retort	Injury to operatives	Low	Medium	The upper body of the machine gets hot during use. Gloves are essential along with thick non-flammable clothing. There should be no need to climb up the side of the retort as tools are provided to operate the butterfly valve and retort flue caps from the ground. These measures will minimise burn risks.

	Retort	**Exposure to fumes**	Low	Low	The gas emitted from the retort flues is fairly unpleasant for a short period of time and care should be taken not to inhale it. However, the risk is not so great that masks are appropriate, being similar to those posed by making a small bonfire.
	Retort	**Exposure to dust**	Low	High	During unloading operations it is recommended that safety glasses and a dust mask are worn. A fair amount of charcoal dust is created whilst emptying the machine and breathing it in should be avoided. There are no acknowledged health issues surrounding charcoal dust but ingestion is best avoided.
	Retort	**Explosive nature of charcoal powder**	High	Low	Charcoal powder is an explosive so unloading the retort must be carried out in the open air and storage of charcoal must be in an open sided facility if in dumpy type bags. Once sealed in plastic bags it can be stored inside. Wherever the charcoal is stored there must be no naked flames or sources of ignition. The same applies when char is being unloaded from the retort after a burn. Charcoal can spontaneously combust when warm, especially when the ambient temperature is high. Dumpy bags of charcoal unloaded from the retort should be left for 24 hours in an open sided dry facility and out of the sun prior to packing in plastic bags.
	Softrak	Injury to operatives	Low	Low	Softrak cutter binder is a commercial machine designed to latest safety standards, Operators must be trained in all aspects of operating this type of machine. Safety glasses should be worn by the operator stacking the baler to prevent eye injuries, along with gloves for handling the reed bundles. Clothing and protective footwear should be suitable to climactic conditions. Dust is not normally an issue with reed but if conditions require then a dust mask should be worn.
	USS Gasifier	Catastrophic failure of gasifier unit	High	Low	Sheffield University staff will complete all the relevant risk assessment and COSHH forms before demonstration trials at Somerset. They will also be equipped with the required safety gears/gloves/masks etc. while operating the unit.

	USS Gasifier	Electric shock injury to operatives	Low	Low	All components will be fully insulated so there is no risk to operatives. There are no acknowledged health issues surrounding the operation of the mobile gasification unit.
Market/ commercial	Retort	/	Low	Low	We have already established a market for the smaller machine as a stand-alone product for manufacturing barbeque charcoal and biochar. Many people have enquired about a larger machine, so at the very least it will be possible to produce charcoal in the UK in a manner that's 80% less polluting than current methods. The association with this project and the established capabilities of our machine along with the UoS gasifier opens up a new market for charcoal altogether.
	Softrak	/	Low	Low	Softrak cutter binder is a standard commercial machine in production so risks are minimal.
Other	Retort	Vandalism to retort/USS Gasifier when left at wetland site overnight	Low	Low	The only area vandalism can really affect to retort is on the outer skin and the insulation underneath although only a very determined attack would puncture the skin. Graffiti type attacks would simply be burnt off at the next lighting. All skin and insulation components can be easily replaced on site. Ditto for towing equipment.
	USS Gasifier		Low	Low	The risk of vandalism can be mitigated by ensuring the mobile Unit is kept in a secure compound and behind locked gates when not in use and located away from public areas.
	Softrak	Vandalism to Softrak if left at wetland site overnight	Low	Low	Machine at some risk from vandalism as any machine of this type. Risk is generally low as access is difficult to wetland sites. If this presents itself as an issue then the machine can be stored at night/weekends in secure area along with other reserve equipment.

