What is the Biomass Resource Available to Leeds City Council, and how can its use be maximised?

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Executive Summary

In the current global climate, it is important for local planning authorities to try to incorporate locally produced bioenergy into their development plans. Before this can be done, the biomass available must be assessed, the possible technologies considered, and the business models analysed. This study quantified a number of different biomass wastes available to Leeds City Council, as well as the future potential of these resources. The annual current biomass potential was calculated to be $(55\pm8)\times10^3$ tonnes per annum, equivalent to $(19\pm7)\times10^7$ MJ/year or 2 ± 0.7 MW_e (electricity generation equivalent). In addition, a potential future annual quantity of biomass was calculated for scenarios where LCC made certain changes to the way they operate. The mass and energy in this case were calculated to be $(90\pm9)\times10^5$ tonnes and $(20\pm5)\times10^9$ MJ/year respectively, equivalent to 210 ± 50 MW_e. A technological analysis indicated both Anaerobic Digestion and Combustion technology represent the best options for treating the currently available and future biomass. A subsequent analysis also revealed that the council faces significant near-term financial and policy barriers regarding their future operations, and that such barriers could be addressed by implementing a Joint Venture, Public-Private Partnership commercial model.

Overall there is enough biomass resource available to Leeds City Council for both small and large scale energy production. Our results suggest that for large scale technologies, non-recyclable wood wastes and high moisture content wastes could be sent to the Veolia Recycling and Energy Recovery Facility for incineration and an anaerobic digestion (AD) plant situated in or near Leeds, respectively.

Introduction

Leeds City Council (LCC) is looking to incorporate bioenergy into their approach towards reaching the Council's carbon reduction commitment target of 40% by 2020 (Leeds City Council, 2015). The city is currently highly reliant on energy sourced from areas outside of Leeds, most of which is derived from fossil fuels, and so a lot of assessment and planning for any new energy infrastructure will be required (Leeds City Council, 2010).

LCC have carried out previous research into the potential biomass resources available in the city area such as wood from the Council's woodlands, roadside and waste wood sources. They also recognise that there could be significant potential in other waste streams such as green waste, food waste and manure. However, these studies were limited to the extent that they only targeted individual waste resource streams and therefore lacked a holistic perspective.

The aim of this study will therefore be to characterise and quantify waste biomass resources available to LCC and consider the possible technologies and applications available for bioenergy generation from waste. The current potential bioenergy resources, and those that are possible in the future with changes to LCC operating procedures, will be analysed in this manner. Possible future development plans will then be considered in a business model recommendation.

Collectively, the findings will be used to form part of the solid evidence base that is required for local planning authorities to incorporate local forms of renewable energy into their development plans.

Methodology

Interviews were conducted with Leeds City Council (LCC) employees possessing relevant expertise in the attempt to ascertain biomass waste availability (quantity by waste type) to the council. Where this was not possible, the authors deferred to alternative methods in order to infer these values.

The interviewees were also asked if there were any possible alterations to the way LCC operates that could increase the quantity of biomass available to it, and if so, how much biomass could be collected. Where such details were not given, but the potential for an increase was evident, new future potential quantities were calculated using alternative methods.

For a full outline of the alternative quantification methods used, and how estimates of the energy contents were calculated for all resources, please refer to the appendices. Research was conducted to determine the applications and technologies most suitable for each waste type and their corresponding quantity available to LCC. This was carried out through the investigation into current approaches taken by other councils throughout the UK and case studies of biomass applications.

Both interview data and open access online reports were then used to analyse both the barriers and potential business model strategies that could help to identify better waste management by the council.

Results

The full results for the woody and wet waste types are given in Table 1 and Table 2.

Table 1 Results for woody biomasses. Note: Energy values are higher heating values

Type of Waste	Source of Waste	Total Mass Available (tpa)	Mass Available for Bioenergy (tpa)	Energy on Burning (MJ/year)	Future Potential Mass (tpa)	Future Potential Energy on Burning (MJ/year)
Wood	Woodland Arisings	1900	1900±600	$(8\pm3)\times10^{6}$	$(6\pm2)\times10^{3}$	$(26\pm9)\times10^{6}$
	Arboricultural Arisings	3×10^{3}	$(3\pm1)\times10^{3}$	$(3\pm1)\times10^{7}$	$(3\pm1)\times10^{3}$	$(3\pm1)\times10^{7}$
	Construction Waste	7802	1400±300	$(10\pm1)\times10^{7}$	$(16\pm4)\times10^{3}$	$(24\pm7)\times10^{8}$
	Household Timber Waste	1×10^{4}	$(3\pm1)\times10^{3}$	$(4\pm2)\times10^{7}$	$(3\pm1)\times10^{3}$	$(4\pm2)\times10^{7}$
Totals		**23×10^{3}**	**$(9\pm3)\times10^{3}$**	**$(9\pm4)\times10^{7}$**	**$(28\pm8)\times10^{3}$**	**$(3\pm1)\times10^{8}$**

