Wetland Conservation Biomass to Bioenergy
End User Report

A DECC funded project

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Contents

1. Executive Summary 6
1.1 Quick Reference Guide 7
2. Introduction 8
3. Harvesting 9
3.1 Machinery specification/comparison 9
3.2 Choosing the right kit for the job 23
3.3 Harvesting decision making tree 30
3.4 Exchange of information 31
4. Monitoring the effects of vegetation cutting and removal 32
4.1 Monitoring the impacts of mechanical harvesting on vegetation 32
4.2 Monitoring the impacts of mechanical harvesting on soil structure 33
4.3 The most effective harvesting pattern 34
5. Turning your biomass into energy 37
5.1 Realising the potential of your biomass 37
5.2 Biomass characteristics 40
5.3 The principles of moisture content and calorific value 42
5.4 Storage and drying 42
5.5 Ensiling 48
5.6 Grazing animals and biomass harvesting 49
5.7 Yields 50
6. Conversion technologies 53
6.1 Combustion 53
6.2 Anaerobic Digestion 70
6.3 Bio-charring 76
6.4 Conversion machinery/technology access requirements 79
7. Energy delivery 80
7.1 Biomass boiler 80
7.2 Combined heat and power engine 83
7.3 Supplying existing conversion plants 84
8. Life Cycle Analysis 85
8.1 Green house gas savings 85
8.2 Biomass energy efficiency 86
8.3 LCA results from the DECC projects 86
9. Which conversion technology is right for you? 87

9.1 Conservation biomass calculator ... 87
10. Funding ... 88
10.1 Feed in Tariffs (FiTS) ... 88
10.2 Renewables Obligation (RO) ... 88
10.3 Renewable Heat Incentive (RHI) ... 89
11. Permissions and Regulatory Requirements ... 92
11.1 Planning Permission ... 92
11.2 Waste Management ... 93
11.3 Grid Connection ... 97
12. Framework and structures to facilitate delivery ... 98
12.1 Payment for Ecosystem Service Approach ... 98
12.2 Energy for Nature ... 99
12.3 Models, frameworks and administrative structures ... 100
13. References ... 106
14. Useful contacts ... 108
15. Acknowledgements ... 109
16. Appendices ... 110
Appendix 1 Monitoring Protocol ... 110

Tables

Table 1 Machine transport dimensions 22
Table 2 Machinery comparison 23
Table 3 Wetland biomass characteristics 40
Table 4 Heathland biomass characteristics 41
Table 5 Passive rush bale drying trials 44
Table 6 Wetland habitat biomass yields - RSPB 50
Table 7 Wetland habitat biomass yields - other 51
Table 8 Heathland habitat biomass yields 52
Table 9 Bulk density 55
Table 10 ISO standards comparison 67
Table 11 A basic comparison of the two briquetting methods, linear and rotary. 69
Table 12 Wetland material characteristics for AD 70
Table 13 Small scale AD outputs 72
Table 14 Medium scale AD outputs 74
Table 15 Charred biomass calorific value comparison 76
Table 16 Conversion technology transport dimensions 79
Table 17 DECC project LCA results 86
Table 18 Delivery administrative structures 105
Table 19 Useful contacts 108

Diagrams

Diagram 1 Harvesting decision making tree 30
Diagram 2 Briquetting of material without any processing – process diagram 59
Diagram 3 Briquetting material after hydrothermal treatment – process diagram 62
Diagram 4 Medium scale anaerobic digestion process diagram 75
Diagram 5 Mark III bio-char kiln flow diagram 78
Diagram 6 DEFRA decision making tree 94
Diagram 7 General framework of the Land Manager Energy for Nature model. 102
Diagram 8 General framework of the Community Energy for Nature model. 104

Graphs

Graph 1 Relative cost per hectare for cut and bundle systems 28
Graph 2 Relative cost per ha for cut and collect systems 28
Graph 3 Kiln temperature ranges during gorse drying trials 45
Graph 4 Kiln temperature ranges during heather drying trials 46
Graph 5 Calorific value comparison 63
Graph 6 Nitrogen oxide comparison 64
Graph 7 Particulate matter comparison 65
Graph 8 Ash content comparison 65

Photographs

Photo 1 Truxor with rake 9
Photo 2 Softrak 65hp with Universal forager 10
Photo 3 Softrak 120 with Ehlo forager 11
Photo 4 Seiga harvester 11
Photo 5 Pisten Bully Greentech & Kemper header 12
Photo 6 The reconditioned Fenland Harvester 13
Photo 7 Olympia mower binder 14
Photo 8 The straight cutting blades of the Universal 14
Photo 9 The jay cutting blades of the Ehlo 15
Photo 10 Kemper header 16
Photo 11 Reed cutter bundler 17
Photo 12 Single chopped reed 18
Photo 13 Double chopped reed 18
Photo 14 Precision chopped reed 18
Photo 15 Tracked dumper truck 19
Photo 16 The Fenland during adaptations 20
Photo 17 Hydraulic powered rubber tracked trailer 20
Photo 18 The sledge cableway 21
Photo 19 The sledge cableway in operation 21
Photo 20 Vegetation monitoring 32
Photo 21 Soil sampling 33
Photo 22 Infiltration test 34
Photo 23 Rejuvenation reedbed management 35
Photo 24 Conservation biomass 37
Photo 25 AgBag for storage and drying 42
Photo 27 Heather sample before kiln drying (left) and after drying (right) 47
Photo 28 Dried heather being lowered out of the kiln 47
Photo 29 Silage being made in a silage pit 48
Photo 30 Silage cutter 48
Photo 32 Pelleting 53
Photo 31 Briquetting 53
Photo 33 Guntamatic boiler auger feed 54
Photo 34 Wetland biomass rotary briquettes 55
Photo 35 Burning rush briquettes. 57
Photo 36 Press-cake briquettes 60
Photo 37 Rotary briquetter in operation 68
Photo 38 Small scale AD 71
Photo 39 Medium scale AD 72
Photo 40 MK III bio-char kiln 77
Photo 41 Biokompakt AWK98 80
Photo 42 Feeding briquette wafers 81
Photo 44 Ash box after 24 hrs burning loose material (left) briquette wafers (right) 81
Photo 45 Installation of a Guntamatic boiler & 2,000L buffer tank 82
Photo 46 powerQube 83

1. Executive Summary

Many habitats managed for the purpose of nature conservation are dynamic systems and maintaining them as such places a huge demand on resources and typically produces high yields of harvested material that is currently surplus. Conservation land management commonly involves removing unwanted vegetation by cutting, which it is not possible to remove by grazing. In many situations, there is currently no commercial market for this cut vegetation (for example, rushes *Juncus* spp, and reeds *Phragmites australis* which are unsuitable for thatching), meaning that the inability to dispose of this material can limit the amount of vegetation cut, and therefore limit the ability to achieve conservation targets. However, this cut material has the potential to generate an income through the production and sale of bioenergy products. Conversion of otherwise unwanted biomass to bioenergy products also has the benefit of reducing fossil fuel use.

The Department of Energy and Climate Change (DECC) has recognised this opportunity by funding the Wetland Biomass to Bioenergy Project. Through this project a number of end-to-end processes were developed, from harvesting of the unwanted material to its final, marketable bioenergy product, for example as briquettes or bio-methane via anaerobic digestion. At a time when the Government is seeking alternative, but economically viable, means of generating energy, and striving to meet important biodiversity targets whilst not reducing food production, exploring these possibilities makes good economic, as well as ecological, sense.

This report provides details of each aspect of the end-to-end processes explored. It also provides information on life cycle analysis, sources of funding, necessary permissions, and frameworks to facilitate delivery. This is with the overall aim of assisting land managers with the decision making required when aiming to convert their unwanted biomass into bioenergy.

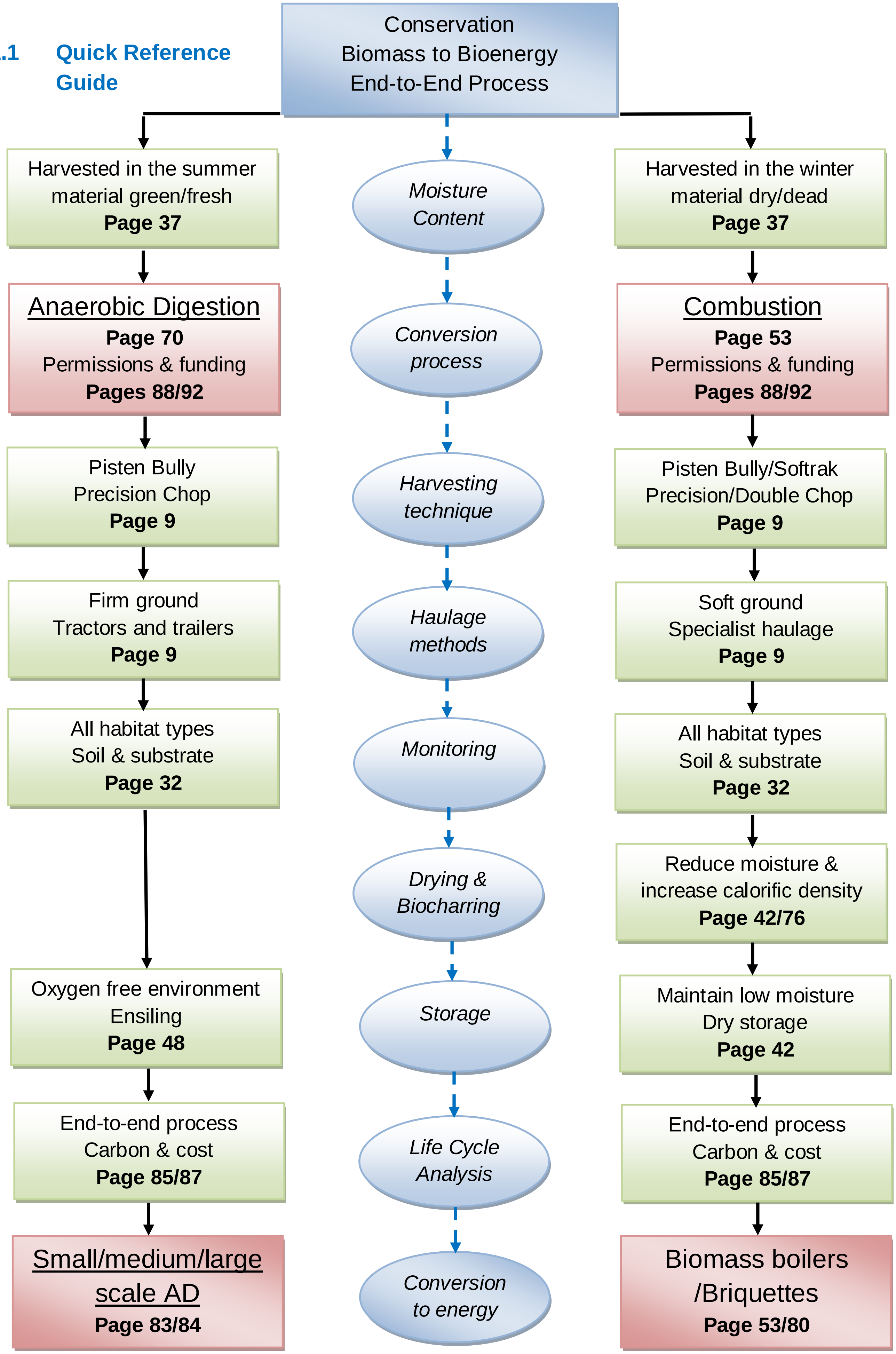
The report describes three different conversion techniques, anaerobic digestion, combustion and bio-charring, and explains their applicability for different types of biomass. The section on harvesting covers specifics on a range of machinery and attachments and looks at their utilisation in harvesting material for the supply of bioenergy systems. Means of transportation of biomass are explored, together with different techniques of drying and storage. Methods for monitoring of the effectiveness of converting biomass to bioenergy are also described, with details on how to assess the impacts of mechanical cutting and collection on vegetation composition and soil structure.

Efficiency of the processes are discussed, both from an economic and carbon perspective. Site specifics pay a significant part in this aspect, which means that only high level guidance can be provided on the areas that need to be considered when selecting an end-to-end process. This is also the case with the section on permissions and regulatory requirements, with pointers given on areas that will need further investigation on a site-by-site basis.

On the ground delivery is considered towards the end of the report, which includes a section on a ‘Payment for Ecosystem Services’ approach. This describes a project developed through a DEFRA pilot scheme, ‘Energy for Nature’, which suggests methods of delivery and the possible relationships, frameworks and payment structures which could be used for practical application of the end-to-end processes developed.

Conservation biomass comes in many forms and types, and with the level of detail provided in the sections of this report, the conversion of this material into energy may appear a complicated process. Whilst the devil is always in the detail, to produce the most effective and efficient system there are some guiding principles that have been summarised in the Quick Reference Guide on the following page.

1.1 Quick Reference Guide



2. Introduction

The Wetland Biomass to Bioenergy Competition was a project which was born out of the Department of Energy and Climate Change's (DECC) UK Bio-energy Strategy (April 2012). In this strategy DECC identified the need to source new feedstocks for bioenergy, which sat within the limits outlined in their sustainability criteria. This states that the production of biomass for bioenergy must take into account impacts on other areas such as food production and biodiversity. Specifically it must not pose a threat to food security, in the UK or internationally or present risks for biodiversity and ecosystems through loss of semi-natural and natural habitats (such as forest clearance), intensification of agricultural production and the potential introduction of non-native invasive species.

The Wetland Biomass to Bioenergy Competition aimed to demonstrate the untapped potential of using biomass produced on nature reserves generated from habitat management works as a possible energy feedstock. It was designed to encourage business and academia to develop a solution for the end-to-end delivery. To design, build and procure the technology needed to create and deliver the complete process from wetland harvesting through to energy production in an energy efficient way.

The project was delivered in 3 phases; Phase 1 commenced January 2013 and concluded March 2013. Phase 2 ran between May 2013 and March 2014, with Phase 3 concluding the project, taking place between April 2014 and March 2015.

The project was undertaken in three geographical wetland areas which were selected based on habitat diversity, scale and complexity, they were:

- The Somerset Levels and Moors.
- The Broads, Fens and Suffolk coast.
- Northern and Eastern Scotland.

Within each of these areas there were consortiums of conservation land managers who provided the sites and biomass needed for the trials and demonstrations undertaken throughout Phase 2 and Phase 3.

Initially 14 applications were submitted for Phase 1 of the project, a large percentage of these were consortiums of applicants, with expertise from academia to engineering. From the 14, seven were selected to proceed to the feasibility stage and were provided with funding to undertake this work. From these seven, three applicants were chosen to receive funding for Phase 2. During this phase, the competition element was removed by DECC and the same three applicants continued through to complete the project to the end of March 2015.

The three successful applicants employed a diverse range of approaches, which have provided the foundations for this report. It aims to cover all the aspects explored in the delivery of the end-to-end wetland conservation biomass into bioenergy process. This report looks to bring together the lessons learnt and experienced gained through the DECC project to facilitate practical application of biomass to bioenergy techniques. The information has been compiled as a portfolio of techniques for land managers, who are considering the conversion of the biomass generated from their land management practices into an energy product. It is an attempt to provide a solid foundation and background on which decisions can then be made on how to proceed and which options to explore further. It is hoped that this information can be used alongside the Wetland Conservation Biomass Calculator to facilitate the use of the tool and to provide the additional detail needed to aid the decision making process.

3. Harvesting

Reasons for the harvesting of conservation wetland materials will be driven by key biodiversity targets. In the case of wet grasslands this may involve the cutting and removal of soft rush to reduce dominance and prevent nutrient build up. For reedbeds, common reed may be harvested in the summer again to reduce dominance or in the winter to create a diverse age structure, create open areas, reduce litter build up and prevent drying out. The nature of the habitat itself will influence which harvesting techniques are employed, for example clearing vegetation in reedbed ditches would probably be best executed with an amphibious machine. The type of substrate and water levels may dictate whether the machinery has to be tracked or not, together with the site specific access limitations. The frequency of cutting and removal will affect machinery selection, with some machines having a limit to the age of vegetation they can deal with. How the material is to be utilised will also influence the decision, especially in the attempt to prevent double handling and to collect the material in the most appropriate form. This latter point may specifically apply to issues such as chop size or moisture content, which are covered in sections to follow.

3.1 Machinery specification/comparison

3.1.1 What are the different machines and what are they designed to do?

The Truxor[1] is a machine which is now regularly used at a number of wetland sites, particularly for the management work needed to keep open water and ditches clear of vegetation. It is essentially a floating cutter, which uses a 1.7m to 2.1m reciprocating cutter bar that can be raised or lowered. The cutter bar can be removed and a rake attachment fitted. The machine has tracks which double up as paddles when in the water and so it can travel on both dry and wet substrates, which facilitates its movement around a site. Between sites it is easily transported on a trailer towed by a 4x4 and works most efficiently in a water depth of 30-50cm. The Truxor, including operator, costs around £600 to £700 per day to hire. (2015)

Estimates suggested that the Truxor (operated by a contractor) could cut a hectare of reed in about 40 hours (250m^2/hr) for a price of £2-3,000/ha. Detailed costings prepared during work at Ham Wall in 2004 varied between 166m^2/hr (£3,700/ha) and 62m^2/hr (£9,900/ha), with the greatest costs on a compartment of 8-year old reed with dense litter. By contrast, staff at Minsmere calculated work rate and costs to vary from 275m^2/hr (£2,400/ha) to 187m^2/hr (£3,500/ha). Clearance of 5m wide ditches was calculated at between £240 and £625 per km. The differences above can in part be attributed to varying habitat density, age, location and structure.

Photo 1 Truxor with rake

The varying costs need also to be carefully evaluated not only against the condition of the area to be cleared (notably the amount of litter and the distance it needs to be moved) but also the end result. Where the Truxor is working in ample water, the cutting and raking operations are likely to be quicker. However, when working in water of around 30cm depth, the machine retains some contact with the underlying bed. This increases its speed and power but also crushes and breaks up rhizomes, and in

[1] Information source - Bringing Reedbeds to Life; creating and managing reedbeds for wildlife Blyth, S, Self, M, White, G, 2014.

consequence, increases the rake-up time and overall cost. This action is likely to set back the reedbed succession significantly and the costs should be compared more with restoration techniques such as bed lowering rather than management that is more regular. At Ham Wall, open areas of water were created which remained for up to ten years by deliberately damaging the rhizome layer as the reeds were cut. The Truxor may therefore have more flexibility than currently appreciated, with depth of water being critical to the management objectives. Although there are concerns that the Truxor lacks power, is not robust enough for the job and disposal of the arisings after raking is problematic, this has proved to be a versatile machine for regular reed and ditch maintenance as well as minor restoration projects. It is particularly useful where land access to the reedbed is impossible.

<u>*Key Facts*</u>

- *The machine is easily transported on a trailer towed by a 4x4.*
- *The Truxor works most efficiently in a water depth of 30-50cm.*
- *Cutting width of the reciprocating cutter bar 1.7m to 2.1m.*
- *The Truxor, including operator, costs around £600 to £700 per day to hire (2015).*

The Loglogic Softrak 65hp[2] is a multi-purpose, rubber-tracked all terrain vehicle, with a very low ground pressure (1.2psi). Provision for front or rear-mounted 3-point linkage allows ancillary machines eg a flail, to be operated. Although not amphibious, it can cope with very wet ground, although cutting in such conditions may be slow.

As with other machines, cutting rates vary with the ground conditions. At Ham Wall, an average cutting rate is one hectare of reed in approximately 40 hours ($250m^2$/hr). However, wetter, denser sections take up to four times as long. By contrast, dryer, sparser reed at Radipole Lake was cut much quicker. The Softrak is a flexible machine capable of dealing with dryer, older stands of reed typical of later stages of succession. It has the distinct advantage of collecting as it cuts, as it has an $8m^3$ bin on the back into which the material can be blown. Repeated tracking to remove the arisings requires a firm access route. The distance that the material is being moved is also a factor that needs to be considered as if being hauled for long distances then the time this takes will dramatically lower the cutting rate.

Photo 2 Softrak 65hp with Universal forager

<u>*Key Facts*</u>

- *The machine is 3,300mm long, 2,100mm wide and 2,240mm high.*
- *The ground pressure un-laden is 1.2psi, with a base machine weight of* 2,200kg*, and a single chop forager weight of approx 400kg.*
- *Cutting width using Universal single chop forager at 1,300mm.*
- *The basic base machine costs £65,664 (2015).*

[2] Information source - Bringing Reedbeds to Life; creating and managing reedbeds for wildlife Blyth, S, Self, M, White, G, 2014.

The Loglogic Softrak 120hp was first produced in the UK in 2014. It is based on the original 65hp machine with rubber tracks and cleats and has been designed to work on soft and delicate ground. Compared to the original smaller Softrak machine, the higher powered Softrak 120 is fitted with longer Bridgestone rubber tracks at 600mm wide, which provide a more stable ride through being able to cope with uneven terrain better. The Softrak 120 is fitted with an Ehlo double chop forager, which blows material in to the $11.2m^3$ collection bin at the back. The machine is well balanced and the collection bin is positioned so that the centre of gravity is maintained near the middle of the tracks. The aim is to keep the weight evenly distributed when the bin is fully laden, resulting in lower ground pressure.

Photo 3 Softrak 120 with Ehlo forager

To address the over heating issue that was sometimes experienced with the original 65hp machine, on the 120hp version there are extra large intake grills which are designed to catch particles without causing blockages. The machine is also fitted with a reversible fan to clean off any debris that collects.
Trails through the DECC project produced the following throughput figures:

- Harvesting reed - 1ha in 2hours 30minutes.
- Harvesting rush - 1ha in 1hour 30minutes.

** Please note all harvesting times are without haulage.

Key Facts

- *The machine is 3,799mm long, 2,250mm wide and 2,568mm high.*
- *The ground pressure un-laden is 1.35psi, with a base machine weight of 2,900kg and a double chop Ehlo forager weight of approx 980kg.*
- *Cutting width using double chop Ehlo forager at 1,700mm.*
- *A new 120hp Softrak base machine costs £96,305 (2015).*

The Seiga Harvester[3] is a large 6-wheeled self-propelled amphibious machine with a 3m long reciprocating blade mounted on a cargo rig with a deck area of 4m x 3m and a capacity of 1-2.5 tons. It is a specialised and efficient reed cutter, seemingly working best on flattish, firm ground in large single/double wale reedbeds. In such conditions, costs may range from £600-800/ha. The Seiga is designed for the cutting and bundling of reed, with two/three people required to operate it. It is capable of cutting and tying 2,000 bundles of reed daily (1-1.5ha).

Photo 4 Seiga harvester

[3] Information source - Bringing Reedbeds to Life; creating and managing reedbeds for wildlife Blyth, S, Self, M, White, G, 2014.

The Seiga Harvester is unsuitable for reed stands over 4 years since previous harvesting, as the accumulated litter causes problems for the cutting blade and bundling mechanisms. Although amphibious and with low ground pressure, it appears that this blade/rig combination would not be ideal in very wet sites. The Seiga may hold succession where single/double wale is employed but will not reverse succession, nor remove litter. The Seiga may only be suitable for extensive flat reedbed sites. Due to its size, most UK sites are likely to be too small and intricate for it.

<u>*Key Facts*</u>

- *The machine is 3,000mm long, 3,000mm wide c.3,000mm high.*
- *A new machine will cost c£100K (2015).*
- *Annual maintenance may be around £9K.*
- *Cutting width using reciprocating blade at 1,200mm.*
- *A low-loader is required to transport it between sites and a movement order is required.*
- *The ground pressure un-laden is <1.5psi.*

The Pisten Bully Greentech is a 330hp German machine, developed for the grooming of ski slopes. The machine adapted for the DECC project has rubber tracks with metal cleats, these have pros and cons. They are excellent for substrates which aren't delicate, as the metal cleats provide the capability of being able to pull the machine out of soft areas, reducing the risk of getting stuck. However their aggressive nature means that they are more likely to cause damage. Rubber tracks and rubber cleats are available but are yet to be trialled. It is felt that these may be more suitable for softer and delicate substrates, but also for smaller areas, when frequent turning is often necessary.

Photo 5 Pisten Bully Greentech & Kemper header

The Pisten Bully has shown to be very capable of harvesting a number of vegetation types, including dense 15-year old common reed with a deep litter layer, thick soft rush tussocks and mixed fen vegetation. The harvester operates a Kemper header (typically used for harvesting maize) to cut, chop and collect the material into 4.3 to 33mm size pieces with a cutting width of 3,000mm. All harvested material is then propelled and collected in the 16m^3 bin at the rear, which once full can be hauled to a collection point for processing.

Trails through the DECC project produced the following throughput figures:

- Harvesting reed - 1ha in 2hours.
- Harvesting rush - 1ha in 1 hour.

** Please note all harvesting times are without haulage.

<u>*Key Facts*</u>

- *The machine is 6,000mm long, 3,500mm wide 4,200mm high.*
- *The ground pressure un-laden is 1.4psi, with a base machine weight of 6,700kg and a Kemper header weight of approx 2,350kg.*
- *Cutting width using Kemper header at 3,000mm.*
- *Reconditioned Greentech machines cost £109,000 (2013).*

The Reconditioned Fenland Harvester is a machine which was originally built for the Broads Authority back in the early 2000's. After 10 years cutting in the Broads, it has been bought by AB Systems Ltd, who has since reconditioned it, replacing the original 73.5kW engine with a reconditioned 120hp one and developing the feed and cutting system. It has a double reciprocating knife at a width of 2,250mm, which produces material of a similar size to a precision chop cutting head at 25-40mm in length. The original harvesting rate was quoted to be up to 0.3ha/hr with a variable cutting height from 0 to 300mm. The bin at the rear can take $8m^3$ of material. Although the harvest rate of the reconditioned machine is still similar, the feed has been improved through widening the feed area easing the intake of material into the feed rollers.

<u>*Key Facts*</u>

- *The machine is 4,880mm long, 2,250mm wide 3,256mm high.*
- *The ground pressure un-laden is 1.5psi, with a machine weight of 3,700kg.*
- *Cutting width using double reciprocating knife at 2,250mm.*
- *Machines not currently available to purchase and have been superseded by the Softrak 120hp.*

Photo 6 The reconditioned Fenland Harvester

The Olympia mower binder[4] is the favoured machine for commercial thatching reed-cutters due to its cutting and bundling ability. The mower has a 9HP diesel Lombardini engine and is pedestrian operated, with a mowing width of 1,370mm. The weight is 435kg. The Olympia can work in up to 9" of water but requires reasonable ground conditions. It can cut 1,000 bundles a day (0.75ha), with the bundles left on the bed ready for collection, and costs £8,500 + VAT. Like the Seiga, it can only cope with beds up to 4 years since previous cutting.

As a hand-operated machine there is the requirement to consider the appropriate health and safety issues, particularly in relation to the vibration regulations. Hand Arm Vibration Syndrome (HAVS), form the basis of the vibration regulations, and how hand-operated mowers perform under these regulations will vary and will be affected by factors such as age, condition, history of usage etc. However a standard reciprocating mower can only be used for 2hours before Exposure Action Value (EAV) and perhaps 3hours to Exposure Limit Value (ELV). Under the regulations, staff using the machine above the EAV will require health screening by occupational health. Although RSPB does not have figures specifically for the Olympia mower, experiences with other mowers are recorded. For the Rapid Mondo mower vibration was exceptionally high with an ELV of 17minutes. However, the Grillo GF1 produced an EAV of 1hour 4minutes and a resulting ELV of 4hours 18minutes.

As a result these restrictions will greatly affect the value and application of pedestrian mowers when undertaking any extensive management. Any harvesting that would take longer than 3 to 4hours of machine usage achieving a work predicted rate of 0.4ha, would need to involve a number of operators to rotate usage to stay below the determined values. The other point of note is that once the cutting has been undertaken it is estimated by staff that it takes at least twice as long again to remove the bundles off

4 Information source - Bringing Reedbeds to Life; creating and managing reedbeds for wildlife Blyth, S, Self, M, White, G, 2014.

site. Whilst this time is determined by how close a collection trailer can be taken to the bundles, at this point all material has to be moved by hand.

Photo 7 Olympia mower binder

Key Facts

- *Machine weight is 435kg.*
- *Cutting width at 1,370mm.*
- *Harvest rate at 1,000 bundles a day*
- *A new Olympia costs £8,500 + VAT (2015).*
- *Vibration regulations need to be considered.*

3.1.2 What are the different attachments and what is their role in assisting the after use?

The type of attachment selected will be determined by a number of points, such as:

1. Machine running the attachment and the power available.
2. Site/habitat conditions – eg reed age, access, water control, substrate.
3. Type of vegetation to be harvested.
4. The desired after use of the biomass.

The Universal single chop direct cut forager is a flail mower attachment which can cope with tussocky, multi-species swards. During flailing, the biomass is cut to lengths of approximately 150-300mm. The biomass is sucked and then blown into a collection vessel to the rear of the harvester. Due to this harvesting method when using the single chop forager; there is a tendency to suck up water if it is operating in wet conditions.

However these types of foragers are sturdy, with a flail rotor and heavy 1.4kg two-piece flails made from hardened steel. The flails are mounted independently and easily maintained, as only the worn tip usually has to be replaced. The patented flail suspension causes centrifugal force to lock the flails during operation and as a result provides high cutting power even in heavy crops. However, the flails automatically swing back to avoid damage when they encounter stones or similar hard resistance.

Photo 8 The straight cutting blades of the Universal

Key Facts

- *The Universal Direct Cut (DC) 1,450 single chop forage harvester has a cutting width of 1,450mm.*
- *The power needed to operate a double-chop attachment can be provided by a 65hp Softrak.*
- *A new Universal Direct Cut (DC) 1,450 single chop forage harvester costs £13,852 (2015).*

The ELHO TC 1700 double chop forage harvester similar to the single chop, cuts and collects the biomass by using a ‘sucking’ action to take it onto the first flail roller. It is then effectively cut again (hence double chop), on another flail inside the attachment and then blown out in a collection bin at the rear to a trailer. During flailing, the biomass is cut to lengths of approximately 40mm-65mm which is ideal for drying purposes (i.e. briquette development). The chop length is adjusted by the number of knives.

- 12 knives produce approximately 40 mm.
- 6 knives produce approximately 50 mm.
- 3 knives produce approximately 65 mm.

This cutter is robust and tends to bounce off hidden tree stumps or stones which may cause damage to other cutters. However one downside of these cutters is their tendency to collect unwanted debris through the sucking mechanism; this can be in the form of soil, stones or water. Depending on the future use of the material will determine whether contamination is deemed a problem. For example it would not be desirable in a wetland situation where additional water may be collected if the material is going to be used for straight combustion. However, this may not such an issue if the material is used for anaerobic digestion or combustion after hydrothermal treatment.

The robust design of the jay bladed double chop has been found to cope well with mixed vegetation types and sizes. The jay blades at the front of the forager cut and shorten the material, before it goes into the second chopping cylinder. This makes the processing action very efficient, particularly with short scrubby vegetation. A singe chop machine has straight, flat blades which all cut at the same time, cutting the material to the same length. This not only takes a lot of power for all the blades to cut at once, but also relies on more suction to propel the material.

