DEPARTMENT OF ENERGY & CLIMATE CHANGE

Wetland Biomass to Bioenergy

Gasification and anaerobic digestion of sustainably-sourced wetland biomass

Phase 1 report and Phase 2 application form

Adapt Commercial Ltd

March 2013

Phase 1 report

Executive summary

'Wetland Biomass to Bioenergy' is a three-stage 'Small Business Research Initiative' that seeks to increase the availability of sustainably-sourced biomass whilst addressing the challenges of wetland management. In Phase 1 of this competition DECC has funded seven projects looking at different end-to-end processes.

This project was carried out by Adapt Commercial Ltd, a spin-out company from the University of East Anglia that provides low-carbon consultancy, and Peter Frizzell Ltd, a contractor of conservation services to wetland managers in the East of England.

Phase 1 of our project on the 'Gasification and anaerobic digestion of sustainably-sourced biomass' looked at the financial feasibility and carbon and energy benefits of:

- Producing briquettes from reed harvested at East of England wetland sites in the winter for use as a feedstock for the University of East Anglia (UEA)'s Biomass Gasifier in Norwich for co-feed with woodchips; and
- Using mixed wetland biomass harvested in the summer as a feedstock for the anaerobic digestion plant at J F Temple & Son Ltd, in Wells-Next-The-Sea, Norfolk, and the Future Biogas plant in Taverham, Norfolk.

From our experience of contracting on wetlands throughout the East of England, particularly with involvement in fen restoration projects, there is not a machine that is currently available in the UK with the capabilities of cutting and collecting on large scale mixed fen and reedbeds. Therefore a harvesting system has also been designed to meet the demands of the wetland biomass competition.

The analysis of the energy and GHG balances of using wetland biomass harvested in the East of England as a feedstock for AD indicate clear net benefits. The energy and GHG balances of using reed harvested in the East of England as a feedstock for the UEA Biomass Gasifier, on the other hand, are not positive.

The financial assessment of the proposed uses for the wetland biomass has shown that **harvesting dry reed in winter, and processing it into briquettes for use in the UEA Biomass Gasifier, is not currently a commercially attractive option**. The high briquetting costs undermine the viability of this option, which must compete with the price point of woodchip which is around £100/tonne.

The AD model suggests a positive net cashflow could be achieved and this is worthy of further investigation. In this scenario we assumed the material would not be classified as a waste stream, and would therefore not be subject to a gate fee, but rather attract a value of £50/tonne, to displace companion feedstock such as maize or improve the biogas yields on farm-based AD.

Both routes to market considered in this study are highly dependent on the wetland biomass not being classified as a waste, in which case it would incur a gate fee rather than a sale price. Consequently, the cash flows would be negative, and there would be permitting implications for use of the biomass.

We have requested DECC funding to develop Phases 2 and 3 of this project for the AD route to market for the mixed wetland biomass harvested in summer. In summary, this will involve the following:

- Commission and build the new harvesting system designed in Phase 1 of the project,
- Carry out summer and winter harvesting trials in the East of England and, if required, implement further modifications to the new harvesting system;

- Develop and build a self-loading tracked dumper to move cut material from the harvesting area to transfer sites for collection by lorry; and
- Carry out bench-scale AD tests co-digesting mixed wetland biomass with other feedstocks, to estimate biogas yields and assess digestate quality, and later demonstrate at scale.

Our Phase 1 preliminary trials briquetting reeds were positive. The similarities between the properties of reed and straw and the emerging number of companies manufacturing straw-based fuels for the UK domestic sector indicate an emerging opportunity. Thus, as an alternative route to market for the reeds harvested in winter, we would like to:

- Carry out further briquetting trials with the reed to optimise fuel quality for domestic use.

The total cost for Phase 2 has been calculated at £365,063.75 (inc VAT) and the cost for Phase 3 at £268,211.00 inc VAT. DECC has valued the potential for IP from the project at £16,000. Adapt Commercial is applying a discounted daily rate of £400, as opposed to its typical of £600, to deliver savings of £21,600 in Phase 2 and £15,600 in Phase 3 of the project.

In addition to the above, for future commercial operation of the harvester on nature conservation sites, the price would not include the capital cost of the machinery. The cost would be based upon labour, operating costs including fuel, insurance and haulage and a percentage to cover breakdowns and further development of the machine.

Section 1 of this report provides a full scale technology assessment for the two routes to market considered in this study and Section 2 presents a detailed project plan for Phases 2 and 3, with the associated timings, costs and deliverables identified. A Phase 2 application is submitted separately.

Section 1 - Full scale technology assessment

This project has been carried out by Adapt Commercial Ltd, a wholly owned subsidiary company of the University of East Anglia that provides consultancy services on low carbon technologies, and Peter Frizzell Ltd, a company that provides contracting services to conservation managers. This section of the document provides a detailed description of the end-to-end processes and the regulatory requirements that apply to the full scale deployment. It also presents detailed mass and energy balances of the processes and the findings from our carbon and energy life cycle assessments. Finally, it presents the findings from the financial analysis and explains the exploitation plan going forward.

1.1 Description of the full scale end-to-end process

This section of the report provides a technical specification of the new harvester design and describes the full scale end-to-end processes, from biomass harvesting to energy production.

1.1.1 Technical specification of the new harvesting system

Initially the option of purchasing a commercially available tracked unit was investigated. However, the machines we looked at were unsuitable for one or more of the following reasons:

- Underpowered and too small;
- Overpowered with light weight track systems; or
- Excessively expensive.

Therefore, the base unit will be constructed from the conversion of a second-hand tracked dumper. This provides a cost-effective robust undercarriage with tracks designed for demanding environments which have undergone development of many years.
The multi-purpose harvester designed in Phase 1 utilises a tracked base unit, a cutting head and a collection and storage system. Table 1 provides a summary specification of the harvester and Figure 1 provides artistic impressions of the design.

Table 1 - Summary specification of the harvester.

Track width*	600 mm	**Overall length***	4,430 mm
Track type	Rubber	**Wheelbase**	3,130 mm
Gross weight*	10,400 kg	**Ground clearance**	470 mm
Carrying capacity *	4,300 kg	**Engine type**	Deutz TCD 3.6 L4
Ground pressure laden*	0.27 kg cm^{-2}	**Engine size**	120 HP
Width*	2,310 mm		

* Based upon a Morooka MST800 which will be subject to availability or similar sized machine.
The weights and ground pressure are based upon a standard machine before conversion.

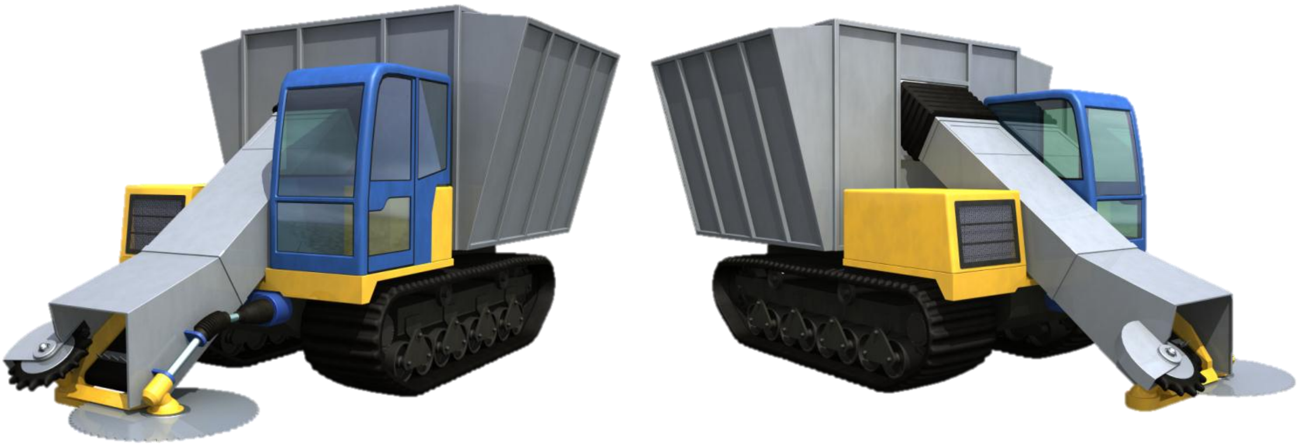


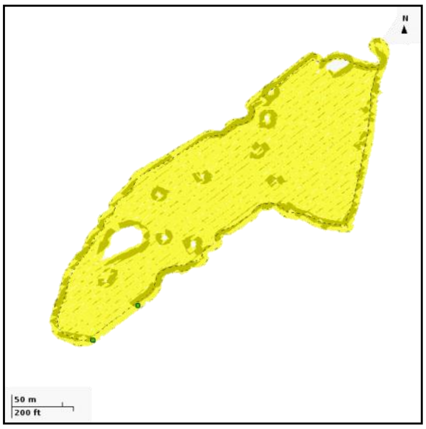
Figure 1 – Artistic impressions of the new multi-functional harvester.

The base unit will be able to cope with a range of ground conditions and capable of working in standing water. It will have low ground pressure to reduce impact on wetlands and will be sufficiently narrow to allow it to pass through a 3m wide gate and be transport on low loader (without requirements associated with the haulage of wide loads). The machine will work effectively in flooded areas and be robust enough to cope with scrub and stumps including high stumps associated with coppiced trees and areas cleared by volunteers.

The conversion of a tracked dumper also allows for an engine to be installed which is specific to the power requirements of the harvesting head and tracks. The engine will be a Deutz TCD 3.6 L4 4 cylinder turbo charged, water cooled, compact engine capable of providing 120 HP at an engine speed of 2300 RPM. The engine will be in compliance with non-road emission standards EU Stage III B and US EPA Tier 4 interim standards. The fuel tank will be designed to allow the machine to work for a full day without requiring refuelling. The hydraulic system of the machine will contain bio-degradable oil. The engine cooling system will have a reversible fan to reduce dust build-up during harvesting operations.

The machine will be mounted using a three point linkage system to allow flexibility and options of carrying other equipment, offering the ability to cut a range of vegetation types. The harvesting head will be powered directly by a power take-off from the engine gearbox as opposed to less efficient hydraulically powered options. Different heads will be available for being mounted to the machine depending on the type of vegetation being harvested. The linkage system for the base unit will be designed for attachment of other conventional agricultural and forestry equipment and therefore allow additional alternative uses of the machine. The linkage system will have a high lift to allow the cutter head to be raised above the ground surface should the front end of the machine dip below the ground surface.

The machine will have an enclosed cab with heating and air-conditioning allowing comfortable winter and summer working. Air conditioning is particularly important to allow safe enclosed summer working to reduce operator exposure to dust and the risks associated with encountering wasp nests. It is intended that the harvester is road registered to allow short distance movement between sites without the requirements of low loader haulage. As the harvester will be custom built, self-certification for CE will be pursuit, to ensure it conforms to the essential requirements of EC Directives.



Finally, a GPS lightbar system will be used with the machine to allow effective harvesting and to record cut areas for future reference (Figure 2). This will allow accurate recording of rotation cuts without the requirement of physically marking the blocks.

Figure 2 - Example of part of GPS event record showing weedwiper coverage.

1.2.2 The winter harvest: gasification of reed

In winter, bundled reeds harvested from wetland sites in the East of England will be transported to a processing plant for storage to enable air drying to take place before being used to manufacture reed briquettes. The briquettes will be used in combination with woodchips as a fuel for the UEA Biomass Gasifier in Norwich. Figure 3 provides an overview of the full scale process.

Step 1: Biomass harvesting

Harvesting services will be provided by Peter Frizzell Ltd, a company with first-hand experience of wetland and conservation management in the East of England. The harvester will be hauled to site using a tractor towed low-loader trailer. The harvesting pattern will be determined by the limitations of the site, to minimise tracking, surface damage and adverse effects on vegetation.

Reed will be cut and bundled in a single pass. The cutter head for harvesting winter reeds will be based upon a mower binder which utilizes a single reciprocating cutter bar. The cutter bar will be approximately 1.4m wide with a binding height of 280mm. Bundles of reed will be transported either directly on the harvester to a suitable collection point for road haulage or on a tracked carrier depending on haulage distances and site constraints.

The reed will be processed at FuelSell Ltd in Norwich. The possibility of briquetting the reed on site using the machine was discussed but rejected because: a) briquetting requires consistent quality material (length and moisture content) so it is better conducted in a controlled, indoor environment; and b) adding a briquetting module to the harvester would require too much power for the weight limit available.

Step 2: Biomass processing

FuelSell Ltd is the current supplier of woodchips for the UEA Biomass Gasifier. As they have experience manufacturing woodchip fuel to the specifications and requirements of the plant, they were considered the preferred partner for receiving and processing the reed onto a suitable fuel. The woodchip size required for effective gasification at the plant is 70mm x 50mm x 15mm.

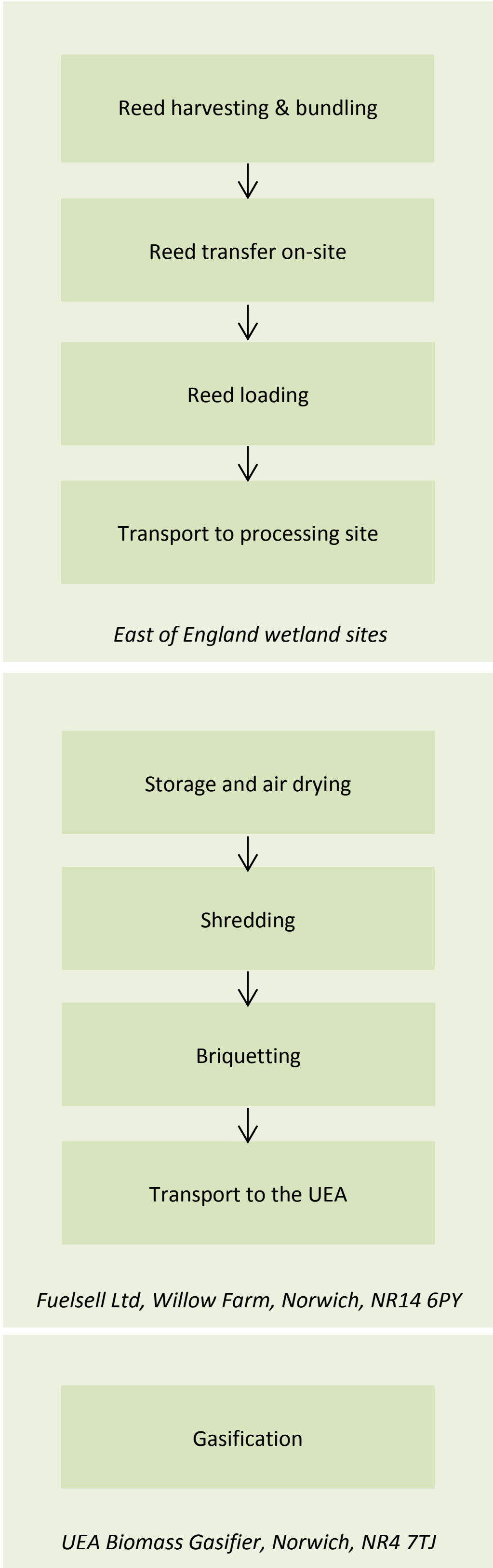


Figure 3 – Detailed process diagram for the winter harvest: reed fuel for the UEA biomass gasifier CHPC.

Discussions on briquetting reed were opened with Fercell Ltd of Aylesford in Kent who are UK sole agents for Weima of Germany who specialise in shredding and briquetting equipment. Fercell have briquetted a range of materials, from straw and hay to Miscanthus, and have sold a machine to a thatcher for briquetting old thatch removed from roofs.

In Phase 1 some recently cut reed bundles were taken to the Fercell trial facility in Kent for a preliminary investigation on its suitability as a feedstock for briquettes. In the machine trialled, biomass is screwed into a tube and compacted with a hydraulic ram. The machine (Figure 4) 'grips' a briquette already produced and the new biomass is compacted against this 'gripped' briquette. The machine is controlled electronically and when the compaction is finished, the first briquette is ejected.

At Fercell the reed was first passed through an initial shredder with a 25mm screen. It was felt though that the general size distribution of the shredded reed was too great so the material was then put through a 10mm screened shredder. This two stage shredding would not be required in commercial operations once the optimum size is determined. Both 40mm and 50mm diameter briquettes were produced at Fercell (Figure 4). The briquettes were produced on two different types of machine. Once the machines were up to operating temperature and pressure some good briquettes were produced.

No 'binder' was used for the trials at Fercell. Komulainen et al. (2008) show that binders, in their case turnip rape powder and grain dust, can improve the internal strength of the reed pellets. For the production of briquettes that meet the specification requirements of UEA, it may be that a binder will be required. Kronbergs et al. (2011) show that the density of reed briquettes during compacting experiments was 956kgm^{-3} without a peat additive and 1045kgm^{-3} for 50:50 reed and peat mixture. Ash (2009) succeeded in making pellets from reed using lignin, an innocuous biodegradable material, as binder.

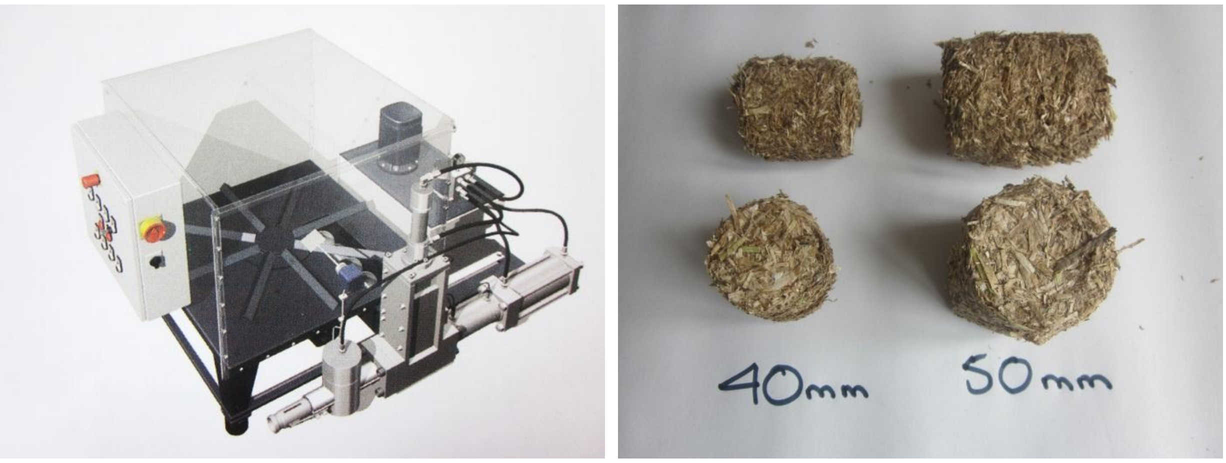


Figure 4 – Example of briquetting machine supplied by Fercell Ltd and images of the 40mm and 50mm reed briquettes produced during a preliminary trial at their facility in Kent.

Moisture content is a critical parameter for the briquetting process. Komulainen et al. (2008) reported failed briquetting trials in Finland due to excessive moisture content. Kronbergs et al. (2011) report the need for moisture content to be below 15% for successful briquette production. The moisture content of the reed used for the preliminary briquetting tests at Fercell, as indicated by a hand held meter (calibrated for straw), suggested a figure in the region of 15%.

The moisture content of the reed depends on a number of factors including harvesting method and weather conditions at the time of harvest. It could vary between 20% (if traditionally harvested) to 75% (when cut and chopped by forage harvester type machinery). Ash (2010) shows that 12% moisture content can be achieved with adequate air drying. Hence, it was decided that prior to being processed into briquettes, the bundled reeds should be stored at FuelSell to dry.

Step 3: Energy production

The reed briquettes will be supplied to the University of East Anglia's Biomass Power Station, a 1.5MWe / 2.5MWth Biomass Gasification Combined Cooling, Heat and Power (CCHP) Plant located in Norwich. The gasification process heats the biomass in a carefully controlled low-oxygen environment. The oils and resins in the biomass vaporise into a gas known as syngas. As it is composed mainly of hydrogen and carbon monoxide, syngas has a lower calorific value than natural gas, which is mainly methane. However, the energy content is sufficient to power a gas engine used to generate electricity. The plant also provides char as a co-product of the process (Figure 5).

The UEA Biomass Gasifier was designed to run on virgin woodchips sourced from Forestry Commission estates in Suffolk and Norfolk. At full load the gasifier reactor vessel uses 1.4 tonnes of woodchip per hour. This produces 3,200m^3 synthetic gas (syngas) which is fuel for a gas engine providing 1.5MWe. By-product heat from the engine is used to heat buildings on campus via a district heating main. The plant is also connected to the university's chilled water main. In summer when heat is not required the hot water can be converted into chilled water by an absorption chiller device. Using heat in winter and chilled water in summer increases the overall efficiency of the plant to around 85%, double that of a typical power station.

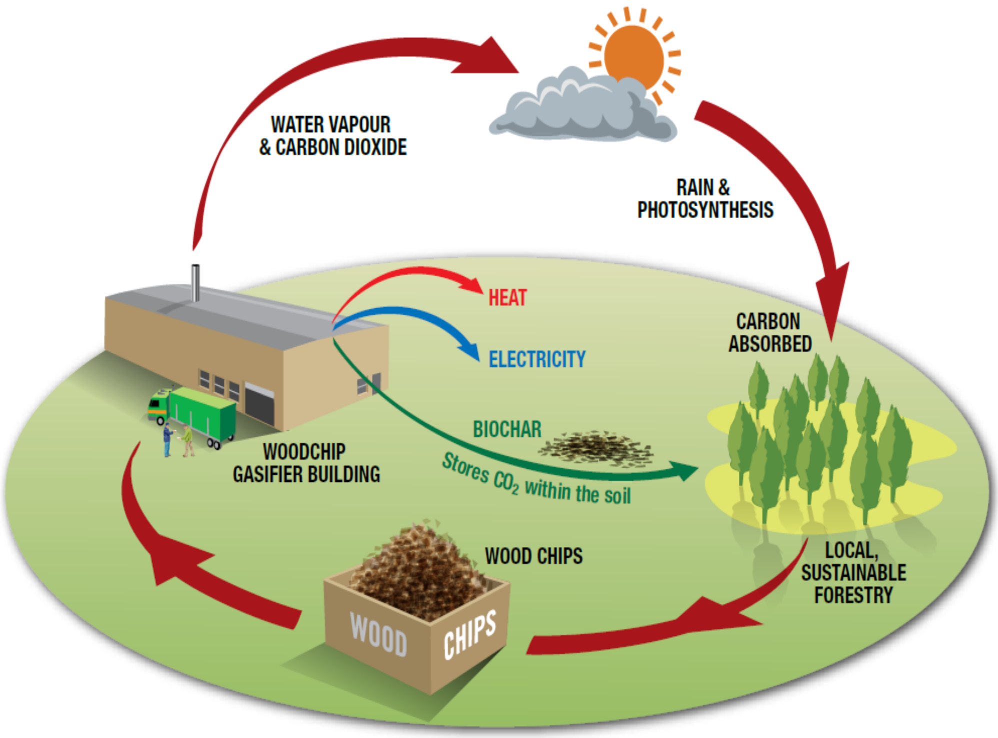


Figure 5 – Schematic showing the input and outputs of the UEA Biomass Gasification CCHP Plant.