Table 2 Results for wet biomasses

Type of Waste	Source of Waste	Total Mass Available (tpa)	Mass Available for Bioenergy (tpa)	Volatile Solids (kg)	Methane Production (m^3/year)	Future Potential Mass (tpa)	Future Potential Methane Production (m^3/year)
Green Waste	Garden Waste	42×10^{3}	$(42\pm4)\times10^{3}$	2×10^{7}	$(28\pm6)\times10^{5}$	$(42\pm4)\times10^{3}$	$(28\pm6)\times10^{5}$
	Parks and Countryside	800	800±80	4×10^{5}	$(5\pm1)\times10^{4}$	$(9\pm2)\times10^{6}$	$(6\pm1)\times10^{8}$
	Farm Waste	10	10±1	4600	700±100	10±1	(700)±100
Manure	Pig Slurry	0.66	0.66±0.07	470	150±40	0.66±0.07	150±40
	Mixed animal manure and straw	2000	2000±200	98×10^{4}	$(15\pm9)\times10^{4}$	2000±200	$(15\pm9)\times10^{4}$
Food	Household food waste	1200	1200±100	83×10^{4}	$(45\pm9)\times10^{4}$	$(80\pm8)\times10^{3}$	$(31\pm6)\times10^{6}$
Totals		**46×10^{3}**	**$(46\pm5)\times10^{3}$**	**2×10^{7}**	**$(30\pm7)\times10^{5}$**	**$(90\pm9)\times10^{5}$**	**$6\pm1\times10^{8}$**

Energy and Power Outputs

The total annual biomass currently available to LCC is (55±8)×10^3 tonnes. The potential future biomass available, if alterations to LCC operating methods (outlined in the appendix) are made, will be (90±9)×10^5 tonnes per year (tpa). Due to the fact that the dry wastes and higher moisture content (wet) wastes are converted into useful energy using different conversion technologies, it is difficult to draw a direct comparison.

To briefly illustrate the idea of the total potential energy production, the energy density of methane was estimated using the method outlined in the appendix. These were then used to calculate the total equivalent electrical power outputs (or MW_e).

Table 3 shows the total current and future powers available, along with the energy contents, while Table 4 shows these power equivalents for the wood and wet wastes separately.

Table 3 The current and future energy potentials

Potential Type	Methane Energy (MJ/yr)	Wood Energy (MJ/yr)	Total Energy (MJ/yr)	Power Equivalent[a] (MW_e)
Current	(11±3)×10^7	(9±4)×10^7	(19±7)×10^7	2.0±0.7
Future	(20±5)×10^9	(3±1)×10^8	(20±5)×10^9	210±50

[a] A 30% conversion efficiency was assumed for the power equivalences

Table 4 Power equivalents for the wood and wet biomasses

Waste Type	Current Power Equivalent (MW_e) [a]	Future Potential Power Equivalent (MW_e) [a]
Wood	1.0±0.3	3±1
Wet	1.1±0.3	210±50

[a] A 30% conversion efficiency was assumed for the power equivalences

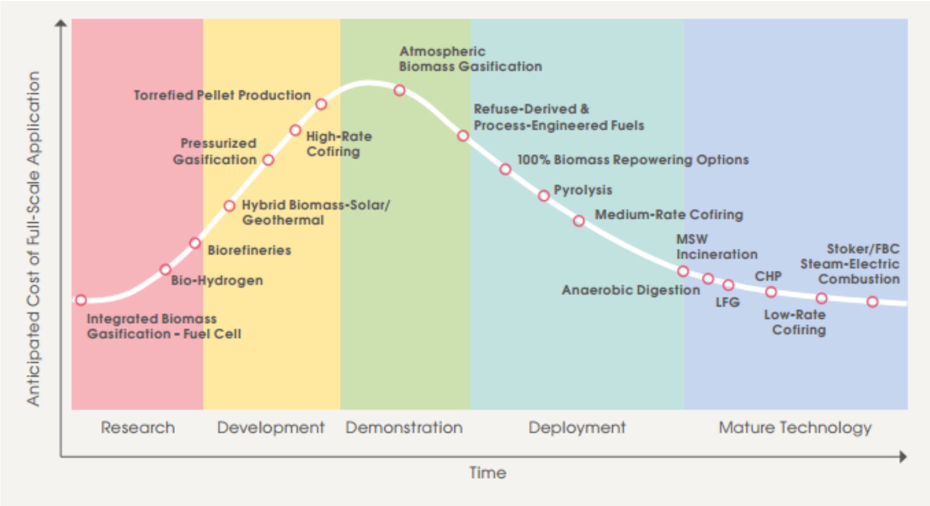
One can see that the energy currently available from the woody wastes is approximately the same as the wet wastes. In the future, however, it seems apparent that the energy available from wet wastes could be much larger than that from the wood wastes if changes to LCC's strategic operations are performed. This is because there is much more room for an increase in the quantity of wet wastes than woody wastes that could be collected by LCC. The potential possible increase in the collection of household food and parks and countryside waste is responsible for the majority of the increase. The feasibility of such changes is considered in the discussion and conclusion. For a detailed explanation of the changes required to increase the quantity of woody and wet wastes, please refer to appendices 1 and 2.