Photo 9 The jay cutting blades of the Ehlo

By comparison the jay blades are curved, and as a result cut the material at different lengths at different times. The curve of the jay blade is designed such for two reasons:

1. Their action results in different cutting times and different lengths of material, multiple cuts of the same stem are made resulting in short stems with reduced effort. As the blades are not all cutting at once the power consumption is more even and does not demand a surge.
2. The curve of the blades encourages the collection of the chopped material which reduces the suction required, again reducing power consumption, and potentially contamination. The design means that the blade does not need to pass through the vegetation a long way, as the jay blade deposits the cut vegetation and then collects it. The trough which houses the auger is situated behind and is lower than the flail head, so instead of throwing the material back on the ground it is caught before it reaches the ground.

<u>*Key Facts*</u>

- ➢ *The ELHO DC 1,700 double chop forage harvester has a cutting width of 1,700mmm.*
- ➢ *The power needed to operate a double-chop attachment can be provided by a 120hp Softrak, but not by a 65hp.*
- ➢ *A new ELHO DC 1,700 double chop forage harvester costs £16,891 (2015).*

The Champion Kemper cutting head is a precision chop and is capable of chopping the material from 30mm down to 4mm, which means that it has the versatility to present the material in the necessary form required for a range of after uses. This type of forage harvester will cut the biomass material and take it through rollers to a chopping fly-wheel. The size of cut is controlled by the speed of the input rollers and the number of blades installed. The Kemper head has a rotary intake which feeds the standing material in a vertical direction towards the chopping mechanism. Rather than through suction like the single and double chop machines, this collection action means that limited contamination materials, eg sand, stones or water are taken up. The material then reaches a high speed chopping wheel with a maximum of 12 blades, which achieves the chop quality. As a result harvesting is more controlled and material collected in a more predicted state, eg the moisture content of the material is as per the standing crop.

Photo 10 Kemper header

However it has been shown from the initial trials that the header seems to require dense vegetation and has a tendency to be unable to cut and collect in thinner stands. On wetland sites it was also found that the mechanism can jam if the header is taken too low into dense common reed litter and to get a clean cut can tend to leave stubble and litter behind.

The cutting mechanism can be adjusted to achieve different lengths of cut material which is achieved by altering the number of blades on the cutting wheel and gear selection as per the table below:

Gear	**1**	**2**	**3**	**4**
12 blades	4.3mm	5.4mm	6.5mm	11mm
6 blades	8.6mm	10.8mm	13mm	22mm
4 blades	12.9mm	16.2mm	19.5mm	33mm

Key Facts

- *The Kemper header has a cutting width of 3,000mmm.*
- *The power needed to operate a precision chop Kemper header is a total of 150hp to drive the Kemper and the machine itself.*
- *Due to the weight of the header at 2,000kg, a further 2,000kg has to be added to the rear of the Pisten Bully, through the use of weights.*
- *A reconditioned Champion Kemper cutting head costs in the region of £27,300 (2013).*

Reed cutter bundler

The reed cutter bundler attachment that cuts and bundles reed fits onto a 65hp or 120hp Softrak. The reaper-binder is a modified BCS harvesting head which is mounted on the Softrak front linkage system. From the cutting head a conveyor which sits on the side of the machine transports the bundles to the rear. The bundles can then be stacked loosed onto the bed or loaded into the baling frame to form a 1,200mm diameter x 2,400mm long bale, comprising 80 bundles. This will not only give the capability of cutting reed for thatching, but also to cut it in a form which can then be stacked in bundles and bales to air dry.

This machine offers an alternative way for the cut material to be stored, enabling it to be used later for straight combustion. This machine is still under trial however the reported throughput depending on conditions is estimated at 20 to 25 bundles per minute. It is felt that this machine would struggle to harvest reedbeds over 3 years old.

Key Facts

- *The machine has a working width of 1,400mm.*
- *The BCS cutting head has a cutting width of 1,270mm.*
- *The power needed to operate this attachment can be provided by a 65hp Softrak.*
- *A new reed cutter binder harvester costs £13,231 (2015).*
- *A new reed baler, producing 1,200mm x 2,400mm bales costs £5,027 (2015).*

Photo 11 Reed cutter bundler

3.1.3 The importance of the material chop-size

The way in which the material is harvested on site is inextricably linked to the desired after use, this is illustrated well in relation to material chop-size. As described above the different heads and chop capabilities should be employed to produce the condition of the material needed. Some conversion technologies are 'less fussy' than others, but some have very little tolerance and material that is of the wrong length can prohibit its use. To overcome material being too long once harvesting has taken place is not impossible, but would involve double handling and extra processing which will have cost and carbon implications.

Photo 12 Single chopped reed

The rule of thumb is that for most anaerobic digestion processes that are dealing with solid material (rather than liquid) the particle size needs to be as small as possible and definitely that harvested with a precision chop rather than a double chop. However if harvesting can only be undertaken with a double chop then a mixer shredder can always be employed to down-size the material further. Although anaerobic digester systems have macerators they are typically equipped to macerate already finely chopped material. Longer cut lengths can be problematic and serve to block up the system.

Photo 13 Double chopped reed

Experience from the DECC project both with Natural Synergies Ltd and Future Biogas, was that material longer than 8mm in length would not be accepted for anaerobic digestion plants. However when supplying material to the anaerobic digester at Wyke Farms, Somerset, both double and precision chopped summer cut reed was accepted.

However for briquetting material using a rotary briquetter, longer lengths like those produced from a double chop forager can be favourable, as they help to bind the briquette together.

Photo 14 Precision chopped reed

However for a linear briquetter shorter lengths are easier to compact, with less spring. Longer material can aid the drying process as it has more structure and tends to support air cavities that aid circulation and so facilitates drying.

For combustion the chop size of the material will potentially have implications for the following:

- **Pellet production**: Material needs to be finely chopped and ground so that it is able to pass through a 5mm to 10mm screen,
- **Briquette production**: Double chopped can help with the binding of material into a briquette when a rotary briquetter is used. The screens used for briquettes are in the region of 30mm.

– **Loose material and auger feed**: For feeding directly into biomass boilers ideally the chop size is between 25mm and 50mm.

The other factor for consideration is that the smaller the chop size of the material the greater the bulk density, which means that more volume can be collected into the harvesting bin or trailer reducing frequency of haulage trips required. Due to the smaller chop of the material produced by the precision chop machine the bulk density measurements are much higher that those for the double chop. In the cases of some material types the differences in volumes can be large and when analysis was done on wetland material, specifically 1-year old common reed it was found that there was 39% more precision chopped material per cubic metre (measured by weight) than double chopped material. When multiplied up by the different bin volumes this would result in a dramatic difference in the material that could be hauled at one time.

The resulting bulk density measurements from those trials were as follows:

– Dry precision chopped reed - bulk density = 54kg/m^3
– Dry double chopped reed - bulk density = 39kg/m^3

3.1.4 The movement of material off the harvested area

Depending on the size of the area being harvested and the distance that the material needs to be hauled, it may be preferable to use a haulage machine alongside the harvester. This means that the time of harvesting is maximised and that an expensive harvester is not being used to haul for long distances. The costs of hiring a haulage vehicle rather than a harvester will be much reduced. This is a practice widely used in the agricultural industry and even if the harvester is sat waiting for a short time whilst the haulage vehicle returns it is more cost efficient.

Haulage vehicles can come in many forms, even the 120hp Softrak has been utilised when working alongside the Pisten Bully. Loaded with precision chop material, more volume can be carried. Whilst hauling is taking place, the Pisten Bully then has the capability of loading itself; this reduces using the most efficient harvester for haulage.

Tracked dumper trucks are typical haulage vehicles, one has been developed by AB Systems Ltd, this has a bin capacity of 16m^3 and although a short track length which can make it prone to getting stuck in very wet conditions its rubber tracks mean that it can travel on tarmac/metalled surfaces without causing damage and has a lighter tread on soft ground.

Photo 15 Tracked dumper truck

The **Fenland Blower** was originally developed for the Broads Authority back in the early 2000's at the same time as the Fenland Harvester. It was a machine which worked alongside the harvester and was developed to blow the cut material from the marsh down a long pipeline as a way of moving the material avoiding haulage. This machine again was built using Loglogic technology and so its performance on soft ground is excellent. The base machine of the fen blower has now been adapted by AB Systems Ltd as a haulage machine.

Using Softrak technology this haulage vehicle offers low ground pressure and long tracks, resulting in very little impact on the substrate. The machine now has 22m^3 bin on the rear for the collection of material. This machine also has the capability to drive other attachments due to its design, so in the case of wetland harvesting it can for example carry and operate a hydrologic winch.

Photo 16 The Fenland during adaptations

The **Loglogic Hydraulic Powered Rubber Tracked Trailer** is designed to be used in conjunction with the Loglogic Softrak or Softrak 120 tracked vehicle. Fitted with either 400mm or 600mm rubber tracks, the tracked trailer can easily follow the Softrak without causing the damage that a conventional wheeled trailer would on delicate habitats. The trailer is primarily designed to carry up to five 1,200mm diameter reed bales produced by the Loglogic reed cutter bundler system. With a purpose built body up to 25m^3 or 2,500kg of chopped vegetation can be transported.

The trailer is fitted with a hydraulically powered front cradle to allow bales ejected from the baler to be lifted onto the trailer and at the same time pushing other bales along the body. The design stops bales rolling off the end of the trailer, but can be easily released to allow the bales to roll off the rear for unloading. The hydraulically controlled front hitch allows the operator to raise the front of the trailer when crossing rough terrain or to facilitate bales rolling to the rear of the trailer when loading or unloading bales. The fully floating track modules mean that the tracks will always follow the ground contours. However check chains are fitted to limit the maximum articulation of the tracks so that the trailer can cross ditches and other obstacles without the track fouling the body.

Photo 17 Hydraulic powered rubber tracked trailer

K*ey Facts*

- *The machine is 6,675mm long, 2,200mm wide 1,566mm high.*
- *The power needed to operate this attachment can be provided by a 65hp or a 120hp Softrak.*
- *A new powered Softrak trailer costs £26,746 (2015).*
- *Ground pressure (laden) 4.4psi. (400 mm tracks).*
- *Ground pressure (laden) 2.9psi. (600 mm tracks).*
- *Payload 2,500kg.*
- *Weight (unladen) 1,300kg.*

The Sledge Cableway is a system which has been developed by Loglogic working with AMW for the movement of material across soft ground. This system is designed to receive the biomass and securely transport it from the harvesting area to the processing/storage area. By using a sledge it potentially limits the detrimental effect of vehicle movements on soft ground and enables direct routes to be used for transporting biomass by being capable of spanning wet features and ditches.

The development of the sledge cableway system allows 1,000kg of biomass to be transported up to a distance of 1,000m from the harvesting area to the processing area with a footprint of 0.2 psi when hauled over land consistent with wetland sites. The sledge cableway is also able to transfer material across watercourses, for which a depth of 150mm is required. In this situation a zero footprint can be achieved. The whole system is powered by a 100hp tractor.

Photo 18 The sledge cableway

The sledge is simply loaded by the harvester reversing into it and tipping the harvested material. A double drum capstan winch tractor then hauls the sledge to the docking station mounted at the front of the tractor. Sensors located on the sledge control its movements along the cableway, when docked the biomass is transferred to the docking station's walking floor using the rear door of the sledge. The biomass is then conveyed underneath the tractor to the baler located at the rear; the biomass is then baled and ensiled which improves transportability, storage and handling.

The sledge cableway is designed to:
- *Help to conserve the site (prevention of mechanical disturbance of the soils, avoidance of damage to rhizomes).*
- *Increase acreage performance and thus biomass volumes.*
- *Negates the need to fortify tracks or access points.*
- *Be of a simple design which ensures that there are efficient set up/dismantle times (essential on sites prone to flooding).*

Photo 19 The sledge cableway in operation

3.1.5 Machinery access requirements

Some basic considerations need to be made when planning to bring machinery to site, not just in terms of access once on site, eg through gateways and down droves but also getting the machinery to the site entrance off a main road.

Typically the harvesting machinery will arrive on an articulated lorry, which will need to be able to travel to the site entrance. For vehicles with metal tracks such as the Pisten Bully, it is preferable that they are not tracked along the road to avoid marking the surface, (for rubber tracked vehicles this is less critical), so close access for a lorry to the site entrance is desirable. Turning for the lorry also needs to be considered and whether a drop-off point is more appropriate with the lorry parked away from site.

When on the lorry the overall height is considerably increased and the following measurements illustrate the effect that this has on the access requirement. The details for the Softrak 120 and Pisten Bully below will provide a guide when planning:

Table 1 Machine transport dimensions

Machine type	Machine/Transport dimensions
Softrak 120hp harvester	➢ In operation: 3.8m long, 2.2m wide 2.6m high ➢ During transport: on an articulated lorry: Lorry width 3.1m, lorry length 13.4m, combined height 4.3m
Pisten Bully Greentech 300 harvester	➢ In operation: 6m long, 3.5m wide 4.2m high ➢ During transport: on an articulated lorry: Lorry width 3.1m, lorry length 13.4m, combined height 4.7m

3.2 Choosing the right kit for the job

3.2.1 Machinery comparison – Softrak 65hp / Softrak 120hp / Pisten Bully / Soucy Tracks / Seiga

Table 2 Machinery comparison

Criteria – Physical	**Softrak 65hp**	**Pisten Bully 300 GreenTech**	**Softrak 120hp**	**Soucy Tracks** Case Maxxum 110	**Siega**	**Olympia mower binder**
Engine size	70hp	330hp	120hp	The hp of the Case Maxxum is 110, c 20hp required to drive the tracks. 90hp machine would be adequate	115hp	9hp
Ground pressure unladen, without attachments	1.2 psi 0.084 kg per cm^2	1.4 psi 0.098 kg per cm^2	1.35 psi 0.094 kg per cm^2	2 psi 0.14 kg per cm^2	3.8 psi 0.27 kg per cm^2	435kg + operator
Width	2.10m	3m	2.25m	2.8m	3m	1.37m
Transportation	Low Loader	Low Loader	Low Loader	Low Loader	Low loader but need a movement order to transport	Road trailer

Criteria – work rate & efficiency – forage rush	**Softrak 65hp**	**Pisten Bully**	**Softrak 120hp**	**Soucy Tracks**	**Siega**	**Olympia mower binder**
Cut and **not** collect per day (8hr)	0.5ha	6 to 8ha	4 to 5ha	4 to 5ha, flail mower	N/A doesn't forage	N/A doesn't forage and collect
Fuel efficiency per hour	3 litres an hour	12.5 litres an hour	3.6 litres an hour	18.75 litres an hour	N/A	N/A
Fuel efficiency per ha	48 litres per ha	75 to 100 litres per ha	14 to 18 litres per ha	30 – 37 litres per ha	N/A	N/A
Energy calculation	144.6 kg of CO_2 per ha	225 - 300 kg of CO_2 per ha	42 – 54kg of CO_2 per ha	90 - 111 kg of CO_2 per ha	N/A	N/A

Criteria – work rate & efficiency – reed cut & bundle	Softrak 65hp	Pisten Bully	Softrak 120hp	Soucy Tracks	Siega	Olympia mower binder
Reed cut and bundle per day (8hr)	4.7ha Based on figures from AMW harvesting at the Tay Reedbed	Doesn't cut & bundle	Still to be trialled ha	Doesn't cut & bundle	1.45ha	0.75ha Bundles left on site, to be removed by hand. Vibration regulations will prevent single operator using the machine for a full day
Fuel efficiency per hour	5 litres an hour	Doesn't cut & bundle	3.6 litres an hour	Doesn't cut & bundle	3.75 litres an hour	3.7 litres an hour
Fuel efficiency per ha	8.5 litres per ha	Doesn't cut & bundle	litres per ha	Doesn't cut & bundle	20.6 litres per day	40 litres per ha
Energy calculation	25.6kg of CO_2 per ha	Doesn't cut & bundle	kg of CO_2 per ha	Doesn't cut & bundle	61.8 kg of CO_2 per ha	120.4 kg of CO_2 per ha

Criteria –Cost & manufacture	Softrak 65hp	Pisten Bully	Softrak 120hp	Soucy Tracks	Siega	Olympia mower binder
Cost of base machine	£65,664	£109,000 reconditioned	£96,305	£30,000	£100,000	£8,500
Cost of forager: Precision Cut Direct Cut DC 1,450 Double Cut TC 1,700	 N/A £13,852 N/A	 £27,300 N/A	 N/A £13,852 £16,891	Does not operate forager	Does not operate forager	Does not operate forager
Cost of bin for forage	£4,847	£19,500	£6,551	N/A	Does not operate forager	Does not operate forager
Cost of reed cutter/bundler Reed Baler	£13,231	£20,000 reconditioned	£13,231	N/A N/A	Part of machine 400 bundles carrying capacity	Part of machine. Reed bundles left on ground – not

2,400mm x 1,200mm bales Powered tracked trailer	£5,027 £26,746	N/A N/A	£5,027 £26,746	 N/A	Cutter no longer made Bundler made in house £1k probable less	collected
Country of manufacture	UK	Germany	UK	Canada	Denmark	Limited information available
Sourcing parts	OK	OK	OK	OK	Can't be sourced, have to be made	
Opportunity for close working on machinery development	Good	Limited due to location outside of UK, but do have UK supplier	Good	Limited due to location	Original manufacturer no longer in business	Limited developments possible

Criteria – Attachments & operation	**Softrak 65hp**	**Pisten Bully**	**Softrak 120hp**	**Soucy Tracks**	**Siega**	**Olympia mower binder**
Cut & bale	Possible could be developed or conventional mower and tracked baler used Loglogic (Softrak) currently looking into a forage baling system				N/A	N/A
Forage & blow	Yes	Yes	Yes	No	No	No
Collection bin size for forage	$8m^3$	$16m^3$	$11.2m^3$	N/A	N/A	N/A
Forage cut width	1.3m	3m	1.7m	N/A	N/A	N/A
Forager type	Single chop	Precision chop	Double chop	N/A	N/A	N/A
Material chop size	150mm to 300mm	4mm to 30mm	40mm to 65mm	N/A	N/A	N/A
Comments	Due to smaller bin size location of dump site for harvested material important to reduce time travelling to empty bin	As for Softrak location of dump site needs to be considered to reduce travel time and ground compaction/churning up. Benefit in using haulage vehicle to reduce harvester tracking		N/A	N/A	N/A

Criteria – Attachments & operation	Softrak 65hp	Pisten Bully **	Softrak 120hp	Soucy Tracks	Siega	Olympia mower binder
Reed cut & bundle	Yes	Yes but does not collect	Yes	No	Yes	Yes but does not collect
Cutting width – reed cutter	1.27m	3.2m	1.27m	N/A	1.2m	1.37m
Bundles a day	4,000 to 5,200 Based on AMW at Tay	3,600	4,000 to 5,200 Based on AMW at Tay	N/A	1,440	1,000
Height of cut adjustment	35 to 160cm	35 to 160cm	35 to 160cm	N/A	0 to 100cm	Follows contours of ground, any adjustment made by operator
Coping with dense vegetation	Partly, lack of power could be an issue	Yes	Yes (still to be trialled)	N/A	Up to 3 year old reed	Up to 3 year old reed
Operation needs reed bundler	2 people	Machine cuts and leaves bundles on the ground that then need to be collected separately by hand	2 people	N/A	No reed can be stacked on machine and tipped off	Machine cuts and leaves bundles on the ground that then need to be collected separately by hand
Manoeuvrability	0.6m tracks	1.5m tracks	0.6m tracks	Good	Large machine, not suitable for smaller sites	Good

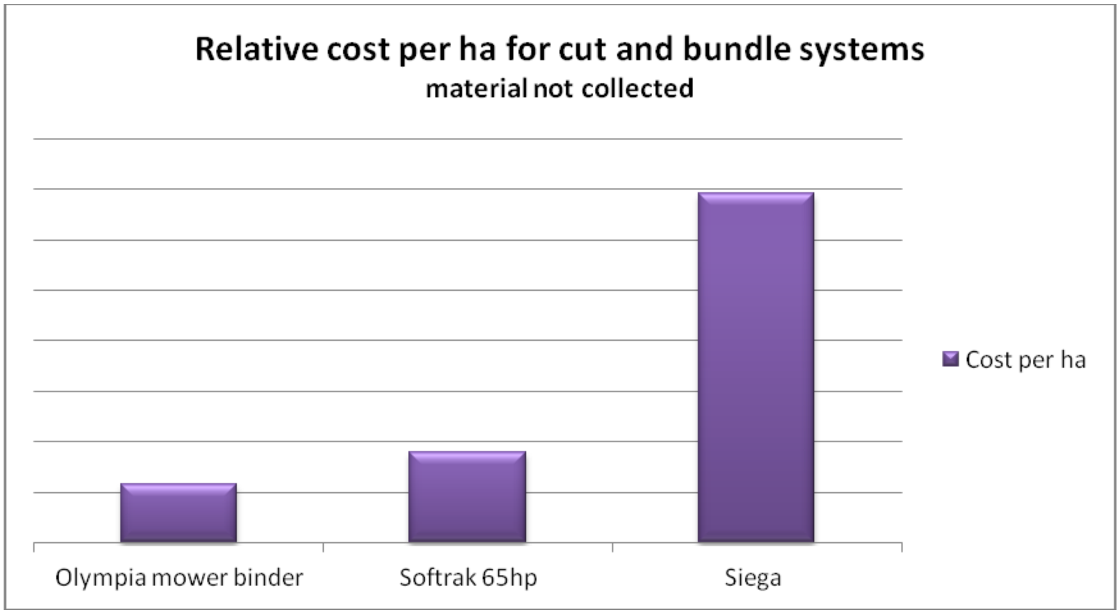
** These figures representational – the Pisten Bully currently operated in the UK does not have a reed cutting attachment

Criteria – Other issues	Softrak	Pisten Bully	Softrak 120hp	Soucy Tracks	Siega	Olympia mower binder
Overheating	Can be prone to	Has adapted radiator to remove dust	Has adapted radiator to remove dust	None	Air cooled no problems	None
Other problems	Lack of power can mean machine struggles to blow wet vegetation	Collection of dry material around exhaust can go on fire		None	Mixture associated with age	Vibration from machine means that it can only be used for a limited time to stay within exposure values set by the regulations.

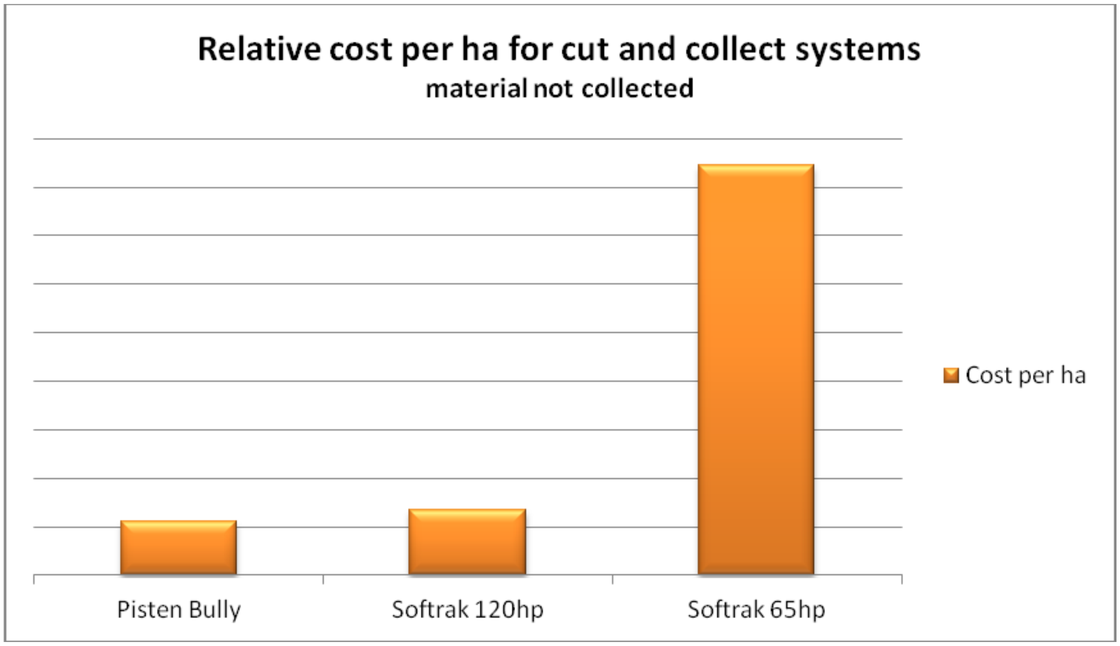
3.2.2 Cost comparison

For cost comparisons to be drawn effectively the same operations need to be compared. In the case of the wetland machinery presented above this presents some difficulties as each machine operates slightly differently: whether in relation to how it cut and collects or its suitability to different conditions. There are also limitations that need to be considered when attempting to make comparisons, eg the vibration regulations in relation to the Olympia mower.

However two caparisons have been presented below, where costs are illustrated in relation to each other for each machine type harvesting a hectare. These take into account the following costs; machinery and attachment purchase, operator and fuel costs and are presented in relation to machinery harvesting rates.



Graph 1 Relative cost per hectare for cut and bundle systems



Graph 2 Relative cost per ha for cut and collect systems

Please note in all cases presented the material is not moved off site and so the manual handling resource needed for the Olympia mower operation is not accounted for.

As illustrated above, some comparisons can be drawn; however more benefit can be gained from seeing the diverse characteristics of the each machinery type and therefore the range of options they present for different site scenarios.

3.2.3 Size of machinery, manoeuvrability and suitability

It may seem obvious to say that the size of the site will determine the size of the kit that it is sensible to use. The danger is to be drawn into to thinking that a higher powered piece of machinery will complete the job more quickly – but the phrase ‘sledgehammer to crack a nut’ should be kept in mind. Typically manoeuvrability will reduce with a larger piece of machinery and weight will increase, damage from tracks turning more frequently will be experienced and tracking over the same areas numerous times will be difficult to avoid.

3.2.4 Bigger vs. smaller

It is important to consider the merits of bigger equipment with larger cutting heads resulting in less passes, compared to smaller kit more passes and tracking, in the context of the site conditions. Bigger kit will generally be able to carry more cut material and so need fewer passes to empty the bin on the back, reducing wear and tear on access and tracks. There will probably be a number of site specific issues that will influence the decision making process, particularly in relation to the ‘type’ and sensitivity of the habitat being managed.

3.2.5 Impact on ground conditions

This is probably going to be the determining factor when the choice of machinery is made and it is important that an objective assessment can be made as to the ‘real’ effect of the operation on the site. It is important to be able to distinguish between the visual effect of tracking and actual effect of tracking in relation to the types of operations being performed, for example from cutting and from removal.

When cutting, the size and shape of the site influencing the number of turns that need to be made will affect the results on the ground. The proximity of high ground on which to manoeuvre will take the pressure off the wetter areas.

When removing material the access points into the site will influence the effect of the machinery used on the ground. For example multiple access points will avoid concentrated impact and may mean that larger machinery can be tolerated.

Knowledge of the individual sites and communicating this to the contractors before appointing them is significant in choosing the right kit for the job. However monitoring guidelines have been produced to allow ongoing assessment to be made of the effect of different machines, these can be found in Section 4 page 32.

Preparation of the site beforehand is also important, for example making sure access points are in good condition and dry will help preserve their life. Ensuring that the site has not been over grazed, grazing animals can take a spine out of a site and over grazing can reduce its ability to aid machinery travel. Leaving a good dense sward will help to prevent churning the ground up and will preserve drier ground conditions for longer. Damage from cattle and a very tight and sparse sward will reduce the sites potential to tolerate vehicle movements, particularly as animals tend to gather around and put pressure on access points.

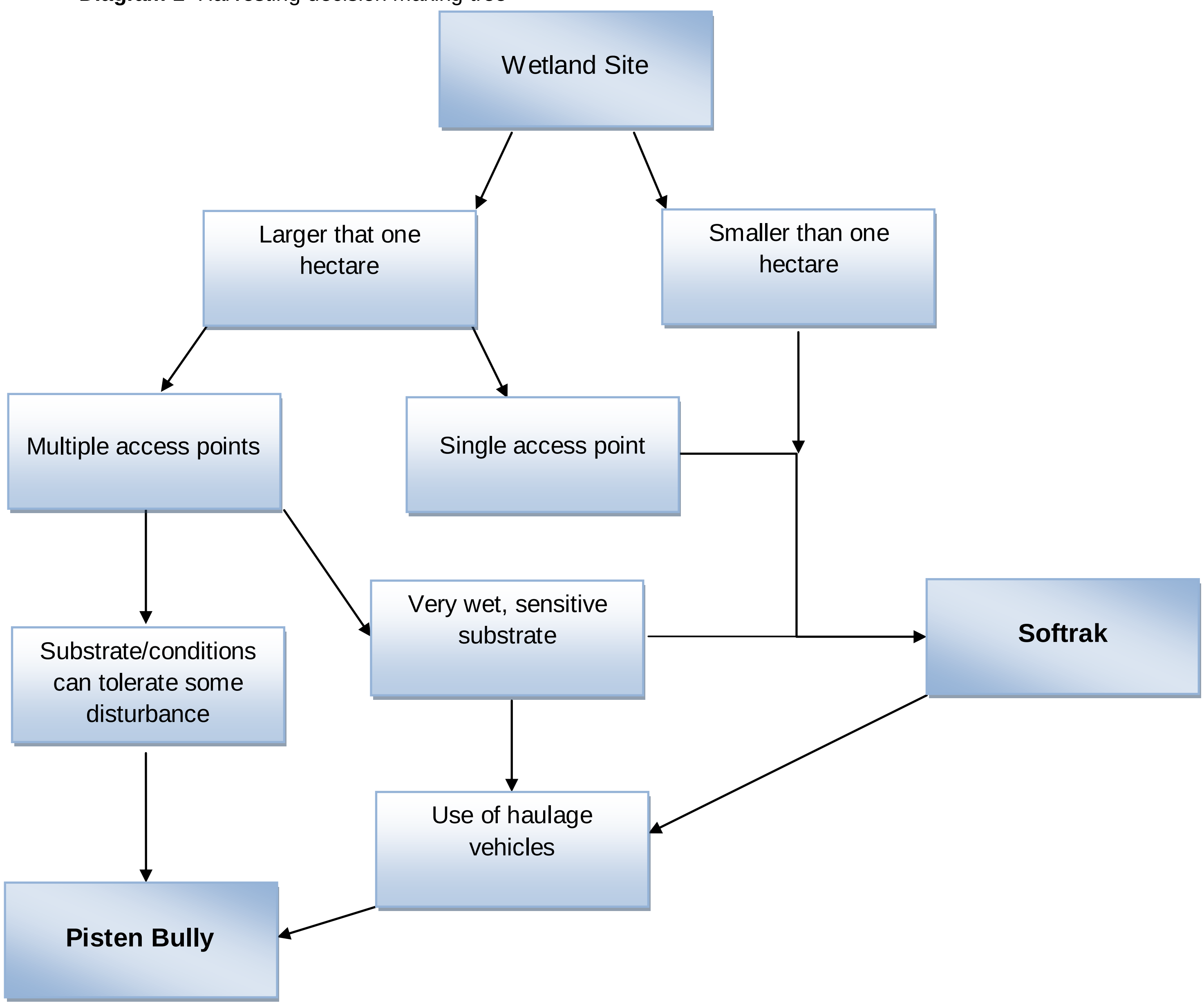
3.3 Harvesting decision making tree

Making a decision about the right harvesting equipment will really depend on site specific details. Smaller equipment may be slower and may cost more, but may be more appropriate, or may be a combination of larger machines with a haulage vehicle to cope with the limited access would be the best solution. The points to consider will be numerous, however some have been suggested below:

1. Size of area to be harvested.
2. Substrate of area and if relevant water level control.
3. Access to the site.
4. Vegetation type and desired after use for the material.

