An Assessment of Food Waste Management Options for the University of Leeds: A Living Lab Approach

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Executive Summary

This report assesses the feasibility of the University of Leeds utilising food and other biologically derived waste for on-site treatment. This was carried out with a goal to reduce the high costs of waste collection, bring about environmental improvements and facilitate campus-wide, interdisciplinary research, teaching and outreach, in-keeping with 'living lab' concept. This report has been split into 3 parts; Part A discusses the characteristics of annual waste resources at the University, Part B examines a range of technologies that can be implemented to treat waste and discusses their credentials and likely environmental, social and economic impact in a scenario analysis. Part C develops recommendations regarding the treatment of food waste on campus and provides information for the University regarding the logistics for implementation.

Volumes of food waste being segregated and collected from campus have been estimated at 122 tonnes per annum. This waste stream is presently collected by Olleco, who transport the waste offsite to an anaerobic digestion (AD) facility ~20 miles away. Additionally, green waste collected by Estates has been estimated to total approximately 610 tonnes per annum and is currently not being utilised. Furthermore, seasonality in both waste streams was identified as a potential problem for the on-site treatment of waste as there is substantial variation throughout the year.

Through extensive literature searches 3 technologies were deemed most suitable for the application on the University campus, these were AD, composting and desiccation. The latter providing more of a pre-treatment step for food waste, as opposed to a single treatment technology, as this method dehydrates and homogenises the waste reducing its volume by 80%. The three technologies were utilised in a scenario analysis whereby the business as usual (BAU) approach (the current contract with Olleco), BAU with desiccation (Scenario 1), on-site anaerobic digestion (Scenario 2) and on-site composting (Scenario 3) were individually analysed in terms of their economic viability, environmental impacts and relevant social considerations. The scenario analysis allowed for the most feasible and sustainable approach to be identified in the context of the University.

From an environmental perspective Scenario 2 showed to have the lowest associated greenhouse gas emissions if the AD was to be situated at the Bardon Grange site, owned by the
University in Weetwood. If green waste (grass) was to be co-digested with the food waste there is potential to substantially enhance the emissions savings.

When considering financial factors, Scenario 1 had the lowest pay-back time of 2 years due to the low cost of the desiccator unit and the reduction in necessary food waste collections from a decreased waste weight of 80%. Scenarios 2 and 3 incurred higher initial investment fees and subsequently longer pay-back times. Additionally, BAU was found to do well with regards to low environmental impact and low financial burden predominantly due to economies of scale, however, it does not allow for social benefit or inclusion in the Food Waste Living Lab.

It is recommended that the University continue with the Olleco contract whereby segregated food waste is transported to an offsite anaerobic digester in the short term (next 5 years), whilst pursuing the implementation of a small-scale, research sized AD unit which the Engineering Faculty currently hold in storage. The running of a pilot AD will allow for social aspects of the living lab to be satisfied whilst providing opportunity to scope out the technical feasibility of scaling up onsite AD at a later date. A potential significant barrier to the progression of this strategy however, is in finding a suitable location to house the pilot AD and this would need to be addressed in the first instance.

Additional recommendations refer to the inclusion of behavioural and demand side changes to the remit of the Food Waste Living Lab. Not only will this reduce the environmental impact of the University’s food waste, it will also widen participation and social engagement with the project. It was also ascertained that improvements in food waste separation schemes in the halls of residences, could in theory, lead to an additional 83.5 tonnes of food waste per annum being moved from general waste to food waste collections. This could save the University almost £7000 per year, due to reduced costs of food waste collection compared to general waste. There would also be notable environmental benefits to this, as food waste is anaerobically digested locally and general waste is incinerated in overseas in Rotterdam and Oslo. Further research recommendations include conducting a full-scale life cycle assessment on the different waste management options available as data availability was limited for this project.

Acknowledgments

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Mike Leonard, James Wright and Chris Davenport. Thanks also to the Sustainability Services for their support in the development of this project, as well as the various University departments who provided information and shared their knowledge on this topic.

Nomenclature

ABP    Animal by-products
ABPR   Animal By-Product Regulation
AD     Anaerobic Digestion
AHVLA  Animal Health and Veterinary Laboratories Agency
AWM    Associated Waste Management Ltd (external contractors)
BAU    Business as usual
BMP    Bio-methane potential
C/N ratio Carbon/Nitrogen Ratio
CO₂    Carbon dioxide
DEFRA  Department for Environment, Food and Rural Affairs
EA     Environment Agency
FW     Food Waste
GHG    Greenhouse Gases
GHGE   Greenhouse gas emissions
GW     Green Waste
HRT    Hydraulic Retention Time
IVC    In-vessel composting
kWh    Kilo watt hours
Mpg    Miles per gallon
N₂O    Nitrous Oxide
NOx    Nitrogen Oxides
PAS100 Publically available specification for producing quality compost
PAS110 Publically available specification for producing quality digestate
RHI    Renewable heat incentive
SU     Student’s Union
1. Introduction

The magnitude of global food waste (FW) generation is reaching astounding levels. In 2013 it was estimated by the Food and Agriculture organisation (FAO) that 1.3 gigatonnes of edible food is wasted annually - accounting for over 20% of all domestic agriculture production. The associated greenhouse gas emissions (GHGE) for this wastage is estimated to be equivalent to 3.3 gigatonnes of CO$_2$, placing food wastage as the third highest emitter of GHGs after USA and China (FAO 2013). Not going unnoticed, the need for action addressing FW has been highlighted by the UN as a key stepping stone towards achieving sustainable development (UNEP 2011; Fenwick 2017).

Within the UK specifically, over 10 million tonnes of FW is generated each year (WRAP, 2017). This accounts for almost a quarter of the all of the food that is sold (41 million tonnes sold/post farm) and has an associated GHGEs equivalent to 20 million tonnes of CO$_2$ being released to the atmosphere (WRAP, 2017). Nine percent of this FW comes from the hospitality and food service (Figure 1)- bracketing the catering services provided by institutional organisations such as universities and hospitals. However, within university organisations, it is worth noting that self-catered halls of residences are regarded as household waste whereby 70% of UK FW originates from. There is therefore, an opportunity for institutions like the University of Leeds (UoL) to develop innovative solutions to treat the FW generated on campus, in the most sustainable way to reduce the associated negative environmental impacts.
1.1 The Concept of the Living Lab for Food Waste

The living lab is a research concept that revolves around its’ users and actors. It is centred on innovation and involves cooperation and collaboration between actors within a virtual ‘laboratory’ platform. In the Context of the UoL, the ‘Living Lab for FW’ has been initiated by the Sustainability Services to develop a network of academics, staff and students who will work on innovative and experimental solutions to deal with the large volumes of FW produced on campus, as well as resource recovery strategies which will improve sustainability at the University. Here different perspectives and areas of expertise can be combined to create broader and more comprehensive research findings on FW, through communication and collaboration.

1.2 Report Aims

The aim of this report is to recommend a feasible and ‘sustainable’ strategy which the UoL can implement to deal with the FW generated on campus. This report will take the form of three parts; Part A will provide a resource assessment of the waste streams identified at the University, Part B assesses three technologies which can be used to treat the waste on site and...
will examine several possible waste management scenarios that could be adopted. Thirdly, Part C will introduce the recommended approach for the University, based on the findings from Parts A and B and will provide details of the regulations that must be followed for implementation, facility and site considerations and further recommendations with regards to increasing the sustainability of the University’s waste management strategy.

The findings and discussion of this report were the result of an extensive desk-based literature search and through discussions and interviews with staff at the UoL Facilities Directorate, Estates, Cleaning and Catering Services, academics and external waste management contractors AWM.

PART A

2. RESOURCE ASSESSMENT

2.1 Introduction

This section of the report provides an assessment of the waste resources generated at the University based on information collated from the estates department and operational teams. Data was limited for some aspects of this assessment; therefore, several assumptions have been made. Where applicable these assumptions are explained and it is recommended that for accuracy future research is conducted to generate a larger dataset.
2.2 Waste Streams

The Schematic in Figure 2 highlights two relevant waste streams at the UoL and their predominant sources. The majority of segregated FW on campus is generated by The Refectory and food outlets on site, but it can also be sourced in large volumes from the catered Halls of Residence Devonshire Hall, and the self-catered accommodation at Central Village.

The green waste (GW) stream on campus includes both grass cuttings and woody waste and is sourced from the University grounds and green spaces. GW is an additional waste stream that should be considered for this project as it is possible that some of this waste stream can be utilised and combined with the FW for optimum use in the technology we are proposing be used in Part B of this report.

2.3 Volumes

Data regarding specific waste volumes is currently limited, however due to a recent change in the waste management contract with external stakeholders AWM, we were only able to obtain FW weight data for the whole campus for the months of July, August and September 2017. The contract is scheduled to continue until 2022, therefore long-term waste generation data...
should be accessible at a later date. Data over this time period should be requested, so that accurate annual food waste production quantities are known.

Similarly, there is currently no recorded data for the GW generated, therefore the data shown below has been estimated by the estates team and is highly speculative. A future scoping study should be conducted to precisely quantify GW generation.

Using the data currently available, Figure 3 is an indication of the averages assumed for the volumes of FW and GW generated on campus. It can be observed that the University produces approximately 122 tonnes of FW per year from The Refectory, cafeterias on campus and the halls of residences, where FW is segregated at source. Moreover, approximately 606 tonnes of grass waste and 10 tonnes of wood waste are produced in green-spaces on campus and at Weetwood sports fields.

![Total waste mix](image)

*Figure 3 - Average green waste and FW mix generated at the University per annum*

**The Refectory and Cafeterias**

A large proportion of the University's waste is generated from plate waste at The Refectory canteen, serving 3 meals a day. The Refectory is the largest and most frequented cafeteria on campus with gross sales of £2.04 million, serving on average 3,500 covers a day and creating
approximately 50 tonnes of FW a year. The waste is separated at source by The Refectory staff, whereby plate scrapings and kitchen preparation waste are added to food caddies before being placed in dedicated FW wheelie bins outside.

In addition to The Refectory, there are a large number of cafeterias located around campus, often situated within each faculty building. FW generated here is typically segregated by staff and added to the same food bins as The Refectory waste. In total, the refectory and cafeterias produce an average of 111 tonnes per annum (when taking an average monthly FW production between July and September, 2017)

Halls of Residences

![Halls of residence food waste production](chart)

Figure 4 - Average annual FW generation and potential production in all on-campus halls of residences

**Devonshire Hall**

Devonshire Hall is a 355-person capacity catered accommodation, producing on average 5 tonnes of FW per annum (Figure 4). At this site the FW is separated from general waste by kitchen staff and added to specific FW bins provided by the external contractors Olleco (similar scheme as The Refectory).
Central Village

Central village is a 979-person capacity self-catered accommodation which produced 5.68 tonnes of FW across the academic year of 2016/2017 (Figure 4) which accounts for 4% of the total waste produced onsite. FW bins are provided in shared apartments on an opt-in basis, therefore segregation is optional. The students themselves are responsible for taking the FW down to a communal FW bin. Around 10% of students in this accommodation will participate in FW segregation.

This optional FW segregation scheme was chosen for Central Village ahead of the other Halls of Residences as it has the greatest volume of FW per head. This is thought to be due to the large proportion of International students who are perceived to cook more frequently with fresh produce than Domestic students.

Charles Morris Hall and Henry Price

Charles Morris and Henry Price Halls are also self-catered accommodation, where waste collection is provided for by the University facilities. Segregated FW is not collected at these sites however, due to economic and social barriers. Assuming that 4% of the general waste could be separated and collected as FW (as with Central Village), then, as shown in Figure 4 Charles Morris Hall and Henry Price residences could produce approximately 2.251 and 0.991 tonnes of segregated waste per year, respectively. This would increase the volume of FW being collected by external contractors by 3.2 tonnes per annum and thus decreases the amount of waste being sent for incineration with general collections.

