Newtown Biomass Hub feasibility report and proposal.

Appendices

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Cronfa Amaethyddol Ewrop ar gyfer Datblygu Gwledig: Ewrop yn Buddsoddi mewn Ardaloedd Gwledig
European Agricultural Fund for Rural Development: Europe Investing in Rural Areas
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Appendix A Policy Context

On 1st April 2016, the Well-being of Future Generations Act (WoFGA) came into force in Wales. This over-arching piece of legislation was the culmination of 15 years work to put into practice the legal obligation set into the foundation of Wales' government to embed the principle of sustainability and sustainable development[1] in all that it does.

It also draws together the previous bodies of work relating to a number of key areas:

- waste, recycling and the reduction of pollution, set out in the '**Towards Zero Waste**' strategy document published in 2010, which included the first statutory recycling and waste minimisation targets in the UK, including a 70% target for recycling and composting municipal waste by 2025.
- materials and energy efficiency, set out in the '**Energy Efficiency in Wales**' strategy published in 2016 and covering actions to be pursued in the 2016-2026 period. These include the related impacts of energy conservation, generation and storage, efficiency gains through the construction sector and the consequent creation of secure, skilled jobs in these new areas of employment
- the impacts and the whole concept of living within the finite resource constraints of our planet, expressed as 'One Planet Living' have driven the further evolution of the materials efficiency philosophy into that of the Circular Economy. The new Strategy '**Beyond Recycling**' has just completed its consultation stage in Aril 2020 and is due for publication shortly.
- the **Climate Change Strategy for Wales** – including the delivery plan for a reduction – published in October 2010 provides for the progressive decarbonisation of Wales' economy by 2025 to a goal of Net Carbon Zero + Zero Waste by 2050.

The important difference between the WoFGA and previous legislation is that it expresses an holistic approach to every aspect of living. It is as much a philosophy as a legal framework and as such supports and encourages actions and developments that move towards the goal of being able to live in harmony with our planetary ecosystem instead of heedlessly damaging and destroying it.

The new law has 7 goals so that all the public bodies know what they must work towards. These are the Wellbeing Goals:

1. A globally responsible Wales
2. A prosperous Wales
3. A resilient Wales
4. A healthier Wales
5. A more equal Wales
6. A Wales of cohesive communities
7. A Wales of vibrant culture and Thriving Welsh Language

This study looks at the potential to take disparate and presently un-connected biomass related ingredients and actors in the Newtown/Welshpool/Llanidloes area and describe a number of scenarios where a new local system could realistically achieve as many of these goals as possible. These are not just laudable aims, but proposals that will provide the basis for sound economic, social and environmental development and demonstrate good business sense.

Just because the biomass waste resources arise and a largely dealt with in this locality does not mean that they do not have a global impact. Emissions of various Greenhouse gasses to atmosphere and leaching of available nutrients to groundwater, rivers and coast water all impact on the global commons. The continuous cumulative build up of micro-plastics in soils and the food chain also pose a direct long-term threat to animal and human health.

[1] *Sustainable development is development that meets the needs of the present without compromising the needs of future generations to meet their own needs.(Bruntland 1987)*

Of particular interest is the impact of nitrogen and its compounds on ecosystems and the climate. In relation to the application of nitrogen to land and thence to water, the regulations are harmonised with the European Nitrates Directive. The Nitrates Directive (91/676/EEC) is designed to protect waters against nitrate pollution from agricultural sources. It requires European member states who do not opt for a whole territory approach to identify waters which are, or could become, polluted by nitrates. The member states are also required to designate as Nitrate Vulnerable Zones (NVZs) all land that drains to those waters and which contributes, as a result, to nitrate pollution. Natural Resources Wales (NRW) has drawn up and implemented a Nitrates Action Programme to manage the flux of nitrogen into soil and water in Wales. EU Member states are required to review their implementation of the Directive every four years and to make appropriate amendments to the Nitrate Vulnerable Zones (NVZs) and/or the measures outlined in the Action Programme. The most recent review was undertaken in 2012 by NRW's predecessors in the Environment Agency Wales. Information about NVZs in Wales was updated in January 2013. Currently, NVZs account for some 2.4% of land area in Wales.

The Welsh Government has proposed extending the NVZ's to cover the whole of Wales and this would have an immediate and pronounced effect on the activities of farmer, land managers and utility companies that manage nitrogen flows as part of their business. Whether this goes ahead under a post-Brexit regulatory revision remains to be seen.

Nitrogen exists in abundance in green biomass and therefore its processing needs to be cognisent of this. Anaerobic digestion of biomass whether it be in the gut of ruminants, in a biogas plant or in the treatment of sewage sludge results in nitrogen in the form of ammonia (NH_3). This is a gas which can be readily dissolved in and dissociated from water and as a greenhouse gas has the equivalent effect of 2.11 x that of CO_2. However, when applied to land as a slurry, much of the ammonia is converted to oxides of nitrogen (N_2O etc) which has the equivalent effect 298 times that of CO_2. Nitrogen compounds also provide a readily available nutrient source to algae in bodies of water resulting in algal blooms during warm weather which in turn can quickly use up the available oxygen in the water, creating a eutrophic environment and asphyxiating other aquatic life.

In parallel to the environmental fluxes of carbon, the flows of nitrogen need to be better managed to make sure that more of them remain in a stable solid form for longer, and that the rate of change from compounds held in the soil reservoir to free forms mobile in water and the atmosphere is controlled. Both policy and regulation are now moving in the direction of enforcing this control.

At the time of writing, there are a number of external factors which are likely to impact the creation and ongoing viability of these scenarios and they can be better described in the 'threats and opportunities' matrix of the resulting business plan. These are:

- The Climate Emergency
- A disruptive 'Brexit' – including the potential for food insecurity
- The Covid-19 pandemic
- A roll-back of the devolution act of 1999 and re-centralisation of power in Westminster

Some of these threats have been implicitly, if not explicitly foreseen in the 15 year development of the policy landscape in Wales, but all of them now highlight the need to create locally-based solutions that engage people, capture and retain benefits locally and build the resilience of communities.

The suggested scenarios take the best of the current knowledge and experience and attempt to describe solutions that address not just current and anticipated regulatory constraints, but the need to target investment towards long-term outcomes. Investors, both public and private are taking a longer-term risk based view and this change in attitude is bearing fruit. In June 2020, Investor Research company Morningstar reported that Environmental, Social and Governance (ESG) funds had out-performed traditional funds by a substantial margin[2]

[2] www.theguardian.com/money/2020/jun/13/ethical-investments-are-outperforming-traditional-funds

The proposals in this study suggest some models which will hopefully address several of these policy areas in an holistic and relational way. The extent to which the elements of these proposals will be sufficiently robust to deliver on the aspirations will need to be validated in greater detail in subsequent studies.

Looking at how the proposals address the seven areas of wellbeing we suggest that:

1. *A globally responsible Wales* – emissions and resource consumption both affect the global commons of water and air, and we find local answers to problems.
2. *A prosperous Wales* – creating local solutions will keep economic activity in the local area assisting wealth retention in local communities
3. *A resilient Wales* – turning waste into resources can help maintain soil fertility and keep toxins from accumulating in the food chain: the essentials of sustainable food production
4. *A healthier Wales* – reducing pollution and producing more nutritious local food helps keep a population in better health
5. *A more equal Wales* – creating job opportunities and income streams in rural areas interrupts the extractive flows that favour big cities.
6. *A Wales of cohesive communities* – forming partnerships by building collaborative systems between different stakeholders builds stronger bonds within local areas.
7. *A Wales of vibrant culture and Thriving Welsh Language* – the economic viability of rural communities is the key factor in determining the continuation of the Welsh Language.

Appendix B The introduction of nitrate vulnerable zones

The rules around nitrogen application through fertilisers can be confusing. If fields are converted to NVZs as part of an environmental protection outfit to land, then this can change the area of application, removing land such as those within certain meterage of water courses etc.

Good practice on non-controlled land allows an application rate of 250kg/ha of organic manures not including manure deposited by animals.

An example farm in Powys is a mixture of broiler hens and cattle:

The total kg N produced are as follow:

Stock	Stock Number	Kg N Stock Unit	Total kg N Produced
1 Broiler	100,000	0.24	24,000
1 Dairy	350	85	29,750
Total kg N Produced			**53,750**

This production has a 94.25ha area of land which this can be applied to. At 250kg this equates to 23.562.5kg leaving 30.187.5kg to be exported. In the planning application for this example, this is exported to a biomass plant. In some cases this has been biomass to energy, through anaerobic digestion or incineration.

What happens then if this land becomes and NVZ? The upper limit for using organic manure on land is 170kg/ha during a calendar year. This *includes* manure deposited by livestock grazing the land too. In this case therefore the amount spread to land is limited to 16,493.75kg, this is a 31.2% reduction in volume needed.

There are 2 other factors however that make this situation more difficult:

1) there is a land reduction where the manure can be spread. For example manure spreading needs to take into account:

- land that's sloping, especially if the slope is over 12 degrees
- ground cover provided by vegetation
- the distance to surface water
- weather conditions
- the soil type and condition
- the presence of land drains

2) That an NVZ includes manure from the animals grazing the land.

In the case above where 29.8k kg of manure is produced from the dairy heard, this is already over the fertilisation limit placed on the land via the NVZ

In summary, where this farm was exporting 30,187kg of manure, this figure rises to 37,256.25kg (23% increase) with the introduction of an NVZ. With additional factors, this may mean that the dairy heard head number has to decrease putting increasing pressure of the farm financially, and having to search for external uses for poultry manure. Broiler manure can sell for a little as £10 a tonne (2018) across the farm gate. There is a market for pelletised poultry manure at around £1410 a tonne

(£14.10 per 10kg 2020) however the market would quickly saturate and doesn’t pre-processing, packaging, marketing and distribution.

Appendix C Chemical characteristics of sewage sludge

Sewage Sludge

Sewage sludge is the residual solid material that is produced as a result of the biological treatment of municipal waste water. Generally this waste stream needs processing before it can be re-introduced back into the environment.

Sewage sludge is produced over a number of stages, each with their own semi de-watering capabilities and utilising bacteria or protozoa. This includes a primary stage where 50% of the suspended solid matter will settle out within 90min. This primary sludge will quickly turn anaerobic and is collected through mechanical scraping through to sludge digestion tanks. Secondary sedimentation takes place where the sludge is removed from the settlement tanks.

Sewage sludge can be a haven for contamination and a concentration point (or in fact the right environmental conditions for growth). Pathogens can thrive in this environment however they are not considered a significant health issue if the sludge is treated properly. Sewage sludge can also contain micro-pollutants including pharmaceutical products and hormones. There can be heavy metal contamination and accumulation of arsenic, cadmium and copper but also silver, lead and chromium. Other hazardous substances can include cumulative toxins such as polychlorinated biphenols, doxins and brominated flame retardants.

Often, the sewage sludge (or biosolids) is landfilled at the end of process however this can cause circulation of pathogens if not properly stabilised or pre-treated. Biosolids have been known to be composted prior to landfill, and if managed properly can render the majority of pathogens inert. Biosolids are also used as fertiliser for land use however there remain concerns over land contamination, leaching problems and emissions.

The PHYLLIS2[3] database has explored sewage sludge extensively. An average analysis of the results is given below.

Proximate Analysis		Dried Sludge (mean)	Wet Sludge (mean)
Moisture Content	wt%	7.32	63.4
Ash Content	wt%	39.09	16.91
Volatile Matter	wt%	49.42	22.33
Fixed Carbon	wt%	6.92	3.6
Macro-elements			
Carbon	wt%	29.28	10.04
Hydrogen	wt%	4.25	1.41
Oxygen	wt%	17.25	6.20
Nitrogen	wt%	3.88	1.65
Sulphur	wt%	1.50	0.37
Halides			
Chlorine	mg/kg	1852.64	366.48
Fluorine	mg/kg	108.53	77.5
Heating Value			
LHV – Net Calorific Value	MJ/kg	11.83	2.41
HHV – Gross Calorific Value	MJ/kg	12.95	4.27

[3] Inset weblink to PHYLLIS2 database location

Appendix D Characteristics of Poultry Litter

Use as fertilizer

Poultry litter is a fertilizer, and much is spread on land for this purpose. Most of the poultry farms around Newtown spread some of the litter they produce on their own land, and sell any remainder to neighbours. Poultry litter contains all of the NPK components typical of the inorganic fertilizer that would typically be used on pasture in Mid Wales, but the nitrogen component is volatile and tends to be lost to atmosphere or leached in water so is not fully available to plants, hence farmers will often augment with a high nitrogen fertilizer. The volatile ammonia and nitrates can pollute groundwater and water courses.

Poultry litter is more bulky and less easy to handle than commercial fertilizer, which suppresses its value, and typically farmers receive around £5/tonne collected. For a typical 25 tonne lorry, this would only amount to £125 per lorry load, illustrating that the value would be dwarfed by the logistics of transporting it unless distances are very short. The value of these nutrients would be far higher if they could be transported to arable areas that have higher need for fertilizer. The equivalent that would be paid for commercial fertilizer with the same nutrient value would be about four times this value. Transporting to arable areas of Shropshire has been investigated, but the cost of transport makes this a not particularly attractive option.

Options for disposal.

Currently most farms around Newtown are able to deal with their litter problem by spreading or selling to neighbours, with just one large farm having its own AD unit. However, there is evidence that the local areas are nearing capacity for this and that if many more egg units are built the disposal problem will become more acute. The financial support for Anaerobic Digestion (Feed in Tariff) has come to an end, so new poultry sheds, even if large, are very unlikely to now install their own on-site digester.

The likely growth of the sector.

The rate of new planning applications for poultry sheds has slowed but there is still incentive for farmers to invest in this sector and hence more units are expected. It is becoming increasing hard for small family farms to remain viable based on traditional sheep/cattle rearing regimes, with few sons and daughters choosing to take over the family farm because of the low income that can be made.