It may be useful to draw a simple decision making tree, like the one below to explore some of the options.

Diagram 1 Harvesting decision making tree



3.4 Exchange of information

3.4.1 Before

Always remember that whilst the contractor will know his machines and their capabilities – it is the site staff who know the site – so working together will achieve the desired and best outcome. The exchange of information prior to any work commencing is in valuable and essential, and a couple of hours spent on a site visit will be a couple of hours very well spent. Briefing the contractor on what is needed and communication on the desired outcome is important and as always the devil is in the detail. For example some of the machinery will be able to deal with driving through wet features, however this may alter the profile of them, it is up to the site manager to both identify these features, but also to discuss how best they should be dealt with.

In addition to a site visit and walking the terrain, an exchange of information, hazard maps, and information on the site's structure will provide the contractor with the information needed to assess how to undertake the harvesting. The contractor will then be able to propose a method of working, eg where to turn round, how to deal with wet features, places to avoid, together with a plan of how to deal with getting stuck if that should happen – including winch points, or access for 360 excavators if needed as a last call of assistance.

3.4.2 After

Working with contractors on the management of a site is an important learning process for both the site manager and the contractor. Making time to provide feedback on the task executed is an essential part of this process and having a debrief on site is always beneficial and leads to a greater understanding not only about the task undertaken but wider management aspirations.

For example, after completing reedbed harvesting at Minsmere discussions were held about the litter layer that is often problematic in reedbeds. When managing the reedbed manually this is typically resolved through double raking. The site is raked removing the loose cut reed which is piled up and burnt revealing the stubble and litter below. This is then raked again, making the stubble more open and often wetter, through the removal of what can be many inches of litter. Through the mechanical work that has been trialled it has shown that some mechanical cutting and harvesting techniques can leave an amount of stubble (due to the presence of litter and its impenetrability) and does not always deal with really dense thick litter. Although once exposed to the air this will begin to breakdown and to a degree oxidise, on site discussions revealed that it would be desirable if it could be removed. Raising these issues with contractors, especially innovative ones can then lead to the development of new machinery, in this case to give thought to a second attachment that would collect the litter and lower the stubble. Although of little value for energy, this material could then be composted and used for the production of a soil conditioner.

Unless the contractor is aware of what the site manager is trying to achieve, it will be hard for them to achieve the desired results. The more this can be communicated and a working relationship developed, the more successful the management will be.

4. Monitoring the effects of vegetation cutting and removal

The harvesting of biomass for bioenergy approach to the management of land important for biodiversity is new and it will involve a change in the way management operations are both employed and perceived. However this change in practice and the ability to manage larger areas more efficiently needs to be handled carefully, with the understanding that all management is underpinned by conservation objectives at all times. Management practices driven by the need for feedstock production would result in the `tail wagging the dog' and could be detrimental to the biodiversity the land is managed and designated for.

This new management approach is accompanied by new techniques, involving the employment on site of different harvesting and processing machinery. The impact of these operations also needs to be considered in the long term and monitoring established to ensure that there are no future detrimental effects on the habitats and sites that are being managed.

In an attempt to address the above issues a monitoring programme has been complied to enable site managers to have the mechanisms they need to assess the effect of the different management operations. The guidance offers techniques that can be used to monitor the impact of machinery and harvesting operations on vegetation structure and substrate composition. It also considers the effect that managing larger areas, in habitats such as reedbeds, may have on specialist target species.

It was considered that monitoring fell into three main areas:

1. The impacts of mechanical harvesting on vegetation.
2. The impacts of mechanical harvesting on soil structure.
3. The most effective harvesting pattern and its relationship to biomass utilisation.

4.1 Monitoring the impacts of mechanical harvesting on vegetation

The impacts of mechanical harvesting on the vegetation was monitored through the use of quadrats and fixed point photographs. This were used to enable an assessment to be made as to whether the change in approach affected the vegetation structure, density, type and any impact on rhizome and root structures in a detrimental way. This was achieved by completing pre-harvest and post-harvest assessments so that comparisons could be drawn. The type and size of quadrats were adapted for the habitat types and information on vegetation structure, density, type and abundance, together with percentage of bare ground cover was recorded.

All the points of the monitoring activity were recorded so that they could then be replicated the following year. At this time, after a growing season and once the vegetation had recovered from harvesting, comparisons would be able to be drawn. The conclusions of the affect on the vegetation would need to be taken within the context of the management objectives. For example reducing rush cover on a wet grassland is desirable and so recording less rush dominance, resulting from harvesting operations would be positive.

Photo 20 Vegetation monitoring

However damage to reed rhizomes may reduce vigour in common reed growth, which could be seen as both a positive and a negative outcome. Positive if more open areas were desired and negative if dense reed cover was the objective. For this guidance as the vegetation monitoring was only completed once, no comparisons could be drawn.

Fixed point photographs were used and taken of representative areas of vegetation within both the areas to be cut and the adjacent (uncut) control. On the cut areas photographs also include any planned access points as well as proposed haulage routes. Follow up photographs were taken after the harvesting in cut areas, access points and haulage routes for any obvious signs of damage caused by harvesting process (e.g. ruts, pools, obvious patches of bare ground among otherwise vegetated areas, direct damage to vegetation). Once again these photographs need to be repeated at timely intervals to assess the visual recovery of the site.

4.2 Monitoring the impacts of mechanical harvesting on soil structure

The impacts of mechanical harvesting on soil structure is important as soil structure can be damaged or destroyed through loading under wet conditions with heavy machinery, particularly when the surface vegetation is a poorly developed. Structural porosity may be reduced or lost due to the tighter packing (soil compaction). Surface pans are compact layers occurring at the surface and can be caused by heavy trafficking or livestock on silty or clayey soils or by heavy rainfall on bare silty and fine sandy soils. Compact layers at the surface and in the soil profile may reduce the rate of water infiltrating into the soil and moving through it. They may also reduce the quantity of water available for plant use and restrict capillary rise.

Substrate compaction measurements consisted of two components:

a) A visual structural assessment of the soil.
b) Measure of the soil infiltration rate.

These measurements were assessed in both uncut and cut areas by digging a soil pit and comparing the soil structure at different depths. They were recorded at three randomly located points within each cut and (uncut) control area.

a) To examine the surface conditions, a small vertically-sided soil pit was excavated to a spade's depth. An undisturbed soil sample was then taken from the side of the pit for examination (in taking the sample, the soil either side of the proposed spade-full is first cut vertically to isolate it from the neighbouring soil, the spade is then forced in vertically to the required depth with a slicing action, so minimising disturbance). The sample was then removed for inspection and broken carefully apart so that it broke along the weakest planes. Photographs were taken of the sample before and after breaking up as an additional visual record. Based on the guidance sheets provided (Appendix 1) a visual soil structure quality assessment was then completed. From all the samples undertaken across the sites harvested, no indications of compaction were seen, on all occasions the soil structure stayed in tact and through comparisons between the cut and uncut areas, no visual differences were recorded.

Photo 21 Soil sampling

b) To measure the soil infiltration rate, a test was performed using a metal infiltrometer ring 30–40 cm diameter and 20-30cm high, hammered into the surface. For assessing the infiltration rate of surface layers, water was then added to the infiltrometer ring to a depth of approximately 10cm. The water level was allowed to fall through an exact distance of for example 5cm and the ring refilled to the initial water level. The time interval between each water addition was noted and the test continued until the interval became reasonably constant. At this stage the infiltration rate was determined as follows:

$$\text{Infiltration rate (m per day)} = \frac{\text{distance of water level drop (cm)} * 864}{\text{time taken for water level drop (s)}}$$

To account for soil variability and the small sample area, the soil infiltrometer test was replicated at least three times and the average infiltration rate determined. This monitoring once again was undertaken in both cut and uncut areas, so that comparisons could be drawn and the measurements compared against each other. Once again no noticeable differences were recorded through the monitoring undertaken. Some difficulties were experienced on completion of this test in very wet areas, where the water table was too high to allow the water level in the infiltrometer to drop.

Photo 22 Infiltration test

4.3 The most effective harvesting pattern

The most effective harvesting pattern and its relationship to biomass utilisation needs to be considered in relation to whether biomass harvested off sites can be utilised for bioenergy. Bringing in suitable machinery to cut and remove material will in part be determined by the size of the area to be managed, which will in turn have implications on the cost.

The cutting and removal of vegetation from reedbeds helps to reduce the effects of natural succession, by counteracting litter build up and promoting new reed growth. The other benefit of management is the creation of open areas, edge, pools and a more diverse structure within the reedbed.

In the 2015 reedbed management handbook, 'Bringing Reedbeds to Life' details are given about the benefits of different cutting regimes. It states that 'A traditional "conservation" cutting rotation may be between 7-15 years. This type of management is largely undertaken under the assumption that it will hold or slow natural succession. In practice, the effect on succession is likely to be minimal in most circumstances. If it does slow succession, the scale of the work is only suited to smaller reedbeds.'

Going on to say that 'Reed cutting over the longer rotations dictated by traditional conservation management may therefore not be as effective for slowing succession as claimed, while short rotation cutting may not be as bad as claimed, being a means of increasing structural variation in a reedbed. It further follows that a carefully designed rotational pattern of cutting can benefit a variety of species, but also has a minimum effect on "interior" reedbed birds, mammals and key reedbed invertebrates. Differing cutting patterns may benefit different species.'

Typically for such rotations reed is cut by manual methods and the resulting material then burnt in situ. Such reedbed practices are labour intensive, weather dependent and it is felt only contribute in a minor way to slowing succession. However with the development of a mechanistic approach to reedbed management and a use for the cut material, opportunities for new approaches to the way we manage reedbeds in the future are presenting themselves.

At Ham Wall the RSPB has been experimenting with a ‘rejuvenation’ approach to reedbed management. This is when a larger area (calculated as a percentage of overall reed area) is managed for consecutive years over a 5-year period through water level control, cutting and intensive grazing, to wipe-out the reed dominance, allowing it to then slowly re-colonise in year 6. This management approach is an attempt to introduce dynamics back in to the system, but also presents a potentially more achievable and sustainable way to manage sites, which reduces demand on resources. Mechanisation presents the opportunity to achieve the desired management objectives for the site, to undertake the work quickly, which is more compatible with water management and winter weather restrictions, and facilitates the use of the harvested material.

This form of management approach lends itself to biomass utilisation, with the management of one large area in a single year. A management method of this type has the potential to be more cost effective, with the focus on one site which involves less machinery movements and will demand less resource commitment, eg for water control, access management.

However consideration needs to be given as to what proportion of a site should be harvested in any one year, so that the operation enhances biodiversity. The Bringing Reedbeds to Life handbook addresses this question; ‘How much reed can you cut annually without damaging the conservation value? A study in the Netherlands (van de Winden 2003) found that “exterior” reedbed birds only declined significantly when 50% or more of the reed was cut in any year. Jose and Hawke (1996) suggest similar proportions as a compromise between conservation and commercial interests. Therefore, with conservation as the priority, removal of up to 30% of the reed annually would seem unlikely to present problems. However, the cutting pattern is important in creating the high degree of desired edge habitat.’

The rejuvenation approach at Ham Wall RSPB Reserve, was initiated during the 2006/07season, when an area of 16ha (as 13.3% of the total site reedbed area), was managed in this way. Within this area approximately 10ha of reed was cut (as 10% of the total site reed area). This area was then managed each year to prevent reed from re-growing and becoming dominant. The area was maintained in this way until 2012/13, when rejuvenation management ceased and the area was allowed to re-colonise with reed and other wetland species naturally. At this time a new rejuvenation area of 8.5ha was initiated on the site, on which all the reed was cut and removed during the season 2013/14. This area will now be treated in the same way to reduce the reed dominance and add dynamics.

Photo 23 Rejuvenation reedbed management

Before this rejuvenation approach to management was adopted, Ham Wall was managed though the rotational cutting of small blocks by hand. In 2005/06 by using this method 4.5ha was cut and burnt, compared to 15.2ha (rejuvenation 10ha plus additional areas) in 2012/13 achieved, of which 96% was cut and removed mechanically.

The effect of this management work has been monitored through the breeding success of key bird species, particularly bittern and bearded tit which between them have a diverse set of reedbed habitat requirements. Over a 10 year period despite the increased area of reed managed at Ham Wall Reserve, (as a percentage of total reed area), the population of bitterns using the site has increased. In the case of bearded tits the breeding population has also increased despite a dip in 2009/10. This site staff thought may have been due to higher than average winter water levels across the site making foraging more difficult, or the effects of the starling roost on the reedbed structure. It also indicates that the new management approach was conducive to the colonisation of the site by new species, with little bitterns breeding for the first time in the season of 2010/11.

The results suggest that the rejuvenation approach offers the way in which to achieve the habitat diversity and dynamics that specialist reedbed species such as bittern and bearded tit require. Eg creation of pools and open water increasing bittern feeding opportunities, longer cutting rotations providing increased nesting and feeding sites for bearded tits. But significantly, it offers a management regime that moves away from the manual, resource hungry techniques previously employed to one which can be achieved through mechanised means more efficiently. The dynamic and destructive nature of the rejuvenation approach also provides land managers with the assurance that site objectives are being thoroughly achieved. Returning the site back to conditions pre reed dominance with the removal of all litter and scrub species guarantees a successful reversal of the successional process.

Please see Appendix 1, page 110 for the full monitoring protocol.

5. Turning your biomass into energy

5.1 Realising the potential of your biomass

If material is going to be used for energy production, the importance of harvesting it in the right form and under the right conditions cannot be stressed enough. This may need a change in the way we think about the biomass produced on conservation sites, which up until recently has been seen as a problematic material with little to no value. With the ability to turn this material in to energy, this biomass must now be treated as a feed stock, with respect and a worth. No longer can it just be stashed in a corner, without cover or protection and left to rot and degrade. The material needs to be stored in the correct fashion to preserve its value as an energy feedstock of the future.

If possible and site conditions allow, harvesting the material in the preferred condition for the desired after use, as mentioned in the section below is desirable. If this is not possible then at least a consideration of how this condition can be attained further along in the process and whether this approach makes carbon and economic sense.

Photo 24 Conservation biomass

The timing of biomass harvest also needs to be considered and may alter the treatment and storage of the material, and could even determine the energy conversion process which is most appropriate. This to a greater extent will probably be driven by conservation objectives; however weather conditions will also be a factor. For example, when managing reedbeds by hand in the winter, dry weather is sought to enable the material to be collected and burnt, harvesting biomass for bioenergy needs to be planned in the same way. Some conversion systems are more flexible than others and the options are described later, however planning the end-to-end process is essential and enables efficient delivery.

Cutting biomass at different times of year can provide marked differences in its characteristics and its suitability for the conversion processes. For example in relation to combustion in 2010 N. Ash undertook moisture comparison studies with reed harvested in Sweden, from the Danube Delta and in Scotland from the Tay Estuary and he found that all showed a steady decline in the moisture content as the season progressed from May through to April. In these cases the reed was either being harvested for thatching or combustion and harvesting was of the stems only (with panicles) with no litter collection. It was found that during January to April the moisture content of this material was typically around 15%.

From the work undertaken in 2010, Ash and Ecological Land and People found the following as the typical moisture content of common reed; this illustrates the variability throughout the year.

Month	Moisture Content %
May	80
July	70
August / September	50
December	40
February	20

In comparison trials undertaken in the Norfolk Broads using the Wetland Harvester, which cut and collected the whole crop including the wet litter, the biomass had high and sustained moisture content levels throughout the season at around 50% or more. Ash concluded that, the optimum time to cut and achieve acceptable moisture content levels for combustion was January to April. Harvesting of the stems only was preferable as too much litter resulted in increased moisture content. This is not completely compatible with conservation requirements, which on many sites cutting needs to be completed by the end of February and litter removed.

For anaerobic digestion V. R. Akulain completed a study in Sweden and found that harvesting reed in October for biogas production, produced higher amounts of gas compared to reed harvested in August. His studies showed that there was a big difference in the levels, with October producing the highest amount of gas at 107.9 l/kg wet weight compared to reed harvested in August which produced 60.6 l/kg wet weight. These findings were surprising as it would be expected that a later harvest may lead to material having an increased lignin content which it is believed to have a negative effect on gas production.

Understanding the different conversion technologies available and their relationship to the types of biomass harvested off conservation sites and the time of year of the harvest is essential in making the right selection for each situation. The need to harvest at the appropriate time for species and habitat conservation will determine the biomass make-up and characteristics. The table on biomass characteristics (Section 5.2, page 40) together with the Biomass Conservation Calculator (Section 9.1, page 87) will assist in the decision making process and help to provide a guide as to which type of conversion processes are suitable.

For each conversion technology the material will need to be in a certain physical form, so for example whole crop anaerobic digestion needs biomass to be in the region of 65% moisture content and precision chopped in a green, fresh state and stored in an anaerobic environment to prevent degradation. Whereas for briquette production the material needs to be dried down to less than 20% moisture content to maximise its calorific value. Size of chopped material is also important, and may avoid double handling in the future. For a rotary briquetter material slightly longer in length can be advantageous, whereas for a linear machine, shorter lengths are preferable.

For combustion, harvesting using a double chop, rather than a single chop forager will also help with the efficiency of the end-to-end process. It will enable more material to be collected in the harvester collection bin at any one time and it will reduce the need for further shredding before the material is briquetted. Storage of the material is also affected by the form in which the material is harvested. If being compacted into a store then the smaller the pieces the less space needed. However, if it is being stored to dry then structure which facilitates air flow, will assist with this process. In the case of reed, Ash found in his study of 2010 that through stacking the reed in lengths and storing in bundles, loosely covered, it dried naturally to equilibrium moisture content of 15%.

The characteristics of the biomass itself will often determine which conversion techniques can be employed to turn it into energy. For example it is widely accepted that woody biomass is not generally suitable for anaerobic digestion. The ability to break down the lignin cellulose content of such materials through digestion is the governing factor and so the extent to which material contains lignin cellulose will have an impact on its suitability.

In addition to biomass type and characteristics, other issues to consider in relation to the choice of conversion technology may be:

- The need for a certain energy type locally (eg heat vs. electricity).
- The location of existing biomass processing plants.
- The proximity to a grid connection.
- Local markets and demand for energy products.
- The area to be harvested and the amount of biomass available.
- Available space for biomass storage and conversion.

5.2 Biomass characteristics

The values presented below are typical values to provide an indication, as these will vary from site to site. All measurements collected by RSPB unless stated otherwise.

Table 3 Wetland biomass characteristics

Biomass type	Month of Harvest	Age Yrs Old	Cut Previously	Moisture content %	Ash %	Bulk Density kg/m^3	Calorific value MWh/t	Methane content %	Notes on potential use
Common reed	Aug	1	Yes	64	2.2	54 Pc 39 Dc	N/A	53.5	Primarily anaerobic digestion as material is green and moisture content too high for combustion, unless wilted in the reedbed.
Common reed cut in winter[5]	Jan	2	Yes	15-20	2.1-4.4	32.5 Sc	3.9-4.2 15% Mc	N/A	Primarily combustion or bio-char, too dry and woody for anaerobic digestion.
Common reed cut in winter[6]	Jan	7	Yes	16		60	4.3	N/A	Primarily combustion or bio-char, too dry and woody for anaerobic digestion.
Soft rush	Aug	1	Yes, but some dead material	66.3	2.7	52[7]	4 10% Mc	53.1	Anaerobic digestion straight from the field or stored appropriately. Combustion & bio-char, if material can be wilted in the field, Drying potential, need to consider chop size to provide structure.
Reed dominated fen	Aug	1	Yes, but some dead material	68.3	2.5	-	-	52.4	Primarily anaerobic digestion as material is green and moisture content too high for combustion, unless wilted in the reedbed.
Rush dominated fen	Sept	-	Dead material present	55.4	2.5	41 Pc 18 Dc	-	52.3	Primarily combustion or bio-char. Potentially too dry and too much lignin for anaerobic digestion, if standing dead material and thatch still present.
Reed sweet-grass	Sept	1	Yes	73.6	1.7	-	N/A	52.6	Primarily anaerobic digestion as material is green and has moisture content to high for combustion, high percentage of moisture may need to be considered.

[5] Komulainen, Simi, Hagelberg, Ikonen & Lyytinen 2008

[6] Ash 2010 Komulainen, Simi, Hagelberg, Ikonen & Lyytinen 2008. Sefai Bilgin, Can Ertekin, Ahmet Kürklü, 2005. Hannes Kitzler, Christoph Pfeifer, and Hermann Hofbauer, 2012

[7] Wynne 2012

Table 4 Heathland biomass characteristics

Biomass type	Month of Harvest	Age Yrs old	Cut Previously	Moisture content %	Ash %	Bulk Density kg/m^3	Calorific value MWh/t	Methane content %	Notes on potential use
Heather	Nov	15-20	No	44.8	6	128 Pc 92 Dc	6.2	N/A	Combustion, bio-char, too woody for anaerobic digestion
Heather	Feb	10-15	No	52	-	92 Dc	4.9[8]	N/A	Combustion, bio-char, too woody for anaerobic digestion
Bracken	Sept	1	Dead material present	61	2.9	-	-	52.2	Combustion, bio-char, however if harvested when still green, may have potential for anaerobic digestion
Bracken	Nov	1	Dead material present	60	4.6	86 Pc 68 Dc	5.3	N/A	Combustion, bio-char, too woody for anaerobic digestion
Gorse	Nov	12-15	No	54	2.4	81 Dc	5.6	N/A	Combustion, bio-char, too woody for anaerobic digestion
Gorse	Feb	5-10	No	42	-	106 Dc	-	N/A	Combustion, bio-char, too woody for anaerobic digestion
Birch scrub	Nov	5-6	No	-	1.9	250[9] 30% Mc	5.8	N/A	Combustion, bio-char, too woody for anaerobic digestion
Rhododendron	Jan		No	-	2.9	-	5.4	N/A	Combustion, bio-char

Notes

Kg/m^3 – Kilograms per cubic metre
MWh/t – Megawatt hours per tonne
Mc – Moisture content
Sc – Single chop
Pc – Precision chopped
Dc – Double chopped

[8] Worrall and Clay 2014
[9] Biomass Energy Centre – www.biomassenergycentre.org.uk

5.3 The principles of moisture content and calorific value

The significance of the moisture content of a material will depend on the conversion process being used. For combustion the wetter the material the less calorific value it will have, as the first part of the burning process will be drying the material out before it can then be converted into heat. The moisture content will also affect the ability to process/convert the material for example briquetting of biomass at a moisture content higher than 20% is generally not advisable and may damage the equipment being used. (Please see Section 6, page 53). Drying and storing the material in a dry state is therefore particularly important when considering combustion as an energy process.

5.4 Storage and drying

Storing the material in the desired condition is key to being able to successfully turn it into energy, whether to preserve the sugars for anaerobic digestion or to maintain low moisture content for combustion, how it is stored will determine its value. Storage is often seen as one of the most problematic parts of the end-to-end delivery; however it can be in many forms and does not have to be expensive or permanent, it is not necessary to have a large barn, on site with easy access – although this can make life easier. Planning permission can often be a difficult obstacle to over come, especially on designated areas, however storage can be temporary, located adjacent to the harvesting/conversion site and variable in size.

5.4.1 Temporary storage

Low-density polyethylene (LDPE) '***AgBags'*** are one solution for temporary storage, they are large plastic sealed bags, up to 3m in diameter and 150m in length. At these dimensions an AgBag has potential to store over a 1,000m^3 of material, how much this physically equates to will depend on the material chop size and how tightly it is packed into the bag. This latter point will be determined by the moisture content and whether drying is needed.

Photo 25 AgBag for storage and drying

During trials completed using summer and winter cut reed from Ham Wall the following approximate kg/tonnes per running metre of AgBag were recorded:

- Winter cut/dry – 9m of AgBag held 7,260kg/7.2 tonnes = 806kg/m or 0.8t/m
- Summer cut/wet – 17m of AgBag held 35,530kg/35.5 tonnes = 2,090kg/m or 2.09t/m.

The material is put into the AgBag via a bagger. The shredded material is loaded into the bagging machine, which pushes the material into the AgBag. As it fills, the machine propels it self-forwards, initiated by the hydraulics pushing the material further into the AgBag. To operate, the machine needs solid ground, which can either be a hard standing or a grassy field. If the material needs to be dried as the material is loaded, a plastic perforated pipe is installed, which runs the length of the bag. This pipe then disperses air generated by a fan, to aid the drying process as described below. As AgBags are not permanent structures and are common agricultural practice, planning permission is not required.

To provide a guide for the time required to bag material and the throughput of the bagging machinery, a flat bed bagger can bag the 16m^3 bin of the Pisten Bully filled with loose material in less than 10 minutes.

5.4.2 The AgBag drying process

The AgBag bagging system has been used to dry grain during storage, during this process the system reduced the moisture content from 24% to 15% by using 0.5 kW fans blowing for 4 hours per day, running on sunny days from midday to 4pm. Each fan would typically blow 200 tonnes of grain and run on average for 12 days.

The system has also been used to bio-dry municipal solid waste (MSW) to aid the removal of recyclables. The drying reduced the moisture content from 32% to 12% which greatly improved the mechanical separation of the recyclables.

Woodchip has also been dried using the same system, which was reduced from 22% moisture content down to 5-6% in a storage period of 3 months, but only blowing for approximately 13 days. In addition paper sludge has been dried from 23% to 7% moisture content during winter, again by blowing only during sunny days.

Throughout these experiences it has seen that if the ambient humidity is measured, power usage can be reduced. The system has been shown to be capable of reducing the moisture content of the materials far lower than average ambient humidity and it has also demonstrated the importance of stopping the re-absorption of ambient moisture into the feedstock unlike when undertaking covered drying.

Solar-powered fans and humidity/temperature controls are used to control the air flow within the AgBags these are operated according to ambient humidity, as a result lowering the power consumption. Based on work undertaken in North Norfolk to dry down compost the system used less than 12amps at 240V to dry down 600 tonnes of material. On this occasion the fans ran for only 4 hours a day over 3 weeks, to bring the moisture content down from 34% to 18%. As a result the total power used was negligible compared to the power used to mechanically process the feedstock

5.4.3 Passive drying

It has been found that stored in the right conditions that reed has the potential to dry down passively. If cut, bundled and stored where the air can circulate, in an open building or stacked and sheeted, the material will continue to dry. This is done by the cut reed exchanging moisture with the atmosphere, depending on the relative humidity. The material will continue to do this until equilibrium is reached. This level of moisture content is referred to as the equilibrium moisture content (EMC). In the UK, the EMC for cut reed is approximately 15%. In Eastern Europe the EMC for cut reed is between 10 to 12%.

By comparison, studies have found that fen material treated in this way does not dry, but rather starts to degrade and ferment, this may well be due to a lack of structure facilitating air flow. However trials to dry rush through passive drying in an open ended barn over a 60 day period have shown to be successful, with the results presented in the tables below.

Table 5 Passive rush bale drying trials

Sample	Rush bales sampled on arrival		Sampled after static barn drying	
	Surface	**Core**	**Surface**	**Core**
1	28%	22%	25%	10%
2	35%	25%	30%	8%
3	(45)%	21%	28%	12%
4	28%	23%	16%	22%
5	35%	28%	27%	25%
6	38%	20%	27%	19%
7	40%	32%	37%	22%
8	20%	19%	14%	16%
9	22%	23%	17%	15%
10	21%	20%	15%	16%

Please note sample 3 at 45% is thought to be an experimental error so should not be considered.

However it should be noted that although in all cases after static barn drying the moisture content had decreased, the drying was uneven and the variation of moisture within the same bale had increased and was recorded to range from 8% to 30%, which was a hugely limiting factor for their conversion into an energy product such as briquettes which need a constant moisture percentage.

Where the bales were wet they had started to decompose and degrade, as a process this itself produces moisture, so although the drying reduced the moisture content of the drier material it was not counteracting the process of degradation. So in effect the wet material was getting wetter and the dry material getting drier. The result was very uneven drying, which made material utilisation difficult.

5.4.4 Kiln drying

Bio-charring or pyrolyis is a method of charcoaling, which is a process of thermal decomposition in the absence of oxygen. This process is conducted in a kiln; some kilns only have a small capacity and as a result can be labour intensive to load. However as part of the DECC project a new kiln 'MK III' was designed which can take 6m^3 of material at one time. The process also produces excess heat and the kiln harnesses this heat to aid in the drying of the biomass before it is bio-charred. Ideally materials need to be at below 15% before charring takes place.

The technology that has been developed by Carbon Gold and AMW, 'Mk III' has the configuration of two kilns and a single combustor. This has the advantage of offering a greater degree of flexibility in its application as it includes the following capabilities:

- Drying - heat generated in the combustor is used for removing moisture in both kilns.
- Single Charring - where char is produced in one kiln and the other is used for drying.
- Double Charring - where both kilns produce char alternatively.

