Wetland Biomass to Bioenergy

Phase 1: Design and Analysis of an innovative Mechanical Process to create high value thermal products from wetland biomass – *'Project DAMP'*

Department of Environmental Science and Technology

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Financial and commercially sensitive parts of the report have been redacted

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Full Scale Technology Assessment

1 Structure of report

The aim of this report is to examine the potential of using a mobile mechanical process (the VMPress and briquetting with interim baling option) to achieve the environmentally benign, financially viable, and energy efficient production of a heating fuel from wetland biomass. The report is structured into nine sections. The first eight sections describe the proposed system. The ninth section describes the project plans for the Phase 2 and 3 development and trials.

2 Detailed description of the end to end process

The full end-to-end process is shown in Fig 1. Each of these processes will be discussed in detail in the following sub-sections. The process has also been described a process flow diagram (Fig 2).

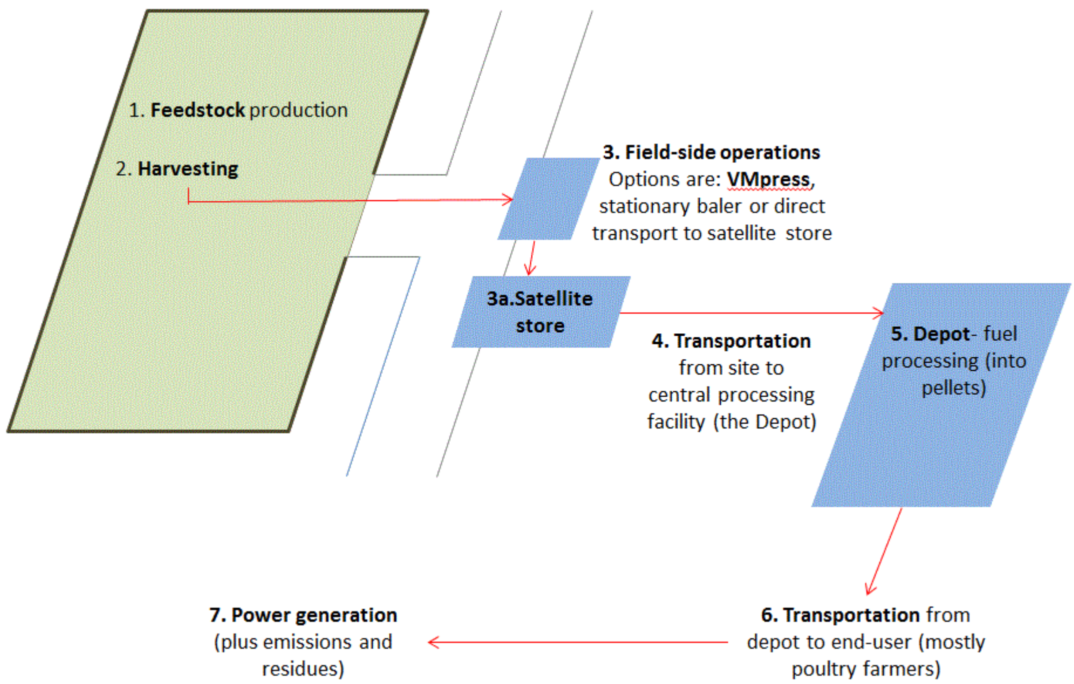

Fig. 1. Schematic diagram of the end-to-end process

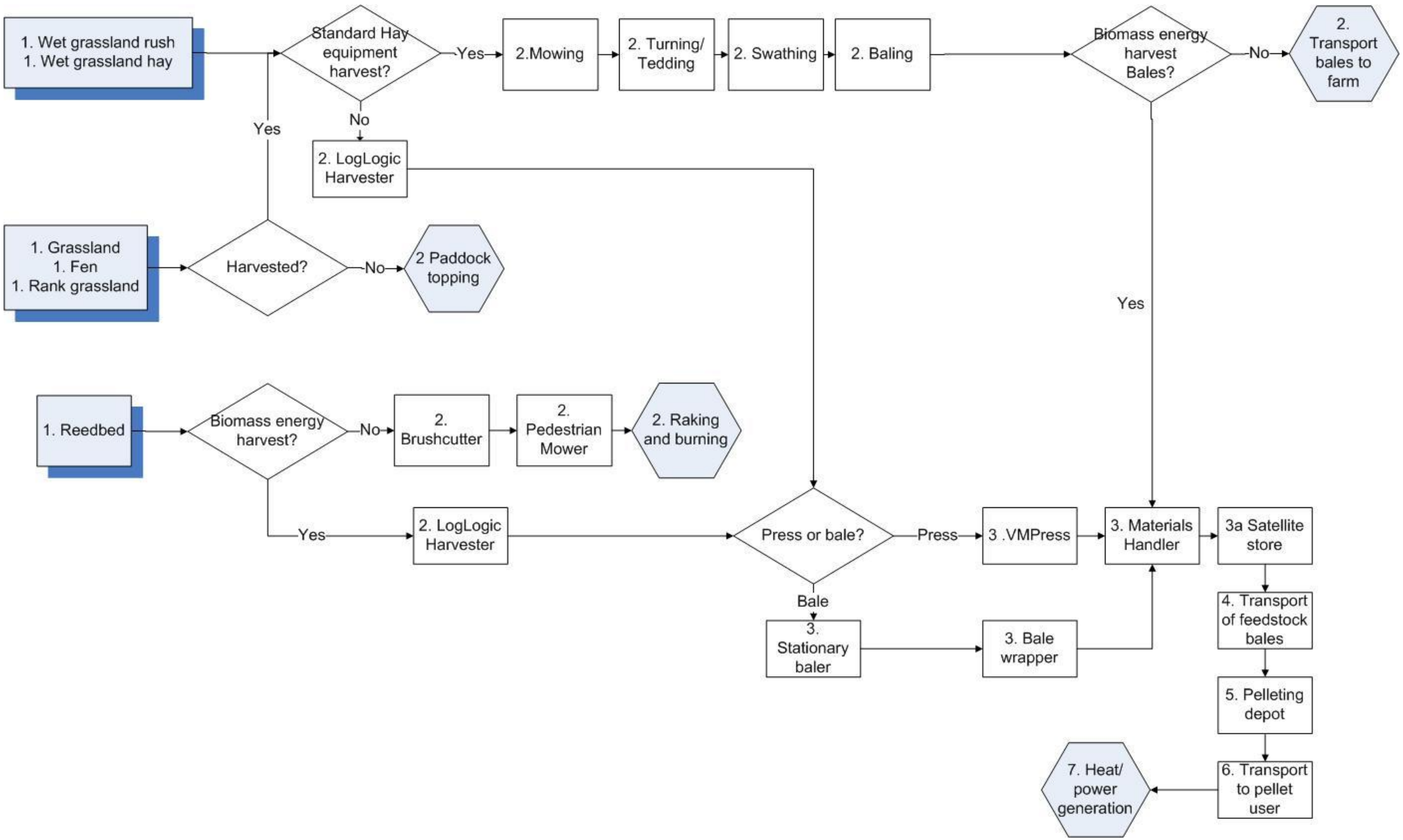

Fig 2. Process flow diagram showing possible options in the process

2.1 Feedstock production

The Somerset Levels and Moorlands, extending to 27,678 ha, was one of the first environmentally sensitive areas (ESA) established in the UK. The Somerset Level and Moorlands "Natural Area" is slightly larger extending to about 35,000 ha, and forms the largest area of lowland wet grassland and associated wetland habitat in Britain (English Nature, 1997). It is bounded to the north by the Mendips, to the east by low limestone escarpments, and to the south and east by the Blackdown and Quantock Hills respectively (English Nature, 1997). Eight major water courses (Kenn, Yeo, Axe, Brue, Huntspill, King's Sedgemoor Drain, Parrett and Tone) flow to the Severn Estuary; and the area is prone to flooding because most is within a few metres of sea-level. There are significant areas of peat and important archaeological sites. The area includes about 26 sites of special scientific interest extending over about 8300 ha (English Nature, 1997).

