energy technologies institute

An ETI Insights report

UNDERSTANDING VARIABILITY IN BIOMASS FEEDSTOCKS AND THE OPPORTUNITIES FOR PRE-PROCESSING

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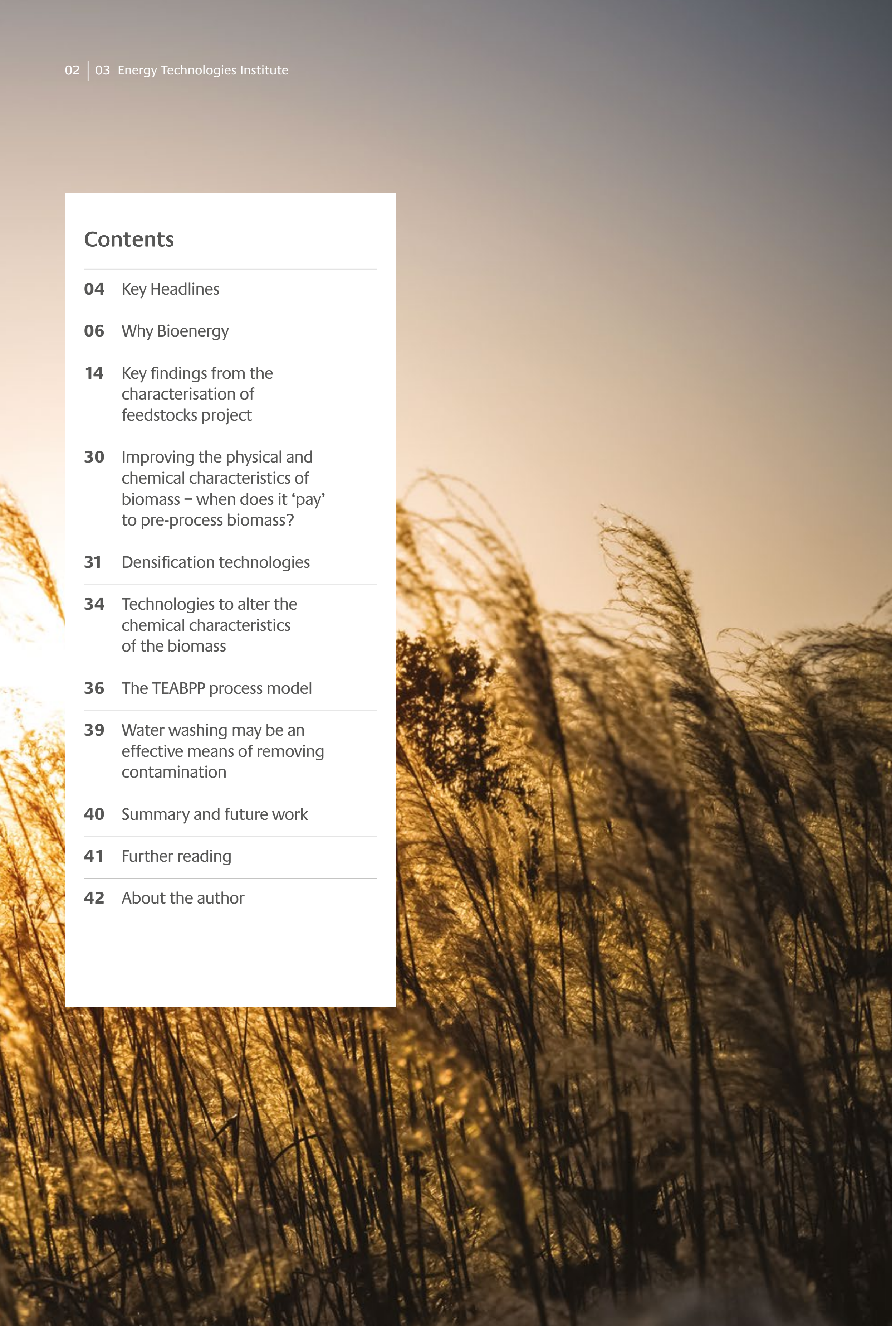
CATAPULT Energy Systems



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Bioenergy sources could provide 10% of **UK energy needs by 2050.**

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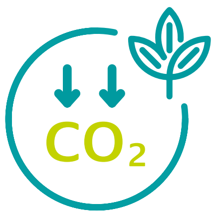


BIOENERGY

Understanding variability in biomass feedstocks and the opportunities for pre-processing

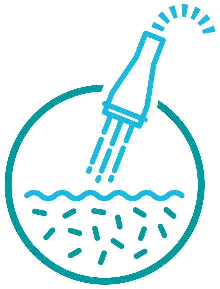
To meet this 10% figure (140TWh/yr) the UK will need **three times more feedstock** (on an energy basis) than is used today.

x3

To **increase the use of second generation crops,** we must overcome technical and market barriers.

Reducing the variability of second generation crops will reassure buyers that **biomass is of the right quality standard** for application.

If **water washing** can be successfully commercially demonstrated this is likely to be **a more cost-effective** option than other pre-processing techniques



KEY HEADLINES

- For bioenergy to sustainably deliver around 10% of UK energy demand in the 2050s, a mixture of UK-grown biomass, residual waste streams and imported biomass will be needed. Expanding UK biomass production will require the UK to make more effective use of new and existing forestry and expand production of second generation energy crops, such as Miscanthus, Short Rotation Coppice willow and Short Rotation Forestry.
- Second generation energy crops are used to generate power and heat in the UK today but the market is nascent. The characteristics of these emerging feedstocks are different to commonly used wood chips and pellets and, if not managed properly, this can cause problems in boilers and other conversion technologies. To successfully integrate new feedstocks, either the end user must be able to accept greater physical and chemical feedstock variability, or feedstock production techniques and pre-processing must be used to make feedstocks more homogeneous.
- Biomass characteristics vary between different species and between different parts of the same plant. Harvest time, separating plant parts and storage duration – all of which can be controlled by the grower – have a significant impact on several key feedstock characteristics.
- There is a high risk of contaminating Miscanthus pellets by using additives during the pelleting process. This is likely to have a detrimental impact on conversion technologies and these downstream impacts should be taken into account by both pellet manufacturers and pellet purchasers when agreeing supply contracts.
- Further research is needed into baled Miscanthus storage techniques to minimise degradation. Our research found that while storage lowered the alkali index, reducing the risk of slagging and fouling, it led to a reduction in quality across most other characteristics with no one type of storage able to minimise feedstock degradation across all parameters.
- Pre-processing technologies can be used to change the physical and/or chemical properties of biomass, but the additional cost of pre-processing biomass needs to be balanced against the potential savings in later transport costs and/or improved conversion efficiency. For UK feedstocks, the cost of densifying biomass is unlikely to pay off in reduced transport costs because of the relatively short distances travelled. However, improving the chemical characteristics of the biomass may be worthwhile, particularly where it brings feedstock characteristics within the range required to retain boiler performance or lifetime guarantees.
- Water washing can improve biomass characteristics by removing surface contamination and encouraging problematic compounds to leech from the biomass.

“For bioenergy to sustainably deliver around 10% of UK energy demand in the 2050s, a mixture of UK-grown biomass, residual waste streams and imported biomass will be needed.”

WHY BIOENERGY?

Bioenergy is a hugely valuable source of low-carbon renewable energy because it can be stored and used flexibly to produce heat, power, liquid and gaseous fuels. Combined with Carbon Capture and Storage (CCS), it has the potential to deliver negative emissions which the ETI anticipates are needed to deliver a low-carbon energy system cost-effectively.

The ETI's internationally peer-reviewed Energy System Modelling Environment (ESME)[1], a national energy system design and planning capability, suggests that producing bio-electricity or bio-hydrogen, in combination with CCS, could provide around 10% of projected UK energy demand (~140 TWh/yr) whilst delivering net negative emissions of approximately -40Mt CO_2 per year in the 2050s. This is just under half the UK's emissions target in 2050 and reduces the need for other, more expensive, decarbonisation measures. Even if CCS is not deployed, our analysis shows that an expansion of the role of bioenergy would still be very valuable because it provides a means to produce heat and biomethane for sectors which are otherwise difficult to decarbonise. ESME analysis suggests that it would cost an additional £200bn[2] to meet our carbon targets if we were to fail to develop the role of bioenergy beyond today's level. This is similar to the additional cost of meeting our 2050 targets if there were no deployment of electric vehicles.

The role of the ETI

The Energy Technologies Institute (ETI) is a £400m industry and government funded research institute into low-carbon energy system planning and technology development to address UK energy and climate change targets. The ETI's bioenergy programme was established to deliver research, technology development and deployment projects which would fill knowledge gaps within the sector and assess and understand the potential for different bioenergy value chains in the UK.

The role of the ESC

The Energy Systems Catapult (ESC) was established by the UK government in 2015 as part of a network of world-leading centres to transform the UK's capability for innovation. The ESC has a mission to unleash innovation and open new markets that help transform the energy system and capture the growth opportunity recognised in the UK Industrial Strategy. Working with government, industry, academia and consumers, the ESC vision for the UK energy sector will see it overcome systemic barriers and delivering the innovation, products, services and value chains required to accelerate the decarbonisation of the energy system at least cost and deliver the UK's economic ambitions.

The ETI's Whole System Analysis Function transferred to the ESC in September 2017 to continue its systems analysis work, providing consultancy services as a project partner to the ETI as it completes its portfolio of energy innovation projects and analysis.

Delivering the 2050 vision will require a variety of biomass feedstocks

Bioenergy can be produced from a range of different biomass and waste feedstocks. Delivering ~140 TWh/yr bioenergy by the 2050s will require around three times more feedstock (on an energy basis) than is currently used. To deliver this using a roughly equal mix of imported and UK-grown biomass feedstocks (alongside wastes), a greater focus needs to be placed on increasing availability of UK-grown biomass.

Afforestation (including Short Rotation Forestry, SRF) and making more productive use of existing forestry can and should play a role in increasing supplies of bioenergy feedstocks which can be produced alongside non-energy wood products (such as construction timber, paper and pulp), and create a stronger value proposition for managing the forest. However, this is unlikely to deliver the quantity of bioenergy feedstock required within the timeframe of meeting our 2050 targets. Alongside forestry there is an opportunity to grow Miscanthus and Short Rotation Coppice (SRC) willow (see page 8 for description) on arable land and grassland to deliver biomass feedstocks in a shorter timeframe.