Campus Grounds and Sports Fields

The University sports fields are located off the main campus site, in the suburb of Weetwood and consist of approximately 40.5 hectares of grass. Within the central campus, it has been estimated that there is approximately 10 hectares of grass. Both locations include a large number of trees and shrubs. Combined, they both produce on average 605 tonnes of grass
cuttings and 10 tonnes of wood waste. The wood waste is chipped and transported to Bardon Grange (next to the sports fields) where it is composted.

2.4 Seasonality

![Food waste produced at the Refectory annually](image1)  
*Figure 5 - Annual variation in FW generation at the University Refectory*

![Food waste produced at central village annually](image2)  
*Figure 6 - Annual variation in FW generation at Central Village (self-catered) accommodation*
Data gathered has shown significant seasonality in the volumes of waste generated throughout the academic year and this can be observed in Figures 5-7.

Food Waste

It can be seen in Figures 6 and 7 that FW production in both of the halls of residences is highly seasonal, peaking during term time whilst values fall during academic holidays when students typically return home. In Figure 6 no FW has been recorded at Central Village during the summer months, however a small volume is still recorded at Devonshire Hall (Figure 7) as this accommodation is often utilised over the summer period when large conferences have been organised. Additionally, a large spike in FW production can be observed at Central Village in December (Figure 6) when an annual ‘deep cleaning’ service is conducted by cleaning staff after the students have left for the Christmas holidays (1/3 of annual volume).

Green Waste

There is a significant proportion of GW generated during spring and summer months when trees, shrubs and grasses are cut back from the green spaces on campus. The volume of GW therefore declines during autumn and winter months; however, the generation of woody waste remains constant throughout the year.
2.5 Current Waste Management Strategy

The University outsources some of its waste management and has started a new 5-year contract with AWM in July of 2017. This contract involves the separate collection of FW at several locations by Olleco, who provide resource recovery solutions for food service businesses and organisations.

In locations where FW is not collected separately, it is included in general waste collections, where the waste is transported for incineration with energy recovery. A quarter of the waste is processed locally by The Multifuel Energy Ltd company at the FM1 site in Ferry Bridge, (approximately 21 miles away). The remaining waste is shipped to incineration sites in Oslo and Rotterdam, incurring higher associated transport emissions.

Food outlets in the Students Union

The Leeds Student Union (SU) is classed as a separate business to the UoL and rents the union building space from the University itself, therefore is subject to its own policies regarding the collection and management of waste generated from the food outlets within.

The SU also has an existing contract with AWM but have chosen to implement source segregation of specific waste streams using recycling bins located across the Union building. Most FW generated in the SU is being directed by Olleco to their AD facilities. Staff at the SU expressed intent to purchase a composting unit that will be located at the delivery entrance to the SU, where source segregated FW can be treated (although no official date has been given). Further to this, the SU have expressed that they are happy for proposed composter to be used for research and outreach, in-line with the living lab initiative.

Olleco

Olleco have provided the University with dedicated FW bins which are collected from various locations on campus, on scheduled collection dates twice a week. Once collected, the FW is taken to an anaerobic digestion plant in South Milford where the waste is used to generate a renewable form of electricity and fertiliser. The fertiliser is sold to local farmers as a replacement to chemical fertilisers and the electricity is used to convert used vegetable oil to
biodiesel. Most of this biodiesel is sold to the transport sector, but some is used to power Olleco's trucks used for waste collection. This biodiesel improves the efficiency of the vehicles, raising average mile per gallon from as low as 3 to around 14mpg (NYU, 2016). The production of biodiesel results in two further by-products; bio-heating oil and glycerol. Bio-heating oil is used to heat boilers and glycerol is sold to cosmetic companies.

2.6 Composition of Waste

In order to obtain an approximate understanding of campus FW composition, a FW gathering exercise took place at The Refectory on January 11th 2017. Subsequent analysis of the FW reported a moisture content of approximately 84%\(^1\), with a volatile matter of 84% (dry-basis) (Table 1 and 2). Proximate analysis of grass waste collected from the UoL campus can also be found in Table 1.

Biomethane potential (BMP) tests (Figure 8) were completed on collected FW samples as scoping exercise to assess the potential methane yields from University FW. Further, desiccated FW obtained from Eco-Sphere Intelligent Technologies Ltd (see Table 2 for proximate analysis) to investigate the applicability of desiccation as a pre-treatment step for end-use in anaerobic digestion. The feasibility of combined processing of University grass waste and FW under a co-digestion regime was also assessed. Results indicate that sole digestion of 100% FW without pre-treatment would enable the highest relative methane production (478 m\(^3\)/tonne VS) when compared to desiccated FW (436 m\(^3\)/tonne VS), a co-digestion of desiccated FW and grass waste (365 m\(^3\)/tonne VS for 50:50 mix), or a co-digestion of FW and grass waste (403 m\(^3\)/tonne VS for 50:50 mix). However, the production of methane from desiccated FW indicates that it would be possible to utilise a desiccation unit as a means of pre-treatment and storage. Literature demonstrating this is extremely limited and as such these BMP tests can increase stakeholder confidence in the performance of desiccated FW in an anaerobic digester. Additionally, co-digestion can be seen to still produce significant quantities of biomethane in each case, highlighting that opportunities are available to the University for combined processing of its food and grass waste streams.

\(^1\) This is the assumed moisture content where a value is required elsewhere in this report.
Figure 8 – Biomethane potential results for FW, desiccated FW and co-digestion experiments with grass.

<table>
<thead>
<tr>
<th>Table 1 - Composition of University FW and grass waste</th>
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<tbody>
<tr>
<td><strong>Proximate (wt%)</strong></td>
</tr>
<tr>
<td>Moisture</td>
</tr>
<tr>
<td>Volatile Matter (dry-basis)</td>
</tr>
<tr>
<td>Fixed Carbon (dry-basis)</td>
</tr>
<tr>
<td>Ash (dry-basis)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2 - Composition of Desiccated FW (Obtained from Dr. Andrew Ross – Leeds University)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proximate (wt%)</strong></td>
</tr>
<tr>
<td>Volatile Matter (dry-basis)</td>
</tr>
<tr>
<td>Fixed Carbon (dry-basis)</td>
</tr>
<tr>
<td>Ash (dry-basis)</td>
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</tbody>
</table>
PART B

3. TECHNOLOGY

3.1 Introduction

At present, there are two technologies available to the University for treating FW on campus, these are anaerobic digestion (AD) and composting. An additional technology known as desiccation could be used as a pre-treatment option and can be combined with both AD and composting or used prior to the collection of waste by external contractors to reduce the weight and volume of collections.

How each technology works in treating FW will be discussed in further detail in this chapter and will also include an explanation of the resulting by-products, the benefits of these systems and their relative limitations. Additionally, a range of waste management scenarios have been developed for the purpose of identifying the most sustainable strategy for the University to deal with FW.

3.2 Anaerobic Digestion (AD)

Anaerobic digestion (AD) is a biochemical conversion process found to occur abundantly in the natural world. It is a process through which certain micro-organisms are able fuel their own growth; as it progresses, complex organic matter is degraded to simpler chemical species. The chemical species produced through AD have many useful real-world applications. This has led to replication of AD in controlled mechanised units, allowing for collection and use of the product streams.

A key condition of AD, is that it can only occur in oxygen free environments. Under anaerobic conditions, the complex microbial community required for AD can convert organic matter into two distinct products – biogas and digestate (Figure 9).

Biogas

Biogas is a gas phase product comprised of roughly 60% methane and 40% carbon dioxide - trace quantities of other gases also present (see below). It can be used to produce heat (using a
biogas boiler), and/or electricity with a combined heat and electricity (CHP) unit. Several pre-treatment steps can also be performed on biogas prior to use - some more necessary than others. Carbon dioxide adds no benefit to the use of biogas as a fuel and can be scrubbed and removed, increasing the percentage of methane in the end product. This adds the benefits of increased calorific value (energy density) of the fuel and can upgrade the gas to 'biomethane' quality. Biomethane can be connected up to and injected into the national gas grid, bringing with it financial incentives. Trace quantities of Hydrogen Sulphide (H₂S) are also present within biogas, a chemical which is corrosive to components of boilers and engines. This can also be removed through a separate pre-treatment step.

Digestate

Digestate is a product stream comprised of both a solid and liquid phase. The liquid fraction of digestate can be used as an alternative to commercial fertiliser whilst the solid portion is useful as a soil enhancer. Various post-AD processing steps can be performed on each phase of the digestate, through which factors such as nutrient value and rate of utilisation within soil can be manipulated. An added benefit of AD, given waste streams are used as a feedstock, is that each product can be used in place of fossil fuel derived alternatives - contributing to a reduced carbon footprint.

Figure 9 - The anaerobic digestion process (GLW Energy, 2017)
AD Operation

There are various operating conditions that can influence biogas yields including feedstock: particle size, system moisture content and homogeneity. Moreover, packaging must be separated from the FW and it must be ensured that there are no contaminants in the FW mixture; especially contaminants such as antibiotics (which can be present in animal manure, as this can be detrimental to the microbial community within AD and can result in the requirement of the entire system being emptied and restarted.

A consideration must also be made to the type of organic material used within AD as a feedstock. Unlike composting, AD is not suited to processing woody biomass (lignocellulosic material). However, green wastes such as grasses and straws can be used. FW is also a feedstock well suited to AD. The mixing of feedstocks such as GW and FW is a practice known as ‘co-digestion’; this can produce favourable conditions for optimal biogas production (Fulford, 2015). Mixing feedstocks alters the carbon to nitrogen ratio (C/N ratio) of material entering the AD, and can be tuned to ensure that the feedstock is of a C/N ratio of around 25-30:1 – which is the optimal region for the AD process (Yen, 2001).

Process Parameters (Considerations for Operators)

There are several key process parameters that are fundamental to the operation of a successful AD unit. It is therefore beneficial to have knowledgeable operator(s) on-site with a degree of understanding of the AD process that can interpret adverse readings from unit instrumentation.

AD can be successfully run at three distinct temperature regions of operation: cryophilic, mesophilic and thermophilic – through which different microbial communities drive the pathway of biochemical reactions outlined above. Cryophilic denotes operating the AD process at around 15°C or lower, this region has a lower rate of gas production than the other operating regions and is not typically selected as the target system temperature in most scenarios. Thermophilic is the highest temperature region that AD can be run in, around 55°C - this enables the highest rate of gas production but does pose a greater risk of the digester undergoing acidification. More parasitic energy (using biogas to generate process heat) is inherently required for the thermophilic region that the mesophilic region due to higher operating temperature. The mesophilic operating region can be optimally run at approximately 35°C. The
AD process will cease to run at temperatures over 73°C (Ward et al., 2008; Batstone and Jensen, 2011; Fulford, 2015).

A sudden shift in system temperature of more than 5°C in over a 24h period can cause the AD system to acidify (meaning the methane producing microorganisms temporarily cease to function). This can cause a build-up of volatile fatty acids (VFAs) in the system and can potentially lead to the unit turning permanently 'sour'. The AD process is naturally buffering i.e. it can 'self-correct' changes in pH. However, if an accumulation of VFAs causes the pH to drop below around 5.75, this buffering capability can be inhibited and the system can be turned permanently acidic. This occurs as the optimal system pH is close to 7 or slightly above (neutral or slightly alkali). Methane producing microorganisms are completely inhibited at a pH below 5.75. Acidic AD systems can be extremely difficult to rectify and often the best course of action is to carry out a complete flush of the unit and start the system from afresh (Batstone and Jensen, 2011; Fulford, 2015).