The two principal habitats of "species poor lowland wet grassland" and "species-rich floodplain meadows and pastures" have been designated as of "international importance" by the 1995 UK Steering Group on Biodiversity (English Nature, 1997). The "species-poor lowland wet grassland" covers about 17,950 ha within the ESA (English Nature, 1997). The grass has typically not been seeded since the 1970s, and the use of inorganic fertiliser and replacement of hay making with silaging has led to a low number of plant species. Dominant species are perennial rye-grass (*Lolium perenne*) and timothy (*Phleum pratense*) (English Nature, 1997) (Appendix A).

Approximately 1750 ha of the Somerset Levels and Moors Natural Area comprises "species-rich fen meadow and flood pasture". Characteristic plants include meadow thistle (*Cirsium palustre*), marsh marigold (*Caltha palustris*), sedges (*Carex* spp), and rushes including jointed rush (*Juncus articulates*). Significant areas of this habitat are managed as nature reserves by the Somerset Wildlife Trust, RSPB and Natural England. The area of actual fen habitat is small (less than 10 ha), and the area of "swamp and reed-bed" is also relatively small including common reed (*Phragmites australis*), reed mace (*Typha latifolia*) and bulrush (*Scirpus lacustris*) (English Nature, 1997).

This project is focused on two principal wetland vegetation types: grassland and rush (perhaps typified by NVC classes MG10 and M22) and areas of reed (perhaps typified by national vegetation communities S25 and S28). RSPB have identified 5646 ha of grass and rush, and about 19 ha of reed in the Somerset Levels and Moors (Appendix B). RSPB assumed an annual reed yield equivalent to 4.3 t/ha. Chisholm (1994), reported by Robbins et al (2012), also reports an annual yield for reed canary grass (*Phalaris arundinacea*) of about 4 t/ha. Lloyd (2006) identifies an average hay harvest yield (1998-2000) for a meadow grassland area at Tadham Moor SSSI of 4.7 t/ha dry matter. It is probable that the potential yield is greater because some of the grass growth after harvest was used by cattle. Kirkham (1996) reports an annual hay yield of 4.69 t/ha (1986-1989) for the full season for a site in the Somerset levels receiving no fertiliser. Hence in the absence of other information, a hay yield of 4.7 t/ha is assumed (Appendix B). On this basis, the annual harvestable production of reed could be about 104 tonnes (dry matter) and that of grass and rush could be about 24,400 tonnes (dry matter) (Appendix B).

2.2 Harvesting and field logistics

This section includes a detailed description of the in-field process. The area of grass and rush is considered first because it occupies the largest area.

2.2.1 General strategy

The harvesting methods must be cross compliant, with particular respect to avoiding soil damage by minimising vehicle weights and ground pressure. Hence the use of low pressure vehicles and reduction of field traffic is recommended. Field vehicles should use headlands for transporting of harvested material to minimise wheeling damage. Access mats or sheets are an option where damage is likely due to trafficking e.g. gateways and regularly used field tracks. Where harvested biomass is to be relayed to gateways for loading, access mats or sheets (e.g. Trakpanels) will be used to avoid surface damage from regular movements. This will also help keep harvested biomass off the ground to reduce soil contamination, whilst providing unloading areas for harvesters and the relaying containers taking the biomass to the gateways.

2.2.2 Grass and rush harvesting

Rush grass harvesting will be carried out in a window from August to late September. In order to facilitate the best ground conditions, every effort will be made to drop the water table at least a few weeks ahead of the harvest. There are two options for the harvest of grass and rush.

Option 1 - the first option is to cut, windrow and dry the grass and rushes as hay before collection. The selected cutting machine is the disc mower (Fig 3a). This is the most flexible machine option for this material, and demonstrates good performance in a difficult sward; it is cost effective and the recommended choice of four contractors contacted. The mower leaves the sward in a windrow which aids drying; this is further improved by using a swath machine which lifts the windrow allowing more air to flow through, further assisting the drying process. The machine also arranges the windrow in a more orderly shape so that it is easier to be collected by subsequent machines. The rate of work for a disc mower is 0.5 to 1.5 ha per hour per metre of cut giving a typical rate for a 3 m machine of 3 ha per hour. The cost of the mowing is taken as £32 per hectare. The work rate for windrowing is taken as 2 ha per hour at a typical cost of £15 per hectare.

Once material has been harvested the process will depend on the site characteristics, biomass species, the weather conditions, ground conditions, and the moisture content of the harvested biomass. Fresh green grass typically has a dry matter content of 18-25%, i.e. moisture content (wet basis) of 75-82%. With appropriate swathing and suitable warm weather over say five days, hay from grassland in the Somerset Levels can be produced with a dry matter content of about 83-88%, i.e. a moisture content (wet basis) of 12-17% (Kirkham, 1996). Leaching of undesirable elements from rainfall during this process can potentially improve the final fuel quality (Prochnow et al, 2009), but at a cost to yields. A moisture content of below about 20% is a precondition for dry storage of grass, without spoiling or risk of self-ignition. By contrast, removal of grass from the field within 48 hours, such as with big-bale silage production will typically result in a dry matter content of about

35-45%. In this case, some form of off-site moisture removal is needed, such as the VMpress described in the next section.

The most common method of collecting the sward in dry conditions is the big baler. There are two types of machine producing either round or square bales. Again, all contractors contacted opt for the round baler for these soil types. The round bale produces bales at either (i) 1.2 m in diameter with a full length of 1.2 m or (ii) 1.8 m diameter with a length of 1.5 m. The preferred bale for this work is the 1.2 m diameter by 1.2 m length, which weighs approximately 120 kg (depending on moisture content). The baler will be operated with a tractor on low ground pressure tyres for minimum substrate damage. Using the smaller bale will produce less ground-loading resulting in minimised soil damage. This round baler will produce 40-50 bales per hour; the cost is usually quoted either (i) per bale (typically £2.6 per bale) or (ii) per tonne (typically £10 per tonne).

It is possible to wrap the bales in the field (Fig 3b) to limit weather damage if the bales are to be left outside. The price for wrapping bales is typically £4-5 per bale. The bales will be transported to the field edge using a tractor with low ground pressure tyres and a loading fork. Access mats will be considered where damage is likely due to trafficking, e.g. gateways and regularly used field edges. An alternative is to use a trailer with twin low ground pressure wheels. The tractor will then load up to 6 bales on the trailer and transport them to the field edge. The choice between individual carting or multiple bale removal with a trailer will be decided on the distance to travel and an attempt to avoid wheeling damage relating to cross compliance. The cost of bale transport will be in the order of £10 per tonne. Alternatively, in the worst case scenario, bales will be removed (un-wrapped) using a 360° excavator grab. It is possible that a tracked tractor could also be used to pull a trailer of bales, or that conventional tractor and trailers are used with the use of access sheets (e.g. Trakpanel) around the headland of the field / reserve where soil level can often be higher.