The ETI's analysis on land use in the UK indicates there is potential to plant around 1.4Mha of second generation energy crops by the mid-2050s (an annual planting rate of 30-35 kha/year – equivalent to an annual increase of 0.2% of utilised agricultural land)[3]. This can be achieved whilst avoiding unsuitable areas (such as very steep slopes and peat soils) and without impacting on the level of UK-grown food consumed, if the UK makes more productive use of its agricultural land as a whole[4]. However, in 2016 the total area of Miscanthus and SRC willow in England was just 10kha – a figure which has remained steady for the past three years.

1 ETI (2017). ESME [online]. Available at: http://www.eti.co.uk/programmes/strategy/esme

2 NPV 2015-2050 at 3.5% discount rate. ESME analysis indicates that it would cost an additional £400bn NPV (2015-2050) to meet our 2050 energy targets relative to meeting energy demand without a fixed emissions target. Without an increase in bioenergy deployment it would cost a further £200bn NPV to meet the same target.

3 In 2016, Total Utilised Agricultural Areas (UAA) was 17.36 Mha. Defra (2017). Non-food crops [online]. Available at: https://www.gov.uk/government/collections/non-food-crops

4 ETI (2017). Increasing UK biomass production through more productive use of land [online]. Available at: http://www.eti.co.uk/library/an-eti-perspective-increasing-uk-biomass-production-through-more-productive-use-of-land

WHY BIOENERGY?

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Second Generation Energy Crops

Miscanthus is a perennial energy crop that can grow to heights of 2.5-3.5m. Rhizomes (an underground stem/bulb) are planted in the spring at a density of 10,000 – 15,000 per hectares. After its first year of growth it can be harvested annually for biomass for 20 years or more. New shoots emerge around March each year, growing rapidly in June-July, producing bamboo-like canes. The Miscanthus dies back in the Autumn/Winter, when the leaves fall off, providing nutrients for the soil, and the dry canes are harvested in winter or early spring.

SRC willow is planted as rods or cuttings in spring using specialist equipment at a density of around 15,000 per hectare. The willow stools readily develop multiple shoots when coppiced and several varieties have been bred specifically for use as energy crops. During the first year it can grow up to 4m in height, and is then cut back to ground level in its first winter to encourage it to grow multiple stems. It is harvested every three years subsequently, giving a total of seven harvests over a typical 23-year crop life[5].

Short Rotation Forestry (SRF) – poplar or conifer – is planted as a single stem species with a harvest rotation of 12-25 years. A SRF plantation could be planted for predominantly bioenergy purposes, meaning that whole tree (stem/trunk, tops and leaves/needles) could be available for bioenergy. More commonly, forestry is planted on a longer rotation to produce wood for a variety of end products. The wood used for bioenergy is generally taken from parts of the tree unsuitable for higher value purposes (e.g. construction), or from thinnings which are smaller trees removed part way through the harvest cycle to provide space for the remaining trees to grow.

5 Forest Research, Energy Crops [online]. Available at: https://www.forestry.gov.uk/fr/beeh-9uhpxh

While there is significant long-term potential, the second generation energy crop sector is nascent

Efforts to increase the area of second generation energy crops will need to focus on overcoming both market and technical barriers[6]. Blending energy crops with other feedstocks or using them for non-energy purposes can help overcome the ‘chicken and egg’ factor that can hinder investment decisions – farmers want a reliable market to sell into before taking the decision to plant, whilst potential end users don’t want to invest in setting up dedicated energy crops supply chains 2-3 years in advance of operations, when there is still uncertainty over whether their conversion plant will be built. For example, Iggesund blends SRC willow with waste wood to power at their Combined Heat and Power (CHP) plant in Workington[7], enabling them to operate whilst building up their SRC willow supplier base, whilst traditionally straw-fired power stations like Ely have diversified to accept Miscanthus bales[8]. Beyond the energy sector, organisations are investigating the viability of Miscanthus as a building material[9].

Developing new markets for second generation energy crops by identifying alternative end uses, or blending them with existing feedstocks could accelerate planting rates for these crops. However, for Miscanthus and SRC willow to be used alongside other feedstocks, the characteristics of these blended feedstocks must be compatible with their end use.

6 ETI (2016). Bioenergy crops in the UK: Case studies on successful whole farm integration evidence pack [online]. Available at: http://www.eti.co.uk/library/bioenergy-crops-in-the-uk-case-studies-on-successful-whole-farm-integration-evidence-pack
ETI (2017). Opportunities for rural job creation in the UK energy crops sector [online]. Available at: http://www.eti.co.uk/library/an-eti-perspective-opportunities-for-rural-job-creation-in-the-uk-energy-crops-sector

7 Iggesund Willow: http://biofuel.iggesund.co.uk/

8 Fuel used at Ely power station: http://www.mreuk.com/elyfuel

9 Aberystwyth University (2017). The world’s first Miscanthus bale house [online]. Available at: https://www.aber.ac.uk/en/news/archive/2017/09/title-206144-en.html

WHY BIOENERGY?

Continued ›

Biomass standards are widely used in the wood pellet market but are less commonly deployed when trading energy crops

Widely recognised and rigorously enforced biomass standards help the development of the bioenergy sector enabling biomass to become a more widely traded commodity, and reassuring buyers that biomass which meets a given standard is of the right quality for their application. Between 2003 and 2006, the European Committee on Standardisation (CEN, under committee TC 335[10]) developed European Norms (EN) to describe different types of solid biomass used within Europe, including wood chips, pellets and briquettes, as well as firewood (logs) and non-woody pellets. These standards have been adopted by the British Standards Institution (BSI), the UK's National Standards Body, to form BS EN[11]. Some standards have also been adopted by the International Standards Organisation (ISO) which is made up of 162 national standards bodies[12]. These standards describe the physical and chemical characteristics of the fuel, the source of the material and cover test procedures to measure the various properties.

The ISO 17225-2 standard is commonly used when trading wood pellets, with different grades of wood pellet available, from premium quality A1 pellets predominantly for commercial and residential use, through to industrial grade 3 (I3) pellets which are used in larger scale applications. Similar standards are not typically used in the Miscanthus and SRC willow markets, although contracts between growers and buyers are likely to specify good practice that the grower should follow and conditions around the form the biomass should take (e.g. bales of a particular size, density and moisture content). This means that Miscanthus and SRC willow sold as fuel could have a wide range of chemical characteristics, many of which could have an impact on biomass performance in conversion technologies and therefore influence the choice of boiler, how it is optimised and its overall performance. These characteristics include[13]:

- Calorific Value (kJ/kg) – The energy density of the feedstock affects the conversion plant size and efficiency, as well as logistics methods and costs.
- Moisture Content (wt.%) – A high moisture content will reduce combustion plant efficiency and potentially affect fuel handling and the rate of degradation during storage.
- Ash (wt.%) – Higher ash levels reduce the calorific value which in turn impacts plant efficiency. Ash handling systems need to be sized to handle the expected ash quantities. High ash levels can increase the occurrence of slagging and fouling[14] within the boiler, which could reduce availability and increase operational costs. However, some components within the ash may mitigate the harmful impacts of other chemicals.
    - Aluminium and silicon – alumino-silicates in the ash may mitigate alkali-metal mediated corrosion, slagging or fouling. However, silica (quartz) may cause abrasion and erosion in boiler plant.
    - Calcium – Principal component of biomass ash which can increase occurrence of slagging but may help acid gas abatement.
- Nitrogen (wt.%) – Impacts level of oxides of nitrogen (NO_x) emissions.
- Sulfur (wt.%) – Impacts level of oxides of sulfur (SO_x) emissions. At high temperatures sulfur can be corrosive, but in lower temperature systems it can mitigate against chloride corrosion.
- Chlorine (and other halides) – Can contribute to boiler corrosion and acid gas emissions. Acid gases also cause amine degradation in carbon capture processes.
- Alkali metals, including sodium and potassium – a key concern for plant corrosion and slagging. May also result in formation of fine particulate matter which is a concern for emissions and amine-based carbon capture processes. The levels of sodium oxide and potassium oxide in the ash are used to derive the alkali index, a measure of the risk of slagging in combustion systems.
- Trace elements such as nickel, arsenic and mercury which are primarily an environmental, rather than operational, concern.

10 CEN/TC 335 – Solid Biofuels Standards [online]. Available at: https://standards.cen.eu/dyn/www/f?p=204:7:0::::FSP_ORG_ID:19930&cs=17158638AB0C35D5E52A369017E54A1D6

11 UK National Standards Body (BSI): https://www.bsigroup.com/en-GB/about-bsi/uk-national-standards-body/UK-National-Standards-Body/

12 International Organization for Standardization (ISO): https://www.iso.org/about-us.html

13 The full list of characteristics tested in the Characterisation of Feedstocks project can be found in Table 2-4 of D13: Synthesis Report [online]. Available at: http://www.eti.co.uk/programmes/bioenergy?size=10&from=20&_type=eti-document&publicOnly=false&query=&programmeName%5B0%5D=Bioenergy&projectName%5B0%5D=Characterisation+of+Feedstocks

14 Slagging is the result of ash deposits in areas of the boiler system exposed to radiant heat (such as the boiler furnace) whilst fouling is the result of ash deposits elsewhere in the system, such as on convection heat surfaces.

WHY BIOENERGY?

Continued ›

As part of its programme of research into UK-grown feedstocks, the ETI set out to understand the characteristics of second generation energy crops, how they varied across different sites and, in particular, whether variability in characteristics could be linked to the provenance of the crop. This could help identify changes in growing and harvesting practices that could improve biomass quality. In parallel to this, the ETI also commissioned a project to understand the extent to which pre-processing of biomass could improve the characteristics of biomass feedstocks, and whether the additional cost and greenhouse gas emissions associated with pre-processing were outweighed by the benefits of reduced transport costs and/or increased downstream conversion effectiveness.

This insight paper sets out the findings from these two projects.

Understanding variability in feedstock characteristics

The ETI's Characterisation of Feedstocks (CoF) project was carried out by Forest Research and Uniper Technologies Ltd and ran from February 2015 to March 2017. Its purpose was to develop our understanding of the variability of different UK-produced bioenergy feedstocks and the causes of this variation.