Other notable parameters of concern include the retention time of matter within the AD. Retention time refers to the average amount of time matter spends inside a digester unit. Organic matter must spend sufficient time within a digester to be converted to biogas. For example, a continuous 200 litre digester – fed 10 litres of feedstock per day – will retain material for an average of 20 days (if 10 litres of matter is fed into a continuous digester, then 10 litres of matter will be emitted from the exit pipe). Alternatively, for digesters operated in batches, the retention time will be equal to the time between filling a batch digester it being emptied.

Retention time is a parameter that will be specified upon the design of an AD unit, and as such an operator should be aware how much matter must be fed on average into a digester each day. Operators should also be aware that feed material must be macerated to a suitable particle size upon entry to the main digester unit. Commercially available small-medium scale AD units typically include a maceration unit as part of the digester system. Though, if malfunction occurs – it is possible that feed material will not be of an optimal particle size for the anaerobic process to occur.

Matter fed into the digester must also be of a suitable moisture content. AD can be run either as 'wet' or 'dry' digestion. Wet digestion refers to feed material being of approximately 15% dry matter or less, whereas dry digestion is operated at 15-40% moisture (Ward et al., 2008). Operators will need to be aware of the desired moisture region specified in the AD design and
whether a purchased unit supplies necessary fresh water to dilute matter or if this must be manually performed.

Depending on the simplicity of an AD unit, a mixing system may be present within the digester. Gentle and/or periodic mixing increases the contact between anaerobic microbes and feed material – promoting gas production; vigorous mixing however can have detrimental effects through excessively disturbing microbial communities (Kaparaju et al., 2008). Mixing can also assist with heat transfer within the digester and prevent the build-up of scum which can form on the top of slurry. Scum formation can be detrimental to the AD process if a mixer fails. Dried scum can prevent biogas exiting slurry and can result in system acidification. As such an operator would need to be vigilant of mixer failure.

An additional area of concern includes the adverse effects of toxins within a digester. Any material designed to kill bacteria can stop an AD functioning. This includes disinfectants, antibiotics and some cleaning agents. Operators will need to assess the feed material supply chain to determine whether the digester could be at risk of coming into contact with these substances. Methane producing microbes are the most sensitive to toxins within the digester; even if small quantities are present, these microbes may be killed. More resilient acid forming microbes will then generate excess VFAs - creating another scenario in which the digester will turn sour (Banks and Stringfellow, 2002; Banks et al. 2008).

It may be beneficial for operators to be aware of the various instrumentation used within digesters. A topic which in itself is extremely diverse and complex – as such detailed explanations have been omitted from this report. Extensive literature and training courses are available should this be deemed necessary.

3.3 Composting

Composting is the term given to the aiding of the natural process of decaying biological waste (aerobic digestion) and is a relatively simple process. In composting, bacteria and worms breakdown the organic material, with the aid of oxygen and water in a process that produces carbon dioxide and a nutrient rich soil (humus). Water, air and worms can be added to speed up the process when choosing to compost FW. The composting process can be carried out in open windrows whereby heaps of waste are turned regularly and systematically, or in closed vessels, also known as In-Vessel Composting (IVC). Whilst AD has the option for energy
generation as the resulting bio-gas can be collected and used for heat and/or electricity, this is not feasible with a composting system and any gases emitted from the process are lost. During the composting process, odour is often a problem from a social perspective and may lead to an increase in vermin.

There are a wide range of suitable feedstocks available for a composting system and typically any FW (including meat products) and GW (including lingo-cellulosic biomass) can be used, thus contamination is of little concern. A smaller particle size is preferable as this helps to speed up the process, but is not essential. Homogeneity is also not a concern with composting, therefore pre-treatment is often not necessary for this process and it is somewhat easier and quicker to use than an AD might be.

**Compost**

Composting creates a high quality fertiliser from its' feedstocks, as the minerals and nutrients from the original material are retained and condensed, as moisture is lost and CO₂ is emitted. When compared to digestate from AD, nitrogen content in compost is typically more than double that of digestate per tonne, whereas compost contains around 7x more phosphates, 4x more potash, more than 8x more Sulphur and 34x more magnesium (WRAP, 2016). Although, AD produces considerably more fertiliser than composting does (Selincourt, 2008; Dhar, 2016), and even though compost is too nutrient rich for soil to take up all the nutrients within it (Selincourt, 2008), composting produces considerably more fertiliser of a higher quality than that of digestate from AD. As a result, composting has more environmental mitigation potential than AD when solely considering substitution with chemical fertilisers.

Composting also sequesters a large amount of carbon. Approximately 60% of the original carbon content of the composted food is lost in the first 6 months. A further 30% of the original carbon content of the feedstock is then lost over the course of 100 years (Selincourt, 2008). As over 50% of the University's food content was found, upon analysis, to be carbon and that 1 Kg of carbon is converted into 3.67 Kg of CO₂, the short-term carbon sequestration that is evident with composting is incredibly significant and even the long-term sequestration of 10% is important regarding GHGE levels of different technologies. Moreover, due to the high carbon content of compost, it can help amend eroding soil, potentially reversing a net trend of carbon being emitted from soil into the environment, to carbon being sequestered into the soil (Selincourt, 2008).
3.4 Desiccation

Desiccation (also referred to as dehydration), is the process of removing water contained within a substance to produce a product with a low moisture content. In the context of foodstuffs, this is frequently performed within units that apply a combination of thermal and/or mechanical action. Desiccation is an established technology in the food industry for producing edible products. However, recent developments in waste management techniques have brought forward the consideration of the technology as a possibly effective tool for managing FW. As a result, a diverse range of FW orientated commercial desiccation units are now available.

Operating strategies of these units can vary significantly. Most units typically deal with batches of FW ranging from 50kg – 500kg per day and operate through the application of heat to a rotary drum or mechanised screw unit. Water and some volatile matter contained within FW evaporates out of the main process compartment, where it passes through a condenser and is disposed of via a connected drainage pipe. Each cycle (dependant on manufacturer and moisture contained within the given batch of FW), can last anywhere from 5-20 hours. Some units support the addition of FW during operation. In such cases the FW is typically added to an intermediate storage compartment; from which the unit passes FW into treatment compartment as appropriate.

Units typically require around 2-4kW of power, with larger energy requirements at the beginning of each cycle. Whether desiccators operate at their upper bound of power consumption is heavily dependent on the presence of heat recovery systems within a given unit – this can vary significantly between suppliers. A distinct difference has also been found to exist between units regarding water consumption. Some desiccators require a fresh water supply during operation whereas others do not.

Several key benefits can arise from the use of desiccation for handling FW:

- FW can be reduced in size and volume by up to 90%, reducing disposal costs and GHG emissions in its transportation.
- Desiccated FW has a high calorific value, leading to opportunities as a potential animal feed, fuel source for combustion or anaerobic digestion (with the re-addition of some moisture after transportation).
  - It can alternatively be used directly as a soil amendment.
- Pathogen content of waste can be dramatically reduced to trace levels.
- Odour of the FW is eliminated, mitigating vermin issues during storage for disposal.

If stored appropriately desiccated FW can feasibly be stored for months at a time, dramatically reducing the frequency of waste collection. However, care must be taken to ensure that appropriate moisture-tight storage containers are used. Desiccators used previously at an institutional level have had issues with fungus growth where moisture has migrated into stored waste; this could also lead to the re-introduction of pathogens.

3.5 Scenario Analysis

As discussed in Chapter 3.1, there are several approaches that the University can take in terms of treating the FW generated on campus. From a technological perspective, it is clear that AD would be the most beneficial choice as it would allow for the generation of heat and/or electricity and the utilisation of digestate to replace inorganic fertiliser use. It is however, important to consider additional opportunities and challenges associated with all the technological approaches, therefore four distinct FW management scenarios have been developed (as well as a ‘Business as Usual’ scenario) as an analysis tool and will be discussed in further detail within this chapter (Table 3).

Table 3 - Chosen FW treatment scenarios for analysis and what they will involve

<table>
<thead>
<tr>
<th>Description:</th>
<th>BAU</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintain current contracts with Olleco (FW collected for offsite AD)</td>
<td>Maintain current contracts with Olleco + desiccation pretreatment onsite</td>
<td>AD of FW onsite</td>
<td>Composting of FW onsite</td>
<td></td>
</tr>
</tbody>
</table>

Scenario 1 represents BAU with the addition of desiccation at source and acts as a potential improved version of the existing waste management plan. Scenario 2 and 3 however, represent decentralised waste management approaches and include the anaerobic digestion of FW onsite.
and the composting of FW onsite. It should be noted however, that the existing waste management contract that the University has in place with AWM will need to be adhered to for the next 5 years, therefore scenarios 2 and 3 of this study are hypothetical representations of waste management routes that could be taken if the University were no longer bound by external contracts.

For a scenario to be deemed most 'sustainable' it is necessary for the approach to satisfy all three of the fundamental pillars of sustainability (economic, social and environmental) without significant trade-offs (Fig. 10). In theory, for any FW management approach to be recommended, it should not only be cost effective to implement but should not negatively impact the environment or society.

![Components of a sustainable strategy](image)

*Figure 10 - Components of a sustainable strategy*

### 3.5.1 Business as Usual (BAU)

As discussed previously the University has existing contracts with external stakeholders AWM and Olleco for dealing with the FW generated on campus. In this ‘business as usual’ scenario it is assumed that these contracts remain in place for both the contractual 5-year period and is extended thereafter so that FW is collected and taken offsite to an AD facility in South Milford.
An average transportation distance from the University campus to the AD facility of 20 miles has been assumed for this assessment (Fig.11). Additionally, it has been assumed based on information gathered from interviews, that the vehicles transporting the waste have an 8 tonne carrying capacity.

Figure 11 - Possible transport route between UoL and Olleco AD facility (Source: Google Maps).

Economics

The current practice of FW collection by Olleco and transportation to an AD facility costs the University £90 per tonne, which is seemingly more expensive than the landfill gate fees when comparing figures in Table 4. However, this gate fee of £86.10 per tonne of waste does not include the cost of collection and transportation, therefore Olleco and AD is likely to be a more cost-effective strategy when all aspects are considered.

Table 4 - Costs associated with both landfill disposal of waste and collection AD by Olleco

<table>
<thead>
<tr>
<th></th>
<th>Landfill Gate Fees</th>
<th>Olleco (AD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
<td>£86.10 per tonne</td>
<td>£90 per tonne</td>
</tr>
<tr>
<td></td>
<td>(standard rate)</td>
<td></td>
</tr>
</tbody>
</table>

Assuming that the University produced 122 tonnes of FW per year, annual FW collection will cost approximately £11,000 with Olleco. As collection rates are based on the weight of the
waste, the annual fees are relatively high, predominately due to the reported high moisture content of FW.

**Environmental Impacts**

The BAU scenario appears to do well at reducing the negative environmental impacts of FW when compared to landfill, particularly so when assessing potential CO\textsubscript{2} emissions from transportation of waste from campus to the AD facility in South Milford. Not only do Olleco try to ensure that their chosen routes from collection to AD are the shortest possible in order to reduce road emissions, the company use a fleet of vehicles powered by bio-diesel they produce themselves from waste cooking oil collected from the service sector. As this form of biofuel is produced from a waste product rather than first generation fuel crops there is the added benefit of avoided GHG emissions from land use change (Gui et al., 2008). The encouragement of a market for waste cooking oil will help to reduce the likelihood of illegal disposal into drains (Kulkarni and Dalai, 2006). It should be taken into consideration that, a fraction of the energy produced from the AD of the University's FW goes to producing the biodiesel used by the vehicles, potentially reducing the positive environmental credentials of this scenario somewhat. However, this current practice is avoiding GHG emissions associated with landfill and incineration.