Technologies and Applications

A technology analysis revealed that combustion and anaerobic digestion (AD) technologies are currently best suited for treatment of low moisture content waste (Table 1) and wet wastes (Table 2), respectively, on a cost and energy generation basis.

Use of combustion and AD technologies for example, are considerably cheaper in comparison to the use of more advanced conversion methods such as pyrolysis and gasification, as shown in Figure 1 below.

Figure 1. Biomass power generation technology maturity status



Source: IRENA, 2012

Case Studies of Combustion and AD Technologies

Table 5 and Table 6 give case studies of combustion and AD technologies that have been implemented in other regions of the UK, as well as Leeds. These case studies will be compared to the biomass resources available to LCC, along with their corresponding quantities, to determine the most suitable types of facilities LCC can implement in Leeds.

Table 5. Case Studies of Combustion Plants in the UK

Name of Facility	**Carwood Close**[a]	**Tyrone**[b]	**Blackburn Meadows, Sheffield**[c]	**Veolia Recycling and Energy Recovery Facility**[d]
Type of Biomass	Wood chips	Wood	Wood	Household mixed waste
Input Capacity (tpa)	~500	~25,000	~180,000	~214,000
Output Capacity	320 kW_e	2.1 MW_e	30 MW_e	11 MW_e

Source: (Econergy, 2006[a]; Energy, 2012[b]; E.ON, 2014[c]; Veolia, 2015[d])

Table 6. Case Studies of Anaerobic Digestion Plants in the UK

Name of Facility	**Basingstoke**[a]	**Melbury Bioenergy Ltd**[b]	**The University of Southampton Science Park**[c], **Muckbuster™**
Type of Biomass	Food waste and agricultural waste	Slurry, maize, grass silage	Food waste, grass cuttings

Input Capacity (tpa)	40,000	22,000	912.5[d]
Output Capacity	1.5 MW_e	500 kW_e	8kW_e

Source: (TEL, 2013[a]; Biogas, 2015[b] ;SEaB Energy, 2014[c] ;SEaB Energy, 2014b[d])

Discussion

Comparison of Results to Technology Case Studies

Figure 2 and Figure 3 compare the types and quantities of biomass resource available to LCC with the case studies for combustion and AD technologies shown in Table 5 and Table 6 above. It can be seen that in terms of current quantities of wood waste available to LCC, only small-scale technologies can be used. In the future, however, if LCC were to utilize all the wood waste available to them, this could power a large-scale biomass plant or waste incineration facility, such as the Veolia Recycling and Energy Recovery Facility in Leeds.

For the wet wastes Figure 3 shows that currently there is enough garden waste collected to fuel a large-scale AD plant (with an input capacity of 40,000 tpa). However, there is only enough waste from parks and countryside, animal waste and household food waste to fuel small-scale technology. Although the future potential quantities are very large, current AD technologies around the world can only take a maximum input capacity of around 40,000 tpa. Consequently, this would currently be the only scale of plant available to LCC, however larger plants may be available in the future.