CoF Characterisation of Feedstocks

Project Scope

Four main feedstocks were investigated – Miscanthus, SRC willow, SRF poplar and SRF conifer.

The fieldwork was run in two Phases. Phase 1 ran from the Spring through to Autumn of 2015 and consisted of four related studies. The first (and largest) study investigated the reasons behind any observed variation in feedstock characteristics within the UK. Potential sources of variation included climate zone, soil type, harvest time, storage duration and plant part.

The three smaller Phase 1 studies explored variability within specific parts of an energy crop or in settings that could make a material difference to end users:

- Feedstock variability within a site (Miscanthus and one variety of SRC willow)
- Leaf properties (SRF poplar and SRC willow) for comparison to the feedstocks containing little or no leaf material
- Miscanthus pellet properties

Phase 2, which ran from November 2015 to November 2016, included four studies which followed up on points of particular interest in Phase 1:

- The impact of harvest time on Miscanthus properties
- The impact of harvest time on SRC willow properties
- The impact of variety on SRC willow characteristics
- The impact of storing Miscanthus bales for six months using four commonly used storage methods

All reports and data from the CoF project are available to download from the ETI's Knowledge Zone[15].

15 ETI Knowledge Zone - Characterisation of Feedstocks: http://www.eti.co.uk/programmes/bioenergy?size=10&from=0&_type=eti-document&publicOnly=false&query=&programmeName%5B0%5D=Bioenergy&projectName%5B0%5D=Characterisation+of+Feedstocks

KEY FINDINGS FROM THE CHARACTERISATION OF FEEDSTOCKS PROJECT

Characteristics of biomass vary by plant part and, for most species, harvest time is a key determinant of feedstock properties

The largest aspect of the Characterisation of Feedstocks (CoF) study was to investigate the influence of soil type, climate zone, harvest time and storage on feedstock composition. Differences in composition by plant part were also measured. The full methodology and results are set out in the final reports for Phases 1 and 2[15,16]. Results were considered statistically significant where $p<0.05$[17].

SRF Poplar

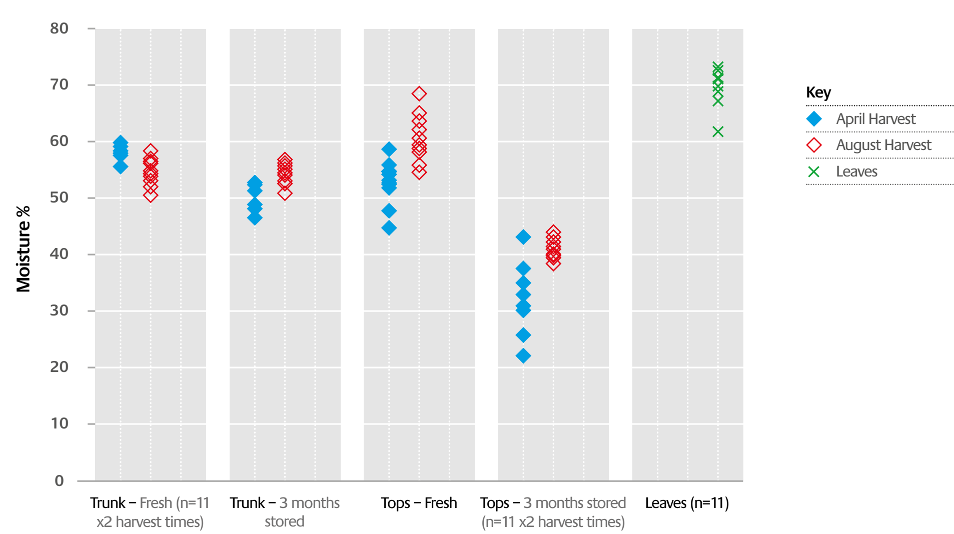
At 11 sites samples were taken of SRF poplar trunks/stems (from the base cutting point up to a point where the diameter has reduced to 7cm) and tops (the top of the stem which is less than 7cm diameter, plus associated branches and leaves) at two harvest times; April – when the amount of leaf material was low; and July/early August – when the trees were in full leaf and the tops samples contained a lot of leaf material. Further sets of samples were taken after three months of storage. To mimic commercial practice, no attempt was made to prevent the loss of leaf material during storage. A separate set of leaf-only samples was taken at the same time as the second harvest in July/early August.

The analysis found that two factors within the control of the forester – storage and harvest time – were the most important in determining several key feedstock characteristics in both the SRF poplar trunks and tops.

As shown in Figures 1 and 2, and as expected, storing SRF poplar trunks and tops reduces moisture content with a corresponding increase seen in net calorific value (also known as lower heating value, LHV). There was a greater decrease in moisture content (and consequently greater increase in net calorific value) seen in the early harvest samples. In terms of ash content, the levels found in the tops are typically 2-3 times those found in the trunk, whilst the concentration in the leaves can be 10 times higher (Figure 3). The ash content of the trunks was similar at both harvests and storage didn't have a significant impact on these levels (although a change in ash composition was observed). In the tops, the ash content of the fresh material from the second harvest was two percentage points higher than the first harvest, likely to be the result of the presence of leaf material during the second harvest. However, following storage (during which most leaf material falls away), there are similar ash levels in the tops from both harvests.

In general, the leaves contained the highest levels of most chemicals. The tops contained lower levels than the leaves, with the trunk containing the lowest levels of chemical contaminants.

Figure 1
Results from the moisture (as received) analysis of SRF poplar showing harvest time impacts and leaf analysis



15 ETI Knowledge Zone – Characterisation of Feedstocks: http://www.eti.co.uk/programmes/bioenergy?size=10&from=0&_type=eti-document&publicOnly=false&query=&programmeName%5B0%5D=Bioenergy&projectName%5B0%5D=Characterisation+of+Feedstocks

16 Both Reports available on ETI Knowledge Zone. Phase 1 Final Report – Deliverable 6: Final Report (Phase 1).
Phase 2 Final Report – Deliverable 12: Final report on investigations into the effect of harvest time and variety on willow SRC and the effect of harvest time and storage method on Miscanthus quality

17 A p-value of less than 0.05 means that there was less than a 1 in 20 chance of obtaining the observed results if the null hypothesis were true.

KEY FINDINGS FROM THE CHARACTERISATION OF FEEDSTOCKS PROJECT

Continued ›

Overall, the findings from the project indicate that SRF poplar growers can adjust several key characteristics through selecting an appropriate harvest time and storage duration (to minimise leaf material and moisture content). They can also separate stem material from the tops if a higher quality fuel is required.

SRF Conifer

At 12 sites samples were taken of SRF conifer trunks/stems (from the base cutting point up to a point where the diameter has reduced to 7cm) and tops (the top of the stem which is less than 7cm diameter, plus associated branches and leaves) at two harvest times; mid-March – these included needles but the trees were in a state of partial dormancy with no newly emergent needles; and late June – when the trees were metabolically active and the tops samples contained that season's needles in addition to previous years'. Further sets of samples were taken after three months of storage. As with poplar, to mimic commercial practice, no attempt was made to prevent the loss of needles during storage. At the two harvest times (but not after storage), separate bark samples were taken at all 12 sites.

As with poplar, the key factors affecting feedstock characteristics were harvest time and storage, with similar trends seen in moisture content and net calorific values between harvests and before/after storage (most needles fell off the tops during storage). In general, most chemicals were found at higher concentrations in the tops and bark than in the trunk of the SRF conifer.

The bark had much better fuel characteristics than expected with concentrations, in general, similar to those in the tops. This was unexpected as it is commonly assumed that the bark will have the highest concentrations of elements. However, this may have been due to the careful sampling techniques which avoided soil contamination. It was expected that silicon would be highest in the bark due to the potential for soil entrapment but in fact silicon levels were only marginally higher in the bark than the trunk, with the tops containing the highest concentrations of all. Overall, this suggests that while commercial harvesting practices may result in a reduction in bark quality, if economic, this could be mitigated with a surface washing step prior to combustion.

Miscanthus (Miscanthus x giganteus)

During Phase 1 samples were taken across 12 sites immediately after the crops were cut at their usual commercial harvest time (February-April). A second set of samples was taken from nine of the sites just prior to baling, after the Miscanthus had been left to dry in the field (three sites baled the crop soon after harvest). A further sample set was taken after the baled crop had been stored for a month. The results of the separate experiment examining

Figure 2
Results from the net calorific value (as received) analysis of SRF poplar showing harvest time impacts and leaf analysis

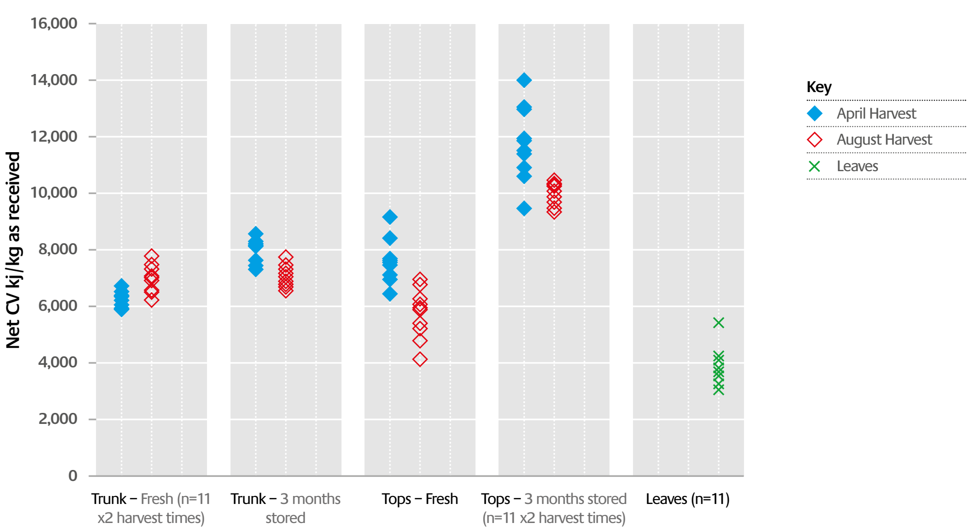
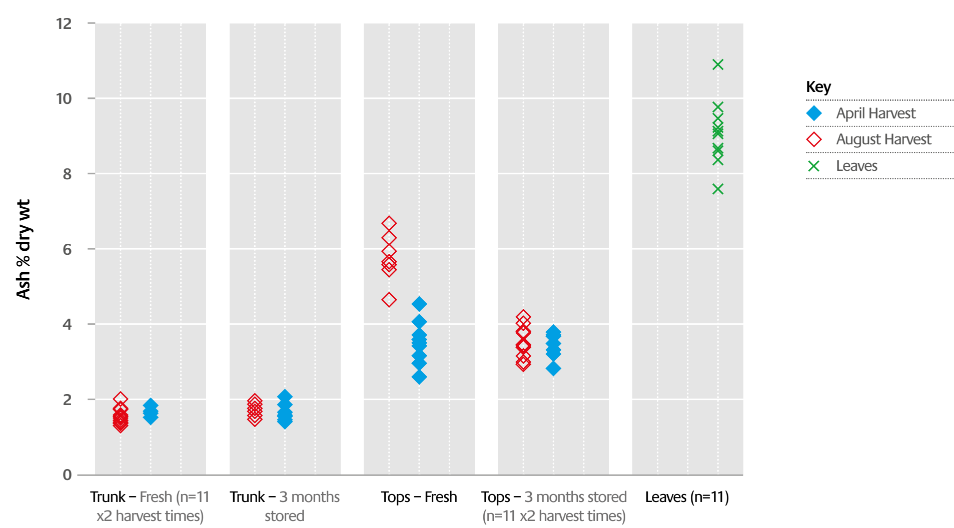