Setting up a poultry unit represents an opportunity to make small family farms viable again and enable the farm to continue to be passed down the generations, in addition to creating more local employment. A traditional 150 acre sheep/cattle family farm can barely afford to employ one or two of the direct family, whereas a 60,000 poultry unit will require 3 or 4 staff supervising egg handling, dealing with deliveries/ despatch and dealing with removal/ disposal of poultry litter.

Feedstock characteristics

The major nutrients of poultry manure include N, P, K, Calcium (Ca), Magnesium (Mg) and Sulphur (s). These naturally are variable due to the addition of bedding material, more prevalent in floor raised broilers as illustrated in Table 1. Total organic carbon is reported to be around[4] 25 to 35% dry weight of poultry manure.[5]

Table 1, Nutrient Contents of Manures and Composts (g/kg dry weight basis) (N.S. Bolan et al)

Nutrients	Poultry Manure Compost		Pig Manure	Mushroom	Green Wastes
	Layer	Broiler	Compost	Compost	Compost
Nitrogen	32.8	25.7	15.2	17.5	21.8
Phosphorus	10.8	6.7	6.5	7.5	10.1
Potassium	15.2	10.1	8.2	9.2	5.9
Calcium	18.5	16.2	4.2	21.5	19.7
Magnesium	6.2	3.5	3.7	5.2	4.2
Sulphur	8.5	5.2	3.4	3.5	7.0

Table 2 shows a direct comparison of fertiliser equivalent saved when using poultry manure as a fertiliser.

Table 2, Nutrient Concentration and the Estimated Total Amount of Nutrients in the Poultry Litter for Poultry Unit with 100,000 birds. (N.S. Bolan et al)

Nutrients	Concentration kg/T	Total Amount T	Fertiliser Equivalent T	Area of Maize ha
Nitrogen	25.7	172	Urea (374)	860
Phosphorus	6.7	45	SSP (473)	1125
Potassium	10.1	68	KCl (136)	453
Calcium	16.2	109	Lime (272)	5450
Magnesium	3.5	23	Dolomite (121)	1150
Sulphur	5.2	35	Gypsum (194)	1167

Calorific Value of Poultry Manure

The calorific values of poultry manure depend on a variety of parameters. As shown above, it is not just the case of poultry producing a known volume of manure, but factors including the moisture content, the living habitat conditions and the diet of the birds. At some point, the cost and calorific value of transport and de-watering has to be taken into account.

G. Quiroga et al[6] gave Higher Heating Values (HHV) between 12,052 and 13,882 kJ/kg for dry material, down to Lower Heating Values (LHV)of 2664kJ/kg (wet), with a moisture content of 74.5%. Phyllis2 (an EU funded biofuels program BRISK2)[7] gives a database of a variety of different fuels and states that poultry litter has a moisture content of 75.2% and calorific values of between 610-2690kJ/kg wet and 9860-10,840kJ/kg dry. M. Tanczuk et al[8] gave LHV of 12,744kJ/kg dry and 3201kJ/kg wet.

4 A. Sharpleyet al, Nutrient Analysis of Poultry Litter, Agri & Nat. Resours. FSA9529 Report to Uof A Division of Agriculture.
5 O.H. Dede & H. Ozer, Enrichment of Poultry Manure with Biomass Ash to Produce Organomineral Fertiliser, Environ. Eng. Res. 23(4) (2018) 449-455
6 G. Quiroga et al, Physico-chemical Analysis and Calorific Vales of Poultry Manure, Waste Management, 30 (2010) 880-884
7 www.phyllis.nl
8 M. Tanczuk et al, Assessment of the Energy Potential of Poultry Manure in Poland, Energies, 12 (2019) 1244

Ref.	Heating Value (kJ/kg) Dry	Heating Value (kJ/kg) Wet
G. Quiroga et al	12,052-13,882	2664
Phyllis2	9860-10840	610-2690
M. Tanczuk et al	12744	3201
Average	12020	2505

Composting Poultry Manure

Composting remains a viable option[9] as a pretreatment before land spreading/using as a fertiliser. Composting can pre-treat the medium and add the missing nutrients to the mixture, including the carbon to balance. Composting is also proposed to decompose pharmaceutical products used in the poultry including hormones, antibiotics, antifungal and parasite treatments. This has been seen to be an important factor as the uptake of pharmaceuticals by plants has been a reported a potential consequence using poultry fertiliser, which passes up the food chain.

Comparing different materials, compost produced from a mixture of poultry manure and woodchip (42.5%), straw (30%) and grass clippings (20%) produced a high quality soil improver in terms of organic matter content, C:P ratio, C:N ratio and stability. However, the poultry manure component was only 7.5% in order to achieve the optimum nutrient ratios.[10]

Other studies have demonstrated a higher input of poultry manure in composting. In one study[11] 83% poultry manure and 17% wheat straw provided the best conditions for the composting process.

Adding a C rich material is necessary to avoid low C:N ratios in the composting mixture which may result in the production of ammonia and inhibit the composting process. Temperatures generated by this mixture during composting were also shown to be sufficient as a pathogen removal step.

Land Spreading Poultry Manure

Spreading fresh and untreated manure to land can result in the emission of nitrous oxides (NO_X) and ammonia (NH_3) contributing to GHGs. High levels of N and P means that application rates are restricted, when spread to land to prevent saturation and leaching to the surrounding environment. These may be even further restricted in Wales if bids to increase the area of nitrate vulnerable zones (NVZs) are successful. In a lot of cases, the application of poultry manure to land is in excess of the amount recommended for forage production and exacerbates run off and leaching. Although high concentrations can be beneficial for plant growth, they can cause deviations in the nutritional content of the grasses causing problems such as grass tetany - a condition where grazing cattle are deficient in magnesium in the blood which can be fatal.

The components of poultry manure are also an artefact of the method in which the poultry are raised. Different farming practices can give a different diversity to the end product. Poultry from floor raised birds (broilers) consists primary of droppings and bedding made from wood shavings or sawdust and include feathers and waste feed. Caged layers and breeders consist primarily of droppings. Typically N:P:K ratios for layer manures was 6:2:2 and 6:2:3 for broiler/turkey litters.

Application of poultry manure to soils is well studied. Kobeirski et al[12] showed that over a 10 year program, the content of organic carbon increased using poultry manure. It also significantly increased the content of P and K available as well as increasing the biological activity, the fertility of the soil. This was related to the change in enzymatic activity of the soil. The

9 W. Stiles, Poultry Manure Management, Farming Connect Report, (2017)
10 B. Vandecasteele et al, Composting for Increasing the Fertiliser Value of Poultry Manure, Waste & Biomass Valorization 5 (2014) 491-503
11 I Petric et al, Influence of Wheat Straw Addition on Composting of Poultry Manure, Proc. Safety & Environ. Protect, 87(3) (2009) 206-212
12 M. Kobierski et al, Impact of Poultry Manure Fertilization on Chemical and Biochemical Properties of Soils, Plant Soil Environ, 63 (2017) 558-563

study however does not factor in growth of plants on this soil and their effect on this carbon content increase. It appears more of a soil regeneration step.

If the opportunity arises, poultry manure has been enriched with biomass ash to produce an organomineral fertiliser. Dede et al incorporated hot biomass ash from wood wastes in a 50:50 ratio at varying temperatures (100 to 250°C). This made an effective plant fertiliser not only stabilising the mixture and reducing the water content, but also adding C and P overall. A.O. Adekiya et al[13] did similar work with biochar (hardwood charcoal) and poultry manure mixing and then fertilising soil at a rate of 15T/ha. Compared to simple NPK fertiliser, they all exhibited plant growth however the soil characteristics were better improved with the addition of biochar. These blended mixtures, and the addition of poultry manure increased pH, organic matter, Ca and Mg signficantly

Energy Generation with Poultry Manure

Poultry manure, particularly when combined with C rich sources, can be used for energy generation. If applied in this method, then there is a reduction in the GHG emissions from the manure. There is an offset too, renewable energy generated by this method will also reduce the emissions associated with fossil fuel consumption. Poultry manure is often combusted as a fuel source, or used in in anaerobic digestion. In addition, the resultant liquor (from AD) or ash (from combustion) can be used as a fertiliser rich in P and K.[14]

Bolan et al gave an example of large scale turkey and broiler farms using poultry manure to generate electricity in the US, burning around half a million tonnes of waste per annum. This generates 50 MW of electricity, sufficient to supply 40,000 households. Similarly a proposal was given to build a poultry power plant in west Australia. This is ported to produce around 0.7MW of electricity by burning 7000T. There is a limit to the adaptation of this technology however, and high capital investment and public concerns over odour etc. Particularly as these plants emit particulates we well as GHGs; nitrogen oxides, carbon monoxide, sulphur dioxides etc.

Biochar derived from poultry manure[15] has also been show to be effective for use as a slow release fertiliser for bean and maize crops. B. Bergfeldt et al[16] worked to pyrolyse poultry manure partly understanding a critical steps to remove antibiotics and organic pollutants from this waste stream. Pyrolysis appeared a significantly more important processing step than straight forward combustion. Because the chemical components in pyrolysis are not being oxidised into an inert material, the biochar product from this manure was more bio-available. The solubility of nutrients was higher than for straight combustion and the utilisation of char in soil was beneficial in terms of overall carbon balance.

Anaerobic digestion of poultry manure does take place and can yield combustion gases of 60% methane, 38% CO_2 and a mixture of water vapour, ammonia and hydrogen sulphide. Fewer producers however utilise AD as a waste treatment technology for a number of economic and physical reasons. Waste/manure based systems produce lower biogas yield compared to virgin biomasses. Poultry waste can contain a significant proportion of grit or sand which is an essential component of the diet of poultry. Grit is a significant disadvantage to AD, fouling the bottoms of the tanks and causing wear to pumps and macerators. Nutriman based in the Netherlands has gone some way to resolve this, blending poultry waste with digestate liquor and then separating out the grit fraction. FreEnergy, Wales, blend poultry waste at 20% with cattle slurry. Their AD design incorporates a grit trap, a sweeping arm inside the digester which deposits grit to a ground level port, which can be then ejected without fouling the tank introducing by oxygen.

These approaches may offer solutions to GHG emissions from simply spreading the manure to land, whilst also generating energy, heat and subsequently sequestering carbon into soils after application. The burning of poultry manure in the UK

13 A.O. Adekiya, Biochar, Poultry Manure and NPK Fertiliser, Open Agriculture 5 (2020) 30-39
14 P. Billen et al, Electricity from Poultry Manure, Jn of Cleaner Prod. 96 (2015) 467-475
15 A. Inal et al, Impacts of Biochar and Processed Poultry Manure, Applied to Calcareous Soil, on the Growth of Bean and Maize, Soil Use & Man. 31(1) (2015)
16 B. Bergfeldt et al, Recovery of Phosphorus and other Nutrients during Pyrolysis of Poultry Manure, Agriculture 8 (2018) 187

requires prior application to the Animal and Plant Health Agency (APHA). In fact through other routes of 'disposal' APHA have to be involved. If litter is made for sale, as a fertiliser or as a precursor to another product or route, such as energy, then there needs to be preprocessing steps. Manure must be heated to at least 70°C for 60min as a sterilisation/pasteurisation step to satisfy APHA.

Appendix E Characteristics of a variety of green organic waste species

The REDIRECT project identified a number of species of available biomass which could be used through the IFBB processes. These species met certain criteria relating to their ease of collection, abundance, impact on the food chain and those of waste or parasitic origin (e.g. invasive species, or species under management).

The identified species for REDIRECT were EU wide however almost identical to the species found available in the UK and around the Newtown site. The table below explores these species as potential resources of biomass and which have low impact on the food chain or other uses. Some of these species may have alternative uses in industry or as fertiliser.

Biomass (feedstock)	Description
Roadside Verge Arisings (Grasses, herbaceous plants & scrub)	Roadside verge material can be a wide variety of species depending on the nature of the management. Often they are comprised of weedy vegetation such as nettles and coarse grasses. They are usually maintained annually (or biannually) by contractors working for the local authority and are cut and the resultant wastes left to compost on top of the cut material. Trunk roads are managed by the Trunk roads Agency who have done a significant amount of work towards creating verge-ways as pollination pathways or wildlife corridors. There is a large campaign for this material outside of trunk roads, to be cut and collected as part of introducing wildlife corridors around the roadsides. Reducing the fertility of the soil by removing the cut biomass encourages the weedy vegetation to reduce and the wildlife species to thrive. Cut and collect is costly however and dangerous considering the proximity to the roadway. Roadside verge materials are contaminated with runoff from the road surface and any wear associated with traffic movement and the products of combustion from fossil fuels, They may need mitigation steps to be re-integrated into composting routes if entering the food chain. There is potentially in excess of 40,000 t of roadside verge arisings available in Wales.
Japanese Knotweed *Reynoutria japonica, Fallopia japonica*	Japanese knotweed is classified as a pest and as an invasive species in the UK (and the EU and US). Having the appearance of bamboo, this herbaceous perennial plant grows during the summer months reaching up to 3-4m in height. It is cultivated as a food in Japan but only as a relatively niche forage. Introduced to the UK in 1850s, this invasive species can grow in a variety of environmental habitats and will drive out the native vegetation. However it is heavily controlled not just due to its invasive nature, but of its destructive qualities. To control knotweed, the large underground network of roots need to be eradicated and only leaving a few centimetres of root behind will result in the plant quickly growing back. Safe disposal of the plant is difficult as it can result in the problem spreading. The root systems can extend for many meters away from the central plant and often penetrate building materials weakening their structural integrity. In the UK, knotweed is classed as a controlled waste and its disposal regulated by law. Whilst a problem material to deal with, this does present an opportunity of a source material as there are few solutions