Option 2- a second option is to forage harvest the grass and rushes directly to a hopper which is transported to the field edge when full. This may be necessary where access to the site is restricted and/or poor weather prevents hay production. The selected low-ground-pressure machine is the Loglogic Softrac (Fig.3c), which can cut grass and rush using a forage harvester attached at the front of the machine, and the cut material is blown into a hopper to the rear. Once the hopper is filled the machine can transport the contents to the edge of the reserve to unload onto a stockpile (Fig 3d). A disadvantage of this system is that there is no air drying time so the harvested material tends to be wetter. However greater timeliness may ensure less impact to the soil structure, and avoid situations where cut biomass is left in the field or reserve to rot.

The hopper (8 m^3) of the Loglogic can, depending on distance and field conditions, deliver harvested grass and rush to the field edge every 20 minutes. Again depending on the site conditions, intermediate skips may be used to collect material to minimise traffic between the reserve edge and the entrance. A 5-6 m open top skip could be placed at the edge of the reserve where the material from the stockpile is collected by a tracked 360° excavator with a suitable grab. Once full the tracked machine (360° excavator) will lift it (using suitable chains) and take it to the access point at the field / reserve gateway where it can unload the contents. However for the purposes of this Phase 1 exercise, it is assumed that the Loglogic will perform 3 cycles per hour (24 m^3 per hour). Each full 8 m^3 load will deliver between 0.8 and 1.6 tonnes (depending on the moisture content). Therefore it can harvest between 19.2 and 38.4 tonnes per 8-hour day. The contract rate (discussed with three contractors) will be £300 to £400 per day (Table 1).


a) A typical disc mower


b) A typical bale wrapper


c) Loglogic Softrac operating in reed


d) The Loglogic Softrac unloading facility

Fig 3. Examples of the equipment for the field harvesting and handling of reed and grass and rush.

Table 1. Description of the work-rates and costs of the harvesting methods

System	Hopper capacity	Work-rate	Work rate per 8-hour day	Contract rate	Cost per tonne (£/t)
Grass and rush harvesting					
Option 1:				£32/ha	
3 m Mower		3 ha/hour			
Windrowing		2 ha/hour		£15/ha	
Round baler	120 kg fresh weight per bale	40-50 bales per hour		£10/tonne	
Bale wrapping				£4-5/bale	
Bale transport				£10/tonne	
Option 2: the Loglogic	8 m^3; equivalent to 0.8-1.6 tonnes	3 loads/hour	19.2-38.4 tonnes	£300-400 per day	£10.4-15.6
Reed harvesting using the Loglogic	8 m^3; equivalent to 1.2-2.0 tonnes	3 loads/hour	28.8-48 tonnes	£300-400 per day	£8.3-10.4

2.2.3 Reed bed harvesting

Reed beds are typically harvested between January and early March. Based on studies in 2006-2007, Smith & Slater (2011) report that the moisture content of reed canary grass can fall from 40-70% in November to 20-30% in January. Hence, at least in some years, winter harvesting of reed canary grass can result in relative low moisture contents.

In order to facilitate the best ground conditions every effort will be made to drop the water table a few weeks ahead of the harvest. As the harvest will only typically take place when the reed is well established it will be on a rotation approximately 7 years (depending on growth) this allows some flexibility to allow of a year when there are poor weather conditions. However, this may need to be optimised to say 3-5 years to avoid build up (and contamination) of woody species in the harvested biomass, which otherwise could cause problems in the consistency and processing of the reed into fuel products (i.e. wet, unseasoned wood takes longer to dry and prepare). The fuel processing stage does have machinery to take this out, so it is a balancing discussion between operating costs, habitat optimisation, yield variance, product quality and overall economics. The wear and tear on the Loglogic is also a consideration for such woody material compared to reed chopping, which could lead to more rapid blunting of cutting knives and potentially more debris deposition on the reserve floor (not desirable for wading bird species).

The Loglogic Softrac, mentioned as Option 2 for the grass and rush areas (Fig. 3c), has been proven to operate on many such sites with minimal substrate damage and can work in up to 30 cm of water. As mentioned, it cuts reed using a forage harvester attached at the front of the machine, and the cut reed is blown into a hopper to the rear. Once the hopper is filled the machine transports the contents to the unloading point at the field edge where it can be bulked up into larger containers and shuttle relayed to the gateway for pressing and out-loading to the centralised facility (Fig 2d).

A full collecting hopper (8 m^3) can be delivered to the field edge approximately every 20 minutes (exact timing will depend upon the distance to transport and the field conditions (Table 1). Based on these figures the machine will perform at 3 cycles per hour which yields an output of 24 m^3 per hour. Each full 8 m^3 load will deliver between 1.2 and 2 tonnes (depending on the moisture content) therefore delivering 3.6 to 6 tonnes per hour. Therefore based on an 8 hour day the rate is between 28.8 and 48 tonnes per day. The contract rate (discussed with three contractors) will be £300 to £400 per day.

By using this Loglogic machine in combination with the VMpress for harvested material, there are greater options to cut the reed under a range of weather conditions. For example, if desired, harvesting could occur prior to leaf drop, reducing debris build up on the reserves (necessary to encourage wading birds and feeding resource, i.e. fish in the shallows), whilst also improving the biomass yields for improved economics and sustainable delivery of this project.

2.3 Track side processing and loading – Mobile VMpress

The benefits from reducing the moisture content of harvested biomass include a) reduced carbon emissions, b) reduced transport costs and emissions, c) reduced respiration losses, d) it reduces the risk of spontaneous combustion that is possible with wet hay, and e) leachate are produced in the field rather than later in the system where they could otherwise become a waste disposal cost, although organic acids from degrading or fermenting bales in bulk storage on fields or reserves is not good for surface water quality (Fig. 4). Hence the carbon-balance of the process is maximised and transportation costs are minimised by field-drying. However it is worth noting that respiration and other losses during the hay making process typically results in a 20% of the overall dry matter (Kirkham, 1996).

Fig 4 Bale left in field with water-logged tracks.

Where it is not possible to get to low moisture contents in the field and the focus on biomass extraction is viable, one method for reducing the water content is the VMpress.

The rest of section 2.3 (including Figure 5) is redacted.

2.4 Transport from site to central processing facility

Several options on the methods to transfer harvested and / or pressed material from the trackside to the depot have been investigated. The distances from each of the sites to the central facility are shown in Table 2.

Table 2. Distances (km) from Somerset reserves to the central facility.

Site	Distance to central facility (km)
Ham Wall RSPB Reserve	6.4
Ashcott Corner	1.1
Shapwick Heath Natural England Reserve	4.3
Avalon Marshes Centre	4.3
Westhay Heath, Somerset Wildlife Trust reserve	7.7
Tealham and Tadham Moor Somerset Wildlife Trust reserve	5.1
Catcott Lows Somerset Wildlife Trust reserve	8.8
Chilton Moor Somerset Wildlife Trust reserve	8.5
Burtle Moor Somerset Wildlife Trust reserve	8.3
Greylake RSPB reserve	9.1
West Sedgmoor RSPB reserve	22.6

2.5 Depot fuel-processing

Section 2.5 has been redacted

2.6 Transport from depot to end-user

The output fuel products will be loaded into suitable trucks and trailers to go to the end markets. They may be sold in bulk to fuel trading and distribution companies as well direct to end users locally, regionally and potentially further away if the economics dictate. Letters of interest have been provided from discussions (Appendix L).