Figure 3
Results from the ash (dry) analysis of SRF poplar showing harvest time impacts and leaf analysis



KEY FINDINGS FROM THE CHARACTERISATION OF FEEDSTOCKS PROJECT

Continued ›

changes during six months of baled storage are described later in this report.

Phase 2 of the experiment looked specifically at the impact of harvest time on Miscanthus properties. At six sites samples were taken on three occasions prior to the normal commercial harvest time (early November, early January and first half of March). Samples were also taken at the commercial harvest and just prior to baling.

Harvest time had a significant impact on several Miscanthus properties – over the course of winter/spring there was a general decrease in moisture content (falling from 60-70% in November to 10-20% in late spring), ash, nitrogen, chlorine, silicon and calcium accompanied by an increase in net calorific value and sodium.

These results broadly reflected findings from existing literature, as the winter season allows the leaves (which typically contain higher levels of unwanted characteristics such as silicon and chlorine) to shed and the standing cane to reduce in moisture content. The winter period also sees a change in the distribution of elements within a plant. Reductions in active growth, photosynthesis and cell maintenance during winter results in several compounds normally used in cell growth and maintenance moving to the roots or rhizome for storage until growth restarts in the spring.

However, some sites (mostly in South West England) showed a pattern, previously unreported in the literature, of increasing nitrogen levels in the late spring which may be associated with a resumption of growth in stems. In conversations with the project team, there was a view amongst some Miscanthus growers that winters in some more southerly areas are not always reliably cold enough to complete the growth cycle of the stems. As a result, when conditions improve in the spring, nutrients and sugars are remobilised and translocated to the overwintered stem to support a continuation of last season's growth.

Considered as a whole, the results suggest that to maximise Miscanthus quality, harvesting should be delayed until at least the beginning of March, with chlorine and ash a particular concern if harvesting is brought forward. Bringing harvesting forward also risks losing the advantages of lower moisture content and a higher net calorific value.

The other factors (up to one month storage post-baling, soil type and climate zone) had less significant impacts on feedstock characteristics although there were some statistically significant relationships between these factors and feedstock characteristics. Figure 4 shows that the moisture content of the Miscanthus fell following in-field drying and one month of storage (however, the six month storage experiment (described later) found that moisture content of *bales* increased). Miscanthus had the most variable moisture content at harvest of all the crops included in the CoF project, but Figure 4 also shows a reduction in variability following in-field drying and one month of storage.

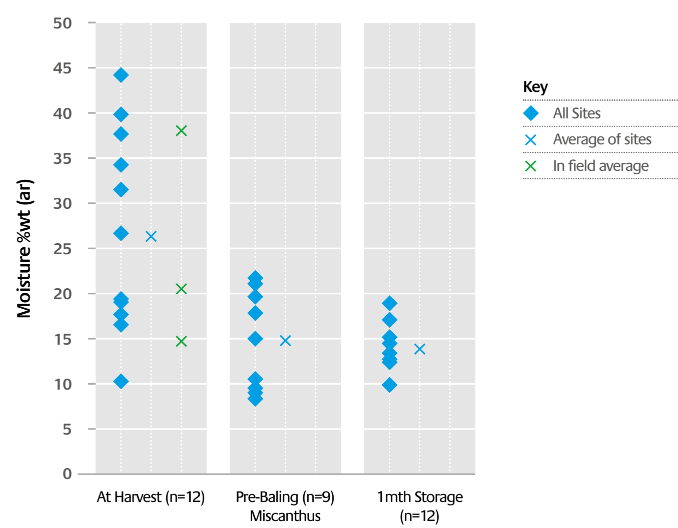
Short Rotation Coppice Willow

In Phase 1, SRC willow samples were taken across seven sites during the commercial harvest and after one month stored as chips. In Phase 2 (when harvest time was being examined), samples were taken from six sites at three simulated harvest times (November, January and March). In September a separate set of leaf samples were collected to analyse how their properties differ from the main part of the plant (normally most, if not all, leaves will have been shed by the point of commercial harvest).

The results did not find many operationally significant links between feedstock properties and soil type or storage (although this is likely to be due to the short storage duration). However, when comparing the composition of the leaves with the harvested SRC willow stems, a more significant difference was apparent. The results showed that willow leaves contain higher levels of ash (around a four-fold increase) and higher mineral and trace element concentrations than the stems. In particular sulfur, which is responsible for SO_x formation and which was virtually undetectable in the SRC willow stems, was found at levels of 0.5% (dry) in the leaves.

Overall, these results suggest that there is flexibility to harvest SRC willow between leaf fall through to bud burst in the spring without significantly impacting the quality of the feedstock, but that inclusion of any leaf material should be avoided.

Figure 4
Results from the moisture analysis (as received) of Miscanthus



KEY FINDINGS FROM THE CHARACTERISATION OF FEEDSTOCKS PROJECT

Continued ›

No one SRC willow variety exhibits the best all-round fuel characteristics, therefore growers should consider the different properties of each as part of their selection criteria

There are several varieties of willow, some of which have been bred specifically for energy crop planting. Commercial SRC willow plantations typically use a mix of varieties to minimise the risk of damage from pests or fungal diseases[18]. The CoF project tested six varieties of SRC willow (Endurance, Tora, Terra Nova, Resolution, Sven, and Nimrod) across sites spanning a wide range of environmental characteristics in the UK to test the consistency of SRC willow feedstock characteristics across these varieties. Sampling at all sites was done within one week to minimise the impact of sampling time on feedstock characteristics.

13 of the 35 parameters analysed showed statistically consistent rankings for the varieties tested. This included moisture content, where Endurance was consistently the lowest, with Tora, Resolution and Sven in the mid-range, and Terra Nova and Nimrod having the highest moisture contents (with an opposite ranking for net calorific value).

Overall, no variety combined the best ranking in all parameters and the majority, including sulfur, chlorine and alkali index, did not show consistent rankings. However, for those characteristics which have been shown to vary by variety, where farmers have an end use in mind, they could manage the overall mix of these characteristics through careful selection of SRC willow varieties.

18 Defra (2004). Growing Short Rotation Coppice [online]. Available at: https://www.forestry.gov.uk/pdf/Growing_Short_Rotation_Coppice_tcm6_2004.pdf/$FILE/Growing_Short_Rotation_Coppice_tcm6_2004.pdf

19 RCUK (2017). SUPERGEN Bioenergy Hub Extension. For further details see: http://gtr.rcuk.ac.uk/projects?ref=EP%2FP024823%2F1

20 Including AFBi's research into the role SRC willow can play in managing nutrient run-off from fields. Project WaterPro: http://www.interreg-npa.eu/projects/funded-projects/project/155/

Soil type was not a significant determinant of feedstock properties in this study but wider research shows that more contaminated soils can impact fuel composition

An initially surprising finding from the analysis across all feedstocks was that soil type was rarely important in determining feedstock composition. Wider literature has found that energy crops, particularly SRC willow, could be suitable for phytoremediation of contaminated lands due to their ability to remove metals from soils, and there is ongoing research in this area[19,20]. However, because the sites used were all rural sites which had not been contaminated through previous uses (such as mining) or through the recent application of sewage sludge, they all contained low levels of soil metals and metalloids. This may explain the absence of a high number of relationships between feedstock and soil properties.

Storing Miscanthus for six months may degrade overall feedstock quality – but more research is needed to validate findings and develop improved storage techniques

Following Miscanthus harvesting and baling, Miscanthus bales are commonly stored on-farm until it is convenient for the buyer to collect them. The CoF project surveyed 20 Miscanthus farmers and found that 19 stored Miscanthus bales on their farm. The majority (11) kept the bales in a partially enclosed shed (three sides and a roof) with a further four storing them in a fully enclosed barn. The remaining farmers stored the bales outside, either uncovered (1) or covered with a sheet (3). There was little consistency in the length of time bales were stored, with a similar number of farmers saying they stored the bales for less than 3 months, 3-6 months, or more than 6 months.