If the digestate produced by the AD process is used as a replacement for inorganic/chemical fertilisers, it has the ability to offset the GHGEs associated with their production and use (WRAP, 2017). Furthermore, as Olleco sell this digestate this contributes to the circular economy and creates a product from food which would otherwise be wasted (Olleco, 2017).

Taking a whole systems approach, the current contract with Olleco contributes towards the development of a circular economy, whereby waste is recovered and utilised in the production of energy, bio-diesel and organic fertiliser which can all be put back on the market for re-use. In this instance, it can therefore be assumed that the current FW management contracts at the UoL are more of an environmentally friendly route to take than traditional approaches of sending waste to landfill but also more sustainable than if AD was to be used solely for the generation of heat and power.
Social Considerations

A significant benefit to this scenario is that under a BAU approach the University does not have to invest time or money into ensuring all the relevant regulations regarding FW and animal by-products are being followed as the waste is treated offsite by an external company. One of the unique selling points to Olleco is that they ensure as an intermediary that the AD facilities used are regularly and thoroughly audited for compliance with waste regulations so that this burden of responsibility is taken away from the client. Additionally, an annual 'Waste Duty of Care' certificate is awarded to Olleco customers along with monthly recycling data breakdowns sent electronically to clients so they can assess changes to their waste volumes, which takes much of the initial complexity out of the picture for the University.

The BAU scenario doesn’t however, offer the opportunity for student engagement or potential for research and teaching as it involves external/offsite treatment of the FWs. Therefore, whilst it can be assumed that the existing contract is quite sustainable from an environmental perspective, the trade-off of social engagement does not lend itself to collaboration between departments at the University which is a key component of the development of the Living Lab for FW.
Table 5 - Summarised advantages and disadvantages of the 'Business as Usual' approach

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>➢ Easy and reliable approach</td>
<td>➢ Would not allow for the development of the FW living lab</td>
</tr>
<tr>
<td>➢ Regulations and legislation criteria met and taken care of by Olleco</td>
<td>➢ Lack of research and teaching opportunities</td>
</tr>
<tr>
<td>➢ Olleco provide monthly, electronic recycling data breakdowns</td>
<td>➢ Lack of innovation from the University</td>
</tr>
<tr>
<td>➢ The University receive an annual Waste Duty of Care certificate from Olleco</td>
<td></td>
</tr>
<tr>
<td>➢ AD facility can process packaging</td>
<td></td>
</tr>
<tr>
<td>➢ Contributing to circular economy</td>
<td></td>
</tr>
<tr>
<td>➢ Olleco produce their own biodiesel from waste oil which fuels their collection vehicles.</td>
<td></td>
</tr>
<tr>
<td>➢ GHG emission reductions from cleaner collection vehicles and CO₂ savings from avoiding landfill.</td>
<td></td>
</tr>
</tbody>
</table>

3.5.2 Scenario 1- BAU with desiccation as a pre-treatment

Scenario 1 involves a continuation of the existing waste management contract and FW collection by Olleco explained in the BAU scenario with the addition of on-site desiccation of FW. The main purpose of using desiccation as a pre-treatment is to remove the water fraction of the FW (which can account for up to 80% of the total weight) and will significantly reduce the volume and weight of the waste collected.

This scenario requires the use of an industrial FW desiccator similar to those implemented in large catering kitchens. It may involve either plate scrapings to be placed in a regular FW caddy before being taken to the desiccator, or if located within the kitchen itself, plate scrapings could be added to the desiccator directly. During the desiccation process, the FW is macerated so that the particle size is substantially reduced, after which dehydration occurs to separate the liquid fraction from the solid waste. The liquid is then drained off while the resulting solid waste can be added to a sealable container and stored until collection by Olleco.
Economics

Theoretically, combining desiccation as a pre-treatment process with a continuation of the existing waste management contract should allow the University to reduce the volume and weight of the FW being collected by Olleco and thus the opportunity for economic savings from a reduced number of waste collections required. However, the current contract with Olleco stipulates that at a minimum, collection be once every two weeks.

On average the University produces 122 tonnes of FW per year and the current cost of waste collection is £90/tonne. Assuming that the moisture content of the University's FW is around 84%, the removal of water through desiccation has the potential to reduce the cost of FW collection substantially, by over £9,000 per annum. Due to such a large reduction in total fees payable to Olleco, it can be assumed that as it stands large scale desiccation of FW would not be accepted within the bounds of the contractual agreement. Furthermore, as Olleco have yet to receive desiccated FW from any of their customers, it would be unfair to assume they would be willing to take large amounts of treated waste from the University without a trial period with small volumes of waste (50kg advised). For desiccation to be included in future waste management strategies it is essential that contractual agreements be re-negotiated, therefore there is a level of uncertainty in predicating how much this pre-treatment technology could save the University in waste collection fees.

Preliminary quotations for a suitably sized FW desiccator have been in the region of approximately £17,000. Energy usage of desiccators fluctuates significantly between suppliers. However, utilising the lowest energy consumption found to be possible during a cycle at 0.29 kWh/kg FW (Somat, 2017), it can be assumed that the minimum electrical consumption of a unit would be over 35,000 kWh per annum to process current volumes of FW. Current electricity prices are approximately £0.15/kWh, desiccation would therefore incur operating costs at a minimum of £5,250 per annum. Average electricity consumption from suppliers contacted could however result in operating costs of £9100 per annum - effectively negating any benefits gained in reduced transportation fees. It would therefore be essential that the university thoroughly scrutinised the energy efficiency of a desiccation appliance before purchase.

Due to the large variation in energy usage and need for further quotations from desiccator suppliers, it is difficult to predict the expected financial gains from implementing a unit within the University. Therefore, no expected pay-back time has been provided. Should the decision
be made to investigate on-site desiccation further, it is recommended that food samples are sent to suppliers and accurate estimates of annual energy consumption of various units requested.

*Environmental Impacts*

The environmental benefits of the BAU scenario, in terms of reduced transport emissions and the AD of FW, are all applicable for this scenario. When desiccating FW, there is potential to substantially reduce the number of collections required by Olleco if the waste was to be stored on site, which would improve the efficiency of the scenario and reduce associated transport emissions. Where concerns should be raised however, are when you factor in the amount of energy that is required to run a desiccation unit to treat the volume of FW that is generated at the University.

When taking into consideration that the likely minimum energy consumption required for total desiccation of the University's food waste (35,000kWh/annum), calculations for the equivalent associated GHGEs indicate there is a net increase of 11.25 tonnes of CO$_2$ equivalent per annum, assuming an average of 0.527kgCO$_2$/kWh mains electricity (Carbon Independent, 2007). This figure is likely to be higher if you are to consider the emissions that are associated with the production of the desiccation unit as well as the treatment that will be required on the process waste water that is deposited down drains. Further, resultant CO$_2$ emissions from desiccator energy consumption will almost certainly be greater than the minimum value assumed; this can be observed in the large variation of possible emissions found to occur between various desiccation suppliers (Figure 12).

Despite it not being possible to store desiccated FW on campus for prolonged amounts of time due to waste regulations and for health and safety reasons, in theory even if waste was stored so that only 3 annual collections were needed, there would only be an additional saving of 0.76 tonnes CO$_2$ equivalent per annum, meaning scenario 1 would still lead to 10.49 additional tonnes of CO$_2$ being emitted annually.
Social Implications

The use of a desiccator in combination with the current contracts with Olleco, will allow for some principles of the Living Lab to be satisfied. It is likely that small volumes of FW could be kept a side for research purposes and the desiccator unit itself may be used as a research tool for inter-disciplinary learning.

An additional benefit of desiccation is the likelihood that the process will help to reduce odour, which would allow for longer storage without negatively impacting student and staff experiences on campus. The reduction in odour is thought to also reduce vermin related issues.

Table 6 - Summarised advantages and disadvantages associated with Scenario 1

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to store waste longer</td>
<td>High energy consumption from desiccation</td>
</tr>
<tr>
<td>Reduce volume and weight of waste</td>
<td>Water likely to be re-added at AD site</td>
</tr>
<tr>
<td>Reduced number of collections and associated transport emissions</td>
<td>Low moisture may become a problem for AD process at the facility</td>
</tr>
<tr>
<td>Potential to reduce odour and vermin issues</td>
<td>Likely to require re-negotiation of contracts</td>
</tr>
</tbody>
</table>
3.5.3 Scenario 2- Anaerobic Digestion

Scenario 2 represents onsite AD of FW and would require a discontinuation of the contract with Olleco. FW would need to be segregated at source to avoid any contamination of the AD process, before being transported to the location of the onsite installation. It should be noted that previous attempts have been made to install an AD unit onsite, however there was some difficulty at the time in finding a site that could feasibly house the technology.

For the purpose of this scenario analysis, it has been assumed that the AD facility would be situated at University owned Bardon Grange, approximately 4 miles from the central campus, in the suburb of Weetwood. This has been assumed as the site has space and land available to comfortably house an AD unit and store the digestate produced and allows for calculations to be made regarding transport emissions which will feed into the scenario analysis. Bardon Grange is also in close proximity to the University sports fields where it has been assumed the digestate could be spread to replace the need for inorganic fertilisers. Furthermore, the bio-gas produced from the AD process could be used to heat the greenhouses on site.

Feedstock Considerations

Food Waste
It is important to consider the condition the FW is in prior to feeding it into the digester. Large scale AD facilities such as Olleco have de-packing facilities capable of removing food packaging and foreign objects from organic feedstock (e.g. Cutlery). Should an AD unit be built for on-site FW management, an extensive de-packing facility will not be financially viable. The bulk of FW already undergoes a form of 'screening' and segregation through kitchen operators disposing of plate scrapings in the refectory. However, careful consideration would need to be made with regards to FW collected from halls of residences; whereby, non-organic waste may be placed into FW bins more frequently.
Seasonality in quantities of FW will also need to be taken into consideration. The hydraulic retention time (HRT) specified in the design of the AD will denote the need for a consistent feeding regime of FW to the digester. If on-site AD is selected as a waste management route, it may be more appropriate for the university to size and purchase an AD capable of having access to the necessary quantities of FW all year round – with excess FW sent for off site management or stored in a suitable condition onsite (e.g. desiccated).

**Green Waste**

Alternative opportunities are available to the University if infrastructure were developed to also utilise its GW in an AD facility through co-digestion. Preliminary tests on the University's FW have highlighted that lower methane yields would be possible per tonne through a mixture of FW and GW (see section 2.6). Although, considering the mass quantities of waste grass generated annually (approx. 600 tonnes), the absolute quantity of methane that the University could produce with an AD would increase dramatically. This could address the issue of seasonality in FW as sports fields are primarily cut more during the summer months (when a drop in FW can occur). Issues would still arise during the Christmas period; however, it is possible that this would be a short-enough period for the AD to handle – further investigation would be required. The University could seek to utilise its grass waste to either make up for the decline in FW generated during summer months, or purchase an AD that could process all FW and GW (combined approx. 720 tonnes p/a). It may be possible to address the seasonality in grass generated through ensiling excess grass obtained during the summer months for use AD processing in the winter. Although, a greater capital expenditure would be required for an AD that could also process green waste, increasing financial risk of an on-site management facility. This would however enable greater long-term financial gains.

**Digestate**

Utilisation of digestate generated through AD could have significant financial savings for the University, as well as reductions in the GHGE associated with current levels of fertiliser usage. The liquid phase of digestate could be used as an alternative to fertiliser currently used on sports field; the current annual costs of which is approximately £16,000. However, the degree to which in-organic fertiliser could be replaced with digestate is subject to further investigation, as direct use of digestate as a fertiliser can be considered to be of low quality (Dhar, 2016).
This could be addressed through further treatment of the digestate prior to use, including the composting of digestate to improve the nutrient balance.

Opportunities for selling digestate to external sources may be limited. Upon the last digestate products summary by WRAP (2012), the market for waste derived digestate products was found to still be in its infancy.