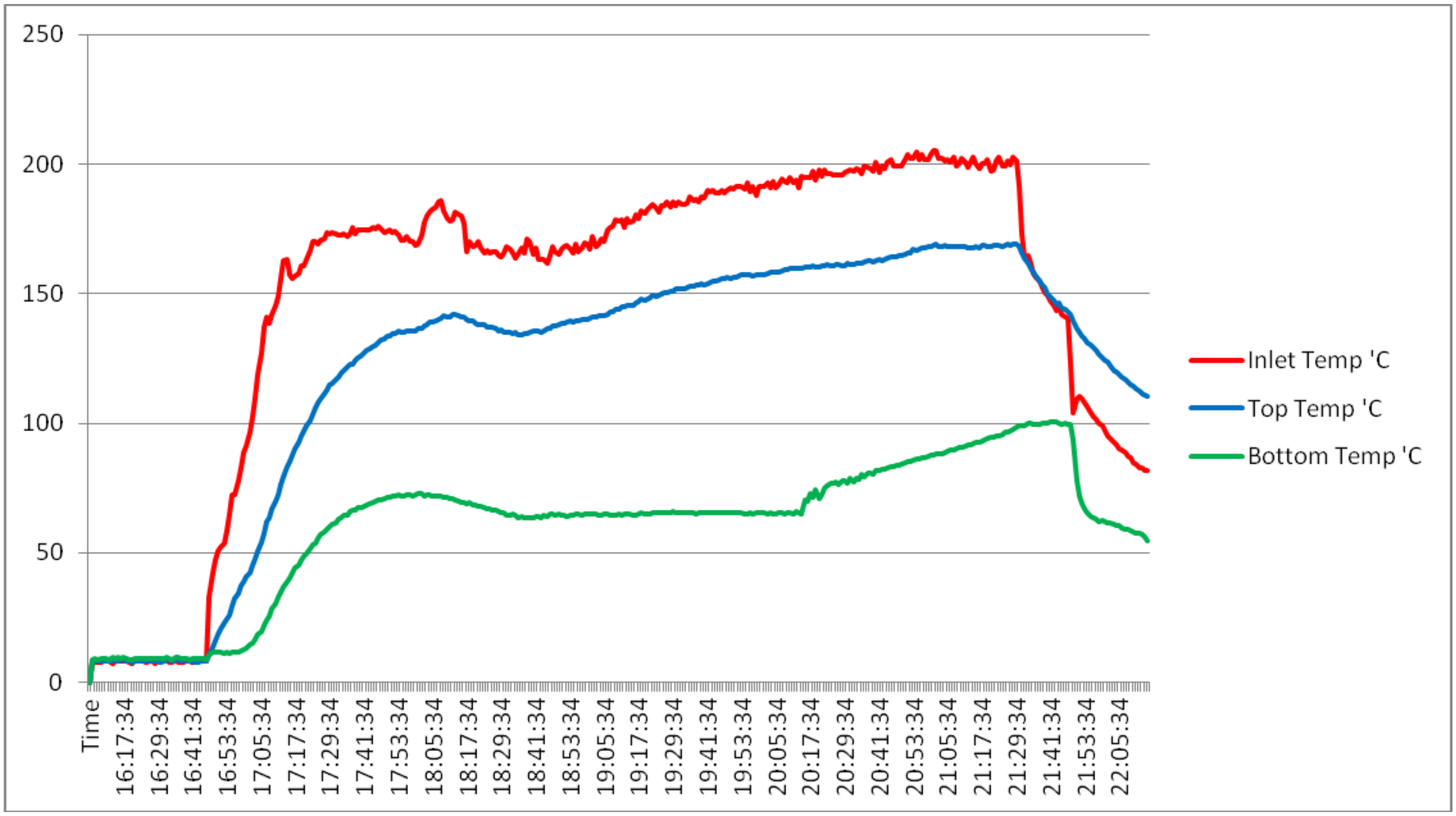
Drying in the MK III is typically a precursor for charring but it can be undertaken separately; wood is used to fuel the combustor and after the moisture has been removed from the feedstock the temperature is elevated into the pyrolysis zone and the resulting gases burnt. Temperature is monitored in the top and bottom of the kiln. Typically the material is charred when the bottom temperature exceeds 400°C.

The kiln works as a steam drier using re-circulated vapour. Heated vapour spirals up the outside of the kiln and is then drawn down through the material to initiate drying in the kiln, this air is then extracted at the bottom of the kiln through a pipe. Surplus vapour is released at this stage and the remaining extracted vapour is reheated, by direct mixing in the combustor with hot combustion gases, and re-circulated.

Examples of drying wet heathland materials in the absence of information for wetland feedstocks are provided below:

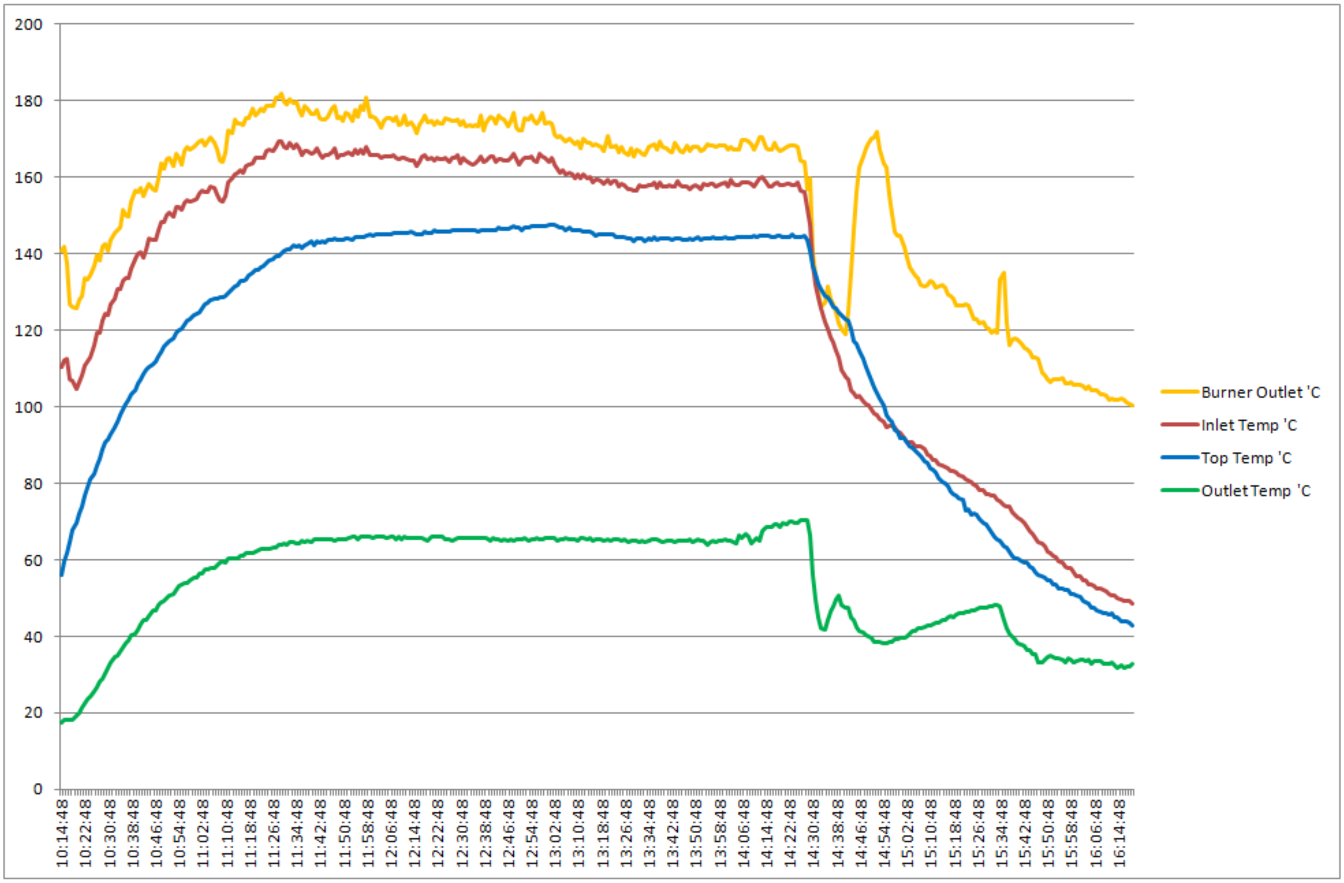
For drying gorse, the kiln was loaded with six (0.5m^3 ~ 2/3 full) bags of wet gorse which had been harvested with a chainsaw and chipped, and recorded at a moisture content of 54%. The drying started at around 13:30hrs when the kiln had warmed up and was recorded to substantially complete by 20:30hrs, as illustrated in the graph below. For the drying process the dryer operated at a heat input of just less than 100kW, the evaporation rate was estimated to be approximately 60kg per hour, reaching 200kg in 3hours.

With the gorse samples, given that the intention was to proceed to charring on this occasion the inlet temperature was allowed to rise to above 200°C. Despite the top temperatures not rising above 170°C, pyrolysis had been initiated - this is indicated by the short bottom temperature hold at 100°C after the kiln had been shut down.



Graph 3 Kiln temperature ranges during gorse drying trials

For drying heather, the drying curve is displayed below, as with the gorse trials, the kiln was loaded with six ($0.5m^3$ ~ 2/3 full) bags of double chopped wet heather at a moisture content of 44%. The drying started at around 11:20hrs when the kiln had warmed up and was recorded to substantially complete by 14:00hrs, as demonstrated below. The fuel rate was lowered at approximately 13:00hrs, which is illustrated on the graph through the input temperatures, but this, had little effect as there is no observable change in the outlet temperatures.



Graph 4 Kiln temperature ranges during heather drying trials

The drying took slightly less time than for the gorse trials, which is probably accounted for in the lower percentage of moisture recorded at harvest. During the drying process the dryer operated at a heat input of just less than 75kW, the evaporation rate was estimated to be approximately 100kg per hour.

Once dried the moisture content of the heather was tested and recorded at 14.7%, 18% and 21%. This provided with an average moisture content of previously 44% wet material of 17.9% once dried for in the kiln for a period of 2hours 30mins and a total kiln time of 4hours.


Photo 26 Heather sample before kiln drying (left) and after drying (right)


Photo 27 Dried heather being lowered out of the kiln

5.5 Ensiling

If storing the material for use in an anaerobic digester or for the hydrothermal pre-treatment and screw-pressing material will need to be ensiled (see Section 6, page 53). Ensiling as a process is an art of its own and may be undertaken a number of ways. It will depend on the facilities on the site where you are storing your material as to which method you choose. This could be one of the advantages of sighting the operation on a farm, as many dairy farms will have disused silage pits which can be utilised. Another temporary way in which to store silage material would be the AgBag system which is what the system was originally developed for and is typically used. Ensiling is undertaken to store material in an anaerobic environment. When processing in this way it is essential that it is done with speed and the material is kept fresh and not left to degrade in the air for too long. When undertaken for agriculture, the material would be cut one day, rowed up, collected/foraged the next. If ensiled effectively, well sealed and oxygen kept from the material in can typically be kept for a number of years. Using the AgBag system, which provides a complete seal from the air, the material can be stored for up to seven years. Having this capability provides continuity of feed and a contingency to cope with wet seasons, when material cannot be harvested.

Photo 28 Silage being made in a silage pit

The material is ensiled/stored in an anaerobic environment to prevent oxygen from enabling it to degrade. Oxygen or water (hydrogen and oxygen) will cause nutrient loss, allowing the growth of aerobic bacteria which will cause degradation, resulting in little to no methane production when it is put through the AD process. When stored the material needs to undergo fermentation and then stop as it reaches a stable state, this is called controlled fermentation, which improves the materials' capability of producing methane when it is digested. Fermentation softens the material and aids digestion and methane production when the material is used. This fermentation can be encouraged through mechanical mangling as the material is ensiled; this is increased through the Agbagging process which can aid controlled fermentation.

Enzymes can also be added to the material at the point of ensiling to encourage and control fermentation. These encourage the bacteria which undertake the fermentation, in some cases these enzymes control and regulate the activity of the bacteria though pH levels. During the fermentation/softening process, liquor may be released from the material; this liquor is the rocket fuel of anaerobic digestion. For this reason and to prevent any contamination issues this liquor needs to be contained within the silage. AgBags are very good at doing this as they are automatically sealed, however a silage pit can be set up to do so, but as mentioned at the beginning of this section – that is an art in itself.

The action of removing the silage to be used in the digester also needs to be considered. Exposure to the air when emptying needs to be kept to a minimum, as this can lead to oxygen penetration, which can reduce the calorific value of the material up to 25%. As soon as a section of the pit is unwrapped, or the AgBag opened, oxygen is allowed to enter. Cutting the material off the store will also increase this oxygen ingress.

Photo 29 Silage cutter

The ideal way is to use a silage cutter on the end of a front loader which cuts the material with a straight face, so preserving the anaerobic conditions of the material remaining. If the material is pulled or torn free, this is more likely to open up air pockets in the remaining material and increase oxygen ingress causing degradation.

5.6 Grazing animals and biomass harvesting

Many sites use grazing animals as part of their management and the relationship between such animals and the harvesting of materials should be considered. The two should work well together providing an end result of the most desirable habitat conditions. However some thought may need to be given into the planning of the relationship between the two to ensure that the effects of both are not detrimental to each other.

Using grazing animals on a sward may result in effects such as **poaching and a sparse sward**, with the reduction of thatch. In the field or site complex this will not impact on the actually harvesting operations, but could affect the stability of entry points and access tracks which can be problematic when combined with harvesting equipment.

Poaching and heavy grazing of the access points and tracks will often have a twofold effect:

1. It could reduce the sward length, often creating or exposing bare areas that are then prone to damage and churning up.
2. It could break the spine of the sward, leaving it unable to hold the substrate together and maintain the integrity of the track.

If at all possible before getting harvesting machinery on site it is preferable to leave thick vegetation in gateways and on grassy access tracks to provide more substrate stability and leave a thatch which provides a better intact surface to travel on.

The other issue in relation to heavy grazing is the **contamination of the biomass,** the significance of this very much depends on the desired after use. Heavy dunging may mean that it is then difficult to process and utilise the biomass for combustion. Whereas for anaerobic digestion, this may not be so problematic especially if the material is to be utilised immediately, however if it is to be stored it may effect the ensiling process. This will also depend on the degree of contamination.

Heavy poaching and ground disturbance can also increase contamination through exposing areas of soil. Such bare patches increase the likelihood of soil being collected as part of the harvesting process. This may particularly be the case if harvesting is being undertaken with a single of double chop forage harvester, which uses suction to collect the material into the bin or trailer at the rear. Soil can be especially problematic if the material is to be processed through compaction machinery such as briquetters or pelleters, with the potential to cause wear and damage.

5.7 Yields

The following information of volumes of materials taken off the listed areas has been complied from the work undertaken leading up to and during the DECC project. As the vegetation on each site will be site specific, these figures should only be used as a guide and indication of what a habitat type may produce.

Table 6 Wetland habitat biomass yields - RSPB

Vegetation Detail	Site	Location (County/ Country)	Dry matter tonnes/ha	Notes
1-yr old common reed	Ham Wall	Somerset, UK	6.2	Reed litter layer depth – no more than 20cm Average reed stem height - between 150 and 200cm Reed stem density percentage of reed coverage in a $2m^2$ – 93%
3-yr old common reed			7	Reed litter layer depth – no more than 30cm Average reed stem height - between 175 and 270cm Stem density percentage of reed coverage in a $2m^2$ – 90%
15-yr old common reed			8.76	Reed litter layer depth – 70 to 90cm Average reed stem height - between 250 and 300cm Reed stem density percentage of reed coverage in a $2m^2$ - 86%
Sparse soft rush at a density > 10% and < 50%	Exminster Marshes	Devon, UK	1	Average diameter of soft rush tussock at the base – between 10 and 20cm
Medium soft rush at a density between 50 to 60%	Minsmere	Suffolk, UK	2	Average diameter of soft rush tussock at the base – between 30 and 40cm
Dense soft rush - densely packed.	Catcott Lows	Somerset, UK	4	Average diameter of soft rush tussock at the base – between 50 and 60cm
Medium density rush/sedge dominated fen	Shapwick Heath	Somerset, UK	1.6	Percentage of rush/sedge cover within a $2m^2$ quadrat – 41% Species density and composition within a $2m^2$ quadrat – Grasses 45%, Herbs 7%
Dense rush/sedge dominated fen			2.2	Percentage of rush/sedge cover within a $2m^2$ quadrat – 66% Species density and composition within a $2m^2$ quadrat – Grasses 6%, Herbs 18%
Medium density common reed dominated fen	Minsmere	Suffolk, UK	1.6	Percentage of reed cover within a $2m^2$ quadrat – 38% Species density and composition within a $2m^2$ quadrat – Rushes/sedges 35%, Herbs 26%
Dense common reed dominated fen			2	Percentage of reed cover within a $2m^2$ quadrat – 61% Species density and composition within a $2m^2$ quadrat - Rushes/sedges 22%, Herbs 15%

Other yields for wetland materials, these figures have been taken from work undertaken elsewhere – the source of the information has been provided.

Table 7 Wetland habitat biomass yields - other

Source	Vegetation Detail	Location (County/ Country)	Dry matter tonnes/ha
Common reed			
Timmermann 2003	Common reed	Germany	3.6 - 43.5
Ash 2010	Common reed	UK	5.5
Komulainen, Simi, Hagelberg, Ikonen & Lyytinen 2008	Common reed	Southern Finland	4 – 12.6
Wendelin Wichtmann,	Common reed	Germany	7.3 - 11.7
Kask, 2007	Common reed	Estonia	6 - 9.34
Common reedmace			
Timmermann 2003	Common reedmace	Germany	4.8 - 22.1
Pratt, D.C. Dubbe, D R. Garver, E. Linton P. J. 1984	Common reedmace	Minnesota	9.6
Reed canary Grass			
Timmermann 2003	Reed canary Grass	Germany	3.5 - 22.5
Sefai Bilgin, Can Ertekin, Ahmet Kürklü, 2005	Reed canary grass	Turkey	4.6
Pratt, D.C. Dubbe, D R. Garver, E. Linton P. J. 1984	Reed canary Grass	Minnesota	10.5
Wendelin Wichtmann,	Reed canary grass	Germany	7.3 – 9.6
Reed sweet-grass			
Timmermann 2003	Reed sweet grass	Germany	4.0 - 14.9
Sedges			
Timmermann 2003	Lesser pond sedge	Germany	5.4 - 7.6
Timmermann 2003	Greater pond Sedge	Germany	3.3 - 12.0
Wichtmann, W. Haberl, A. Tanneberger,F	Sedge fen	Belarus	7.0
Wendelin Wichtmann,	Sedge	Germany	7
Grassland			
Bullock J, Pywell R, Walker K. 2006	Species rich grassland	UK	3.25-4.5
Prochnow, A. Heiermann, M. Plöchl, M. Amonb, T. Hobbs, PJ. 2009	Semi natural grassland	UK	6.7
Melts I, 2009	Floodplain meadows	Estonia	6.5

For interest and as a comparison, yields for heathland biomass have been included in the table below:

Table 8 Heathland habitat biomass yields

Source	Vegetation Detail	Location	Dry matter tonnes/ha	Notes
Heather				
Woodcock & Stephens, 2012	Heather	SE England UK	12.6 – 19.2	
Kirkham *et al, 2012*	Heather	UK	6.3 – 9.6	
Worrall & Clay, 2014	Degenerate heather	UK average	2.1	Low tonnage due to averaging across the UK
Mills, 2014	Mature heather	Kent UK	7.24	
Bracken				
Drake-Brockman, 1998	Dense bracken	UK	7.2 – 9	
	Moderate bracken		5.7	
Corton etal, 2012	Dense bracken	Mid Wales, UK	3.31	
Gorse				
Lake & Cruickshanks 2013	Degenerate gorse	Dorset, UK	12.54	
Mills, 2014	Degenerate gorse	Kent, UK	16.26	
Mixed heath				
Hanbury-Tenison	Mixed heath, gorse, heather and bracken	SW England UK	18 - 27	Moisture content not stated assumed at 10%
Price, 2012	Mixed heath	SE England, UK	18 - 27	

6. Conversion technologies

6.1 Combustion

Combustion of material appears to be perhaps one of the simplest ways of producing energy. However, although a simple process, there are many different approaches and many different combinations of ingredients for combustible products. Depending on which recipes or processes are selected will depend on the results obtained, especially in relation to process efficiency, calorific value and emissions.

The three main options that have been considered are briquettes/pellets/chopped material, each have pros and cons and their selection will depend on issues such as site conditions, machinery available and market/place of combustion. As mentioned in the previous section, selection of which combustion technique is most suitable will also determine the harvesting and collection method employed. This will help to ensure that the material is received with the appropriate moisture content and at the required chop length.

Briquetting and pelleting are both processes that compact material under a great deal of pressure in a contained die/former. Both processes are similar in that briquettes are like large pellets. Additional power is needed in the production of pellets compared to briquettes. Not only due to the higher degree of compaction to force the material through a pelleting press that is required, but also the grinding of feed stock that is needed to achieve a smaller particle size. For pellet production material needs to be able to pass through a 5mm to 10mm screen compared to briquette production, for which material to travel through a 30mm screen. In discussion with briquetting and pelleting manufacturers, it is understood that briquetting uses less power by about 25% for the same calorific value.

Photo 30 Pelleting

The amount of compaction needed to briquette/pellet material, can cause significant wear on the machinery used and any contamination with ‘rubbish’ such as stones or other hard objects can result in serious damage. Comparing the two products, due to the larger surface area of briquettes less wear occurs during compaction.

Briquetting can also handle a greater range of moisture content often found in problematic fuel stock. This again can be attributed to the to larger product size, together with a slightly reduced rate of compaction.

One of the advantages of pellets is their ease of use through larger commercial boilers and in the increase in popularity of such boilers. However with the advances in automated log boilers and also multi-fuel boilers, which can take both briquettes and briquette wafers (small sections of briquettes), it is now becoming possible to use briquettes in commercial and domestic boilers.

Photo 31 Briquetting

Another consideration is the effect that the degree of compaction used to produce the product has on its combustion. High density briquettes and pellets form stable products which are more favourable in the reduction of particulate emissions, for which a standard is set under the Renewable Heat Incentive. This aspect is considered later under the section efficient combustion and emissions.

The transportation and storage of briquettes and pellets both require different approaches however this is likely to be site specific, depending on storage capacity, amounts and combustion location.

Contamination was named as one of the significant problems and challenges as part of the work done by Little in 2010 for the Forestry Commission on the pelleting and combustion of heathland materials. This is an additional advantage of briquetting, which results in less wear on the compaction equipment, but also as an effect of calorific value. Spread over the larger product of a briquette the impact of contamination may have some effect on calorific value, but as a percentage of a larger final product the significance will be much lower.

It may be that **loose shredded material**, without going through the briquetting or pelleting process can also be used and this is currently being assessed as part a boiler review being undertaken for the RSPB. However due to the low bulk density, this approach would require that the material is harvested close to its final place of use, as it would not be economical to transport in this loose form. Many boilers with the appropriate feeds, such as augers will feed loose, un-compacted biomass, however some consideration may need to be given to the ‘light nature’ of the material and that it may need to be blended with a ‘heavier’ loose material such as wood chip to aid the feed. By feeding loose material without blending, it may also be difficult to conform to the particulate emissions. (Please refer to Section 7.1.1, page 80 for the results of the burn tests undertaken). The length of the chop size may need to be considered depending on the profile of the auger. Longer material may tend to get ‘wrapped around’ rather than ‘shuffled through’ the auger system.

Pelleting, due to some of the points described above was not explored in any depth as part of the Wetland Biomass to Bioenergy project and so nothing further on this process of conversion will be included.

6.1.1 Loose material

Many biomass boilers now on the market can deal with a number of different fuel types and forms, from pellets, loose material to briquette wafers and these are loaded from a storage hopper via an auger. Each feed system is adapted for the different fuel types, for example through different size augers and the provision of overload protection, so if the system clogs then the auger reverses to free the blockage.

One of the considerations with feeding loose material is its low bulk density and the continuity of supply, which may mean that it is just not practical, due to the frequency at which the hopper would need to be replenished. This is demonstrated by the different bulk densities illustrated below, which provides a comparison of material forms and so an indication as to the frequency at which the supply would potentially need to be replenished.

Photo 32 Guntamatic boiler auger feed

Table 9 Bulk density

Material type	Material form	Kg/m^3	Reference
Common reed	Loose	52	Ash, Wynne
Common reed	Pellets	666	Ash
Common reed	Briquettes	1198	Bilgin, Ertekin, Kurklu, Wynne
Soft rush	Briquettes	1,200	Wynne

The comparisons above also have implications for the movement and storage of each of the different material types. It is therefore only economic and carbon efficient if loose material is utilised close to the site of production, for transportation further a field then it is more efficient for the material to be compressed.

6.1.2 Briquetting

Briquetting can be achieved one of three ways; through an auger screw, hydraulic ram or a crank and piston mechanism. Each of these has a different application and the choice of technique is particularly important in relation to the characteristics of the biomass being processed. For example the auger screw can be regulated to produce a lower density briquette which is more tolerant of a higher moisture content (up to 30%) than the hydraulic ram (10% maximum), the latter being more prone to steam explosions.

Mobile rotary briquetters are now operated by contractors, AB Systems and AMW, these machines are reported to be able to cope with material up to a maximum of 30% moisture content, however the desirable level is 15% or less. If briquetted at the higher moisture content, the briquetting process will reduce the moisture in the material, but then produce a briquette not so dense which is more friable and has a lower calorific value. The mobile nature of the machines means that material can be processed on site and loose material does not have to be hauled. Temporary in field storage as mentioned in Section 5.4.1, page 42 also works well for this conversion approach.

The degree of compaction will determine the composition/density of the resulting briquette and of course the calorific value and the burn rate. For example the burn rate of brash wood in a high density briquette at 7cm x 22cm long is similar to that of poor coal and will burn for approximately 1½ hours, (Wynne 2011, pers. comm.). With some materials it may be that the lower density briquettes require a form of binding agent, to enable the material to adhere together. Such agents can also improve burning qualities, particularly if the briquette is made from slightly moister material. Oil such as rape oil can be used as an effective binding agent. Although there will be increase in the cost of adding a binding agent; this needs to be set against the reduced cost of drying.

Photo 33 Wetland biomass rotary briquettes

Size of briquettes will vary depending on the machine used to produce them; this also means that they can be produced for both domestic and industrial markets. Size could be influenced by the feedstock, however the bigger the briquette generally means that there is less wear on the production equipment. Some briquettes are produced with a hole in the centre which can aid burning through enhanced air circulation. Shape is also significant depending on the desired after use, eg rectangular briquettes, or those with edges cannot be used in a log boiler with an automated feed as they will not roll down the feeding mechanism. Packaging can also be affected as it may be more difficult to fit larger briquettes into bags; however in this case bundles or boxes can be used.

Coatings can be added to briquettes, such as wax, which can serve a number of functions:

- Helps bind the briquette together.
- Improves fire-lighting qualities – aids burning.
- Improves moisture resistance - briquettes due to the dryness of the material are vulnerable to taking on moisture at which time they will swell and start to break up.
- Assists with marketing as it increases the clean appearance of the product.
- Increases the opportunity for branding – by wrapping a brand around the outside of the briquette such as logo, which is then sealed in the wax.
- Can be used to add an aroma, which can increase marketing opportunities.

If the wax is added when the briquette is warm then the briquette will take on a limited amount and provide a thin coating. If added when cold the briquette will absorb more wax and the coat will be thicker and of course cost more. The cost of waxing is dependent on throughput, but on average for a domestic briquette, of 7cm x 22cm it is 10p, (Wynne 2012, pers. comm.).

The benefits of briquettes as a product:

- Clean.
- Easy to handle.
- Easy to transport and move.
- Not dusty, or damp, will not mould, smell or harbour insects which can be problematic in a domestic situation.

However it must be noted that as with any material being used for combustion, dry storage of materials to be used to combustion is the secret to maximising their calorific value. In the case of briquettes, unless they are coated, for example with a wax covering, they will absorb moisture and deteriorate if not kept dry. In addition depending on how the briquettes have been produced will affect their friability and a tendency to crumble if handled frequently. This is particularly the case with the lower density products made with a rotary machine.

6.1.3 Efficient combustion and emissions

Domestic solid fuel burning can be inefficient and lead to high emissions of gaseous pollutants such as carbon monoxide (CO), oxides of nitrogen (NOx) and particulate matter (PM). However these issues can be dealt with through achieving complete and efficient combustion, which is particularly important when dealing with the combustion on unconventional materials. For example combustion systems which incorporate continuous feeds of fuel have lower average emissions because they can maintain the appropriate temperatures necessary for efficient combustion. This is in part achieved by air circulation promoting the re-circulation of gases and air, which not only reduces any emissions through the flue, but is also able to achieve a far more efficient burn.

Two key considerations for the successful combustion of materials are: understanding of the effect of the mineral composition of the materials and the behaviour of the particulates, when combusted. For example chlorine as a mineral can be difficult on two counts; firstly because it is a component in dioxin formation and this is a problematic pollutant and secondly it has corrosive capabilities and so it has the potential to damage the combustion chamber of the boiler. However the appropriate choice of boiler type, which has the necessary, attributes in the form of metal or ceramic liners to counteract corrosive issues or moving grates which reduce problems with ash will deal with such issues, as discussed in Section 7.1.1, page 80. Dusty material can prove to be problematic in is tendency to produce particulate emissions, which may not conform to desired standards. Particulate matter emissions legislation typically refers to particles below 10 micrometers (PM_{10}) and 2.5 micrometers ($PM_{2.5}$). However, further boiler adaptations such as filters and efficient feed systems can help control such problematic emissions.

The Renewable Heat Incentive (RHI) sets rigorous standards for both oxides of nitrogen (NOx) and particulate matter (PM). From work done to date it is felt that for both briquette wafers and loose material it may be difficult to reach the PM standard of less than 30gs per gigajoule due to the high percentage of loose particles present during combustion. Higher density briquettes would reduce this, however could not be fed through the standard boiler auger feed systems, however pellets may be an option that offer the potential to satisfy both requirements – further tests are required.

Thought is also needed into the production of a combustion product that increases the combustibility of the materials; for example highly compacted briquettes can be difficult to ignite which can produce higher carbon monoxide emissions until combustion is established. Briquettes which have a central hole burn more effectively as this aids air flow, it has also been noted that briquettes made of fibrous material and small particles can also be problematic during the ignition phase. Blending biomass types helps to produce a reduction in peak emissions at different time of the burn. This may be particularly appropriate to a landscape approach that produces a range of materials from one area; these can then be combined to produce the best quality combustion product

Photo 34 Burning rush briquettes.

Another option to achieve cleaner combustion, reduce emissions and the effect of minerals on equipment is to use processes such as demineralisation, which would increase the potential for products to be sold in the retail market through non-specialist equipment. However this involves further processing and needs to be weighed up in relation to material specifics. With the exception of sulphur and chlorine other mineral elements pose little danger in relation to emissions. Demineralisation is discussed in Section 6.1.6, page 53.

6.1.4 Ingredients and the right recipe

The ingredients used in a briquette may well be determined by the characteristics of the biomass, for example straight combustion of wetland material through briquetting has often had a bad reputation, due to emissions and by-products. However some of these are misconceived and it largely depends on how and what the material is burnt in. The new emission standards introduced for the RHI now means that all new biomass boilers are adapted to be able to combust material to the necessary standards. These boilers are equipped with oxygen metres that monitor the flue gases to enable the correct amount of oxygen to be imputed so reducing the chance of flue gases discharging emissions, but providing enough oxygen to enable efficient combustion. The only way to truly determine the suitability of different biomass types and the right combinations is through completing a thorough characteristic analysis with emissions testing in a domestic boiler scenario.

6.1.5 Briquetting of material without any pre-processing/demineralisation

Briquetting of raw reed and rush of suitable moisture content without further processing obviously has its advantages and avoids more stages in the conversion process. To look at the viability of this approach combustion and emissions testing of rush and reed briquettes burnt in a domestic stove were undertaken, these tests were then compared to a replicated burn using the soft wood, pine.

In summary the results from these tests demonstrated good performance from the reed briquettes, with more mixed results from the rush briquettes however it was felt that this could probably be attributed to the material being of a higher moisture content. In detail Leeds University found the following:

Both rush and reed briquettes had comparable carbon monoxide (CO) compared to pine. The oxides of nitrogen (NOx) levels were highest during flaming combustion and lower during smouldering combustion; however the general trends and concentration levels were similar for all the fuels tested. Other emissions indicating poor combustion such as formaldehyde and ammonia were higher for rush briquettes. Sulphur dioxide levels were observed at only low levels for both briquette types, suggesting that the sulphur content of the fuels were low. Fuels containing high levels of chloride can produce hydrogen chloride (HCL) upon combustion, which is corrosive and can lead to flue damage. The HCL levels found during testing were only at trace amounts, suggesting that chlorine was not significantly high in either material.