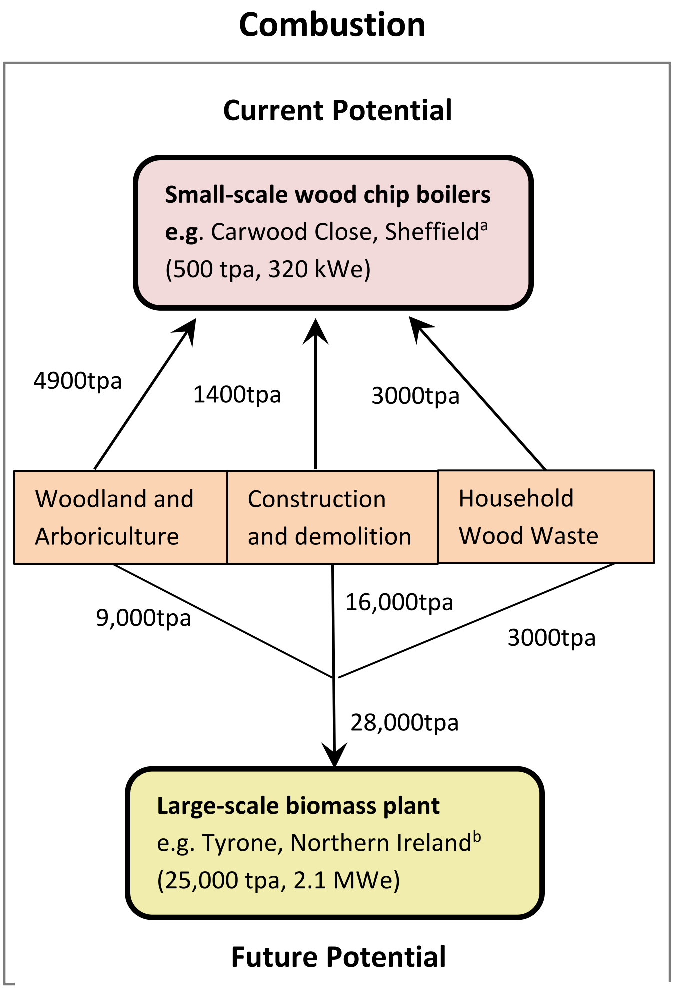


Figure 2 Comparison of current and future potential wood waste quantities to case studies

Source: (Econergy, 2006; TEL, 2012)

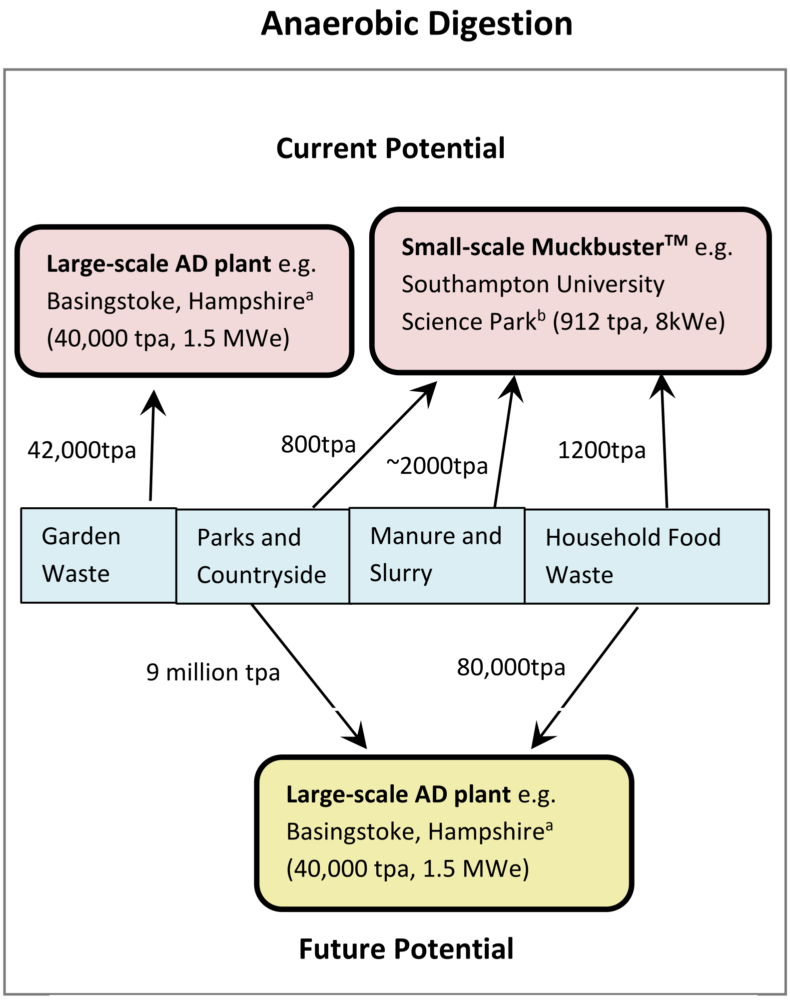


Figure 3 Comparison of current and future potential high moisture content waste quantities to case studies

Source: (SEaB Energy, 2014; TEL, 2013)

Other non-energy output applications

According to the UK's waste hierarchy, waste recycling is more desirable than energy recovery. For wood, only that proportion unfit for recycling (e.g. due to contamination) will be considered suitable for energy conversion. High moisture content wastes can not only be considered for energy conversion but also for conversion to compost or, in the case of using AD, biofertiliser from the digestate (the material left over from the AD process).