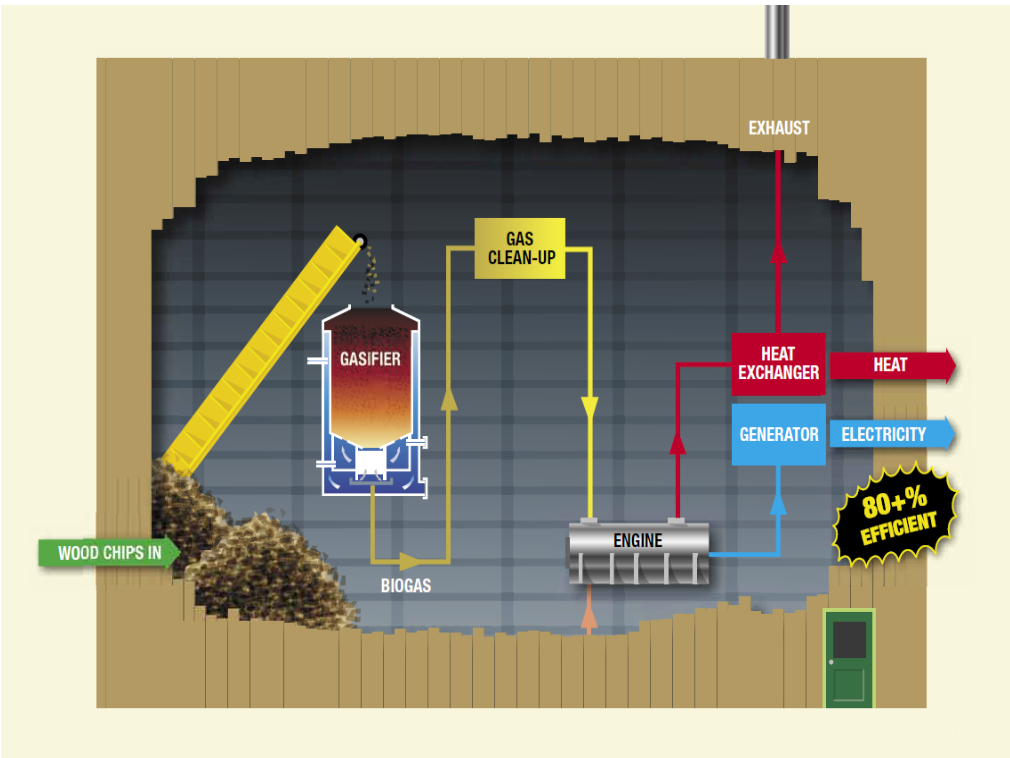


Figure 6 – Schematic of the UEA Biomass Gasifier showing the process flow.

Using figures provided by the RSPB (2011) (Table 2), it has been established that 1,830 oven dried tonnes of reed will be available per year. This would be about 2,100 tonnes at 15-20% moisture content and would represent about 20-25% of the annual input of biomass fuel into the UEA Biomass Gasifier. This is a conservative figure, as the data provided by RSPB does not include all sites in the East of England, and there may also be larger areas available in the Broads.

Different gasifier operating designs exist. The UEA's Biomass Gasifier is a downdraft version. This means that the gas generated inside the reactor is pulled down through the fuel using a large fan (or blower) before being cleaned and used in a gas engine. The blower exerts a negative pressure on the reactor vessel to suck the gas from the reactor and through the clean-up system. For effective operation of this system it is vital that the suction pressure induced by the blower does not exceed -250mbar.

Table 2 – Estimated annual oven dried tonnes (ODT) of reed available in the East of England as informed by RSPB. The ODT stated for reed assumes reed returning 5.5 tonne/ha. The typical time period for winter is 1st Nov-31st Jan.

Site	Ownership / management	Habitat type	Current annual harvest - ha	Estimated management rotation in years	Indicative Annual Oven Dried Tonnes
Waveney Valley & the Suffolk Broads	Suffolk Wildlife Trust	Reedbed	5	7	27.5
Ouse Fen	RSPB	Reedbed	25	7	137.5
Lakenheath	RSPB	Reedbed	40	7	220
Minsmere	RSPB	Reedbed	40	7	220
The Norfolk Broads	Mixed	Reed	250	4 to 5	1200*

* The potential winter reed output from the Norfolk Broads has been derived from the Ash (2009).
It assumes that the higher winter water levels will not prevent harvesting operations.

The gasification process involves heating the biomass fuel with minimal but controlled oxygen present. Fuel is fed into the top of the reactor which is a large cylindrical vessel about 6m high and 3m diameter. The fuel needs to be sufficiently strong that it will not be easily broken by the feed auger system of the plant. This involves five horizontal augers and two vertical augers, in total transporting the fuel about 30m from the storage area through the dryer to the reactor. The recommended density for high quality wood briquettes is >1000kgm^{-3} (Kronbergs et al. 2011).

On entering the vessel the fuel is further dried at about 150°C. Under gravity the fuel moves downwards through the reactor vessel. As it does it passes from the drying zone to the pyrolysis zone (250°C - 350°C). At this point the resins in the fuel boil off into the syngas. The fuel then progresses downwards into the combustion zone (800°C - 1200°C). Oxygen is inputted into this zone to drive up the temperatures. As the syngas is sucked through the combustion zone the complex long-chain molecules are cracked into simpler gases, typically carbon monoxide and hydrogen. At this point the solid fuel has been reduced to a char and the syngas is drawn off into the gas clean-up system.

The char continues to drop through the reactor in the final area – the reduction zone. Here, hot char can be reacted with water to create more hydrogen and carbon monoxide to enhance the calorific value of the syngas. The char is then removed from the reactor using an auger. This auger is the steering wheel of the system, which otherwise works entirely by gravity. By changing the rate of extraction the different temperature zones, essential for effective gasification, can be maintained.

Depending on the nature of the fuel, in particular its ash content, the extraction rate needs to be varied. Ideally the char extraction auger should work slowly and continuously. This keeps the material in the reactor moving downwards and helps to prevent fuel or char sticking. The bottom auger design and operation should ensure that there is even flow of material across the reactor. If too much material is drawn from the centre then the temperature zones risk being disturbed. This can result in syngas passing through the combustion zone at too low a temperature so that tars are carried over into the gas clean-up system. It can also lead to ungasified fuel reaching the bottom auger, which is not only inefficient but can also cause blockages.

Two critical elements for achieving good reactor operating conditions are to use appropriate size fuel and to ensure that dust is kept to a minimum. The fuel particle size required for effective gasification at the UEA Biomass Gasifier is about 70mm by 50mm by 15mm. Larger particle sizes are likely to cause blockages in the reactor feed auger system, whilst particles that are too small may leave insufficient pore space for the syngas to pass freely between the pieces of fuel. If particles are too dusty then the pore spaces will block, again reducing gas transmission. Also, pieces should be square or rectangular. Long thin fragments can get trapped between the auger flights and the casing, leading to blockages and shut-down.

The ash content of feedstock, which is characterized by non-flammable fuel minerals, has an important impact on the quality of fuels for gasification. Increased ash reduces the calorific value of fuel and complicates the operation of the heating system. The ash-melting and sintering temperature is another important quality for system operation. A low ash melting temperature leads to ash sintering the production of slag. Tars and other viscous liquids can be generated from the hot woodchips particularly at start-up and shut down. These tend to clog the gas clean-up processes thus forcing the blower to work harder. If this is coupled with blockages in the reactor, the suction pressure can exceed -250mbar and lead to plant shut down.

Kronbergs et al (2011) reports that the ash content of reed range from 2.7% to 4.4%. This greatly exceeds the amount of wood fuel ash (Table 3), but it is at least two times lower than the straw fuel ash content. Nevertheless, reed ash starts to deform (melt) at close to 1200°C, roughly the same as wood ash, potentially not leading to problems with the production of slag..

In comparison to woodchips, the sulphur and chlorine content of reeds, particularly those grown in brackish waters, may pose increased corrosion risk within the gasifier reactor vessel. Most reactor vessels are clad internally with a protective refractory lining to help minimise corrosion. This should be sufficient to reduce any potential impacts of increased concentrations of sulphur and chlorine.

As the calorific value of reed is lower than that of woodchips (Table 3), attention should be paid to the moisture content of the biomass, which can vary from 20% to 75%. For the UEA Biomass Gasifier, the moisture content of fuels should be between 15-18%. The plant’s in-house dryer, which uses low grade waste heat from the gas engine to dry woodchip fuel from 55% to 15-20%, could be used to dry the reed briquettes prior to gasification if required.

Table 3 - Properties of reed and woodchips. Source: Wilk et al 2010.

		Woodchips	(Dried) Reed
Water content	% dry	19	13
Volatile matter	% dry	84.02	76.98
Ash content	% dry	1	7.47
Ash deformation temperature	^{o}C	1420	1340
Ash flow temperature	^{o}C	1460	>1500
Carbon	% dry	48.82	45.48
Hydrogen	% dry	5.87	5.84
Oxygen	% dry	58.20	40.52
Nitrogen	% dry	0.15	0.47
Sulphur	% dry	0.015	0.07
Chlorine	% dry	0.003	0.15
Net Calorific Value	MJ/kg	18.178	16.187

The UEA Biomass Gasifier converts around 8-12% of its annual feedstock intake into biochar, a carbon-rich material that is attracting increasing interest for its potential to improve water and nutrient retention in soils and support soil microbial and plant growth. This absorptive capacity also offer potential for using char to act as a filtration medium in the form of activated carbon or as a means of locking up heavy metals on contaminated sites enabling land to return to some form of productivity.

In the UK, char produced from pyrolysis and gasification of biomass is finding its first routes to market as a soil improver or component in growing media formulations. There are four companies selling biochar-enriched horticultural products in the UK; internationally the number is in the dozens. Between 40-60% of the carbon in biochar is available in a recalcitrant form, being unavailable for soil microorganisms for 100-1,000 years. Hence, biochar also provides opportunities for carbon sequestration in soils.

1.2.3 The summer harvest: anaerobic digestion of mixed wetland biomass

The biomass harvested in wetland sites in summer is a mixture of vegetation, including reed (phragmites), sedge and rush. As the moisture content of these is relatively high, we propose that they are used as feedstock for anaerobic digestion (AD), a natural process in which bacteria break down organic matter, in the absence of oxygen, into biogas and digestate. This route involves cutting and chopping the mixed wetland biomass and transporting it to local AD plants to be used ‘fresh’, where it will be co-digested with other feedstocks. We selected two local AD plants on which to be our analyses: Copys Green Farm and Future Biogas. Figure 7 provides an overview of the end-to-end process.

Step 1: Biomass harvesting

Typically, summer mowing fens will be species rich consisting or a diverse range of common and rare plant species depending on hydrology, water quality, ground conditions and management. Mixed fens may have extensive areas of grasses including reed-canary grass, reed sweet grass or purple moor grass and include blunt flowered rush or black bog rush. Other plant species present can include meadowsweet, hemp agrimony, reed mace, flag iris and water mint. Some fens may develop species poor areas dominated by common reed or saw sedge. In under managed fens, scrub including alder, sallow and birch may be present. Other woody plant species can include bog myrtle, guelder rose, rose and hawthorn.

Table 4 shows the typical yields for wetland biomass harvested in summer in conservation areas where management is currently undertaken. The numbers presented are based on management plans which in some areas may be constrained by the wetland managers' ability to cut. The values given are for a typical year. There can be annual variation in the quantity of biomass available and the ability to access the sites.

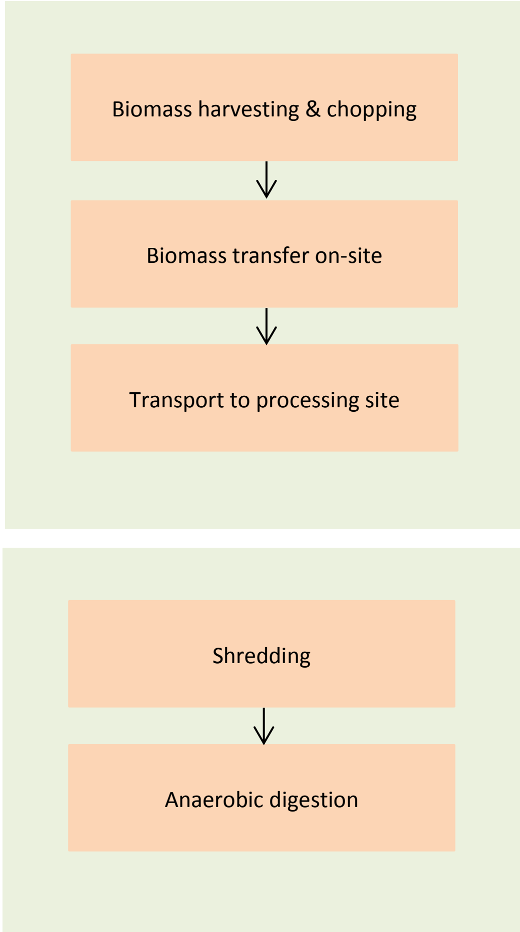


Figure 7 – Detailed process diagram for the summer harvest: green wetland biomass for AD

Table 4 - Estimated annual oven dried tonnes (ODT) of mixed wetland biomass harvested in summer in the region. The ODT stated for dense rush and sparse rush assume a bulk density of 4.3 tonne/ha and 1.4tonne/ha respectively. The ODT for hayfields and fen are not known. The typical summer harvesting season is from 1st Aug-1st Oct.

Site	Ownership / management	Habitat type	Annual harvest area (ha)	Annual ODT
Suffolk Coast	NE	Fen	10	N/A
		Grazing marsh / fen	60	N/A
Great Fen	Beds, Cambs & Northants Wildlife Trust	Grazing marsh	150	N/A
Woodwalton Fen	NE	Grazing marsh / fen	15	N/A
Bure Marshes	NE	Fen	2	N/A
Waveney Valley & the Suffolk Broads	Suffolk Wildlife Trust	Fen	30	N/A
		Wet grassland - rush	90	387
Nene Washes	RSPB	Wet grassland	100	285
Ouse Washes	RSPB	Wet grassland	100	140
The Norfolk Broads	Mixed	Reed / fen	250	1225

On the same principle as the reed, fen and mixed fen will be cut in a single pass. The cutter head will be based upon a cutting disc of 1.2m in diameter. A disc is the most appropriate method for cutting, as opposed to a reciprocating cutter bar or flail head, for the following: it is robust and capable of withstanding hitting stumps and unseen objects; it will be able to cut through scrub and stumps; it requires less energy than a flail; and it won't experience a power loss when it hits standing water.

A single larger disc will be used as opposed to two smaller discs to provide greater tip velocity. A collecting system will be located to the side of the disc to transfer the cut material to a conveyor. Only half the width of the harvester will be used to cut material in order to reduce the volume of material to be collected and reduce the risk of complications when cutting tall and dense fen vegetation. The disc will be situated directly in front of the operator to allow greatest vision of the cutter area.

The collected cut material will be transported on a chain conveyor, passing over adjustable fixed knives to cut the material, before passing into a collection bin on the rear of the harvester. As the material is transported from the cutter head to the storage bin on the harvester it will be chopped to between 70-140mm in length. The collection bin will have a simple walking floor arrangement to compact the cut material and ensure the bin is completely full. To increase the carrying capacity of the vehicle the sides of the collection bin will open hydraulically. This will increase the volume whilst harvesting but keep the vehicle to a minimum width for transport. The carrying capacity of the harvester will be a minimum $12m^3$ (Table 5). The walking floor will also be used to assist in emptying the collection bin.

Table 5 - Carrying capacity of the harvester.

Material	Estimated weight per m^3 (kg)	Estimated carrying capacity of harvester (kg)*
Dry reed	96	1.15
Wet reed with litter layer	160	1.92
Mixed wet fen	200	2.40

* Assuming a carrying volume of $12m^3$

The cut material will be transported either directly on the harvester to a suitable collection point for road haulage or on a tracked carrier depending on haulage distances and site constraints. Our consultation with AD operators indicate that end users prefer the feedstock to be fresh material, so cutting and collecting the biomass on one pass will be ideal.

Step 2: Biomass processing and energy production

Various types of AD technologies are available. Digesters can be wet or dry, mesophilic or thermophilic, and single or multistage. Dry AD uses only minimal mechanical sorting, in wet AD the waste is first turned into a pulp prior to being processed. Systems using bacteria that live optimally between 35–40°C are known as mesophilic; those using bacteria that can survive at 55–60°C are called thermophilic. Operation at higher temperatures facilitates faster gas yields and helps to sterilise the digestate. A single-stage digestion system is one in which all biological reactions occur within a single tank, which can reduce construction costs. In a multi-stage system different tanks are used to optimise the reactions. In the UK the most common type of AD technology deployed is the mesophilic, wet, single stage.

Sizes of AD plants vary considerably. A plant of around 1.5MWe will required the order of 25,000 tonnes per annum of grown crops, predominantly maize. The smaller AD plants of around 100kwe will require around 8,000 tonnes of feedstock (slurry + grown crop). Given the relatively small volumes of biomass available from wetland sites in the East of England and the timeline for harvesting from 1st August to 1st October, it is unlikely that any single plant could be built and operated only on this reed feedstock. It is felt therefore that the wetland biomass should be used as an additional feedstock on existing plants.

Two AD plants located in the Norfolk have been engaged as case studies for our analyses and invited for consideration as potential routes to market for the biomass:

- J F Temple & Son Ltd at Copys Green Farm

  Located on the North Norfolk coast, Stephen Temple has won various awards for his AD plant running on a mixture of cattle slurry and grown crops such as ensiled maize and fodder beet. The digester tank is 800m^3 with a residence time of 40-50 days at 37-42°C. The tank is fed daily with 16 tonnes of dairy cow slurry, cheese whey and grown crop. The output is in the range 140-170kwe.

- Arnold Renewables Ltd run by Future Biogas

  At Taverham, west of Norwich, Arnold Renewables Ltd was the first AD plant built by Future Biogas. The 1.4MWe plant takes around 25,000 tonnes per annum of maize. They have a second plant a few miles away and are in the process of building two others, one of which on the edge of the Broads.

AD produces biogas and digestate. The biogas is a mixture of methane, carbon dioxide and other gases. It can be used directly in engines for Combined Heat and Power or burned to produce heat or be upgraded and injected into the grid or used as vehicle fuel (Figure 8).

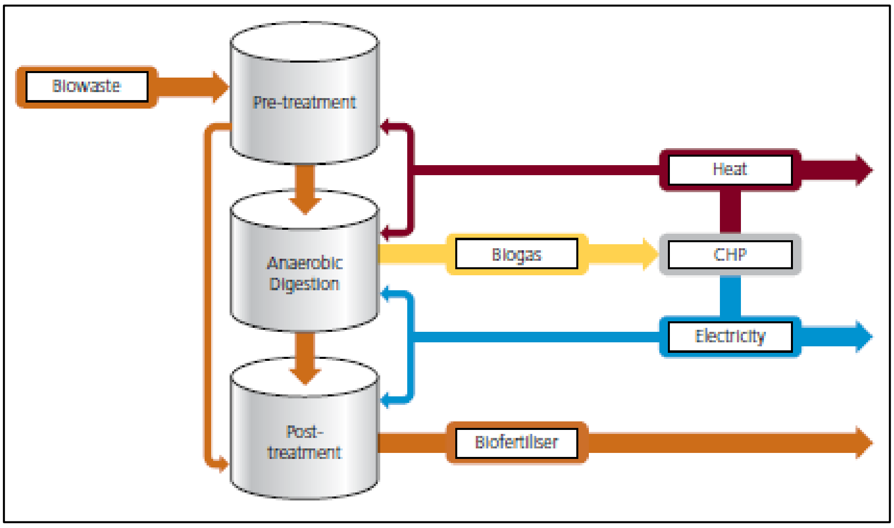


Figure 8 - A schematic of the AD process.

The yield of biogas from a particular feedstock depends on a number of factors, including the dry matter content of the feedstock and its calorific value. It is challenging to estimate the biogas yields that could be obtained from mixed wetland biomass harvested in the East of England. However, below we discuss some findings from academic studies on potential gas yields from common reed (*Phragmites Australis*) from other countries. No work on sedge or rush, in the UK or abroad, has been identified.

The Swedish study (Aldentun 2013) shows that in batch wet digestion trials, reeds were shown to produce almost double the amount of biogas produced from cattle slurry (Figure 9). These results provide a first indication of the potential use of reed as a feedstock for AD. Gas yields for reeds were comparatively lower than those observed for food waste though.

Compared with bioenergy crops used as feedstock for AD, such as maize and grasses, reeds harvested in winter are high in lignin, cellulose and hemicellulose, which could result in longer digestion times. Aldentun (2013) shows that the methane yields from reed in continuous digestion trials was around only half as much when compared with the batch digestion trials.

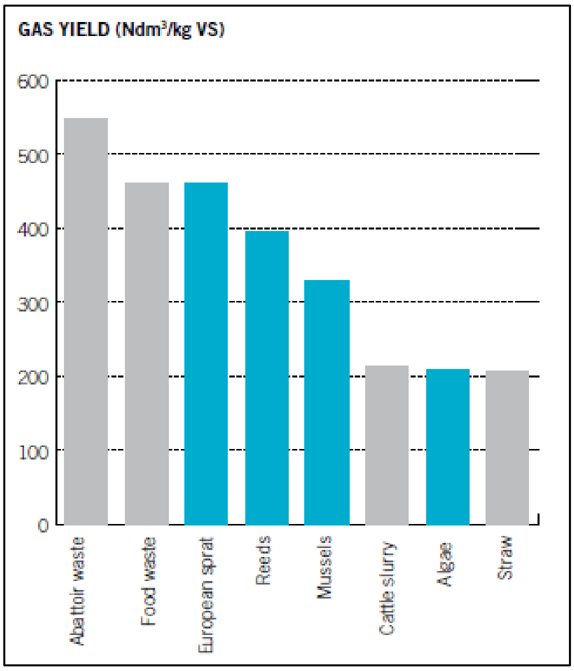


Figure 9 – Results of batch wet digestion trials. Results from trials with common AD feedstock are shown in grey; new feedstocks investigated are represented in blue.

Dubrovskis & Kazulis (2012) look at the effect of reed particle size (1mm up to 20mm) on biogas yields. The smaller reeds were chopped, the greater the biogas yield. The study also show that more methane can be extracted from fresh reeds (0,281 lCH4/gDOMadd) than from dry reeds (0,226 lCH4/gDOMadd) and that reeds were more useful in biogas production when co-digested with other AD feedstocks.

Lin (2012) used *Phragmites australis* from three different wetlands in Sweden to produce biogas. The methane production using reed material harvested from agricultural wetland was 144 ml/g VS, which was lower than the suggested number 180ml/g VS. It was felt gas yields could be improved by harvesting in summer to reduce the lignin content and use co-digestion with other feedstock to achieve the optimal Carbon/Nitrogen ratio, an important factor in good digestion. It was proposed that when reed is harvested too late in the growing season, chopping or milling could improve the effectiveness in hydrolysis process, assisting biogas production. One possible drawback of chopping is the energy costs.

Hansson and Fredriksson (2004) compare three strategies for wetland biomass disposal: to chop the harvested material and spread it directly on farmland; to compost the material before spreading on land; and to use the biomass as feedstock for biogas production and spread the digestate on land. The energy balances for the three systems were calculated to −0.35, −0.43 and +4.05 MJ kg^{-1} dry matter, respectively. The economics of the AD system were sensitive to changes in income provided by the gas produced and the cost of the chopping operation.

AD has a transforming impact on the molecular makeup of the feedstocks. Complex organic molecules are broken down into simpler molecules, more readily available to soil bacteria and plants. Hence, the properties of the digestate depend on the composition and quality of feedstocks.

This is particular important in the case of wetland biomass. Aldentun (2013) shows that the nitrogen content of reed declines by a quarter, and its phosphorus and potassium content by a third, in the space of a month from mid-June to mid-July (Figure 10).