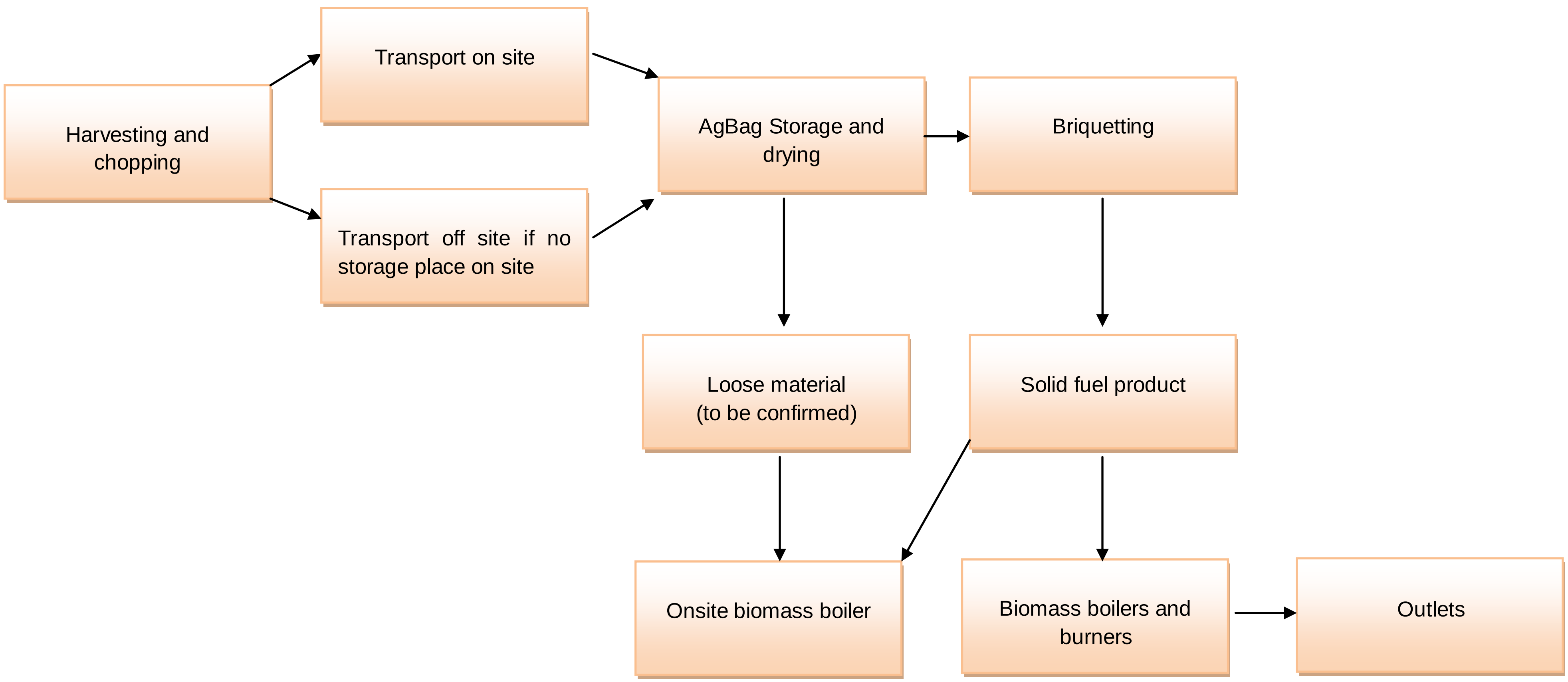
The particulate mass (PM) emissions from the reed briquettes and the pine were similar, much higher particulate mass emissions were observed with the rush briquettes at approximately twice the level.

Visual observation indicated that the most rapid burning rate was demonstrated by the reed briquettes burning hotter and faster than the rush briquettes or pine. The reed briquettes were found to burn at high temperatures with a strong flaming combustion accompanied with a high temperature peak at over 330°C, before reducing considerably as the transition into the smouldering combustion phase. Conversely, the rush briquettes did not produce as much heat as the pine baseline of 220°C and only reached highs of 130°C. This was because a good level of flaming combustion was not maintained, which resulted in a longer smouldering period.

It was noted that the fibrous, small particulate nature of the briquettes had an effect on the available surface area and gaseous diffusion characteristics of the fuels in comparison to pine. The density of the briquettes also had an impact on the burning characteristics.

Substantially higher ash levels were observed for both the reed and rush briquettes compared to the pine. The majority was as over-grate ash which remained on the grate in the approximate shape of the original fuel. However the colour was grey, suggesting little unburned carbonaceous material remained at the end.

Diagram 2 Briquetting of material without any processing – process diagram



6.1.6 Briquetting material after hydrothermal treatment

This process is the conversion of material into briquettes once it has undergone a number of treatments designed to lower the mineral content. Although it does involve more complicated processing it can offer more flexibility and a solution which will cope with inconsistent materials of various moisture contents. It also means that the material can be harvested in inclement weather conditions and does not rely on the crop being dry. This process uses screw-pressing to separate the feedstock, utilising the remaining solid fraction only for briquettes, and the liquid fraction for anaerobic digestion. Once the material has been foraged and collected it is stored through ensiling, (either through plastic wrapping of bales, AgBags, or through conventional on-farm means in a sealed silage pit) to maintain the material in a fresh state. Prior to processing, depending on the moisture content, water is added to the harvested material before screw pressing, from which two products are collected:

1. Liquid fraction - press-fluid - full of soluble nutrients, which potentially cause problematic emissions.
2. Solid fraction - press-cake – the press solids reduced in nutrients.

The ‘press fluid’ which comes from the dewatering/screw pressing of the biomass, which is high in minerals, is collected into a settling tank, where it is allowed to concentrate by being left to settle overnight. The concentrated press fluid at the bottom of the tank can then be used to power a small scale anaerobic digester, (AD) to generate gas. The remaining un-concentrated press fluid is recycled for use as pre-treatment water for subsequent processing. The biogas from the digester is converted to thermal and electrical energy via a combined heat and power unit which is then available to be utilised. The provision of power in this way means that if required the system is able to operate in remote locations.

The fibrous biomass ‘press-cake’ is collected in a hopper beneath the screw press and is dried; this could be through the excess heat off the AD process. The dried press-cake is then briquetted.

Hydrothermal pre-treatment through separating the biomass into a liquid and solid fraction in this way enables demineralisation. It has been shown that the liquid fraction contains as high percentage of the minerals, with a ‘cleaner’ solid faction remaining. This type of approach, using hot water pre-treatment also negates the need for drying the whole biomass prior to conversion into a combustion product. Drying is only needed for the solid fraction, once de-watering is complete. To look at the viability of this approach emissions testing of mixed composition briquettes (10% charred reed, 65% rush press-cake and 25% woodchip) and press-cake briquettes with a comparison to pine, in a domestic stove were undertaken.

Photo 35 Press-cake briquettes

Results from these tests showed good performance for both briquette fuels. The gaseous and particulate emissions were only slightly higher for the biomass briquettes compared to pine. Better performance was measured for the mixed composition briquettes compared to the press-cake.

Carbon monoxide (CO) emissions were higher for the briquettes during smouldering combustion only. The average oxides of nitrogen (NOx) were higher for the briquettes compared to pine, although this is probably related to a higher fuel nitrogen content and could be mitigated during blending.

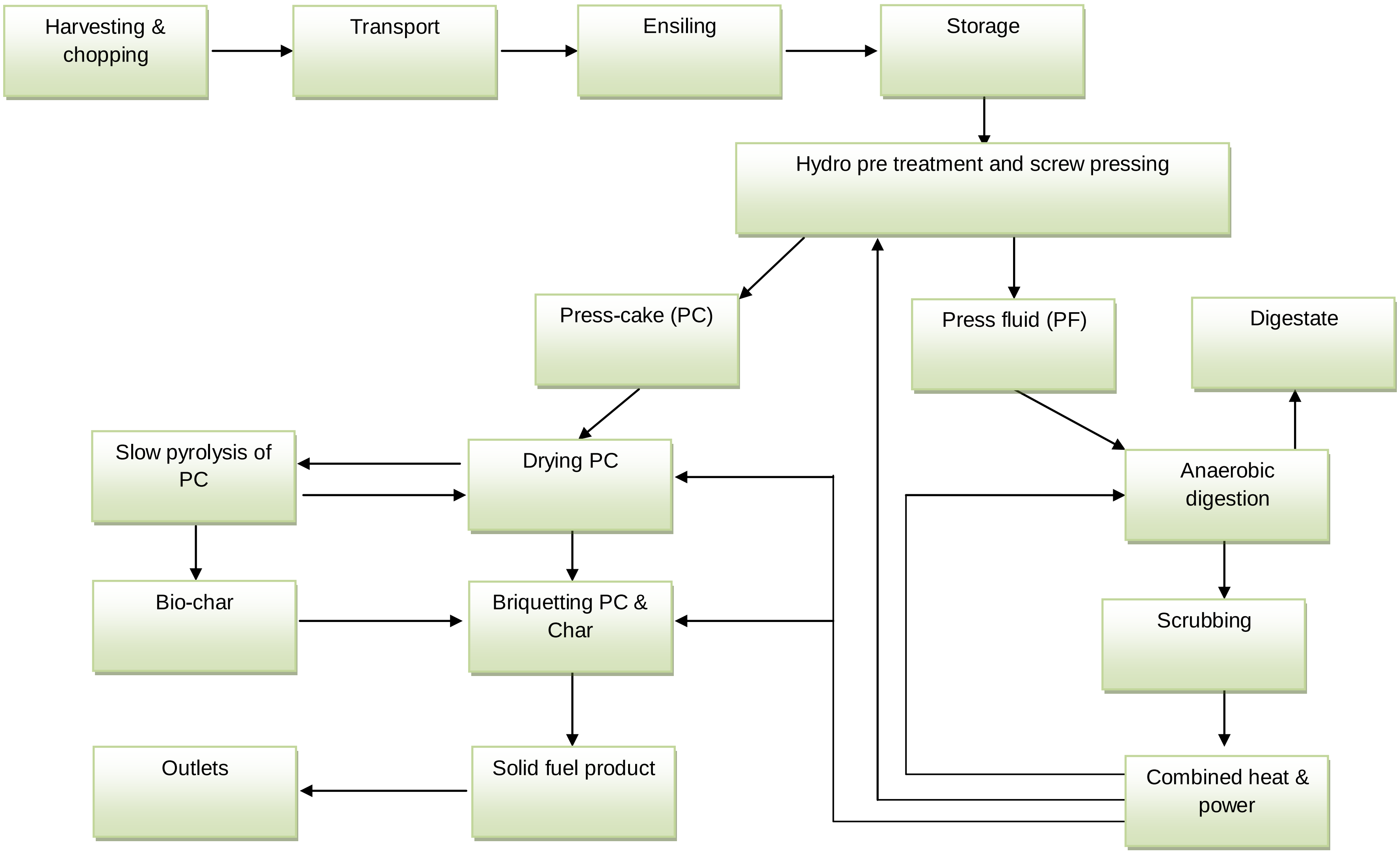
The press-cake produced slightly higher particulate emissions (PM) during flaming combustion. However particulate emissions during the smouldering phase were similar for all fuels.

There was little visible difference between the combustion of the two briquette types. In both cases, the flaming zone spread gradually across the samples, with a flaming phase lasting around 40 minutes, followed by a smouldering phase lasting for a further 20-30 minutes. There were few measurable emissions after a total run time of 60 minutes. The strong flaming combustion corresponding to higher temperatures was observed between 20 and 35 minutes for all the fuels. The temperature profiles were very similar for all the fuels with an average of 240°C, with pine reaching the lowest level. In each case, the temperature dropped as the proportion of smouldering combustion increased.

Sulphur dioxide (SO_2) was observed at only low levels, suggesting that the sulphur contents of the fuels are low. The highest values were observed with the press-cake fuel, however there was a rapid drop correlating with the time at which the briquettes were smouldering. As mentioned previously, fuels containing high levels of chloride can produce hydrogen chloride (HCL) upon combustion, which is corrosive and can lead to flue damage. The HCL levels found during testing were only at trace amounts, suggesting that chlorine was not significantly high in either material.

The briquettes retained their original size and shape (approximately) as ash, and so there was very little measurable under-grate ash. However the over-grate ash levels were very high, particularly for the press-cake, which need to be considered if using as a fuel. The proportion of ash loss to the original mass of fuel indicated poorer efficiency for the briquettes compared to pine, especially for the press-cake.

Diagram 3 Briquetting material after hydrothermal treatment – process diagram

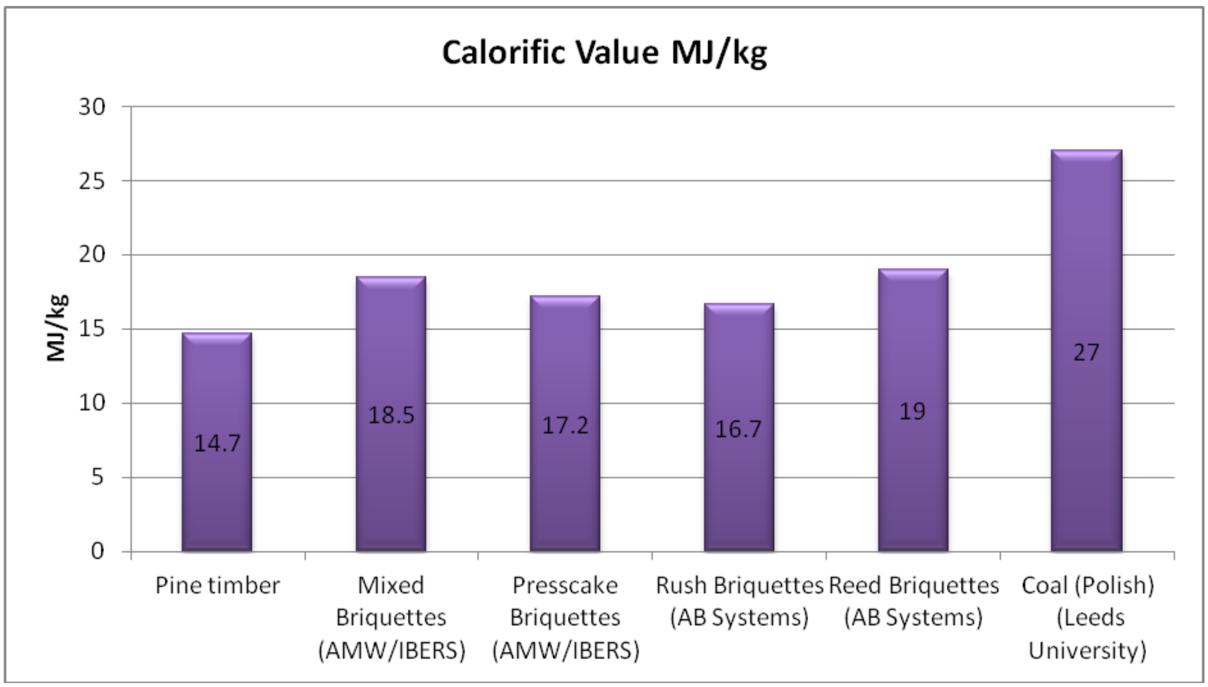


6.1.7 Conclusions on emissions testing

From the analysis undertaken by Leeds University it can be concluded that the fluctuations in values recorded are characteristic of hand fed stove combustion using large pieces of biomass as fuel, and are due to the non-uniform break up and movement of the fuels during the tests. Other combustion systems, such as continuous feed boilers, would give more consistent and steady emissions due to the constant re-fuelling. In addition other combustion systems which incorporate continuous feeds of fuel would have lower average emissions because they would maintain a temperature sufficient for more constant complete combustion. An effect of reloading would be to disturb the ash layer, causing smouldering char to break up more and potentially leading to more complete combustion. As a result the tests results present the worse case scenario.

With regard to all the fuels that were examined, (rush, reed, mixed biomass and rush press-cake briquettes) the following comparisons can be made and conclusions drawn:

The **calorific value**, (MJ/kg) of all the biomass types were higher than pine, but as might be expected none were a great as coal.

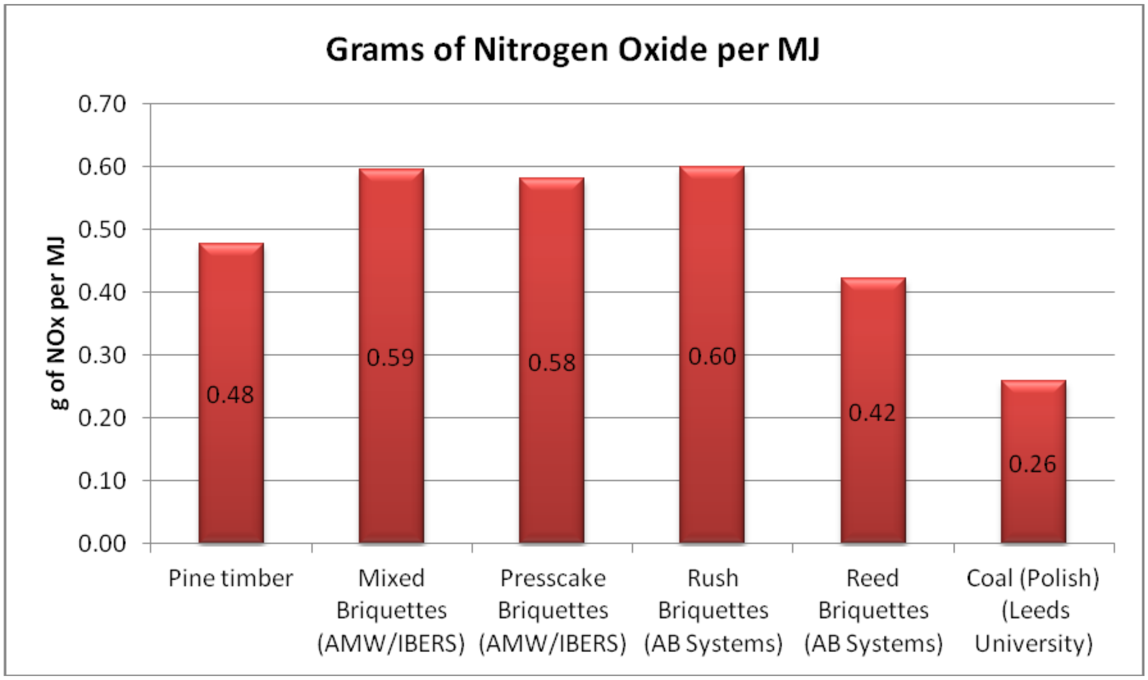


Graph 5 Calorific value comparison

The **sulphur dioxide levels** (SO_2) were suitably low and SOx emissions were not problematic. This illustrates the low sulphur levels in the biomass feedstock.

The **chlorine** (Cl) levels of all the fuels were also suitably low (described as trace amounts' and 'not significantly high'). This is positive as low Cl levels are important especially if the fuels are to be used in some commercial burners where corrosion can occur if Cl levels are high.

The **carbon monoxide** (CO) emission levels for all fuels were demonstrated as similar to pine (apart from the smouldering burn phase).



Graph 6 Nitrogen oxide comparison

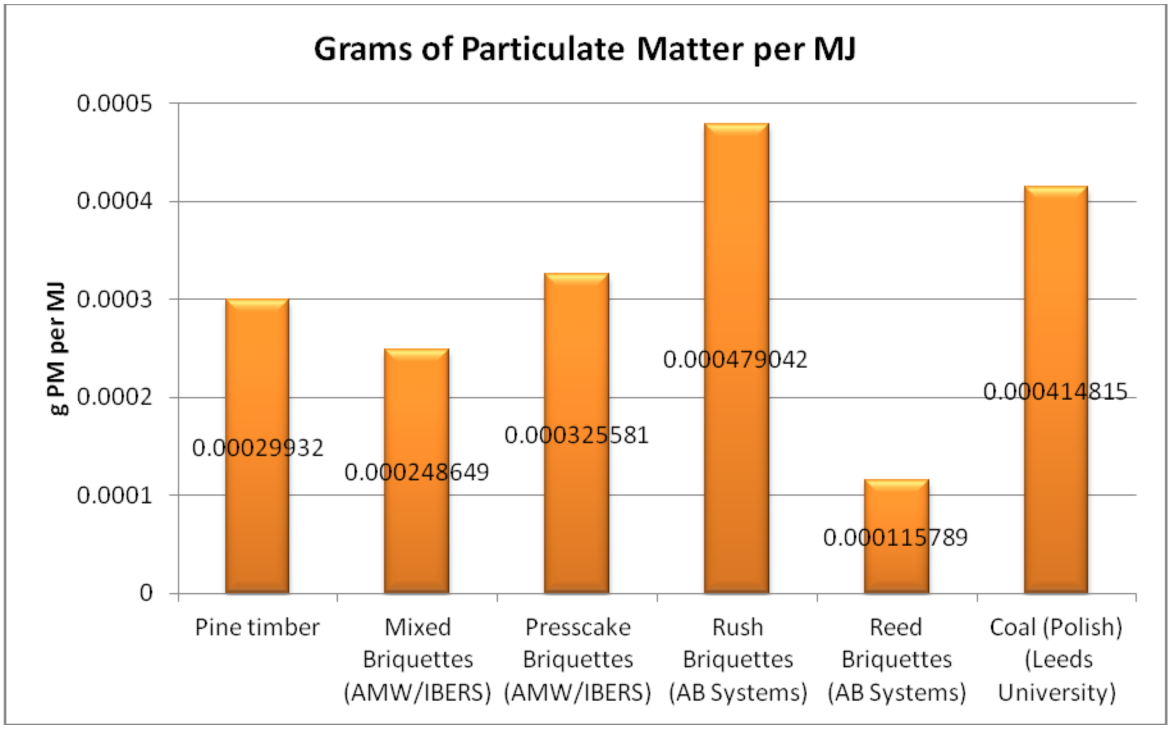
As illustrated above, the **oxides of nitrogen** (**NOx**) emission levels recorded for coal, in relation to its high calorific value were lower than all the other fuels.

However it is interesting to observe that the reed briquettes produced results lower than the pine, with the other biomass types only slightly higher. For the other biomass types it was considered by Leeds University that the NOx emissions were 'similar to pine' and so were happy to conclude that they are acceptable at the levels recorded. However all fuel types, apart from coal are above the 300g/GJ[10] permitted NOx emissions set by the EU limits for non-woody biomass pellets, (there are currently no limits set for briquettes).

As illustrated on the following page, for the briquetted reed **particulate matter** emissions results were low and for the other biomass types are described by Leeds University as slightly higher than pine in the flaming phase but similar to pine in the smouldering phase. The AMW-IBERS mixed briquettes appear to have very similar total PM emissions to pine (this will be very important in smoke free zones)[11]. As a guide, all fuel types fall well below the 35g/GJ permitted PM emissions set by the EU limits for non-woody biomass pellets.

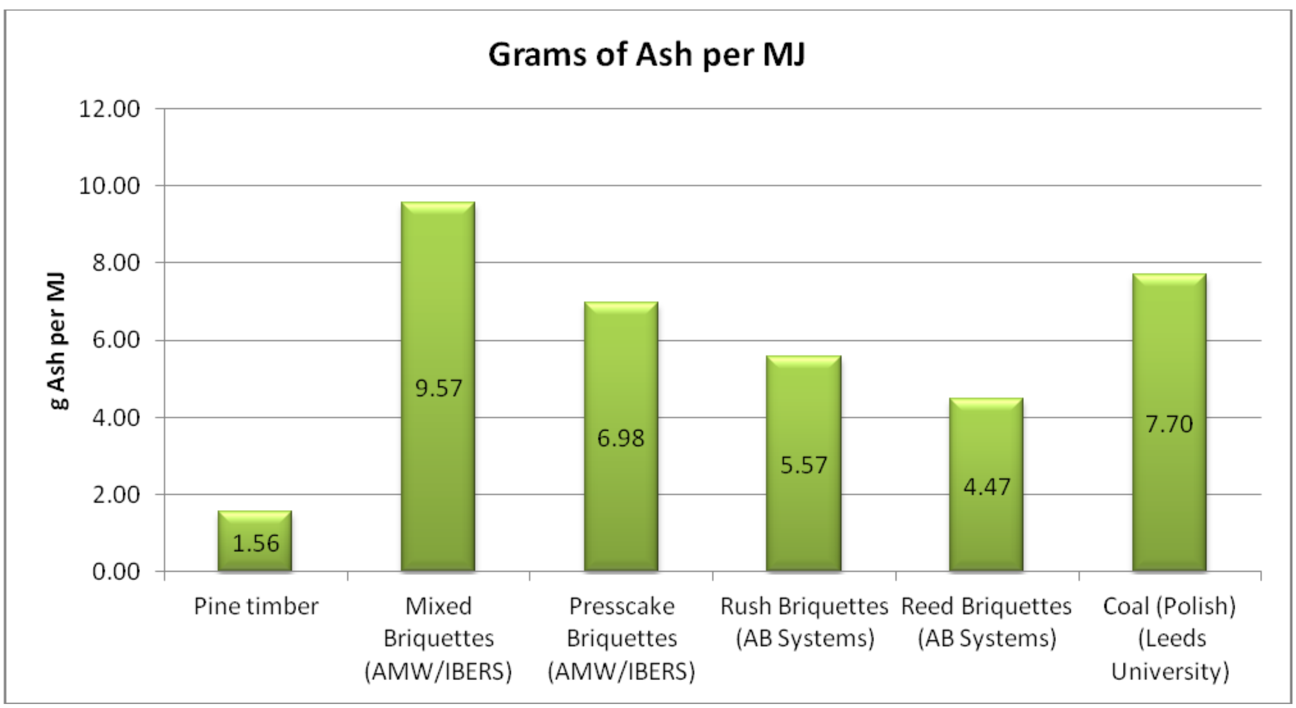
[10] Current data presented for MJ multiplied by 1000 to provide g/GJ
[11] Dr John Corton, Aberystwyth University

Graph 7 Particulate matter comparison



The **ash composition** of all the materials was generally higher than pine but much lower than coal. Despite unconventional biomass types such as rush and reed having a bad reputation for ash production, when compared to pine this is the case, but alongside coal, only the mixed briquette failed to produce less ash, as illustrated below.

Graph 8 Ash content comparison



Other studies have shown that the ash production from reed is approximately 1/3rd that of coal (Polish coal; Mitchell 2014). So although for all the briquette types tested ash generation levels were high compared to pine, the management activities relating to ash management would be much reduced compared to coal.

To put the above results in context and to understand the place of wetland materials as a combustion fuel, it is useful to set them against the ISO standards for graded non-woody briquettes. The ISO International Standards provide the specifications to measure against to ensure that any products, processes or services are fit for purpose. The following table demonstrates that wetland materials, reed and rush are comparable to the standards for all the essential properties and trace elements listed. The only currently undeveloped parameter is the consistent production of a stable/non-friable product; this aspect is being progressed through further trials. The comparison below confirms the potential of these materials as briquette feedstocks.

6.1.8 Comparison of essential properties of wetland briquettes against ISO standards for graded non-woody briquettes

Table 10 ISO standards comparison

Essential Properties	Unit	ISO 17225 A	ISO 17225 B	Reed Briquettes	Rush Briquettes
Dimensions	mm	State diameter, width and length		175mm width x 80mm diameter	
Moisture	w-%	<12	<15	5.3	3.8
Ash	w-% dry	<6	<10	4.7	3.9
Particle density	g/cm3	>0.9	>0.6	0.8 to 1.198	1.2
Additives	w-% dry	<5	<5	N/A	N/A
Calorific Value	MJ/kg	>14.5	>14.5	19	16.7
Nitrogen	w-% dry	<1.5	<2.0	1.04	0.58
Sulphur	w-% dry	<0.2	<0.3	<0.01	<0.01
Chlorine	w-% dry	<0.10	<0.3	<0.01	<0.01
Surface Incl. Hole	cm^2	Should be stated		140	140
Trace Elements					
Arsenic	mg/kg dry	<1	<1	0.3	0.3
Cadmium	mg/kg dry	<0.5	<0.5	0.1	0.1
Chromium	mg/kg dry	<50	<50	0.7	1
Copper	mg/kg dry	<20	<20	1.9	1.1
Lead	mg/kg dry	<10	<10	0.7	0.5
Mercury	mg/kg dry	<0.1	<0.1	<0.1	<0.1
Nickel	mg/kg dry	<10	<10	<0.5	<0.5
Zinc	mg/kg dry	<100	<100	16.8	17.9
Burning time	Min	Should be stated		60mins	60mins

In conclusion from the work completed by both Aberystwyth University and Leeds University when compared against the ISO standards for non-woody biomass briquettes and on comparison with two other fuel types, namely pine and coal, each of the wetland biomass briquettes perform satisfactorily to be burned as an alternative to pine. In addition from the results recorded if the emissions were presented as mass per calorific value (mass/megajoule), the indications are that the higher calorific value of the mixed briquette would have out performed the pine. (Corton 2015, pers. comm.)

6.1.9 Type of briquetter used

The briquetter that has been used to deliver the DECC projects is the Biomasser BMP6 (manufactured by ASKET in Poland). This machine was originally selected for its appropriateness for wetland biomass for the following reasons:

1. It was easily incorporated into a mobile system.
2. It is a ‘rotary’ machine (it takes the feedstock into a circular moving drum before pressing it into briquettes) and therefore takes more varied feedstocks (i.e. bales, chopped material, loose arisings, etc.).
3. It can make briquettes with a hole through the centre, which assists the drying process after manufacture and increases the burning capability.
4. The manufacturer (ASKET in Poland) was able to increase the diameter of the finished briquette, to improve production throughput and the length of burn when ignited.
5. It is able to handle straw-like material of varying moisture content and copes well if an error is made and moist material is fed into the machine. This particular type of machine handles the resultant steam explosion well.
6. The hole through the centre of the briquette aids the production of the briquette from mixed moist material as it provides an escape route for the steam. (This also has the added advantage of improved burn characteristics and easier ignition of the briquettes.)
7. ASKET were able to produce a new parallel 80mm die - this enabled an increased throughput and reduced maintenance costs as the die’s now have replacement wear collars. (Previously, whole die replacement was required).
8. This machine exhibited the best throughput capacity which is 500kg/hr.

It was thought that the above advantages highlighted for wetland materials could have a wider application and benefit for processing other conservation biomass. However if the material is of a more woody nature, with larger particle sizes, it may well be more appropriate to use the linear high compaction briquetter, for which material is milled. Unfortunately such a machine was not available to undertake any such trials during the DECC project.