APPENDIX I: Retort & gasifier - Pre-competitive 2013 scenario

	Capital costs	On-going costs	
Harvester	£70,000.00		
Modifield baler frame	£6,000.00		
Low ground pressure, powered, tracked trailer	£21,000.00		
Development work	£3,000.00		
Employment costs		£452.40	2 operatives at £120 per day per person
Avg. diesel costs		£42.41	Avg. of typical and hard working
Servicing, parts and labour		£71.72	Based on average costs over 2500 hours of use
Secure storage of machinery		£35.00	1% of capital costs spread across 20 projects
Baling twine		£8.35	44 bales at £0.18/bale
Machinery		£35.00	1% of capital costs spread across 20 projects
Liability insurance		£35.00	1% of capital costs spread across 20 projects
Total costs	**£100,000.00**	**£679.89**	
Production cost £/bale		£14.65	
Production cost £/t		£50.86	Based on harvester cost spread over 10 years and between 20 projects and on-going costs
Annual production costs for 23.2 tonnes		**£1,179.89**	

Harvesting	
Wetland biomass yield (odt/ha)	5.5
Wetland biomass yield (t/ha @ 15% MC)	6.5
Min harvester output (bales/day)	20
Max harvester output (bales/day)	32

Bale weight (kg)	500		
Min amount of material processed per day (tonnes)	10		
Max amount of material processed per day (tonnes)	16		
Min area of reed processed per day (ha)	1.5		
Max area of reed processed per day (ha)	2.5		
Amount of material required (tonnes/yr)	23.2		Based on 4.3 tonnes/yr of char required and a conversion ratio of wetland biomass to char of 5.4:1. Max amount of reed in the retort = 212.5 kg per load (based on a bale density of 125 kg/m3). This equals 109.3 retort loads per year
No of bales	46.4		
Min number of days harvesting/yr	1.5		
Max number of days harvesting/yr	2.3		
Avg. number of days harvesting /yr	1.9		
Amount of diesel required day (typical)	20		
Amount of diesel required day (working hard)	40		
Red diesel cost (£/litre)	0.75		
Cost per normal day			
Diesel cost per year (typical)	£21.75	£34.80	
Diesel cost per year (hard working)	£43.50	£69.60	
Amount of wetlands required to produce sufficient fuel single retort (ha)	**3.6**		
Servicing charge for Softrak for 2500 hours used	£11,890.29		
Hourly rate including service labour costs and parts	£4.76		
No of hours days	8		

	Capital costs	On-going costs	
Retort	£11,250.00		Costs reduced by 25% in real terms due to increase in orders
Employment costs		£2,025.00	Annual production costs (Voluntary labour, 3 hours per day for 100 days a year costed at £6.75/hou 2.7% per year
Diesel costs		£37.27	100 journeys of 2 miles (round trip). Diesel vehicle fuel economy of 50 mpg = 11 miles per litre). Fue price increase of 6% per year.
Servicing		£112.50	1% of capital costs
Parts and labour		£1,612.50	Replacements required (retort chamber £2,625 after 225 burns; new outer £4,125 assuming the ins burns). Cost spread over 10 years. Spare parts costs reduced by 25% due to increase in orders.
Secure storage of machinery		£0.00	Existing barn or garage
Sealants		£50.00	More permanent solution found. Replaced once a year.
Wood for starting the process		£141.00	50 kg of wood to start process therefore 4.7 tonnes/year per retort @ £30/tonne to allow for harve wetland sites
Machinery		£0.00	Covered by overall equipment budget
Liability insurance		£0.00	Covered by overall equipment budget
Total costs	**£11,250.00**	**£3,978.27**	
Processing cost (£/t)		£108.58	
Annual production costs for 47 tonnes		**£5,103.27**	Based on retort cost spread over 10 years and on-going costs
Number of burns per year	94		
Number of burns over 10 years	940		
Amount of reed processed (tonnes/yr)	47		

	Capital costs	On-going costs	Notes
10 kW_e Gasifier	£70,000.00		
Grid connection	£0.00		Not connected to the grid
Fuel store	£0.00		Small hopper accepting bagged fuel. Included in the capital costs
Operations and maintenance		£2,100.00	3% of capital cost per year
Insurance		£0.00	Covered by site insurance
Total costs	**£70,000.00**	**£2,100.00**	
Annual costs of electricity production		**£5,600.00**	Based on gasifier cost spread over 20 years and on-going costs