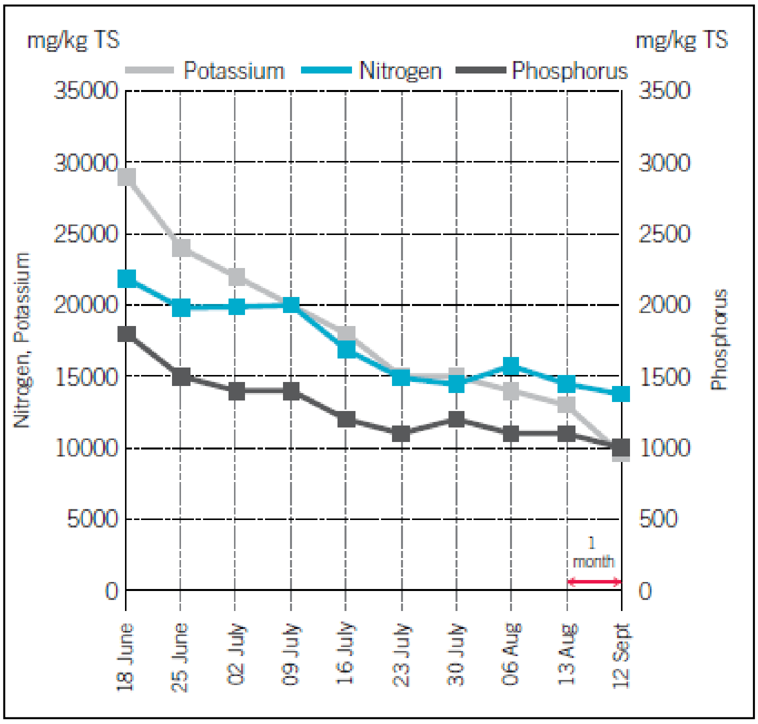


Figure 10 - Annual changes in the nutrient content of reeds harvested in Kalmar, Sweden. Source: Aldentun 2013.

1.2 Regulatory requirements

This section highlights the regulatory requirements that would apply to the full scale technology. As discussed below, special attention needs to be given to the requirements of the Environment Agency (EA) with regards to the classification and handling of waste. This is considered the legislative factor with greatest impact on the viability of this project, as discussed below and later in section 1.7.

If a designated wetland site has areas to be cut and collected within its management plan then it is likely that this has been agreed with Natural England (NE) and consent has already been obtained. If NE consent for the activity has not already been obtained by the site managers, the consent will be applied for by Peter Frizzell Ltd.

Table 6 contains non-native species that pose a biosecurity risk in wetland areas, as indicated by RSPB. It is not envisaged that trials will be carried out on or near to high risk sites. Unless otherwise requested, the measures taken to control biosecurity will be on a risk assessment approach determined with the assistance of the site manager. A 'check, clean and dry' approach will be taken when transferring equipment between sites posing a risk.

If harvesting takes place on a high risk site, then a detailed method statement will be produced outlining control measures. To ensure operators are aware of species of concern, information sheets will be produced. Information sources including the websites of the Broads Authority, Non Native Species Secretariat and Norfolk Non Native Species Initiative will be used to obtain information on descriptions and the current status of biosecurity risks.

Broads, Fens and Suffolk Coast
New Zealand pygmyweed/Australian stonecrop - *Crassula helmsii*
Parrot's feather - *Myriophyllum aquaticum*
Floating pennywort - *Hydrocotyle ranunculoides*
Ash dieback disease - *Chalara fraxinea*
Japanese Knotweed - *Fallopia japonica*.
Water fern - *Azolla filiculoides*
Himalayan Balsam - *Impatiens glandulifera*
Giant hogweed - *Heracleum mantegazzianum*
Canadian pondweed - *Elodea Canadensis*
Wolfberry - *Lycium barbarum*
Pirri-pirri bur *Acaena novae-zelandiae*
Least duckweed - *Lemna minuta*
Killer shrimp - *Dikerogammarus villosus*
Demon Shrimp - *Dikerogammarus haemobaphes*
Giant knotweed - *Fallopia sachalinensis*
Somerset Levels and Moors
Parrots Feather - *Myriophyllum aquaticum*
Japanese Knotweed - *Fallopia japonica*.
Water fern - *Azolla filiculoides*

Table 6 - Species that offer biosecurity risks at wetland sites. Provided by RSPB.

Our consultation with key stakeholders in the sector indicates that if the mixed wetland biomass is harvested and transported off-site to be processed, it is currently likely to fall into the classification of waste. If the EA deems that the harvested wetland biomass is a 'waste' material, a waste carrier license will be required to take the biomass off-site for processing. Peter Frizzell Ltd has a waste carrier licence and would be able to haul small quantities of bundled or chopped material for the trials in Phases 2 and 3.

Of greater concern, however, is the impact of end-of-life regulations on the potential routes to market for the wetland biomass. These are discussed in detail below. Normally determinations of such matters start at a local level. Historically there has been a good relationship with local EA officers in the East of England when it comes to AD. It is hoped that DECC and RSPB can engage with the EA and OFGEM at a National level, to help to ensure the viability of projects being funded thought this competition.

1.2.1 Gasification

The UEA Biomass Gasification plant is already operational with all of the necessary licences and permissions in place. It is licensed to operate with virgin materials - currently Corsican Pine from local forests. It is NOT permitted to take any waste. Hence, the EA definition of the reed material is critical to its use in the plant. Were the reed material to be classified as a waste, then the UEA gasification plant would require special derogation from the permitting authority to use it as a fuel in the gasification process.

Regulation of biochar, a co-product of gasification, is currently an un-resolved matter in the UK. Three key aspects apply here: whether the feedstock chosen for biochar production is considered a waste; whether the biochar produced is considered a waste of an energy process; and whether it is lawful to apply biochar to land. The classification of biochar as waste can have major impact on the costs associated with taking new products to the market due to challenges associated with end-of-life regulations.

The issue of whether biochar is produced from a feedstock considered a waste

Firstly, the defining of a material as a waste under the EU Waste Framework Directive has legal implications for its handling and use, and may mean that permits or waste exemptions need to be granted before it can be re-used. The EA has a number of formal mechanisms in place for defining the point at which a material is no longer considered to be a waste, or for developing 'low risk positions' on specific issues to reduce the burden of regulation. Once a material is considered to have been fully "recovered" through its processing, it can be used as a product outside of waste regime controls.

The issue of whether biochar is considered a waste of a bioenergy process

The EU Waste Framework Directive (WFD) is the starting point for most debates here. In the UK there are two broad mechanisms that can be used to avoid a substance being classified as a waste. The first relates to the intention to discard. To achieve this, an organisation would have to demonstrate that it never intended to discard the substance.

In 2010 the WFD was revised to account for by-products that need not be classified as waste. Article 5(2) contains four criteria that apply: further use of the substance or object is certain; the substance or object can be used directly without any further processing other than normal industrial practice; the substance or object is produced as an integral part of a production process; and further use is lawful - i.e. the substance or object fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts. The adoption of Article 5(2) is optional for Member States.

The second point is the original purpose of the activity or plant. The planning application and subsequent permission will likely demonstrate the extent to which biochar is, or is not, intended to be a product. If it is, then the passage for its subsequent use is likely to be easier. If it isn't, then the argument will need to be made that biochar is a by-product achieving all four criteria above.

The issue of whether biochar can be applied to land

In the UK there are provisions for exempting wastes from the requirement for permitting or licensing, if a benefit to agriculture can be demonstrated. Biochar is not presently exempted. In England and Wales, the EA is moving towards standard rules and standard permitting for all uses of wastes (exempted or otherwise) upon land, which is intended to simplify and streamline the regulatory process for waste materials to be approved for application. Some regulation and voluntary schemes that apply, or are relevant to, the use of waste-derived products on land are highlighted on Table 7.

A Biochar Risk Assessment Framework (BRAF) is being developed and should work as a prelude for a PAS and / or Quality Protocol for the material in the UK. The BRAF Steering Group is consulting with industry to develop a suitable definition for biochar and has proposed a two-tier approach to prevent and minimize the risks associated with biochar production and deployment in the UK (Figure 11).

Table 7 - Examples of UK legislation and voluntary schemes that may need to be observed with regards to the use of waste-derived products in agricultural land or in the food supply chain.

Regulation / Scheme	Details
Sludge Regulations (Use in Agriculture)	These provide guidance for stakeholders who supply or spread sewage sludge (bio-solids) or septic tank sludge to agricultural land. They cover e.g.: the amount of organic and inorganic nitrogen fertiliser to be used; the limit on the concentration of metals in the soil; and the type of farm activities and production to be conducted on soils that have been treated with sludge.
Safe Sludge Matrix	The matrix provides guidance for the application of sewage sludge to agricultural land. It consists of a table of crop types, together with clear guidance on the minimum acceptable level of treatment for any sewage sludge which may be applied to that crop or rotation.
PAS 100	These are baselines quality specifications for waste-derived materials used in a range of markets, including horticulture. PAS 100 specifically relates to the use of compost.
PAS 110	As per above, but PAS 110 covers whole digestate and liquor and fibre derived from the anaerobic digestion of source-segregated biodegradable materials.
Farm Assurance Schemes	Voluntary schemes which producers can join to assure customers that certain safety, welfare and environmental standards have been maintained in the production process. Most cover crops and livestock fed on crops or grassland where organic waste has been applied. The schemes that might be relevant for biochar use in agriculture and horticulture include the Red Tractor scheme, the LEAF Marque and the Soil Association organic standard.
Waste Protocols	The Waste Protocols offers guidance for specific materials, outlining the end-of-waste criteria and minimum processing standards that must be met by products. It developed in response to the uncertainty over the point at which waste has been fully recovered and ceases to be waste within the meaning of Article 1(1)(a) of the EU Waste Framework Directive (2006/12/EC).

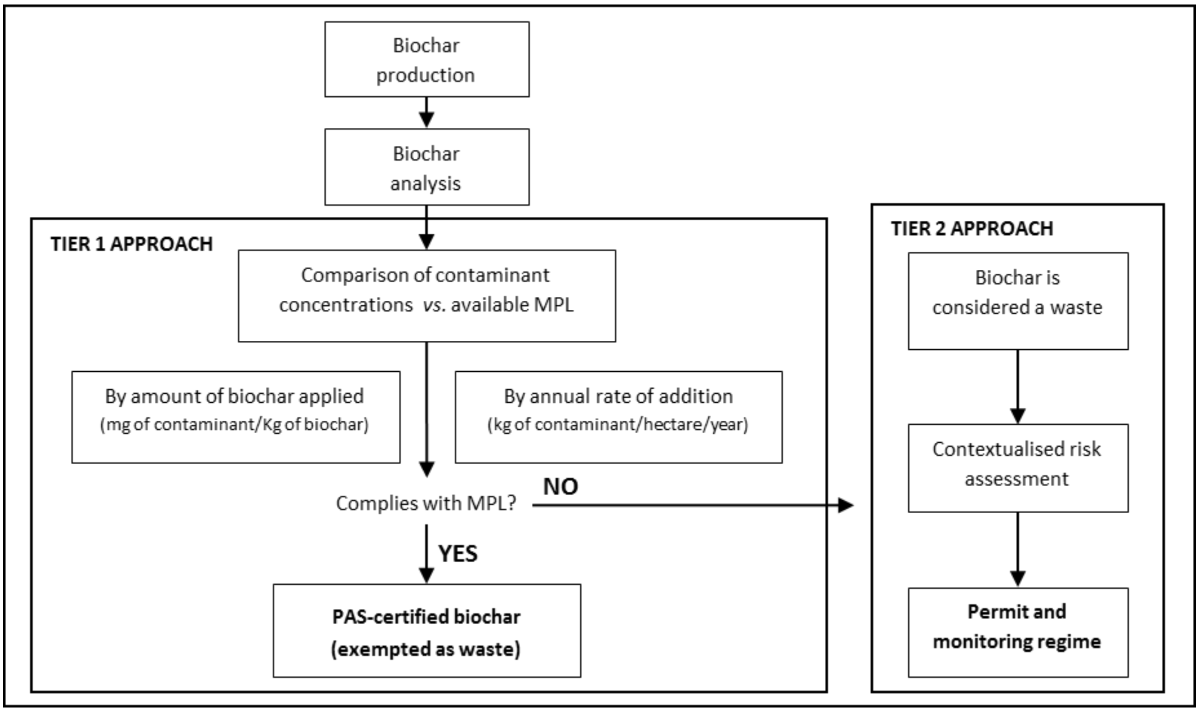


Figure 11 – The two-tear regulatory approached proposed by the Biochar Risk Assessment Framework.

A risk of particular importance in the context of this project relates to the potential of reed, for example, to remove pollutants, including heavy metals, from the environment (Patuzzi et al 2012). This is of particular concern because heavy metals are conserved during the gasification and in majority will be present as ash within biochar. It may be possible to remove these contaminants through selective removal of ash, but valuable elements such as phosphorus and potassium are also present in the ash.

1.2.2 Anaerobic digestion

The EA support the use of AD as one of the ways of diverting biodegradable wastes from landfill, recovering value from them and reducing emissions of greenhouse gases. All AD operators in England must comply with regulations concerning environmental protection, animal by-products, duty of care, health and safety, waste handling and planning permission. Those regulations that could be affected by the introduction of wetland biomass as a co-feedstock are discussed herein.

Environmental Permitting (EP) is a scheme in England and Wales for regulating business activities that could have an impact on the environment and human health. It requires AD plants to obtain a permit or exemption to operate and then to spread digestate. There are three permitting types:

- Exemptions

  There are two specific waste exemptions for AD. T24 covers treatment of manures, slurries and certain plant tissues at premises used for agriculture. The total quantity of waste treated or stored at any one time must not exceed 1,250 m^3 and the appliance used must have a net rated thermal input of less than 0.4 megawatts.

  T25 is for AD at premises not used for agriculture and burning of resultant biogas and includes the use of food waste as feedstock. Operators can store or treat up to 50 m^3 of waste at any one time and any biogas produced must be burned in an appliance with a net rated thermal input of less than 0.4 megawatts. Registration is required but there is no charge.

- Standard permits

  These are available for plants which fit within a number of pre-defined standard rules, including throughput, output and nature of material being digested. The Standard Rule Permit SR2012 No12 "Anaerobic digestion facility including use of the resultant biogas" enables AD operators processing no more than 100 tonnes per day to carry out anaerobic digestion of wastes and also combustion of the resultant biogas in gas engines. Permitted wastes include those controlled by the Animal-By-Products Regulations but do not include hazardous wastes. Fixed charges apply to standard permits.

- Bespoke permits

  If the AD facility does not meet one or more of the standard rules defined in the above, operators will require a bespoke permit. This process is more costly and time consuming, but provides greater coverage and flexibility in plant operations.

The routes to market selected for the full scale project will depend heavily upon the issue of the biomass being or not deemed a ‘waste’. Stephen Temple’s farm has a permit for feedstock arising on the farm (Exemption T24) and thus special permission might be required from the EA for trials. Similar problems might arise for the Future Biogas plants as they use energy crops.

As an alternative route, we also engaged with Adnams Bioenergy, at Southwold, in Suffolk, who use brewery wastes and organic food waste sourced from the company's pubs. The plant has three digesters at its core and produces 500kw of energy, not as electricity, but the biogas is upgraded to pure methane and injected directly into the local gas grid. The feedstock is in the order of 12,000 tonnes per annum.

Long term use of waste-base models, such as the Adnams plant, could be more commercially challenging given that such plants rely on waste producers paying a 'gate fee' for having the waste digested. Use at an agricultural plant would mean displacing grown crops for which there is obviously a growing cost. As such the financial situation is different, as discussed in detail later.

Digestate is rich in nutrients easily accessible to soil bacteria and plants and can constitute a useful renewable fertiliser or soil improver to provide critical resources such as nitrogen and phosphorus. Assuming that the main purpose of any AD plant is to recover energy from the biogas produced, in order for the digestate to be considered as a non-waste, it must meet three tests: i) be certain to be used, ii) without any prior processing, and iii) as part of a continuing process of production.

If the criteria above are not met, then two routes are available: the permit and exemption route to apply digestate to agricultural and non-agricultural land to confer benefit or ecological improvement; or compliance to the Quality Protocol and certification to PAS 110, for the digestate to no longer be regarded as a waste. In detail:

- Exemption or permit to apply digestate to land

  U10 covers the spreading of digestate from pre-defined feedstock on agricultural land to confer benefit and U11 covers the spreading of digestate from pre-defined feedstock on non-agricultural land to confer benefit. There are specific waste types that can be used under these exemptions. U10 and U11 relate only to digestate produced under T24 or T25 with a quantity limit of 50 tonnes per hectare and a storage limit of 200 tonnes, at any one time.

  For AD projects that do not fit the criteria for an exemption, Standard permit SR2010 No.4 must be obtained for the spreading of no more than 250 tonnes per hectare and that no more than 3,000 tonnes of waste material is stored at any one time and for no longer than 12 months. For each spreading of material to land, there is a charge related to the type of material being spread.

- Compliance to Quality Protocol and certification to PAS110

  The Quality Protocol sets out criteria for the production of quality outputs from anaerobic digestion of biodegradable wastes. Producers and users are not obliged to comply with the Quality Protocol. If they do not, the digestate will be considered to be waste and waste management controls will apply to its handling, transport and application.

  The Publicly Available Specification (PAS110) for digestate, derived from the anaerobic digestion of source-segregated biodegradable materials, creates an industry specification against which producers can verify that the digested materials are of consistent quality and fit for purpose. If an AD plant meets the standard, its digestate will be regarded as having been fully recovered and to have ceased to be waste, and it can be sold with the name "bio- fertiliser".

1.3 Detailed mass and energy balances of the process

A mass and energy flow is given in Appendix 1.

1.4 Carbon and energy Life Cycle Assessment (LCA)

The analysis of the energy and GHG balances of using wetland biomass harvested in the East of England as a feedstock for AD indicate clear net benefits (Table 8 and 9). For the reed to gasification route considered in this study, on the other hand, no energy and GHG benefit is apparent (Table 10). The assumptions of these models are given in Appendix 2.

Table 8 - Energy balance of AD plant utilising Fenland Biomass (>70% soft rushes) modelled for a single feedstock but assuming co-digestion with a 10% uplift in biogas yield.

Stage	Description		
	Inventory below is per tonne of fen biomass received at		30%
Harvesting	Harvest of fen biomass, energy use $tonne^{-1}$		154
	Baling of fen biomass, energy use $tonne^{-1}$		46
Transport	Average distance to AD plant from Fens, km		30
	Energy for transport of baled fenland biomass, $tonne^{-1}$		41
	Energy for loose bulk transport of fenland biomass, $tonne^{-1}$		104
Processing	Bale shredding, energy		43
AD Plant operation	Plant size	<500kW	>500kW
	Electricity(MJ) for processing to 12% DM	7.2	12.1
	AD plant electrical demand MJ per tonne of original feedstock	39	89
	AD plant thermal demand MJ per tonne of original feedstock	371	285
	Total electricity generated MJ	979	1187
	Total captured heat energy MJ	1484	1425
	Net exportable electricity	**979**	**1187**
	Net exportable Heat	**1113**	**1140**
	Final Energy Balance per original tonne of fen biomass	**1391**	**1657**

Table 9 - GHG emissions modelled for AD plants utilising Fenland Biomass (>70% soft rushes) modelled for a single feedstock but assuming co-digestion with a 10% uplift in biogas yield.

Stage	Description			Units
Harvesting	Harvest of fen biomass, GHG emissions $tonne^{-1}$	13.5	13.5	kgCO_2 eq
	Baling of fen biomass, GHG emissions $tonne^{-1}$	4	4	kgCO_2 eq
Transport	Transport of baled fenland biomass GHG emissions	3.7	3.7	kgCO_2 eq
	Option 1)* Total for baled transport (inc shredding)	14.6	14.6	kgCO_2 eq
	GHG emissions for transport of loose fenland biomass $tonne^{-1}$	9.2	9.2	kgCO_2 eq
	Option 2) Total for loose transport (inc shredding)	16.2	16.2	kgCO_2 eq
Processing	Plant size	<500kW	>500kW	
	Biomass shredding, emissions	7.0	7.0	kgCO_2 eq
	GHG emission from electricity for processing to 12% DM	1.2	2.0	kgCO_2 eq
	kg moisture deficit/surplus per tonne feedstock	-580	-580	litres
	Assumed emissions for supply of mains water	0.20	0.20	kgCO_2 eq
AD Plant	AD plant electrical demand GHG emissions per tonne of original feedstock	6.42	14.58	kgCO_2 eq
	Total process emissions (including CHP slip) per tonne of original feedstock	24.6	24.6	kgCO_2 eq
	Digestate storage emissions	130	130	kgCO_2 eq
	Transport and splash plate spreading of digestate	10.3	10.3	kgCO_2 eq
	Emissions credit for electricity	194	235	kgCO_2 eq
	Credit for heat	97	99	kgCO_2 eq
	Digestate fertiliser substitution value kgCO2 eq per tonne original feedstock	75	75	kgCO_2 eq
	Total GHG saving per original tonne biomass	**165**	**199**	kgCO_2 eq

Table 10 - Gasification of Reed - GHG and energy balance.

Stage	MJ ODT[-1]	$kgCO_2e$ ODT[-1]	MJ tonne[-1] (12% moisture)*	$kgCO_2e$ tonne[-1] (12% moisture)*
Harvesting				
Harvesting and bundling reed	139	12.2	124	11
Stacking bundles	6	1	5	0.5
Air drying to 12%	0	0	0	
Baling	37	3.1	33	2.8
Loading	17	1.5	16	1.4
Transport				
Transport to briquetting facility	54	4.7	48	4.2
Storage				
Covered storage (no drying)	0	0	0	0.0
Shredding				
Bale chopping	37	6	33	5.5
Shredding	266	44	238	39
Briquetting				
Hydraulic briquetting press	327	54	292	48
Transport to gasifier	50	4	45	3.9
Char disposal	1.4	0.1	1.3	0.1
Total fuel chain	**933**	**130**	**833**	**116**
Gasification energy				
MJ electricity generated	5676		5068	
MJ heat supplied	8864		7915	
Total MJ	14540		12982	
GHG savings				
†Electricity kgCO2 eq		-1124		-1003
†Heat kgCO2 eq		-771		-689
Char kgCO2eq	-	-73.9		-66
†Using the RED fossil fuel comparator as a method for calculating GHG saving credit				
Net balance per tonne				
Energy MJ	**-13,607**	-	**-12,149**	-
GHG savings kg	-	**-1,969**	-	**-1758**

***Important caveats:** Figures assume no artificial drying to achieve 12% moisture content - and a further assumption is that moisture remains constant at 12% and material losses occurring post-harvest are negligible. Assumes biogenic CO_2 emissions in biomass combustion are not included and that harvester exploited reed beds are GHG neutral, compared with counterfactuals, excluding GHG profile of natural succession etc.

1.5 Emissions

The UEA gasification plant has to conform to all of the emission limits stated in its licence to operate. Given the similarities between wood and reed as a biomass fuel it is not envisaged that the use of reed material, which would be equivalent to around 20-25% of the annual load, would cause any issues leading to the breach of the operating licence.

The water clean-up system removes many of the particulates and other contaminants within the syngas stream. Any particulates that pass through are removed by the wet electrostatic precipitator, designed specifically for the removal of micro-particles. A final fabric filter is applied to ensure the gas is clean enough for the engine, which does not tolerate particulates.

Digester gas is typically 60% methane (CH_4) and 35% carbon dioxide (CO_2). The remainder are additional trace gases, such as oxygen, nitrogen and hydrogen sulphide. Combustion results in emissions of e.g. oxides of nitrogen (NOx), carbon monoxide (CO), volatile organic compounds (VOCs), particulate matter (PM), and oxides of sulphur (SOx), as well as greenhouse gases such as carbon dioxide (CO_2).

Emissions of these pollutants vary depending on the type of combustion device, the presence of air pollution control equipment, and the composition of the gas; fewer impurities will result in emissions similar to natural gas while more impurities result in a different emissions profile. See table 1 and 2 below.

Table 11 – Criteria pollutant emissions from stationary turbines fired with natural gas and digester gas.