Both compost and biofertiliser can be used to provide essential nutrients such as nitrogen, phosphate and potash to soil, and therefore aid crop growth (David Border Composting Consultancy, 2002). DEFRA states that AD is generally the preferred treatment option for high moisture content wastes, as it is capable of producing both bioenergy and a nutrient rich digestate (DEFRA, 2011).

Furthermore, anaerobic digestion of household food wastes also can be , in certain circumstances, categorised as waste recycling and so could significantly contribute toward LCC's waste recycling targets (DEFRA, 2011).

Barriers analysis

This section summarises three key barriers currently affecting LCC's biomass waste management strategy. They include technology, financial and policy barriers.

Technology Barriers

Although the results show significant potential for LCC to implement both combustion and AD, key technology barriers restricting such implementations and potential solutions are highlighted below:

Wood waste

- Locating a suitable storage site that isn't affected by weather.
- Contamination of construction/demolition wood waste (i.e. by paint, varnishing, or nails/screws).
    - ➢ Solution: Treatment of wood waste might be needed. Otherwise a WID (Waste Incineration Directive) compliant boiler would have to be used.
- Additional financing to train employees for fixing and handling biomass boilers.

Wet waste

- Cost of collecting green grass, which was previously estimated to be 4 times (Frosdick, 2015) more expensive than the current applications LCC is using i.e. LCC Parks Operations contract.
    - ➢ Solution: This can be addressed if energy prices rise, as bioenergy plants could then afford to pay LCC for the grass waste they provide to the plant.
- Seasonality of green waste: i.e. no grass and less shrub and hedge prunings are done during the winter.

    - ➢ Solution: Select a technology that is also capable of using other feedstock types during winter.
- 'Chicken and egg' problem – Either the feedstock supplier or the plant developer has to make the first move to invest in the project (Greenhalf, 2011).

Policy and financial barriers

Key policies and directives underpinning LCC's current biomass waste management strategy highlighted in Table 7 are heavily in support of waste recycling, which in turn promotes LCC to prioritize on waste recycling at the expense of energy recovery.

Furthermore, additional evidence also suggests that government's inconsistent, 'Feast or Famine' and often delayed approach to renewable energy policy implementation (i.e. that of ROCs and FITs) can severely affect market sentiments and consequently, long term local planning by LCC for renewable technology adoption due to investment uncertainty (APSE, 2014).

The findings also indicate that this uncertainty is potentially exacerbated by LCC's existing contractor-based model, where the council pays for the end-treatment of their biomass wastes, in light of diminishing core funding. The authors speculate that continuation of this existing model will likely impose increased financial constraints on the council and can lead to significant scalability issues at least in the short term up until 2019.

In response to these barriers, the authors identified two key implementable countermeasures which the council can reliably adopt to mitigate both the financial and policy challenges.

The first involves adopting a new business strategy that would enable LCC to derive additional financial benefits from its biomass wastes, for mitigating both financial & operational risks the council currently faces. The authors are also aware that the council will likely require significant political and financial will for carrying this out, and has therefore conducted further research in identifying potential business models and strategies that could benefit the council to minimize the risk of doing so (see Business Model section).

The second will be to build towards a comprehensive database for improving waste data tracking and to evaluate the implementation feasibility of the proposed business model on a cost and feedstock quantity basis, i.e. by using findings from this and any previous relevant studies as a suitable starting point. To this end, the author also strongly recommends for the council to collaborate with other council groups (ideally those belonging to UK's core council group) to maximise knowledge sharing and information exchange on a local government level. The use of open source database, such as the Leeds Data Mill, is also strongly encouraged for promoting data transparency and public accessibility to set an appropriate standard of best practice which other city councils could also follow. Where sufficient waste data are collected in support of a suitable business model (either the one proposed in this study or an alternative variable), a well justified case can then be formulated and proposed to the central government to argue for appropriate changes to be made to existing policies and core funding arrangements.

Business model

Here the author's aim to explore business model ideas and recommendations in the context of existing findings on biomass quantification, technology, policy and barriers presented in this study. An initial research yielded three pre-existing models specifically designed by Convention of Scottish Local Authorities (COSLA) and Scottish Futures Trust (SFT) for promoting renewable development by local authorities are explored and summarized in

Table 7.