In terms of volume of digestate that would be produced onsite, a volume approximately equal to the volume of feedstock fed into the digester will be produced – with its mass reduced by roughly 15% (WRAP, 2012).

 Macronutrients present within the digestate will most likely be in the region as follows (NNFCC, 2012):

- Nitrogen: 2.3 - 4.2 kg/tonne
- Phosphorus: 0.2 - 1.5 kg/tonne
- Potassium: 1.3 - 5.2 kg/tonne

All nitrogen, phosphorus and potassium present within the feedstock will be present within the digestate. As such, future work should conduct a detailed analysis on FW samples to obtain more accurate estimates for the nutrient balance of university produced digestate. The nutrient balance of digestate can be altered with enhancement technologies; a thorough descriptions are outlined by WRAP (2012). It is possible that co-composting digestate with the University's woody waste would present a low-cost option for digestate enhancement. Many of the more advanced enhancement technologies are still at research level, and only proven at laboratory scale.

*Energy Use*

For effective implementation of a decentralised AD facility, it is essential that an appropriate use for biogas is specified. As discussed, it is possible to scrub biogas of most CO₂ and produce biomethane – this can subsequently be injected into the gas grid in exchange for financial incentives or used in biogas powered vehicles. However, installation of scrubbing systems requires an increased initial investment in additional process units.

Lower initial investments are required if a direct use for biogas can be located. If combined heat and power were installed at the university (at a cost of ~£19300 for a unit sized for AD of
university generated FW), approximately 13,100 kWh of electricity per annum and 34,900 kWh of heat per annum could be generated in a 100% FW system\(^2\).

Alternatively, the installation of a biogas boiler would require a lower initial investment of ~£14000 (for a 33 kWth boiler). This option would also provide a more efficient means of energy production than with CHP and enable the generation of 70,700 kWh of heat output per annum. Hot water produced could be used for domestic heating in offices or contribute to the heating of standalone university facilities requiring large heat input\(^3\).

**Economics**

The initial capital cost of an AD unit large enough to treat the University campus FW would likely reside in the range of £170,000 - £240,000 (based upon preliminary enquiries for quotations). Factors such as the purchase of a biogas boiler vs CHP unit, a pasteuriser and the sizing of the AD unit to handle all/some FW will affect the end purchase price.

If all FW is to be sent to an onsite AD, then 70,700 kWh of heat could be generated if a biogas boiler only unit was selected. This generation would allow the university to be eligible for renewable heat incentive (RHI) payments. Based upon current RHI payment brackets for small biogas fixtures at £0.0288 per kWh thermal, the university could receive an annual RHI in the region of ~£1870 (Ofgem, 2017). Furthermore, with current energy prices at approximately £0.15/kWh, approximately £9,750 in energy payments could be avoided each year\(^4\).

These energy savings would be in conjunction with savings made from avoided FW removal fees, which currently are approximately £11,000 per annum. Total effective annual financial gain would therefore be in the region of £22,600. This excludes any costs associated with transportation of waste, hiring an operator to oversee and manage the AD and any other peripheral costs. Any financial gain possible from digestate usage as fertiliser on university sports fields is also excluded; this is due to the degree of uncertainty surrounding the nutrient balance expected from the digestate and whether a pre-treatment facility (resulting in further initial investment) would be required.

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\(^2\) Assuming all 122.3 tonnes of FW is sent to AD, BMP results are accurate at 478 m\(^3\)/tonne VS, moisture values are representative of typical FW at the university and a 3kW electrical 8kW heat CHP unit is installed requiring 3m\(^3\) biogas per hour (CouchPerryWilkes, 2016)

\(^3\) Assumptions are as above. Further assumptions include: biogas produced has been assumed to be 60% methane, a biogas boiler with an efficiency of 90% will be installed and the AD unit will have a parasitic energy load of 8%.

\(^4\) When using the same assumptions as in footnote 3.
A large degree of uncertainty surrounds the implementation of an on-site AD, however upon the values stated above, a pay-back time of approximately 10 years could be expected. Based upon the preliminary BMP studies outlined in section 2.6, additional opportunities are available to the university if utilisation of its GW was also pursued with an on-site AD. Grass waste generated at UoL was estimated to be in the region of 600 tonnes per annum as opposed to the 122 tonnes of FW. This would obviously incur a dramatic increase in the initial capital investment required for an AD facility, but could also enable much larger financial gains from increased energy savings and RHI payments. Should the University decide to investigate large-scale co-digestion further, additional study would be required to more accurately determine grass waste generation and the feasibility of a much larger on-site AD operation.

**Environmental Impacts**

Transport emissions are estimated to be lower than those calculated for the BAU scenario due to the shorter distances incurred from using an onsite AD. Furthermore, as AD will produce a replacement to chemical fertiliser and compost, the University will no longer have to have this transported to site from an external producer, thus transport emissions are reduced here too. The digestate produced is also of environmental benefit as it does not involve harmful chemicals (WRAP, 2016). Moreover, the vehicle that would be used for transporting the food waste from the University to Bardon Grange could potentially be converted so that it runs on used vegetable oil produced by the University. If there was a sufficient amount of waste vegetable oil produced by the University, this could greatly decrease transport emissions further (Altin et al., 2001).

In this scenario, all the energy generated by the AD can be used at the University for either heating water or for CHP. Therefore, avoiding GHG emissions associated with the production of electricity from the National Grid which often involves the burning of fossil fuels.

A key benefit to Scenario 2 is that there is potential to utilise the GW generated on campus in the AD system through co-digestion with FW. This should have environmental benefits as this waste stream is not being wasted or allowed to decompose on its own.

An additional point to be noted, is that to treat the FW on site in an AD facility, environmental permits and exemptions must be applied for before installation and operation can begin. Furthermore, as the FW on campus will include meat and dairy products, stringent criteria must be met for the treatment of FW under the Animal By-Product Regulation (see
Chapter 3.7). These regulations ensure the removal of pathogens and reduce the negative impact they may have on human health and the environment. As currently Olleco and AWM ensure these criteria and regulations are adhered to, the additional responsibility that this scenario places on the University may be seen as a further barrier to implementation.

**Social Implications**

Potential social barriers to an AD installation may include lack of support or concern from local communities with regards to the chosen location of the plant. It is therefore important that the University state their intent and communicate with the public early on in the process so that potential concerns can be addressed and resolved. Similarly, planning permission has been a roadblock for progression in establishing an AD system in the past and this could still be an issue if a site is not located away from the listed buildings and conservation zones on site.

Other social implications may include the potential odour that may be released from the AD system and the health and safety concerns regarding gas handling and risk of explosions. This risk could easily be remedied by limiting activities using the biogas to properly trained staff and ensure thorough risk assessments are carried out regularly. It will also be necessary to identify members of staff who can incorporate the maintenance and operation of the AD into their existing roles as well as staff who will be able to transport and add the feedstock to the unit on a daily basis.

One of the significant benefits to this scenario is that it will provide the University with an innovative technology and system which not only will allow for research and teaching opportunities, it can be used for public engagement and will provide a promotional tool to generate external interest and funding. All of which would fulfil many of the guiding principles of the Living Lab concept.

**Table 7 - Summarised advantages and disadvantages to Scenario 2 approach at Bardon Grange**

<table>
<thead>
<tr>
<th><strong>Pros</strong></th>
<th><strong>Cons</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>➢ Reduced transport emissions as distance from central campus to treatment site are smaller</td>
<td>➢ Economic investment required to set up an AD and associated infrastructure</td>
</tr>
<tr>
<td>➢ Using digestate on sports fields will save money on chemical fertilisers</td>
<td>➢ Planning permission may be a barrier</td>
</tr>
<tr>
<td></td>
<td>➢ Potential periodic odour when feedstock is added</td>
</tr>
</tbody>
</table>
Bio-gas can be used to heat greenhouses or provide hot water which reduces reliance on fossil fuels

Opportunity to develop the living lab and collaborate between departments

Economic Incentives (RHI)

No longer paying for external contractors

The GW generated on campus can be used for co-digestion in AD

University is responsible for meeting regulations and ensuring standards are met and maintained

Seasonality of the feedstocks may become an issue if there is not enough in some months

Who will maintain AD over dates the University is closed?

3.5.4 Scenario 3 - Composting
The third scenario included in this report involves the use of a composting system. FW would need to be segregated at source so that non-organic wastes and packaging are removed and disposed of separately. In terms of plate waste from The Refectory, this could be conducted by kitchen staff, with FW being added to a caddy before being taken to the onsite composter.

Composting systems like the ‘Rocket Composter’ have been installed at several University’s in the UK, and are often situated outside at the back of the kitchens where it is easily accessible for staff. An example unit which the University could seek to implement would be the ‘A1200 Rocket Composter’ from TidyPlanet; this unit can process up to 3500 litres of FW per week, making it suitable for processing all FW generated each week on the University campus. Once the process is complete, organic compost can be taken out of the composter and can be placed into storage or transported directly to the site where it is to be spread.

In theory, this scenario offers a simplistic approach to treating the FW on site as composting feedstock is not restricted to a set particle size or homogeneity and can be mixed with the GW from campus. However, foods with high moisture content (e.g. curry or pasta sauces) may inhibit aerobic digestion and delay the process. Additionally, Universities using the 'Rocket Composter' have observed several technical difficulties over time.
**Economic**
Composting does not produce any energy like the AD system in Scenario 2 does, but instead can use up energy depending on the technology used. This is a key disadvantage economically when comparing with AD technology from Scenario 2, as no financial incentives like the RHI can be utilised.

Economic savings could however be made from reducing or ending waste management contracts with AWM and the cost of a composting unit is significantly less than the investment needed to implement an AD installation. Furthermore, the resulting compost can be used as a replacement to that currently being procured by Estates and if the volume produced was great enough, this product could be sold.

**Environmental**
Transport emissions could be significantly reduced with composting, as waste could be managed on campus. Transport emission reductions would be approximately 6 tonnes of CO$_2$ a year when compared to the BAU scenario (Table 8).

Composting would lead to increases in soil quality including an increased amount of nitrogen and phosphate produced, thus increasing GHGE savings from the substitution of chemical fertilisers. This fertiliser would also not have the level of transport emissions found in currently used fertiliser. Moreover, composting results in an increased level of carbon sequestration when compared to AD, which improves the CO$_2$ mitigation potential of this scenario. This is likely to be most pronounced in the short term, as compost slowly releases CO$_2$ over the course of 100 years. Furthermore, high quality composting technology could improve the composting effectiveness of the GW that is currently left to decompose on a compost heap at Bardon Grange.

Similarly, to Scenario 2, the composting system will be subject to a number of regulations and treatment criteria due to the nature of the feedstock and the inclusion of animal by-products (see Chapter 3.7). This may be seen as a potential barrier to implementing a composting system as treatment regulations can be stringent and complicated.

**Social Implications**
A major limitation to this scenario is that composting is likely to produce an odour as the feedstock is aerobically digested, especially if it is not properly managed. This may be a significant social implication in that it could affect the usability of green and outdoor spaces if
the smell was to become a consistent problem. This could also attract more vermin, an already significant and persistent problem for the campus estates department.

Considering the large amounts of FW that we are proposing this system will have to manage, it is likely that a large volume of usable compost will be generated. It is therefore necessary for the University to consider where this compost can be stored and whether it will need to be transported to this facility.