Biomass (feedstock)	Description
	to mitigate it. If effective however, it should be considered as a finite resource and not something to be cultivated as a biofuel.
Small Wood Particles Wood Dust	Small wood particles are a bi-product of the wood industry and are generally classified to be between 0-1mm and 1-3.15mm in size. Although wood waste can be taken for incineration and to biomass boilers, these small particles can create inconvenient problems. Particles can exhibit themselves as a mobilised suspended dust on production and cause respiratory problems to the professionals who manage them (delivery and boiler management). Wood particles exposes the user to irritants in the wood saps which can cause problems on contact and allergic reactions. Exposure can result in respiratory effects such as asthma, hypersensitivity pneumonitis and chronic bronchitis and an increased sensitivity to wood dust with prolonged exposure. Wood dust material can increase the level of particulates in biomass combustion. Woody material is often sieved to remove the fine particulates from larger materials. This presents an opportunity for a combined material stream, where the fine nature of the material when blended with higher moisture content material benefit each other. Fixing the dust into other material can add a readily available carbon rich source into other materials.
SRC Woodchips Short Rotation Coppice (Poplar, Willow)	SRC is generally considered to be an energy crop however has applications in green woodworking and sustainable building materials (fencing etc). They generally consist of densely planted, high yield varieties of poplar or willow. The solid wood biomass can be used to create heat and power either as stand alone products, or in combination with other fuels. In the UK, grants are available for the establishment of SRC plantations. Due, however, to the longer term investment (up to 4 years before harvesting), high initial capital cost of equipment and larger area of land needed to be economical their uptake and future can be jaded. SRC has the reputation of being carbon net neutral if managed sustainably however this maybe offset by the machinery needed to process it, transport it and its heavy use of water. SRC however presents an opportunity as a balancing species, adding carbon into blends where it is pure to balance composting or other end of life material streams.
Gorse *Ulex europaneus*	Gorse is widespread in the UK and a particular familiar natural feature of the hillsides and coastal areas in Wales. A relative of the pea family gorse grows into thorny evergreen shrubs which can be, but rarely in modern times, used as fodder for cattle and horses. Rarely too, it was cut, dried and stored to be used to heat traditional bread ovens. Gorse readily becomes dominate in suitable conditions and can thrive in poor growing areas establishing in rocky, sandy and dry soils. It is also considered to be a valuable plant for wildlife providing dense thorny protection for birds nests. Gorse however is highly flammable with an oil content of over 2% of the dry mater and has caused significant problems on upland areas of land when, often deliberately, it has been set on fire. As such, large areas of land are stripped of gorse to prevent fires, or with the addition of fire

Biomass (feedstock)	Description
	breaks. Often, gorse is removed from the sides of trunk roads incase of accident or arson causing a bottle neck of problems. This material is often shredded and taken elsewhere to be processed as leaving the material can represent further fire hazard.
Horticultural Compost	Horticultural waste is a stream of biomass originating from the disposal of green material from gardens, parks and through landscaping companies. The material is highly variable and co-mingled and will be a mixture of garden & green wastes, grass and hedge cuttings, plant material from trees and shrubs and will probably be contaminated with soils and stones. Some local authorities and agencies offer pick up services at cost and often the material is composted. In Baden-Baden the civic amenities site pay for the material that is brought to them and thereafter sort the material into separate streams. Rather than purely composting, they can produce graded woodchip, fuel logs and briquettes, grits and composts for retail back to the community. Ireland produces around 35-45,000t per annum of horticultural wastes.
Purple Moor Grass *Molina sp.*	Molina is a common grass species native to Europe. Able to grow in fairly poor conditions it can be quick to establish in wet peatlands. It grows into dense tussocks with grasses extending 90cm in height. Generally it is found with rushes and a whole variety of other plants however if not properly controlled it can begin to outcompete other plants and provide thick coverage. Controlling usually takes place through mechanical intervention of sympathetic grazing. It can be found however prevalent on upland sites and on steep slips which makes it very difficult to harvest. It is a fairly carbon rich species making it ideal for using in co-composting or other applications. If accessible it can be cut and baled however generally where it is, it has been eradicated.
Bracken *Pteridium sp.*	Bracken species are large coarse ferns. Once gathered and valued for use as animal bedding, tanning, soap and glass making, and as a fertiliser, bracken is now seen as a pernicious and invasive plant. It is toxic to most grazing animals however there can be some minimal control through trampling by grazing cattle looking for fodder. At one time it was so invasive and considered a danger to pastureland that there were eradication programs even going so far as to use filters on water supplies to remove the bracken spores. Whilst it can be difficult to harvest on wetlands it is widespread through Wales with approximately >150,000t. The current method prescribed by Glastir is to continuously cut the plant before sporing (twice a year) to weaken the rhizome although this make take a number of years.
Soft Rush *Juncus effusus*	Soft rush is highly prevalent in the UK and particularly in Wales. Soft rush is a perennial herbaceous flowering plant and favours wet or marsh land. At the height of growth around water courses it can be found to be 1.5m in height. Soft rush is not a fodder species and is little grazed by common agricultural animals due to its unpalatability. It is more favoured as a habitat for insects and nesting birds and is therefore highly important in

Biomass (feedstock)	Description
	wetland reserves alongside purple moor grasses. It however is particularly noticeable in Wales, and has become an invasive species, rapidly taking over pasture and requiring mitigation. Harvesting soft rush can be problematic due to the environment it grows in however with its encroachment onto pasture it can be better controlled. In some cases used as bedding, rushes can be topped before seeding and then baled for removal or further use.
Rhododendron *R. ponticum*	Rhododendron is a genus of 1000+ species of woody plants, that can be evergreen or deciduous. Although relatively native to the UK, the species *R. ponticum*, which is most prevalent, had been reintroduced with human interaction. It easily naturalises and becomes a pest in some situations covering whole hillsides. This has been a particular problem in West Wales and Snowdonia with its roots and abundant seed production propagating it with ease. Rhododendron control is considered a key element in nature conservation with large areas flailed and cut down followed up with herbicide spraying. It is even reported that the nectar of these Rhododendron plants are toxic to European honeybees containing grayanotoxins (a group of neurotoxins). Complete removal is essential from clearance as the vegetation can form a toxic layer, reported to retard the new growth of other plants.
Fruit Stones (Cherry)	Fruit stones are a waste by-product of a number of industries. They are a waste produce from the food production and alcohol fermentation industries. Due to their nature, they are not readily compostable and have no significant further use. The are however readily available and easily transportable and can be used in combustion processes to make heat and power. Fruit stones are also an excellent candidate for biochar due to their uniform size eliminating the need for end processing through pelletisation.
Nature Conservation Hay	Nature reserves manage their land differently to conventional pasture lands. Material taken from the lands are usually from a late cut, after flowering and seeding has taken place and well after organisms have made use of the habitat. This material could be used as fodder however is nutrient poor, and of a more woody nature. It can also be seen to be ‘contaminated’ for example nature conservation hay harvested in Wales for the IFBB project contained significant ragwort (Jacobiea vulgaris). Ragwort is a divisive species, blamed for deaths of animals however considered vital by some for pollinating insects.
Green Cut	Green cut, from urban or rural situations, pertains to the maintenance of green spaces. Not harvested at their peak like hay or silage, they are a mixture of grasses and small herbaceous plants and regularly cut and disposed of. In the UK this is generally cut and left to mulch on the ground however is also often composted as a mono-culture nearby. Cutting is predominantly during the fairer weather months with lower volumes in wintertime. In some cases the material is considered as a waste product which needs to be pre-treated before use.

Biomass (feedstock)	Description
	Contamination can be through litter, leachate from surrounding farmland, exposure to products of combustion from traffic and the road surface and through general usage including faeces. In Baden-Baden the material has to be cut and collected which is then treated at the municipal treatment works through either IFBB or composting. Whilst low in cellulosic material, fresh green cut tends to be high in water soluble sugars and starches and are thus idea for the IFBB process to generate heat and power. Baden Baden is a small town in Germany and has a population density of around 55k people. This area produces around 12,000t of green cut annually.

Average Chemical Properties of Biomass Types

Biomass	DM	Ash	C	N	S	K	Cl	Lignin
	%	%	%	%	%	%	%	%
Roadside Verge	54.67	12.84	44.27	2.12	0.24	2.51	0.72	7.39
Japanese Knotweed Young	26.01	7.13	47.44	1.03	0.11	1.61	0.55	12.73
Japanese Knotweed Old	59.54	12.40	43.89	0.44	0.06	<0.60	<0.10	22.92
Small Wood Particles (soft)	69.5	1.30	35.35	0.20	0.27			
Small Wood Particles (hard)	88.10	2.92	43.06	0.36	0.07		<0.10	
SRC (energy Willow Phyllis)	49.90	0.90	24.85	0.35	0.02			
Gorse (leaf)[17]		6.10	45.90	2.19	0.49			
Gorse (stem)		4.35	44.50	1.51	0.51			
Horticultural Compost								
Molina	10.26	2.60	47.62	0.87	0.10	0.20	0.07	8.96
Bracken	31.96	5.36	47.53	1.08	0.13	0.79	0.54	31.61
Juncus effusus	35.95	3.33	46.69	1.42	0.15	0.82	0.43	6.70
Rhododendron								
Fruit Stones	95.92	0.84	54.36	0.52	0.11	<0.35	<0.05	42.12
Nature Conservation Hay	51.35	6.62	48.01	1.92	0.22	0.65	0.18	6.11
Green Cut	16.17	14.18	46.22	3.14	0.26	2.67	0.32	8.28

Heating Values of Biomasses

The heating value is one of the most important thermo-physical parameters which can describe the energy potential of materials. This parameter can be the basis for assessing the quality of the fuel as an energy source. The higher heating vale (HHV) is determined by the amount of heat released by a specific quantity of medium – initially at 25°C - and the end products of combustion are returned to 25°C. HHV is useful in calculating heating values for fuels where condensation of the reaction products is practice. HHV assumes all water is in a liquid state at the end of combustion and that the heat delivered at temperatures below 150°C can be put to use.

17 D.F. Osorio-Castiblanco et al, Physiochemical Analysis and Essential Oils Extraction of the Gorse and French Broom, Sustainability, 12 (2020) 57

The lower heating value (LHV) appears much more important and is associated with the moisture content of the medium and its energy potential depends on the medium chemical composition. LHV is also known as the net calorific value. LHV calculations assume that the water component of combustion is in a vapour state at the end of of the process and is therefore subtracted from the HHV. LHV takes into account the energy required to vaporise water and is not released as heat. It is useful in comparing fuels where condensation of combustion products is impractical, or heat at a temperature below 150°C cannot be put to use.

The lower heating values of the species detailed by REDIRECT were examined. For some species, where practical, the LHV of the IFBB press cake was examined. This press cake is formed firstly by taking the raw biomass through a 40°C mash stage to mobilise the sugars and starches, and then pressed through a screw press to remove as much liquid phase as possible.

Biomass (feedstock)	Low Heating Value Silage / Raw Biomass LHV (MJ/kg Dry)	IFBB Press cake LHV (MJ/kg Dry)
Roadside Verge	15.2	15.9
Japanese Knotweed Young	15.5	16.3
Japanese Knotweed Old	14.7	16.6
Small Wood Particles	15.1	n/a
Small Wood Particles (soft)[P]	12.0	n/a
Small Wood Particles (hard)[P]	15.5	n/a
SRC	12.6	n/a
RC (Willow)[P]	7.97	n/a
orse	16.0	n/a
Horticultural Compost	10.8	n/a
Molina	16.1	17.0
Bracken	16.0	17.3
Juncus effusus	15.5	16.8
Rhododendron	16.0	n/a
Fruit Stones	19.8	n/a
Nature Conservation Hay	16.5	17.0
Green Cut	15.2	16.6

P – Phyllis Database

Appendix F   Proposed operational scenarios for a biomass hub in the Newtown area.

We have proposed three possible solutions for the hub solution in Newtown, to be examined in more detail in the next stage of the feasibility work. Two of these incorporate AD as part of the process, and one does not. These solutions are:

A. Anaerobic Digestion of sewage sludge (with or without IFBB) + Pyrolysis
B. Non AD solution
C. Anaerobic digestion of high energy feedstock, non-AD solution for low energy feedstocks, Pyrolysis of sewage sludge.

A fuller description of each scenario is as follows:

Scenario A: Anaerobic Digestion (With or without IFBB) + Pyrolysis

Scenario A has a new anaerobic digestor and CHP built at the Newtown Sewage works, together with a pre-processing IFBB plant to increase the energy content of the digester feedstock by adding high energy content material so that the biogas yield could at least cover all the energy use on site. This scenario envisages the import of green waste and poultry litter to the site to be added to sewage sludge to improve the viability of on-site anaerobic digestion.

This is dependent either on the regulatory conditions changing to limit the amount of poultry litter from poultry farms that could be spread to land in an untreated form OR on the economics of the upgraded treatment plant justifying a payment for the additional feedstock, based on accessible energy content.