Fuel	Emissions Factor (lb/MMscf)				
	NO_x	CO	VOC	PM	SO_x
Digester gas (uncontrolled)	96.0		3.48	NA	3.9
Natural gas (uncontrolled)	336.0	86.1	2.21	6.9	3.6

Table 12 - Criteria pollutant emissions from engines fired with natural gas and digester gas.

Fuel	Emissions (lb/MMscf)		
	NO_x	CO	SO_x
Digester gas	324 (18 to 918)	546 (222 to 948)	870 (6 to 3,180)
Natural gas	588	892.5	0.6

1.7 Process cost analysis

Table 13 below presents the forecasted cash flows for using wetlands biomass under the two scenarios assessed as part of this project: firstly, harvesting dry reed in winter, and processing it into briquettes for use in the UEA biomass gasifier; and secondly harvesting mixed biomass during summer months, for use in AD plants. Finally, we have modelled an alternative AD scenario where the wetland biomass is classified as waste and incurs a gate fee rather than a sale price.

Our sensitivity analysis indicates that there are three key factors affecting the economic viability of the overall project: the sales price of briquettes (modelled at £100), the cost of processing briquettes (modelled at £85), and the sales price of the mixed wetland biomass for AD (modelled at £50). The assumptions for the models presented herein are available in Appendices 3 to 5.

Table 13 - Discounted cash flow analysis.

		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Harvester Cost Capital		200,000	0	0	0	0	0	0	0	0	0
	Maintenance	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000
		202,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000
Gasifier											
Income:	Briquette sales	198,000	201,960	205,999	210,119	214,322	218,608	222,980	227,440	231,989	236,628
Costs:											
Harvest	Diesel	10,722	10,937	11,155	11,379	11,606	11,838	12,075	12,316	12,563	12,814
	Labour	10,800	11,016	11,236	11,461	11,690	11,924	12,163	12,406	12,654	12,907
	Bailing	1,734	1,769	1,805	1,841	1,877	1,915	1,953	1,992	2,032	2,073
	Loading	867	885	902	920	939	958	977	996	1,016	1,036
Processing	Outsourced	168,300	171,666	175,099	178,601	182,173	185,817	189,533	193,324	197,190	201,134
Transport	Reed	23,760	24,235	24,720	25,214	25,719	26,233	26,758	27,293	27,839	28,395
	Briquettes	2,211	2,255	2,300	2,346	2,393	2,441	2,490	2,540	2,591	2,642
		218,395	222,763	227,218	231,762	236,398	241,126	245,948	250,867	255,885	261,002
Net cashflow from Gasifier		(20,395)	(20,803)	(21,219)	(21,643)	(22,076)	(22,518)	(22,968)	(23,427)	(23,896)	(24,374)
AD (*NOT* classified as waste)											
Income:	Sales to AD plants	84,300	85,986	87,706	89,460	91,249	93,074	94,935	96,834	98,771	100,746
Costs:											
Harvest	Diesel	25,108	25,610	26,122	26,645	27,178	27,721	28,276	28,841	29,418	30,006
	Labour	22,480	22,930	23,388	23,856	24,333	24,820	25,316	25,822	26,339	26,866
	Bailing	1,477	1,506	1,537	1,567	1,599	1,631	1,663	1,697	1,730	1,765
	Loading	738	753	768	784	799	815	832	848	865	883
Transport	Rush etc	20,232	20,637	21,049	21,470	21,900	22,338	22,785	23,240	23,705	24,179
		70,035	71,436	72,865	74,322	75,808	77,325	78,871	80,449	82,058	83,699
Net cashflow from AD		14,265	14,550	14,841	15,138	15,441	15,749	16,064	16,386	16,713	17,048
AD (classified as waste)											
Costs:											
Harvest	(as above)	49,803	50,799	51,815	52,852	53,909	54,987	56,087	57,208	58,353	59,520
Transport	(as above)	20,232	20,637	21,049	21,470	21,900	22,338	22,785	23,240	23,705	24,179
AD	Shredding	2,954	3,013	3,073	3,135	3,197	3,261	3,327	3,393	3,461	3,530
	Gate cost	69,126	70,509	71,919	73,357	74,824	76,321	77,847	79,404	80,992	82,612
Net cashflow from AD (as waste)		(142,115)	(144,957)	(147,857)	(150,814)	(153,830)	(156,907)	(160,045)	(163,246)	(166,511)	(169,841)

1.5.1 Anaerobic digestion

Considering AD as a standalone project, **if the green biomass can be sold for AD for more than £54 then a positive return could be achieved**, recovering the harvester cost (see Table 14). If the biomass is classified as waste then instead of receiving a price for sales a gate fee would have to be paid. This would give a discounted return on the project of -£1.7M (negative), or a Rate of Return of -855%. The discounted cost of the harvestings being classified as waste is therefore nearly £2M.

Rate of Return3	
Sales Price	Total
£10	-347
£20	-269
£30	-190
£40	-112
£45	-73
£50	-34
£52	-18
£54	-2
£55	5
£56	13
£58	29
£60	45
£65	84
£70	123
£80	201
£90	280
£100	358

Units: Rate of Return %

Table 14 – Impact of sale price of the wetland biomass on the Rate of Return of the project.

1.5.2 Gasifier

At present the high briquetting costs undermine the viability of this option, which must compete with the price point of woodchip which is around £100/tonne. The sales price and the processing cost of the briquettes have a linear relationship in their impact on the overall discounted return and ROR of the project. As a standalone gasifier project a positive return could be achieved over the ten years if the sales value is greater than the processing costs by more than £35, which will allow the capital costs invested in the harvester to be recovered (Table 15).

Rate of Return	Proce							
Sales Price	80	85	90	95	100	105	110	115
£40	-701	-747	-793	-839	-885	-931	-977	-1,023
£50	-609	-655	-701	-747	-793	-839	-885	-931
£60	-517	-563	-609	-655	-701	-747	-793	-839
£70	-425	-471	-517	-563	-609	-655	-701	-747
£80	-333	-379	-425	-471	-517	-563	-609	-655
£90	-241	-287	-333	-379	-425	-471	-517	-563
£100	-149	-195	-241	-287	-333	-379	-425	-471
£105	-103	-149	-195	-241	-287	-333	-379	-425
£110	-57	-103	-149	-195	-241	-287	-333	-379
£115	-11	-57	-103	-149	-195	-241	-287	-333
£120	35	-11	-57	-103	-149	-195	-241	-287
£125	81	35	-11	-57	-103	-149	-195	-241
£130	127	81	35	-11	-57	-103	-149	-195
£140	219	173	127	81	35	-11	-57	-103
£150	311	265	219	173	127	81	35	-11
£160	403	357	311	265	219	173	127	81
£170	495	449	403	357	311	265	219	173

Units: Rate of Return %

Table 15 - Impact of briquette sales price *vs* processing cost on investment Rate of Return.

An alternative way of improving the financial viability of this supply chain is to explore the market for premium-priced biomass briquettes, for domestic wood burner use, instead of gasification route. A Warwickshire company called Straw Fuels Ltd retails compressed straw briquettes for the equivalent of over £1,100/tonne. The cost of energy table below illustrates that reed briquettes could compete very effectively with straw logs in this market and deliver good economic returns. There may be attractive marketing benefits for the RSPB and others around a product in this niche.

Table 16 - Cost of energy comparison.

	MJ/kg	kWh/kg	kWh	£/ODT	£/kWh	£/MJ
Straws (www.straws.co.uk)	17.6	4.88	618	1136	0.23	0.84
Kiln-dried logs	14.4	4.00	600	1000	0.25	0.90
Reed briquettes	16.2	4.50	4500	150	0.03	0.12
Woodchip (bulk for gasifier)	18.2	5.05	5050	100	0.02	0.07

Finally, considering a harvester that is used for both reed and green biomass, the sales price of the briquettes and the sales price of the AD could be given different weightings in order to contribute unequally towards the repayment of the capital investment. In other words a dual project would be viable where the rows and columns intersect on a black figure.

Table 17 – Cost of energy production.

Sales price of Briquette less: cost of processing (£/ODT)

	Rate of Return	Gas.										
	AD Sale	-10	-5	0	5	10	15	20	25	30	35	40
	10	-672	-626	-580	-534	-488	-442	-396	-350	-304	-258	-212
	20	-594	-548	-502	-456	-410	-364	-318	-272	-226	-180	-134
	30	-515	-469	-423	-377	-331	-285	-239	-193	-147	-101	-55
	40	-437	-391	-345	-299	-253	-207	-161	-115	-69	-23	23
Sales Price for AD /tonne	50	-359	-313	-267	-221	-175	-128	-82	-36	10	56	102
	60	-280	-234	-188	-142	-96	-50	-4	42	88	134	180
	70	-202	-156	-110	-64	-18	28	74	120	166	212	258
	80	-123	-77	-31	15	61	107	153	199	245	291	337
	90	-45	1	47	93	139	185	231	277	323	369	415
	100	33	79	125	171	217	263	309	355	401	447	493
	110	112	158	204	250	296	342	388	434	480	526	572
	120	190	236	282	328	374	420	466	512	558	604	650
	130	268	314	360	406	452	498	544	590	636	682	728
	140	347	393	439	485	531	577	623	669	715	761	807
	150	425	471	517	563	609	655	701	747	793	839	885
	160	503	549	595	641	687	733	779	825	872	918	964
	170	582	628	674	720	766	812	858	904	950	996	1,042

Units: Rate of Return %

1.6 Exploitation

DECC has value the IP potential from this project at £16,000. Partners believe that the potential for IP lie around added value modifications and integrations that could be made to the harvesting system designed in Phase 1. Testing of that machine in Phase 2 and 3 will be essential to collect data to inform how we approach protection of IP. If commercially attractive, we intend to pursue protection and would adhere to DECC's terms and condition on benefit sharing as stated on the competition documents.

For future operation of the harvester on nature conservation sites, the price would not include a capital cost of the machinery. The cost would be based upon labour, operating costs including fuel, insurance and haulage and a percentage to cover breakdowns and further development of the machine. The base unit of the harvester is intended to be flexible and will be designed to allow other attachments to be fitted on the linkage system.

Many wetland sites in East Anglia are under-managed, where restoration and rotation cutting of vegetation is required and not currently undertaken. These sites are too wet for conventional cutting and collecting machinery or too large to make manual clearance economically viable. The development of a harvesting system would permit more of these sites to be managed in a cost effective and beneficial manner. Peter Frizzell Ltd would work with wetland managers to produce a plan for efficient harvesting during summer and winter periods. They have existing clients, including wildlife trust, and conservation trusts who would benefit from the developed harvesting system. Negotiations and agreements with nature conservation managers for harvesting were facilitated by Sally Mills from the RSPB. 'Statements of intent' from wetland managers are provided as attachments to this report.

Gasification is not a particularly new technology though its development as a means of producing electricity is not yet well developed, particularly in the UK. To date only a handful of small-scale gasification plants have been built and commissioned in the UK. There are several in the planning stage. Gasification qualifies for double ROCs (Appendix 6) making it a financially attractive technology compared to other renewables. Some of the planned gasifiers are designed to use waste which improves the financial implications of fuel sourcing. However, these plants are considered to be waste treatment plants and so require much greater clean-up technologies, thus increasing the overall capital cost of the plant.

The UEA Biomass Gasification Plant (see image to the right) is undergoing the final stages of its commissioning test runs. It will be fully operational by the time the reed material is ready for use. Locally sourced fuel supplies are important to the UEA, so the project on reed-based briquettes would be attractive providing that the price is similar to that of the woodchips currently used (£100 per tonne).

Figure 12 – Photo of the UEA Biomass Gasification Plant in Norwich.

Our financial analysis has indicated, however, that as a standalone gasifier project a positive return could be achieved over the ten years only if the sales value of the reed briquettes was is greater than the processing costs by more than £35, and those costs were modelled at £100. That has led us to look for alternative routes to market for the biomass harvested in winter and, as discussed in section 1.7, the domestic heat sector would make this an attractive commercial proposition. FuelSell Ltd would be our preferred partner for full commercial deployment of the reed briquette project, but a bigger range of companies operating in the domestic heat sector will be approached in Phases 2 and 3.

AD is a proven technology. In the UK, it has been adopted in the wastewater treatment sector for over 100 years. Recent times have seen farmers building AD plants to treat agricultural manures. The potential methane yield from manures is not high and, to make projects more attractive, crops such as maize and grasses are often used as supplement. Plants that use 100% grown crops as feedstock are also being built. More recent is the adoption of AD for treating food waste, to avoid biodegradable wastes going to landfill.

Three AD companies have been approached as part of Phase 1: Temple Farms, located on the North Norfolk coast; Future Biogas with two plants west of Norwich, and with two more about to be built; and Adnams Bioenergy at Southwold, Suffolk. All three have expressed an interest to continue discussions during Phases 2 and 3. Our preferred route to market for the mixed wetland biomass would be an agricultural-based plant like the one at Temple Farms or energy crop-based plant like the ones run by Future Biogas, if the feedstock was not deemed by the EA as a waste.

There are around 40 agriculturally based AD plants in England and NI (Figure 13). Some of the smaller plants only produce up to 100kwe and are fed on a mixture of slurry/manures with added feedstock such as maize. The more recently constructed AD plants start at around 500kwe and progress up to 1.5MWe. The size of the latter plants is driven by commercial factors and the added green tariffs for electrical power generation. A plant of around 1.5MWe will required the order of 25,000 tonnes per annum of grown crops, predominantly maize. The smaller AD plants of around 100kwe will require around 8,000 tonnes of feedstock (slurry + grown crop).

Figure 13 - Farm-based AD plants in the UK. Source: http://biogas-info.co.uk/maps/index2.htm

With regards to wetland sites in the Somerset levels, there are farm based AD plants at Ilfracombe, Taunton, Cullompton (Exeter) and Dorchester, for instance. Andigestion Ltd, the partner who will carry out the AD digestion trials at their R&D facility in Waterbeach, Cambridgeshire, in Phases 2 and 3 of this project, have a long established food waste plant at Holsworthy, Devon.

1.7 References

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Section 2 – Project plan for Phases 2 and 3

Phase 1 of our project on the 'Gasification and anaerobic digestion of sustainably-sourced biomass' looked at the financial feasibility and carbon and energy benefits of:

- Producing reed briquettes from biomass harvested at East of England sites in winter, as a feedstock for the University of East Anglia's Biomass Gasifier in Norwich, for co-feed with woodchips;
- Using mixed wetland biomass harvested in the summer as a feedstock for the AD plant at J F Temple & Son Ltd, in Wells-Next-The-Sea, and the Future Biogas plant at Taverham.

The energy and GHG balances of using wetland biomass harvested in the East of England as a feedstock for AD indicate clear net benefits. The energy and GHG balances of using reed harvested in the East of England as a feedstock for the UEA Biomass Gasifier, on the other hand, are not positive.

The financial assessment of the proposed uses for the wetland biomass has shown that:

- At present the high briquetting costs undermine the viability of harvesting reed and processing it into briquettes for use in the university's biomass gasifier;
- Assuming the mixed wetland biomass is not classified as a waste stream, and is therefore not subject to a gate fee, an attractive net cashflow could be achieved for its use in AD.

Therefore, for Phases 2 and 3 of this project, DECC funding is requested to:

- Commission and build the new harvesting system designed in Phase 1 of the project, carry out summer and winter trials in the East of England and if required implement further modifications;
- Develop and build a self-loading tracked dumper to move cut material from the harvesting area to transfer sites for collection by lorry;
- Carry out bench-scale AD tests co-digesting mixed wetland biomass with other feedstocks, to estimate biogas yields and assess digestate quality, and later demonstrate at scale.

As an alternative route to market for the reeds harvested in winter, we would like to explore the possibility of developing higher-value products for use in the domestic heat sector, so we also ask for funding to:

- Carry out briquetting trials with the reed to optimise fuel quality for domestic use, and later carry out combustion tests to measure emissions.

This section of the Phase 1 report provides a detailed project plan for Phases 2 and 3, with the associated timings, costs and deliverables identified. For supporting evidence please refer to Section 1.

2.1 Project plan

The Gantt Chart in Appendix 7 shows the timescale for Phases 2 and 3. This section provides a detailed description of the Work Packages of the project.

Work Package 1 – Harvester commissioning and construction

In Phase 2 machine construction and development will take place from May 2013 to February 2014, and continue into Phase 3 of the project, as the experience with harvesting trials in summer and winter 2014 will provide information on how to improve the design. After the new harvester has been demonstrated to work, development of the self-loading tracked dumper for haulage (to move cut material from the harvesting area to transfer sites for collection by lorry) will commence.

The machine will be built by Peter Frizzell Ltd and Stephen Eyles. Peter Frizzell has extensive experience of conservation management, being a supplier of contracting services to many site managers in the East of England. Stephen Eyles is an agricultural engineer who has been involved in several projects of relevance to this work, including the harvester built for the Great Fen Project and the hemp harvester built for the InCrops Enterprise Hub (part of the Adapt Low Carbon Group at UEA).

Work Package 2 – Harvesting trials

As the new harvester will not be available for trials during summer 2013 and early winter 2013/2014, in Phase 2 any material required for the bench-scale AD tests and briquetting trials will be harvested by alternative methods. The objective for the harvesting trials in Phase 2 is to produce material to support the conversion tests; in Phase 3 the objective is to test the new harvester commissioned in Phase 2.

Summer harvesting trials will take place on fen, mixed fen and grazing marsh. Table 18 describes the methodology to be adopted in the summer harvesting trials in Phases 2 and 3. In Phase 2 biomass samples will be obtained from routine mowing of sites managed by the Little Ouse Headwaters Project, which would provide a complete range of materials. If alternative sites are required, Norfolk Wildlife Trust has indicated interest in providing trial sites. The sites for Phase 3 trials will be selected during Phase 2.

For the reed, winter harvesting trials will take place on reedbeds. Table 19 describes the methodology to be adopted with the winter harvesting trials. It is intended that reed samples for the briquetting trials in Phase 2 will be collected from RSPB Lakenheath Fen reserve. It is expected the same site will be used for the harvester trials in Phase 3, though other sites may be selected during Phase 2.

Wetland sites vary in sensitivity to the impacts of management. Peter Frizzell Ltd has experience of working on sites throughout Norfolk and Suffolk. Harvesting will only take place at an appropriate time taking into consideration the cutting height of the vegetation and other specific management requirements of the sites. The key aim will be to restrict movement of machinery on sensitive sites and if possible harvest and extract on a single pass to keep tracking on sites to a minimum.

Table 18 - Overview of methodology for summer harvesting fen and grazing marsh in Phases 2 and 3.

Aspect	Phase 2	Phase 3
Access requirements	Only limited access is required and material may be cut using brushcutters or mowers.	A minimum 3.0m wide access will be required to the areas to be harvested. Ideally there will be an area to unload the machinery and load the cut material for road haulage.
Time of harvesting	Aug, Sepr 2013.	Aug, Sep 2014.
Composition of material	A range of material from different fen types can be provided including: mixed fen consisting of sedges, rush, reed and grasses; *Cladium*; and rush.	A similar range of material can be harvested to Phase 2.
Methods and expected timescale of harvesting	Samples harvested using brushcutters and reciprocating mowers. Drier grazing marsh rush areas will be flail collected if required.	Harvesting will be carried out using the developed tracked machine.
Methods and expected timescale for removal of harvested material	Removal of cut material will be immediate.	As soon as practically possible after harvesting.
Amount of material to be harvested and size of area required	Small areas are only required to provide samples for bench-scale AD tests.	The size of area and amount of material to be harvested will be determined in Phase 2.
Storage requirements	None required.	None required. The biomass will be chopped by the harvester and delivered fresh to the AD.

Table 19 - Overview of methodology for harvesting reed in Phases 2 and 3. Habitat type: reedbeds.

Aspect	Phase 2	Phase 3
Access requirements	A minimum 3.0m wide access will be required. Ideally there will be an area to unload the machinery and load the cut material for road haulage.	A minimum 3.0m wide access will be required. Ideally there will be an area to unload the machinery and load the cut material for road haulage.
Time of harvesting	Nov, Dec and Jan to provide samples for the briquetting trials, and late Feb or early Mar for demonstration of harvester.	Oct through to Jan.
Composition of material	Reed.	Reed.
Methods and expected timescale of harvesting	May require pedestrian mower bundler to provide samples early in harvesting season. Harvester trials will be late in season for a short period of time determined by completion of fabrication and limited by the beginning of bird breeding restrictions.	Harvesting will be carried out using the developed tracked machine.
Methods and expected timescale for removal of harvested material	As soon as practically possible after harvesting.	As soon as practically possible after harvesting.
Amount of material to be harvested and size of area required	Small areas are only required.	A sufficient area will be harvested to demonstrate how the harvester works and to determine the rate of harvesting.
Storage requirements	None required.	None required.

Work Package 3 - Briquetting tests

Preliminary trials carried out in Phase 1 indicate that reed can be a suitable feedstock for producing briquettes. Since the financial assessment on the utilisation of reed as a fuel for the UEA Biomass Gasifier has shown that this route to market for the biomass is not a commercially attractive, in Phase 2 we propose to explore the possibility of developing high-value biomass fuels for the domestic sector.

Phases 2 and 3 will involve carrying out further briquetting trials to optimise the manufacturing process and the quality of the fuel for the domestic market. Reed will be harvested from East of England reedbeds as explained above, and transported to the Fercell R&D facility in Kent for processing. The exact number of days required to achieve 12% moisture content will be investigated in Phases 2 and 3.

Fercell Ltd of Aylesford in Kent are UK sole agents for Weima of Germany who specialise in shredding and briquetting equipment. Fercell were selected as the partners for the briquetting tests because they have experience briquetting a range of materials, from straw and hay to Miscanthus, and have sold a machine to a thatcher for briquetting old thatch removed from roofs.

One problem experienced by Fercell in past with arable crops such as straw is that there is ‘creep’. This is the inability to totally grip the first briquette due to the nature of arable crops. Although hardly noticeable, it can affect the density and hardness of the briquette. To avoid this, the briquettes will be produced using a ‘matrix’ machine, which works by using a metal plate introduced into the tube mechanism and this acts as a solid interface against which the biomass is compacted. As this metal is immovable there is no resultant ‘creep’ and the briquette quality is much improved as a result.

Work Package 4 - AD bench-scale trials and demonstration

Previous studies indicate that the biogas yield from reed can be double that of cattle manure and close to that of food waste. The bench-scale and demonstration tests that we propose to carry out in Phases 2 and 3 of this project, co-digesting mixed wetland biomass with more traditional feedstocks for AD, will generate valuable data for the industry as little work has been done in this area.

The key objective of the bench-scale tests to be carried out in Phase 2 of the project will be to determine the potential metabolisable energy from the mixed wetland biomass harvested in the East of England. We will also investigate the potential biogas yields from the wetland biomass when co-digested with common feedstock used for AD, such as cattle manure, bioenergy crops and food waste.

This Work Package will be carried out by Andigestion Ltd, at their R&D AD facility in Waterbeach, Cambridgeshire. This is the largest AD facility built in the UK for the sole purpose of research and development, which includes a suite of 18 CSTR bench-scale digesters and 14 batch bench-scale reactors with advanced semi-continuous feeding capability. As well as its in-house research of over six years, Andigestion has for several years participated in cooperative AD research with universities, such as Southampton (Prof Charles Banks); Imperial College London (Prof Stephen Smith); Cranfield University (Prof Richard Smith); and Loughborough University (Prof Andrew Wheatley). Edgar Blanco, R&D Manager for Andigestion Ltd, has over 15 years R&D experience in the wastewater treatment and AD sectors.

The plan is to carry out a two-month bench-scale trials with six reactors, with mixed wetland biomass harvested in summer and co-feeds of the biomass with: cattle manure, energy crops and food waste. Yields will be measured from both batch and continuous laboratory test units. As certain wetland biomass types such as reed have the potential to accumulate contaminants, we will also assess the quality of the digestate. Standard analyses of biogas yields, volatile solids, dry solids, pH, fatty acids, nitrogen and ammonia and digestate safety will be carried out. The cost for this work will be £40,000 + VAT.