Table 7 Business model options available to LCC

Investment risk & Returns	Model type	Details	Suitability
High	Ownership or Operator	• Financial risks to LCC all areas: development, design, construction, operation & maintenance • Majority income from waste retained	Too high risk to take Low external support
Medium	Joint Venture Partnership (JVP)	• All risk shared significantly by LCC & private partner • Can be under LCC or private sector control, depending on degree of risk sharing • Income commensurate to risk shared by each party	Right levels of risk & external support
Low	Arms-Length (AL)	• Huge risk transfer to private "contractor" • Income limited to land & asset rental	Too low returns on risk Low control over

Source: (COSLA and SFT, 2011)

Further analysis suggested that the Joint Venture Partnership (JVP) model is considered the most suitable for adoption, based on four key aspects (COSLA and SFT, 2011) (Table 8).

Table 8 Reasons for selecting the joint business model.

	JVP business model basis	Compared to contractor based model
1	Scalability	More scalable for all applicable waste streams
2	Investment risk relative to financial returns	Higher financial and operational risk & returns, but quite flexible and can therefore be tailored to meet LCC's current budgeting goals
3	Waste management control	More flexible & generally sufficient to influence use of recommended technologies (AD & combustion)
4	Non-financial support or additional expertise	Greater support in additional areas, i.e. technical, policy and market through partnership collaboration. More likely to address

One key benefit which the JVP brings is the additional expertise which LCC potentially lack, i.e. in technology. On this basis, the authors propose for the JVP model to be implemented between LCC and a private sector company with extensive knowledge in the biomass waste sector to address the classic ‘Chicken and egg’ problem resulting from lack of multi-lateral commitment and financial will to invest by the enabling parties, i.e. technology companies and the council.

Incorporating findings from the biomass quantification and technology analysis, the authors devised the following key recommendations for how the JVP could potentially go forward from a supply and demand perspective (Table 10).

Table 9 Near to short term business model recommendation (2016-2020)

Technology	**Feedstock**	**Scale**
AD plant	Household Food Wastes Park & countryside Green Wastes	Large, centralized
Combustion technology - biomass boiler	All non-recyclable wood wastes	Small, decentralized

Table 10 Medium to long term business model recommendation (2020 and beyond)

Technology	**Feedstock**	**Scale**
AD plant	Household Food Wastes	Large, centralized
Combustion technology - Biomass boiler	All non-recyclable wood wastes	Small, decentralized for boilers

For AD the authors propose for initial collection to include all food and green wastes so that sufficient feedstocks are available to justify a large scale plant construction. The authors then recommend a strategy involving simultaneous decrease in green waste collection and proportional increase in food waste collection on financial, technology and local policy (on waste management) grounds as food wastes are cheaper to collect and treat.

For combustion technology the authors maintain the position of incorporating small scale technology at designated sites (i.e. near woodlands & construction sites) close to wood collection in a decentralized manner to minimize emissions associated with waste transportation. The authors also believe that Veolia’s Energy Recovery facility will be sufficient for handling majority of remaining wood wastes, therefore rendering construction of a large scale incineration plant unnecessary.

Conclusion

In this study the authors determined combustion and AD to be most suitable technologies for processing low and high moisture content wastes, respectively. Quantitatively, there is enough biomass resource available to LCC to justify both small and large scale energy production.

For wood, this amounts to $(9\pm3)\times10^3$ tonnes per annum (tpa), which equates to $(9\pm4)\times10^7$ MJ and 1.0 ± 0.3 MW_e. Alterations to LCC operating procedures (see appendix 1) could increase biomass availability to $(28\pm8)\times10^3$ tpa, which equates to $(3\pm1)\times10^8$ MJ or 3 ± 1 MW_e.

Currently $(46\pm5)\times10^3$ tpa of high moisture content biomass are available to LCC, and equates to $(11\pm3)\times10^7$ MJ or 1.1 ± 0.3 MW_e extractable through anaerobic digestion. Alterations to LCC operating procedures as specified in appendix 2 could increase this to $(90\pm9)\times10^5$ tpa to give $(6\pm1)\times10^8$ MJ from methane and power a 210 ± 50 MW_e power plant.

The vast majority of this mass increase comes from a change in the management of LCC owned grass and parkland outlined in appendix 2. Further analysis revealed that this new management approach is unfeasible on a cost basis, and therefore should not be implemented. On the other hand, the potential increase in future household food waste quantities is appreciable (equivalent to estimated $(11\pm2)\times10^8$ MJ or 34 ± 6 MW_e), and likely to yield greater financial returns from anaerobic digestion.