To test the extent to which Miscanthus fuel properties and composition are influenced by storage methods and duration, the project team set up four stacks, comprising 48 Miscanthus bales each, in different storage environments on a farm in South West England:

- Outside uncovered
- Outside covered by sheet
- Open barn – covered by a roof but no sides
- Closed barn – a fully enclosed building

KEY FINDINGS FROM THE CHARACTERISATION OF FEEDSTOCKS PROJECT

Continued ›

A sample was taken from the bales at the start of the storage period[21] (May 2016) and then every month (excl. July) for six months (until November[22]. The analysis found that:

- 14% of the 42 analysed feedstock characteristics were affected by storage duration and the type of storage. This included:
  - Ash levels in bales stored outdoors increased steadily and by the end of the experiment were around 20% higher than at the start. Barn-stored bales had much higher ash levels the month after storage began and then declined so that by November the ash levels were around 50% higher than at the start.
  - Calcium (a component of ash) increased by around a third in all storage types but the greatest increase was seen in the outdoor uncovered bales. It was speculated that this may have been due to contamination by wind-blown lime or soil.
  - Nitrogen content fell throughout the storage period and was about 15% less than the initial value at the end of the experiment. The greatest decrease was in the uncovered bales stored outside.
  - Sulfur increased by between approximately 40% and 150% across all samples over the six month period. Larger increases were seen in bales stored in barns compared to the bales stored outdoors.
- 43% of analysed feedstock characteristics were affected by storage duration, but not storage type. These included increases in moisture content, chlorine, and (in ash) the oxides of aluminium, calcium, and silicon. There were decreases in net calorific value, potassium, potassium oxide (in ash) and the alkali index.
- 43% of feedstock characteristics were not affected by storage duration or type. These included levels of sodium oxide in ash.

Overall, during this experiment, where there was a significant change in Miscanthus composition during storage, in almost every instance, this indicated a deterioration in Miscanthus condition. The only improvements in condition were a reduction in potassium, potassium oxide (K_2O) and alkali index (all of which can contribute to boiler corrosion and slagging, and which were not affected by the *type* of storage), and a reduction in nitrogen (which is linked to NO_x formation) where the greatest decrease was seen in uncovered bales stored outside. There was no single storage type which provided the least deterioration/most improvement across all characteristics, going against a common assumption that the most protected storage conditions result in the best quality feedstock.

It is important to note that this experiment was conducted on one farm in a single year, so the results should be treated with caution. However, given the widespread practice of on-farm storage, these findings would suggest that further investigation is needed into the impact of Miscanthus storage and how storage techniques can minimise feedstock deterioration.

Figure 5
Techniques used during six-month Miscanthus storage experiment.
1. storage outside, uncovered; **2.** storage outside, covered by a waterproof sheet protecting the top of the bales and the sides of the top 2-3 bales; **3.** open barn storage providing roof cover only; **4.** storage inside a fully enclosed barn

21 It is important to note that this experiment measured the changes in the composition of baled Miscanthus. The difference in composition at the point of harvest and at the point of baling (e.g. after being left in the field to dry) was covered in Phase 1 of the project, results from which are summarised on page 17.

22 For full results, please see Table 4-6 in Deliverable 12. For the sampling method, please see Appendix 9 of Deliverable 12. D12: Final report on investigations into the effect of harvest time and variety on willow SRC and the effect of harvest time and storage method on Miscanthus quality [online]. Available at: http://www.eti.co.uk/programmes/bioenergy?size=10&from=0&_type=eti-document&publicOnly=false&query=&programmeName%5B0%5D=Bioenergy&projectName%5B0%5D=Characterisation+of+Feedstocks

KEY FINDINGS FROM THE CHARACTERISATION OF FEEDSTOCKS PROJECT

Continued ›

Additives used during the Miscanthus pelleting process can have a detrimental impact on feedstock quality

Biomass is pelleted to increase its bulk density, reduce its moisture content and make it easier to handle, both during transport and in conversion technologies. The costs associated with the pelleting process (drying, grinding and pelleting the biomass) need to be weighed against savings later in the supply chain (notably transport where capacity limits are generally set by volume, not weight) and additional benefits for the end user. For example, domestic boiler owners may find that the convenience of automated feed handling systems and smaller storage requirements outweighs any additional feedstock costs when compared to chip or log-fuelled systems. For converted pulverised coal power stations, using pellets may reduce the capital costs of conversion compared to using baled or chipped feedstock which would have very different handling requirements. In some cases, such as for biomass imported from outside of the EU, pelleting is required to meet phytosanitary rules designed to prevent the spread of diseases.

As noted earlier, there are internationally agreed standards for biomass pellets which help to make them a tradable commodity. Data on internationally traded wood pellets provided by Uniper Technologies Ltd from their commercial operations show these pellets to be consistent and homogeneous.

In the CoF project, the project team tested the properties of three batches of Miscanthus, before and after pelleting at a commercial pellet plant, to understand its impact on fuel properties and composition[23].

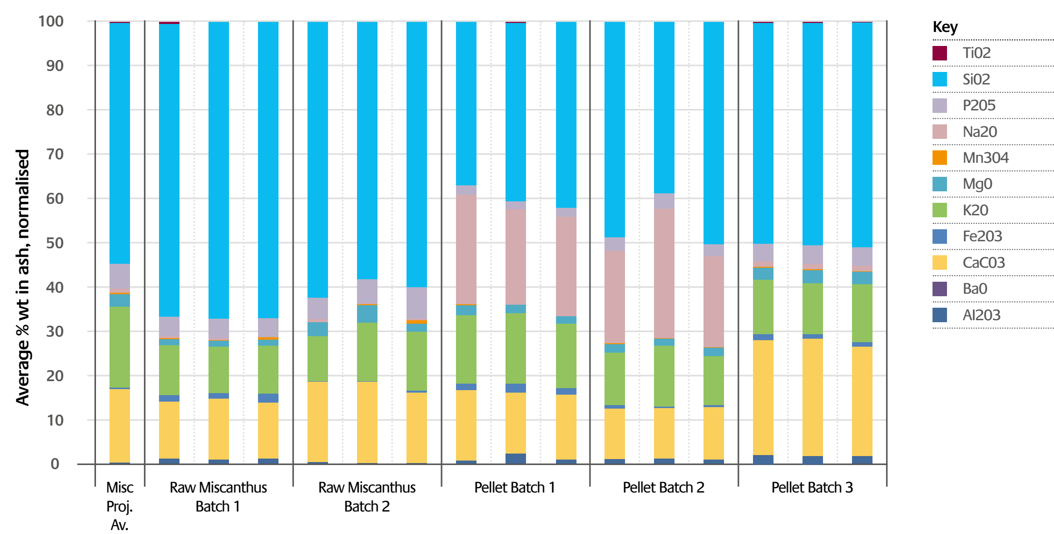
Other than reducing moisture content, and thereby increasing net calorific value, the simple process of drying, grinding and pelleting Miscanthus was not expected to have a significant effect on its chemical characteristics. However, various materials may be added during the pelleting process, for example binders to improve pellet strength and lubricants to improve throughput and pellet die life (part of the equipment used to compress the biomass material into pellets). These additives could alter the final chemical characteristics of the pellet. In a commercial setting, such as the one used for this project, contamination might also occur through unintended contact with other types of biomass species being processed in the pellet plant, or contamination from the pellet mill itself (from wear materials – parts of the system expected to be worn down over time).

23 Raw input material and pellets made from this material were provided for Batches 1 and 2. In Batch 3 only the pellets were provided to the project team, so no comparison could be made with the raw material. For full results, see page 202 in D6 Final Report (Phase 1) [online]. Available at: http://www.eti.co.uk/programmes/bioenergy?size=10&from=10&_type=eti-document&publicOnly=false&query=&programmeName%5B0%5D=Bioenergy&projectName%5B0%5D=Characterisation+of+Feedstocks

In all three batches, there were significant changes in chemical composition when the pellets were compared with the raw input material.

- In Batch 1, the pellets contained more than twice the level of chlorine (Cl) found in the raw biomass, and almost twice the level of nitrogen (N) (all measured on wt.% dry basis). This was not seen in Batch 2 where the chlorine and nitrogen levels were similar in the pellets and raw material. Despite discussions with the supplier, it was not possible to identify probable causes for the increases in chlorine and nitrogen in Batch 1.
- In Batches 1 and 2, the chemical composition of the pellet ash had much higher levels of sodium oxide (Na_2O) than the raw Miscanthus ash (Figure 6). Discussions with the pellet plant revealed that caustic soda (also known as sodium hydroxide, NaOH) is often added during the pelleting process to improve pellet die lubrication and increase its overall lifespan. The third batch of pellets was requested specifically without the addition of caustic soda, although in this case no equivalent raw input material was received. However, Figure 6 shows that the calcium carbonate ($CaCO_3$) content in these pellets is higher than in any of the other batches of material, suggesting that the caustic soda may have been replaced with limestone as an additive.

Figure 6
Normalised ash composition of fresh and pelletised Miscanthus



KEY FINDINGS FROM THE CHARACTERISATION OF FEEDSTOCKS PROJECT

Continued ›

Overall, while these results are not able to provide conclusive evidence of the impact of pelleting on the chemical composition of the Miscanthus itself, the results highlight the relatively high risk of contamination of the pellet, either from deliberate use of additives or from other materials or wear products used in the grinding process or the pellet mill itself which could have a significant impact on the conversion process. For example, the caustic soda that was added to the pellets in Batches 1 and 2 would pose severe slagging, fouling and corrosion risks to downstream combustion plants.

These findings highlight the need for good communication between end users and pellet producers and further testing to understand the downstream impact of any additives and ensure that pellet quality isn't compromised.

The characteristics of different feedstocks, and different parts of feedstocks, differ in ways which are significant for downstream conversion processes

The net calorific value of Miscanthus was strongly influenced by seasonal changes, but by spring it had the highest net calorific value – up to 16,000 kJ/kg as received. The woodier parts of SRC willow, SRF poplar and SRF conifer had values in the range 6,000 – 8,000 kJ/kg whilst willow and poplar leaves had values below 4,000 kJ/kg.

Whilst Miscanthus had the highest energy density, it is commonly seen as a 'problematic' fuel due to levels of chlorine and a high alkali index making it prone to slagging and fouling. Table 1 below compares the alkali index and levels of ash and chlorine in the different feedstock parts analysed in the CoF project. While the level of chlorine is higher than all other feedstock types apart from willow leaves, the levels of ash and alkali index are comparable with poplar and spruce tops. However, when comparing the ash composition (Figure 7), Miscanthus ash contained high levels of silica (SiO_2) whilst ash from all other feedstock was predominantly calcium carbonate ($CaCO_3$). Silica in combination with potassium oxide (K_2O) which is the second largest component of Miscanthus ash, can form low melting point mixtures which could increase the probability of slagging or fouling in boilers.