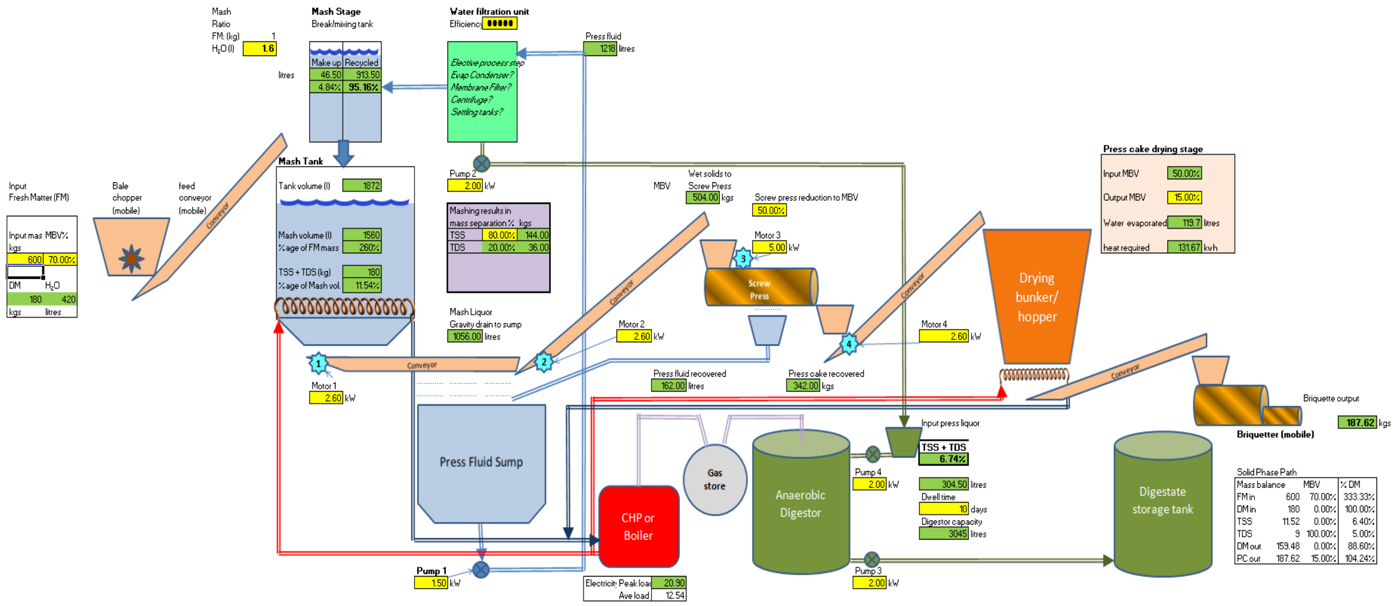
Green waste is separated from the woody fraction by shredding and using a star-screen separator plus a grading sieve. The green fraction is mixed with leaves and grass cuttings and ensiled to allow for partial fermentation and storage. Poultry litter would need to be stored in a container on site at the farm and despatched when full to the processing plant. When required the ensiled green material is opened and mixed with poultry litter and then finely chopped or shredded, before addition to the digester, the design of which must include a grit separator to ensure continued effective operation.

Alternatively, if the plant operators want to exclude as much solid material from the digester as possible, an IFBB pre-treatment stage can be added. This will involve placing the ensiled green matter and the chicken litter into a warm-water solution at a ratio of 4:1 for a short period to mobilise the constituent elements, prior to maceration. Depending on the design the macerator, this can also allow for grit and sediment to drop out of the solution and be removed from the process before entering the digester. The resulting material is fed through a screw press to separate the solid and liquid fractions and the resulting liquor can be further concentrated using an evaporator to drive off <75% of the water which can be returned to the front of the process. The remaining liquid concentrate can then be added to the sewage sludge in the biodigester to increase biogas yield.

Where this process has been used in a municipal plant at Baden Baden in Germany (in this case using food waste instead of poultry litter) the resulting increase in gas yield changed the output from the on-site combined heat and power plant enabled the facility to go from importing 25% of its unmet electricity needs from the grid to exporting a surplus of 25%. This process was originally developed at the Department of Grassland Science and Renewable Plant Resources at the University of Kassel and has been the subject of three successive development projects under the Interreg North West Europe programmes, in which the authors of this study have been directly involved. The process is known as IFBB which stands for the integrated generation of solid fuel and biogas from biomass.

The solid fraction of the blended wastes ejected from the screw press (known as press-cake) will contain the ligno-celulosic fibres from the green waste and the poultry litter and can be dried and blended with compost as a Peat substitute (following sterilisation), or added to woodchip and pyrolised to produce a biochar.

If a pyrolysis kiln is co-located with the IFBB plant, then the excess heat can be used in the liquor evaporation stage, for sterilisation of press cake or compost and for drying the press-cake fibres and woodchip.



Schematic diagram of a farm-scale IFBB pre-processing plant

Recent research from the Wales Centre of Excellence for Anaerobic Digestion has shown that the removal of Ammonia from the material in a biodigestor has also resulted in an increase in gas yield[18]. A Struvite precipitation reactor could also possibly be inserted in the IFBB process between liquid separation and evaporative concentration to further pre-condition the liquid concentrate prior to anaerobic digestion.

This scenario uses anaerobic digestion as the tried-and-tested method of degrading the organic fraction of the sewage sludge, and increases the efficiency of the digestion process by introducing a higher energy waste-derived concentrate to reach an operating optimum. The design of the Anaerobic digester is important and will be dictated by the assessed energy requirement to make the STW sewage plant self-sufficient, and also whether the digester will need to cope with additional solid material or only an additional liquid concentrate. An example we have investigated is an on-farm digester located near Wrexham.

The on-farm 160kW biodigester at Lodge Farm, near Holt in Wrexham has been operating for about 8 years. This design incorporated several (then) novel features in its design that drew on experience of problems with sewage sludge digesters. The authors visited the plant as it was being commissioned in 2011 and discussed the features with one of the technical advisers with whom we have worked on other projects. One of the important features was a grit trap cast into the floor of the reactor vessel into which debris was swept by the rotating agitator arm at the bottom of the vertical drive shaft that runs up the centre of the vessel. This sweep arm also includes gas nozzles that feed biogas back into the base of the substrate to help mix it and prevent stratification.

[18] Dave to insert citation from Sandra Esteves

The grit trap has a double lock valve arrangement incorporating an inner valve which opens allowing slurry to propel grit deposits down the drain channel. This valve is then closed and the outer valve opened to allow discharge of the grit and slurry. Grit and stones are a problem with cattle slurry as they can be picked up on the hooves of cows and deposited in the shed or milking parlour and swept up with the manure slurry collection system. Chicken litter will also contain grit from the birds crops consumed as part of their diet to enable digestion of cereal grains.

Fre-Energy make the following claims on their website[19]

At Holt, to ensure that the slurry was delivered to the digester as fresh as possible, a separate lagoon was constructed within the larger storage lagoon at the farm in order to store the slurry and pump it underground to the digester half a mile away on a fortnightly basis. This provided a clean and convenient solution as an alternative to transporting the slurry either across the land or by road.

Day to Day Resources : *The operation requires about 2 hours daily spent loading the feedstock into the digester and simple maintenance of pumps and mixers etc. Current inputs are 30 tonnes of cow slurry plus 6 tonnes of chicken litter from a local broiler unit*. (This translates to about 10kT per annum cattle slurry and about 2200 tons of chicken litter)

Outputs

Energy Production : *The outputs are 160kW of electricity and 200kW heat.*

- *Approx 30kW electricity is used on site to power the engineering business, the Fre-energy office, and a large 7 bedroom farmhouse.*
- *Approx 60kW of heat is used to heat the cow slurry and chicken litter in the digester up to 40°C and the rest is used to heat the house and office.*
- *The surplus of the electricity is exported to the National Grid*

Digestate Usage : *All the digestate goes through a separator. The liquid is stored in a lagoon that has 6 month storage capacity and from there it is spread onto the grassland using either umbilical cord through a spike aerator followed by a low level trailing shoe or by a 3000 gallon low ground pressure Vaccy tank with the same system attached. The solid digestate, which contains a higher proportion of the phosphate and potash, is transported by road to land used for growing winter crops to feed the dairy herd.*

Several allotment owners in the local village have used this product and have been so impressed that we could market it for a substantial sum. Trial work done by Bangor University has demonstrated that the BOD [biological oxygen demand] of both these products is reduced by up to 90%. This represents a substantial environmental benefit.

As a design, the system appears to work well and has not suffered (as far as we know) from some of the shortcomings of designs at other agricultural sites in Wales and the border counties. The operators note that much of the Nitrogen (N) stays with the liquid fraction, whilst the majority of the Potassium and Phosphorus (K,P) stays bound to the solid fraction. Anecdotally, the low amounts of heavy metals encountered are only detectable in the discharge from the grit trap, the assumption being that they gravitate to the lowest point in the system with the heavy particles.

[19] http://www.fre-energy.co.uk/lodge-farm-development.html

The authors have encountered a similar phenomenon when undertaking a research project for the Welsh Government in 2014/15 on the effect of the IFBB process on road leaf sweepings[20]. Here the groups of contaminants being tracked were heavy metals and Polycyclic Aromatic Hydrocarbons (PAH's). We found that, contrary to expectations, the heavy metals remained with the grit, sand and sediment in the bottom of the primary stage wash tank, whilst the PAH's seemed to adhere to organic tissue of the leaf fragments that were removed by agitation and sieving. A comparison of leaf debris material that was processed fresh and that which had been sealed in air-tight containers (ensiled) was also made. Again of interest was the observation that the levels of PAH's dropped markedly after ensilement.

The advantages of anaerobic digestion of manures and slurries are stated on the Fre-Energy website: *"Environmental Advantages of the Fre-energy Closed Loop System: A waste digester that utilises farm derived inputs and then returns those inputs back to the land in the form of digestate is a closed loop system. Lodge Farm does not import any artificial fertiliser to grow grass or crops; it is completely served from the outputs of the AD. Another benefit is that any weed seeds that enter the digester are no longer viable when returned back to the land. The other social benefit is that digestate has ~80% less odour than straight cow slurry, thus making the spreading of manures far more socially acceptable."*

The objective here is to prevent fugitive losses of CH_4, NH_3 and N_2O from the manures and transfer as much of those elements to the soil as possible. However, as stated elsewhere, we now know that the fluxes of these greenhouse gasses do not cease with application to soil, which is itself a biodynamic environment. Aside from the beneficial treatment of agricultural wastes, the economics of the on-farm digester are finely balanced. The value of the net energy production of the plant (after deducting heat and electricity requirements for parasitic load) depends on offsetting the cost of importing that energy to site for running other parts of the operation.

During the period when Feed-in Tariffs applied to on-farm AD, these, together with the sales of electricity to the grid made for an economically viable operation. Since the end of subsidies and most forms of capital grant, the value for money equation becomes more complex.

If we are to propose the use of an AD plant to treat sewage sludge on-site for STW at Newtown, then the cost savings on displacing imported electricity, need to be carefully considered against the costs of bringing in additional feedstock to enable sufficient biogas to be produced to create enough power to meet the needs of the whole plant. Alternatively if local commercial partner can be found in the area, any surplus power could be sold under a Private Purchase Arrangement giving an increased value above that of selling into the grid.

Scenario B: (Struvite + Pyrolysis) and (Composting + Pyrolysis)

Scenario B is a twin-site operation with sewage sludge being treated at the existing works by a twin-stream pyrolysis unit and woodchip being imported to produce biochar and to provide sufficient heat release. The second site could be located on a local farm and would take in the green waste arisings from Open Newtown and from commercial landscape contractors and would also use animal manure and bedding in a rotary In Vessel Composter to produce high quality compost into which Struvite and Biochar could be blended.

This scenario focuses on creating products which are primarily intended as replacements for artificial fertilizers produced using fossil fuels. The objectives are to displace emissions from fossil fuels, to capture fugitive emissions of

[20] The Conversion of Street Leaf Sweepings. Dr D. Ellis and C. Keyse, edited Dr David Tompkins. WRAP COL012-000 Published February 2016

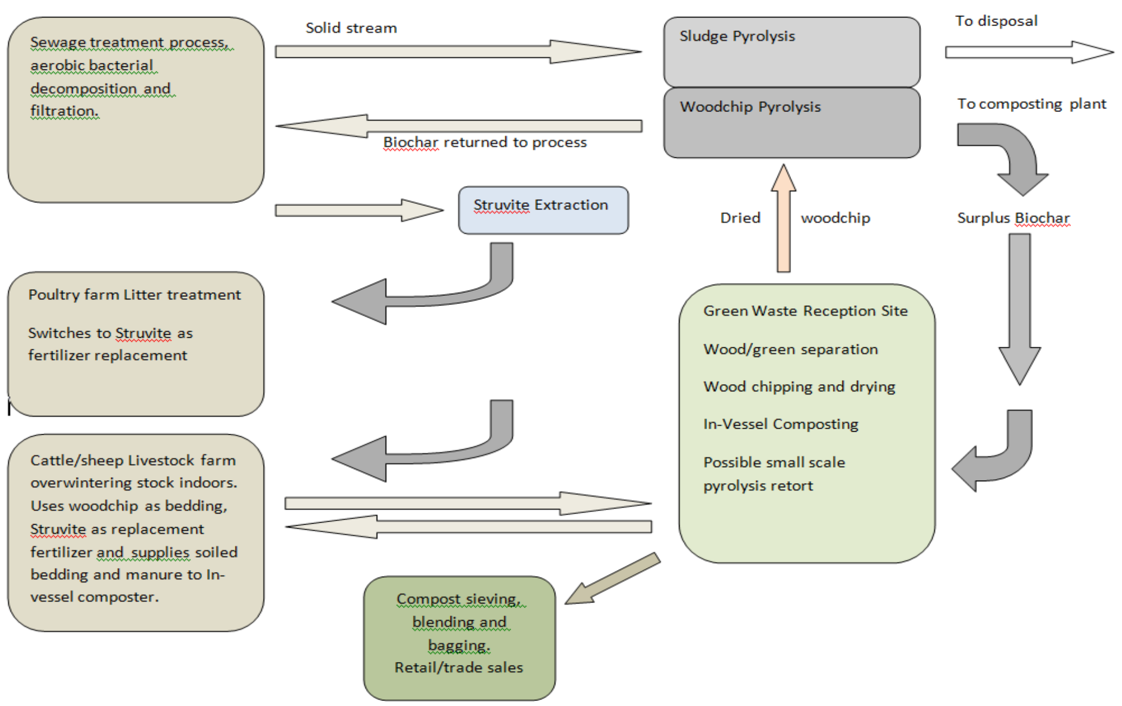
Ammonia and NO_x and to create products which benefit the long term health of soils and reduce leaching of Nitrates and Phosphates to water.

This scenario involves the deployment of one or more struvite precipitation reactors in the waste water treatment works and also possibly to extract the Ammonia from poultry litter. This could be either by bringing the litter material to the precipitation plant at the sewage works site, or by having a mobile processing unit which could be moved from location to location, processing batches of material at each site. The technology, a version of which is manufactured by Canadian firm Ostara[21], has been deployed at the Thames Water facility in Slough since 2013. The solid residues of both waste streams, sewage sludge and poultry litter, will both still contain grit and sand as well as the remaining organic fraction.