*Table 8 - Summarised advantages and disadvantages associated with Scenario 3*

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>➢ No transport emissions</td>
<td>➢ No energy can be produced</td>
</tr>
<tr>
<td>➢ Compost produced can be used on University grounds or sold</td>
<td>➢ Potential odour problem</td>
</tr>
<tr>
<td>➢ Carbon sequestration potential?</td>
<td>➢ Potential to increase vermin issues</td>
</tr>
<tr>
<td>➢ All food and GW can be utilised</td>
<td>➢ University responsible for following relevant regulations and ensuring compliance with treatment standards</td>
</tr>
<tr>
<td>➢ Less stringent requirements with feedstocks</td>
<td></td>
</tr>
<tr>
<td>➢ Relatively easy approach</td>
<td></td>
</tr>
</tbody>
</table>
3.6 Discussion
Environmental Comparison

Table 9 - Comparing the climate change mitigation potential of the different scenarios

<table>
<thead>
<tr>
<th></th>
<th>BAU</th>
<th>S1 – Olleco w/ Desiccation</th>
<th>S2 – AD at Bardon Grange</th>
<th>S3 - Composting</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHGEs production factors (tonne CO$_2e$/yr)$^5$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport emissions</td>
<td>5.96</td>
<td>0.93</td>
<td>5.10</td>
<td>0</td>
</tr>
<tr>
<td>Energy usage (treatment)</td>
<td>Parasitic load from AD</td>
<td>16.2 (desiccation) and parasitic load from AD</td>
<td>Parasitic load from AD</td>
<td>Minimal- dependant on composting technique</td>
</tr>
<tr>
<td>GHGEs offsetting factors (tonne CO$_2e$/yr)$^6$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy produced</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertiliser produced</td>
<td>16.04</td>
<td>16.04</td>
<td>16.04</td>
<td>0</td>
</tr>
<tr>
<td>Carbon sequestered Total</td>
<td>-1.85</td>
<td>-1.85</td>
<td>-1.85</td>
<td>-6.14</td>
</tr>
<tr>
<td></td>
<td>-11.93</td>
<td>-0.68</td>
<td>-12.71</td>
<td>-10.13</td>
</tr>
</tbody>
</table>

Table 9 shows that Scenario 2 has the most climate change mitigation potential of all the technologies. The emission savings compared to BAU result from reduced transport emissions, due to treatment taking place closer to campus. If the University powered the FW collection vehicle with waste vegetable oil (Altin et al., 2001), scenario 2 would have significant reductions in transport emissions, when compared to BAU.

$^5$ Positive figures show Carbon released into the atmosphere

$^6$ Negative figures show carbon sequestered from the atmosphere
An additional area where GHGE savings could be increased in Scenario 2 is from utilising grass cuttings for AD, through co-digestion with the FW. As there is ~600 tonnes of grass cuttings produced each year from University grounds. Moreover, the use of digestate as a replacement for chemical fertiliser aides in the reduction of associated transport emissions as Bardon Grange is adjacent to adjacent Weetwood sports fields.

As Table 9 indicates, composting in Scenario 3 is less environmentally friendly when considering potential GHGEs, than both BAU and Scenario 2. Despite producing more useable fertiliser, sequestering more carbon in soil and reducing transport emissions, the inability of this system to produce energy that can be captured and used onsite means that it pales in comparison to AD. Furthermore, some carbon is sequestered with AD, meaning the scenarios using AD would, in reality, have further enhanced environmental mitigation scores. This would make scenario 3 even less competitive, when compared to the other scenarios, regarding GHGEs.

Scenario 1 cannot be justified environmentally, as GHGEs related to the power usage of desiccation significantly outweighs any emissions offset from the reduced transport emissions. Moreover, other environmental issues are associated with desiccation such as the removal of water from the food waste which is disposed of in the drainage system. It is also likely that water will need to be re-added for AD at Olleco's facilities. On the other hand, if the desiccator was to be powered by renewable energy, then desiccation could become environmentally viable, greatly increasing the environmental competitiveness of scenario 1.

It can be seen therefore, that if significant environmental improvements were to be sought from BAU the only viable option to achieve this would be with scenario 2 and the co-digestion of the food and grass waste produced by the University. Conversely, the environmental credentials of Olleco as a whole should be considered (see part A). The environmental benefits of from mitigating water treatment issues from pouring used oil down the drain (Kulkarni and Dalai, 2006), from utilising by-products made from the biodiesel production (Ma and Hanna, 1999) and aversion of land use issues such as deforestation, fertiliser and pesticide use and food verses fuel conflicts related to bioenergy crops (Gui et al., 2008), should be considered.

**Economic Comparison**

With regards to the economic performance of each technology analysed, scenario 1, scenario 2 & BAU can be directly compared, as end processing methods of waste in each of these
involves anaerobic digestion. Summarising the economic investigation of each individual scenario (Figure 13) it can be seen that despite the high initial capital investment required for an on-site AD unit, anaerobic digestion at UoL could pose the lowest cumulative waste management fees over a ten year period. Although it has been highlighted that there is a high degree of uncertainty in a number of economic factors concerning both AD and desiccation. The energy usage of a desiccation unit could be prohibitively higher than the usage assumed in Figure 13; though if assumed values are correct, it can be seen that a desiccation unit would have a vastly more rapid pay-back period than with a successfully, run on-site AD unit. Efforts to obtain an accurate quotation for an A1200 Rocket Composter were not successful at this time. However, estimates for a much smaller unit (A700) are in the region of approximately £18,000.

![Economic Assessment of Food Waste Management Scenarios](Figure 13 - Economic Comparison of BAU, S1 & S2)

**Summary**
To summarise the detailed scenarios analysis outlined above, there are distinct barriers and opportunities associated with the implementation of waste processing technologies at the university itself. The addition of a desiccator to BAU (Scenario 1) would potentially provide
opportunities to decrease the cumulative waste management fees when compared to current practice. Desiccation was also found to require the lowest initial investment out of the available on-site technologies examined. However, it has been highlighted that more detailed information is required from desiccator suppliers to draw definitive conclusions; information such as accurate energy consumption using University FW would be needed.

With regards to the calculated increase in GHGE that would occur through desiccation of University FW, this could be overcome with if UoL were to switch to a green electricity tariff. As mentioned, grid electricity is widely regarded to have emissions of 0.527 kg CO₂ / kWh. However, green electricity tariffs can be considerably more environmentally favourable and regarded as effectively 0 kg CO₂ / kWh, pending choice of supplier. In terms of research potential, the homogenised waste produced during desiccation has been speculated to be useful as both a soil enhancer and as an animal feed; these areas could be investigated further should the University purchase a desiccation unit. Additionally, it was confirmed through performed BMP tests that desiccated University FW is suitable for use in an anaerobic digester. BMP tests also highlighted that considerable methane yields could be generated if Scenario 2 were to be implemented and an on-site anaerobic digester developed at the University.

In terms of innovation and collaborative partnerships, it is likely that an on-site AD (Scenario 2) would generate research opportunities within the University than other scenarios. Resources are also currently available to the University to grow and develop a pilot-scheme AD framework. A pilot-scheme would be able to mitigate some of the risk associated with the large initial capital investment required for a large on-site AD system (see Part C). Future scoping studies may be able to determine the realistic potential for co-digesting the University's FW and green waste. As mentioned, a more thorough resource assessment of grass generation is required. However, should generation be of a similar magnitude to that highlighted in this report, a much more sizeable AD operation may be possible at the University – bringing with it the potential for much greater long term financial returns. Co-digestion aside, it has been demonstrated that with FW alone it may be possible to recover the initial investment in an on-site AD system within approximately ten years – perhaps sooner. When taking into consideration the possible research grants that may accompany a university practising novel urban waste management practise, Scenario 2 could become a significantly more favourable option.
In contrast, the implementation of an on-site composting unit (Scenario 3) would likely not bring with it the same opportunities in terms of revenue streams and potential research grants. AD, as shown, would enable financial incentives such as RHIs, diverted energy (and fertiliser) costs as well complete diversion of waste management gate fees. Whereas composting could only provide the latter plus some degree of revenue stream from compost if a suitable market could be sourced. Composting units such as the 'Rocket Composter' have already been implemented at other Universities nationwide – greater competition would therefore exist for any suitable research grants. Anecdotal evidence has also suggested that these operations have not been successful elsewhere due to frequent system malfunctions – suggesting Scenario 3 would be met with elevated levels of risk associated with any capital investment.

3.7 Regulations and Legislation
Kitchen and catering waste collected on campus would fall under the UK governmental waste code of 200108 and is therefore subject to compliance with several waste regulations and quality protocols outlined in Table 10 and discussed in further detail in this chapter.

In the likelihood of AD (or composting) technologies being implemented on campus to treat the FW generated, then all relevant regulations and protocols in this chapter will need to be followed.

*Table 10 - Regulations and Legislation applicable to activities within the anaerobic digester system for FW. Adapted from CCN Micro AD Phase I Report (2009).*

<table>
<thead>
<tr>
<th>RELEVANT REGULATION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AD sub-activities:</strong></td>
</tr>
</tbody>
</table>
| **Installation of AD system** | • Planning regulation  
• Environmental permitting/Exemption (T25) |
| **Use of FW as feedstock** | • Animal By-Product Regulation (ABPR)  
- EU/National treatment standards |
| **Gas Handling** | • Regulation on Gas Safety |
| **Digestate** | • AD Digestate Quality Protocol  
• PAS110  
• U11 |
| **Composting sub-activities:** |
**Installation of composting system**
- Planning regulation
- Environmental Permitting/Exemption (T23)

**Use of FW as a feedstock**
- Animal By-Product Regulation (ABPR)
  - EU/National treatment standards

**End-use of compost**
- PAS100
- U11

---

**Environmental Permitting Rules**

New Environmental Permitting (EP) rules were introduced in England and Wales in 2010 to regulate activities that may be harmful to the environment and human health. Permits and exemptions would be granted for new installations after the University has registered the AD or composting unit with the Environment Agency (EA). Registration can be carried out online free of charge by providing both technical information and proof of competency in operating the proposed system. At present, there are two schemes that can used for proof of competency when applying for an environmental permit, either through the CIWM/WAMITAB course or the ESA/EU Sector Skills Scheme. It should also be noted that failure to register with the EA could result in prosecution under the Waste Regulations (2011) for England and Wales (Yaman et al, 2013).

Exemptions are granted to small scale AD installations and composting systems where activities and the low risk nature of the feedstocks used, will not pose a threat to the environment or human health (Yaman et al, 2013). The most relevant exemptions for the use of FW in an AD and composting system are the T25 and T23 exemptions, both of which would be applicable to the University.

**T25 Exemption**

The T25 exemption is applicable if AD is conducted at the University using FW and other biodegradable matter as feedstocks. The resulting digestate can be spread on land and biogas can be used for generating electricity, however use of flaring to dispose of biogas is not acceptable. If the FW contains animal by-products, appropriate authorisation from the Animal Health Veterinary Laboratory Agency (AHVLA) must be granted before the waste can be processed.
Additionally, to remain within the exemption rules, it is only appropriate to store and treat up to 50m$^3$ of waste at any one time. Further conditions that must be met include the collection and burning of biogas in an appliance, AD systems are to have a net rated thermal input of less than 0.4MW and that the waste is to be treated within the digester for at least 28 days (DEFRA, 2013).

**T23 Exemption**

The T23 exemption is applicable for aerobic composting of FW in small volumes and for spreading the compost on land afterwards. For the use of kitchen and canteen waste as a feedstock, there is a maximum waste treatment weight of 10 tonnes at any one time and the waste can only be stored up to 7 days prior to treatment. Post-treatment however, the compost can be stored on site for up to 12 months but this would be included in the 10 tonnes weight limit for storage and treatment.

As animal by-products will be present in the catering waste stream, authorisation again, must be granted prior to composting and further approval may need to be sought from the AHVLA.

**Animal By-Product Regulations (ABPR)**

For the treatment of both meat and non-meat FW together in an AD or composting system, the European Animal By-Product Regulation (ABPR) must be followed. The ABPR was established under the AHVLA to ensure that any product originating from animals follows standardised pre-treatments to remove pathogens. This then allows the resulting digestate to be applied to land, ensuring the risk of harm to the environment and human health has been reduced (DEFRA, 2008). Within this regulation, 3 risk categories of ABP waste are stated.