There are some companies using blower trucks for pellets and discussions have been held with two companies, who already have a growing customer demand for pellets, especially if they can be provided at a competitive rate, which is otherwise holding back the uptake of pellet boilers. One potential end user could be poultry farmers, who are increasingly installing biomass boilers to provide heat to their livestock. These boilers are eligible for support under the Renewable Heat Incentive [RHI] scheme. A summary of distances from the central facility to poultry farmers in the local area is shown in Table 3. Whitaker et al (2011a) reports that transporting wood chips for 50 km requires 73.80 MJ/t and emits 5.15 kg CO_2eq./t. These values are higher than that associated with roundwood (46.26 MJ/t and 3.23 kg CO_2eq./t) and brash bales (53.23 MJ/t and 3.71 kg CO2eq./t).

2.7 Heat generation

It is anticipated that the primary local users of the fuel products will be by those in the poultry industry using the material for heat. The products may also be used for bedding of animals during the interim period of testing and trial combustion (in Phase 2 and 3). These are local, regional and all-year-round end users of the fuel, so provide a steady customer base and cash flow for this project to stand up commercially after Phase 3. Using this fuel as a heat load input also provides a higher energy efficiency than using the fuel for power production only. If end users with combined heat and power (CHP) can be sourced then the energy efficiency will be even greater.

The Renewable Heat Incentive (RHI) is a significant catalyst to growth in the uptake of biomass heating and this is why poultry farmers are installing such systems. There are less tangible benefits in terms of animal welfare also to the poultry birds, which offers an interesting synergy to this project's biodiversity benefits of harvesting wetland biomass. Depending on the quantities of biomass fuel outputs and the growth in biomass boiler installation, the end market size locally and regionally will be monitored alongside the development of Phase 2's data analysis. Appendix L includes a letter of support from the Commercial Biomass Partnership to engage in the development of biomass fuel for local poultry farmers.

3 Regulatory requirements

This section identifies and addresses any permission needed for the full scale technology and the demonstration. Although this proposal does not propose to produce a transport fuel, it is interesting to note the sustainability principles of the UK Renewable Transport Fuels Obligation (Table 3), which is also supported by EU Directive 2009/28/EC (Black et al. 2011). These sustainability principles state that biomass production should not lead to the damage of high biodiversity area, lead to soil degradation, or contaminate water sources. In this case, conservation organisations such as RSPB are supportive of biomass removal, as it can create habitats for specific bird species. However it is also noted that measures to increase biomass production per unit area, such as fertilizer use, may create problems. Hence in this analysis we assume no additional fertiliser application.

Table 3 Sustainability principles of the UK Renewable Transport Fuels Obligation, (RFA, 2008).

Sector		Biomass production does **not….**
Environmental	1	destroy or damage large above or below ground carbon stocks
	2	lead to the destruction of or damage to high biodiversity areas
	3	lead to soil degradation
	4	lead to the contamination or depletion of water sources
	5	lead to air pollution
Social	6	adversely affect workers rights and working relationships
	7	adversely affect existing land rights and community relations

It is expected that no Environment Agency issues will arise from the Phase 2 and 3 processed proposed, although they will be consulted on the discharge of pressed water from the harvested biomass from the VMpress and also any leachate arising in the building during Phase 2 storage and Phase 3 processing.

Fuel storage guidance and Regulations will be followed for any fuel oil stored on site at the building and used for the VMpress. Notably, fuelling of the VMpress will be performed at the storage building (secure and locked) to avoid any spillages occurring at the reserves. The fuel tank on the trailer mounted VMpress will be double lined (bunded) and will only hold sufficient fuel for one day's operation. The depot building will have spill kits and a bunded, movable fuel tank (standard design).

4 Mass and energy balances of the process

The mass and energy balance of the counterfactual and the proposed process can be described as a material stream and energy flow (Fig. 7). The properties of each stream are described in Table 4.

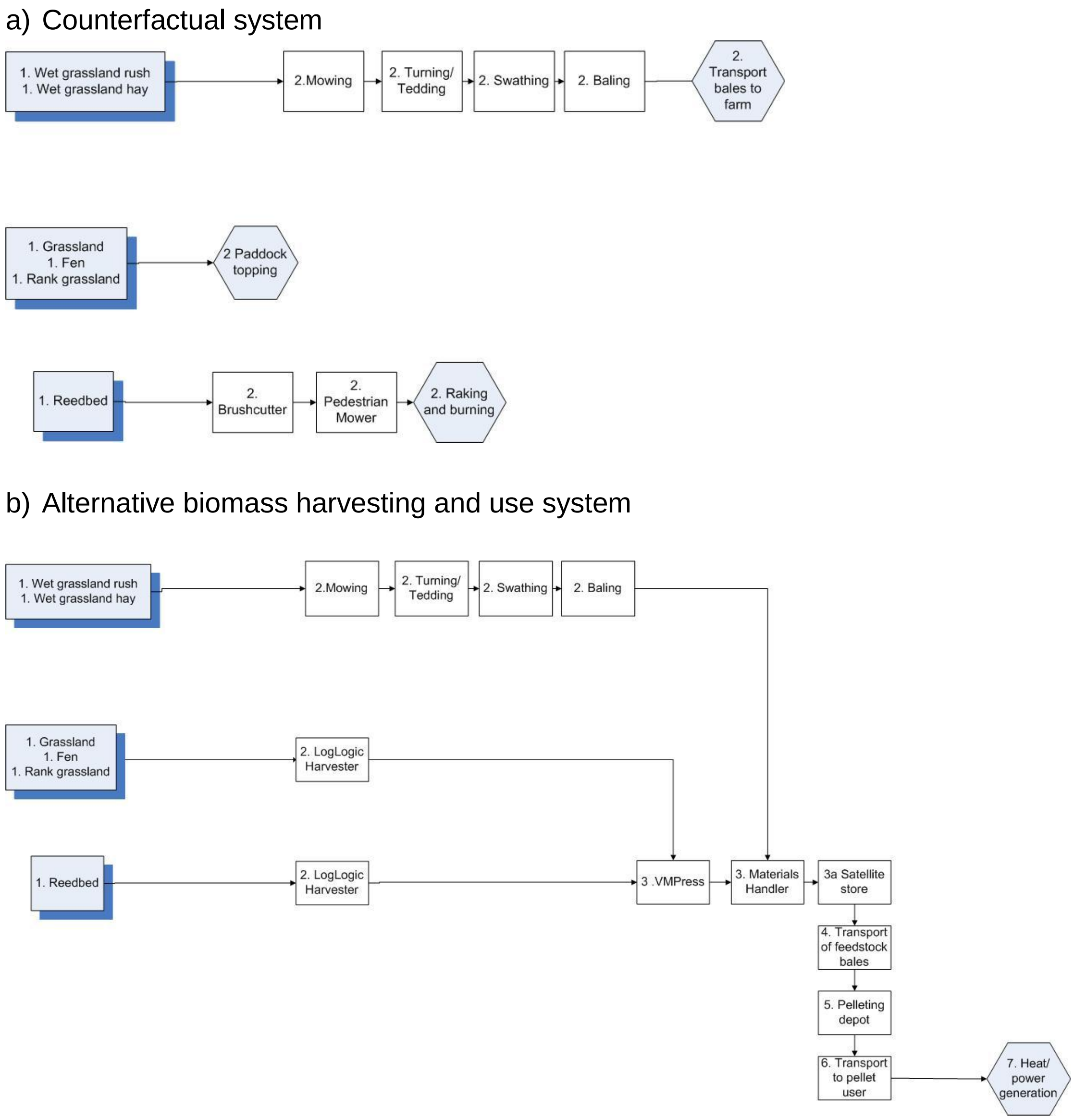

Fig 7. Schematic description of the flow for the counterfactual and the alternative system