The authors therefore identified large scale anaerobic digestion and small scale combustion technology to be suitable for processing food with green waste and non-recyclable wood wastes, respectively, in the short term. A long term approach may however involve use of local anaerobic digestion and small or large scale combustion facility to process food or non-recyclable wood wastes, such as Veolia Recycling and Energy Recovery Facility.

The authors also recommend for the council to adopt Joint Venture Public-Private Partnership model to address the key technology, policy and financial barriers identified in this study to enable the council to derive greater financial as well as environmental value from their biomass wastes.

Due to constraints within this project, not all possible avenues have been investigated. Future studies could therefore explore the following:

- Quantification of biomass resources missing from the current report. These include, for example, food waste from council commercial outlets and council contracts.
- Investigation into the possibility of utilising wastes produced by other organisations within the Leeds area.
- The moisture content of the woody biomasses should be accounted for in the calculation of the energy quantities, as mentioned in appendix 1.
- Mapping of the LCC area and its biomass resources (e.g. using GIS, national heat maps, poverty maps etc.) to inform optimum placement of conversion technologies (e.g. AD plants).
- To make publically available all data on biomass wastes on the Leeds Data Mill for better waste tracking to enable LCC to assess its wastes (by quantity and type) more accurately.

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Appendix 1: Woody Biomass and Energy Quantification Methods

Woodland and Arboricultural Arisings

Mass Calculations

The volumes provided by interviewee 5 were converted into masses using densities calculated from the database in Hogan (2011). In these calculations a hardwood to softwood ratio of 95:5 was assumed. For the woodland arisings, a green moisture content of 50% In these calculations a hardwood to softwood ratio of 95:5 was assumed. For the woodland arisings, a green moisture content of 50% was assumed. For the arboricultural arisings a moisture content of 40% was assumed. This is because a portion of the volume had been air dried. The mass calculation is outlined in equation 1.

$$Mass\ (kg) = Volume\ (m^3)\ \times Density\left(\frac{kg}{m^3}\right) \tag{1}$$

Energy Calculations

Hogan (2011) was again used, with the same assumed values as previously, to give energy densities.

Using these values, with equation 2, annual potential energies for woodland and arboricultural arisings were calculated. These energies do not take into account the energy required to vaporise the moisture within the wood, so are higher heating values and are therefore upper estimates.

$$Potential\ Energy\ (MJ) = Energy\ Density\ \left(\frac{MJ}{kg}\right) \times Bioenergy\ Mass\ (kg) \tag{2}$$

Future Potentials

Interviewee 5 stated that the woodland resources are not currently being used to maximum sustainable capacity, and so there is a larger future potential biomass yield possible. For the woodland arisings, the Forestry Commission sustainable forestry yield of 4.5 m^3/ha/yr was applied to the 1300 ha of woodland that Interviewee 5 stated comprised the total estate. This gave a volume of 5850m3, and using the same methods as previously stated, the mass and energy were calculated.

Construction Waste Wood and Household Waste Wood

Mass Calculations

Interviewee 1 could give no mass or volume estimates for the quantity of construction waste wood produced per year from LCC projects.

The general method that was followed to calculate estimates was to use national values of the waste wood production from the construction industry, and then take a proportion of this based on the number of LCC construction workforce versus the national construction workforce. This gave a value, which was then quartered to make a realistic estimate of the amount of wood available for bioenergy purposes.

Energy Calculations

This waste wood mass was then converted into a potential energy using the same technique as for the woodland and arboricultural arisings. Interviewee 1 was able to state that the waste wood was “more softwood”, and so a hardwood/softwood ratio of 20/80 was assumed. Using this ratio, in combination with a moisture value for construction waste wood of 20%, the energy density was calculated. This was used, with the mass, to give an annual energy yield via equation 2.

Future Potentials

A new potential estimate could be achieved if LCC collected the waste wood from all construction projects in Leeds, instead of only LCC-run projects. The value for construction waste wood produced in Leeds calculated previously was used with the same 25% bioenergy availability assumption to give mass. Using the same moisture and composition assumptions as previously, a potential energy yield was calculated.

No additional source for household waste wood was found.

Household Timber Waste

Mass Calculation

Interviewee 4 estimated the mass of timber waste available from household waste sites to be 10000 tpa. Again, a bioenergy-suitable percentage of 25% was applied to give a new lower mass available for bioenergy.

Energy Calculation

This waste wood was thought to have had a similar history to the construction waste wood, and so the same 20% moisture value was assumed. Interviewee 4 stated that the composition of the wood was “a range of hardwood [and] softwood”, and so an average hardwood/softwood proportion of 50/50 was estimated. Hogan (2011) was again employed, with the above assumptions, to calculate a the energy density using equation 1. The potential energy yield was then calculated using equation 2.