Annual cost of pre competitive electricity production

Electricity produced (MWh/yr)	8.672
Harvesting	£1,179.89
Processing of reed into charcoal	£6,971.40
Gasification of charcoal to electricity	£5,600.00
Total costs per year	**£13,751.29**
Cost of electricity generation including harvesting (£/MWh)	**£1,585.71**
Cost of electricity generation excluding harvesting (£/MWh)	**£1,449.65**

APPENDIX II: Retort & gasifier - Commercial 2020 scenario

	Capital costs	On-going costs	Notes
Harvester	£63,000.00		Costs reduced by 10% in real terms due to increase in orders
Modifield baler frame	£5,400.00		
Low ground pressure, powered, tracked trailer	£18,900.00		
Development work	£0.00		
Employment costs		£901.12	2 operatives at £140.8 per day per person. Inflation at 2.7% per year.
Avg. diesel costs		£71.83	Avg. of typical and hard working, Diesel price increase of 6% per year
Servicing, parts and labour		£121.86	Based on average costs over 2500 hours of use. Inflation at 2.7% per year
Secure storage of machinery		£31.50	1% of capital costs spread across 20 projects
Baling twine		£20.21	94 bales at £0.215/bale
Machinery		£31.50	1% of capital costs spread across 20 projects
Liability insurance		£31.50	1% of capital costs spread across 20 projects
Total costs	**£87,300.00**	**£1,209.52**	
Production cost £/bale		£12.87	
Production cost £/t		£35.02	Based on harvester cost spread over 10 years and between 20 projects and on-going costs
Annual production costs for 19.35 tonnes		**£1,646.02**	
Harvesting			
Wetland biomass yield (odt/ha)	5.5		
Wetland biomass yield (t/ha @ 15% MC)	6.5		
Min harvester output (bales/day)	24		Increased productivity by 20%
Max harvester output (bales/day)	38		

Bale weight (kg)	500		
Min amount of material processed per day (tonnes)	12		
Max amount of material processed per day (tonnes)	19		
Min area of reed processed per day (ha)	1.9		
Max area of reed processed per day (ha)	2.9		
Amount of material required (tonnes/yr)	47		Based on 10.4 tonnes/yr of char required and an improved conversion ratio of wetland biomass to char of 4.5:1. Max amount of reed in the retort = 500 kg per load (based on an increased retort size of 4m3 and a bale density of 125 kg/m3). This equals 94 retort loads per year
No of bales	94		
Min number of days harvesting/yr	2.5		
Max number of days harvesting/yr	3.9		
Avg. number of days harvesting /yr	3.2		
Amount of diesel required day (typical)	20		
Amount of diesel required day (working hard)	40		
Red diesel cost (£/litre)	0.75		
Cost per normal day			
Diesel cost per year (typical)	£37.11	£58.75	
Diesel cost per year (hard working)	£74.21	£117.50	
Amount of wetlands required to produce sufficient fuel single retort (ha)	7.3		
Servicing charge for Softrak for 2500 hours used	£11,890.29		
Hourly rate including service labour costs and parts	£4.76		
No of hours per day	8		