The result from bench-scale co-digestion of mixed wetland biomass with other AD feedstocks will be used to inform a demonstration trial at an AD facility in the East of England to be defined.

Work Package 6 – Carbon and energy LCA

Primary data collected on: fuel consumption of the harvester; fuel consumption associated with transporting the wetland biomass from conservation sites to the processing plants; moisture content of the biomass; energy consumption associated with chopping the biomass at the briquetting and AD sites; and biogas yields from the bench-scale AD trials; will be used to refine the carbon and energy LCA.

Work Package 7 - Project management

Partner meetings will be hosted every month, to enable the findings from each Work Packages to be discussed by the group, with the view to identify potential impact on the progress of the project and introduce mitigation measures to address any challenges. In addition, Adapt Commercial, who will act as Project Manager on behalf of the group, will circulate progress updates on a monthly basis to partners. Adapt will coordinate and be responsible for the reporting to DECC on the deliverables associated with each payment as per the schedule available on Appendix 8.

2.2 Cost Breakdown

The total cost for Phase 2 has been calculated at **£365,063.75** (inc VAT) and the cost for Phase 3 at **£268,211.00** inc VAT. Table 20 shows the breakdown of cost as per the heading requested by DECC. Appendix 9 and 10 provide a more detailed breakdown of costs for Phases 2 and 3.

Table 20 – Breakdown of costs for Phases 2 and 3.

Cost type	Phase 1		Phase 2		Phase 3		Total project value	
Labour costs			£	126,263.40	£	59,271.00		
Capital expenditure			£	159,620.35	£	162,240.00		
Sub-contracts			£	73,080.00	£	40,600.00		
Travel & subsistence			£	6,100.00	£	6,100.00		
Other costs			£	-	£	-		
Total (inc VAT where applicable)	£	36,560.00	**£**	**365,063.75**	**£**	**268,211.00**	**£**	**669,834.75**
Costs indicated in the Phase 1 bid	£	36,560.00	£	272,530.00	£	416,730.00	£	725,820.00

DECC has valued the potential for IP from the project at £16,000. This should be demonstrated as a cost saving offered as a result of the risk-sharing approach to SBRI. Adapt Commercial is applying a discounted daily rate of £400, as opposed to its typical of £600, to deliver savings of £21,600 in Phase 2 and £15,600 in Phase 3 of the project. Appendix 11 provides more information on these savings.

In addition to the above, for future commercial operation of the harvester on nature conservation sites, the price would not include the capital cost of the machinery. The cost would be based upon labour, operating costs including fuel, insurance and haulage and a percentage to cover breakdowns and further development of the machine.

2.3 Deliverables

An invoicing schedule, linked to the deliverables for Phases 2 and 3, is presented in Appendix 8. In order for Peter Frizzell Ltd, the subcontractors responsible for the design, commissioning and construction of the new harvesting system, to be able to finance the construction of the harvester, invoices will need to be submitted to DECC every two months for labour and parts costs.

The Phase 2 report will detail: the design of the harvesting system and lessons learned from preliminary trials in reedbeds in the winter 2013/2014; the results from the bench-scale AD trials on the potential biogas yields from mixed wetland biomass and on the briquetting trials with harvested in the winter; and an updated LCA on the carbon and energy benefits of the system.

The Phase 3 report will detail: the key successes and lessons learned from the development of the harvester and trials in summer and winter, clearly explaining any deviances from the original system design; the output from the demonstration-scale AD trial with mixed wetland biomass; the key findings from the briquetting trials, including lessons learned; and a final LCA using the trial data collected in Phases 1, 2 and 3; and a roadmap for commercial exploitation.

2.4 Key risks and mitigation

Table 21 lists the risks associated with the project their likelihood and impact and proposed measures to mitigate the risk. Of all the risks identified, the timescale for developing the harvester system is particularly critical. Delays in commencement of Phase 2 could have an impact on the success of completing the construction in time for trials in early March 2014.

The uncertainties about the volumes of wetland biomass that might be available in the East of England is another area where the group will focus attention. Uncertainties are even greater for wetland biomass harvested in summer. In the region the largest source by area is the Norfolk Broads which is a mix of reed and fen, the precise proportions of which are unknown. The RSPB recognises that the figures provided to contractors of this DECC competition are based on management plans which are likely to be conservative estimates based on current harvesting abilities. Contractors will work with conservation managers in Phases 2 and 3 to try to refine the figures provided.

Finally, as previously discussed, a major risk to the commercial viability of the project, is the classification of the wetland biomass as a waste. To mitigate this, contractors will continue to engage with the EA at local and national levels to understand their concerns and ensure data is provided to enable progress.

Table 21 - Likelihood and potential impact of risks identified for the project and mitigation strategies.

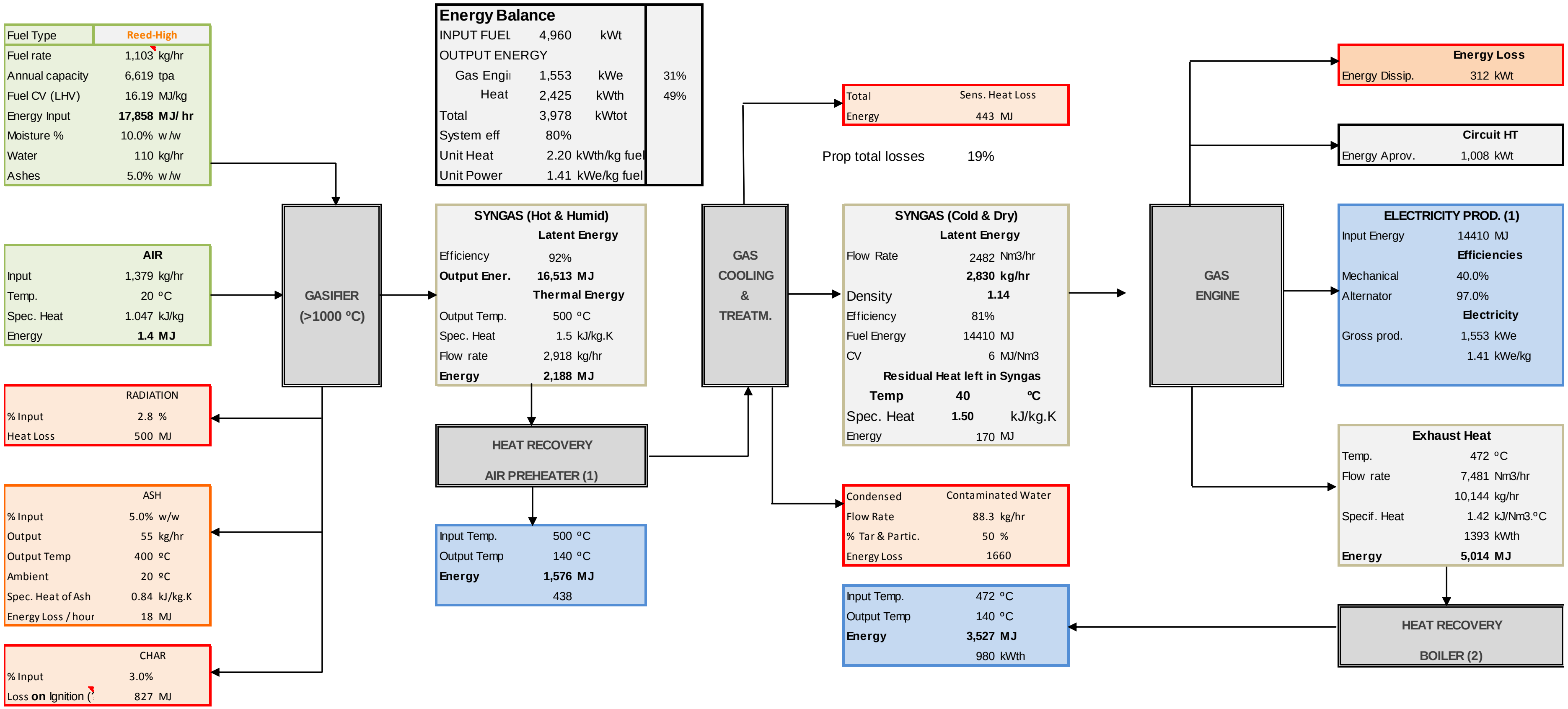
Type of risk	Likelihood	Impact	Mitigation
Technical			
Design failure for base unit	Low	High	Previous experience
Design failure of cutting head	Medium	High	Previous experience of fen cutting, engineering capability to develop cutter
Design failure of conveyor and collection system	Low	High	Previous experience of fen cutting, engineering capability to develop system
Presentation of material incorrect	Medium	High	Prior knowledge of end use requirements and post-harvest processing
Programme			
Completion of harvester construction	Low	High	Planning
Site selection incorrection	Low	High	Sites will be chosen carefully
Sites unavailable at time of trial	Low	High	Flooding, bird breeding planning and site selection
Environmental			
Fuel leaks	Low	High	Spill kits and good maintenance, bundled fuel tanks, controls during refuelling
Hydraulic leak	Medium	Medium	Bio oil and spill kits
Machine stuck	High	Low	Knowledge of sites
Permissions and regulatory requirements			
EA consent issues	Medium	High	It is assumed that most sites on management will have consent. If not, the group will apply for it.
NE consent issues	Low	High	It is assumed that most sites on management will have consent. If not, the group will apply for it.
Budgets and resources			
Lack of funding	Medium	High	Invoice planning
Harvesting labour	Low	High	Use of known contractors.
Market and commercial			
Biomass availability	Low	High	It is believed that sufficient biomass is available to support trials at bench- and demonstration-scale.

APPENDIX 1

Mass and energy balance for the gasification route (adapted from a model developed by Dr Murat Dogru)

UEA GASIFICATION SYSTEM: MASS AND ENERGY BALANCE RESULTS

Adapted from original schematic/mass balance estimates developed by Dr Murat Dogru (April 2012)



APPENDIX 2

Assumptions of the GHG end energy analyses

General Assumptions

Carbon Stock Changes

The EU RED methodology requires any carbon stock changes to be accounted for as a result of exploitation of biomass, although releasing carbon dioxide through recovering energy from short cycle biogenic carbon sources is considered to be neutral by the RED. This can have significant political implications for proposed biomass for energy schemes[1]. It is thought that further exploitation may cause a net reduction in overall existing carbon stocks and also impact the future potential for sequestration, which is not represented by assuming combustion of exploited biomass releases carbon is considered GHG neutral.

In this GHG and energy assessment the following criteria are made:

- Land use changes such as reed bed expansion and rewetting are not considered as the areas under management are required to remain constant for the purposes of the assessment.
- Counterfactuals (required by DECC) show only existing biomass removal practices for conservation. The carbon budgets of the natural succession of wetlands to scrub and carr, and woodland, if left unmanaged, is not a scenario within the scope of this assessment.
- Due to lack of substantive data, changes in the carbon stock due to removal of biomass from wetlands for conservation and energy generation are not assumed in this assessment.

In consideration of any intention of expanding reed bed habitats it would be necessary to investigate impacts on net GHG flux and respective carbon stock changes in greater depth.

Wetlands as a GHG sink and GHG source

Phragmites dominated wetland, have previously been considered a net source of GHG emissions over time periods less than 60 years (Brix et al 2001). This is considered to be the relatively greater global warming potential of methane emissions released in the early stages of reed bed establishment before a substantial quantity of carbon is sequestered in the biomass can ‘offset’ the relatively greater radiative forcing potential of methane[2]. In the longer term biogenic carbon sequestered by the reed beds are reported to counterbalance and negate the methane burden from reed beds.

More recent studies on the GHG flux show of re-established wetlands indicate areas of fenland vegetation may be net sources and also net sinks of greenhouse gases in different years. This may also be due to management influence, rather than climate related factors (Herbst et al 2013). The

[1] http://www.rspb.org.uk/Images/biomass_report_tcm9-326672.pdf

[2] The global warming potential (GWP) of methane is currently 25 times that of carbon dioxide when measured over a 100 year time frame, though over a 20 year time frame methane has a significantly greater GWP.

authors considered grazing to influence the dominance of soft rush to be a biological mechanism releasing more methane compared to grassland.

Global warming potentials

The global warming potentials (GWP's) of GHG gases follow the RED, (GWP's of 23 for methane, and 298 for nitrous oxide). However, the majority of energy sources GHG emissions are dominated by carbon dioxide from combustion and overall differences are negligible when using GWP of methane and nitrous oxide following RED and that of the DEFRA GHG reporting GWPs. Grid electricity was recalculated to follow the RED GWP's.

Functional unit for GHG and energy assessment

As agreed, the methodology for calculating the carbon balance follows the EU Renewable Energy Directive[3] (RED) to ensure that allocation methods are consistent. However, the goal of the assessment is to compare the emissions associated with the current function of conservation management activities of areas of reed beds and fen wetlands (so called 'counterfactuals') with that of harvesting conservation biomass to produce units of energy.

This approach is not really within the scope or purpose of the RED methodology which would probably regard biomass removed by conservation management as a residue, and therefore exclude emissions associated with harvesting from GHG reporting. However, the relevant aspects of the RED methodology are more prescriptive, and therefore more likely to result in consistency amongst the project assessments, so this is preferable to more flexible standards such as PAS2050.

In summary, the production of biomass energy is a very different function to compare with conservation management of an area of wetland. In this respect the GHG savings from net energy generation, calculated in line with the RED methodology, can be credited back to the function of conservation management of a fixed area of land, or flow of biomass resulting from that management. This is the approach taken here.

GHG credits from energy substitution

In this respect the GHG savings made by any generation of biomass energy will be calculated using the fossil fuel comparators documented in the RED biomass methodology, rather than UK specific emission factors. These are documented at 198 gCO_2eq and 87 gCO_2eq per MJ electricity and per MJ of heat generated, respectively. The table below shows the differences between emission factors that could be used under different circumstances.

[3] Directive 2009/28/EC as augmented by COM(2010)11: Report from the commission to the council and the European Parliament on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling.

Table 22 - Emission factors for electricity and heat alongside the EU Renewable Energy Directive standard default values for estimating GHG savings of renewable energy for Directive compliance purposes.

Substitution	Units	Average	Marginal	RED Fossil Fuel comparator
Generated Electricity	kg CO_2eq MJ_{el}^{-1}	0.1530 a	0.0963 b	0.1980
Industrial heat	kg CO_2eq MJ_{th}^{-1}	0.0908 c	0.0733 d	0.0870

a) GHG EF (scope 3) from average mix at point of generation (no transmission losses accounted for)
b) Marginal source assumed to be CCGT - (DEFRA 2009)
c) Average heat supplied assumes GHG (scope 3) from a weighted average mix of natural gas, heating oil, solid or electricity sources for industrial or domestic use respectively (DECC 2009)
d) Assumed typical gas furnace with 85% heating efficiency fuelled by natural gas (scope 3) - LHV

Allocation

GHG emissions from processing wetland biomass are allocated between electricity and heat generated as per the RED's methodology involving relative exergy of heat and electricity produced:

For the electricity coming from energy installations delivering useful heat:

$$EC_{el} = \frac{E}{\eta_{el}}\left(\frac{C_{el} \cdot \eta_{el}}{C_{el} \cdot \eta_{el} + C_h \cdot \eta_h}\right)$$

For the useful heat coming from energy installations delivering electricity:

$$EC_h = \frac{E}{\eta_h}\left(\frac{C_h \cdot \eta_h}{C_{el} \cdot \eta_{el} + C_h \cdot \eta_h}\right)$$

Where:

C_{el} = Fraction of exergy in the electricity, or any other energy carrier other than heat, set to 100 % ($C_{el} = 1$).

C_h = Carnot efficiency (fraction of exergy in the useful heat).

Source: European Commission (2010)

Char from the gasifier as a co-product?

Although char is produced by the gasifier, no allocation of feedstock GHG emissions has been made to it in this assessment. As outlined in other sections of this report the status of this char as a co-product is uncertain; it may be defined as a waste by regulators, rather than a product. If landfilled, the char is likely to remain inert with no subsequent GHG emissions. In this context only an additional GHG burden from transport emissions to a controlled disposal or reprocessing point may be required. The mass balance of the gasifier assumes 3% of the mass of feedstock is converted into char. This is likely to be transported no more than 30km to local waste disposal processers. Conservatively the carbon content of the char is considered to be around 60% and would be equivalent to sequestering 60-70 kg of biogenic carbon dioxide per tonne of biomass feedstock that is gasified – the emissions associated with transport of 30kg biochar 30km as waste approximately 100gCO_2 per tonne of feedstock consumed.

Bulk transport emissions

Data on transport GHG emissions from DEFRA are published on per tonne km basis for fixed lorry loads, which also account for fuel production emissions (scope 3) and loading of return journeys. These fixed loads are not representative for transporting more bulkier biomass. To estimate the emissions per transport journey the DEFRA emissions have to be 're-calibrated' to account for the lower load of transporting bulky chopped biomass. Fortunately DEFRA GHG emissions per vehicle km are linearly related to the % mass load, so an emission factor per tonne of biomass at the above loose bulk densities can be estimated to compare with the baling transport and the added GHG cost of baling.

Table 13 - Assumptions on baled feedstock.

Baled transport (weight constrained) by flat-bed articulated lorry at maximum load (19 tonnes)				
	60	m^3		
Max per load[a]	19	tonnes		
Bulk density[b]	600	kg m^{-3}	Load per trip	
assumed	19.0	tonnes per load	31-32	bales
OUTWARD	100%	laden	44	m^3
	1.43	kgCO_2e per vehicle.km		
	0.075	kgCO_2e per tonne.km		
RETURN	0.889	kgCO_2e per vehicle km		
	0.047	kgCO_2e per tonne.km		
Resulting EF	**0.122**	**kgCO_2e per tonne.km**		
	0.04	**litres diesel per t.km**		
	1.38	**MJ per t.km**		

[a] Taken from DEFRA 2012 assumptions for >33tonne articulated lorry.

Table 24 – Assumptions on chopped feedstock.

Chopped (volume constrained) biomass - box-body articulated lorry at maximum volume (60m^3)		
	60	m^3
Max per load[a]	19	Max tonnes per load
Bulk density[b]	70	kg m^{-3}
assumed	6.3	tonnes chopped fen per load
OUTWARD	33%	laden
	1.049	kgCO_2e per vehicle.km
	0.17	kgCO_2e per tonne.km
RETURN	0.89	kgCO_2e per vehicle km
	0.14	kgCO_2e per tonne.km
Resulting EF	**0.305**	**kgCO_2e per tonne.km**
	0.10	**litres diesel per t.km**
	3.46	**MJ per t.km**

[a] Taken from DEFRA 2012 assumptions for >33tonne articulated lorry. [b] Bulk density of chopped rush and grasses assumed to be similar to chopped straw/Miscanthus.

Using this method it is necessary to also account for an additional return journey. A return journey of the same length as delivery is assumed in this study, but with emissions for a zero load.

Winter reeds harvesting

Counterfactual scenario

The assumptions of the counterfactual scenario, and associated estimated GHG emissions and energy demand are given below in **Error! Reference source not found.**. The overall GHG emissions per hectare are 450kgCO_2eq requiring 4,400 MJ of fossil fuel energy (estimated as lower heating value, following the RED).

Table 25 - Reedbed management counterfactual scenario GHG emissions and energy estimates.

Reedbed counter factual	Hours per Ha	litres petrol /hour	Petrol per Ha	kgCO2e	MJ $_{LHV}$
Brushcutting	4	1.0	4.02	10.9	132.2
Mowing	35	3.8	131.25	356.6	4317.3
Manual raking and burning	200	0	0	0.0	0.0
				367.6	4449.5
Assumed labour	3.5	people per 4 x 4 car			
	8	hours per person per day			
	28	hours work per journey			
Transport	32	km per journey			
	8.5	Journeys per Ha cut			
	27	litres diesel for transport			
	985	MJ $_{LHV}$ for transport			
	85.9	kgCO_2 e per Ha Staff transport			
	5.5	ODT per Ha			
	12%	Baled dried moisture			
Estimated emissions per Ha	**453.5**	**total kgCO_2 e per Ha cut**			
Estimated energy per Ha	**5434.7**	**total MJ $_{LHV}$per Ha cut**			
Estimated emissions / tonne biomass	**73.6**	**kgCO_2 e per tonne 12% moisture**			
	82.5	**kgCO_2 e per ODT**			
Estimated energy per tonne biomass	**882.2**	**MJ $_{LHV}$ per tonne 12% moisture**			
	988.1	**MJ $_{LHV}$ per ODT**			

Harvester fuel use assumptions

The assumptions made for the GHG and energy assessment are shown in Table 264 overleaf. The engine parameters were indicated through discussions with the harvester designer. However at this early stage the exact parameters are not easy to determine. The fuel rates may be conservatively high compared to the final design.

Moisture

The process assumed air drying is required and will result in moisture being reduced to 12% if bundled reeds are stacked to keep the worst of the rain from penetrating the stack (Ash 2009). Passive barn drying trials for the RSPB has shown moisture to drop to this level. This is a critical assumption and would require further validation beyond just a desk based assessment.

Table 25 – Moisture of reed bales (%) and drying characteristics in a static air barn, Source: Report on the utilisation of arisings at RSPB reserves- David Wynne, AGBAG (2012).

Sample	Bales sampled on arrival		Sampled after static barn drying	
	Surface	**Core**	**Surface**	**Core**
1	91%	15%	8%	12%
2	12%	19%	9%	17%
3	12%	24%	6%	19%
4	14%	20%	10%	14%
5	11%	17%	10%	14%
6	11%	16%	9%	12%
7	12%	20%	7%	13%

Baling

The harvester should not be required to chop reeds whilst harvesting, given the need for a similar format to baling/bundling and stacking to allow reed to air dry. Subsequent baling has been shown to be a better format for transporting the biomass due to increased bulk density and also practicalities for storage capacity. The specifications for baling and loading, respective fuel use and energy, are taken from the Ecoinvent V2.0 data base for lifecycle assessment inventories and are based on grass silage (700kg) bales using Swiss farming machinery that is around 10 years old. The inventory suggests 23% factor applying the baling data for straw or similar materials. This factor was applied here.

Table 26 - Assumptions used to estimate reed biomass harvesting and baling energy and emissions.

Harvesting		
Harvester engine make/model	Deutz 4 Cylinder TCD 3.6 L4	
Specific fuel consumption	210	g kWh^{-1}
Nominal operating power	90	kW
Average operating power*	67.5	kW
Diesel density	835	g /litre @ 15°C
Minimum time per Ha coverage - Reed	1.0	hr
Non-productive operational time	0.25	hr per Ha^{-1}
Reed cutting time per Ha	1.3	hrs Ha^{-1}
Reed cutting gross engine energy	84	kWh Ha^{-1}
Reed cutting diesel use	21	litres Ha^{-1}
Reed harvesting, fuel energy	764	MJ_{LHV} Ha^{-1}
Reed harvesting, emissions	67	$kgCO_2$ e Ha^{-1}
Harvesting 1 ODT of bundled reed, energy	139	MJ_{LHV} ODT^{-1}
Harvesting 1 ODT of bundled reed, GHG	12	$kgCO_2$ e ODT^{-1}
Baling	Ecoinvent data based on a 3.6 tonne 60kW engine tractor†	
Mass of 1 bale	228	kg
Moisture assumed for $Tonne_{fresh}$	12%	w/w (after field drying as bundles)
No. Of 1.4m^3 bales per ODT	5	
MJ fuel required for baling 1 ODT	37	MJ_{LHV} ODT^{-1}
GHG for baling 1 ODT	3.1	$kgCO_2$ e ODT^{-1}
Loading 1 ODT into lorry. MJ	17.4	MJ_{LHV} ODT^{-1}
Loading 1 ODT into lorry. GHG	1.5	$kgCO_2$ e ODT^{-1}
No. bales/ tonne Fresh weight	4.4	
MJ per fresh weight tonne baled	32.3	MJ_{LHV} $tonne_{fresh}^{-1}$
GHG per fresh weight tonne baled	2.7	$kgCO_2$ e $tonne_{fresh}^{-1}$
Loading fresh weight tonne into lorry. MJ	15.3	MJ_{LHV} $tonne_{fresh}^{-1}$
Loading fresh weight tonne into lorry. GHG	1.3	$kgCO_2$ e $tonne_{fresh}^{-1}$

†Ecoinvent database v2.0. Fresh weight is taken to be reed stems field dried to 12% moisture after bundling or stacking

Reed biomass transport to Briquetter

Bulk density of Common Reed

According to a Finnish report, bulk density of baled winter cut Phragmites tend to be 163 kg m^{-3} with a range between 140 to 170 kg m^{-3}, though moisture content is not given[4]. Also stated is that chopped common reed to supply 1 MWh requires 7.6m^3, whereas hard baled this requires 1.5 m^3. At the specified baled bulk density this volume factor of 5 would equate loose chopped reed to approximately 30 kg m^{-3}. However, the reeds cannot be chopped during harvesting to particularly short lengths that would prevent bundling/baling so as to allow passive drying.