In both compaction techniques, solid particles are the starting materials and those that will determine the nature of the briquettes. In the rotary products the individual particles are still identifiable to some extent in the final product. The rotary and linear action extrusion both represent compaction i.e. the pressing together of particles in a confined volume. If fine materials which deform under high pressure are pressed, no binders are required. Natural components of the material may be activated by the prevailing high pressure forces to become binders. However it has been found that even under high pressure conditions, the briquettes produced are friable and some of the materials are likely to need binders to produce a higher density/stable briquette.

Photo 36 Rotary briquetter in operation

Table 11 A basic comparison of the two briquetting methods, linear and rotary.

Issues	High density briquette	Rotary briquette
Material preparation	Milling is required to reduce particle size before compaction, resulting in more energy being used during the process	Milling is not required, briquetter can deal with precision and double chopped material
Material type	Able to handle material of all types, due to particle size reduction before briquetting	Not able to process large chunky material like large woodchip
Particle size and contamination	The small particle size means contamination often found in non-conventional materials is a serious problem	More ability to tolerate contamination
Moisture Content	Has to be below 10%	Can tolerate up to 30%
Drying	More energy used in achieving the necessary low moisture content	Such extensive drying not needed due to a higher moisture content tolerance
Burning	Can be difficult to ignite due to high compaction	Easier to ignite as more air present due to reduced compaction
Calorific value	Due to higher bulk density, calorific value can also be a little higher	Lower bulk density can mean a reduction in the calorific value
Handling	Can be more robust when handled and do not break up so easily	Can be more friable as not so compacted and prone to breaking up when handled
Movement of briquettes	The higher bulk density of this briquette means a greater weight per volume. However size of lorry loads are more likely to be restricted by volume rather than weight.	Lower bulk density can mean briquettes slightly lighter by volume.
Machinery	Mobile machines not currently available	Mobile machines currently operated by two contractors in the UK

6.2 Anaerobic Digestion

What is Anaerobic Digestion?

Anaerobic digestion can be used for processing green material, of a higher moisture content, ideally freshly harvested or if stored, in a deoxygenated environment. Anaerobic digestion is the digestion of material in anaerobic conditions to produce biogas, which is then harvested and either fed directly into the gas grid or converted through a combine heat and power plant to produce electricity and heat. This process deals with green material well, but may struggle with material of a high lignin content such as common reed, which the micro-organisms struggle to break down due to its cell structure.

So that material which is to be used for anaerobic digestion does not loose its biogas potential ensuring that it is stored in the absence of oxygen is important. As mentioned in previous sections, this can be achieved either in a conventional silage clamp, as wrapped bales or in an AgBag, depending on onsite facilities.

One of the by-products of anaerobic digestion is digestate, this is the residual material post digestion, which still has nutrient value and can be used as a replacement fertiliser.

Anaerobic digestion is a process commonly used to convert grass rich in sugars, purposely grown maize, farm waste, such as slurry or food waste into energy. The digestion of wetland biomass has been trialled through the DECC project and the biogas potential of the different vegetation types are presented below.

Table 12 Wetland material characteristics for AD

Material	Oven Dry Matter %	Moisture %	Total Gas yield M^3/t	Total Methane Content %
Reed sweet-grass	26.4	73.6	138	52.6
Common reed	35.3	64.7	185	53.2
Mixed tall fen	31.9	68.1	165	52.4
Soft rush	33.7	66.3	173	53.1
Grass silage			120-215	
Maize silage			180-210	

Typically the materials processed by whole-crop AD plants are measured by their dry matter content. The margins for the dry matter they generally operate between are 30 to 36%. If materials have more dry matter than this it could mean that there a higher percentage of lignified/woody material is present. In general the older the material gets the woodier it becomes which in turn increases the percentage of lignin. Although this material may have a high total gas yield it is difficult to realise as a high amount of it would be tied up in the lignin. Grinding this material to free up the gas yield from the lignin can help, but it is still hard to unlock. With this in mind and knowing that a high percentage of the above samples harvested conformed to the AD requirements – then this opens up another opportunity as an outlet for biomass. The figures for grass/maize silage (typical AD feedstock) are included so comparisons can be drawn.

Some wetland vegetation types, such as common reed (particularly older material) can be high in lignin and through the project; trials have been undertaken looking at methods which aid the breaking down and destroying the cell structure of such woody vegetation.

Different mixes of vegetation may be required to make anaerobic digestion a viable option for the processing of wetland material into energy; this would also build in flexibility and the insurance that a range of materials are available nearby. Consistency and continuity of supply are important for anaerobic digesters, unlike processing though combustion, anaerobic digestion needs a constant supply to maintain the activity of the micro-organisms for biogas production. To enable this continuity, it is likely that materials harvested at the appropriate time for conservation objectives will need to be cut and stored to provide a supply at times when material cannot be harvested eg through the bird breeding season.

6.2.1 Different Anaerobic Digestion Systems

6.2.1.1 Small Scale Anaerobic Digestion – 7 to 20kW System

This system is more of a plug and play type approach, based on a modular system that can be used as individual units or linking units together. There are a number of these types of systems on the market and the one trialled through the DECC project has been the bioQUBE or quickQUBE model. This system is delivered through modules of 20 foot shipping containers or through flexi cubes as illustrated below. The modular nature of this approach means that an increase in feedstock availability can be accommodated by simply scaling up the number of units.

As with other digestion systems each module is heated and stirred to provide the right environment for biogas production to take place. The system is fed as a continuous process, small volumes of feedstock material to be processed are loaded each day and the same volume is unloaded each day in the form of digestate; this process is automated.

There is very little odour from the process, all of which is contained. The spreading of the digestate may cause some odours, but not as great as the spreading of unprocessed slurries and manures.

Photo 37 Small scale AD

Each system comes in a standard configuration consisting of:

- Reception chamber, with macerator pump to mix feedstock and transfer to the digester.
- Heat exchangers to keep the digesters at a set operating temperature to ensure rapid digestion and biogas production.
- Control panel to automate pumps, heating and gas/generator controls – the bioQUBE has an intuitive user interface; all of the processes are controlled by small PLC computer.
- The system can also be operated remotely; for example from an app on a mobile phone if required.

During the DECC project this system was operated using press fluid only, resulting from the screw-pressing of ensiled wetland biomass. The press fluid concentrate is fed into the anaerobic digester, at a particular daily volume (480 litres per single module), this is a fully automated process controlled by computer located in the digester container. The fluid digests quickly with a hydraulic retention time of around 19 days. The digester produces biogas that is cleaned through a hydrogen sulphide filter. The biogas then enters into a combined heat and power unit and delivers thermal and electrical energy.

With the utilisation of fluid only produced through screw-pressing the estimated through put per year is 520 wet tonnes of total biomass which results in a total feed of 160,000 litres per year. The daily requirement of approximately 500 litres of feed will on average result in 1,000kg of press cake (the solid fraction left from the screw-pressing process).

Table 13 Small scale AD outputs

Small Scale Anaerobic Digestion – 7 to 20kW System - bioQUBE	
Total Biomass	400 tonnes
Total Feed	400 tonnes
Bio-Methane production	47,714m^3 biogas with 25,765m^3 of methane the rest CO_2
Electricity	7 kW
Operational hours	8,000 h/year
Electrical output	53,956kWh-e
Heat output in hot water	91,447 KWh heat which would raise 2,870 litres of water from 10°C to 70°C per day or 1,047m^3 of water per year

6.2.1.2 Medium Scale Anaerobic Digestion – 100kW System

This is a bespoke system developed as part of the DECC project by Natural Synergies Limited. It is a medium scale anaerobic digestion plant that utilises a series of modular units and an atypical horizontal digester. The digester has a four stage digestion process which enhances the rate of reaction and is designed to improve conversion efficiencies.

Photo 38 Medium scale AD

System dimensions

- The complete AD Plant is comprised of the following systems: Pre-treatment, Digester, Biogas and digestate units. Potential plant footprint is ~ 15m x 15m.
- The pre-treatment unit consists of a maceration unit to reduce and homogenise particle size and a pasteurisation unit to comply with PAS110 and to enhance the AD process. The foot print of this system is approximately 12m x 3m (size of a forty foot container).
- The digester consists on a horizontal vessel the foot print of which is approximately 12m x 3m, a full-scale 100kW system will require four of these digesters.
- The main product of the AD plant is biogas which is converted into heat and electricity through a combined heat and power (CHP) engine. The biogas produced during anaerobic conversion of the biomass is stored on the digester head space and sent to the biogas unit. The foot print of the biogas system is of approximately 12m x 3m.

Odour Control System

The Pre-treatment unit is skid mounted with no open tanks. The vents of the tanks are connected to a common ventilation duct which has been provided with a passive activated carbon filter.

Pre-Treatment Unit

The pre-treatment unit is critical to this AD process as it ensures a homogeneous feedstock, giving a continuous and consistent feed to optimise bio-methane potential, this includes.

- Maceration Unit – To reduce particle size to less than 4mm.
- Enzymatic Addition - The addition of enzymes leads to “roughening up” the surface of the feed particle. This stimulates attachment of fibrolytic bacteria and aids microbial colonisation of the feedstock; this can aid the breakdown of components such as lignin.
- Pasteurisation Unit - Pasteurisation is a requirement under PAS110, which is required UK legislation for utilising digestate as a natural fertiliser.
- Ultrasounds Unit - To use ultrasonic waves to blow the material cells apart, which again help with the breakdown of woody materials higher in lignin.

The Ultrasounds Unit

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

Through the trials it was found that this technology requires low energy input and due to its low energy consumption, it is a suitable technology for application to small scale anaerobic digestion systems.

The Digesters

The pre-treated material is fed to the digester which partially separates and fully optimises each stage of the digestion process. It is split into four zones, each zone is monitored, ensuring stable operation by maintaining biological integrity with cross mixing between zones to enhance reaction rates and conversion, though minimising competition between active bacterial populations. The digestion is a thermophilic process with an overall operation temperature of 52°C with a hydraulic retention time of 15 to 28 days.

The digester consists of a horizontal stainless steel tank with dimensions of approximately at 3m diameter x 12m long with a gross capacity of $70m^3$. The digester is mounted in cradles and will be located on a flat concrete area.

Biogas Unit

The main product of the AD plant is biogas which is converted into heat and electricity in a combined heat and power (CHP) engine. The biogas produced during anaerobic conversion of the biomass is stored on the digester head space and sent to the biogas unit. This unit includes the CHP engine, a biogas boiler and a fuel oil boiler. Both biogas boiler and CHP engine come fitted with flare arrestors. The fuel oil boiler is only required during commissioning of the digester. The biogas boiler is required during maintenance of the CHP engine. The system has being designed to operate the biogas boiler in case of an emergency breakdown of the engine.

Bio-methane potential

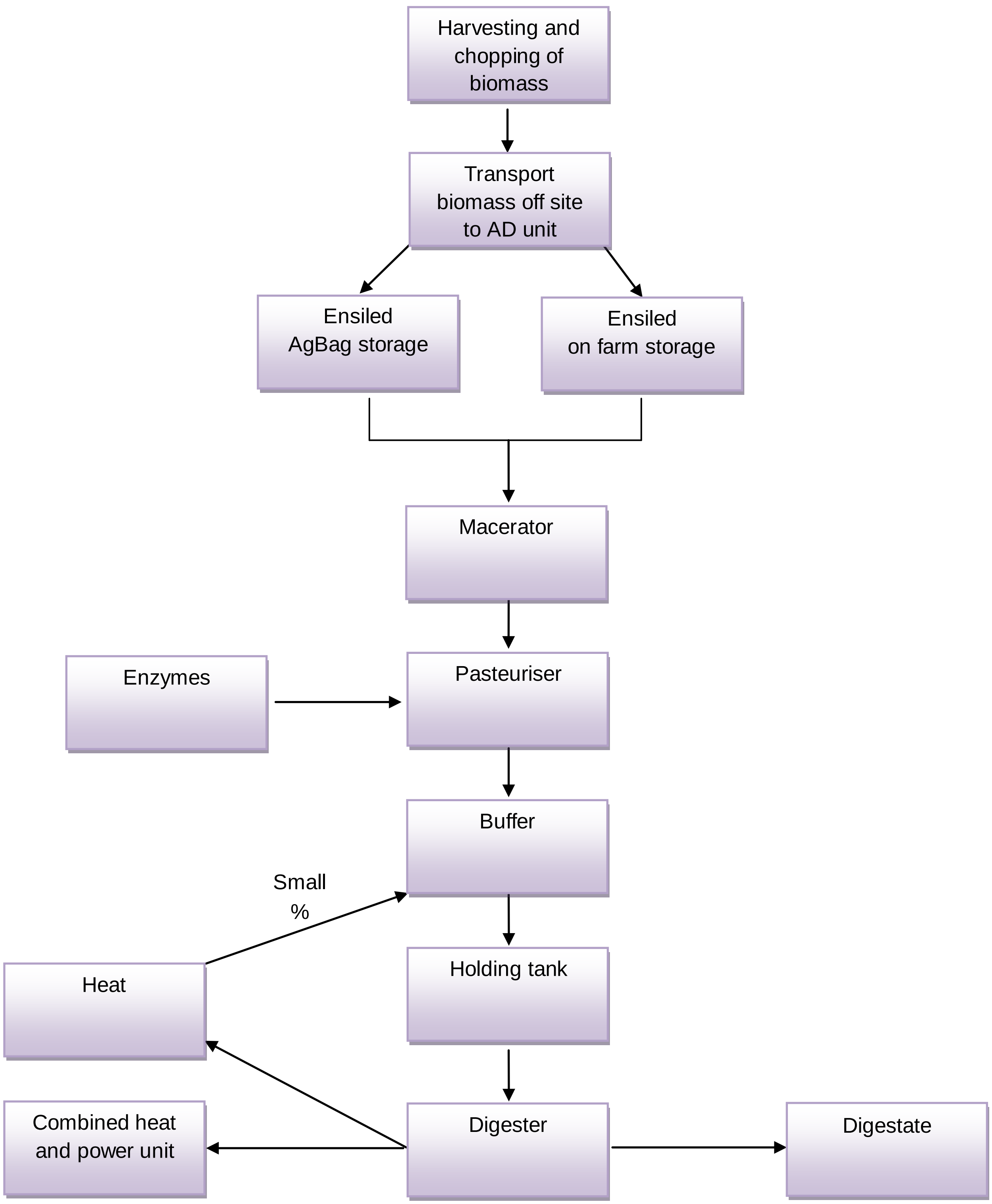
The figures below are based on a projected energy yield bio-methane potential (BMP) from the mixed biomass suitable for AD to be of approximately 300Nm^3 of bio-methane/tonne of volatile solids (VS) or ~50Nm^3 of bio-methane per tonne of fresh biomass.

Medium Scale Anaerobic Digestion – 100kW System – Natural Synergies	
Total Biomass	2,162 tonnes per year (based on 80% soft rush & 20% common reed)
Total Feed	3,137 tonnes per year
Bio-Methane production	230,970 Nm^3
Electricity	100 kWe
Heat	185 kWth
Operational hours	8,000 h/year
Electrical Output	800,000 kWh-e
Heat Output	1,480,000 kWh-th

Table 14 Medium scale AD outputs

Now the DECC project has concluded, further trials and investment are needed to progress this system beyond pilot stage and to the desired 100kW scale. As part of these trials significant changes need to be made to the design of the feed mechanism and the movement of material through the system as a whole, so that it is able to cope with a range of whole-crop wetland feed stocks.

Diagram 4 Medium scale anaerobic digestion process diagram



6.3 Bio-charring

Bio-charring or pyrolyis is a method of charcoaling, which is a process of thermal decomposition in the absence of oxygen. This can be undertaken at different temperatures to created different results. When executed at lower temperatures (around 400ºC) the input material will be converted into a more solid char, this method is called slow pyrolysis, whereas using higher temperatures (around 500ºC) this will produce a much higher proportion of liquid (bio-oil).

Timber products particularly can be bio-charred successfully as they have a high content of woody material. Leafy materials have a low proportion of fixed carbon and generally form limited and brittle chars, typically as a by-product of combustion. However it has been demonstrated that biomass such as rush and reed can be successful. Many companies sell the idea of bio-charring as a way to improve soil structure and enhance fertility whilst sequestering carbon. Some feel that further work needs to be undertaken on the long term effects of adding char to soils of different types. However it has an additional application in the production of energy, as it has the ability to reduce the volume of materials, whilst increasing their energy density and so producing a high calorific value additive which can be utilised in the briquetting process alongside other materials.

An illustration of this is provided through the results of charring test burns of wetland biomass through which it can be seen that the net calorific values, recorded as megajoule/kilogram for charred materials were increased in all cases following the charring process:

Table 15 Charred biomass calorific value comparison

Biomass type	Net calorific values of input biomass MJ/kg	Moisture content of input biomass %	Net calorific values of charred biomass MJ/kg	Moisture content of charred biomass %
Rush/grass	14	20	20.7	3.7
Willow	12.5	30	23.6	2.7
Reed	14	20	30.9	3.8

The char figures are comparable with fossil fuel and other fuel equivalents:

- House coal 27 – 31MJ/kg
- Anthracite 33MJ/kg
- Miscanthus bale 13MJ/kg

The process of bio-charring is conducted in a kiln; however many that are used only have a small capacity and as a result can be labour intensive to load. As part of the DECC project a new kiln 'MK III' was developed by Carbon Gold and AMW. As detailed in Section 5.4, page 42, this kiln has an increased capacity of $6m^3$ at any one time.

The 'Mk III' kiln has the configuration of two kilns and a single combustor. This has the advantage of offering a greater degree of flexibility in its application with the following specifications:

- **Burn time** – around 8 hours – 4hour drying process and 4hour charring process.
- **Moisture content** – up to 60%.
- **Feedstock size** – rice husk and wood shavings up 30cm length logs.
- **Feedstock type** – most types of biomass.
- **Feedstock volume** – two x $6m^{3.}$

- **Fuel source** – dry woodchip and wood pellets.
- **Char yield** – up to 800kg per burn (400 per 6m^3 chamber).
- **Infrastructure used** – four electric fans and a generator.

The kiln is a versatile commercial kiln that is capable of both drying and charring a wide range of feedstocks. It is built in a frame the size of a 20ft container for the ease of transport. The kiln consists of two kiln bodies and an external combustor; there is 6m^3 capacity for feedstock in each kiln body. The kiln can run in three ways:

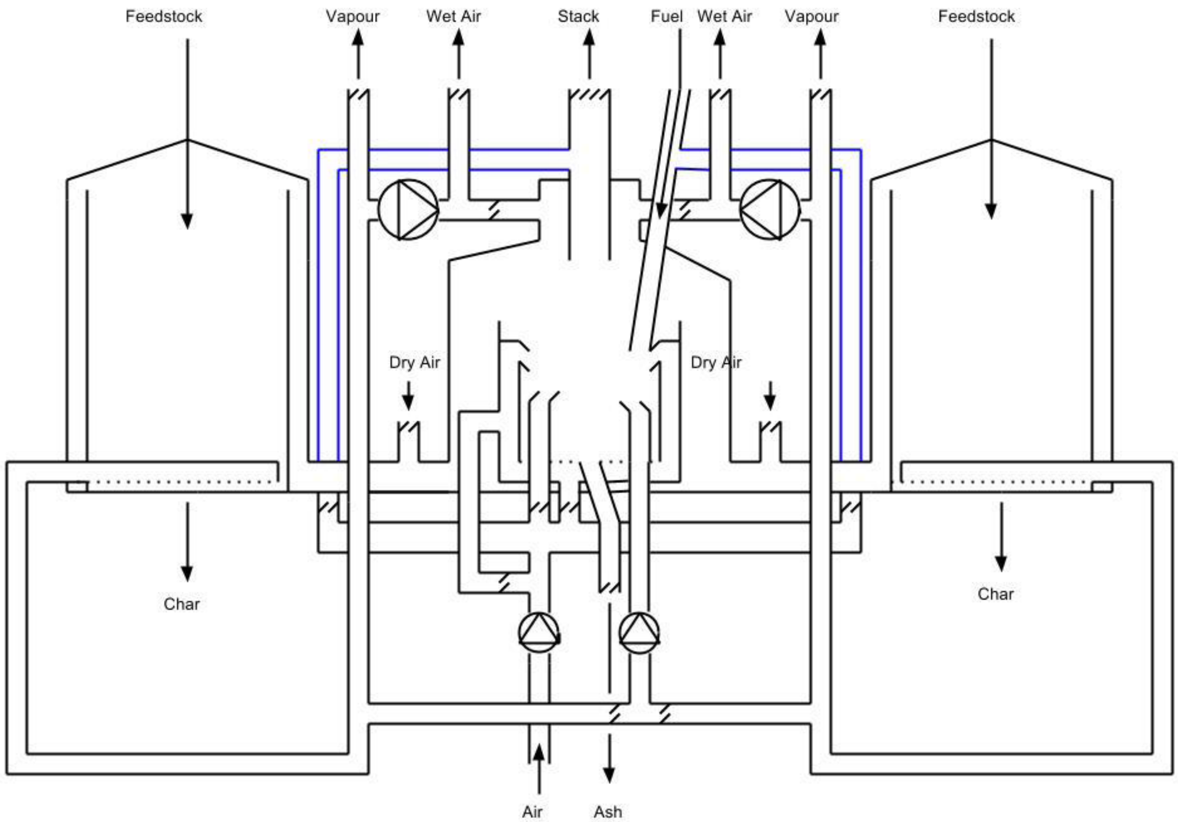
Photo 39 MK III bio-char kiln

1. Drying – Both kiln bodies are filled with wet feedstock which is air dried using wood chip in the combustor, the heat generated in the combustor is used for removing moisture in both kilns.
2. Charring 1 – One kiln body is filled with dry material, such as reed bundles, to be charred. Gas produced during the pyrolysis is used to fuel the combustor and the excess heat is used to dry the material in the other kiln body.
3. Charring 2 – Kilns are alternatively filled with wet material which is initially dried using the excess heat from the other kiln body and then charred; this provides heat for the drying of the other refilled kiln body.

Wood is used to fuel the combustor and after the moisture has been removed from the feedstock the temperature is elevated into the pyrolysis zone and the resulting gases burnt. Temperature is monitored in the top and bottom of the kiln. When the bottom temperature exceeds 400°C the material is generally charred.

The kiln works as a heated gas pyrolyser. Hot products of combustion are drawn from the combustor up the outside of the kiln and then pulled down through the pyrolysing material. This combination of pyrolysis gas and re-circulated combustion gas is extracted and incinerated in the combustor, with the majority of the burnt gas released through the chimney.

Diagram 5 Mark III bio-char kiln flow diagram



Increasing the energy density of materials can have a number of applications in the conversion of nature reserve biomass into energy products. It provides the ability to process small amounts of material on site which can then be moved for inclusion into an energy product off site, without moving large volumes of bulky materials. In some test burns it has been found that the conversion rate of fresh reed to charcoal was 5.4 to 1, rush and grass at 6 to 1 and seasoned willow at 4.2 to 1.

The measured densities and moistures of materials were:

- Rush 50kg/m^3 @ 33% moisture content
- Reed 100kg/m^3 @ 15% moisture content
- Press cake 145kg/m^3 @ 45% moisture content (in small quantities it can be as light as 50kg/m^3, but tends towards 200kg/m^3 in large bags).
- Wood chip 285kg/m^3 @ 37% moisture content

The challenge with lighter materials is to achieve a meaningful throughput within the context of the energy balance. Drying materials with a moisture content greater than 50% will consume a significant amount of fuel and have long drying times.

6.4 Conversion machinery/technology access requirements

As with the harvesting equipment, some basic considerations need to be made when planning to bring conversion machinery/technology on to site, not just in terms of access once on site, eg through gateways and down droves but also getting the machinery to the site entrance off a main road.

As with the harvesters, typically the machinery will arrive on an articulated lorry, which will need to travel to the site entrance and the following dimensions should be taken as a guide when planning:

Table 16 Conversion technology transport dimensions

Machine Name	Type	Machine dimensions
Bio-char Kiln	Drying kiln	In operation: 5.9m long, 2.4m wide 2.9m high on legs During transport: on a lorry: Lorry width 3.1m, lorry length 10m, combined height 3m (legs removed)
AgBagger	Bagging machine	In operation: long N/A, 6m wide 2m high During transport: on an articulated lorry: Lorry width 3.1m, lorry length 13.4m, combined height 5m
Asket Briquetter	Briquetter	In operation: remains on car trailer: Trailer width 2.1m, trailer length 4.9m + towing vehicle, combined height 3.6m

7. Energy delivery

7.1 Biomass boiler

There are a number of biomass boilers now on the market, however it is those capable of burning multi fuels which appear to be most appropriate for burning conservation materials, as they have the necessary adaptations to best deal with the challenges already discussed posed by unconventional fuels. Two such boilers were explored as part of the DECC project. The Biokompakt and the Guntamatic Powerchip; both are versatile boilers and through the research undertaken appear to have the potential to cope with unconventional fuel types.

7.1.1 The Biokompakt is an Austrian manufactured multi-fuel biomass boiler, which can burn a wide range of alternative, high calorific and alternative biomass types.

- The Biokompakt boilers are triple fuel and can burn up to 3 different fuel types, simultaneously, from over 30 pre-tested fuel sources, including agricultural and factory waste.
- These boilers are capable of co-firing and all have a ceramic chamber which prevents corrosion.
- The Biokompakt can take a wood chip size of up to 60mm which means a local tree surgeon's chipper can be used and there is no need to invest in a dedicated biomass chipper.
- They are easy to operate, reliable, and come with a fully automated fuel feed system.
- They are microcomputer controlled, with self-optimizing fuel adjustment for optimum efficiency.
- The boiler systems are available from small 15kW to large 130kW and can be cascaded to 1MW.
- They offer an efficiency rating of up to 94.3%.

Specifications for the Biokompakt AWK98

- Boiler width 886mm.
- Boiler height 1,727mm
- Depth 1,520mm
- Minimum space requirement: H x D x W – 2,700mm x 3,000mm x 2,800mm
- Power connection 400V
- Transportation weight 1,690kg
- Flue pipe diameter 160mm

Results from burn tests undertaken

The Biokompakt AWK98 with the industrial auger option has been used for preliminary burn trials using loose wetland biomass and briquette wafers. These trials produced the following results:

Photo 40 Biokompakt AWK98

Loose reed and rush

- Both fuels in their chopped form generated large amounts of ash in the burn chamber, the secondary chamber as well as the fly ash tray.
- Reducing the primary air flow, increased the feeding time as well as the pulse time and reduced the amounts of ash and un-burnt fuel building up in the burn and secondary chambers.
- The feed auger was engaged for longer periods of time due to the low bulk density of the chopped reed and rush.
- When cleaning no clinker was observed in the ash box or burn chamber.

Briquette wafers

- Although the fuel was in a semi compressed form a large percentage of the fuel was made up of uncompressed reed or rush
- The fuel passed through the Biokompakt feed system with no problems, but the larger briquette pieces sometimes skipped passed the auger feed the first time round.
- Although the fuel was in a compressed form by the time it reached the boiler through the auger system it was broken up into smaller pieces, which added to the fly ash.
- The auger worked a lot less when feeding the compressed fuel compared to the loose chopped product.

Photo 41 Feeding briquette wafers

- When cleaning after the trial no clinker was observed in the ash box or burn chamber.
- The amounts of ash in the burn chamber, the secondary chamber as well as the fly ash tray were much reduced compared to the loose material.

Photo 42 Ash box after 24 hrs burning loose material (left) briquette wafers (right)

Conclusions

- The ash softening temperatures for reed was 1,340°C and rush was 1,500°C, which is comparable to soft wood at 1,100°C, which explained the lack of clinker formation.
- The boiler burned both the chopped and briquetted fuels easily and without significant problems.
- The ash removal would be increased to a daily routine with the loose reed and rush.
- With the briquette wafers the ash removal would be around 4-7 days but with more adaptations this could be increased.
- The density of the supplied briquette wafers was low. The fuel was very easy to break in the boiler auger, which its size significantly by the time it entered the burn chamber (was more akin to the form of chipped straw). This caused an increased amount of fly ash being generated during the burning process, even after a reduction of the primary air injection to 80%.
- The low density of rush and reed briquettes, caused inconsistent fuel delivery into the burn chamber; resulting in higher electric consumption of the auger, stoker and ash removal motors.
- Setting the boiler at 900°C helped to avoid NOx being admitted.
- It is considered that the friability of the fuel trialled may make achieving the PM standards difficult.

7.1.2 The Guntamatic Powerchip is also an Austrian manufactured fully automated multi-fuel biomass boiler, which can burn a range of biomass fuels including wood chips, wood pellets, grain or miscanthus.

- It is part of a range of Guntamatic boilers with outputs from 20-400kW (up to 100kW with a single unit).
- The boilers are able to maintain maximum 96% efficiency between 26-100% of output.
- The Guntamatic Powerchip is fully automated and the automatic hot air ignition means a fast and easy start with the lambda probe introduces the required oxygen amount to enable optimum combustion.
- The self-cleaning moving step grate system helps the boiler to cope with a wide variety and quality of fuel types.
- The constant motion of the turbulators keeps the heat exchanger tubes free from efficiency-reducing deposits.
- Changing between fuel types is simple, via the built-in, menu driven touch screen control panel supplied as standard.
- A levelling auger helps to fit as much ash as possible into the large 60-80 litre ash bin.

Specifications for the Guntamatic Powerchip 100
- Width 1,874mm (boiler 1,090mm)
- Height 1,845mm
- Depth 980mm
- Transportation weight 1,400kg
- Powerchip Boiler (without stoker unit) - 865kg Bottom box - 430kg Stoker unit - 75kg

2,000 litre buffer tank with insulation
- Weights & Dimensions:
- Height 2,370mm
- Diameter with insulation 1,300mm
- Diameter without insulation 1,100mm

Photo 43 Installation of a Guntamatic boiler & 2,000L buffer tank

Flue system
- 200mm internal diameter, twin wall stainless steel flue, insulated with ceramic.
- Flue to terminate with a cone top discharge.

Results from burn tests undertaken
No fuel tests using wetland materials have been undertaken using the **Guntamatic Powerchip**.

7.2 Combined heat and power engine

On large anaerobic digestion units the gas produced may be cleaned up and put straight into the grid; however on smaller plants the most common way to convert the gas into heat and electricity is via a combined heat and power engine or CHP.

A typical biogas unit set up would include the combined heat and power engine, a membrane gas holder, scrubber unit and may have a dual gas (propane and biogas) boiler. The gas holder regulates the pressure of the biogas in the digester and overall system and it provides buffer capacity to feed the CHP engine. The biogas at this stage is saturated with water, as the gas temperature drops, water will condense and at this point should be extracted from the gas holder, often via a simple lute.

The biogas scrubber as part of the unit is needed to bring hydrogen sulphide (H_2S) values to safe operational levels. Typical recommended values for H_2S levels by CHP manufacturers are approximately < 300ppm.

7.2.1 Small Scale Anaerobic Digestion – 7kW System

The gas from the small 7kW system can be put into a powerQUBE to generate electricity and hot water. PowerQUBE is a small combined heat and power (CHP) generator neatly packaged up into its own self-contained pod. It is similar a small scale generator complete with control panels and connections however it is able to run off 100% biogas including being able to start on biogas alone.