**Category 1**- Wastes in this classification are strictly not allowed to be used as substrate in biogas production as they are ABPs of a ‘Specified Risk Material’ e.g. animals infected with TSE disease, or are catering waste products from means of international transport.

**Category 2**- Includes high risk ABPs and cannot be used as a biogas plant substrate unless they have been rendered to an approved EU pressure-rendering standard of 113 at 3 bar for 20 minutes.
**Category 3**- Catering and kitchen wastes fall within this category along with other low risk ABPs as they would include parts of animals that are fit for human consumption. This waste stream can therefore, be used in an AD system and composting unit, but will be subject to either EU treatment standards or national level hygiene and management regulations.

**EU Treatment Standards**

EU treatment standards are applicable for AD systems, whereby the category 3 waste collected on site must be treated at 70°C for 1 hour with a maximum particle size of 12mm (DEFRA, 2008). While EU treatment standards for composting dictate that only a single composting stage is required within a closed vessel.

**National (UK) Treatment Standards**

These standards are based on a matrix system which reflects relevant risk assessments and provides the minimum standards, specifying the minimum temperature and time of treatment as well as the maximum particle size that can be processed (Table 11). Furthermore, all systems must include the additional barriers outlined below.

---

**Table 1 - National standards for treatment of Category 3 ABP catering waste when using AD and composting systems. Adapted from Defra (2008).**

<table>
<thead>
<tr>
<th>System</th>
<th>Temperature</th>
<th>Min time at temperature</th>
<th>Max particle size</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD</td>
<td>57°C</td>
<td>5 hours</td>
<td>50mm</td>
</tr>
<tr>
<td>AD or Composting (Closed reactor)</td>
<td>70°C</td>
<td>1 hour</td>
<td>60mm</td>
</tr>
<tr>
<td>Composting (Closed reactor)</td>
<td>60°C</td>
<td>2 days</td>
<td>400mm</td>
</tr>
<tr>
<td>Composting (housed windrow)</td>
<td>60°C</td>
<td>8 days (windrow must be turned 3 times at no less than 2 day intervals)</td>
<td>400mm</td>
</tr>
</tbody>
</table>
Additional Barriers

Where category 3 catering waste is being treated to national standards, it is mandatory to further adopt at least one additional barrier. However, if EU treatment standards are being met by the premises, then the additional barrier rule does not apply, as EU standards require much smaller particle sizes which removes the need for a second treatment phase.

i. **AD system**

   To store the material after initial treatment for a minimum of 18 days, but this can include ‘storage’ within the digester itself.

ii. **Composting**

   A second phase of composting is required. While the first composting stage required the system to be closed under EU standards, second stage composting does not require the windrows to be housed and can be carried out in the open (Table 11).

Green Waste

GW is not subject to any EU or National Treatment Regulations prior to use in an AD or Composting system due to its low risk nature. However, if it is to be co-digested or mixed with category 3 catering waste, it must be considered as catering waste and the EU and National treatment regulations and minimum standards must be applied. It is not necessary however to reduce the GW particle sizes.

Gas Handling & Health and Safety

As an AD system produces a biogas the UK Gas Safety regulations need to be met. As this biogas will be handled and stored, it is also necessary for relevant risk assessments to be conducted for each stage of the AD process and for appropriate training to be provided. Additionally, AD can be considered a chemical process therefore there are several associated risks that will need to be considered. For example, toxic gases, explosive and flammable atmospheres, high pressure systems and COSHH.

Digestate and Compost Regulations

For digestate to no longer be considered as ‘waste’ by the EA (End of Waste Criteria) both the Digestate Quality Protocol and the BSI Standard PAS110 must be complied with, after which there are less restrictions regarding the use of the digestate on land. This is similar for compost
whereby the Compost Quality Protocol and BSI Standard PAS100 criteria must be met for compost to no longer be considered as a waste.

If the University complies with these standards, it is then possible to use the digestate or compost on land onsite or to sell this product on following the provision of a U11 exemption from the EA.

**Exemption U11**

This exemption allows digestate and compost to be spread on non-agricultural land to replace manufactured and chemical fertilisers used to improve and maintain soil. The EA have specified quantities of digestate and compost material that can be used on land annually and stored at any one time for a maximum of 12 months, based on the type of waste streams these products are derived from. Relevant examples are outlined in Table 12.

*Table 2 - Quantities of waste that can be used on land per annum and stored onsite depending on their waste type (Adapted from Defra, 2013).*

<table>
<thead>
<tr>
<th>Waste Type</th>
<th>Quantity (tonnes ha(^{-1}) a(^{-1}))</th>
<th>Storage (tonnes)</th>
<th>Condition*</th>
</tr>
</thead>
<tbody>
<tr>
<td>190599</td>
<td>Compost produced from waste allowed under the T23 Exemption</td>
<td>50</td>
<td>500</td>
</tr>
<tr>
<td>190604</td>
<td>Digestate produced from waste allowed under T25 Exemption</td>
<td>50</td>
<td>200</td>
</tr>
</tbody>
</table>

*Condition A - the location where waste is stored or land where it is to be spread must be at least 10 metres away from a watercourse and 50 metres from a spring, well or borehole. Additionally, storage must be in a secured location.*

**Exemption U10**

For use on agricultural pasture lands (like those at the University Farm), a non-grazing period of 2 months for pigs and 3 weeks for other farmed animals must be followed after the application of compost or digestate and a U10 exemption must be granted by the EA. This rule is also applicable for croplands (DEFRA, 2008).
Additional Environmental Considerations
The compost or digestate must not be spread on land which is waterlogged, covered by snow or has been frozen for 12 hours or more in the 24 hours prior to spreading. Additionally, the land should not be treated if it has been forecast to rain heavily in the 48 hours post-spreading. This is of importance for land that falls within classified Nitrate Vulnerable Zones (NVZs).

Nitrate Vulnerable Zones
Specific areas of land, where it has been identified that drain into water sources known to be polluted by nitrates have been mapped in the UK as NVZs under the legislation set by the EC Nitrates Directive. In England NVZs account for approximately 58% of the land area (DEFRA, 2017). While this shouldn’t be an issue for use on sports fields, if the digestate or compost was to be taken to the University farm, the NVZ map provided and regularly updated by the EA, should be consulted.
PART C

4. Developing the Food Waste Living Lab

4.1 Introduction
Chapters within this section of the report discuss the recommendations for the development of the FW Living Lab and outline the necessary requirements and additional factors that must be considered prior to moving forward with the project.

4.2 Recommended Approach
As the University is bound by a 5-year contract with external waste management contractors AWM and sub-contractors Olleco, commitments made in the contractual agreement must be abided by. It is therefore not possible to recommend a fully decentralised approach for FW management on campus at this time. Plans could be developed over the coming years so that once the contractual agreement ends, new technology could be implemented and established on site to make the switch to decentralised approaches, if it is deemed feasible by 2022.

From the assessments carried out in this report it has been assumed that the University’s existing process for managing FW through contracts with Olleco, is both cost effective and relatively environmentally friendly. However, this report recommends the utilisation of a small-scale AD unit which the University currently owns and has in storage, to treat a small volume of FW for research purposes. This would allow the University the opportunity to ‘scope out’ or test how well the AD system performs with FW on site, before any significant commitments or financial investments are made for scaling up.

A further recommendation can be made with regards to behavioural change and consumer demand. While it is commendable that the University is seeking innovative ways to reduce the environmental impact of FW on campus, it is important that the benefits of reducing consumer demand and the promotion of behavioural change are not overlooked. ‘The Waste Hierarchy’, which is a legal requirement in the UK, highlights the most preferable to least preferable actions available for dealing with FW in the UK (Figure 14). This is a clear indication that the current practice of sending segregated FW to a centralised AD plant, is mid-way between most and least preferable options available in the UK. However, this strategy does skip out the more preferable, higher tiers which fall within the ‘prevention’ category and include actions such as reducing the volume of food wasted.
The Courtauld Commitment developed by WRAP is a voluntary agreement that could be of interest to the University. By signing up the UoL would be pledging to reduce its volume of FW by 20% by 2027, which would have potential for financial savings and GHG emission reductions. Additionally, the inclusion of behavioural change and demand reduction aspects in the Living Lab for FW would widen the scope of the project allowing for greater participation across academic departments as well as improving student engagement opportunities. Peripherally, there are significant economic, environmental and social opportunities regarding improved FW segregation in Halls of Residences.

Potential to Increase Food Waste Segregation

There is scope for the UoL to increase the volume of segregated food waste to improve the viability of implementing a decentralised waste management system by increasing the uptake of the 'opt-in' schemes in accommodation. Assuming that 4% of total waste collected as FW is 10% of the total FW generated, you can assume that around 40% of the general waste could be separated out as FW. As illustrated in Figure 15, if this were the case, the total FW segregated from all the halls of residences under the University's remit could theoretically total of 94.51 tonnes of FW a year, an increase of 83.54 tonnes a year compared to present.
As mentioned, economic viability is an issue regarding FW segregation in halls. There are cost savings that can be made from the halls of residences where waste collection is the responsibility of the University. In the current waste contract, it costs £90 per tonne for FW to be collected, as opposed to £173 per tonne for general waste, a cost saving of £83 per tonne. Currently in Central Village, there is an annual saving of £476 from food waste segregation.

On the other hand, the initial outlays for getting the bins to facilitate FW separation was relatively high (£2,500) with a high payback time of around 12 years, when compared to the 1-5-year payback time desired by the estates team. Further to this, it was suggested that for cleaners in halls of residences to collect segregated FW from apartments, it would incur an increase in fees. Moreover, with the current FW collection arrangement, total fines by cleaning staff (if everyone was to opt in to FW collection, but no one removed the FW from their flats) could be as high as £20,000 a year.

There are a number of other University residences where there is potential to separate FW, however the FW collection would be within the remit of Leeds City Council and carried out for free. As a result, there would be no savings from FW collection and thus, the economic outlays for food bins could not be justified. Despite, these economic barriers, if around 40% of
the general waste were FW and all FW at all of the halls were separated, then there could be an annual saving of £6,934, due to the lower costs of food collection compared to general waste.

There are behavioural barriers as well as economic issues hindering FW separation in the University accommodation. As previously mentioned, students at Central Village have to separate their FW in their kitchen and take their bins out to a communal area on the ground floor of block A, for the whole year. This can be considered a large commitment, especially if apartments are in different blocks or the top floor. Whilst some students may be willing to do this for ethical/environmental reasons, others may be unwilling without financial rewards.

Currently, the halls elect volunteer student representatives to promote FW separation, as well as educate fellow residents of its' environmental credentials. Moreover, a booklet is handed to all new residents that includes waste recycling information. Refectory incentive/reward schemes have also been trialled with FW to limited effect. A key issue here is that every year there are new students, thus it is difficult to make yearly improvements in FW segregation uptake. Key areas to consider for improving FW segregation in halls of residences would be to include enticing rewards to incentivise students to 'opt in' to FW separation (e.g. discounts at The Refectory, SU, or sports facilities). Moreover, a small hard-hitting infographic with key environmental facts on FW bins could increase uptake. Furthermore, a renegotiation of contracts to include the collection of FW from each flat would greatly decrease the commitment of the students.

4.3 Logistics
For the pilot AD, it is recommended that only FW collected from The Refectory is used as this location ensures source segregation conducted by staff in the kitchens. This will reduce the risk of feedstock contamination which would be problematic for the functioning of the AD unit.