Table 4. Summary of the material streams in the counterfactual and the alternative system of the mass flow of a) biomass and b) fossil energy.

a) Material flow of biomass

		Area (ha)	Yield (t DM)	Use	Biomass (t DM)
Counterfactual	Grass rush	5593	24378	⇒ Hay for farm use	
	Reed	19	104	Burnt	
	Other	65	728	Topped	
	Total	5677	25210		
Alternative	Grass rush	5593	24378	Hay ⇒ Bioenergy	21103
	Reed	19	104	Reed ⇒ VMpress ⇒ Bioenergy	90
	Other	65	728	Grass ⇒ VMpress ⇒ Bioenergy	630
	Total	5677	25210		

b) Fossil fuel use

Process		Counterfactual (GJ/year)	Alternative (GJ/year)	Difference A minus C (GJ/year)
2. Harvesting reed (19 ha)	Bushcutter	3		-3
	Pedestrian mower	97		-97
	Raking and burning			
	Loglogic harvester		7	7
2. Rush hay (5593 ha)	Mowing	1515	1515	
	Tedding	489	489	
	Swathing	489	489	
	Baling	1551	1551	
	Transport to farm	2404		-2404
2. Misc grassland (65 ha)	Topping	-48		-48
	Loglogic harvest		-19	-19
3. Field edge	VMPress		-532	-532
	Store material handler		-142	-142
	Satellite store			
4. Transport	Reed transport to depot		1	-1
	Rush grass transport to depot		720	-720
	Misc. Grass to depot		4	-4
5. Depot			12010	-12010
6. Transport			2755	-2755
Displaced hay		-3007		-3007
Displaced propane			-259083	-259083
Net use of fossil fuel		3590	-238847	-242438

5 Carbon and energy life cycle assessment (LCA)

This section details the carbon and energy LCA of the process starting from the point of harvest of the biomass to the delivery of the briquettes.

5.1 Goal and scope

The life cycle assessments of the biomass processes were based on quantifying the energy and carbon burdens per GJ of produced energy (Fig 8). However they are also specified per hectare of wetland harvested.

The overall process follows that described for other agricultural systems described by Williams et al (2006, 2012).

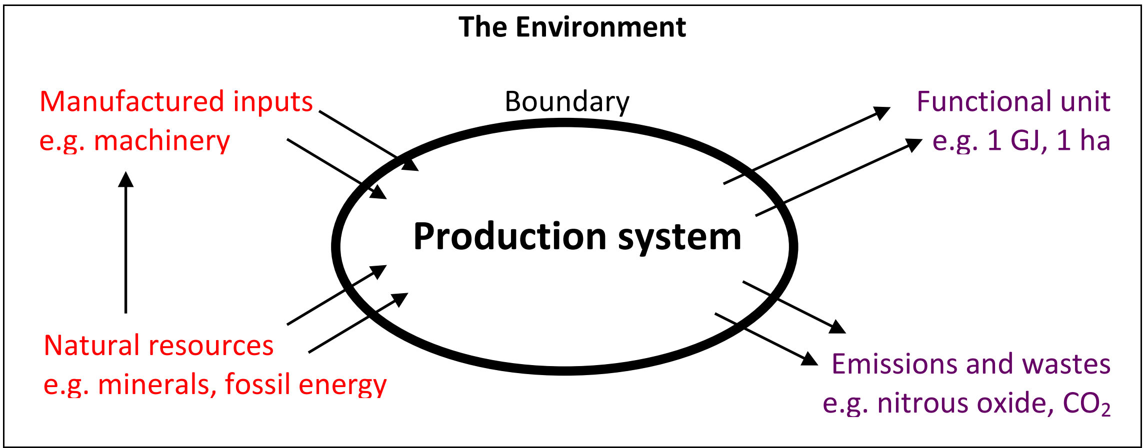

Fig 8. Outline of the life cycle assessment with one MJ as the functional unit.

The Life Cycle Assessment follows the PAS 2050 standard. Greenhouse gas emissions are weighted by their global warming potentials (GWP) and summed. These are related to carbon dioxide equivalents (CO_2e) of gases emitted during production. The main ones are CO_2 (e.g. from fossil fuels), methane (CH_4) with GWP of 25 (IPCC 2006 values), and nitrous oxide (N_2O) with GWP of 298. The carbon footprint of the functional unit is the sum of all the sum of all greenhouse gas (GHG) emissions (GHGE) incurred in the delivery of that unit, assuming the specified boundaries and data sources.

5.1.1 Counterfactual

The reference default system (counterfactual) contains three components:

Grass Counterfactual: a wet grassland with 70% soft rush, which is cut, baled for hay and passed to farmers as poor feed / animal bedding, whose farm is located within a 20 mile radius. Reed counterfactual: a reedbed (dominated by common reed) that is cut manually through brushcutters and pedestrian mowers, raked and burned by hand. It is assumed that the remaining "other area" of 65 ha of fen and rank grassland which it is assumed is simply topped.

5.1.2 Alternative

The alternative assessed again comprises three components:

Grass alternative: produce hay (14.5% moisture content) from the current grassland and rush areas, store at satellite sites, then transport to a central depot, and the production of pellets, briquettes, and small bales. The reed and the "other area" is managed in a similar way. They are harvested using a Loglogic harvester, transport to edge of field, use of the VMPress, satellite storage, and eventual transport to central depot where it is used for the production of pellets, briquettes and small bales.

5.2 Life cycle inventory

Annex V of EU Directive 2009/28/EC outlines the methodology for calculating the total emissions (*E*; g CO_2eq per MJ) associated with the use of renewable fuels (European Commission 2009). In this analysis carbon capture is not a factor, and it is assumed that annual effect of the practice on soil carbon accumulation is minimal and there is no land use change. Lloyd (2006) reviewed the in-field net carbon assimilation (C_n) of a wetland site in the Somerset Levels.

$E = e_{ec} + e_p + e_{td} + e_u$

Where: e_{ec} is the emissions from the extraction or cultivation of raw materials; e_p is the emissions from processing; e_{td} is the emissions from transport and distribution; e_u is the emissions from the fuel in use. In this analysis, the life cycle is considered in seven stages, using the format and systems outlined in the preceding sections of the report.

Stage 1 Feedstock production: the potential annual yields from identified sites in the Somerset Levels and Moors are described in Appendix I. The feedstock was divided into three classes: 5593 ha of grassland and rush, which can provide a mean yield oven dried yield of 4.7 t/ha; 19 ha of reed bed with a mean oven dried yield of 5.5 t/ha. The third class comprised 65 ha of fen and rank grassland, which was assumed to be currently topped. It was assumed that this could yield 4.7 t/ha.

Stage 2 Harvesting: the data for the counterfactual harvesting options are outlined in Appendix I. The life cycle assessment includes fuel use and the manufacturing of the harvest equipment.

Stage 3 Field-side operations: the principal option for a field-side operation considered in this report is the VMPress. Although not considered in this report, the model has also been set up to allow consideration of producing bales from material harvesting with the Loglogic. This section also includes storage losses. Assumptions are made assuming the mean storage period (6 months) and the mean dry matter loss per month (Appendix I).

Stage 4 Transport to depot: the distance from each site to the depot was calculated using geographical co-ordinates and an assumed rate of road meandering (Appendix I).

Stage 5: Depot processing: a potential central site has been identified. A provisional cost of leasing the site has been obtained (Appendix I), and an initial life cycle assessment for handling the biomass material and producing pellets, briquettes and or small bales has been established.