Transport distances

The transport distances were obtained using web-based road network distance mapping tools. Data for the Norfolk Broads areas available for harvesting were limited, therefore a scenario of low medium and high was applied. A high scenario represented here assumes 1000 Ha of reedbeds are harvestable (based on the realistic maximum potential area reported by Ash 2010), a low scenario of 250 and medium of 500 Ha was applied. The weighted average distance for transporting reeds to the briquetting plant changed from approximately 70km to 50km, with a low and high scenario of availability of harvestable area. The higher, 50km scenario is used in the assessment, assuming costs are likely to be prohibitive, and a limiting factor, for the sites furthest away.

Table 27 - Estimating the weighted average transport distances for reed biomass supplied to the briquetter from wetland sites in the Eastern region of the UK.

Site name	Indicated annual harvest (ODT)	Fresh weight moisture (after baling)	Baled fresh weight	Wetland distance to Briquetter km	Briquetter to UEA gasifier km
RSPB Minsmere	220	12%	250	40	32
RSPB Lakenheath	220	12%	250	95	
RSPB Ouse Fen, Cambridge	138	12%	157	151	
Norfolk Broads High Scenario	1000	12%	1136	30	
Total reed biomass	1578		1793		
Total t.km	91,520				
Weighted average t.km / tonne	51				

Briquetting

The choice of briquetting machinery is dependent on throughput and storage capacity, which is also dependent on the availability of harvestable reed biomass. There is considerable uncertainty in the availability of accessible reed biomass (this may also be limited by the feasibility of storing

[4] Komulainen et al (2008). Reed energy - possibilities of using the common reed for energy generation in Southern Finland. Report 67. Turku University of Applied Sciences, Finland. 'Reed Strategy in Finland and Estonia' published as part of an EU Interreg IIIA programme.

required for passive drying at site reserves, through both aesthetic and practical reasons). The relative specific energy efficiency of a variety of briquetting machinery is show in Figure .

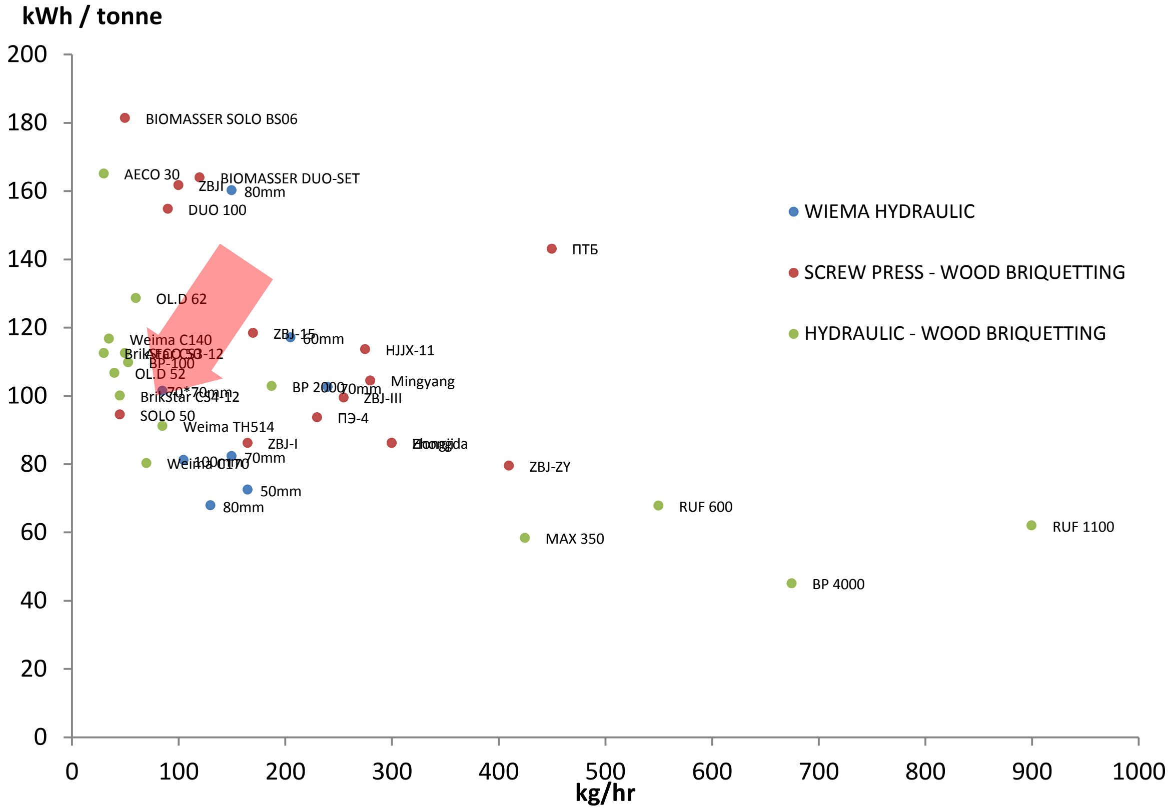


Figure 16 - Sizes of various briquetting machines throughput and reported specific energy per tonne of biomass briquetted (typically this is wood). The data is derived from nominal kW and source from sales literature provided by Fercell Ltd and also a review by Repsa et al (2012). The red arrow indicates the characteristics of the machine selected for reeds. Typical power demand data was obtained from Fercell Ltd.

Pre-treatment

Shredding of reeds is a prerequisite to briquetting and the estimates for shredding energy requirements were supplied by Fercell Ltd based on shredders manufactured in Germany by Wiema Gmbh. No losses are assumed in the assessment since most of the reception areas and transfer of biomass should be designed to be enclosed to prevent dust problems and allow efficient flow of process (using hoppers). Energy for conveyors/automatic feeds were included in the energy estimates supplied by Fercell Ltd.

Transporting briquettes to the UEA Gasifier

The UEA gasifier is currently burning 75mm by 50mm by 15mm woodchips supplied by articulated lorry at around 20 tonnes per load this is similar to the transport load scenario Table 24. Given that the size of woodchips will be similar to the reed briquettes, it can be assumed that the lorry will be transporting loose briquettes at maximum or close to maximum load of 19 tonnes per delivery given the relatively similar bulk densities of both fuels. Therefore the same t.km emission factor and energy in Table 23**Table 1** is used for transporting briquettes to from the processers to UEA.

Gasification

There are no formal performance data for the UEA gasifier since it is still in a commissioning phase. The assumptions on energy yields here are based on a mass balance model provided by Dr. Murat Dogru, from the Chemical & Process Engineering Department at the University of Newcastle[5]. This model, as received, gave an apparent lower efficiency and feed rate (4000 tpa) and higher char yield than outlined for the gasifier elsewhere in this report.

Considering the lack of alternative data, this model has been adapted by applying more appropriate char production and feed rate assumptions. The ash content and calorific parameters for Phragmites are applied to this mass balance model (Table 28). The values are taken from DIN standard measurements reported by Kitzler et al (2012) as part of combustion trials using winter harvested Phragmites and woodchips in a 3 MW district heating plant in Güssing, Austria[6].

Table 28 - Fuel parameters used as inputs in the gasifier mass balance model.

Fuel type	Fuel rate	Energy content MJ/kg_{LHV}	Ash w/w	Moisture w/w	Charcoal w/w
[a]Woodchips	1500	[a]16.72	[a]1.56%	[a]15%	[a]3%
Reed-High	1500	[b] 16.19	[b] 5.00%	[c] 10%	[d] 3%
Reed-Low	1500	[b] 15.79	[b] 7.50%	[c] 12%	[d]3%

[a] Data on woodchips used in the original gasifier mass balance for comparison, this also includes a fixed charcoal ('biochar') production rate of 3% of the input fuel as received. b. LHV measured using DIN standards. Data from Kitzler et al 2012[7]. c. Moisture is assumed to be as received from the briquetting plant in a high and low yield scenario. d. Biochar yields are assumed to be the same for gasified woodchip.

Table 29 - Mass balance model results and allocation of briquette fuel chain GHG emissions (using the RED methodology).

Fuel type	Fuel specific energy yield		Energy specific GHG emission from fuel chain		Feed rate
	Electricity yield MJ_{el}/ kg	Heat yield MJ_{th}/ kg	Electricity gCO_2eq/MJ_{el}	Heat gCO_2eq/MJ_{th}	kg/hr
Woodchips	5.3	8.2	n/a	n/a	1028
Reed-High	5.1	7.9	14.5	5.2	1070
Reed-Low	4.9	7.7	15.0	5.3	1103

[5] Dr. Dogru has been involved in commissioning UEA's gasifier as an expert consultant.
[6] Reed was comparable to good quality straw biomass, and performed well with up to 50% chips in the feedstock. However, during test runs with 100% reeds problems occurred with regards to the feed system. Recommendations were made to adapt the feed mechanism for light fibrous materials.
[7] Kitzler, H., Pfeifer,C., and Hofbauer, H. (2012). Combustion of Reeds in a 3 MW District Heating Plant. International Journal of Environmental Science and Development, Vol. 3, No. 4: pp407-411.

GHG and energy assessment for fen biomass harvested for anaerobic digestion

Counterfactual management scenario

For fen management, the counterfactual scenario is based on tractor cutting, baling and loading for transport to local farms for animal bedding and poor feed. The total fuel use for these operations per hectare and respective lower heating value of fuel energy (LHV) and GHG emissions for the counterfactual scenario are given below.

25.1	Litres diesel per ha
78.9	kgCO_2 e per ha
1,300	MJ_{LHV} per ha

No data were found on the typical moisture content and composition of fen biomass. The typical fresh weight yields were based on the number of bales removed per hectare given by the counterfactual case for fen management. Extrapolating bulk density typical for baled grass (700 kg m^{-3}) at 30% moisture this gives approximately 6 tonnes per hectare. This is similar to the 4.3 ODT per hectare given by the RSPB for dense rush.

Fen Harvesting

The assumptions made for the GHG and energy assessment of the proposed fen harvester and associated baling operations are given in Table 30.

Table 30 -2 Assumptions used to estimate fen biomass harvesting and baling energy and emissions

Harvesting		
Make/model	Deutz 4 Cylinder TCD 3.6 L4	
Specific fuel consumption	210	g/kWh
Nominal operating power	90	kW
Average operating power*	67.5	kW
Diesel density	835	g /litre @ 15°C
Typical harvester travel speed for fen	8	km/hr
Effective cutting width	1	m
Minimum time per Ha coverage - Fen	1.3	hr
Non-productive operational time	0.25	hr per Ha
Fen cutting time per Ha	1.50	hrs/Ha
Fen cutting gross engine energy demand	101	kWh/Ha
Fen cutting diesel use	25	litres/ Ha
Harvesting fen, energy	916	MJ_{LHV}/Ha
Harvesting fen, emissions	80	$kgCO_2$ e/Ha
Harvesting fen dense rush, energy	213	MJ_{LHV}/ODT
Harvesting fen dense rush, GHG	19	$kgCO_2$ e/ODT
Passive air drying	n/a	No energy demand
Baling Summer Fen (>70% Rush)		
kg per bale	700	(assumed fresh weight)
Moisture assumed	30%	
No. Of 1.4m^3 bales per ODT	2.0	
MJ per ODT baled	65	MJ_{LHV}
GHG per ODT baled	5.6	$kgCO_2eq$
Loading ODT into lorry. MJ	7.1	MJ_{LHV}
Loading ODT into lorry. GHG	0.6	$kgCO_2eq$
No. bales/ tonne Fresh weight	1.4	
MJ per fresh weight tonne baled	45.7	MJ_{LHV}
GHG per fresh weight tonne baled	7.2	$kgCO_2eq$
Loading fresh weight tonne into lorry. MJ	5.0	MJ_{LHV}
Loading fresh weight tonne into lorry. GHG	0.4	$kgCO_2eq$

Fen biomass transport to AD plants

Bulk density of Soft Rush and Fen grasses

There were no data for the bulk density of chopped fenland biomass such as mixtures of soft rush or grasses. A proxy bulk density of 70 kg m^{-3} for fresh chopped straw/Miscanthus was obtained from the FAO[8], and used instead.

Implications of baling on transport emissions

The assumptions made for haulage of baled and loose chopped fenland biomass show that the extra energy and emissions associated with baling biomass would break even with the emissions associated with transport emissions with biomass haulage distances greater than 25km (Figure 17 - Figure 17).

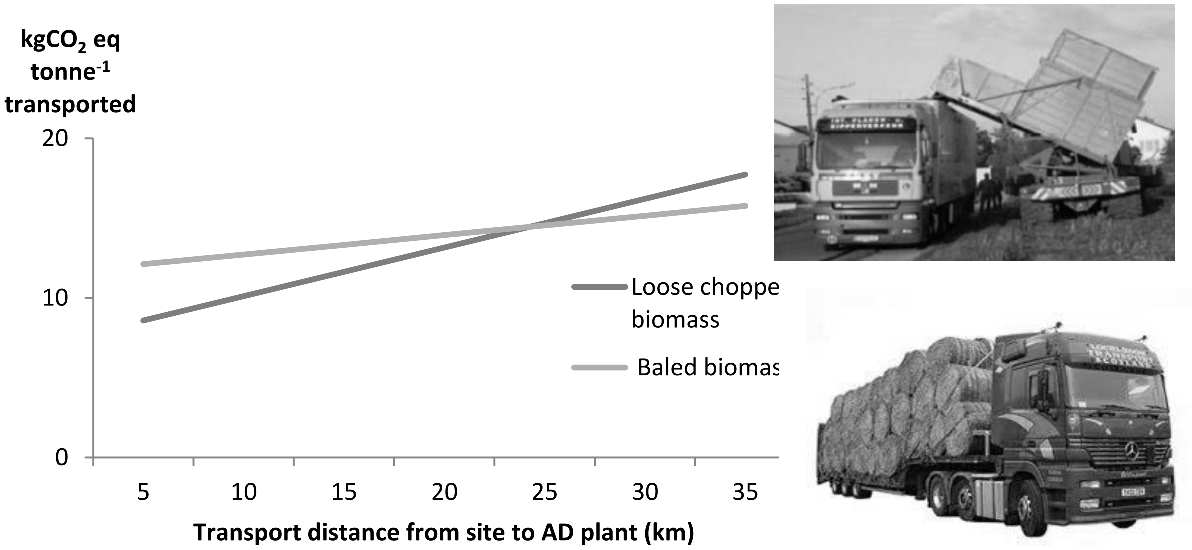


Figure 17 - GHG emissions modelled for haulage transport distances for a tonne of baled and loose chopped fen biomass, includes shredding of biomass at AD plant.

Graphing the data on bulk density to haulage volume and load limitations given in Table 23 and Table 24 indicates that, for distances greater than 25 km, loose chopped biomass transferred to a box-body semi–trailer would be more GHG and more fuel intensive than baling.

These are based on assumptions of empty loads for return journeys and emission factors supplied by DEFRA, which in turn are based on average fuel economy data compiled by the UK Department for Transport. However, these data may not be representative of the driving characteristics associated with rural biomass haulage. This does not factor in the requirement for additional demands for shredding bales compared to bulk loose biomass or operation of a tele-handler or forklift for transferring bales from the lorry to the biomass shredder at the AD plant. It is assumed

[8] Source: http://www.fao.org/docrep/007/j4504E/j4504e08.htm

this would be a minor energy and GHG burden. Further work would be necessary to substantiate this assessment in order to make any robust recommendations.

Table 31 - Site locations for fen biomass transport estimates. No yield data was given for fen biomass – the 6.0 tonne per hectare is a token estimate assuming similar density of silage bales density at 30% moisture is similar to the bales biomass removed from fen, based on the numbers given in the counterfactual scenario.

Time of harvest	Site	Management	Habitat type	Current annual harvest - ha	Indicative Annual Oven Drive Tonnes	Assumed harvest fresh tonnes/ha	Nearest AD Plant	Distance assumption km	t.km
Summer	Suffolk Coast	NE	Fen	10	No fig	6.0	Southwold	30	1785
Summer	Suffolk Coast	NE	Grazing marsh / fen	60	No fig	6.0	Southwold	30	10710
Summer	Great Fen	Wildlife Trust	Grazing marsh	150	No fig	6.0	Crowland, Peterborough	30	26775
Summer	Woodwalton Fen	NE	Grazing marsh / fen	15	No fig	6.0	Crowland, Peterborough	38	3392
Summer	Bure Marshes	NE	Fen	2	No fig	6.0	Taverham	30	357
Summer	Waveney Valley & the Suffolk Broads	Suffolk Wildlife Trust	Fen	30	No fig	6.0	Southwold	20	3570
Summer			Wet grassland - rush	90	387	6.0	Southwold	20	10710
Summer	Sutton Fen	RSPB	Fen	5	No fig	6.0	Taverham -	40	893
Summer	Nene Washes	RSPB	Wet grassland	100	285	6.0	Crowland, Peterborough	24	14280
Summer	Ouse Washes	RSPB	Wet grassland	100	140	6.0	Crowland, Peterborough	47	27965
					Average tonne.km per tonne	**30.036**			

AD plant assumptions

Most of the following documented assumptions and data inventory used to model the GHG and energy yield for a commercial mesophilic anaerobic digestion are taken directly from research presented by Poeschl et al[9,10] (2012, 2010). In addition it is assumed that fen biomass is mainly soft rush (as given in the counterfactual scenario), and this is chopped, at 30% moisture, to around 10-10mm lengths on arrival at the AD plant using a commercial 33kW electrically powered shredder.

Biogas yields from Fen soft rush and grasses

Mesophilic laboratory scale solid phase batch fermentation of ensiled soft rush, (*Juncus effusus* L.) indicates specific methane yields to be smaller than those from pure grass stands, but still within a range of common late-cut biomass[11] (Muller et al 2011). The experiment provides a very crude scaling factor for modelling commercial scale anaerobic digestion methane modelled by Poeschl (2012). A major caveat here is that ignoring technology differences between solid phase digestion and the more typical wet digestion modelled by Poechl is not a very robust approach, so the following assessment is only indicative at best, given the paucity of relevant data.

AD plant energy requirements

Following Poeschl et al 2010,2012 operating electrical demand is assumed to be 4% of the total electricity yielded from the CHP for smaller AD plants (<500 kW electricity) and 7.5% for larger plants (>500 kW electricity). For simplicity the parasitic electricity required by AD plant operation is assumed to be supplied by the national grid. The RED methodology requires an average emission factor for consumed electricity where this is supplied for plant operation, so a UK average supplied emission factor is used. Since there are unlikely to be externally generated heat supplies the heat demands from the digesters is assumed to directly consume the CHP heat generated. Again, following Poeschl et al (2010) 25% of CHP heat is assumed to be required by smaller AD plants (<500kWel) and 20% for larger plants (>500kWel). The AD CHP generation efficiencies are also taken from Poeschl et al 2010. It is noteworthy from Poeschls 2010 assessment that the thermal generation efficiency of large-scale units are typically lower than of small-scale units. This is reflected in the lower heat yields captured from the biogas of the larger modelled plant per tonne of the same feedstock digested (**Error! Reference source not found.**).

Digestate assumptions

Poeschl et al 2012 provide estimates of the dry matter of the digestate produced for individual feedstocks. The apparent loss of solids from the original feedstock reported by Poeschl et al (before dilution to 12% dm AD influent) to those given in the digestate differ between the different types of feedstock (Table). For example straw only loses approximately 5% of the dry matter content through digestion, yet appears to still yield considerable biogas per tonne. No information was found on the likely volatile solids, related dry matter losses of fenland biomass and the nutrient content of the resulting digestate. These will need to be determined empirically in further trials.

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[9] Poeschl,M., Ward.S, and Owende,P., (2012) Environmental impacts of biogas deployment e Part I: life cycle inventory for evaluation of production process emissions to air. Journal of Cleaner Production 24: pp168-183.

[10] Poeschl,M., Ward.S, and Owende,P., (2010) Evaluation of energy efficiency of various biogas production and utilization pathways. Applied Energy 87:pp 3305–3321.

[11] Müller J., Jantzen, C. and Kayser, M. (2011). The biogas potential of Juncus effusus L. using solid phase fermentation techniques.

Given the lack of existing data, 30% losses of dry matter is assumed. This is an educated guess for a substrate of 70% soft rushes on the basis that this is somewhere between the values Poeschl et al (2012) reported for grass and straw substrates (Table 32). The nutrient content of the digestate is assumed to be to that which Poeschl et al (2012) ascribe to digested grass. This assumption is not at all robust and, again, will require confirmation by empirical measurement.

Table 32 – DM content of crops used for AD and from the digestates produced from them.

Single feed stock	DM content of original feedstock (w/w) [a]	% DM digestate (per tonne original feedstock)[b]	Apparent % DM LOSS from original feedstock	Biogas energy (MJ) per tonne original feedstock[d]
straw	86%	81.6%	5%	5367
corn silage	35%	11.1%	68%	3763
grass silage	25%	9.0%	64%	2385
Fenland biomass assumption	**70%**[c]	**49%**	**30%**	**2968**[e]

[a,b,d] Data in these columns are taken from Poeschl et al 2012. [a]Assumed from DECC's counterfactual data.[e] This is derived from data on methane yield in a solid phase laboratory scale mesophilic reactor, applying the % difference in yield per dm between grass and soft rush to the yield for grass silage reported by Poeschl 2012 to obtain a yield for dense rush fenland biomass.

Table 33 -3 Digestate fertiliser substitution assumptions.

Single feed stock	Active fertiliser ingredients in digestate **kg t^{-1} dm**			GHG credit per tonne of feedstock as received
	N	P_2O_5	K_2O	$kgCO_2eq$
straw	5.8	1.8	12	35.05
corn silage	13.4	2.9	8.5	9.64
grass silage	20.8	9	36	13.73
Fenland biomass assumption	**20.8**	**9**	**36**	74.75

Data are taken from Poeschl et al 2012; Fenland biomass is assumed to yield, on a dry matter basis, digestate with the same nutrient content of digestate from grass reported by Poeschl et al 2012. GHG credits are taken from Biograce v4 for RED reporting, www.biograce.net. The fenland biomass credits differ from grass for due to the differences in dm content assumed for their digestate.