This type of CHP can be bought with varying sizes of CHP generators, from 3.2kW up to 30kW and can be used easily with a range of anaerobic digestion systems, with simple plug in connections via the standard fittings in the pod. PowerQUBEs are very efficient, particularly when recovering heat from exhausts and engines; up to 30% of the output will be electricity and 50% heat in the form of hot water at 60 to 80°C. The unit has been designed to be super silent – even with the CHP running the noise level is less than 56 dBLeq at 10m.

The system can operate in two modes:

- Island mode – when the CHP is not connected to the electricity grid, but rather provides heat and power locally.
- Grid mode – when the system is connected to the electricity grid to allow export of excess electricity generated.

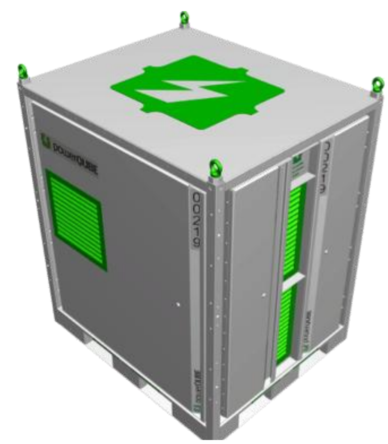


Photo 44 powerQube

7.2.2 Medium Scale Anaerobic Digestion – 100kW System

The type of CHP engine installed will ideally deal with the flow of gas produced from the digester. The Natural Synergies' medium scale AD plant has a 20kWe asynchronous CHP engine. The biogas boiler has been designed with excess capacity to ensure that can take the maximum biogas produced in case of an emergency shutdown of the CHP engine. The engine efficiency is of approximately 30%. The Biogas unit is skid mounted and has been designed to fit within a forty foot container.

On large biogas plants of more than 300 kWe, synchronous CHP engines are typically used. However on smaller plants were there may less of a constant and predictable supply of gas an asynchronous combined heat and power (CHP) engine may be more appropriate. Small biogas plants can particularly benefit from a CHP engine that can operate at different gas levels such as offered by an asynchronous engine. This type of engine allows the small plant to operate without the requirement of a biogas holder, whose main purpose is to buffer the gas pressure of the system.

The engine efficiency of CHP's, particularly operating off medium plants are not high and in the case of the 100kW system being developed as part of the DECC project, sits at approximately 30%.

In addition to the CHP, a biogas dual fuel boiler is typically required during commissioning of the medium scale digesters. This also provides a back up to ensure that the parasitic heat load of the plant is always met and if there is a problem with the CHP then the gas produced can be utilised. However, both biogas boiler and CHP engine should be fitted with flare arrestors to allow the gas to be dispersed in the event of a breakdown of both units. The biogas boiler should be designed with excess capacity to ensure that it can take the maximum biogas produced in case of an emergency shutdown of the CHP engine. The biogas boiler is also required during maintenance of the CHP engine.

7.3 Supplying existing conversion plants

7.3.1 Large scale anaerobic digestion

Consideration should also be given to the potential of supplying an existing anaerobic digestion (AD) plant within the local area. On provisional testing of suitable materials for their biomethane potential, it would seem that they may well be attractive to local AD operators. (See biomethane potential figures presented in Section 6.2, page 70).

7.3.2 Large scale combined heat and power

A set up such as Estover Energy, which is a 12-15MWe biomass CHP plant planned for south-east England, may be happy to take material for combustion. The plant will use approximately 140,000 tonnes of wood each year, to supply electricity to the grid as well as heat and power to a local industrial office park. Some of RSPB sites have been approached by Estover in relation to possible feedstock supply contracts. Another option is linking with a set up such as that developed in the east by Anglia Farmers. This is a farmers' cooperative acting as an agricultural purchasing group who operate to facilitate the small suppliers in the provision of materials for the larger consumers such as Ely Straw power station, which is 38MW and uses 240,000 tonnes of straw a year.

7.3.3 Supply Contracts

To supply existing set ups whether AD or CHP it is likely that there will be a need to set up a supply contract between the organisations involved. Whilst in principle this may seem straight forward, there are a number of factors to consider especially in relation to the key drivers for the management work. Supply contracts usually form the basis on which investment is secured for large scale plant development. As a result they will typically be for a set period of time and for a minimum amount of material, so that the energy organisation can demonstrate continuity of feedstock supply. Before agreeing to such terms it would need to be ensured that material can be supplied each year without being detrimental to the site and compromising the conservation objectives.

8. Life Cycle Analysis

Life Cycle Analysis (LCA) is a technique used to assess environmental impacts associated with all the stages of a product's life from end-to-end (i.e. from biomass harvesting through to energy production). It enables an assessment of all the steps necessary for or caused by the product's existence. The aim of LCA is to provide information so that comparisons can be made of the environmental effects assignable to products and services by quantifying all inputs and outputs and assessing how these may impact on the environment. This information is used to improve processes, support policy and provide a sound basis to inform decisions about product and process development.

In basic terms with regards to converting conservation biomass into bioenergy, the LCA ensures that we are not using more energy than we are delivering. It enables us to ensure that our process is as energy efficient as possible.

8.1 Green house gas savings

Green house gas (GHG) savings was one of the two main components of the LCA's produced for the DECC project. The LCA looked to assess the total greenhouse gas (GHG) emissions, consisting of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), of each process comparing them to the counterfactual of existing practice, through which the savings were then calculated.

The counterfactuals were produced based on information which described the way in which the operation was currently undertaken so that a comparison could be made with the new approach. For example in the case of reedbed management the following counterfactual was used:

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

Details of machinery used:
Brushcutter – Stihl FS 450/2.1kW.
1 tank of petrol/oil mix will last 40 minutes cutting.
1 tank of petrol/oil mix will hold 0.67litres.
Purchase Cost of machine £874.

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

2.5% cost of the machine goes into maintenance each year.

Time taken to cut 1 hectare of reed
Brushcutter operation = 4hours to cut edges and inaccessible spots.
Pedestrian mower operation = 35hours cutting
Raking up and burning = 199.5hours.

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

The harvesting of reeds using the biomass to bionergy approach, for example with either a Pisten Bully or a Softrak and converting the biomass into an energy product is then compared to above. This comparison then shows the GHG emissions of each process and any associated savings.

In addition to the process replaced, counterfactuals were also used to assess the associated savings with the replacement of fossil fuels by the energy product produced. So this will be in the form of conventional heating (mainly fossil fuel-fired) displaced by briquettes and loose biomass-fired heating. The figures and savings of the latter will depend on the choice of fuel classed as displaced.

Additionally, the GHG emissions associated with the manufacture and maintenance of plant, equipment, machinery and vehicles were also taken into account as part of the LCA calculations.

The approach used by the DECC project was adopted to provide the most appropriate and useful life cycle analysis of the systems being developed. In this respect it employs one of two traditional LCA approaches, that which is known as consequential LCA rather than the attributional LCA.

By comparison, attributional LCA is more typically used when looking at financial incentives which are linked to sustainability criteria and are then applied to the sale of heat and electricity from biomass. This methodology excludes GHG emissions associated with the manufacture of plant, equipment, machinery and vehicles. It also avoids the direct use of counterfactuals by applying a co-product allocation procedure, based on energy, to determine the total GHG emissions of heat and electricity derived from the biomass. Minimum levels of net GHG emissions relative to fossil fuel comparators are stipulated as part of the sustainability criteria.

8.2 Biomass energy efficiency

The biomass energy efficiency is the other major component considered as part of the DECC project LCA. This is defined as the total energy output from the process, in the form of heat and electricity, which can be used for other purposes (rather than within the process) as a percentage of the total energy input from the biomass sources. This final figure illustrates the total energy produced through the conversion of the biomass, once any energy needed for the process has been removed. This is then presented as a percentage of the known total energy input from the biomass, providing an efficiency figure.

8.3 LCA results from the DECC projects

The following table provides a summary of the LCA results from each of the three DECC projects:

Table 17 DECC project LCA results

Participant	Energy Conversion Technology	Greenhouse gas savings (Megajoules/annum)	Biomass Energy Efficiency (Megajoules/annum)
AB Systems	Briquette production	89.8%	65.0%
AMW-IBERS	Briquette production	84.1%	68.7%
Natural Synergies	Anaerobic Digestion	73.4%	58.9%

If considering a biomass to bioenergy approach it is always valuable to complete a simple LCA for the end-to-end process to ensure that energy used is not greater than energy produced. This may be aided by the conservation biomass calculator, (see Section 9, page 87).

9. Which conversion technology is right for you?

9.1 Conservation biomass calculator

The conservation biomass calculator is a tool which is designed to assist land managers assess the potential of the biomass harvested during site management activities as an energy product. The calculator aims to help managers to unlock the concept of a currently wasted feedstock to be rather seen as a valuable contribution in the generation of bioenergy.

The calculator is a software tool which enables land managers to assess their biomass in a number of ways:

- To determine the economic costs and benefits
- Understand the net greenhouse gas emissions of specific options, and the contribution of the process to savings
- The potential reduction of fossil fuel use.

The tool performs a simplified life cycle analysis to identify where improvements could be made and where the carbon and economic expenditure is being generated. The software is an evolving system, designed with the capacity to build in new conversion technologies as they are developed and habitat requirements as they arise.

The calculator requires the land manager to input site-specific data which the software will then use to generate options for energy conversion based on material composition, moisture content, etc. This results in an energy balance and a form of life cycle analysis which are set against counterfactuals of current practice to provide a benchmark and assess feasibility. The software also has the capability to generate the monetary cost of the process and any associated investment needed. The economic evaluation of alternative options of utilising biomass for energy production could be performed in different ways depending on specific circumstances and requirements.

The calculator is structured the following basic elements:

- A **Guidance Section** which summarises the purpose and use of the software for the assistance of general users.

- A **Basic Input/Output Section** which provides a user-friendly means for general users to enter key values for prominent parameters and summarises overall results in terms of the economic costs and net GHG emissions of current reserve management practice and alternative options involving biomass utilisation for energy production.

- An **Assumptions Section** which houses all baseline information, eg, monetary and carbon cost of fuel, staff time, contractor cost, but also number of working hours in a day, calorific value of fuels etc. This is controlled by the ‘owner’ of the software so that it can be changed as needed to be up to date and current. This information forms the basis for all calculations, from which the final information is generated.

The results of the inputted information can then be taken by the site managers/project manager and used to progress through the necessary channels to gear the site up to take the work forward in the most practical and efficient way.

10. Funding

Government funding may be available for the production of energy utilising biomass, this applies to both energy generated through combustion and anaerobic digestion. The payments are based on amount of energy produced, whether through heat or electricity, the rates per unit do vary according to amounts, import/export etc, and the tariffs are regularly reviewed by the Government.

10.1 Feed in Tariffs (FiTS)

Feed-in Tariffs were introduced on 1st April 2010 and replaced UK Government grants as the main financial incentive to encourage uptake of renewable electricity-generating technologies. Technologies which qualify for the scheme include:

- Solar electricity (PV) (roof mounted or stand alone).
- Wind turbines (building mounted or free standing).
- Hydroelectricity.
- Anaerobic digesters.
- Micro combined heat and power (CHP).

The UK Government's Department for Energy and Climate Change (DECC) makes the key decisions on FITs in terms of Government policy, however the energy regulator Ofgem are the administrators of the scheme.

To qualify for FITs, the installer and the products used must both be certified under the Microgeneration Certification Scheme (MCS), except hydro and anaerobic digestion which have to go through the ROO-FIT process.

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 grid. You also save money on your bill as you are using your own electricity.

Only anaerobic digestion (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.

Tariffs are Retail Price Index (RPI) linked; since April 2014, there has been a baseline degression in tariff rates of 5% per year, which will accelerate or decelerate based on annual deployment numbers.

10.2 Renewables Obligation (RO)

The Renewables Obligation (RO) is the main support mechanism for renewable electricity projects in the UK, and is available to any generator over 50kW in size. Smaller scale generation is mainly supported through the FITs scheme.

The RO came into effect in 2002 in England and Wales, and in 2005 in Scotland and Northern Ireland. It places an obligation on UK electricity suppliers to source an increasing proportion of electricity they supply to customers from renewable sources.

Renewables Obligation Certificates (ROCs) are green certificates issued by Ofgem to operators of accredited renewable generating stations for the eligible renewable electricity they generate. Operators can then trade the ROCs with other parties, with the ROCs ultimately being used by suppliers to demonstrate that they have met their obligation.

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.

10.2.1 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.
- ROCs potentially higher returns but value of ROCs varies.

10.3 Renewable Heat Incentive (RHI)

As its name suggests the renewable Heat Incentive or RHI provides a fixed income (per kWh) to generators of renewable heat, and producers of renewable biogas and biomethane. The RHI is designed to increase development of renewable heat technologies and contribute towards the Government's target of 15% of total UK energy consumption being generated from renewable sources by 2020. Broadly speaking, the scheme provides a subsidy per kWhth of eligible renewable heat generated from accredited installations and a subsidy payable to producers of biomethane for injection.

A range of renewable heat technologies are supported under the Renewable Heat Incentive;

- Solid biomass.
- Ground and water source heat pumps.
- Geothermal.
- Solar thermal (Under 200 kWth in size).
- Biogas combustion (Under 200 kWth in size).
- Biomethane injection.

Payments are made on a quarterly basis over a 20 year period to the owner of the RHI installation or producer of biomethane.

The RHI applies to commercial, industrial, not for profit and public sector purposes and producers of biomethane, together with domestic installations**.** The RHI policy and tariff rates are set by the Government, but the RHI will be administered by Ofgem.

In order to receive support under the RHI, an eligible installation has to be accredited by Ofgem. Accreditation (which is defined in the Regulations) is the term that is used to denote admission by Ofgem of an applicant to the RHI once determined that the installation meets the eligibility criteria of the scheme and that the application for accreditation is properly made.

In order to gain accreditation for an installation, an applicant has to demonstrate that an installation meets the RHI eligibility criteria, including that the installation is of an eligible renewable heat technology type and size, the heat is used for an eligible purpose, that metering arrangements are appropriate, and that grants for certain purposes have not been received.

Evidence needs to be provided in support of an application that shows the installation company details, date of installation and installation serial number for your installation. Because each application will be different, this evidence could be any one (or a combination) of the following:

- Receipts and/or invoices relating to the installation of the equipment.
- Commissioning certificate.
- Commissioning report.
- Photograph of the installation clearly showing the serial number of the equipment.

The date of accreditation for the installation is the date from which the RHI payments will be calculated. The date of accreditation is the later of either the date on which an application (which is complete and which demonstrates the eligibility of an installation) is received by Ofgem and they are satisfied that the application was properly made, or the date the installation was first commissioned.

10.3.1 Grants and RHI

RHI support is only available for an eligible installation if no grant from public funds has been paid or will be paid in respect of any of the costs of purchasing or installing the eligible installation, or where a grant from public funds has been paid for an eligible installation that was completed and first commissioned on or after 15th July 2009 but before the date the regulations come into force, it has been paid back to the grant-making body or person.

In practice, this means:

- An installation can only be accredited where the purpose of the grant is, or will be, to meet costs other than the costs of purchasing or installing the installation; and

- An installation will not be accredited where a grant (of any value) has been, or will be, paid in relation to the costs of purchasing and installing it, if it was completed and first commissioned between 15 July 2009 and the date the Regulations come into force **and** that grant has not been repaid in full to the person who made it.

10.3.2 Tariffs

Broadly speaking, the scheme provides a subsidy per kWhth of eligible renewable heat generated from accredited installations and a subsidy payable to producers of biomethane for injection. However it should be noted that the tariff payment per kWhth is regularly reviewed.

10.3.3 Degression on Anaerobic Digestion payments

Although once an application has been accredited and signed it is not vulnerable to tariff fluctuations there are indications that the rates could change dramatically over the RHI's lifetime. This is referred to as degression and can affect both RHI and FiT payments. The trigger for degression rates is determined by the growth rate of the scheme, based on take-up and is therefore a budget management mechanism.

10.3.4 Degression on Combustion payments

As with anaerobic digestion there is also degression on combustion payments. Again this works by gradually lowering tariffs paid to new applicants if deployment exceeds expected levels, set out in advance in the regulations. These levels, or triggers, are expenditure thresholds and are currently based on modelled forecasts dating from the scheme's launch in November 2011.

10.3.5 Drying of biomass

The tariffs can also be applied to the heat generated for the drying of biomass and is classified by Ofgem by the following point:

> ***Carrying out a process (within a building)****: the use of heat to carry out a specific process such as industrial cooking, drying (including drying of wood and other biomass fuels), pasteurisation or chemicals manufacture. Other examples include heat that is used for cooling, eg passing renewable heat through absorption chillers. It does not include heat used for the generation of electricity.*

10.3.6 Making an application

The guidance notes on the RHI are updated regularly, in March 2016 they produced revised guidance Volumes One & Two and a Fuel Measurement and Sampling Guidance – it is essential to read these before considering an application.

There are also strict criteria that need to be followed in relation to the source and type of the biomass to be used for RHI and this is currently found in a briefing note produced by DECC: 'New biomass sustainability requirements for the Renewable Heat Incentive'.

11. Permissions and Regulatory Requirements

The need to acquire different permissions and conform to different regulations as part of turning biomass into bioenergy will really depend on site and location specifics. For example in relation to designated land different requirements will need to be satisfied compared to non-designated land. However some experience in relation to the relevance of different regulations was gained as part of the DECC project and have been highlighted below. They provide examples of how different situations were dealt with which may provide a guide as to the necessary processes which may need to be followed under particular scenarios.

11.1 Planning Permission

11.1.1 Anaerobic Digestion - Small Scale – 7kW System – as part of a suite of biomass conversion technologies

This plant was located in the Cairngorm National Park, Strathspey, Scotland and the authority raised concerns around the potential nuisance impact on the park, particularly in relation to the importing of feedstocks to site. To satisfy the authority the project had to address issues around plant position and layout, water resources, noise, odour, emissions, visual impact assessment and traffic movements.

With the provision of this information both the Park Authority and the Scottish Environment Protection Agency (SEPA) agreed to allow the plant to operate for an 80 day trial period within the designated area, with the following comment from SEPA:

'However, as the proposal is to trial the process over a limited period (80 day period) - then provided all necessary measures to prevent any offensive odours, smoke, or contamination of soils and/or the water environment are put in place SEPA would have no regulatory issues with the Pilot operation proceeding. Once the developer/operator has demonstrated that the process is viable, and prior to any further continuance or increase in scale, they should discuss the need, if any, for a Waste Management Licence with a member of the local Operations team.'

The 80 day trial period was extended to cover the complete term of the DECC project and 12 months further.

11.1.2 Anaerobic Digestion - Medium Scale - 100kW

This plant was located on an existing farm, planning permission was not needed, as planning legislation on anaerobic digestion plants states that on farm AD plants with a foot print of less than 500m^2 do not require planning permission, and only require notification to the local council.

However the Environment Agency (EA) needed information to address issues on the following:

- Potential contamination to *water courses*, which could result from the silo, resultant leachate and a catastrophic tank failure of the digester.
- Possible *odour* nuisance.
- *Noise.*
- *Transport and* movement of material and equipment.
- The impact of the AD operations to *air quality* particularly in relation to the Clean Air Act.

This was then followed up through the operation of the plant under a T24 waste exemption, as described below in Section 11.2.2.

11.2 Waste Management

11.2.1 Waste Management Regulations

After consultation with DEFRA and the Environment Agency with regards to the waste management regulations the outcome was that each situation will be assessed on a case by case basis.

DEFRA have produced a guidance note; ‘Guidance on the legal definition of waste and its application. A practical guide for businesses and other organisations’, August 2012 in this they conclude that the classification basically rests on the intention, the legal definition of a waste is:

“…any substance or object which the holder discards or intends or is required to discard…”

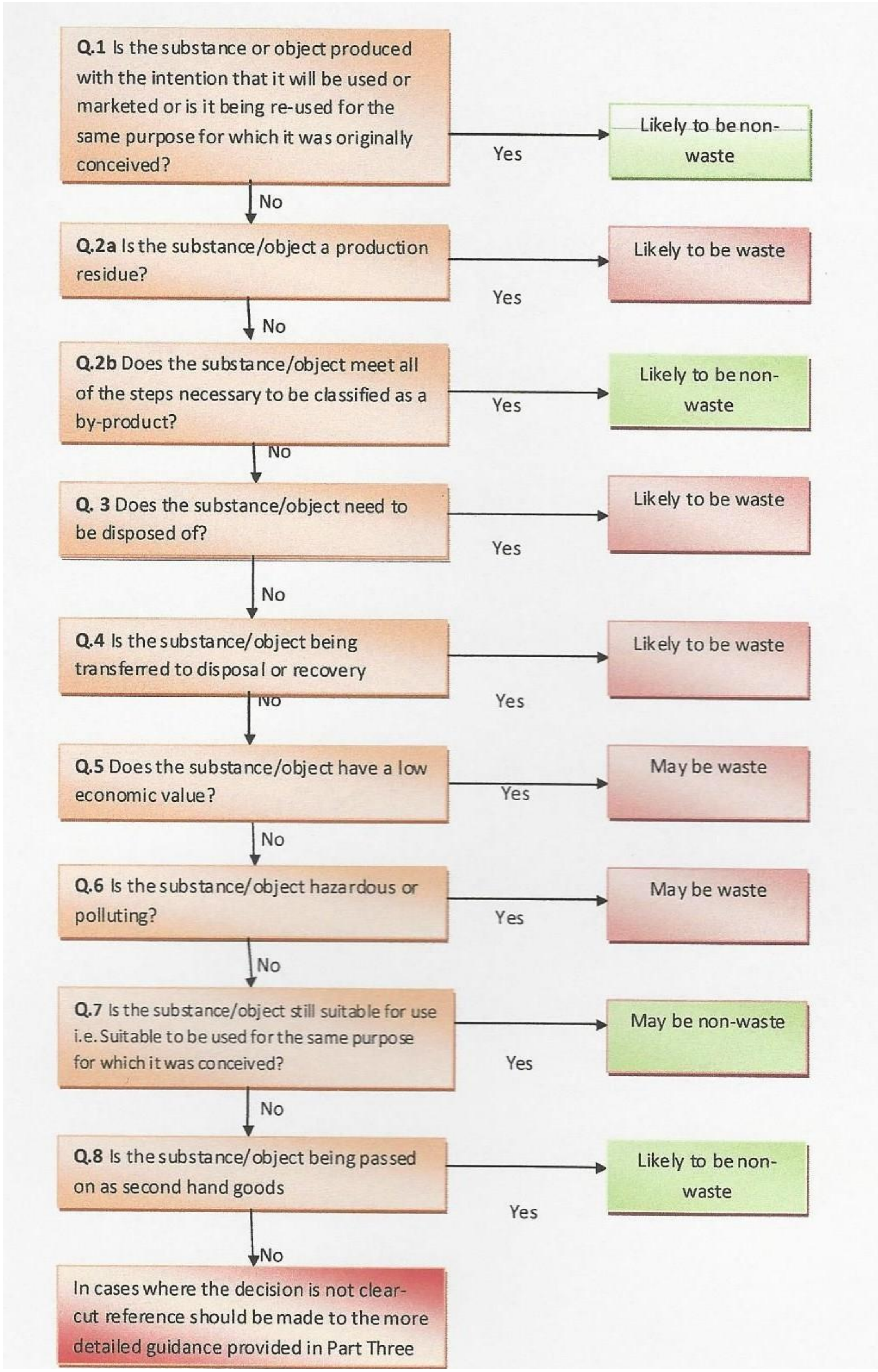


Diagram 6 DEFRA decision making tree

However one grey area is in relation to if the material is being cut to make a biofuel then it's not a waste. The argument is that the cutting is only happening because there's a demand for a product and nature is the by-product. However strictly speaking, if the primary purpose is to produce a habitat for wildlife then the material is a waste by-product. By-products aren't always counted as waste especially if they have a proven after use, however under the DEFRA decision making tree biomass could fail the "no further processing needed" test to be a by-product.

Currently with regards to the DECC project the material off reserves has been dealt with on a project by project basis. For example in Scotland following discussions with SEPA's National Operations Waste Unit SEPA issued the following response regarding the classification of the feedstocks from wetland operations:

'We have had some discussions and we are happy that we can let this happen without waste controls. The biomass you propose to use is equivalent to a purpose grown crop so there is no reason why it should be treated any differently. This is on the understanding that if you change any of the inputs, it may change the way we regulate this activity.'

However in England for use in the anaerobic digester, the reserve biomass has been classified as a waste, however it is seen as low risk and where it needs to, is operating under an exemption. In relation to the operation of the anaerobic digestion unit the use of wetland biomass is permitted through the T24 exemption which relates to its farm location or T25 exemption if located at a reserve.

11.2.2 T24 Exemption

This exemption covers AD set ups at premises used for agriculture and the burning of the resulting biogas. It allows farmers to anaerobically digest manure, slurry and vegetation on their farms to produce digestate that can be used as a fertiliser or soil conditioner. The AD process also produces biogas, which can be burnt to generate energy, either to use on the farm or to export to the National Grid.

https://www.gov.uk/waste-exemption-t24-anaerobic-digestion-at-premises-used-for-agriculture-and-burning-resulting-biogas

Types of waste covered

The waste codes are those listed in the List of Wastes (LoW) Regulations. The waste needs to fit within the relevant waste code and description.

Waste code	Type of waste
020103, 020107, 170506, 200201	Plant tissue waste
020106	Horse and farmyard manure only
020199	Fully biodegradable animal bedding

Quantity of waste that can treated

- You can store or treat up to 1,250 cubic metres of waste at any one time.
- This storage limit does not include manure and slurry pits where these materials have been produced on the same farm and are being stored before being treated in the digester.
- If you import manure and slurry from other farms and store it before it is fed into your AD plant, the storage of this waste is included within the 1,250 cubic metre limit.

- When manure and slurry is mixed with plant tissue waste the 1,250 cubic metre limit will include the storage of plant tissue waste, material in the digester and the storage of the resulting digestate.

Key conditions

- The waste must be kept in the digester for at least 28 days (retention time).
- The biogas produced by the AD process must be collected and burned to produce energy.
- There must be a net rated thermal input of less than 0.4MW on the AD plant biogas burner.
- There must be a combined net rated thermal input of less than 0.4MW if there is more than one burner associated with the AD plant.

Digestate

Once the AD process is completed it produces a digestate. If the only waste feedstock to the anaerobic digestion process is farmyard manure or slurry only, it is accepted that the digestate can be spread on agricultural land as a fertiliser or soil conditioner without being regulated as waste. However, compliance with the code of good agricultural practice and any requirements for Nitrate Vulnerable Zones are still required.

11.2.3 T25 Exemption

This exemption covers anaerobic digestion at premises that are not used for agriculture and the burning of the resulting biogas. It allows you to treat food and other biodegradable waste by anaerobic digestion to produce a digestate, which can be used to benefit land. The gas produced (biogas) must be used for generating energy.

https://www.gov.uk/waste-exemption-t25-anaerobic-digestion-at-premises-not-used-for-agriculture-and-burning-resulting-biogas

Types of activity you can carry out

- A business or organisation, such as a hotel, prison or hospital using a small anaerobic digestion plant for their kitchen waste producing digestate for use on the gardens and biogas to generate electricity.
- Sorting, screening, cutting, shredding, pulverising and chipping the waste to help the AD process.

Types of activity you cannot carry out

- Aerobically treat the waste.
- Release the gas produced into the air.
- Dispose of the biogas by flaring except if appliances burning biogas breakdown or are being routinely maintained.
- Treat hazardous waste.
- Treat waste that is an animal by-product without an appropriate authorisation from Animal Health.

Types of waste covered

The waste codes are those listed in the List of Wastes (LoW) Regulations. The waste needs to fit within the relevant waste code and description.

Waste code	Type of waste
020103, 020107, 170506, 200201	Plant tissue waste
020106	Horse and farmyard manure only
200101	Paper and cardboard
200108	Biodegradable kitchen and canteen waste
020199	Fully biodegradable animal bedding
020202	Animal tissue waste
020501, 020601	Materials unsuitable for consumption or processing
200302	Biodegradable waste from markets only

Quantity of waste that can treated

You can store or treat up to 50 cubic metres of waste at any one time.

Key conditions

- Any gas produced by the anaerobic digester must be collected and burned in an appliance
- You must use an appliance with a net rated thermal input of less than 0.4MW. If there is more than one appliance, the total net rated thermal input must be less than 0.4MW (for example four 0.1 MW appliances)
- You must treat the waste within the digester for at least 28 days (retention time)

Digestate

If you comply with the anaerobic digestate quality protocol and produce a digestate that complies with the PAS 110 standard, the Environment Agency would not consider the digestate as waste.

11.3 Grid Connection

For some small scale and all medium scale and above anaerobic digestion plants a grid connection is needed both to operate the plant, but also to export the excess electricity, not required by the plant into the grid. This requires a transformer and 3-phase connection on site and involves liaison with the appropriate District Network Operator for the installation of the required export and import meters, to and from the grid. This operation will require the issuing of a new MPAN number and will involve liaison between an appointed meter operator, the operational organisation, such as Western Power and the electricity suppliers, such as Scottish and Southern Electric. A Power Purchase Agreement (PPA) contract is then set up between the energy provider and the meter operator who are the power purchase organisation. This together with project specific information such as details on continuity flow (forms D155 and D142) required by the operational organisation, will enable import/export meters to be directly set up to the grid.

Unlike solar or wind systems, anaerobic digestion, especially small scale are not seem a problematic from a grid connection perspective for two reasons. Firstly the electricity they are providing is small and secondly the electricity is constant and does not fluctuate with the intensity of the sun or wind.

12. Framework and structures to facilitate delivery

12.1 Payment for Ecosystem Service Approach[12]

12.1.1 What are Ecosystem Services?

‘Ecosystem services, simply defined, are the benefits we derive from the natural environment. These include, for example, the provision of food, water, timber and fibre; the regulation of air quality, climate and flood risk; opportunities for recreation, tourism and cultural development; and underlying functions such as soil formation and nutrient cycling. Maintaining and enhancing ecosystem services – and restoring them where they have been lost or degraded – is increasingly recognised as essential for sustainable economic growth, prosperous communities and promoting peoples’ wellbeing.’

12.1.2 What is Payment for Ecosystem Services or PES?

PES is often used as an umbrella term for the entire suite of economic arrangements used to reward the conservation of ecosystem services. However in practice, PES schemes involve payments to the managers of land or other natural resources in exchange for the provision of specified ecosystem services (or actions anticipated to deliver these services) over-and-above what would otherwise be provided in the absence of payment. Payments are made by the beneficiaries of the services in question, for example, individuals, communities, businesses or governments acting on behalf of various parties. Beneficiaries and land or resource managers enter into PES agreements on a voluntary basis and are in no way obligated to do so.

The basic idea behind PES is that those who provide ecosystem services – like any service – should be paid for doing so. PES therefore provides an opportunity to put a price on previously un-priced ecosystem services like climate regulation, water quality regulation and the provision of habitat for wildlife and, in doing so, brings them into the wider economy.