Stage 6: Transport of dried biomass to consumer: this was based on the distances presented in Appendix I.

Stage 7: Combustion of the material: the final stage of the process is the combustion of the briquettes by local poultry farmers. The potential emissions from the hay from grass, rush, and reed are described in Appendix I. It is assumed that the biomass will replace propane, and that 90% of the energy of the propane is available as heat. By comparison, it is assumed that 66% of the energy of the biomass is available as heat.

In this initial analysis, some of wastes from the process have not been included. The analysis does not include the effluent from the VMPress, the steam and dust production at the depot or the formation of ash from the combustion.

5.3 Life Cycle Impact caveat, assessment and interpretation

The results from the life cycle assessment are presented in Table 5. In interpreting the results it is important to highlight various qualifications in the presented values. The general caveat that a substantial number of judgements have been used in the assessment of what is a novel system. Unfortunately at this stage we have not completed a sensitivity or uncertainty analysis based on variations within a realistic range of biomass sales values and of the project life of equipment. We have perhaps taken "optimistic" assumptions in assuming a 15 year lifetime for major equipment such as the pelletisation and briquetting equipment, and also for the VMpress. A delivered price of £150/odt for pellets and briquettes may also be optimisation, given that it is three times the value of straw. We have also not studied the impact of yield and harvest uncertainty on financial performance. This can be addressed robustly in the phase 2 pilot scale study. Some of the other key limitations are outlined in Table 5. Whilst we have attempted to derive robust estimate of the major costs, overall there is likely to be an underestimation of costs as smaller items will add up

Table 5. Description of some of the limitations of the life cycle assessment

Not modelled	Impact of any leachate at the VMPress or ash at the biomass combustor is not modelled Land use change. carbon and nitrogen impact of bringing areas into regular harvest for the first time Plastic consumed by bale wrapper option Interplay between the VMpress and the transport and briquetter drying costs The briquetter drier has only been included as ancilliary equipment The burdens of capital items Steel used in replacing the dies of the briquetter Administrative and managerial overheads and insurances in financial budget
Assumption	Users have already invested in biomass burners and that aspect is outside the boundary but given that we are displacing propane rather than woodchip it's a arguable point. It is an open question if the analysis shoudl consider the displacement ofwood chip rather that propane.

The initial life cycle assessment indicates that for the baseline scenario the primary energy use is equivalent to 632 MJ/ha. The global warming potential over 500 years is equivalent to a net emission of 260 kg CO_2eq/ha (Table 6). The counterfactual system has a tendency to reduce eutrophication and acidification, primarily because of the grass removal.

Table 6. Phase 1 results from the life cycle assessment

Input/Output	Quantity	Unit	Primary energy used (MJ)	GWP 500, (kg CO_2e)	Eutrophication potential (kg PO_4 equiv.)	Acidification potential (kg SO_2equiv)	Mineral use (antimony equ, kg)
a) Baseline							
Petrol/oil mix	77	L	3028	223	0	0	1
Petrol	2461	L	96566	7114	0	5	45
Diesel	93910	L	4042959	281468	0	128	1900
Electricity	0	MJ	0	0	0	0	0
Transport	1009777	t km	2455434	168261	0	107	1093
Rush-grass hay	-24378	ODT	-3007105	-1950281	-120216	-55825	-1542
Reed field burnt	0	ODT	0	3253	16	4	0
Biomass combustion	105	ODT	0	0	0	0	0
Propane	0	GJ	0	0	0	0	0
Transport	0	t km	0	0	0	0	0
Total			3590000	-1500000	-120000	-56000	1500
Total per ha	5677	ha	632	-260	-21	-10	0
b) Alternative							
Petrol/oil mix	0	L	0	0	0	0	0
Petrol	0	L	0	0	0	0	0
Diesel	181547	L	7815880	544137	1	248	3673
Electricity	2762065	MJ	8890901	493246	4	2099	3072
Transport	1808395	t km	4397403	301337	0	192	1957
Rush-grass hay	24378	ODT	0	0	0	0	0
Reed field burnt	0	ODT	0	0	0	0	0
Biomass combustion	21959	ODT	0	0	0	0	0
Propane	-229797	GJ	-259083046	-18064387	-2206	-22599	-137599
Transport	655123	t km	724108	49620	0	32	322
Total (3 sig figures)			-240000000	-17000000	-2200	-20000	-130000
Total per ha	5677	ha	-42000	-3000	-0.4	-3.5	-23
Total per ODT pellets	21959	ODT	-10929	-774	-0.1	-0.91	-5.92
Total per GJ thermal	229797	GJ_{therm}	-1044	-74	-0.01	-0.09	-0.57
Difference: a minus b							
Petrol/oil mix	-77	L	-3028	-223	0	0	-1
Petrol	-2461	L	-96566	-7114	0	-5	-45
Diesel	87637	L	3772921	262668	0	120	1773
Electricity	2762065	MJ	8890901	493246	4	2099	3072
Transport	143495	t km	348932	23911	0	15	155
Rush-grass hay	24378	ODT	3007105	1950281	120216	55825	1542
Reed field burnt	-104	ODT	0	-3253	-16	-4	0
Biomass combustion	21959	ODT	0	0	0	0	0
Propane	-229797	GJ	-259083046	-18064387	-2206	-22599	-137599
Transport	655123	t km	724108	49620	0	32	322
Total	0		-243590000	-15500000	117800	36000	-131500
Total per ha	0		-42632	-2740	21	7	-23
Total per ODT pellets	21959	ODT	-10929	-774	-0.1	-0.91	-5.92
Total per GJ thermal	229797	GJ_{therm}	-1044	-74	-0.01	-0.09	-0.57

The alternative system presented in Table 6 comprises the use of the hay from the grass and rush area, and of the reed from the reed beds and other areas to produce pellets, briquettes and bales. In this scenario the level of electricity use increases and additional transport is used to transport the pellets and briquettes to the consumers. In this case, it is assumed that the biomass is used as an alternative to propane. In this vase it is also possible to express the results in terms of fossil fuel saving. The energy input to produce one ODT of pellets or briquettes is about 0.92 GJ. Assuming that the pellets have an energy content of 10-15 GJ/ODT and that the reed and grass growth is carbon neutral, the process energy represents 6-9% of the embedded energy.

The life cycle assessment indicates that using the alternative biomass process instead of the use of propane would saves about 1.04 GJ of fossil energy for each GJ of thermal energy output.

Indicative values for other energy crops, such as miscanthus and willow are given in Appendix J. Whittaker et al (2011b) also considers the energy and greenhouse gas emissions associated with straw removal.

6 Emissions

In this Phase 1 analysis, the study has been conducted assuming that in total 5677 ha of wetland grass, rush and reed are utilised. This has the effect of spreading the cost of the VMpress and the briquetting facility across a large business. This is a substantial assumption. In the establishment phase of the project, the use of such a large area of resource will not be possible. Hence prior to exploitation, it would be wise to establish the financial and life cycle sensitivity of the project to smaller areas. In addition, it would also be wise to establish the likely effects if sustainability criteria currently applied to road transport fuels (such as constraints of use of resources from area of high biodiversity and high soil carbon) are applied to heating fuels.

The material produced in our proposed fuel preparation process is designed for burning in contained conventional boilers, rather than open air, and this will help minimise the emission of particulates. Unlike some other biomass processes, the material is not composted and this will minimise bio-aerosol issues. Because the process uses directly-harvested, rather than waste, biomass this minimises contamination problems.