	Capital costs	On-going costs	
Retort	£11,250.00		Costs reduced by 25% in real terms due to increase in orders
Employment costs		£2,025.00	Annual production costs (Voluntary labour, 3 hours per day for 100 days a year costed at £6.75/hour. No employers NI. Inflation rate of 2.7% per year
Diesel costs		£37.27	100 journeys of 2 miles (round trip). Diesel vehicle fuel economy of 50 mpg = 11 miles per litre). Fuel price of £2.05/litre. Annual fuel price increase of 6% per year.
Servicing		£112.50	1% of capital costs
Parts and labour		£1,612.50	Replacements required (retort chamber £2,625 after 225 burns; new outer £4,125 assuming the insulation can be reused after 340 burns). Cost spread over 10 years. Spare parts costs reduced by 25% due to increase in orders.
Secure storage of machinery		£0.00	Existing barn or garage
Sealants		£50.00	More permanent solution found. Replaced once a year.
Wood for starting the process		£141.00	50 kg of wood to start process therefore 4.7 tonnes/year per retort @ £30/tonne to allow for harvesting and processing costs from wetland sites
Machinery		£0.00	Covered by overall equipment budget
Liability insurance		£0.00	Covered by overall equipment budget
Total costs	**£11,250.00**	**£3,978.27**	
Processing cost (£/t)		£108.58	
Annual production costs for 47 tonnes		**£5,103.27**	Based on retort cost spread over 10 years and on-going costs
Number of burns per year	94		
Number of burns over 10 years	940		
Amount of reed processed (tonnes/yr)	47		

	Capital costs	On-going costs	Notes
20 kW$_e$ Gasifier	£35,000.00		£4,000 per installed kW. Costs reduced by 43% in real terms due to increase in demand. Electricity production increased to 35% efficiency.
Grid connection	£0.00		
Fuel store	£1,000.00		
Operations and maintenance		£1,050.00	3% of capital cost per year
Insurance		£0.00	Covered by site insurance
Total costs	**£36,000.00**	**£1,050.00**	
Annual costs of electricity production		**£2,850.00**	Based on gasifier cost spread over 20 years and on-going costs

Annual cost of commercial electricity production

Electricity produced (MWh/yr)	20.24	20 kW gasifier. Electrical generation efficiency increased to 35%, Capacity factor of 33%
Harvesting	£1,646.02	
Processing of reed into charcoal	£5,103.27	
Gasification of charcoal to electricity	£2,850.00	
Total costs per year	**£9,599.29**	
Cost of electricity generation including harvesting (£/MWh)	**£474.37**	

Cost of electricity generation excluding harvesting (£/MWh)	**£393.03**	This presents a 73% reduction in the cost of electricity generation compared to the pre-competitive scenario. This is broadly comparable to the cost of the most expensive marine RE technology.
Heat produced (MWh/year)	17.35	30% efficiency, capacity factor of 33%
Total energy required for visitor centre per year	**37.58**	
Total cost of renewable energy system per year	**£9,599.29**	
Total cost of renewable energy system per year (excluding harvesting)	£7,953.27	
Cost per MWh inc. harvesting	**£255.43**	
Cost per MWh excl. harvesting	**£211.63**	

APPENDIX III: Diesel generator 2013 off grid scenario

	Capital costs	On-going costs	
10 kVa generator	£4,275.00		www.vitaltools.co.uk/generators-12-c.asp
10,000 litre storage tank	£4,479.00		www.commercialfuelsolutions.co.uk/systems/fuel_tanks/bunded/
Cost of diesel (including delivery)		£10,972.23	Based on current costs
Operations and maintenance costs		£262.62	3% of capital costs
Insurance		£0.00	Covered by site insurance
Total costs	**£8,754.00**	**£11,234.85**	
Annual costs of diesel generation		**£12,110.25**	Based on generator cost spread over 20 years and on-going costs
Electricity produced (MWh/yr)		**£10.90**	
Cost of electricity generation (£/MWh)		**£1,110.95**	
Output of diesel generator (kVa)	10		
Output of diesel generator (kW)	8		
Load (%)	75		
Efficiency (%)	20.7		www.dieselserviceandsupply.com/Diesel_Fuel_Consumption.aspx
Amount of diesel required (litres/hr)	2.63		
Amount of diesel required per year (litres)	17279.1		
Cost of diesel (£/litre)	0.635		www.boilerjuice.com/heatingOilPrices.php
Calorific value of diesel oil (kWh/litre)	11		www.carbontrust.com/media/18223/ctl153_conversion_factors.pdf
Output per hour (kWh)	6		