APPENDIX 3

Assumptions used for the Process Cost Analysis of the gasification route

Potential?	Hectares available of reed	360	ha
	(See "HectaresAvailable" worksheet)		
1. Harvest	Diesel cost	0.876	£/litre
	Diesel consumption (reed harvest)	34.00	litres/ha
	Harvesting labour	20	£/hr
	Reed cutting time per hectare	1.5	hours/ha
	Oven dried tonnes (ODT) per hectare	5.5	ODT/ha
	Baling cost on site @ 1L diesel per ODT	0.876	£/ODT
	Loading cost from harvester @ approx 0.5L diesel	0.44	£/ODT
	Cost of harvest step	**12.2**	**£/ODT**
2. Trans to processor	Average speed of lorry is	60	Km/Hr
	Haulage per hour incl fuel	72	£/hr
	Loading time	0.5	hrs
	Av. distance from wetland > processing (x2 for returi	120	km
	Assumed dry tonnage capacity	15	
	Cost of transport 1 step	**12.00**	**£/ODT**
3. Processing	Chopping, briquetting, labour and o/heads	85	£/tonne
	Cost to briquette one tonne	**85**	**£/ODT**
4. Trans to UEA	Average speed of lorry is	60	Km/Hr
	Haulage per hour incl fuel	72	£/hr
	Loading time	0.5	hrs
	Distance from NR14 to NR4	37	km
	Assumed dry tonnage capacity	25	
	Total transport cost	**3.22**	**£/ODT**
	Total cost per briquetted tonne	**112.4**	**£/ODT**
	Cost of woodchip is around	100	£/tonne

APPENDIX 4

Assumptions used for the Process Cost Analysis of the AD route

Potential?	Hectares available of fen	562	ha
	(See "HectaresAvailable" worksheet)		
1. Harvest	Diesel cost	0.876	£/litre
	Diesel consumption (reed harvest)	51.00	litres/ha
	Harvesting labour	20	£/hr
	Fen cutting time per hectare	2	hours/ha
	Oven dried tonnes (ODT) per hectare	3	ODT/ha
	Baling cost on site @ 1L diesel per ODT	0.876	£/ODT
	Loading cost from harvester @ approx 0.5L diesel	0.44	£/ODT
	Cost of harvest step	**29.5**	**£/ODT**
2. Trans to AD site	Average speed of lorry is	60	Km/Hr
	Haulage per hour incl fuel	72	£/hr
	Loading time	0.5	hrs
	Av. distance from wetland > processing (x2 for returi	120	km
	Assumed dry tonnage capacity	15	
	Cost of transport 1 step	**12.00**	**£/ODT**
3. AD	Forage shredding to 6mm step @ 2L diesel per ODT	1.752	£/ODT
	Waste disposal gate cost per ODT	41	£/ODT
	Total AD cost	**42.75**	**£/ODT**
	Total cost per tonne sent to AD	**84.3**	**£/ODT**

APPENDIX 5

Assumptions used for the Process Cost Analysis on hectares available

Site	Ownership / management responsibility	Habitat type	Current annual harvest area hectares	Indicative Annual Oven Drive Tonnes	Time of harvest
Suffolk Coast	NE	Fen	10	No fig	Summer
	NE	Grazing marsh / fen	60	No fig	Summer
Great Fen	Bedfordshire, Cambridgeshire & Northamptonshire Wildlife Trust	Grazing marsh	150	No fig	Summer
Woodwalton Fen	NE	Grazing marsh / fen	15	No fig	Summer
Bure Marshes	NE	Fen	2	No fig	Summer
Waveney Valley & the Suffolk Broads	Suffolk Wildlife Trust	Fen	30	No fig	Summer
	Suffolk Wildlife Trust	Wet grassland - rush	90	387	Summer
	Suffolk Wildlife Trust	Reedbed	5	27.5	Winter
Ouse Fen	RSPB	Reedbed	25	137.5	Winter
Sutton Fen	RSPB	Fen	5	No fig	Summer
Lakenheath	RSPB	Reedbed	40	220	Winter
Nene Washes	RSPB	Wet grassland	100	285	Summer
Minsmere	RSPB	Reedbed	40	220	Winter
Ouse Washes	RSPB	Wet grassland	100	140	Summer
The Norfolk Broads	Mixed	Reed / fen	250	1225	Winter
		Summer	**562**		
		Winter	**360**		
		Total	922		

APPENDIX 6

Revenue-based incentives available for renewable energy in the UK

Feed-in Tariffs (FITs)

Since April 2010, Feed-in Tariffs (FITs) have provided a guaranteed price for a fixed period to small-scale electricity generators. FITs are intended to encourage the provision of small-scale low carbon electricity. Only AD facilities with less than 5MW capacity, completed after 15 July 2009, are eligible for FITs. The Government offers preliminary accreditation for AD, with a guarantee that the project will be eligible for the tariff payable at the time of accreditation. Each tariff runs for 20 years.

There are two elements to the scheme; the generation tariff for every kWh of electricity generated, and the export tariff for every kWh of electricity exported to the national transmission network. The current generation tariffs for AD are as follows (from April 2013):

- Facilities of less than or equal to 250kWe are entitled to 15.16 p/kWh;
- Facilities of between 250 and 500kWe are entitled to 14.02 p/kWh;
- Facilities of between 500kWe and 5MWe are entitled to 9.24 p/kWh.

The export tariff is currently 4.64 p/kWh; a generator can claim either this or the market value payable by their electricity company. Tariffs are Retail Price Index (RPI) linked, see the Ofgem website for a table of annual RPI linked increases to FITs. From April 2014, there will be a baseline degression in tariff rates of 5% per year, which would accelerate or decelerate based on annual deployment numbers.

The Government announced in July 2012, that they will monitor the use of purpose grown crops; accepting they are important for co-digestion, but not ruling out limiting future FITs eligibility to plants treating waste, if voluntary measures to limit their use prove ineffective.

Renewable installations using “generating equipment” that has previously received support under the Renewables Obligation or Feed-in Tariff schemes are not entitled to receive support through the FIT scheme. Generating equipment is defined by Ofgem for the purposes of claiming FITs as "all equipment required to convert gas formed by the anaerobic digestion of material (which is neither sewage nor material in a landfill) into electricity". Ofgem go on to state that "we will view all engines, turbines and alternators (or any part thereof) of an eligible installation to be generating equipment. We will not consider any gas blowers, anaerobic digestion vessels, gas clean-up equipment and any associated pipe work to be generating equipment."

Renewables Obligation (RO)

The Renewables Obligation (RO) is the main support scheme for large-scale (>5MW) renewable electricity projects in the UK. A Renewables Obligation Certificate (ROC) is a green certificate issued to an accredited generator for eligible renewable electricity generated within the United Kingdom and supplied to customers within the United Kingdom by a licensed electricity supplier.

Anaerobic digestion is among the technologies that receive additional support in the form of multiple ROCs. An anaerobic digester will receive 2 ROCs/ MWh until April 2015, this will then fall in line with DECC estimations of costs to 1.9 ROCs/MWh in 2015/16 and 1.8 ROCs/MWh in 2016/17. The value of ROCs varies. Generators are accredited by The Office of Gas and Electricity Markets (OFGEM). All information including application forms and guidance notes can be found on the OFGEM website.

In 2014, the Feed-in Tariff Contracts for Difference (FIT CFD) will be introduced as part of the Electricity Market Reform and new generators will have the option to claim the RO or the new FIT CFD. After 2017 the RO will close to all new generators. For more information on the FIT CFD visit the DECC webpage on the forthcoming Electricity Market Reform.

ROCs or FITs?

- Schemes between 50kW and 5MW will get a one off choice between support under ROCs or FITs
- FITs offer fixed long-term security
- RO potentially higher returns but value of ROCs varies

Renewable Heat Incentive (RHI)

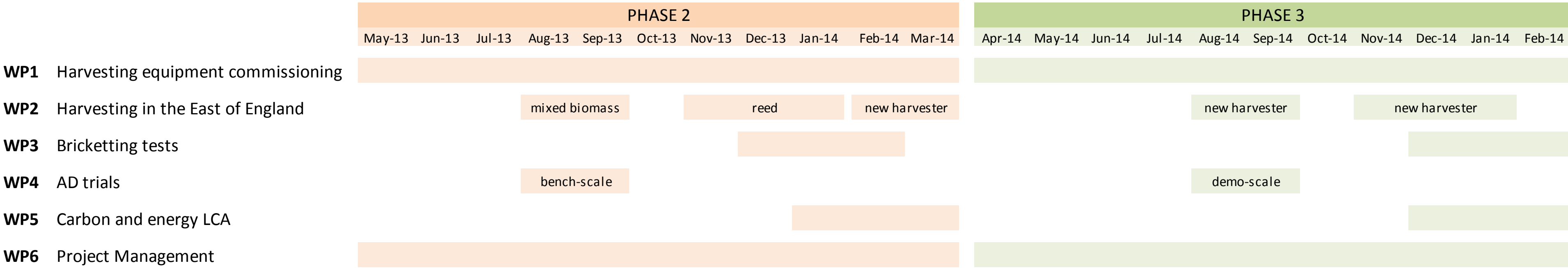
The RHI provides a fixed income (per kWh) to generators of renewable heat, and producers of renewable biogas and biomethane. AD facilities completed after 15 July 2009 are eligible for the RHI. The lifetime of the tariff is 20 years. The current RHI for AD (Phase 1) is as follows (from April 2012):

- Biogas combustion up to 200 kW scale receives 7.1 p/kWh;
- Biomethane injection to the grid receives 7.1 p/kWh;
- Useful information on how to apply for accreditation can be found on the Ofgem website.

Phase 2 of the RHI is expected to be introduced in the summer of 2013 following the UK Government consultation published in September 2012. Phase 2 of the RHI will support larger scale biogas combustion (above 200 kW). Details of the consultation can be found on the DECC pages on renewable heat along with all other information on the RHI.

Appendix 7

Gantt chart for Phases 2 and 3 of the project



Appendix 8

Invoicing plan for Phases 2 and 3 and deliverables

	PHASE 2						
Deliverable	Jun-13	Aug-13	Oct-13	Dec-13	Feb-14	Mar-14	PROJECT VALUE
Update report on harvester commissioning & construction	x						
Update report on summer harvesting at wetland sites		x					
Update report on AD bench-scale trials			x				
Update report on winter harvesting at wetland sites				x			
Update report on briquetting tests					x		
Phase 2 report						x	
Value of invoice (inc VAT)	82,265.30	70,028.90	81,215.30	73,502.90	37,352.90	20,698.45	365,063.75

	PHASE 3						
Deliverable	May-14	Jul-14	Sep-14	Nov-14	Jan-14	Feb-14	PROJECT VALUE
Update report on harvester modification and self-loading tracked dumper construction	x						
Update report on summer harvesting at wetland sites		x					
Update report on AD bench-scale trials			x				
Update report on winter harvesting at wetland sites				x			
Update report on Briquetting tests					x		
Phase 3 report						x	
Value of invoice (inc VAT)	93,529.00	66,025.00	53,345.00	14,481.00	29,462.00	11,369.00	268,211.00

Appendix 9

Detailed breakdown of costs for Phase 2

Breakdown of costs (inc VAT)	May-2013	Jun-2013	Jul-2013	Aug-2013	Sep-2013	Oct-2013	Nov-2013	Dec-2013	Jan-2013	Feb-2013	Mar-2013
Total labour cost	9,729.00	7,505.40	9,969.00	10,449.00	10,449.00	10,449.00	10,269.00	10,749.00	11,709.00	17,973.00	17,013.00
Capital costs of harvesting equipment											
Second hand track base unit with new tracks	36,000.00										
DEUTZ engine and cooling system		12,120.00									
Transmission gearbox		10,560.00									
Prop shaft and coupling			1,620.00								
PTO take off box			3,840.00								
Cooling systems cover dust extractor and fan			2,544.00								
Specialist hydro pump reversing			1,776.00								
Heating System and airconditioning					2,280.00						
Cab Controls cables switch gear					960.00						
GPS Trimble CFX-750 GPS								2,874.00			
Fuel and oil tanks				1,440.00							
Hydraulic pumps valve blocks				4,320.00							
Hydraulic pipe work				3,360.00							
Hydraulic bio oil					984.00						
Battery and cabling					480.00						
Cab air seat					3,360.00						
Cleanfix fan					1,440.00						
Safety cab parts					1,862.40						
Cutting head and storage bin						18,240.00					
Floor body unloader							18,240.00				
Reciprocating cutter head							24,000.00				
Steel, extras and sundries	665.45	665.45	665.45	665.45	665.45	665.45	665.45	665.45	665.45	665.45	665.45
Further development costs											
Subcontracting costs											
AD bench-scale trials				24,000.00	24,000.00						
AD demonstration trial											
Briquetting trials											
Specialist subcontracting labour	1,860.00	1,860.00	1,860.00	1,860.00	1,860.00	1,860.00	1,860.00	1,860.00	1,860.00	1,860.00	1,860.00
Field trials				660.00	660.00		660.00	660.00	660.00	660.00	660.00
Travel expenses	800.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	800.00	500.00	500.00
Other costs											
VALUE TO BE INVOICED TO DECC	49,054.45	33,210.85	22,774.45	47,254.45	49,500.85	31,714.45	56,194.45	17,308.45	15,694.45	21,658.45	20,698.45

TOTAL COST OF PHASE 2 (INC VAT)	**£365,063.75**

Appendix 10

Detailed breakdown of costs for Phase 3

Breakdown of costs (inc VAT)	Apr-2014	May-2014	Jun-2014	Jul-2014	Aug-2014	Sep-2014	Oct-2014	Nov-2014	Dec-2014	Jan-2015	Feb-2015
Total labour cost	2,145.00	804.00	2,145.00	-	6,573.00	5,052.00	3,825.00	5,856.00	8,157.00	15,285.00	9,429.00
Capital costs of harvesting equipment											
Second hand track base unit with new tracks											
DEUTZ engine and cooling system											
Transmission gearbox											
Prop shaft and coupling											
PTO take off box											
Cooling systems cover dust extractor and fan											
Specialist hydro pump reversing											
Heating System and airconditioning											
Cab Controls cables switch gear											
GPS Trimble CFX-750 GPS											
Fuel and oil tanks											
Hydraulic pumps valve blocks											
Hydraulic pipe work											
Hydraulic bio oil											
Battery and cabling											
Cab air seat											
Cleanfix fan											
Safety cab parts											
Cutting head and storage bin											
Floor body unloader											
Reciprocating cutter head											
Steel, extras and sundries											
Second-hand access tracked dumper	86,400.00										
Access crane and conversion			60,000.00								
Further development costs	1,440.00	1,440.00	1,440.00	1,440.00	1,440.00	1,440.00	1,440.00	1,440.00	1,440.00	1,440.00	1,440.00
Subcontracting costs											
AD bench-scale trials											
AD demonstration trial					18,000.00	18,000.00					
Briquetting trials											
Specialist subcontracting labour											
Field trials					920.00	920.00		920.00	920.00	920.00	
Travel expenses	800.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	800.00	500.00	500.00
Other costs											
VALUE TO BE INVOICED TO DECC	90,785.00	2,744.00	64,085.00	1,940.00	27,433.00	25,912.00	5,765.00	8,716.00	11,317.00	18,145.00	11,369.00

TOTAL COST OF PHASE 3 (INC VAT)	**£**	**268,211.00**

Appendix 11

Cost saving offered as a result of the risk-sharing approach to SBRI

		Costs calculated using the SBRI cost saving approach						Costs at full commercial rate for Adapt staff						SAVINGS
Organisation / staff	Role in the project	Discounted rate (exc VAT)	Phase 2 days	Phase 2 cost	Phase 3 days	Phase 3 cost	Total staff cost	Commercial rate (exc VAT)	Phase 2 days	Phase 2 cost	Phase 3 days	Phase 3 cost	Total staff cost	
Adapt Commercial														
Bianca Forte	Project management	£ 400.00	28.5	£ 11,400.00	18.5	£ 7,400.00	£ 18,800.00	£ 600.00	28.5	£ 17,100.00	18.5	£ 11,100.00	£ 28,200.00	£ 9,400.00
Pete Metcalfe	Carbon & energy analysis	£ 400.00	16.5	£ 6,600.00	16	£ 6,400.00	£ 13,000.00	£ 600.00	16.5	£ 9,900.00	16	£ 9,600.00	£ 19,500.00	£ 6,500.00
Richard Parker	Briquetting trials management	£ 400.00	40.5	£ 16,200.00	29.5	£ 11,800.00	£ 28,000.00	£ 600.00	40.5	£ 24,300.00	29.5	£ 17,700.00	£ 42,000.00	£ 14,000.00
Peter Frizzell Ltd														
Peter Frizzell	Harvesting manager	£ 335.00												
Stephen Eyles														
Stephen Eyles	Development engineering	£ 300.00												
Andigestion Ltd														
Edgar Blanco	AD trials management	£ 300.00												
													Total savings in labour costs (exc VAT) - SBRI approach	£ 29,900.00

IMPACT OF THE SBRI APPROACH ON PROJECT COSTS	Phase 2	Phase 3
Labour costs being charged	126,263.40	59,271.00
Capital expenditure being charged	159,620.35	162,240.00
Sub-contracts being charged	73,080.00	40,600.00
Travel & subsistence being charged	6,100.00	6,100.00
Other costs being charged	-	-
Total value of project being charged (inc VAT)	**£ 365,063.75**	**£ 268,211.00**
Additional cost that would have been incurred per phase if commercial rates for Adat staff had been applied	£ 17,100.00	£ 12,800.00
Total project cost per phase should the cost savings approach of SBRI not been applied (inc VAT)	**£ 385,583.75**	**£ 283,571.00**

DEPARTMENT OF ENERGY & CLIMATE CHANGE

Application Form

Applicants are urged to read the Guidance Notes at the beginning of this document carefully before completing this form and are asked to ensure that they provide sufficient information to demonstrate compliance with the Evaluation Criteria, referring to the Phase 1 report where appropriate.

Section 1 – Full Scale Technology Assessment

1.1 Detailed description of end to end process	Weighting – 10%

Please provide a detailed description of the process from harvesting to energy production paying particular attention to practical considerations including issues such as:

- Physical access to the selected site for equipment and movement of material, please include weight, ground pressure and size of machinery.
- Cutting and collection methods. Please include machinery specifications.
- The form in which harvested material is to be collected and transported to the site boundary or off site.
- Methods and distances of transportation, for equipment to the site and biomass off of the site.
- Any storage requirements for the harvested / processed material or equipment, for example the area of any dedicated storage required, any associated resources, and the timescales for these requirements.
- On site processing requirements.
- Utilisation of energy from processed material, for example identification of the end user, infrastructure required and the location of the final conversion system.

The description should also consider:

- Projected energy yields from different vegetation types.
- Production and treatment of any waste material / bi-products.
- Potential use of bi-products.
- Any inputs required by the process e.g. chemicals, power.
- Any re-cycling aspects.

1.1 Detailed description of end to end process — Weighting – 10%

- Identifying losses, inefficiencies and emissions.
- Predicted bioenergy conversion efficiencies.
- Measures to improve efficiency.

Please limit your response to 1000 words and refer to Phase 1 report as appropriate.

As there are no machines available in the UK with capabilities of cutting and collecting mixed fen and reedbeds on large scale, we have designed a multi-functional system. The base unit for the harvester will be a conversion of a second-hand tracked dumper. The linkage system will be designed for attachment of other conventional agricultural and forestry equipment. The maximum width of the machine will be sufficiently narrow to allow through 3.0m gate and transport on low loader without the haulage of wide loads.

The technical specifications of the new harvester are given in Table 1. For a detailed description of the machine, see Section 1.1.1 of the Phase 1 Report.

Table 1 - Summary specification of the multi-functional harvester.

Track width*	600 mm
Track type	Rubber
Gross weight*	10,400 kg
Carrying capacity *	4,300 kg
Ground pressure laden*	0.27 kg cm^{-2}
Width*	2,310 mm
Overall length*	4,430 mm
Wheelbase	3,130 mm
Ground clearance	470 mm
Engine type	Deutz TCD 3.6 L4
Engine size	120 HP

Reed harvesting and gasification

The harvester will be hauled to the wetland site using a tractor towed low loader trailer. Reed will be cut and bundled in a single pass and the harvesting pattern will be determined by the limitations of the site. The cutter head for harvesting winter reeds will be based upon a mower binder which utilizes a single reciprocating cutter bar, which will be 1.4m wide with a binding height of 280mm. The bundles of reed will be transported either directly on the harvester to a suitable collection point for road haulage or on a tracked carrier.

The bundles of reed will then be transported to FuelSell Ltd, in Norwich, the current suppliers of woodchips for the University of East Anglia (UEA)'s Biomass Gasification Combined Cooling, Heat and Power (CCHP) Plant. At FuelSell the reed will be stored to allow air drying to 12% moisture content, and then shredded to 10mm particle sizes to produce briquettes using a Weima machine.

The UEA Biomass Gasifier uses 1.4 tonnes of woodchip per hour. This produces 3,200m^3 of syngas, which is fuel for a gas engine providing 1.5MWe. By-product heat from the engine (2.5MWth) is used to heat buildings on campus via a district heating main. When heat is not required, the hot water is converted into chilled water by

1.1 Detailed description of end to end process   Weighting – 10%

an absorption chiller device. The overall efficiency of the plant is 85%, double that of a typical power station.

Approximately 1,830 oven dried tonnes (OVT) of reed are harvested in the East of England per year. This would be about 2,100 tonnes at 15-20% moisture content and would represent about 20-25% of the annual input of biomass fuel into the UEA Biomass Gasifier. The reed briquettes would need to be supplied at a cost competitive with that of woodchips and within the permitting constraints under which the gasifier operates.

In addition to producing cooling, heat and power, the UEA Biomass Gasifier converts around 8-12% of its annual feedstock intake into char, a carbon-rich material with potential to improve water and nutrient retention in soils and support microbial and plant growth. Char also provides opportunities for carbon sequestration: 40-60% of the carbon in the material is available in a recalcitrant form, resisting degradation for 100-1,000 years.

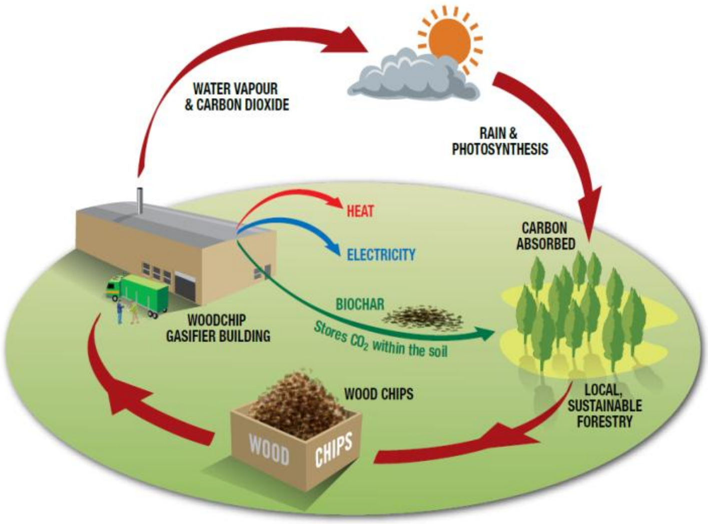


Figure 1 - Inputs and outputs of the UEA Biomass Gasification CCHP Plant.

There is increasing demand for char in the horticultural sector in the UK. Currently, the char produced by the UEA Biomass Gasifier is classed as a 'waste' by the Environment Agency, and thus is subject to end of life regulations. The UEA has made progress in obtaining permission to carry out trials to demonstrate its safety and suitability as a soil improver and it is looking to develop routes to market for the material.

Harvesting and digesting mixed wetland biomass

Approximately 812 to 2,037 OVT of mixed wetland biomass is harvested in the East of England in the summer every year. Fen and mixed fen will be cut in a single pass. The cutter head will be based upon a single cutting disc of 1.2m in diameter. A collecting system will be located to the side of the disc to transfer the cut material to a conveyor, which will have adjustable fixed knives to cut the material, before passing into a collection bin on the rear of the harvester. The material will be chopped to between 70-140mm in length.