DECC (2011) have announced that the key air quality issues associated with biomass are particulate matter (PM10) and oxides of nitrogen (NOx) emissions. The proposal is to have an emissions limit of 30 g/GJ for particulate matter and 150 g/GJ for NOx.

The carbon dioxide and nitrogen oxides emissions are likely to be similar to other biomass materials such as wood. A possible but highly unlikely risk from burning wetland biomass could be elevated levels of chlorine which can accelerate corrosion.

An initial literature analysis from Phyllis suggested that the levels of nitrogen and sulphur appear similar to wood (Table 7). However Prochnow et al (2009) report that the nitrogen content of grass biomass should not exceed 0.6% (% weight dry basis) to constrain nitrogen oxide formation. Kirkham reported that the nitrogen level in September harvested hay was about 1.6%. By contrast, Smith and Slater (2011) report that the nitrogen content of reed canary grass in the UK in January can decline to 0-5-1.0%. Remobilisation of nutrients to the roots and leaching of nutrients from cut vegetation to the soil is seen as beneficial.

Prochnow et al (2009) also report that the sulphur content should remain below 0.1% (% weight dry basis) the study by Smith and Slater (2011) suggests that sulphur should not be a problem with reed canary grass, as do the values from Phyllis. Smith and Slater (2011) also reported that reed canary grass had lower potassium contents than Miscanthus, and similar levels of nitrogen and phosphorus.

Table 7. Indicative target elemental composition of biomass, three examples for forestry wood, reed canary grass, and grass (source: Phyllis), reed canary grass harvested in January (Smith & Slater, 2011) and hay from the Somerset levels harvested in September (mean of 1991 and 1992) (Kirkham, 1996).

Element	Proportion of weight (% weight dry basis)					
	Target	Forestry wood	Reed canary grass	Grass	Reed canary grass in January (Smith & Slater, 2011)	Somerset Levels hay (Kirkham, 1996)
Carbon		50.3	45	46.4		
Hydrogen		4.59	5.7	5.1		
Oxygen		40	38.8	37.6		
Nitrogen	<0.6	1.03	1.4	1.33	0.5-1.0	1.55
Sulphur	<0.3	0.11	0.14	0.09	0.05-0.25	
Phosphorus						0.12
Potassium	<0.2				<0.2	0.52
Sodium						0.55
Calcium						0.69
Magnesium						0.20
Chlorine		0.04	0.064	1.03		
Ash		4	8.9	8.4		

Briquetting can reduce smoke (particulates) emissions by more controlled and slower burning. In this case, we would not anticipate greater particulate emissions from the wetland biomass than observed from other wood-derived biomass fuels. Some wood-derived biomass briquettes are currently used as smoke-free fuels for conventional biomass boilers and comply with the Clean Air Act 1993.

By contrast, Robbins et al (2012) report that an issue with reed canary grass is its high ash content (about 8.5% DM). This can impact the combustion process. Robbins et al (2012) note the benefits of delaying some harvest to winter, and Burvall (1997) note that delaying harvest of reed canary grass to the winter can lower potassium and sulphur levels. The Vermont Energy Partnership (2011) also report that the ash content of 100% grass pellets (4-7%) was substantially greater than premium-grade wood pellet (<0.5%). In this example, they recommended that the grass be blended with wood.

An additional benefit of incorporating some wood could also be to reduce the mean moisture content of the pellets. The Vermont Energy Partnership reported that pellets made from 100% hay, or dried reed canary grass or switchgrass (which had not received additional drying beyond that in the field) could be 7-9%. This was marginally higher than the value for wood pellets (5%).

Compared to reed, grass is likely to have higher levels of ash and nitrogen and is thus likely to emit more particulates and more NOx (Vermont Energy Partnership, 2011).

Full emission tests should be undertaken during trials within Phases 2 and 3.

7 Process cost analysis (redacted)

8 Exploitation (redacted)

9 Project plans for Phase 2 trials and Phase 3 development (redacted)

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Appendices

Appendix A. National Vegetation Communities (NVC) codes categorised as common, ubiquitous or widespread within the Somerset levels and moors (English Nature, 1997), and three less common communities (M22, M24, S25) mentioned by Swetnam et al (2004).

Generic description	NVC	Name	Occurance in area and brief description
Swamp	S12	Reed mace (*Typha latiflolia*)	Common in Brue Valley – 1-2 m high shoots
	S14	Branched bur-reed (*Spargaganium erectum*)	Widespread community; shoots over 1 m tall
Tall herb fen	S22	Floating sweet grass (*Glyceria fluitans*) water margin vegetation	Fairly frequent and widespread community
	S25	Common reed (*Phragmites australis*) and hemp agromony (*Eupatorium cannabinum)*tall-herb fen	Occurs in the Brue Valley
	S28	Reed canary grass (*Phalaris arundinacea*)	Widespread – forming a dense canopy 1-1.5 m tall
Mires	M22	Blunt flowered rush (*Juncus subnodulosus*) and Marsh thistle (*Cirsium palustre*) fen meadow	Found on some moors but limited to small areas
	M24	Purple moor grass (*Molinia caerulea*) and meadow thistle (*Cirsium dissectum*) fen meadow	Small areas
Grassland	MG1	False oat grass (*Arrhenatherum elatius*)	Common – associated with badly managed pastures
	MG6	Perennial rye grass (*Lolium perenne*) and crested dog's tail (*Cynosurus cristatus*)	Ubiquitous, particular in dairy areas
	MG7	Perennial ryegrass (*Lolium perenne*) leys and related grasslands	Widespread and abundant
	MG8	Crested dog's tail (*Cynosurus cristatus*) and marsh marigod (*Calthus palustris*)	Limited, but largest area in Britain – grasses abundant with some sedges
	MG9	Yorkshire fog (*Holcus lanatus*) and tufted hair-grass (*Deschampsia cesiptosa*)	Fairly widespread
	MG10	Yorkshire fog (*Holcus lanatus*) and soft rush (*Juncus effusus*) rush pasture	Common – tussocks of Juncus up to 80 cm tall

Appendix B: Potential areas of "grass and rush" and reed and other areas in the Somerset Levels and Moors as identified by RSPB.

Grass and rush: summer harvest (August – Late September)

Site		Current annual harvest area (ha)	Indicative yield (t/ha)	Indicative annual oven dried yield (t)	Owner
Chilton Moor	Hay	2	4.7	9	SWT
	Rush	17	4.3	73	
Burtle Moor	Rush	15	4.3	64	SWT
Catcott Lows	Rush	60	4.3	258	SWT
	Hay	25	4.7	117	
Tealham & Tadham	Hay	44	4.7	207	SWT
Greylake	Rush	40	4.3	172	RSPB
West Sedgemoor	Hay	250	4.7	1175	RSPB
	Rush	140	4.3	602	
Wider Somerset Levels[b]	Hay	500	4.7	2350	Mixed
Wider Somerset Moors[b]	Rush	4500	4.3	19350	Mixed
Total		5593		24377	

Reed bed: winter harvest (January to early March)

Site	Current annual harvest area (ha)	Indicative yield (t/ha)	Indicative annual oven dried yield (tonnes)	Ownership
Ham Wall	10	5.5	55	RSPB
Shapwick Heath	6	5.5	33	Natural England
Westhay Moor /Heath	3	5.5	16	SWT
Total	19		104	

Other: summer harvest (August – Late September)

Site		Current annual harvest area (ha)	Indicative yield (t/ha)	Indicative annual oven dried yield (t)	Owner
Shapwick Heath	Rank grassland	3	4.7	14	NE
Westhay Moor /Heath	Grassland	40	4.7	188	SWT
	Fen[a]	12	4.7	56	
Catcott Lows	Fen	10	4.7	470	SWT
Total		65		728	

Rush yields were based on a dry matter yield of 4.3 tonne/ha in a typical year. There can be annual variation in the quantity available and the ability to access the wetlands. Owners are Natural England (NE), Somerset Wildlife Trust (SWT) and RSPB.