APPENDIX IV: Diesel generator 2020 off grid scenario

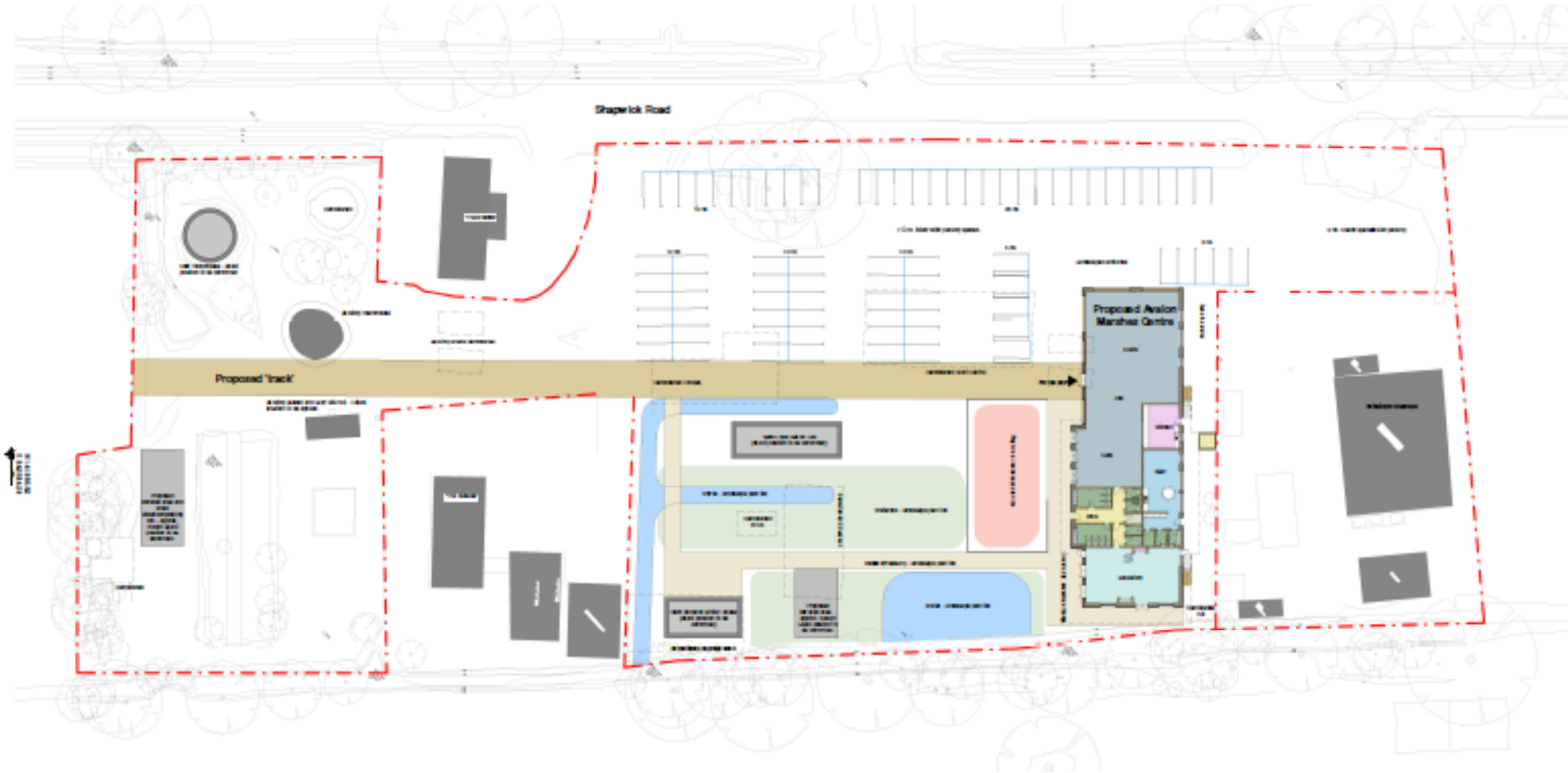
	Capital costs	On-going costs	
10 kVa generator	£5,016.00		Based on 2013 price with 2.7 % annual inflation
10,000 litre storage tank	£5,255.00		Based on 2013 price with 2.7 % annual inflation
Cost of diesel (including delivery)		£15,931.33	Based on 2013 price with 6% annual price increase. 2020 price = 92p/litre
Operations and maintenance costs		£308.13	3% of capital costs
Insurance		£0.00	Covered by site insurance
Total costs	**£10,271.00**	**£16,239.46**	
Annual costs of diesel generation		**£17,266.56**	Based on generator cost spread over 20 years and on-going costs
Electricity produced (MWh/yr)		**10.90**	
Cost of electricity generation (£/MWh)		**£ 1,583.97**	
Output of diesel generator (kVa)	10		
Output of diesel generator (kW)	8		
Load (%)	75		
Efficiency (%)	20.7		
Amount of diesel required (litres/hr)	2.63		
Amount of diesel required per year (litres)	17279.1		
Cost of diesel (£/litre)	0.922		
Calorific value of diesel oil (kWh/litre)	11		
Output per hour (kWh)	6		