These can be pyrolised or incinerated, but incineration would have to be undertaken at a licensed facility outside the locality. Pyrolysis could take place on-site as there would be no emissions to atmosphere and the resulting char could be used in a construction product in a similar way that fly-ash has previously used in making concrete blocks.

If the pyrolysis plant were a dual-stream kiln with the sludge + litter residue being pyrolised in a separate chamber from woodchip, then better management of the process heat between the two retorts could be achieved and the excess, high grade heat used in another process, for example evaporation to increase the output of the struvite reactor. To avoid unnecessary transport, only the amount of woodchip required to make the duel stream kiln run at optimum efficiency would be imported to the site, and the residual biochar from the woodchip added back into the sewage treatment process.

Elsewhere, the Open Newtown project's own green waste arisings together with material from commercial landscape management contractors could be processed to create compost and woodchip. It is proposed that a continuous feed rotary composter be developed, by adapting successful small scale designs such as the Rocket composter, to handle material at this intermediate scale. In order to create a year-round output of compost, consideration should be given to finding a livestock farm in the area that would be prepared to rent an area on which to



[21] Ostara Struvite extraction https://ostara.com/nutrient-management-solutions/

operate this facility. During the winter months when green waste arisings dropped to a minimal level, the inputs could be replaced by soiled bedding and manure from livestock housing. The process would be fully automated and able to be supervised at intervals by farm staff in between other jobs.

Some of the woody fraction of the green waste from Open Newtown, together with prunings from landscape contractors and possibly chip from hedge cutting (if a cut and collect vacuum head system were used with a flail mower) could be stored throughout the year and sold to the farmer as bedding material for livestock and would also help with the C/N balance of the input to the composter. Excess woodchip could be diverted to the twin stream pyrolysis kiln at the sewage plant, or fed to a small scale rotary hearth style kiln on the farm to produce clean biochar to add to finished compost as required, and to provide high grade heat either to the farm or to sterilise the finished compost prior to bagging.

The struvite product could be supplied back to both the poultry and livestock farms to replace artificial NPK fertilizers, and the compost could be finished and bagged for sale at the farm gate to the retail market giving optimum revenue generation.

Scenario C: Integrated Biomass Processing Hub (IBPH)

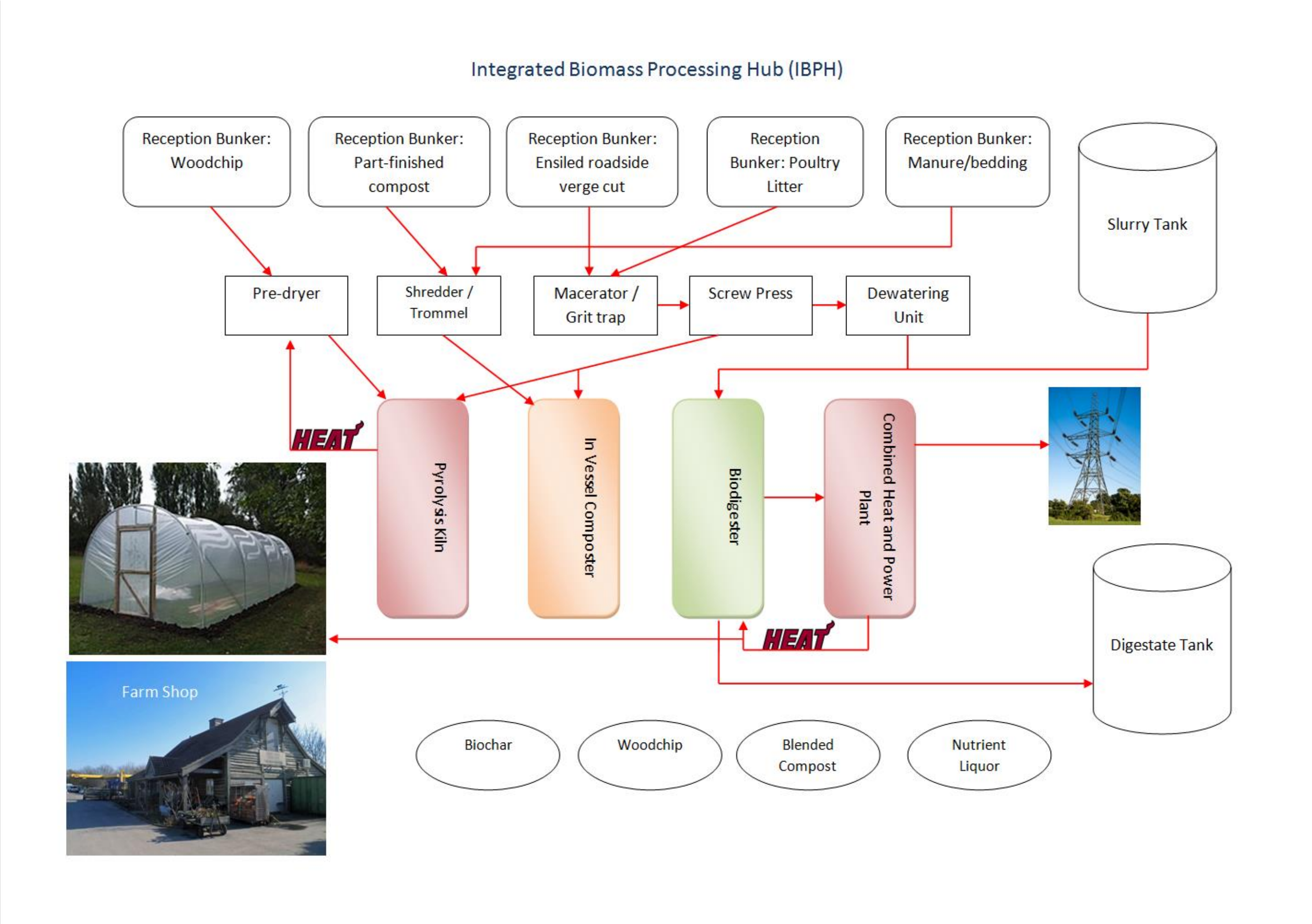
Scenario C is an amalgam which concentrates a complete suite of processes in one location to make optimum use of process energy, staff time and infrastructure, but which excludes sewage sludge which would be kept separate and processed by Pyrolysis.

The other principle being introduced here is that of market integration – off co-locating other agricultural and horticultural businesses together with a direct sales outlet to the general public for the final food and non-food products. Whether all the processing options would be included in the final version is a matter for further analysis but the scenario does have the potential to sustain additional employment in the related business by having posts which could cover a number of roles in different parts of the operation.

Normally a recommendation is based where possible on the proximity principle to minimise unnecessary transport and to make optimum use of shared infrastructure and energy. The distribution of the potential partners in this local network means that each of the previous three scenarios contains, to some extent a number of compromises; none are perfect. In order to move to a firmer recommendation we also need to consider the end market(s) for the products or services this network can serve and derive income from.

The final scenario is a little bolder in that it creates a centralised location into which materials are transported and where a suite of processes can operate side by side, sharing infrastructure, energy and staff time. It also includes an on-site down-stream market for some of the outputs which enable further value to be added to the operations.

The concept relies on taking in waste material preferably with as much contamination pre-excluded as possible and using one of several approved processes to create post-waste products and energy. Surplus energy from one process can support the pre conditioning or finishing of a product elsewhere in the system. Waste low-grade heat, CO_2, compost, digestate, biofibres, woodchips, biochar and struvite can all contribute to food production through horticulture (at field scale, under cover and in controlled environments) and livestock rearing. If the location also includes a retail outlet at the 'farm gate' then there is the opportunity to capture the additional mark-up from wholesale to retail price for at least some of the outputs. A dairy farm or beef farm that overwinters cattle indoors might be a suitable host location. The cluster might look like this:



To give an example of possible material flows: Poultry farms are encouraged to introduce locally produced biochar into their poultry litter to reduce bacterial loading, the need for antibiotics, and to suppress the release of NH_3 The waste litter is sealed in containers prior to transport and then shipped to the IBPH, where it passes through a pre-treatment grit separator and macerator prior to co-digestion with ensiled shredded green waste or road verge/park cuttings and the resulting slurry passed through a screw press to separate fibres from liquid. A dewatering stage might be inserted here to increase the energy concentration of the liquor prior to it being mixed with cattle slurry in the case of a dairy farm.

Woodchip separated from the green waste and recovered from seasonal hedge cutting etc. can be dried and sold as winter bedding in the case of a beef/sheep livestock operation and the resulting manure/chip mixture added to a continuous feed In Vessel Composter together with any soil contaminated green waste or part-finished municipal compost to create a good quality compost for horticultural use. Some of the woodchip can also be converted to biochar in a small batch-fired kiln to supply the poultry units and if the source material is a virgin non-waste biomass to use as a feed supplement for ruminants. Excess heat from the pyrolysis kiln can be used to dry more woodchip. Waste heat and CO2 from the Biogas CHP can be used to heat and flood the greenhouses/polytunnels. Various permutations of this cluster could be created based on the economics of the various process streams.

An indicative budget is provided in Appendix 3 as a guide to the possible capital and operating costs of an IBPH purely for illustrative purposes. The actual layout, selection of equipment and costs will need to be developed further following the production of a more in-depth business plan.

This proposal does not deal directly with the treatment of sewage sludge from the Newtown STW treatment works. At present this material is being transported out of area, but it could be treated as a separate material stream at the proposed IBPH. The recommendation here is again to use twin-stream pyrolysis as the treatment method to produce a 'contaminated' biochar material. This could be incorporated into building and construction materials in a small-scale manufacturing operation so that the elements contained in the material were effectively sequestered or 'locked up' in the product for many years. As such, there is the possibility that such products could generate Carbon sequestration credits such as those being traded by the Carbofex exchange in Finland.

The relative suitability of each of these scenarios will depend on the economics of the system and the willingness of the partners to adapt their working practices and share the benefits via collaboration. It is unlikely that any of these systems will work without a co-operative approach where one partner could monopolise the benefits at a single point in the system.

Regulatory constraints on mixing waste streams

During the project to evaluate the processing of street leaf sweepings undertaken for WRAP, the authors used the table of permissible contaminant levels of sewage sludge as a guide to threshold levels of Heavy Metals and PAH's in material that could be spread to farm land.

In researching this work, we were made aware of the position of the regulator, Natural Resources Wales in regard to the treatment of wastes to enable them to pass these controls. The regulator's thinking in relation to the creation of a post-waste material by an approved mechanical, thermal or biological treatment process is that separation and capture, or modification of contaminants is acceptable, but that dilution of contaminants by mixing with larger volumes of uncontaminated waste is not. The mingling of a contaminated waste with an uncontaminated stream, does not reduce the contamination, it increases the amount of contaminated material.

This poses problems for the use of animal slurries and manures which can, if processed by anaerobic digestion to reach the standard set out in protocol PAS110, be classified as a post-waste product under the EU waste framework directive as transposed into UK law. The addition of sewage sludge with persistent levels of contaminants is however, likely to make PAS110 unachievable – meaning that there is a much larger volume of contaminated waste to be dealt with.

The increase in the volume of road traffic as a result of bringing in more material to be digested at the Newtown STW site, as well as taking the larger combined volume out again, would seem to create an additional burden for the operation that may be difficult to justify both in economic and public relations terms.

Appendix G Carbon Tracing & Life Cycle Analysis

An important aspect of this project that is different from a standard AD proposal is that the intention is to optimise for carbon outcome as well as financial outcome. It is important therefore to understand the relative carbon locking potential of each process.

Full carbon life cycle analysis (LCA) is a very complex process, beyond the scope of this project proposal, but one that will be a high priority for the detailed feasibility study. Appendix E looks at the specific issues around AD, composting, incineration and pyrolysis, and contains an overview of the considerations that will need to be taken into account in this analysis.

Part of the complexity is that for each of the technologies, there are a multitude of issues that would need to be addressed. These include:

In the case of AD:

- Transport
- Mechanical processing
- Emissions from storage
- Emissions from mitigation of end products before use (e.g. pasteurisation of AD liquor)
- Emissions from removal of waste
- Leakage of CH_4 etc from the process plant
- Continued production of CH_4 after ejection from the digestion tank
- Long term breakdown of digestate once spread to land
- saved carbon resulting from displaced electricity generation

Other processes are similarly complex, in the case of simple composting, the issues include:

- Transport
- Mechanical processing
- Gases produced during the process (mix of CO_2 , CH_4 and others)
- Longevity of the carbon in the soil when spread as compost (this will depend on how and where it is used)
- Carbon saved as a result of the enhanced soil properties (more rapid growth, greater crop yield)

inevitably since the issue is so complex there will need to be approximations and simplifications made, but the investigation would take a high level view to make sure that the size of the wood was not missed in the detailed examination of each tree.

In addition, it would be a mistake to assume that once organic Carbon has been applied to soil it becomes inert. There is a large body of evidence to indicate that the various types of topsoils and the interaction between organisms operating both above and below the surface is extremely complex. The roles of soil bacteria and fungi in modifying soil pH, breaking down minerals, moving nutrients around and combating plant and animal diseases is not yet fully understood but the introduction of organic Carbon to soils will cause numerous interactions. As a generalisation, ‘healthy’ soils and their supported vegetation have a critical role to play in the ongoing draw-down of atmospheric Carbon, and the introduction of Carbon in the form of biochar needs to be considered as a catalyst and applied intelligently.

The intention for this feasibility study would be to access existing research to answer the question “How does AD stack up, in a real world implementation, against other types of organic material processing, in a comparison of the total climate change impact.”The route of carbon – existing as captured carbon and emissions— throughout each process step is a complex matter. Often the greenhouse gas (GHG) emissions and how macro and micro elements are traced is through a life cycle analysis (LCA) of the process. This however adds complexity as strictly speaking, LCAs are performed on a cradle-to-grave basis. This makes each LCA for each process rather unique to its individual setting and a complex calculation based on a wide variety of parameters.