Figure 7
Average normalised ash composition for the fresh feedstock samples in Phase 1

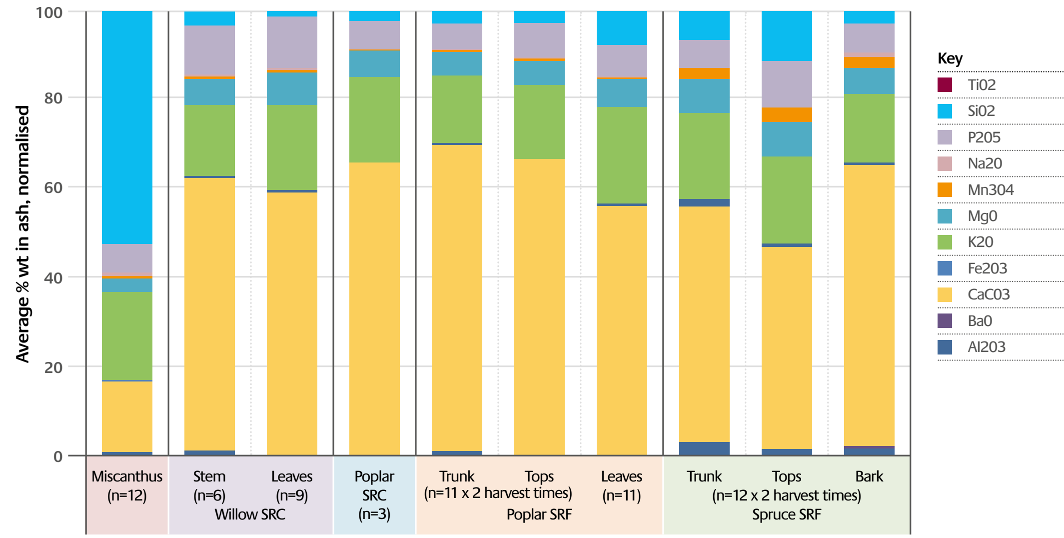


Table 1
Comparison of ash, chlorine and alkali index averages for all fresh feedstock samples in Phase 1

Feedstock	Ash %wt (dry)	Chlorine % (dry ash free)	Alkali index (kg(Na_2O+K_2O)/GJ)
Miscanthus	2.3	0.14	0.204
Willow SRC	1.8	0.02	0.147
Willow SRC – Leaves	8.0	0.16	0.706
Poplar SRF – Trunk	1.6	0.01	0.112
Poplar SRF – Tops	4.5	0.03	0.340
Poplar SRF – Leaves	9.1	0.09	0.871
Spruce SRF – Trunk	0.4	0.01	0.038
Spruce SRF – Tops	2.4	0.04	0.195
Spruce SRF – Bark	2.3	0.04	0.158

Colour coding for ash and chlorine relates to the wood pellet standards given in Table 2: green denotes that the samples met the A1 standard, amber denotes that the samples met the I3 standard but not the A1 standard; and red denotes that the samples did not meet the I3 standard. For alkali index, green denotes that there is a low risk of fouling/slagging; amber denotes that fouling/slagging is probable; and red denotes that fouling/slagging is certain.

KEY FINDINGS FROM THE CHARACTERISATION OF FEEDSTOCKS PROJECT

Continued ›

Only stem wood from Short Rotation Forestry can meet industry standards in raw form. There is a need to blend or pre-process feedstocks to improve overall quality.

As mentioned in the introduction, wood pellet standards are commonly used in the bioenergy industry ranging from the highest quality, A1, for domestic and small commercial use through to I3, for industrial applications.

While these standards only apply to wood products, it is useful to test all the crops in the CoF project against them to understand the extent to which they can meet the standards and identify characteristics which may be problematic for end users if not treated through pre-processing, blending with other feedstocks, or adjustments to the end conversion technology.

Table 2 summarises the results from all fresh (not stored) samples taken during the project. It shows that only SRF conifer stem wood met the standards for either the A1 or I3 standards in all samples. Some SRF poplar stem samples also met both standards, but more than half of the samples tested contained too much cadmium, an element which is of environmental concern. Cadmium levels were also too high in the SRC willow samples to meet the I3 standard and most samples were too high in nitrogen. Most Miscanthus samples contained too much chlorine to meet the I3 standards, while some also contained too much sulfur.

At first glance, these results could be interpreted as suggesting that the UK bioenergy sector would be best placed to focus on developing supplies of cleaner long or short rotation forestry wood pellets. While this is, and should continue to be, an important source of biomass, research commissioned by the ETI's Bioenergy Programme has highlighted the potential for energy crops to make a significant contribution to UK biomass feedstock supplies and deliver wider environmental benefits such as increased soil carbon sequestration. In addition, the use of Miscanthus and SRC willow in commercial applications today shows that, when managed well, these feedstocks can be used successfully. However, to broaden the appeal of these feedstocks in energy applications it is important to consider whether there are ways to improve and homogenise the characteristics of different feedstocks through blending, pre-processing, or adapting conversion technologies.

Table 2
Comparison of all fresh feedstock samples against two wood pellet standards

Property Class	Reference standard	A1	I3	Miscanthus		Willow SRC		Poplar SRF		Conifer SRF	
Origin/ source (permitted feedstocks)	ISO 17225-1	Stemwood Chemically untreated wood residues	Forest, plantation, virgin wood. By-products and residues from wood processing industry. Chemically untreated wood residues.	A1	I3	A1	I3	A1	I3	A1	I3
Nitrogen %wt. (dry)	ISO 16948	≤0.3	≤0.6					Stems	Stems	Stem wood	Stem wood: bark
Sulfur %wt. (dry)	ISO 16994	≤0.04	≤0.05			Stems	Stems	Stems: tops with no leaves	Stems: tops with no leaves		Stem wood: bark
Chlorine %wt. (dry)	ISO 16994	≤0.02	≤0.1				Stems	Stems	Stems	Stem wood	
Arsenic mg/kg (dry)	ISO 16968	≤1	≤2								
Cadmium mg/kg (dry)	ISO 16968	≤0.5	≤ 1					Stems	Stems		
Chromium mg/kg (dry)	ISO 16968	≤10	≤15								
Copper mg/kg (dry)	ISO 16968	≤10	≤20					Stems: tops with no leaves			
Lead mg/kg (dry)	ISO 16968	≤10	≤20								
Mercury mg/kg (dry)	ISO 16968	≤0.1	≤0.1								
Nickel mg/kg (dry)	ISO 16968	≤10				Stems		Stems; tops			
Zinc mg/kg (dry)	ISO 16968	≤100	≤200				Stems	Stems: tops with no leaves			

Dark green = all samples were lower than selected wood pellet standards;
light green = most samples were lower than wood pellet standards;
orange = some samples were lower that the wood pellet standards but many were above;
red = no samples were lower than selected wood pellet standards.
Where plant parts have been analysed separately, the parts meeting the wood pellet standard are noted.

IMPROVING THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF BIOMASS – WHEN DOES IT ‘PAY’ TO PRE-PROCESS BIOMASS?

TEAB
Techno-Economic Assessment of Biomass pre-processing

The ETI’s Techno-Economic Assessment of Biomass Pre-Processing (TEABPP) project was commissioned to understand the impact that pre-processing technologies could have on UK bioenergy value chains. The project was led by E4tech, working with Process Systems Enterprise (PSE), CMCL Innovations, Imperial College Consultants, Black & Veatch, the University of Sheffield and the University of Leeds. The project set out to assess when it ‘pays’ to pre-process biomass – in other words, under what circumstances can pre-processing reduce costs, lower emissions and/or increase efficiency when considered as part of a whole bioenergy value chain.

Firstly, a detailed literature review and data collection exercise was carried out on current and potential biomass pre-processing and conversion technologies and the impacts they have on, or how their performance is impacted by, feedstock characteristics.

Pre-processing technologies generally have one of two primary purposes:

- Densifying the biomass to reduce transport costs (as haulage limits for biomass are generally based on volume, not weight) and to improve handling.
- Altering the chemical characteristics of the biomass by removing problematic elements from solid biomass or, in the case of pyrolysis, converting the biomass into an oil. In some cases altering the chemical characteristics can improve the grindability of the biomass, which reduces the energy required to grind the biomass before it is fed into a conversion technology.

There are also simple pre-processing steps such as chipping and screening which are used to reduce the size of biomass particles and remove any larger contaminants (such as soil and stones). These simple steps may be the only pre-processing techniques used or the first step in a more complex process.

DENSIFICATION TECHNOLOGIES

Forced drying

The Characterisation of Feedstocks (CoF) project showed that natural drying (seasoning) post-harvesting in the field or forest can reduce the moisture content of biomass feedstocks. If a lower moisture content is needed than can be achieved through natural drying alone, or if another pre-processing step increases the moisture content of the biomass, forced drying is necessary.

Forced drying is a mature commercial technology, often integrated as part of a pelleting process. Two commonly used technologies are:

- Drum dryers – the biomass is fed into a rotating cylinder which is heated directly by hot gases
- Belt dryers – the biomass is spread on a moving perforated conveyor with fans blowing hot gases through the belt to dry the biomass in a continuous process

The cost and greenhouse emissions associated with forced drying are heavily dependent on the fuel used to generate the heat. Belt dryers typically operate at lower temperatures than drum dryers and, when integrated into a wider process (e.g. pelleting) can make use of waste heat sources from elsewhere in the process or use waste biomass materials such as bark (if removed prior to pelleting) to significantly reduce the emissions associated with this process.

Pelleting

Pelleting biomass compresses fine biomass particles into pellets with uniform physical and chemical characteristics. Pelleting biomass reduces downstream transport costs and improves handling. The pelleting process consists of:

- Chipping and screening – This reduces the size of the biomass and removes any oversized particles
- Forced Drying (described above) – This is used to reduce the moisture content to around 10%
- Grinding – Using a hammer mill to reduce the size of the particle to the level required for the pellet die
- Conditioning – Steam is used to soften the lignin in the biomass[24], which aids in binding the particles. The use of steam also destroys pathogens in the biomass which enables imported wood pellets to meet UK phytosanitary rules designed to stop the spread of diseases

24 Lignin is a compound which is a crucial part of the structure of woody biomass

DENSIFICATION TECHNOLOGIES

Continued ›

- **Pelleting** – In a pellet mill, rollers feed the biomass through a pellet die which compresses the biomass into a pellet. Lignin acts as a binder. In lower lignin feedstocks a binder, often starch, is added
- **Cooling** – the pelleting process increases the temperature of the wood. The cooling step is needed to ensure high durability of the pellets.