It is important to recognise that land or resource managers may be subject to regulation which, if properly enforced, could limit adverse impacts on ecosystem service provision. They may also undertake measures to protect and enhance services where this is in their best interests, for example, through reducing water usage to make cost savings. Many land or resource managers may also seek to protect or enhance ecosystem service provision in their role as custodians. PES schemes should therefore be carefully designed so as not to undermine existing stewardship on the part of land or resource managers.

PES provides one means to increase the supply of an ecosystem service, or services. However, PES is only one instrument among many for combating ecosystem degradation. The government is committed to facilitating and promoting the emergence of PES schemes. The 2011 Natural Environment white paper, The Natural Choice: securing the value of nature, proposes various measures to mainstream the value of nature across society. In particular, the white paper emphasises the *“…real opportunities for land managers to gain by protecting nature’s services, and trading nature’s benefits with businesses, civil society and the wider public sector”*.
(Source - Payment for Ecosystem Services, A Best Practice Guide, DEFRA, May 2013)

From initial studies already undertaken it is likely that underutilised biomass could present a number of opportunities to provide a sustainable means of financing essential management of key habitats for biodiversity. By finding economically viable ways to utilise this material presents the opportunity for

[12] Source - Payment for Ecosystem Services, A Best Practice Guide, DEFRA, May 2013

managing increased areas of habitat more effectively and efficiently, together with facilitating the potential for habitat expansion in the future, not only for the benefit of biodiversity but also for the delivery of ecosystem services.

In conjunction with the DECC project, the RSPB has undertaken a DEFRA Pilot Payment for Ecosystem Services (PES) Project, which looked at the delivery of the biomass to bioenergy approach as a PES scheme entitled ‘Energy for Nature’. This work involved working with the RSPB’s economists to understand markets and business models, liaising with local and national stakeholders, and the development of a conservation biomass calculator (see Section 9, page 87), to assist land managers to realise the potential of their land management operations. The PES framework provided a solid basis on which to start developing a payment model for the conversion of biomass into a sustainable product which both has the potential to generate income from previously uneconomic land and reduce reliance on fossil fuels. This framework could then be used to deliver sustainable ‘Energy for Nature’ schemes focused on landscape conservation areas around the country.

12.2 Energy for Nature[13]

The Energy for Nature vision is to develop a mechanism that links land managers, through intermediaries and markets, to the buyers of their biomass products. In doing so the aim is to create a sustainable funding stream that enables essential nature conservation work to continue, contribute to carbon reduction targets and potentially increase financial returns.

As well as enhancing the management of conservation land holdings the biomass to bioenergy work could position these areas with an importance both nationally and locally as a source of energy feedstock, with no impact on food production. This added value could provide protection, appreciation, potential investment, and income generation, raising the profile of nature conservation areas, making them more relevant to more people.

The PES framework helps to identify the linkages between the service providers (i.e. RSPB and other land managers) and the beneficiaries (e.g. local communities), establish the role of intermediaries and SMEs, and develop a model of how payments and service provision are related via the processing pathways developed through the DECC project. For example, within a landscape there will be a range of stakeholders who can act as buyers and sellers of ecosystem services, organisations or individuals who could act as intermediaries, and several potential knowledge providers. Energy is the primary ecosystem service being delivered to the buyers. ‘Payments’ would fund enhanced conservation management within the buyers’ locality as a co-benefit, creating a landscape scale, input-based, private payment scheme[14].

This provides a simplistic overview of how an Energy for Nature scheme could operate. The need to process the biomass from its raw state into a more financially valuable bioenergy product which can then be sold in markets (and therefore provide the income for enhanced ecosystem service provision by the seller[15]) means that an Energy for Nature scheme would be more complex than a traditional PES model. The scheme would conform to certain elements of PES more than others. However, whether truly a ‘PES

[13] Energy for Nature RSPB final report, DEFRA, 2015

[14] ‘Input based’ payments are made for the implementation of specified land or resource management practices which are likely to secure ecosystem service provision. This is in contrast to ‘output based’ payments which are made in relation to the ecosystem service itself, e.g. paying for a specified increase in biodiversity. ‘Private’ payment schemes are self organised schemes in which the beneficiaries are in contract directly with the service providers and don’t involve the use of government/public funds for service delivery (Defra, 2013).

[15] N.B. this doesn’t consider the mechanism of how the payments are transferred between actors or the role of the intermediary at this stage.

scheme' or not, it has the potential to generate a sustainable income stream to fund essential habitat management for conservation, or provide local 'green' energy for rural communities.

12.3 Models, frameworks and administrative structures

How Energy for Nature could work in the future depends on a number of factors around supply and demand and the framework, relationships and agreements that are put in place to facilitate this. Through the DEFRA project two models (Land Manager and Community) were developed which make Energy for Nature schemes accessible to a wider range of stakeholders within a landscape. The models identify opportunities for land and/or conservation managers to improve their habitat management, and the Community Model enables local communities to become involved, growing resilience and promoting rural development at the same time as improving their landscape. Whether the driver is land management or community development both models increase the potential opportunities for delivering biodiversity at the landscape scale, and help contribute to a low carbon, more sustainable economy through providing communities with greener, locally sourced alternatives to fossil fuels.

12.3.1 Coordinator role

Feedback from all of the stakeholder engagement activities carried out during the DEFRA work pointed towards the need for an 'Energy for Nature Coordinator' to act as an intermediary in any form of scheme that is developed. Sellers and processors are both time and resource limited; therefore the intermediary is required to act as a link between the two actors, identifying suitable sellers and linking them to the relevant processors. Who carries out the role is likely to vary from scheme to scheme, but most likely it would be an individual from an organisation interested in developing biomass to bioenergy and working locally in the area in which the scheme is developed. The coordinator would operate across several 'catchments' within the landscape that the scheme operates

The coordinator role would vary subtly within and between schemes depending on the level of existing stakeholder knowledge and engagement. Consequently, there are multiple entry points for intermediaries to join in with a scheme. For example, in a conservation driven scheme it is likely that some form of grouping of the key land managers will already exist, will know where the majority of potential core production sites are located, and also who owns/manages them. In this instance input from the scheme coordinator may start at stage further into the process. Conversely, in a community led scheme there may be little prior knowledge of suitable sites and the coordinator would need start at the very beginning of the process.

Funding the role of the coordinator needs to be considered. It is possible that the form of co-operative structure adopted by the members of the Community Model provides a simple administrative structure for paying the coordinator from the revenues generated through bioenergy sales. This may also work in the Land Manager Model, although the administrative structure required to pass payment on to the coordinator would be different and would need to be established early on in the process.

12.3.2 Land Manager Model

This model is based on generating an income to fund land management, particularly for land managers who need to deliver more, and enhanced, habitat management for the benefit of wildlife. As such, the model assumes that sellers are predominantly site managers from conservation organisations, statutory bodies (e.g. Natural England), or private companies (e.g. water companies). The model may also apply to private individuals, such as farmers. As the level of payment relates to the market value of the bioenergy product being sold, the most economically optimal option would be for sellers to retain ownership of their biomass and sell briquettes or raw (chopped) biomass direct to the buyers. This pathway presents the most similar framework to the typical PES model. However, this may not always be the most viable or practical option for sellers (for example, in the initial stages of the scheme where uncertainties may remain about the quality or quantity of supply, or local markets may not be well developed), therefore this framework also outlines the pathways for sale of biomass from the seller to AD operators and the option to sell the biomass outright to the processor.

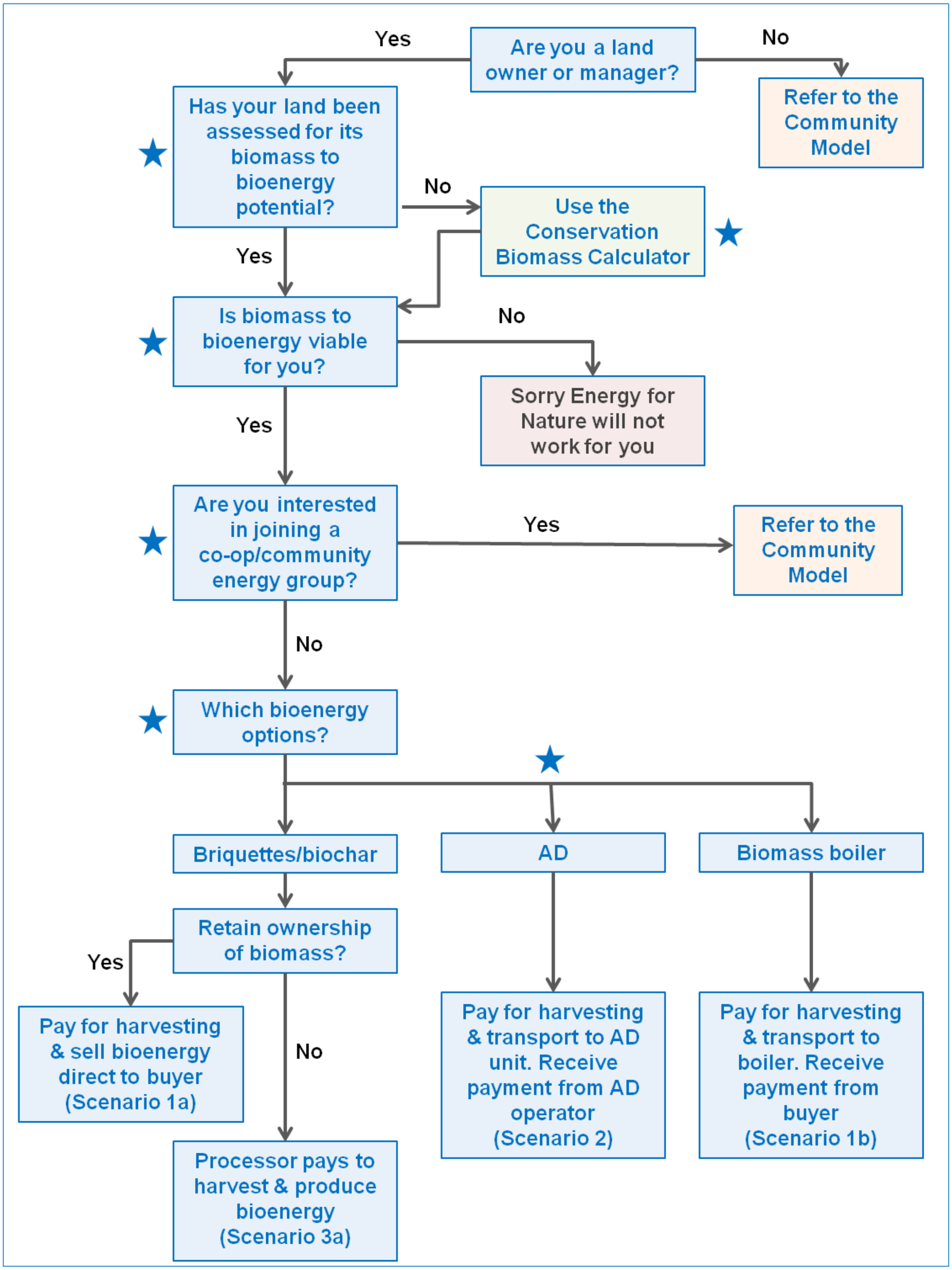


Diagram 7 General framework of the Land Manager Energy for Nature model.

The ★ indicates points at which the Energy for Nature Coordinator can enter the process to provide help and advice to the land manager on the viability and their options for biomass to bioenergy.

12.3.3 Community Model

This model is based on developing resilience in rural communities through community energy initiatives, such as districting heating[16]. The model assumes that a community group (e.g. parish council or community energy group) is driving the process to deliver cheaper and more sustainable energy for the benefit of the local community through biomass to bioenergy (rather than via solar or other energy options). As such, in this model the buyers, sellers and processors pay for membership of some form of co-operative organisation and receive a share of the profits from the sale of bioenergy or receive cheaper energy. As in the previous model, land managers (either conservation or statutory agencies, or private companies/individuals) act as the sellers of the biomass, and the local community (through the community group) act as the buyers of bioenergy. Processors are required to act as the harvesters and/or producers of the bioenergy products. An Energy for Nature Coordinator would still be required to coordinate contracts between the actors, as the same challenges in terms of variability in quality and supply remain relevant in this model.

As the model is driven by the creation of low carbon, cheap, community energy it is more complex than the Land Manager Model. Although the actors remain the same, in this instance they all have a stake in the energy initiative through membership of the co-operative[17]. This ensures benefits are felt by the community, and not just the land managers/SMEs involved in producing/processing the biomass. This structure also enables caveats to be placed on membership to ensure than environmentally sensitive practices are use to harvest the biomass and in the management of land for service delivery.

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[16] District heating is the term used to describe a network of insulated pipes used to deliver heat, in the form of hot water or steam, from one or more sources to an end user.

[17] This does not have to be a formal co-operative but could take the form of a Community Interest Company (CIC), a local Land Trust, or similar. The Forestry Commission have recently published guidance on developing community woodfuel bioenergy schemes (Forestry Commission, 2015). The guidance provides useful information on how to set up a suitable community group structure for this type of project.

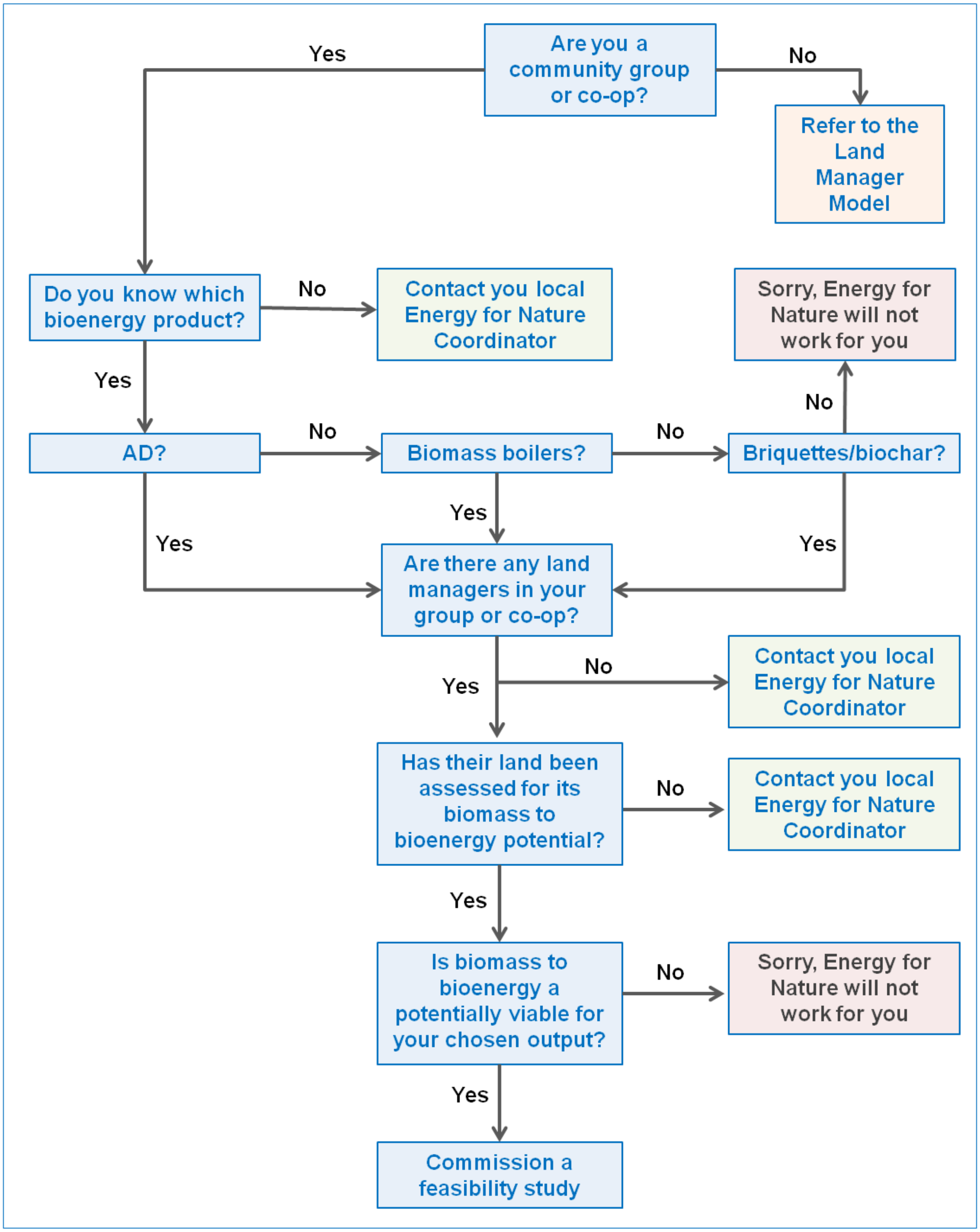

Diagram 8 General framework of the Community Energy for Nature model.

What formal administrative structures are put in place to facilitate delivery will be landscape specific; there are a number of options and each needs consideration in relation to the benefits each provides. The document 'Simple Legal' published by Cooperatives UK, presents details of all such potential structures, a summary of which is provided below.

Table 18 Delivery administrative structures

Legal Form	Does its members have limited liability?	What is the governing document called?	Can it issue shares?	Can it pay a return on shareholding?	Does it have to register with a regulatory body?	Is it suitable for chartable trusts?	Does it have an asset lock?
Partnerships	No	Deed	No	No	No	No	No
Associations	No	Constitution	No	No	No (unless charity)	Yes	No (unless charity)
Trusts	No	Deed	No	No	No (unless charity)	Yes	No (unless charity)
Limited Liability Partnership (LLP)	Yes	Agreement or deed	No	No	Companies House	No	No
Company Limited by Guarantee	Yes	Articles	No	No	Companies House	Yes	No (unless charity)
Company Limited by Shares	Yes	Articles	Yes	Yes	Companies House	No *	No (unless charity)
Community Interest Company (Limited by guarantee)	Yes	Articles	No	No	Companies House & CIC Regulator	No	Yes
Community Interest Company (Limited by shares)	Yes	Articles	Yes	Yes – although it is subject to a cap	Companies House & CIC Regulator	Yes	Yes
Charitable Incorporated Organisation	Yes	Constitution	No	No	Charity Commission	Yes	Yes
Industrial & Provident Society (bona fide cooperative)	Yes	Rules	Yes	Yes	Financial Services Authority	No	No
Industrial & Provident Society (society for the benefit of the community)	Yes	Rules	Yes	Yes	Financial Services Authority	Yes	Yes (optional)

* In the past some charities have been registered as companies limited by shares

Energy for Nature has been designed around landscape scale wetland management for biodiversity. The Land Manager Model is based on solving a conservation/land management problem through the sale of biomass. This can, therefore, be applied across similar landscapes in the UK and across Europe where surplus biomass is an issue, and sustainable funding streams are required to continue habitat management. The Community Model would be transferable across the UK, it may also be applicable to other areas of Europe, but consideration around different socio-economic structures would be needed.

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14. Useful contacts

Table 19 Useful contacts

Business / Organisation	Contact	Email
AB Systems Ltd	David Wynne	david@agbag.co.uk
AMW Arboreal Ltd	Jonathan Walker	jonathan@amwpartnership.co.uk
Carbon Gold	Ian McChesney	ian.mcchesney@gmail.com
IBERS, Aberystwyth University	John Corton	jcc@aber.ac.uk
Loglogic	Marcus Frankpit	marcus@loglogic.co.uk
Natural Synergies Ltd	Faisal Salam and Victoria Melchor	natsynltd@gmail.com
Qube Renewables	Mark Clayton	markclayton@aardvarkem.co.uk

15. Acknowledgements

Thank you to DECC for both seeing this project as an opportunity and allocating funding to enable innovation, technological advancement and allow time to be dedicated to bring ideas to fruition. Special thanks must go to all the participants, as without their dedication and commitment, the project would never have been the success it was.

Thanks must also go to the KTN team, whose organisational skills made the demonstration days run so smoothly and last but not least to the partner organisations who allowed their nature reserves to be used as biomass donors and their infrastructure to accommodate some of the processing areas. They also showed much appreciated patience when trials didn't always go to plan!

16. Appendices

Appendix 1 Monitoring Protocol

Monitoring the impacts of mechanical harvesting on vegetation

Pre-harvest

For each cut area identify an adjacent area of the same or similar habitat that will not be cut and can therefore act as a control site. Control sites will help with interpretation of any changes between years caused by factors besides the biomass harvesting (e.g. hot/dry spells, etc).

Fixed point photographs

Take fixed point photographs of representative areas of vegetation within both the areas to be cut and the adjacent (uncut) control. On the cut areas photographs should also include any planned access points as well as proposed haulage routes. Photographs should be accompanied with a 12 figure grid reference and a brief description of where the photograph was taken and the direction of view to enable points to be relocated on future dates. Where possible, and appropriate, try to use easy to recognise landmarks (e.g. fence posts) as your fixed points to ease relocation.

Vegetation measurements

2m x 2m quadrats will be used to record vegetation. Quadrats to be fixed by 12 figure grid reference recorded at SW corner with west edge of quadrat aligned approximately along north-south direction. Minimum of twelve quadrats to be recorded on the cut area and a further 12 quadrats recorded on the (uncut) control (ideally aim for 15-20 quadrats on each depending on size of area). Quadrats should be placed in representative vegetation in each case. Measurements to be made at each quadrat will depend on vegetation type.

i. **For reedbed sites:** 2m x 2m quadrat to record all higher and lower plant species present and their percentage cover (note that bryophytes can be recorded as a single category if necessary). In smaller sub-area (0.20m x 0.20m) of quadrat (in SW corner) count all reed stems attached to substrate (multiply by 100 to give reed density per square metre). Reed stem diameter (recorded at a height of 1m) to be recorded for 10 randomly chosen stems within each quadrat and average diameter calculated. Maximum vegetation height in each quadrat to be recorded at 5 points (centre and main cardinal points) and average height calculated.

ii. **For wet grassland sites:** 2m x 2m quadrats to record all higher and lower plant species present and their percentage cover (as above bryophytes can be recorded as a single category if necessary). Maximum vegetation height in each quadrat to be recorded at 5 points (centre and main cardinal points) and average height calculated.

Post-harvest

To be undertaken between 3-10 days after harvesting completed

In cut areas only survey access points, haulage routes and the managed area for any obvious signs of damage caused by harvesting process (e.g. ruts, pools, obvious patches of bare ground among otherwise vegetated areas, direct damage to vegetation).

In each case record the following:

- grid reference
- repeat fixed point photographs
- description of damage including rough dimensions (including depth of any ruts or pooled water)

Monitoring the impacts of mechanical harvesting on soil structure

Soil structure can be damaged or destroyed through loading under wet conditions with heavy machinery, particularly when the surface vegetation is a poorly developed. Structural porosity may be reduced or lost due to the tighter packing (soil compaction).

Surface pans are compact layers occurring at the surface and can be caused by heavy trafficking or livestock on silty or clayey soils or by heavy rainfall on bare silty and fine sandy soils.

Compact layers at the surface and in the soil profile may reduce the rate of water infiltrating into the soil and moving through it. They also reduce the quantity of water available for plant use and restrict capillary rise.

Compaction may be assessed in the field by digging a soil pit and comparing the soil structure at different depths. Where the requirement is to identify the presence or absence of surface compaction, the depth of the sample need only be one spades depth from the surface. If compaction is suspected to be occurring in layers further down, the sample needs to be taken through the potential pan area.

Such compaction can be measured through a visual inspection of the soil to identify signs of compaction and also conduct an infiltrometer test to measure infiltration rate

Substrate measurements

Substrate measurements to consist of two components; a) visual structural assessment of the soil, and b) measure of the soil infiltration rate. These measurements are to be recorded at 3 randomly located points within each cut and (uncut) control area.

a) visual structural assessment

Soil sampling

To examine the surface conditions, a small vertically-sided soil pit is established to spade's depth. An undisturbed soil sample is then taken from the side of the pit for examination (in taking the sample, the soil either side of the proposed spade-full is first cut vertically to isolate it from the neighbouring soil, the spade is then forced in vertically to the required depth with a slicing action, so minimising disturbance). The sample is then removed for inspection and broken carefully apart so that it breaks along the weakest planes. Photographs should be taken of the sample before and after breaking up as an additional visual record.

Assessing soil compaction

The following information sheets should be used as a guide to complete a Visual Soil Structure Quality Assessment.

Ministry of Food, Agriculture and Fisheries
Danish Institute of Agricultural Sciences

Visual Soil Structure Quality Assessment

A numeric test based on the appearance, strength and structure of a block of soil dug out with a spade. The scale ranges from Sq1, good structure, to Sq5, poor structure

Supporting the land-based industries for over a century

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Equipment:

Flat-faced spade approx. 20 cm wide, 22-25 cm long; light-coloured plastic sheet, sack or tray approximately 50 x 80 cm; measuring tape; small knife; digital camera (optional)

When to sample:

Any time of year but preferably when the soil is moist, so that a block of soil can be dug out without altering the structure. If the soil is dry, it may feel harder and be more difficult to break apart so that a higher score may be given. Roots are best seen in an established crop or for some months after harvest.

Where to sample:

Select an area of uniform crop or soil colour; within this, plan a grid to look at the soil at 10, preferably 20 spots. On small experimental plots, it may be necessary to restrict the number to 3 or 5 per plot.

Method of assessment:

1)Extracting a block of soil:

If the soil is loose enough, remove a block of soil directly, to the full depth of the spade, some 10-15 cm thick. Place this on the sheet or tray for evaluation.

If the soil is firm, first excavate a hole slightly wider and deeper than the spade, leaving one side untrampled. From this undisturbed side of the hole, trim off from the face any smeared or compressed soil before carefully lifting out an entire block to the full depth of the spade, some 10-15 cm thick. It may be helpful to first cut down each side of the block with the spade. Place the spade plus soil onto the sheet or tray (see illustrations).

2) *Evaluation of structure:*

Gently manipulate the block using thumbs and fingers of both hands to uncover and identify any cohesive layers or lumps (and take a photograph at this preliminary stage, if required). Further manipulate the soil to separate the soil into natural aggregates and man-made clods. Break larger pieces apart and look at the internal structure of the cross-section. If the spadeful separates into two (or occasionally more) horizontal layers, assess these separately.

The position and pattern of roots can be used to confirm the quality of the structure as a rooting medium. Look for root clustering and other signs of restricted root growth such as deflections and thickened roots.

Success through Knowledge

Method of assessment (continued)

3. Assignation of score (Sq1 best; Sq5 worst)

Evaluate the structure of the entire block of soil by referring to the key. Bear in mind that the properties of the block are being considered for their worth as a rooting medium. The criteria include:

A. The ease or difficulty encountered when pushing the spade into the ground and extracting the block.

B. The size, angularity and strength of the largest aggregates, including man-made clods. Finer, rounded and porous aggregates of low cohesion score lower.

C. Pockets or tongues of anaerobic soil, identified by their grey colour, sulphidic smell, or the presence of ferrous ions, would increase the score to Sq5.

D. If a significant crust is present, measure the depth and assess separately.

E. Where there are two layers, give the average score weighted for depth. Multiply the score of each layer by its thickness and divide the product by the overall depth to give the weighted score.
e.g. a loose surface layer (Sq5) 10 cm thick overlying a compact layer (Sq3) 20 cm thick has an average of Sq3.7 = (5 x 10) + (3 x 20)/30

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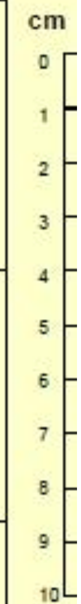
Structure quality	Ease of break up (moist soil)	Size and appearance of aggregates	Visible porosity	Roots	Appearance after break-up: various soils	Appearance after break-up: same soil different tillage	Distinguishing feature
Sq1 Friable (tends to fall off the spade)	Aggregates readily crumble with fingers	Mostly < 6 mm after crumbling	Highly porous	Roots throughout the soil			 Fine aggregates
Sq2 Intact (retained as a block on the spade)	Aggregates easy to break with one hand	A mixture of porous, rounded aggregates from 2-70 mm. No clods present	Most aggregates are porous	Roots throughout the soil			 High aggregate porosity
Sq3 Firm	Not difficult	A mixture of porous aggregates from 2mm -10 cm; less than 30% are <1 cm. Some angular, non-porous aggregates (clods) may be present	Macropores and cracks present. Some porosity within aggregates shown as pores or roots.	Most roots are around aggregates			 Low aggregate porosity
Sq4 Compact	Quite difficult	Mostly large > 10 cm and sub-angular non-porous; horizontal/platy also possible; less than 30% are <7 cm	Few macropores and cracks	All roots are clustered in macropores and around aggregates			 Distinct macropores
Sq5 Very compact	Difficult	Mostly large > 10 cm, very few < 7 cm, angular and non-porous	Very low; macropores may be present; may contain anaerobic zones	Few, if any, restricted to cracks			 Gray-blue colour



b) soil infiltration rate

The test is performed using a metal infiltrometer ring hammered into the surface as shown Figure 1 below. A convenient size for the ring is 30–40 cm diameter and 20-30cm high. Timber is used to protect the ring from damage during hammering.

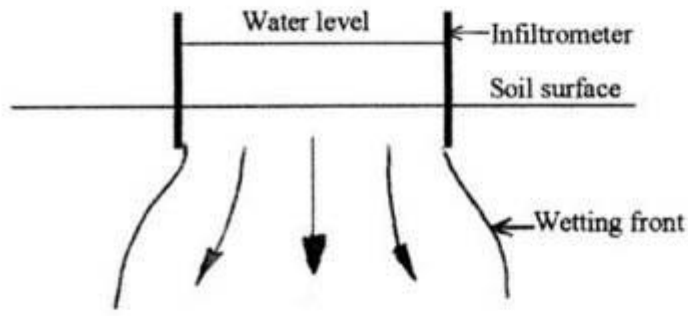


Figure 1. Experimental set up for infiltration rate measurement

For assessing the infiltration rate of surface layers, water is added to the infiltrometer ring to a depth of approximately 10 cm. The water level is allowed to fall through an exact distance of say 5 cm and the ring refilled to the initial water level. The time interval between each water addition is noted and the test continued until the interval becomes fairly constant. At this stage the infiltration rate is determined as follows:

$$\text{Infiltration rate (m per day)} = \frac{\text{distance of water level drop (cm)} * 864}{\text{time taken for water level drop (s)}}$$

The high and low measuring limits can be best identified using pointed wooden or metal markers, the pointed ends being orientated upwards and adjusted within the infiltrometer to the desired levels.
When using wetland features to determine infiltration rate, water is added for a much longer period before the measurements are made. This allows the wetted zone below the wetland feature to penetrate much more deeply, thus being more representative of the longer term situation. In this case the wetland feature can be allowed to almost empty between additions, accurate measures of the water level fall and the time interval only being required after deeper water penetration.

To account for soil variability and the small sample area, the small infiltrometer test needs to be replicated at least 3 times and the average infiltration rate determined.

Post-harvest
To be undertaken between 3-10 days after harvesting completed

In cut areas only survey access points, haulage routes and the managed area for any obvious signs of damage caused by harvesting process (e.g. ruts, pools, obvious patches of bare ground among otherwise vegetated areas, direct damage to vegetation).

In each case record the following:

- grid reference
- repeat fixed point photographs
- description of damage including rough dimensions (including depth of any ruts or pooled water)