Future Potential

Interviewee 4 gave no prediction of increased possible future potential biomass availability, and so it was assumed that the current values are the highest that can be reasonably achieved.

Appendix 2 - Wet Waste Arisings and Energy Quantification Methods

Mass Calculations

All of the wet waste arisings currently available to LCC were given by the interviewees.

Green Wastes

Interviewees 2, 3 and 4 gave an estimated total green waste arising mass of green waste. These arise from parks and countryside, home farm and household garden waste.

Manure Arisings from Home Farm

A value of pig manure was given by interviewee 2, the energy for which was calculated as outlined in equation 3, using the relevant information from table 10. They also estimated a quantity of mixed animal manures with straw were collected per year. Interviewee 2 was unable to provide estimates of the proportional composition for this.

Food Waste

Interviewee 4 estimated the mass of food waste currently collected by LCC.

Energy Calculations

The masses given by the interviewees outlined above were converted into potential methane productions using equation 3 in combination with the relevant information in table 4.

The only waste that required a tailored approach was the mixed waste manure and straw. This mixed waste required various assumptions to be made. Firstly it was assumed that the waste consisted of 50% manure and 50% straw. Because cows produce by far the largest volume of manure, the calculation was simplified by assuming all of the manure originated from cows. The energy contents of cow manure and straw were then calculated using the previous method, but with values appropriate to the material from Table 10. The two resulting values were summed to give a total potential methane yield for the mixed animal manures. This was then converted into an equivalent energy using the energy density of methane, as shown in equation 4.

$$Total\ Methane\ (m^3/year) = Bioenergy\ Mass\ (kg/year) \times Solids \times Volatile\ Solids \times Methane\ Yield\ \left(\frac{m^3}{kg}\right) \quad (3)$$

$$Methane\ Energy = Energy\ Density\ of\ Methane \times Volume\ of\ Methane \quad (4)$$

Table 11 Moisture, volatile solid and potential methane yields of wastes suitable for anaerobic digestion.

Feedstock	Percentage Solids	% Volatile Solids (of total solids)	Methane Yield (m^3/kgVS)

Green Waste	50.4%	92%	0.143
Cattle Manure	13%	84%	0.21
Pig Manure	10%	78%	0.33
Straw Waste	90.54%	84%	0.145
Food Waste	20%	90%	0.54

Future Potentials

Green Wastes

The interviewees for home farm and household garden wastes gave no possible future increase in yield. For the parks and countryside, however, an opportunity for a vast expansion exists. Interviewee 3 said that there is 1500 hectares of intensively managed parkland distributed across the city, but that the green waste from these is not collected. There is therefore a potential to increase the quantity of green waste available to LCC if these parks were managed as intensively as the current resource. The proportion of extra land that would be harvested was calculated, and multiplied by the mass that is already being collected, to get an estimated mass potential. This mass potential was again divided equally into wood, leaves and grass, and the energies for each calculated using the same equation 3.

Manure Arisings from Home Farm

The quantity of manure stated above is not the full quantity produced by the animals because not all of it is collected. A potential future biomass quantity for this could be calculated if combined with the average daily manure production rates for livestock, given in the methodology. However, Interviewee 2 was unable to give an estimation of the number of animals at Home Farm, so this calculation could not be performed.

Food Waste

Only a small area of Leeds currently has its food waste collected (Interviewee 4). Assuming that the average number of occupants per house is approximately constant over the area of Leeds, the total food waste produced by all homes in Leeds was calculated using equation 5. A methane production was then estimated using the same methodology, with equation 3, as outlined above for the food waste.

$$Total\ Mass\ from\ Leeds = \frac{Total\ Properties\ in\ Leeds}{Properties\ currently\ collected} \times Mass\ of\ food\ currently\ collected \qquad 5$$

Interviewee 4 provided a document which outlined the other sources of food waste potentially available to LCC in the future. These sources included commercial and industrial food wastes, food manufacturing wastes and household food wastes originating from neighbouring local authorities. The sum total of these, in combination with the above food calculation, was used to estimate a future potential energy with equation 3.

Appendix 3: Methane Energy Density

A methane energy density of 55.5MJ/kg was combined with the density of methane at normal temperature and pressure of 0.668 kg/m^3 to give a result of 37.07 MJ/m^3, using equation 6.

$$\frac{MJ}{m^3} = \frac{MJ}{kg} \times \frac{kg}{m^3} \qquad (6)$$