Pelleting is a mature commercial technology with more than 25 Mt wood pellets consumed globally in 2015[25] in many applications, from large scale power stations to domestic heating systems. Pellets produced in this way are often called 'white wood pellets'. Other types of biomass can be pelleted but are not produced on the same scale as wood pellets.

Steam Explosion

Steam explosion technology is used to create biomass pellets which are dark in colour (sometimes known as "black pellets") and are more energy dense and durable than standard white wood pellets. They are also safer to store and handle because they are less prone to self-heating and produce less dust.

Steam explosion works by treating the biomass with high pressure steam, holding it at a high temperature and pressure before exposing the biomass to atmospheric pressure again. This causes the biomass to 'disintegrate' into smaller particles and the lignin, which binds the pellet, to melt enabling a harder, more tightly bonded pellet to be produced. However, the steam explosion process is energy intensive and generates waste water which must be treated.

Steam explosion technology is used commercially in the production of fibreboard and in the production of ethanol from lignocellulosic biomass, where the aim is to maximise the release of cellulose from the biomass feedstock. The production of black pellets is less common but commercial scale plants are in operation[26], although there are a limited number of market players. Steam explosion technology can be retrofitted to existing white pellet production facilities, so there is potential for the technology to scale up rapidly.

Torrefaction

Torrefaction involves heating (normally chipped) biomass to temperatures between 250 and 300°C in a reduced-oxygen environment. This drives out moisture as well as various volatile low calorific compounds from within the biomass. The resulting product can be sold as chips or ground down and formed into pellets.

Laboratory scale tests have shown torrefied biomass to be hydrophobic (it does not readily absorb water) and, once pelletised, to have a greater energy density than white wood pellets. Trials at commercial facilities indicate that less energy is needed to grind torrefied biomass pellets because of their more brittle properties compared to white wood pellets. This is often seen as a key advantage of torrefied pellets when co-fired in pulverised coal plants. However, the removal of volatile compounds during torrefaction results in an energy loss in the feedstock of between 5% and 20%.

Torrefaction is a developing industry, with several companies worldwide developing pilot and demonstration plants using several different designs. A few commercial scale plants using wood have been commissioned[27]. Torrefying non-woody biomass (straw, Miscanthus) has not been demonstrated commercially.

> **"Laboratory scale tests have shown torrefied biomass to be hydrophobic (it does not readily absorb water) and, once pelletised, to have a greater energy density than white wood pellets."**

25 IEA Bioenergy (2017). Global Wood Pellet Industry and Trade Study 2017 [online]. Available at: http://task40.ieabioenergy.com/wp-content/uploads/2013/09/IEA-Wood-Pellet-Study_final-2017-06.pdf

26 Such as the plant operated by Valmet and Zilkha. http://www.valmet.com/media/articles/biofuels-and-biomaterials/introducing-valmet-black-pellet-plant/

27 Including New Biomass Holding (2017): http://newbiomass.com/

TECHNOLOGIES TO ALTER THE CHEMICAL CHARACTERISTICS OF THE BIOMASS

Water washing

The purpose of washing biomass in water is to remove surface contamination and encourage the leeching of problematic species such as metals and halides which are associated with slagging, fouling and corrosion of boilers.

Prior to washing, the biomass is screened to remove stones and large particles of soil and, if necessary, chipped. Other simple pre-processing steps may be added to remove larger contaminants, for example removing pieces of metal by passing the biomass through a magnetic drum. The biomass is then added to the washing machine where it is mixed with water. The temperature of the water, the residence time and the level of agitation can be adjusted depending on the type of biomass used and the quality of biomass required. For example, washing at higher temperatures has been shown to increase removal efficiency.

Washing increases the moisture content of the feedstock and a forced drying step is required to reduce this back down to a level suitable for the end user. Allowing the biomass to dry naturally is not recommended as storing wet biomass poses an increased fire risk and there is a higher likelihood of degradation during storage. Another drawback of water washing is the waste water treatment burden it creates, with phosphate and sulphate levels two of the limits that will need to be monitored and managed.

The value of water washing is a trade-off between the downstream benefits of improved biomass quality and the added costs of washing and then drying the biomass. Therefore, water washing is more likely to be an economic pre-processing step for more contaminated feedstocks, such as waste wood, and/or feedstocks high in ash and alkali metals.

Water washing of biomass for the energy industry has not yet been demonstrated at a commercial scale, but research by the University of Leeds[28] has demonstrated, at lab-scale, the potential for water washing to reduce levels of contaminants in waste wood feedstocks and reduce variability between samples (creating a more homogenous feedstock). Commercial-scale water washing machinery is used in the agricultural industry to wash potatoes and sugar beet. If this can be successfully adapted for biomass, water washing could be deployed at a commercial scale relatively rapidly.

Chemical washing

Chemical washing is a similar process to water washing but with the addition of more expensive chemical treatments, followed by a final water washing step. Like water washing, it has not been demonstrated at a commercial scale, but lab experiments have indicated that adding ammonium acetate ($NH_4CH_3CO_2$) followed by hydrochloric acid (HCl) could remove more alkali metals and other problematic species than water washing alone[29]. However, the addition of chemicals will alter the pH and increase the contaminant loading in the waste water, requiring further treatment steps before it is safe to discharge.

The extent to which chemical, as opposed to water, washing is developed commercially will be dependent on whether there is a commercial premium for the product, over and above water washed biomass.

Pyrolysis

Pyrolysis is a thermal degradation process in the absence of oxygen which produces three products – a biochar (charcoal), a syngas (a mixture of carbon monoxide, hydrogen and other gases) and a bio-oil. The relative proportions of each component can be adjusted by altering conditions in the reactor. The use of pyrolysis products for energy applications typically focuses on production of a combustible gas or bio-oil[30]. As a pre-processing technique for heat and power applications, pyrolysis has the benefit of producing a dense, liquid product. However, it is an expensive process and there is a substantial efficiency loss. Bio-oil can be used as a heating fuel although this is not widespread. Bio-oil is acidic (pH 2-3) which means additional safety measures are required during handling and storage. It is also not a stable liquid and is prone to phase separation, particularly with changes in temperature. There is interest in upgrading bio-oil for use in transport fuels but the feasibility of this is still being researched at the pre-commercial scale.

28 Gudka B; Jones JM; Lea-Langton AR; Williams A; Saddawi A (2016) A review of the mitigation of deposition and emission problems during biomass combustion through washing pre-treatment. Journal of the Energy Institute, 89 (2), pp. 159-171. https://doi.org/10.1016/j.joei.2015.02.007
Gudka, B. Pre-treatment of waste wood via washing and the use of an additive to optimise fuel properties. Presentation available at: https://irp-cdn.multiscreensite.com/57706d10/files/uploaded/B%20Gudka%2C%20Leeds%2C%20Leeds%2C%2027-06-17.pdf

29 Now available – Review and Benchmarking Report: http://www.eti.co.uk/programmes/bioenergy?size=50&from=0&_type=eti-document&publicOnly=false&query=&programmeName%5B0%5D=Bioenergy#search-block

30 However, syngas can be produced in greater quantities through gasification.

THE TEABPP PROCESS MODEL

The TEABPP model was developed using the techno-economic results from the literature review and data provided by the project participants. It was built in PSE's gPROMS advanced process modelling platform and allows users to construct bioenergy value chains from components within the following libraries: Basics (including biomass and end vectors), Pre-Processing, Storage, Transport and Conversion. It will be available to download for free from the UKERC Energy Data Centre[31] but requires a gPROMS licence[32].

10 case studies were modelled as part of the TEABPP project (Table 3) and the cost (£/MWh), net efficiency and greenhouse gas emissions of those chains with and without pre-processing steps were compared. Each chain was analysed using Miscanthus, SRC willow and SRF. Figure 8 provides an example of one chain and its base case results chart. Sensitivity analysis was carried out around the 200+ parameters in each chain.

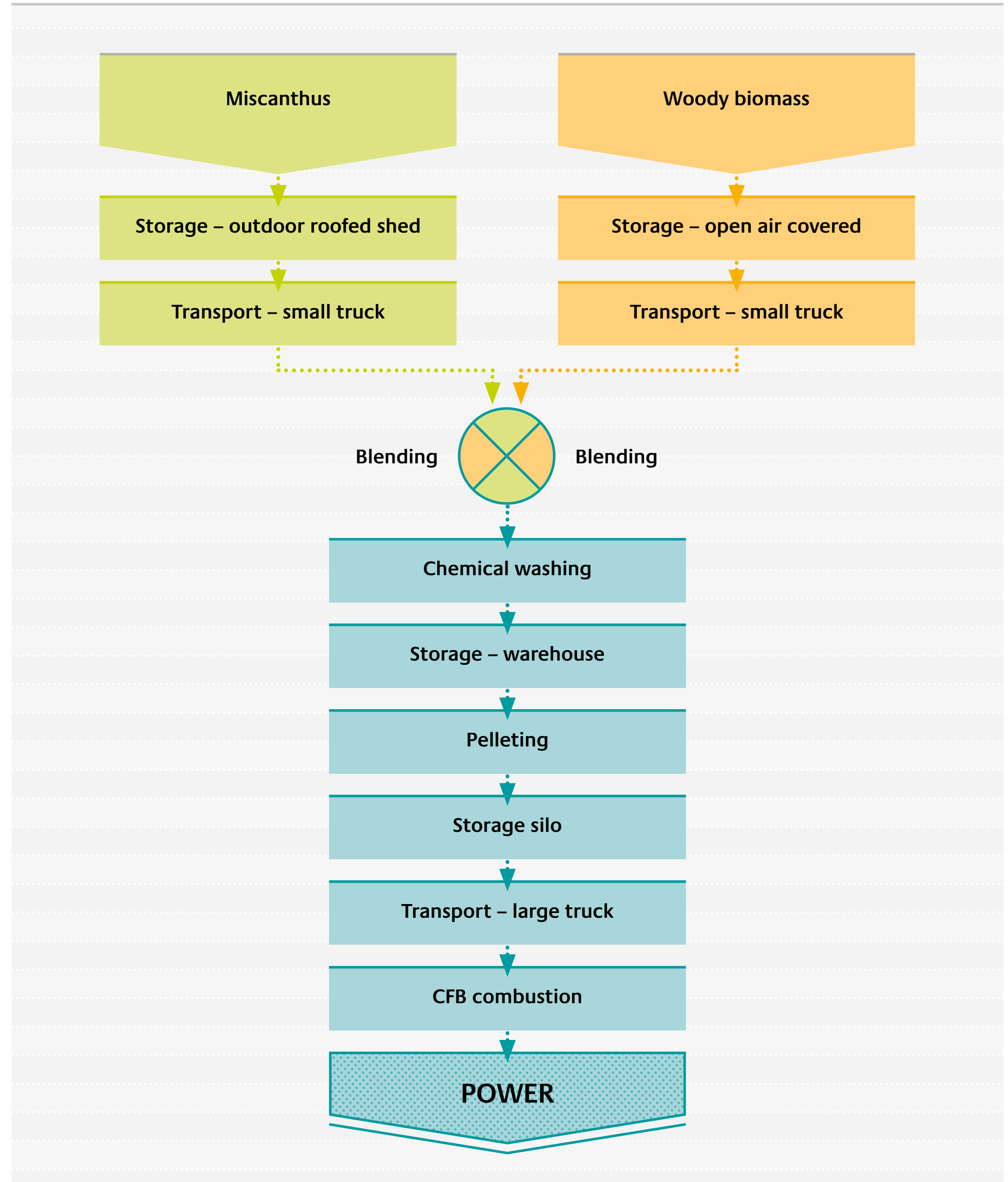
Table 3
Description of the 10 chains analysed in the TEABPP project