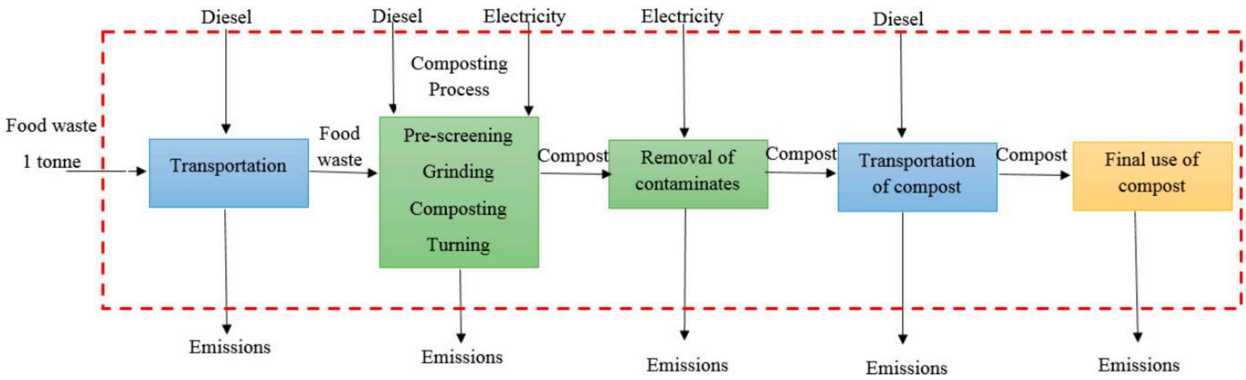


Figure 1: Windrow Composting Boundary

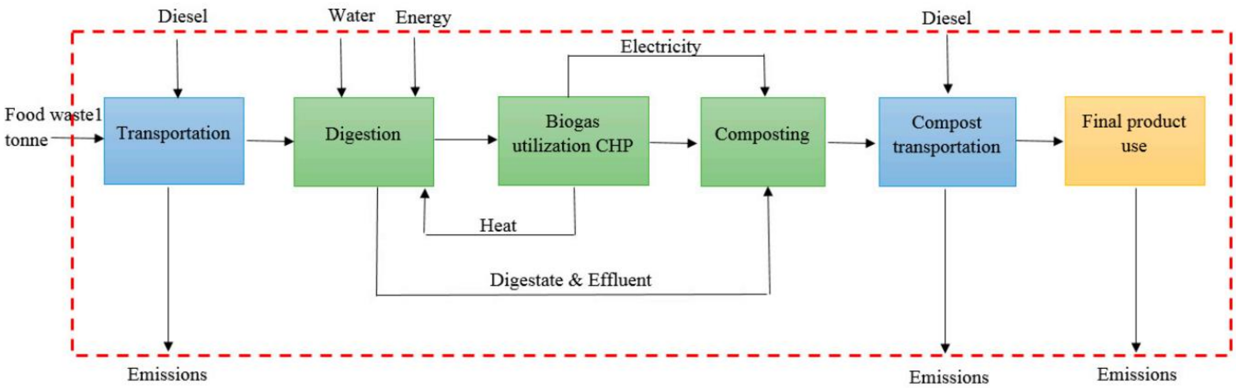


Figure 2: Anaerobic Digestion – Composting Boundary

Purely as an example, the boundary of the process must be set before considering 'where does the carbon go'. Al-Rumaihi et al[22] illustrated, in figures 1 and 2 above, the complexity of the LCA when considering where to draw the line to assess the components causing emissions. This can be further extrapolated into a qualitative method giving a breakdown of what each of the GHG and associated emissions are. Figures 3 and 4 below illustrate this process for both windrow composting and for a combined AD – Composting situation.

22 A. Al-Rumaihi et al, Environmental Impact Assessment of Food Waste Management using Two composting Technigues, Sustainablity, 12, 2020, 1595

Process	Input	Amount	Unit	Output	Unit
Collection and transportation	Food waste	1	tonne	Diesel emissions: CO_2, CO, NO_x, SO_2, CH_4, N_2O, PM10, Hydrocarbons	kg
	Diesel	90	kg		
Loading	Food waste	1	tonne	Diesel emissions: CO_2, CO, NO_x, SO_2, CH_4, N_2O, PM10, Hydrocarbons	kg
	Diesel	0.46	kg		
Pre-screening	Food waste	1	tonne	Electricity emissions: CO_2, CO, NO_x, N_2O, PM, PM10, PM2.5, SO_2, SO_3, CH_4, TOC, VOC, N_2, Ar, O_2, H_2O, 1,3–Butadiened, Acetaldehyde, Acrolein, Benzene, Ethylbenzene, Formaldehyde, Naphthalene, PAH, Propylene, PAH, Toluene, Xylenes	kg
	Electricity	1.8	kWh		
Grinding	Food waste	940	kg	Diesel emissions: CO_2, CO, NO_x, SO_2, CH_4, N_2O, PM10, Hydrocarbons	kg
	Diesel	0.15	kg		
Composting	Food waste	940	kg	Diesel emission: CO_2, CO, NO_x, SO_2, CH_4, N_2O, PM10, Hydrocarbons	kg
	Diesel	1.07	kg	Composting emissions: CH4, N2O, NH3	
Curing windrow turners	Compost	330	kg	Diesel emission: CO_2, CO, NO_x, SO_2, CH_4, N_2O, PM10, Hydrocarbons	kg
	Diesel	0.11	kg		
Post-screening + removal of contaminants	Compost	330	kg	Electricity emissions: CO_2, CO, NO_x, N_2O, PM, PM10, PM2.5, SO_2, SO_3, CH_4, TOC, VOC, N_2, Ar, O_2, H_2O, 1,3–Butadiene, Acetaldehyde, Acrolein, Benzene, Ethylbenzene, Formaldehyde, Naphthalene, PAH, Propylene, PAH, Propylene, Toluene, Xylene	kg
	Electricity	0.9	kWh		
Transportation of product	Compost	330	kg	Diesel emissions: CO_2, CO, NO_x, SO_2, CH_4, N_2O, PM_{10}, Hydrocarbons	kg
	Diesel	0.46	kg		
Windrow composting Final use	Compost	330	kg	300 kg Compost consisting of nitrogen, phosphorus, and potassium	kg
	Artificial fertilizer (avoided)				

Figure 3: Windrow Composting Inventory

Process	Input	Amount	Unit	Output	Amount	Unit
Collection and transportation	Food waste	1	tonne	Diesel emissions: CO_2, CO, NO_x, SO_2, CH_4, N_2O, PM_{10}, Hydrocarbons		kg
	Diesel	14.57	kg			g
Anaerobic digestion	Food waste	1	tonne	Biogas	150	m^3
	Energy for feedstock preparation	11.25	kWh	Digestate	0.85	tonne
	Heat for digester	19.25	kWh	Effluent	0.57	tonne
	Water	0.5	tonne			
Biogas utilization	Biogas	148	m^3	Emissions from biogas use: NMVOCs, NO_x, CO, PM, SO_x, HCL, HF		Kg
				Electricity	178.1	kWh
				Heat	120.9	kWh
Composting	Energy from biogas utilization	9.52	kWh	Compost	225	kWh
	Air	0.9	tonne			kg
	Digestate	0.85	tonne	Emissions from composting: CH_4, N_2O, NH_3		kg
	Effluent	0.57	tonne			kg
Transport of compost (product)	Compost	255	tonne	Diesel emissions: CO_2, CO, NO_x, SO_2, CH_4, N_2O, PM_{10}, Hydrocarbons		kg
	Diesel	4.56	kg			kg
Final use of compost	Avoided product (inorganic fertilizer)			Compost consisting of nitrogen, phosphorus and potassium	225	kg

Figure 4: Anaerobic Digestion Combined Composting Inventory

This illustrates here the careful need for considering all the outputs. The Newtown project itself appears to need a combination of technologies and, to realise local potential, cast a wider net capturing local problem wastes. On top of that, technologies have impacts requiring transportation, processing and other factors which can add to emissions.

E.g. Some local authorities do not have AD facilities able to take food waste, or that it is more cost effective to sub-contract the collection and mitigation. In this case, food waste can be transported up to 150 miles – before – any gains are made with processing through AD. Aptly dubbed Green Freight Math in the US, we can illustrate that:

1. An average waste load of 20 tonnes will equate to **3000** tonne miles for each load transportation.
2. The average freight truck (US) emits **161.8g** of CO_2 per ton-mile.
3. So, for each journey there is an emission of **0.5** metric tonnes of CO_2 for this one move.
4. In 2018, the combined total food waste[23] to make this journey was **366t**
5. Therefore there is a yearly average of **9 metric tonnes of CO_2 emitted**.

1% of the total emissions 'saved' is lost in this single one-way journey to move the waste. This does not include curbside collection, return journeys, storage processing etc...

What does this mean for Newtown

Envisioned are a series of technology options, process steps, potential partners and thereafter scenarios based around an overview of a model business plan. A full true LCA can only take place at the end stage, when all parameters are known, and understood, and can be part of an emissions/life cycle analysis into a business plan. This needs to set the boundaries as below in figure 5:

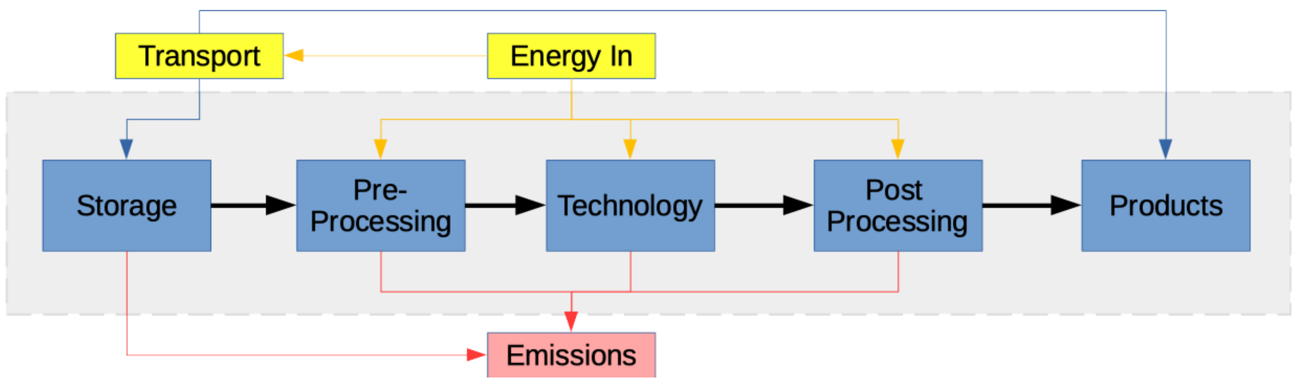


Figure 5: Example Boundary Diagram

We can however break apart the boundaries and examine each technology option in absentia. Whilst not giving the 'overall' balance for emissions, they will show the routes and pathways of a general breakdown. It must be kept in mind however that the gains made in environmental savings on this surface level are not negated by the additional processes needs up, or down, the process scale.

23 myrecyclingwales.org.uk

Windrow Composting

Windrow Composting, or in fact any iteration of composting, is not a simple equation as to say 'if I put X in, Y & Z come out. To be an effective composting process the moisture content needs to be controlled which may entail adding water, the materials need to be mixed effectively which will release moisture and gasses and the temperature at such a level to promote breakdown.

With composting the 4 main gases released from decomposition are carbon dioxide, methane, nitrous oxide and ammonia. The IPCC considers CO2 emissions from degradation of organic material to be biogenic and are often not reported in accounting for the global warming potential.

On a purely mass balance basis for windrow composting, R Robinzon et al[24] found that in order to maintain a water content of windrow to 40% about 45% more water was required in a once a day turned windrow. Over 50 days, the energy generation by microorganism activity was found to be 2700 kJ/kg. J Anderson et al[25] demonstrated that for a 14 month long compost, the loss of carbon was 56% of the starting weight and of that 2.1% were losses from methane. Again, because of the biogenic nature, the only relevant parameters noted were from nitrogen based emissions.

An example of a mass balance from composting:[26]

<table>
<tr><th></th><th>Green Waste Composting</th><th>Mixed organic waste composting (50% green waste)</th></tr>
<tr><td>Starting mixture</td><td>100%</td><td>100%</td></tr>
<tr><td>End of ACT step</td><td rowspan="2">50-60%</td><td>60-70%</td></tr>
<tr><td>End of curing step</td><td>50-60%</td></tr>
<tr><td>Compost (under-screen)</td><td>30-40% (15mm screen)</td><td>20-30%</td></tr>
<tr><td>Over-screen (to be re-circulated)</td><td>10-30%</td><td>20-30%</td></tr>
</table>

Figure 6: Mass Balance of Composting Waste and 50:50 Green Waste/Food Waste

Carbon dioxide emissions are measured from windrow composting, although it can be complex due to the nature of the composting environment. To measure emissions from windrow, the composting has to be under more static controlled conditions which do not necessarily reflect an open windrow in a changing climate environment. CO2 emissions have been noted to be at around 250g of C/T dry weight.

Compost, although impractical, can be used as a larger scale agricultural fertiliser however tends to be lacking in available nitrogen for plant grown. Repeated use on the same land has a liming value, and can increase the organic matter in the soil. This changes the soil density allowing it to be less mineralised, more easily workable and with greater water retention properties.[27]

Anaerobic Digestion

AD is a much more closed system and thus easier to measure the parameters under its remit. Again, for this exercise we look at the mass balance of the system, rather than the life cycle assessment. AD is largely used for food waste digestion, as greener materials (in particular anything fiberous or woody) is not necessarily suitable for processing or co-processing. Green waste options are available, but require further mitigation steps (for example for IFBB).