The Refectory kitchen staff are already placing plate scrapings into a FW caddy before adding this to FW bins provided by Olleco. Staff would only be required to put aside several kilograms of FW per day which can then be transported to the AD site. For transportation of waste from kitchen to AD, it will be necessary to identify a member(s) of staff who will take responsibility for this daily role.

As the pilot AD system can be run under either a batch or continuous operating regime, a variety of studies will be possible. Academics may also wish to investigate the influence of
particle size on AD performance; as such a shredding device or blender may also be required. However, this will not incur a large expense due to the small scale that the pilot plant will be operating within. As discussed previously, the use of GW as a co-digester in the AD process is a possibility. In such a scenario, it will be necessary for Estates to either store some of the grass waste they generate near the AD unit, or have a member of their team transport a set amount to the AD site several times a week.

The AD process itself should take a minimum of 18 days from the feeding the substrate to removal of the digestate at the end. During this time, the biogas produced will need to be vented away from the unit/out of the building, however it should be noted that the volume of gas produced by this small-scale unit will be minimal and not considered harmful to human health. Once the process is complete the digestate can be removed and placed into a sealed container so it can be transported by estates to storage facilities close to where the Digestate will be used (likely to be taken to Bardon Grange or the Sports facilities). To comply with the U11 exemption for digestate use on non-agricultural land, it is necessary for the digestate to be stored on the same site as where it is intended to be used. Other environmental considerations as outlined in (Chapter 3.7) should be considered prior to use.

4.4 Facilities and Site Requirements
The biggest challenge in developing the Living Lab for FW is in locating and securing a site for a small-scale AD unit. However, at present the University owns a Gunt AD unit (Figure 16) which is in storage and has yet to be used, it therefore makes economic sense to retrieve this technology and have it running for research purposes.
This technology will require electricity, water, access to drainage and ducting to extract the biogas away from the unit. It would therefore be easier to have the AD placed within a research lab on campus as these specific requirements can be easily met. It would make it easier to find members of staff who may be willing to incorporate aspects of maintaining the AD into their daily roles. Additionally, it may be easier to install in an existing lab from a health and safety perspective. This kind of site may however become a barrier to cross-disciplinary collaboration and may restrict the amount of time available for teaching and departmental sharing of the technology.

Conversely, to overcome the social and academic engagement barriers, a mobile laboratory (Figure 17 and 18) as a temporary solution, would be beneficial for the University. Not only would this provide a ‘neutral’ laboratory space to promote departmental sharing of facilities, it would offer the University a chance to enhance social engagement with students and the public who might otherwise not have access to such equipment if it was held within a research lab. This would align with many of the principles of the living lab concept and provides the opportunity to generate external interest and positive PR. Furthermore, the temporary nature of a mobile lab may make it easier for the Sustainability Services to be granted permission by the University to go ahead with development of the living lab, as the structure can be relocated across the campus as and when temporary sites become available.

Figure 17 - Example of a mobile laboratory by Portakabin (Source: http://www.portakabin.co.uk/portable-buildings.html)
Additional facilities needed:
- Space is needed for sample preparation of the feedstock and digestate
- Space will be needed for teaching small groups
- Storage facilities and space will be required to store the digestate produced
- Transportation may be required if the AD is located out of walking distance from The Refectory

4.5 Possible Site Locations
During the initial feasibility assessment conducted by the Sustainability Services in 2015/2016, 3 site locations were proposed on the central campus. Since this time, some of the suggestions made are no longer viable, therefore a number of potential site locations are proposed below.

Site A- Mobile Laboratory on Campus
As discussed above, a mobile laboratory space has several benefits and can overcome issues of planning if it is considered a 'temporary' space. In Figure 19 the red space indicates a possible area to house the mobile laboratory or Portakabin style out-building in the space between the Student's Union delivery entrance and the social sciences building. At present there are 2
shipping containers situated here amongst the waste bins which are due to be removed, therefore there will be ample space for similar sized units. Additionally, access to mains electricity has already been established so only water access will have to be implemented.

As the site is at the delivery entrance to the Student's Union building, it would make transporting FW from The Refectory to the AD unit a relatively simple task for those involved and would not require new infrastructure. While this location is not on a public thoroughfare or walking route between University buildings, it is however overlooked by walkways and in close proximity to designated campus conservation zones which may be problematic when looking to implement the AD facility. Conversely, the fact that the facility can be seen from public walkways may aid in generating interest and participation and could be used as an opportunity for publicity.

![Aerial image of the proposed site of a mobile laboratory on central campus](image)

**Figure 19- Aerial image of the proposed site of a mobile laboratory on central campus**

**Site B- Research Laboratory**

The pilot-AD could feasibly be housed within existing or new research laboratory space. It has been suggested by staff from the Food Science and Nutrition Department, that there is potential
for space to be found in the new research labs they are in the process of developing in the E.C. Stoner building on campus (Figure 20).

Food Science and Nutrition believe there would be ample space for the AD unit alongside work benches, and that time could be shared across departments to utilise this technology. The route between The Refectory and E.C. Stoner building is walkable and would be easy for those involved to transport a caddy of FW to the research lab on a daily basis. This option would also mean that access to electricity, water/drainage and ventilation would be instantaneous.

It should be noted, that the final plans for this laboratory space will be made by March 2018, therefore contact should be made with Food Science and Nutrition before March if this location is preferable.
Site C- Bardon Grange
As discussed in previous chapters, the Bardon Grange site is situated about a 4-mile drive away from the central campus in the suburb of Weetwood. The site offers an ideal location for the implementation of an outbuilding for an AD unit, as there is an abundance of underutilised space (Figure 21). Furthermore, it may be easier to be granted planning permission at this site given the remoteness of the location.

As Bardon Grange adjoins the sports fields, the digestate produced from AD can feasibly be stored here and used as a direct substitute for the chemical fertilisers currently being procured and used on the sports fields. Additionally, if the AD installation was to be scaled up in the future, it may be possible for the greenhouses at Bardon Grange to be heated by the bio-gas generated from the AD if there was a great enough volume being produced.

Difficulty however may arise from the distance that will need to be travelled to transport the FW from The Refectory to the AD. Finding existing members of staff who will be willing to take on this duty daily may be difficult and the distance from the central campus may also be an additional challenge for teaching and research.
4.6 Planning Permission
The University would need to be granted planning permission by the local authority for the implementation of an AD installation for site locations A and C. There is no way to guarantee approved planning permission, however ‘The official information portal on Anaerobic Digestion’ suggests the following steps to reduce the likelihood of refusal:

a) Inform the public and local community of plans as early as possible.

b) Prepare for an Environmental Impact Assessment (EIA) if the facility is likely to treat over 50,000 tonnes of waste per annum, or if the system will be installed close to a residential area. It may be the case that the council, due to treatment system being implemented on a university campus, take a precautionary approach and request an EIA report anyway.

c) Refer to the planning policy statements when submitting plans to the council. Relevant documents may include the Renewable Energy and Planning Policy Statement and

d) Proposals could include details regarding emissions to air and an assessment of their likely impact on the environment, modelled emission dispersions from the AD unit.

e) Gain community acceptance and support.

4.7 Maintenance
Even with a pilot-AD unit it will still be necessary to have a technician or member of academic staff available to directly deal with malfunctions or technical problems with the AD. It is likely that general maintenance will have to take place on a regular, potentially weekly basis, therefore it may be necessary to negotiate this within existing contracts with staff members.

Issues may arise regarding acidification, foaming, scum layers, sediment and grit, blockages, mixer failure, low gas production and odour, which will need to be remedied. This may include adding alkali materials if there are acidification issues, mixing the top layer of the substrate, or spraying water on the surface if there are foaming problems.
4.8 Monitoring and Sampling
At all locations, it will be necessary for training to be provided for those responsible in maintaining and monitoring the AD system. Monitoring tasks may include taking samples of the substrate to ensure optimal pH and temperature, assessing biogas production and composition and checking pathogen levels. The feedstock should be sampled regularly to check for contaminants and that may cause problems with the AD.

4.9 Health and Safety
It is also important to note that health and safety checks, risk assessments, machine standards check would need to be carried out. These tasks should be carried out by the appropriate health and safety staff and complied by all appropriate staff and researchers.

4.10 Regulatory Considerations
As outlined in Chapter 3.7 several regulations exist for AD at all scales when ABPs are included in possible feedstocks. For this reason, it will be necessary for the University to register their intent to establish the AD on site with the EA online before applying for the T25 exemption. Only once this exemption has been granted will it be possible to run the AD on FW from The Refectory.

Further to this the following regulations and exemptions will be relevant at the University (see Chapter 3.7 for more detail):

- EU Waste Duty of Care
- ABPR (EU or National Treatment Standards)
- U11 Exemption for digestate use on non-agricultural land (Sports fields)
- U10 Exemption for digestate use on agricultural land (University Farm)
- Digestate Quality Protocol
- BSI PAS110

4.11 Further Considerations
- Identify who will be responsible for maintaining and monitoring the AD system
- Identify is responsible for transporting the feedstock from The Refectory to the AD
- Someone will need to be available to feed the AD over University holidays, as if it is left, it will take a further 3-4 weeks to start up again.
- Will need to source a quality inoculum for the AD process.
4.12 Expertise Mapping and Interest Generated

This project has involved contacting and discussing the campus FW issue with several academics from across the university, students, estates and cleaning services, sustainability services and external waste management contractors. In doing so, we have generated an interest in participation with the living lab for FW. As the concept appeared to be relatively new to many, it would be advised that sessions similar to the FW seminar that was conducted in November 2017. Are continually run to generate new interest and enhance engagement across campus.

While student involvement with the pilot scale technology we have proposed, is likely to be limited to those who are conducting research projects with the Living Lab etc. for health and safety reasons, there is potential for large scale student engagement to take place in the form of front-end campaigns. An example of this could involve awareness and behavioural change campaigns led and developed by students volunteering or interning with the sustainability services.

A list of interested parties, their contact details and University departments has been provided in Appendix 1 in the form of a network map.

4.13 Research Opportunities

Throughout the development of this report several knowledge gaps have been identified. Of which, we believe provide a range of interdisciplinary research opportunities for students and academics and would help in the development of a fully functioning living lab, as well as ensuring the longevity of the recommended FW solutions.

A summary of these research opportunities are highlighted in Figure 22 (below).
4.14 Additional Recommendations
While a major component of the Living Lab for FW involves treating generated waste to enhance the sustainability of the University’s day to day functioning, it is important not to overlook the significance of consumer demand and behavioural change in tackling this ever-growing issue.

Including front end commitments like the Courtauld Commitment and researching behavioural change as part of the living lab concept, would take the vision a step further by following an integrated, 'whole systems' approach to address a cross-disciplinary problem.

Moreover, the University should consider buying a biomass boiler and putting it at Bardon Grange, for combusting wood waste producing heat energy to partly heat the greenhouses there (Davison, 2017).
5. References


Defra (2008), Guidance on the treatment in approved composting or biogas plants of animal byproducts and catering waste, version 8, sept 2008, Department for Environment, Food and Rural Affairs, UK.


Defra (2013), Environmental Permitting, Environmental Permitting Core Guidance, Department for Environment, Food and Rural Affairs, UK.


6. Appendices

Appendix 1: Expertise map for the initial development of the Food Waste Living Lab
Appendix 2: Supplier List

Desiccators

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Anaerobic Digesters

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### Appendix 3: Qube Renewables Quote

#### Proposal

**Client:** University  
**Date:** 06-Oct-17  
**Status:** Draft  
**Project:** Sam Fetchwood - Food Waste Bio Qube Trial  
**Version:** Run 5  
**Type:** BQ +0t +20t

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Ex VAT, EU VAT. “Shipping estimated to Port to Port

This is excluding a pasteuriser at £28k, and a boiler, which for 3kWth you’d be looking at around £14k.
### Appendix 4: Estates Annual Energy Expenditure

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