Chain	Pre-processing	Storage step(s)	Blending point	Conversion technology	End vector
1	Screening	Shed	At conversion	Underfeed stoker combustion boiler	Heat
2	Screening + field wash	Shed	At conversion		Heat
3	Screening	Shed/tarpaulin	At conversion	Bubbling fluidised bed (BFB) gasifier + syngas engine	Power
4	Water wash + pellet	Shed/tarpaulin, warehouse	At pre-processing		Power
5	Screening	Shed/tarpaulin, warehouse	At pre-processing	Circulating fluidised bed (CFB) combustion + steam turbine	Power
6	Pelleting	Shed/tarpaulin, silo	At pre-processing		Power
7	Chemical wash + pellet	Shed/tarpaulin, warehouse, silo	At pre-processing		Power
8	Pelleting	Shed/tarpaulin, silo	At pre-processing	Entrained Flow (EF) gasifier + syngas CCGT	Power
9	Torrefy + pellet	Shed/tarpaulin, silo	At pre-processing		Power
10	Pyrolysis	Shed/tarpaulin, tank	At pre-processing		Power

31 Available later this year

32 Process Systems Enterprise (PSE): https://www.psenterprise.com/products/gproms

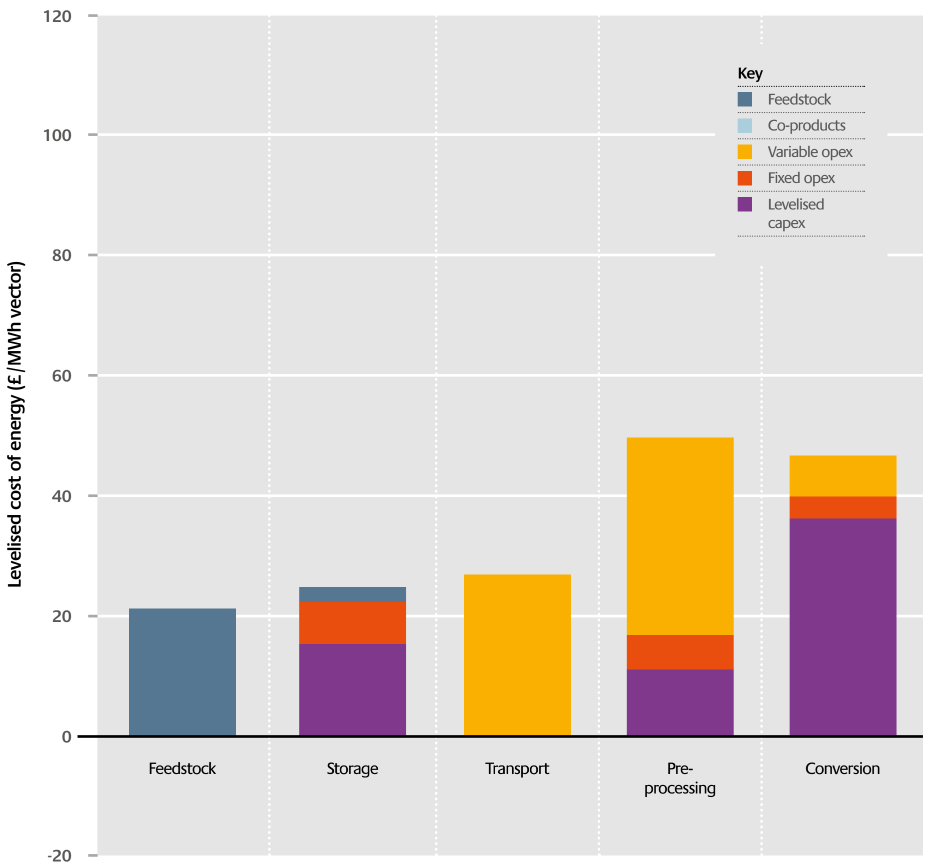
Figure 8.1
Examples of a bioenergy value chain modelled in the TEABPP gPROMS platform



THE TEABPP PROCESS MODEL

Continued ›

Figure 8.2
Results chart showing the breakdown of levelised cost of energy (£/MWh) by stage



WATER WASHING MAY BE AN EFFECTIVE MEANS OF REMOVING CONTAMINATION

The model results from the TEABPP project did not highlight many clear circumstances under which pre-processing would reduce the costs or emissions of the bioenergy value chains considered. Most cross-over points (the point at which it would be cheaper to include a pre-processing step than not) came when the transport distance following pelleting (or torrefaction + pelleting) was extended to several hundred kilometres. Whilst this shows that densification is cost-effective for imported biomass, purely from a transport cost basis it does not appear to be cost-effective for biomass grown and transported within the UK. However, densification also improves the handling and storage properties of biomass and these additional benefits make it a preferred choice in several applications, such as domestic boilers.

Whilst the headline modelling results didn't appear to demonstrate the value of pre-processing UK-grown biomass, taking a closer look at the results from the modelling did provide some interesting insights. The results flagged that in most of the 10 chains modelled, the end conversion technologies would have to operate with feedstocks which have characteristics outside of their normal operating range. The TEABPP model showed that only water washing, chemical washing and pyrolysis could clean the biomass sufficiently (or produce a sufficiently clean bio-oil in the case of pyrolysis) to operate within the normal ranges of the conversion technology. While there are several industry examples of the problems heavily contaminated feedstocks can cause with slagging and fouling, the exact relationship between the level of a biomass contaminant and its impact on efficiency/availability is not well defined, meaning that the benefits of pre-processing biomass to remove particular species may be undervalued in these chains. Ensuring biomass characteristics sit within the normal operating range may also be a requirement of the conversion technology manufacturer in order for end users to retain their performance and/or lifetime guarantees.

SUMMARY AND FUTURE WORK

The Characterisation of Feedstocks project has generated valuable data on the composition of UK-grown feedstocks and their provenance. Some findings from the project corroborated existing knowledge and practice but others, such as the impact of storage type on Miscanthus bale quality, challenge existing assumptions and warrant further research. The testing of Miscanthus pellets also highlights the potential for the pelleting process to unintentionally affect the composition of the pellets, with potentially detrimental impacts on a downstream conversion technology.

The comparison of feedstocks against existing criteria for woody biomass highlights areas where the chemical composition of feedstocks may be problematic for end users. These could be areas of focus for future breeding programmes or pre-processing technologies.

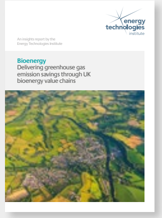
The TEABPP project developed a process model which uses best available data to model bioenergy value chains with and without pre-processing. Whilst the model results from the TEABPP project did not highlight many clear circumstances in the UK under which pre-processing would reduce the costs of the bioenergy value chains considered, it did show that most conversion technologies would have to operate with feedstocks characteristics outside of their normal operating range if using Miscanthus, SRC willow or SRF. The TEABPP model showed that only water washing, chemical washing and pyrolysis could clean the biomass sufficiently (or produce a sufficiently clean bio-oil in the case of pyrolysis) to operate within the normal ranges of the conversion technology.

Neither chemical nor water washing of biomass have been demonstrated at commercial scale but the University of Leeds' research has shown promising results for water washing at a lab-scale. If water washing can be successfully commercially demonstrated this is likely to be a more cost-effective option than chemical washing as it requires fewer inputs and has a lower waste water treatment burden.

The TEABPP project focused on assessing the value of pre-processing in creating cleaner, more homogenous feedstocks from UK-grown second generation energy crops, for conversion technologies to manage. In future, the scope of this research could be broadened to look at other biomass feedstocks, in particular waste wood feedstocks which are likely to be more contaminated. Another area for further research would be to look at the other side of this question – could improvements to conversion technologies make them better able to manage more contaminated, variable feedstocks? Would this be more cost-effective than a pre-processing step?

> “Some findings from the project corroborated existing knowledge and practice but others, such as the impact of storage type on Miscanthus bale quality, challenge existing assumptions and warrant further research.”

FURTHER READING



Delivering GHG savings through UK bioenergy value chains

Bioenergy Crops in the UK – Case studies report and perspective

Land use perspective

All of these reports are available via the dedicated insights report page of the ETI website – www.eti.co.uk/insights

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Hannah Evans was part of the ETI's Bioenergy team from 2014-2017.

At the end of 2017 Hannah was part of the ETI's strategic analysis function which transferred to the Energy Systems Catapult. As part of the transfer, the team provides consultancy services as a project partner to the ETI as it completes its portfolio of energy innovation projects and analysis.

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