The Ludlow AD plant in Shropshire operated on food waste:

24 R. Robinzon et al, Energy and Mass Balance of Windrow Composting System, Transactions of the ASAE, 43(5) 2000, 1253-1259

25 J.K. Anderson et al, Mass Balances and Life-Cycle Inventory for a Garden Waste Windrow Composting Plant, Waste Management and Research, 28, 2010, 1010-1020

26 M. Ricci et al, Technical Guidance on the Operation of Organic Waste Treatment Plants, ISWA, 2016

27 Digestate and Compost Use in Agriculture, WRAP 2016

- Inputs (yearly) 15,500t, of which 11,900t was biowaste and 4,500t of industrial and domestic water.
- Its gaseous outputs were 2,250t Biogas (Methane and carbon dioxide and GHGs)
- Its physical outputs where 12,000t, consisting of 11,900 Liquid and 69t of solids

A typical breakdown analysis of the gas from AD:[28]

Products	Composition %
CH_4	50-57
CO_2	25-50
N_2	1-10
H_2	0-1
H_2S	0-3
O_2	0-2

Table 1: The range of percentage composition of the products of biogas.

Yields in table 1 will be dependant on the feedstock composition and the dwell time in the reactor. Ingress of oxygen will promote aerobic bacteria action which will form more carbon dioxide.

Food waste as the primary source medium tends to be less carbon rich than grassy or lignatious materials and leads to lower methane gas yields. The economic model however for the majority of food waste digesters is not completely revenue from energy generation but a combination of gate fees and council contracts to meet waste diversion targets.

Feedstock	CH_4 Composition %
Cattle manure	50-60
Pig manure	60
Poultry waste	68
Sheep manure	65
Horse Manure	66
Grass	84
Wheat straw	78
Dried leaves	58
Barley straw	77
Beet leaves	84
Corn silage	55

Table 2: An example overview of gas yields from AD.

From work conducted by S Esteves et al[29] showed that for food waste, the total solids made up around 10-30% of the wet mass and that total carbon content of that solid fraction was around 30-50%. Therefore it can be assumed that food waste consists of approx 3-15% carbon.

28 A. Anukam et al, A Review of the Chemistry of Anaerobic Digestion: Methods of Accelerating and Optimizing Process Efficiency, Processes, 7 (2019) 504

29 S. Esteves, Food Waste Chemical Analysis, WRAP March 2010

Anaerobic digestion liquor however presents further problems. Whilst it is used widely as a fertiliser, in fact it has little other application, it is a bio rich and active material. Pasturisation processes are used as a kill step after the AD process however the material is significantly rich and bio-available so will rapidly be recolonised with bacteria. R. Nkoa reviewed the literature in his work which highlighted how rich the liquor is, but also how it contains a wide variety of GHGs.[30]

Parameters	Value range	References
DM (%)	1.5–45.7	Svoboda et al. 2013a, b; Teglia et al. 2011a, b; Gutser et al. 2005
OM (% DM)	38.6–75.4	Teglia et al. 2011a, b; Möller et al. 2008; Voća et al. 2005
Total N (% DM)	3.1–14.0	Fouda 2011 ; Möller et al. 2008; Voća et al. 2005
Total N (% FM)	0.12–1.5	Gutser et al. 2005; Kluge et al. 2008; Poetsch et al. 2004
Total NH_4^+ (% FM)	0.15–0.68	Svoboda et al. 2013a, b; Ökologischen and Bodenschutz 2008
NH_4^+ (% Total N)	35–81	Gutser et al. 2005; Möller et al. 2008; Martin 2004
Total C (% DM)	36.0–45.0	Möller et al. 2008
C/N	2.0–24.8	Gutser et al. 2005; Fouda 2011; Möller et al. 2008
Total P (% DM)	0.2–3.5	Teglia et al. 2011a, b; Pötsch 2004; Voća et al. 2005
Total P (% FM)	0.04–0.26	Möller et al. 2010; Ökologischen and Bodenschutz 2008; Kluge et al. 2008
Total K (% DM)	1.9–4.3	Möller et al. 2010; Pötsch, 2004; Voća et al. 2005
Total K (% FM)	0.12–1.15	Möller et al. 2010; Ökologischen and Bodenschutz 2008
Total Mg (% FM)	0.03–0.07	Kluge et al. 2008; Voća et al. 2005
Total Ca (% FM)	0.01–0.023	Pötsch 2004; Kluge et al. 2008; Voća et al. 2005
Total S (% FM)	0.02–0.04	Kluge et al. 2008
CEL/LIGN	0.22–1.71	Tambone et al. 2009; Teglia et al. 2011a, b
CEC (meq/100 g)	20.3–53.4	Teglia et al. 2011a, b
OUR_{max} (mg O_2/h/kg OM)	1,129–6,187	Teglia et al. 2011a, b
pH	7.3–9.0	Chantigny et al. 2008; Kluge et al. 2008; Möller et al. 2008; Fouda 2011

OM organic matter, *DM* dry matter, *CEL/LIGN* cellulose/lignin, *CEC* cation exchange capacity, *OUR* oxygen uptake rate

Figure 7: Biochemical Properties of Anaerobic Digestate

Figure 7 shows the range of constituents in the liquor. It is important to note that this material is rich in ammonia and nitrogen, both considered important green house gases to be controlled. Noted too is the bio-active nature with the oxygen uptake (OUR). This is almost certainly being converted by organisms and chemical reactions to carbon dioxide and nitrous oxides.

Data on the long term impacts of AD liquor to land is scarce. Short term (<5 years) analysis shows an improvement of the quality of soils amended with AD liquor. The situation was evidenced by the increase in microbial biomass and N, P contents. Some work highlights the reduction in soil bulk density over time with AD liquor input. The trace element content however is of much more concern with repeated land use as there can be an accumulation of copper, zinc and magnesium, introducing toxicity to soils.

Incineration

Incineration almost renders the waste material being processed to be inert. By its nature, incineration is in the presence of oxygen and aims to almost completely convert any carbon source into carbon dioxide. Incineration is usually the route of problematic materials rendering the result to primarily gasses and a small residual ash proportion. The ash proportion can be as little as 10% of the original biomass and can be more easily controlled and transported as a residual waste.

If focusing on the LCA of incineration it should be noted that the initial process steps require fuel to initialise the incineration burn. EU waste directives show that the flue gasses have been heated up to 850C which may require additional oil or gas powered fuelers. If the heating value of the input material is too low, for example for higher moisture content wastes, then this additional step is needed and can negate the overall saving from diversion from fossil fuel sourced energy generation.

Fresh grass cuttings for example can be 70-80% water and would need to be dried significantly before incineration. Of the dried material (1.3% moisture) it would leave a residual ash of 13.62% (815C). Carbon equates to 22-45% of

30 R. Nkoa, Agricultural Benefits and Environmental Risks of Soil Fertilisation with Anaerobic Digestates,Agron. For Sus Devel. 34(2) (2014), 473-492

the dry material which is converted largely to CO_2. Poultry litter as a biomass source has a moisture content of around 40% and will leave a residual ash of 10-11% of the input material. Of the weight, carbon is around 25% of the biomass however that is subject to the conditions the poultrys have been raised in, for example the addition of sawdust.

Incineration of biomass leads to ashes, either as flue particulates or a residue at the bottom of the incinerator. Ashes historically have been used as a significant source of P and K as a fertiliser however the material can be considered to be a toxic waste. Although in trace levels, micro elements are present and when continually dosed to land can accumulate into toxic levels. An example of ash from different scenarios are illustrated:

Constituent		Grass	Poultry Litter	Sewage Sludge
CO_2	wt% (ash)	3.1	-	-
SO_3	wt% (ash)	3.25	2.54	1.14
Cl	wt% (ash)	4.51	2.6	-
P_2O_5	wt% (ash)	8.56	12.09	15.4
SiO_2	wt% (ash)	33.60	15.92	38.3
Fe_2O_3	wt% (ash)	0.45	3.34	12.5
Al_2O_3	wt% (ash)	1.06	1.45	14.8
CaO	wt% (ash)	11.00	27.26	9.1
MgO	wt% (ash)	3.18	9.11	2.8
Na_2O	wt% (ash)	0.35	0.66	2.21
K_2O	wt% (ash)	28.20	23.48	2.19
Pb	mg/kg (ash)	3.0	0	180
Cd	mg/kg (ash)	0.0	0	5.3
Cu	mg/kg (ash)	57.0	-	410
Hg	mg/kg (ash)	0.0	-	-

Table 3: Ash % Constituents from different source materials

Pyrolysis

The REDIRECT project was concerned primarily with the conversion of natural resources into carbon products. This was achieved through the pyrolysis process at both medium and large scale. The conversion into carbon products is largely dependant on the temperature of the charing and the dwell time of the material inside the reactor. As charing takes place in the absence of oxygen, carbon is captured in either a solid form, a liquid oil fraction or used as a volatile burnt off driving the process. Slow pyrolysis is considered to be the most feasible production process, allowing the temperature to ramp up around 1-30C per minute and driving off the majority of moisture before reaction takes place. Slow pyrolysis also allows for a lower temperature to be used, easing off the heat load needed initially.

Carbon is the most abundant element in biochar and can be classed as carbonate and bicarbonate in the inorganic phase, and aliphatic, aromatic or functionised carbon in the organic phase. Carbon transformed from more woody materials, for example cellulosic, hemicellulose or lignin become aliphatic carbon in the middle pyrolysis temperature range and result in further aromatic carbon at a higher temperature. Carbon content of biochar fluctuates depending on the source materials. Pyrolysed matter with carbon content below 50% are not classified as biochar but as pyrogenic carbonaceous materials. Woody biomasses provide more carbon rich biochar compared to other feedstocks. Mineral rich feedstocks – e.g. animal manure, sewage waste – may result in pyrolysed products containing more ashes that carbons.

REDIRECT studied a wide variety of species primarily derived as marginal biomass, which have little application elsewhere as feedstocks or are directly classes as a waste or nuisance product. Rather than pure analysis of the materials and the products that they make, they are also taken through the IFBB process to maximise the product outlay from the materials. The virgin materials were sampled from across Europe and analyses by IBERS in Aberystwyth:

Biomass	**Weight (kg)**	**Dry Weight (kg)**	**DM (%)**	**Char (kg)**	**Char (%)**
Roadside Verge	6.9	4.0	59.0	1.6	39.7
Japanese Knotweed	19.0	6.9	36.5	1.1	14.6
Communal Greencut	**26.1**	**8.7**	**34.9**	**3.0**	**36.1**
Nature Conservation Grass	20.9	12.5	60.0	6.0	47.6
Fruit Stones	31.2	28.9	92.6	16.4	57.3
Small Particle Wood	13.2	9.7	73.4	3.4	34.7
Knotweed (old)	11.3	7.1	62.8	2.9	40.6
Raspberry Prunings	13.4	9.3	70.1	3.2	33.6

Table 4: Average char production data for biomass

Biomass	Weight (kg)	Dry Weight (kg)	DM (%)	Char (kg)	Char (%)
Roadside Verge	10.1	5.0	48.9	2.2	44.3
Japanese Knotweed	7.4	3.6	48.4	1.7	48.3
Communal Greencut	8.2	3.7	45.0	1.2	33.3
Nature Conservation Grass	11.8	6.8	57.5	2.3	33.5
Horse Manure	13.6	8.9	65.7	2.4	26.6
Knotweed (old)	10.2	5.5	53.4	2.0	36.1

Table 5: Average char production from IFBB processed biomass / presscake

To reiterate the front end of the IFBB process, the materials above (apart from those which are woody in nature) have been pre processed. These material have been through a hot mash stage, basically an agitated stage at 40C for at least 20 min and then the resultant wet material passed through a screwpress. The resultant press cake was dried and pyrolysed. By pre-processing by this method, there was a higher dry matter percentage indicating that volatiles were lost and water and water soluble products have been removed by this preprocessing stage. The resultant char may be lower in percentage however becomes much more carbon rich as a result.

(Raw) Biomass Feedstock	C (% DM Mean)	H (% DM Mean)	molare H/C(org) Ratio	N (% DM Mean)	Ash (% DM Mean)	Biochar Yield %	pH (Mean)	Temperature C
Roadside Verges	56.6	2.9	0.6	2.4	20.5	45.2	9.8	315.0

Japanese Knotweed	64.6	2.5	0.5	1.4	14.3	18.4	9.3	286.0
Japanese Knotweed Old	59.1	2.3	0.5	0.8	25.8	31.0	8.9	298.0
Raspberry Prunings	69.7	2.8	0.5	2.1	8.2	29.9	10.0	335.8
Small Wood Particles	72.7	2.7	0.4	0.9	8.1	34.7	9.4	377.0
Woodlike Compost	75.6	2.0	0.3	0.7	-	34.3	8.7	386.5
SRC Woodchips	80.0	2.5	0.4	0.7	3.4	26.0	8.4	398.0
Gorse	80.2	2.6	0.4	1.7	17.5	27.8	9.5	376.3
Horticultural Compost	30.2	1.2	0.5	1.0	-	56.6	9.6	429.0
Molinia sp.	72.6	2.8	0.5	1.9	5.3	32.4	6.9	358.3
Bracken	68.2	2.6	0.5	1.8	12.0	37.1	9.6	411.7
Juncus Effusus	63.0	55.3	0.4	1.7	13.8	30.5	9.7	390.0
Rhododendron	73.6	2.9	0.5	0.8	13.2	36.8	7.5	382.5
Nature Conservation Hay	54.1	2.7	0.6	2.7	15.8	41.0	9.3	344.3
Communal Greencut	**41.3**	**2.7**	**0.8**	**2.6**	**28.9**	**42.5**	**10.2**	**370.0**
Horse Manure	54.2	2.9	0.6	1.7	11.5	22.8	8.4	-

Table 6: Elemental analysis of raw biomass feedstocks processed through pyrolysis

(IFBB) Biomass Feedstock	C (% DM Mean)	H (% DM Mean)	molare H/C(org) Ratio	N (% DM Mean)	Ash (% DM Mean)	Biochar Yield %	pH (Mean)	Temperature C
Roadside Verges	55.7	3.7	0.8	2.8	19.2	43.3	-	-
Japanese Knotweed	63.2	3.7	0.7	1.9	14.8	48.3	-	-
Japanese Knotweed Old	64.5	3.0	0.6	1.0	14.7	33.1	8.6	341.0
Molinia sp.	71.6	2.4	0.4	1.9	8.8	20.9	8.9	394.5
Bracken	71.3	2.2	0.4	1.8	11.3	27.4	412.0	428.0
Juncus Effusus	70.0	2.8	0.5	2.3	6.7	27.3	7.7	-
Nature Conservation Hay	62.4	3.3	0.6	3.1	4.4	33.5	7.0	-
Communal Greencut	**61.5**	**4.0**	**0.8**	**3.7**	**20.2**	**33.3**	**8.7**	**340.0**
Horse Manure	61.9	2.6	0.5	1.6	7.4	33.7	-	-

Table 7: Elemental Analysis of IFBB processed press cake processed through pyrolysis

Communal green cut, for example, is show in in table 6 and 7. By using an IFBB process to pre-treat the material, the end product can be seen to have been de-watered and demineralised (lower ash) and considered to be a biochar. This process is actively locking carbon into an end product. The final end biochar of any of these materials will be largely dependant on the source material and the operational temperature of the pyrolysis kiln.