Grass hay yields are based on 4.7 tonne/ha (Lloyd, 2006). Kirkham (1996) recorded a mean hay harvest yield of about 4.69 t/ha in the Somerset levels (1986-1989)

Appendix C-H redacted

Appendix I. Assumptions for the life cycle assessment of the different systems

Table I.1: Grass and rush counterfactual and hay harvesting: wet grassland with 70% soft rush is assumed to be cut, baled for hay and passed to farmers as poor feed / animal bedding, whose farm is located within a 20 mile radius.

Machinery	Mower	Turning	Rowing	Baling	Moving bales
Labour (hr/ha)	0.22	0.10	0.10	0.21	0.28
Fuel use (litres diesel/hr)	28	20	20	30.0	25.0
Fuel use (litres/ha)	6.2	2.0	2.0	6.4	8.5
Bales (bales/ha)				8.5	
Distance of round trip (miles)	10	10	10	10	10

Purchase cost of John Deere 6930 150 hp tractor = £70000
Annual costs of maintenance assumed to be 2.5% of capital cost
Tractor and trailer which carries 20 round bales is used to transport to a farm which is located within a 20 mile radius

Table I.2: Reed bed counterfactual: Reed beds (dominated by common reed) are normally cut manually through brushcutters and pedestrian mowers, raked and burned by hand.

Machinery	Brushcutter FS 450 2.1 kW	Pedestrian mower Aebi HC 44 9.2 kW	Raking and burning	Transport[a]
Cutting edges and inaccesible spots (hr/ha)	4			
Time cutting (hr/ha)		35		
Raking and burning (hr/ha)			199.5	
Use of petrol/oil mix (litres/hr)	0.44	3.75		
Purchase cost of machine (£)	874	9000		
Annual maintenance (% of capital cost)	2.5	2.5		
Distance of round trip (mile)				10

[a]: Transport of machinery and labour to site with 4 x 4 vehicle and trailer.

Table I.3 Other vegetation counterfactual: Paddock topping

	Paddock topping
Labour (hr/ha)	1.21

Table I.4. Assumptions regarding "edge of field" operations and storage characteristics of material

Characteristics	Value
Storages losses (%/month)	2
Average storage duration (month)	6
Unladed weight factor	1.8
Reed moisture content at harvest, (% wet basis)	18.5
Rush and grass moisture content as hay (% wet basis)	14.5

Table I.5. Characteristics of the VMPress

Redacted

Table I.6 Assumptions for transport

	Distance straight, (km)	Distance, by road,[a] (km)	Reed, (t km)	Rushgrass, (t km)	Optional rushgrass, (t km)
Ham Wall	6.4	8.4	460	0	0
Shapwick Heath	4.3	5.6	186	0	80
Wedthay moor/heath	7.7	10.0	161	0	2454
Chilton moor	8.5	11.1	0	915	0
Burtle Moor	8.4	10.9	0	702	0
Catcott Lows	8.9	11.5	0	4321	541
Tealham and Tadham	5.1	6.7	0	1384	0
Grey Lake	3.5	4.6	0	792	0
West Sedgemoor	22.7	29.5	0	52420	0
Wider Somerset levels	20.0	26.0	0	61100	0
Wider Somerset moors	20.0	26.0	0	503100	0

[a]: road meander factor = 1.3

Table I.7. Assumptions regarding the emissions associated with combustion of grass hay, rush, and reed.

Material		Hay	Rush	Reed a	Reed b
Moisture	(%)	10	18.9	14.1	10.1
Carbon dioxide	(kg/t)	1481	1314	1361	1456
Nitrogen oxide	(kg/t)	30.92	35.72	4.35	0.18
Sulphur dioxide	(kg/t)	2.38	3.70	0.49	1.19
Nitrogen	(kg/t)	3760	3762	3748	3746
Hydrogen chloride	(kg/t)	2.18	3.43	1.84	1.57
Air	(kg/t)	64	64	64	64
Water	(kg/t)	444	457	511	519
Oxygen	(kg/t_	167	302	250	151

Table I.8. Assumptions regarding emissions and relative global warming potential

Constituent	Value	Relative GWP		Reference
		Over 20 years	Over 100 years	
Particulates (kg/t)	3			EPA 1992
Carbon monoxide (kg/t)	17	1	1	EPA 1993
Methane (kg/t)	3.2	72	25	EPA 1994
Non-methane (kg/t)	10			EPA 1995
Carbon dioxide (kg/t DM)	1550			IPCC 2006
Nitrous oxide (kg t/DM)	0.06	289	298	IPCC 2006
NOx (kg t/DM)	1.1	247	97.88	IPCC 2006

Appendix J: Examples of data for comparison with the derived values.

Table J.1 Selected input data for UK biomass for fuel from Miscanthus and Willow SRC (quoted Brandão et al 2010 and based on Elsayed et al., 2003 and BEAT2 (2009).

Input	Miscanthus	Willow SRC
Net yield at traded moisture content (t ha^{-1} yr^{-1})	18	14
Traded moisture content (%)	30	50
Yield of biomass (odt ha^{-1} yr^{-1})	12.6	7
N fertiliser (kg N ha^{-1} yr^{-1}) (Ammonium nitrate)	5.26	0
P fertiliser (kg P ha^{-1} yr^{-1})	4.82	0
K fertiliser (kg K ha^{-1} yr^{-1})	5.07	0
Lime (kg C ha^{-1} yr^{-1})	157.89	0
Diesel fuel consumption in cultivation (MJ ha^{-1} yr^{-1})	477	440
Diesel fuel consumption in harvesting (MJ ha^{-1} yr^{-1})	1,158	308
Diesel fuel consumption in handling (MJ ha^{-1} yr^{-1})	847	39

Table J.2 Estimates of costs and volumes within the UK MARKAL technology-focused energy systems dynamic cost optimisation model (Jablonski et al 2010).

	Cost (£ GJ^{-1})	Volume (PJ a^{-1})
Domestic wood (poplar, willow)	1.50-2.10	39
Domestic grass (miscanthus)	1.80-2.90	35
Domestic straw residue	2.00	8
Imported wood pellets and woodchips	4.30-4.90	4-121

Table J.3 Estimates of costs of pelletisation (Jablonski et al 2010).

	Efficiency (%)	Investment costs (£ per year per GJ)	Fixed O&M costs (proportion of total investment) (%)
High quality pellets (wood feedstock)	97	8.60	4
Low quality pellets (grass feedstock)	97	6.10	4

Table J.4 Estimates of efficiency and costs of end use of pellets and woodchips (Jablonski et al 2010).

	Technical efficiency (%)	Investment costs (£ per kW_{th})	Fixed O&M costs (proportion of total investment) (%)
Pellets boiler (residential sector)	90	240	3
Woodchips boiler (residential sector)	60-85	200-260	3-10
Pellets boiler (service sector)	90	240	3
Woodchips boiler (service sector)	85	260	3

Appendix K: Key features of the financial analysis (redacted)

Appendix L: Letters of support (redacted)

Appendix M: Sampling and analysis methodologies (redacted)