To increase the carrying capacity of the vehicle, the sides of the collection bin will open hydraulically. This will increase the volume whilst harvesting but keep the vehicle to a minimum width for transport. The carrying capacity of the harvester will be a minimum 12m^3. The cut material will be transported either directly on the harvester to a suitable collection point for road haulage or on a tracked carrier depending on site constraints.

As the material harvested in summer is 'wet', we propose to use it as a feedstock for anaerobic digestion (AD), a biological process in which biogas and digestate is produced. Biogas, a mixture of methane, carbon dioxide and other gases, can be used directly in engines for Combined Heat and Power or burned to produce heat or be upgraded and injected into the grid or used as vehicle fuel (Figure 2).

1.1 Detailed description of end to end process Weighting – 10%

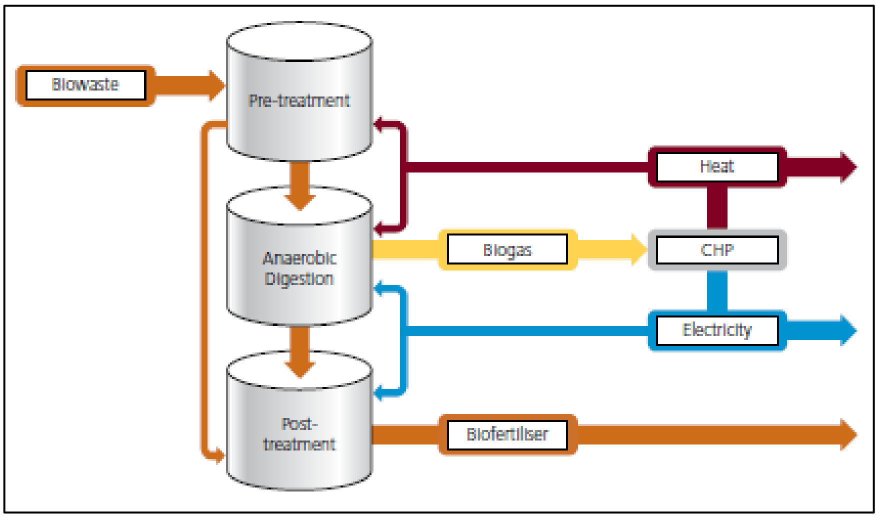


Figure 2 – Schematic of the AD process.

Given the relatively small volumes of biomass available, and the short harvesting season, the biomass will be co-digestate with other feedstocks on existing AD plants. Little data is available on the potential biogas yields from mixed wetland biomass, but preliminary studies with reed by academic groups indicate good potential.

Two plants located in Norfolk have been approached as case studies and potential end-users for the biomass:

- Arnold Renewables Ltd, run by Future Biogas: Located at Taverham, west of Norwich, this 1.4MWe plant takes around 25,000 tonnes per annum of maize as feedstock.
- J F Temple & Son Ltd: Located in Wells-Next-The-Sea, on the North Norfolk coast, this 140-170kwe plant takes a daily input of dairy cattle slurry, cheese whey and grown crops 16 tonne.

Both plants above use the biogas to generate electricity to the grid.

1.2 Regulatory requirements Weighting – 5%

Please identify and address any permissions needed for the full scale technology and the demonstration. Specifically, but not exclusively, consideration should be given to the following:

- Requirements of the Environment Agency with regards to classification and handling of waste, and working within close proximity to watercourses.
- Any requirement by Natural England in relation to designated sites such Special Protection Areas and Sites of Special Scientific Interest.

Please limit your response to 200 words and refer to the Phase 1 report as appropriate.

If a designated wetland site has areas to be cut and collected within its management plan, then it is likely that this has been agreed with Natural England (NE). If NE consent for the activity has not already been obtained, the consent will be applied for by Peter Frizzell Ltd.

An important aspect that would affect the commercial viability of this project is whether the biomass is deemed as a waste by the Environment Agency (EA). The UEA Biomass Gasification Plant is already operational

1.2 Regulatory requirements — Weighting – 5%

with all of the necessary licences and permissions in place. It is not permitted to take any waste materials. Were the reed material to be classified as a waste, then special derogation from the permitting authority would be required to use it as a fuel in the process.

If the mixed wetland biomass was classified as a waste, then only AD plants with a permit to process waste would be able to accept the material. That is not the case with Arnold Renewables Ltd and J F Temple & Son Ltd, so a special permit would need to be obtained. Alternatively, we have opened a dialogue with Adnams Bioenergy, in Suffolk, who process food waste.

Given the total tonnes available of wetland arisings and the biodiversity benefits of adequate management, it is hoped that discussions with the EA can result in the biomass not being deemed a waste, as this will have negative consequences for any projects looking to utilise the biomass off-site for energy production.

1.3 Detailed mass and energy balances of the proposed process — Weighting – 10%

Please provide detailed mass and energy balances of the proposed process using a clearly labelled engineering Process Flow Diagram.

Please limit your response to 300 words and refer to the Phase 1 report as appropriate.

Please refer to Appendix 1 in the main report for an overview of the mass and energy balances of the processes.

1.4 Carbon and energy life cycle assessment (LCA) — Weighting – 10%

Please detail the carbon and energy LCA of the entire process at full scale, starting from the point of harvest of the biomass to the final delivery of the energy. The LCA should include, but not be limited to:

- All transport and haulage - from the movement of equipment to the transportation of materials and wastes (e.g. fuel usage, manufacture of transport equipment).
- Cutting and collecting (e.g. fuel usage, manufacture of harvest equipment)..
- Storage of material.
- Processing and conversion (e.g. materials and energy inputs, manufacture of equipment).
- End system operation (e.g. emissions from combustion etc.).
- Disposal of any wastes produced in the process.

1.4 Carbon and energy life cycle assessment (LCA)	Weighting – 10%
LCA should follow the PAS 2050 standard and include the reference systems described in the report guidance. Any deviation from this process **will not be considered for assessment**. Please limit your response to 300 words, referring to the Phase 1 report as appropriate	
The analysis of the energy and GHG balances of using wetland biomass harvested in the East of England as a feedstock for AD indicate clear net benefits. The energy and GHG balances of using reed harvested in the East of England as a feedstock for the UEA Biomass Gasifier, on the other hand, are not positive.	

1.5 Emissions	Weighting – 5%
Please illustrate how you have considered and assessed the likely emissions arising from the range of different feedstocks during the energy generation process. Guidance on acceptable emissions can be found in Annex A of DECCs Renewable Heat Incentive publication. Emissions may include particulate matter and NOx. This section should also consider: • Measures that could be employed with the chosen technology to counteract emissions if required. • Evidence that all emission types have been considered. • Consultation with local councils regarding site-specific air quality requirements for the process. This consultation should consider one rural and one urban location. • The long term impact of burning these feedstocks in conventional boilers, and measures / adaptions that can be made to counteract such impact. Please limit your response to 300 words, referring to the Phase 1 report as appropriate.	
The UEA gasification plant has to conform to all of the emission limits stated in its licence to operate. Given the similarities between wood and reed as a biomass fuel it is not envisaged that the use of reed material, which would be equivalent to around 20-25% of the annual load, would cause any issues leading to the breach of the operating licence. The water clean-up system removes many of the particulates and other contaminants within the syngas stream. Any particulates that pass through are removed by the wet electrostatic precipitator, designed specifically for the removal of micro-particles. A final fabric filter is applied to ensure the gas is clean enough for the engine, which does not tolerate particulates.	

1.6 Process cost analysis — Weighting – 5%

Please provide process cost analysis for the **full scale technology**, this should include analysis of:

1. A discounted cash flow analysis of the full-scale project over its lifetime, accounting for the capital costs, revenues and operating costs (e.g. labour, consumables, waste disposal, overheads, sub contracts, maintenance etc.).
2. The cost of energy (e.g. £/MWh, £/MJ) associated with the technology solution and how this compares to other forms of energy.
3. The rate of return on investment.

Please limit your response to 200 words, using appropriate tables, and referring to the Phase 1 report as appropriate.

Considering AD as a standalone project, if the wetland biomass harvested in summer can be sold for AD for more than £54, then a positive return could be achieved, recovering the harvester cost. Given the lack of data on the potential biogas yields from mixed wetland biomass, we have been unable to calculate the cost of energy for the AD route. Our sensitivity analysis indicates that if the biomass is classified as waste, then instead of receiving a price for sales, a gate fee would have to be paid. This would give a discounted return on the project of -£1.7M (negative), or a Rate of Return of -855%.

As a standalone gasifier project a positive return could be achieved over the ten years only if the sales value for the briquettes is greater than the processing costs by more than £35. At present the briquetting costs undermine the viability of this option, which must compete with the price point of woodchip which is around £100/tonne. An alternative way of improving the financial viability of this supply chain is to explore the market for premium-priced biomass briquettes in the domestic market. The cost of energy as shown on Table 2 below illustrates that reed briquettes could compete very effectively with straw logs in this market.

Table 2 – Cost of energy production.

	MJ/kg	kWh/kg	kWh	£/ODT	£/kWh	£/MJ
Straws (www.straws.co.uk)	17.6	4.88	618	1136	0.23	0.84
Kiln-dried logs	14.4	4.00	600	1000	0.25	0.90
Reed briquettes	16.2	4.50	4500	150	0.03	0.12
Woodchip (bulk for gasifier)	18.2	5.05	5050	100	0.02	0.07

1.7 Exploitation	Weighting – 5%

Please give details of with how the final system will be used and marketed. Showing consideration of:

- Protection and use of any IP generated during the course of the project
- Agreements with the land managers for harvesting and collection of biomass (and other aspects e.g. storage and processing if relevant).
- Negotiations and agreements with end users of the bioenergy.
- Commercialisation plans and market potential, including any requirement for future development work.
- Scalability and adaptability to different land types, including networks of remote sites.

Please limit your response to 300 words, referring to the Phase 1 report where appropriate.

Phases 3 trials with the new multi-purpose harvesting system will inform how we approach IP protection. If commercially attractive, we will seek to protect IP.

Peter Frizzell Ltd have existing clients who would benefit from the developed system. 'Statements of intent' have already been put in place with three site managers for Phases 2 and 3. For future operation of the harvester on nature conservation sites, the price would not include the capital cost of the machinery. It would be based upon labour, operating costs including fuel, insurance and haulage and a percentage to cover breakdowns and further development of the machine. The base unit of the harvester is intended to be flexible and will be designed to allow other attachments to be fitted on the linkage system.

As our financial analysis has indicated that the production of reed briquettes for the UEA Biomass Gasifier is not an attractive commercial model, we will focus our efforts on developing higher value applications for the reed. Product development in Phases 2 and 3 will be supported by Fercell Ltd, UK suppliers of briquetting equipment. FuelSell Ltd would be our preferred partner for full commercial deployment of the reed briquetting project, though others will be approached in Phases 2 and 3.

There are around 40 agriculturally-based AD plants in England and NI. The smaller AD plants of around 100kwe require around 8,000 tonnes of feedstock per annum, while the 1.5MWe plants require 25,000 tonnes of feedstock. Should the results from our AD trials in Phases 2 and 3 be successful, and provided that positive outcomes are achieved with the EA on the classification of wetland biomass as a non-waste material, the wetland biomass harvested in summer could be sold as an 'energy crop' for AD.

Section 2 – Project plans for Phase 2 and Phase 3 development and trials

2.1 Project Plan — Weighting – 20%

Please provide a detailed project plan, with each aspect of Phase 2 and 3 divided into tasks with associated timings, costs, risks and deliverables.

The project plan should include details of the Phase 2 and 3 demonstrations, including the sites to be used for demonstration purposes, together with the following information:

- Habitat types to be harvested.
- Access requirements.
- Time of year for harvesting.
- Composition of material to be harvested.
- Methods and expected timescale of harvesting.
- Methods and expected timescale for the removal of harvested material.
- Amount of material to be harvested and size of area required.
- If storage is needed and if so, for what, how much and for what time period.

Please limit your response to 800 words, referring to the Phase 1 report as appropriate.

Work Package 1 – Harvester commissioning and construction

Harvester construction and development will take place from May 2013 to February 2014, with adjustments being made during Phase 3, following the harvesting trials in summer and winter 2014. Development of the self-loading tracked dumper for haulage will commence in April 2014.

Work Package 2 – Harvesting trials

The biomass required for the Phase 2 bench-scale AD trials and briquetting trials will be harvested by alternative method in summer 2013 and early winter 2013/2014. In summer 2014 and winter 2014/2015 we will carry out field trials with the new harvester and use the machine to produce mixed wetland biomass for the AD demonstration trial in summer 2014.

Summer harvesting trials will take place on fen, mixed fen and grazing marsh. Table 3 describes the methodology to be adopted in the summer harvesting trials in Phases 2 and 3. In Phase 2 a range of biomass samples will be obtained from routine mowing of sites managed by the Little Ouse Headwaters Project. If alternative sites are required, Norfolk Wildlife Trust has indicated interest in providing trial sites.

2.1 Project Plan Weighting – 20%

Table 3 - Overview of methodology for harvesting mixed wetland biomass in Phases 2 and 3. Habitat type: Fen and grazing marsh.

Aspect	Phase 2	Phase 3
Access requirements	Only limited access is required and material may be cut using brushcutters or mowers.	A minimum 3.0m wide access will be required to the areas to be harvested. Ideally there will be an area to unload the machinery and load the cut material for road haulage.
Time of harvesting	August, September 2013.	August, September 2014.
Composition of material	A range of material from different fen types can be provided including: mixed fen consisting of sedges, rush, reed and grasses; *Cladium*; and rush.	A similar range of material can be harvested to Phase 2.
Methods and expected timescale of harvesting	Samples harvested using brushcutters and reciprocating mowers. Drier grazing marsh rush areas can be flail collected if required.	Harvesting will be carried out using the developed tracked machine.
Methods and expected timescale for removal of harvested material	Removal of cut material will be immediate.	As soon as practically possible after harvesting.
Amount of material to be harvested and size of area required	Small areas are only required as the aim of the harvesting here is to provide samples for bench-scale AD tests.	A sufficient area will be harvested to demonstrate how the harvester works and to determine the rate of harvesting. The size of area and amount of material to be harvested will be determined in Phase 2.
Storage requirements	None required.	None required. The biomass will be chopped by the new harvester and delivered fresh to the AD plant which will shred it further before using it.

Winter harvesting trials will take place on reedbeds. Table 4 (on the next page) describes the methodology to be adopted with the winter harvesting trials. It is intended that reed samples for the briquetting trials in Phase 2 will be collected from RSPB Lakenheath Fen reserve.

The sites for Phase 3 trials will be selected during Phase 2.

Work Package 3 - Briquetting tests

Preliminary trials carried out in Phase 1 indicate that reed can be a suitable feedstock for producing briquettes. In Phases 2 and 3 we will optimise the manufacturing process and the quality of the fuel for the domestic market. These tests will be carried out at the Fercell R&D facility in Kent.

2.1 Project Plan Weighting – 20%

Table 4 - Overview of methodology for harvesting reed in Phases 2 and 3. Habitat type: reedbeds.

Aspect	Phase 2	Phase 3
Access requirements	A minimum 3.0m wide access will be required to the areas to be harvested. Ideally there will be an area to unload the machinery and load the cut material for road haulage.	A minimum 3.0m wide access will be required to the areas to be harvested. Ideally there will be an area to unload the machinery and load the cut material for road haulage.
Time of harvesting	November, December and January to provide samples for the briquetting trials, and late February or early March for demonstration of harvester.	October through to January
Composition of material	Reed	Reed
Methods and expected timescale of harvesting	May require pedestrian mower bundler to provide samples early in harvesting season for briquetting trials. Harvester trials will be late in season for a short period of time determined by completion of fabrication and limited by the beginning of bird breeding restrictions.	Harvesting will be carried out using the developed tracked machine.
Methods and expected timescale for removal of harvested material	As soon as practically possible after harvesting.	As soon as practically possible after harvesting.
Amount of material to be harvested and size of area required	Small areas are only required.	A sufficient area will be harvested to demonstrate how the harvester works and to determine the rate of harvesting.
Storage requirements	None required.	None required.

Work Package 4 - AD bench-scale trials

Academic studies indicate that the biogas yield from reed can be almost double that of cattle manure and close to that of food waste. The key objective for Phase 2 is to determine the potential biogas yields from mixed wetland biomass. A two-month bench-scale trial with six reactors will be carried out at the Andigestion AD R&D Facility in Cambridgeshire. Mixed wetland biomass harvested in summer and co-feeds of the biomass with cattle manure, energy crops and food waste will be tested. Yields will be measured from both batch and continuous experiments. Standard analyses of biogas yields, volatile solids, dry solids, pH, fatty acids, nitrogen and ammonia and digestate safety will be carried out. The cost for this will be £40,000 + VAT.

Provided that results from Phase 2 are encouraging, in Phase 3 we will move on to a demonstration-scale trial at a location to be determined. Arnold Renewables Ltd and J F Temple & Son Ltd have shown initial interest.

Work Package 5 – Carbon and energy LCA

Primary data collected on: fuel consumption of the harvester; fuel consumption associated with transporting

2.1 Project Plan — Weighting – 20%

the wetland biomass from conservation sites to the processing plants; moisture content of the biomass; energy consumption associated with chopping the biomass at the briquetting and AD sites; and biogas yields from the bench-scale AD trials; will be used to refine the carbon and energy LCA.

Work Package 6 - Project management

Partner meetings will be hosted every month, to enable the findings from each Work Packages to be discussed by the group, with the view to identify potential impact on the progress of the project and introduce mitigation measures to address any challenges. In addition, Adapt Commercial, who will act as Project Manager on behalf of the group, will circulate progress updates on a monthly basis to partners. Adapt will coordinate and be responsible for the reporting to DECC on the deliverables associated with each payment as per the schedule available on Appendix 8.

2.2 Cost Breakdown — Weighting – 10%

This section should clearly demonstrate how the **costs for each task** have been derived. Costs should be classified according to type e.g. capital expenditure, equipment hire, labour, travel and subsistence, sub-contracts, other costs (including overheads).

Please include an invoicing plan.

The cost breakdown must clearly indicate the cost saving offered as a result of the risk-benefit sharing approach to SBRI. This cost saving should be informed from negotiations with DECC.

Please limit your response to 200 words and refer to the Phase 1 report where appropriate.

The total cost for Phase 2 has been calculated at **£365,063.75** (inc VAT) and the cost for Phase 3 at **£268,211.00** inc VAT. Table 20 and Appendix 9 and 10 in the main report show the breakdown of costs.

DECC has valued the potential for IP from the project at £16,000. Adapt Commercial is applying a discounted daily rate of £400, as opposed to its typical of £600, to deliver savings of £21,600 in Phase 2 and £15,600 in Phase 3 of the project. Appendix 11 provides more information on these savings.

In addition, for future commercial operation of the harvester on nature conservation sites, the price would not include the capital cost of the machinery. The cost would be based upon labour, operating costs including fuel, insurance and haulage and a percentage to cover breakdowns and further development of the machine.

In order for Peter Frizzell Ltd, the subcontractors responsible for the design, commissioning and construction of the new harvesting system, to be able to finance the construction of the harvester, invoices will need to be submitted to DECC every two months for labour and parts costs. An invoicing plan in given in Appendix 8.

2.3 Deliverables — Weighting – 5%

Please provide a list of deliverables for Phases 2 and Phase 3 that is linked to the invoicing schedule in section 2.2. The minimum requirement for deliverables is:

Phase 2:

1. An on-site demonstration of the technology at agreed sites.

2. An evidence-based report detailing the development of the system, including lessons learned, and a trials report detailing the output of preliminary trials of the system on the key wetland sites.

Phase 3

1. Second on-site demonstration of the technology at agreed sites.

2. An extended report detailing the output of these further trials, and refinements made to the system. This report needs to detail the key successes and lessons learned from the development and trials, clearly explaining any deviances from the original system design. It should also provide a roadmap for further development and commercial exploitation. A finalised LCA using the trial data will be produced.

Please limit your response to 400 words and refer to the Phase 1 report as appropriate.

An invoicing schedule, linked to the deliverables for Phases 2 and 3, is presented in Section 2.2.

The Phase 2 report will detail: the design of the harvesting system and lessons learned from preliminary trials in reedbeds in the winter 2013/2014; the results from the bench-scale AD trials on the potential biogas yields from mixed wetland biomass and on the briquetting trials with harvested in the winter; and an updated LCA on the carbon and energy benefits of the system.

The Phase 3 report will detail: the key successes and lessons learned from the development of the harvester and trials in summer and winter, clearly explaining any deviances from the original system design; the output from the demonstration-scale AD trial with mixed wetland biomass; the key findings from the briquetting trials, including lessons learned; and a final LCA using the trial data collected in Phases 1, 2 and 3; and a roadmap for commercial exploitation.

2.4 Key Risks and Mitigation — Weighting – 15%

Please detail the risks associated with the project and the full scale technology. You should illustrate the likelihood and impact of the risk arising and how you intend to mitigate the risk. Risks should be classified into type and may fall into the following categories: technical; programme; environmental; permissions/regulatory requirements; budget/resource; and market/commercial. Please limit your response to 200 words, and refer to the Phase 1 report as appropriate.

2.4 Key Risks and Mitigation — Weighting – 15%

Type of risk	Likelihood	Impact	Mitigation
Technical			
Design failure for base unit	Low	High	Previous experience
Design failure of cutting head	Medium	High	Previous experience of fen cutting, engineering capability to develop cutter
Design failure of conveyor and collection system	Low	High	Previous experience of fen cutting, engineering capability to develop system
Presentation of material incorrect	Medium	High	Prior knowledge of end use requirements and post-harvest processing
Programme			
Completion of harvester construction	Low	High	Planning
Site selection incorrection	Low	High	Sites will be chosen carefully
Sites unavailable at time of trial	Low	High	Flooding, bird breeding planning and site selection
Environmental			
Fuel leaks	Low	High	Spill kits and good maintenance, bundled fuel tanks, controls during refuelling
Hydraulic leak	Medium	Medium	Bio oil and spill kits
Machine stuck	High	Low	Knowledge of sites
Permissions and regulatory requirements			
EA consent issues	Medium	High	It is assumed that most sites on management will have consent. If not, the group will apply for it.
NE consent issues	Low	High	It is assumed that most sites on management will have consent. If not, the group will apply for it.
Budgets and resources			
Lack of funding	Medium	High	Invoice planning
Harvesting labour	Low	High	Use of known contractors.
Market and commercial			
Biomass availability	Low	High	It is believed that sufficient biomass is available to support trials at bench- and demonstration-scale.

Scoring Method

Each question will be scored from 0 to 5. The following illustrates the meaning of each score:

Score	Description
0	**Unacceptable:** Proposal does not meet the requirement. Does not comply and/or little or no evidence to support the response.
1	**Serious reservations:** Proposal significantly fails to meet the requirement with major reservations.
2	**Minor reservations:** Proposal satisfies the requirement with minor reservations.
3	**Satisfactory:** Proposal satisfies the requirement.
4	**Above Satisfactory:** Proposal satisfies all requirements and exceeds some requirements.
5	**Excellent:** Proposal meets the requirement and exceeds most of the major requirements. Evidence identifies factors that will offer significant added value and/or innovative solutions.

Declaration

This declaration should be signed by a senior representative of the Lead Applicant. Only the single hard copy that will be submitted to DECC needs to be signed; for electronic copies please fill in the name, address and position of the signee but there is no need to include an electronic signature.

In signing this declaration, the lead applicant confirms that all information contained in the application is up to date and correct to the applicant's best knowledge.

The applicant must inform DECC if the applicant later realises that any of the information is incorrect, becomes out of date or is otherwise misleading. The applicant may not make any changes to their proposal after submitting their application.

I, Bianca Forte signing on behalf of Adapt Commercial Ltd (Lead applicant)

Certify that all information in this application form and associated attachments is correct. I will inform DECC if any of the information is incorrect, becomes out-of-date or is otherwise misleading, using the contact details provided in the guidance notes.

Name, address and position:

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