It has been extrapolated that besides biochar there are losses of C medium into the liquid and gas phases. Whilst these will offset a fuel balance needed from fossil fuel derived sources for heating, they are technically not being recovered or locked down into 'inert' carbons which do not go back to the atmosphere.

If we continue the example of the communal greencut material, we can see that the initial product is approx 40% carbon by weight of dry matter. Therefore for every tonne of greencut material there is approximately 0.4t of carbon. Pyrolysis of the material has been demonstrated to result in an approx 35% of the dry matter as biochar. We can therefore conclude that for every tonne of dry material in the front end, an approximation of at least 5% of the carbon is lost into the liquid or gaseous phase. Further work is needed to understand this balance for the source material for Newtown, and the overall benefit from reduction of fossil fuels needed.

Summary

It can be concluded that there are a vast variety of routes where carbon interacts with a process. This often complex matter does not just involve the source material and its end products, but the entire process. An overview of the processes involved has been demonstrated and a pure look at the cycle within demonstration processes have been analysed. It is understood that the end process will be a variety of different techniques, pre-processing steps and also factor in external parameters such as transportation, storage of biomass materials etc. Caution is urged, that whilst there may be a net positive gain in removing carbon from the local cycle and locking it down, that there are not insurmountable losses using one technology over another due to ill-considered carbon running costs.

Appendix H Draft financial model *(Lead: Colin/Dave)*

This is a pre-feasibility proposal and as such we are not able to obtain accurate estimates of costs and income for the proposal. However, it would be pointless pursuing a more detailed feasibility study unless there was an approximate calculation to indicate what the financial implications would be. We have therefore prepared a very crude financial projection for option 2 which would be refined in the next stage of feasibility work.

The principal financial drivers that would affect the project viability would be as follows:

Capital expenditure			Estimate for budget		Variables
Planning permission			£35,000		Includes consultants fees and LA costs, but not an appeal
Other development fees and permits			£20,000		Environmental permits, and where possible agri-exemptions but not a bespoke permit
250kW AD plant with CHP			£1,650,000		Uses latest low cost multi-vessel modular designs - to reduce civils costs
Construction of storage facilities			£40,000		Covered bunkering and storage with odour control
Construction of In-Vessel Composter			£60,000		Mid-scale continuous feed rotary IVC unit
Batch or C/F pyrolysis kiln			£30,000		Batch kiln for woody material only single or twin chamber design
Dewatering unit			£12,000		Source ex-food industry evaporative condenser unit
Screw press			£35,000		Similar to Vincent 10" unit in container with control system
Macerator/ grit trap			£18,000		Eliptical plate dual-purpose unit with pumps
Shredder + trommel/screener			£40,000		If purchased as static unit - could replce with hired-in mobile plant
Pre-dryer			£8,000		Design and build simple high airflow chamber
Miscelleaneous machinery			£25,000		Pipes, pumps, controll systems
Pellet press / Briquette press			£30,000		Either for pellet fertiliser or if liquid - then solid biomass fuel logs from chip + cake
Digestate/slurry tanks			£12,000		Multiple 10kL polytanks reduces risk and cost
Sub total capital expenditure			-£2,015,000		
Revenue (annual expenditure)					
Rent			-£4,500		Comparative rent for PCC 23.5Ha smallholding inc farmhouse is £10,000 per annum
AD maintenance contract			-£4,000		For AD plant and control systems
Labour (3 full time staff)			-£90,000		Site manager and two operators/growers inc pension and payroll costs
Fuel			-£1,500		vehicle and plant fuel
Vehicles			-£3,000		Tractor/loader or telehandler plus trailers and one road vehicle
Insurance			-£6,500		All risks including plant and vehicles
Income	£/kWh	load cap			
Sale of electricity (250kW)	0.045	50%			
	tonnes	rate per tonne			
Chicken litter gate fee	2,000 @	£ 10			
Sewage sludge gate fee	7,000 @	£ 20			Risk of land contamination if Heavy metal content not removed
Green waste gate fee	2,000 @	£ 10			
Sale of chicken litter pellets	200 @	£ 150			
Sale of briquettes	200 @	£ 150			
Sale of high grade compost - bulk	800	25			Converting 2000T of green waste p.a. To 1200T of High grade copost
Sale of high grade compost - retail	100	400			Bagging 200T of High grade compost into 20l /10kG sacks for retail sale @ £4.00/bag
Sale of biochar - bulk	50	300			for addition to poultry bedding or if Q/A source for animal feed supplement
Sale of biochar - retail	50	1000			As a soil conditioner in 5kg bags for retail sale at @
Sale of solid fuel briquettes - retail	40	150			Made from dried woodchip and presscake for retail sale @ £1.50 / £10 kg bag
~~Sale of woodchip for animal bedding~~	~~150~~	~~40~~			~~If fuel briquettes not permitted by changes in regulations.~~
Sale of Nutrient liquor - bulk	150	15			If AD plant achieved PAS110 then bulk digestate can be landspread, subject to NVZ
Sale of Nutrient Liquor - retail	5	4000			If AD plant achieved PAS110 and liquor is filtered and sold in 5L cans retail @ £4.00/L

With these costs and income streams, the 20 year financial projection would be as follows:

year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Capital expenditure			Estimate for budget																			
Planning permission			£35,000																			
Other development fees and permits			£20,000																			
250kW AD plant with CHP			£1,650,000																			
Construction of storage facilities			£40,000																			
Construction of In-Vessel Composter			£60,000																			
Batch or C/F pyrolysis kiln			£30,000																			
Dewatering unit			£12,000																			
Screw press			£35,000																			
Macerator/ grit trap			£18,000																			
Shredder + trommel/screener			£40,000																			
Pre-dryer			£8,000																			
Miscelleaneous machinery			£25,000																			
Pellet press / Briquette press			£30,000																			
Digestate/slurry tanks			£12,000																			
Sub total capital expenditure			-£2,015,000																			
Revenue (annual expenditure)																						
Rent			-£4,500	-£4,590	-£4,682	-£4,775	-£4,871	-£4,968	-£5,068	-£5,169	-£5,272	-£5,378	-£5,485	-£5,595	-£5,707	-£5,821	-£5,938	-£6,056	-£6,178	-£6,301	-£6,427	-£6,556
AD maintenance contract			-£4,000	-£4,080	-£4,162	-£4,245	-£4,330	-£4,416	-£4,505	-£4,595	-£4,687	-£4,780	-£4,876	-£4,973	-£5,073	-£5,174	-£5,278	-£5,383	-£5,491	-£5,601	-£5,713	-£5,827
Labour (3 full time staff)			-£90,000	-£91,800	-£93,636	-£95,509	-£97,419	-£99,367	-£101,355	-£103,382	-£105,449	-£107,558	-£109,709	-£111,904	-£114,142	-£116,425	-£118,753	-£121,128	-£123,551	-£126,022	-£128,542	-£131,113
Fuel			-£1,500	-£1,530	-£1,561	-£1,592	-£1,624	-£1,656	-£1,689	-£1,723	-£1,757	-£1,793	-£1,828	-£1,865	-£1,902	-£1,940	-£1,979	-£2,019	-£2,059	-£2,100	-£2,142	-£2,185
Vehicles			-£3,000	-£3,060	-£3,121	-£3,184	-£3,247	-£3,312	-£3,378	-£3,446	-£3,515	-£3,585	-£3,657	-£3,730	-£3,805	-£3,881	-£3,958	-£4,038	-£4,118	-£4,201	-£4,285	-£4,370
Insurance			-£6,500	-£6,630	-£6,763	-£6,898	-£7,036	-£7,177	-£7,320	-£7,466	-£7,616	-£7,768	-£7,923	-£8,082	-£8,244	-£8,408	-£8,577	-£8,748	-£8,923	-£9,102	-£9,284	-£9,469
Income	£/kWh	load cap																				
Sale of electricity (250kW)	0.045	50%		£50,261	£51,266	£52,291	£53,337	£54,404	£55,492	£56,601	£57,734	£58,888	£60,066	£61,267	£62,493	£63,742	£65,017	£66,318	£67,644	£68,997	£70,377	£79,760
	tonnes	rate per tonne																				
Chicken litter gate fee	2,000 @	£ 10		£20,400	£20,808	£21,224	£21,649	£22,082	£22,523	£22,974	£23,433	£23,902	£24,380	£24,867	£25,365	£25,872	£26,390	£26,917	£27,456	£28,005	£28,565	£29,136
Sewage sludge gate fee	7,000 @	£ 80		£571,200	£582,624	£594,276	£606,162	£618,285	£630,651	£643,264	£656,129	£669,252	£682,637	£696,290	£710,215	£724,420	£738,908	£753,686	£768,760	£784,135	£799,818	£815,814
Green waste gate fee	2,000 @	£ 10		£20,400	£20,808	£21,224	£21,649	£22,082	£22,523	£22,974	£23,433	£23,902	£24,380	£24,867	£25,365	£25,872	£26,390	£26,917	£27,456	£28,005	£28,565	£29,136
Sale of chicken litter pellets	200 @	£ 150		£30,600	£31,212	£31,836	£32,473	£33,122	£33,785	£34,461	£35,150	£35,853	£36,570	£37,301	£38,047	£38,808	£39,584	£40,376	£41,184	£42,007	£42,847	£43,704
Sale of briquettes	200 @	£ 150		£30,600	£31,212	£31,836	£32,473	£33,122	£33,785	£34,461	£35,150	£35,853	£36,570	£37,301	£38,047	£38,808	£39,584	£40,376	£41,184	£42,007	£42,847	£43,704
Sale of high grade compost - bulk	800	25		£20,400	£20,808	£21,224	£21,649	£22,082	£22,523	£22,974	£23,433	£23,902	£24,380	£24,867	£25,365	£25,872	£26,390	£26,917	£27,456	£28,005	£28,565	£29,136
Sale of high grade compost - retail	100	400		£40,800	£41,616	£42,448	£43,297	£44,163	£45,046	£45,947	£46,866	£47,804	£48,760	£49,735	£50,730	£51,744	£52,779	£53,835	£54,911	£56,010	£57,130	£58,272
Sale of biochar - bulk	50	300		£15,300	£15,606	£15,918	£16,236	£16,561	£16,892	£17,230	£17,575	£17,926	£18,285	£18,651	£19,024	£19,404	£19,792	£20,188	£20,592	£21,004	£21,424	£21,852
Sale of biochar - retail	50	1000		£51,000	£52,020	£53,060	£54,122	£55,204	£56,308	£57,434	£58,583	£59,755	£60,950	£62,169	£63,412	£64,680	£65,974	£67,293	£68,639	£70,012	£71,412	£72,841
Sale of solid fuel briquettes - retail	40	150		£6,120	£6,242	£6,367	£6,495	£6,624	£6,757	£6,892	£7,030	£7,171	£7,314	£7,460	£7,609	£7,762	£7,917	£8,075	£8,237	£8,401	£8,569	£8,741
Sale of woodchip for animal bedding	150	40		£6,120	£6,242	£6,367	£6,495	£6,624	£6,757	£6,892	£7,030	£7,171	£7,314	£7,460	£7,609	£7,762	£7,917	£8,075	£8,237	£8,401	£8,569	£8,741
Sale of Nutrient liquor - bulk	150	15		£2,295	£2,341	£2,388	£2,435	£2,484	£2,534	£2,585	£2,636	£2,689	£2,743	£2,798	£2,854	£2,911	£2,969	£3,028	£3,089	£3,151	£3,214	£3,278
Sale of Nutrient Liquor - retail	5	4000		£20,400	£20,808	£21,224	£21,649	£22,082	£22,523	£22,974	£23,433	£23,902	£24,380	£24,867	£25,365	£25,872	£26,390	£26,917	£27,456	£28,005	£28,565	£29,136
Finance	interest rate																					
Bank loan	5%		£1,730,725	-£138,878	-£138,878	-£138,878	-£138,878	-£138,878	-£138,878	-£138,878	-£138,878	-£138,878	-£138,878	-£138,878	-£138,878	-£138,878	-£138,878	-£138,878	-£138,878	-£138,878	-£138,878	-£138,878
Grant			£500,000																			
Cash flow																						
Cash at start			£0	£106,225	£741,553	£1,392,364	£2,058,970	£2,741,685	£3,440,832	£4,156,740	£4,889,743	£5,640,184	£6,408,411	£7,194,781	£7,999,655	£8,823,404	£9,666,406	£10,529,046	£11,411,716	£12,314,817	£13,238,757	£14,183,954
Cashflow			£106,225	£635,328	£650,812	£666,606	£682,715	£699,147	£715,908	£733,003	£750,441	£768,227	£786,369	£804,874	£823,749	£843,002	£862,640	£882,670	£903,101	£923,940	£945,197	£974,854
cash at end			£106,225	£741,553	£1,392,364	£2,058,970	£2,741,685	£3,440,832	£4,156,740	£4,889,743	£5,640,184	£6,408,411	£7,194,781	£7,999,655	£8,823,404	£9,666,406	£10,529,046	£11,411,716	£12,314,817	£13,238,757	£14,183,954	£15,158,808