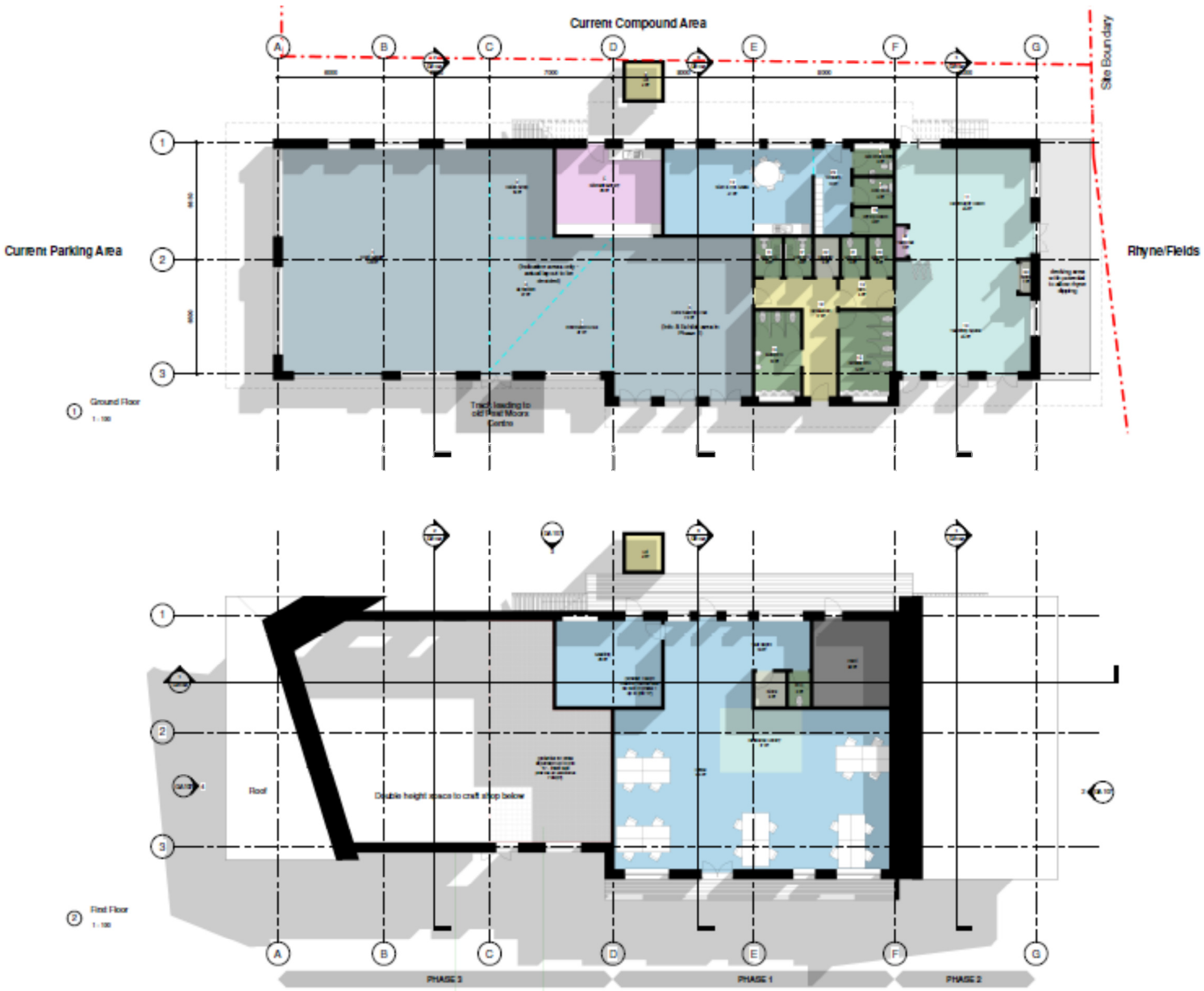
APPENDIX V: PV, Wind & GSHP off grid scenario

	Capital costs	On-going costs	
8.8 kWp PV system	£11,095.57		www.solarguide.co.uk/solar-pv-calculator#bestresult
Batteries	£5,832.75		3,333 ampere hours of storage; £350 per 200 AH battery. www.wirefreedirect.com/solar-system-batteries.asp
Storage location for batteries		£150.00	Rental costs of storage room
Disposal costs of batteries		£130.05	Estimated costs £1000/tonne. Cost spread over 10 years.
Operations and maintenance costs		£174.98	Checking on batteries for leakages and replacements. 3% of capital
Insurance		£0.00	Covered by site insurance
Total costs	**£16,928.32**	**£455.03**	
Annual costs of PV generation		**£2,147.86**	Based on costs spread over 10 years.
Electricity produced (MWh/yr)		**7.68**	
Battery lifetime	10 years		
Battery weight	76.5		
No of batteries	17		
Total weight of batteries (tonnes)	1.3005		
6 kW wind turbine	£30,000.00		http://www.enviko.com/technology/wind-turbines/wind-output-calculator#
Operations and maintenance costs		£900.00	3% of capital
Insurance		£0.00	Covered by site insurance
Total costs	**£30,000.00**	**£900.00**	
Annual costs of wind generation		**£3,900.00**	Based on costs spread over 10 years.
Electricity produced (MWh/yr)		**9.09**	5 m/s wind speed

Cost of electricity generation (£/MWh)		**£360.70**	
25 kW ground source heat pump	£15,000.00		670 m2 of floor area, built to current building regulations, 1,072 m of horizontal pipework, 1,000 litre buffer. 33 x 30 litre containers of antifreeze. (COP of around 3) http://www.vaillant.co.uk/homeowners/products/heat-pumps/ground-source-heat-pumps/ground-source-heat-pump-calculator/
Underfloor heating	£13,400.00		£20 per metre squared for 670m2 building
Operations and maintenance costs		£450.00	3% of capital
Insurance		£0.00	Covered by site insurance
Total costs	**£28,400.00**	**£450.00**	
Annual costs of wind generation		**£3,290.00**	Based on costs spread over 10 years.
Heating produced (MWh/yr)		**32.85**	25 kw system, 1314 hours per year
Total energy required for visitor centre per year (MWh/yr)		**38.67**	
Total cost of renewable energy system per year		**£9,337.86**	
Cost per MWh		**£241.49**	

APPENDIX VI: Plans of Avalon Marshes Visitor Centre




Current Compound Area
Site Boundary
Current Parking Area
Rhyne/Fields
Track leading to old Peat Moors Centre
Ground Floor
1 : 100
Roof
Double height space to craft shop below
First Floor
1 : 100
PHASE 3
PHASE 1
PHASE 2