Programme Area: Bioenergy

Project: Energy From Waste

Title: Executive Summary - Technology Assessment

Abstract:

The objective of the Distributed Energy (DE) Programme is to increase the up-take of DE through the development of integrated systems in order to reduce through-life costs, improve ease of installation and increase efficiency in the combined generation of heat and electricity. Within this programme framework the Energy from Waste project seeks to quantify the opportunity for the use of UK Waste arisings as a fuel to be used in the combined generation of heat and electricity.

The UK generates around 330 million tonnes of waste per annum, of which around 90 million tonnes is energy bearing.Government legislation seeks to incentivise the diversion of waste from landfill through the existing landfill tax and landfill diversion targets. In parallel the UK is committed to reducing its GHG emissions by 80% by 2050 and supplying 15% of its energy demands from renewable sources by 2020. These drivers lead to a requirement for technology solutions which enable wastes to be used as a cost effective, low carbon and indigenous energy resource for the UK. The Energy from Waste FRP was commissioned to address these requirements and identify potential opportunities for a large scale demonstration project.

Context:

The Energy from Waste project was instrumental in identifying the potential near-term value of demonstrating integrated advanced thermal (gasification) systems for energy from waste at the community scale. Coupled with our analysis of the wider energy system, which identified gasification of wastes and biomass as a scenario-resilient technology, the ETI decided to commission the Waste Gasification Demonstration project. Phase 1 of the Waste Gasification project commissioned three companies to produce FEED Studies and business plans for a waste gasification with gas clean up to power plant. The ETI is taking forward one of these designs to the demonstration stage - investing in a 1.5MWe plant near Wednesbury. More information on the project is available on the ETI website. The ETI is publishing the outputs from the Energy from Waste projects as background to the Waste Gasification project. However, these reports were written in 2011 and shouldn't be interpreted as the latest view of the energy from waste sector. Readers are encouraged to review the more recent insight papers published by the ETI, available here: http://www.eti.co.uk/insights

ETI Executive Summary

Programme: Distributed Energy

Project Name: Energy from Waste

Deliverable: DE2001 / WP2.2: Technology Assessment Report

Introduction

The objective of the Distributed Energy (DE) Programme is to increase the up-take of DE through the development of integrated systems in order to reduce through-life costs, improve ease of installation and increase efficiency in the combined generation of heat and electricity.

Within this programme framework the Energy from Waste project seeks to quantify the opportunity for the use of UK Waste arisings as a fuel to be used in the combined generation of heat and electricity.

The UK generates around 330 million tonnes of waste per annum, of which around 90 million tonnes is energy bearing, this could provide 1 to 5% of UK energy [depending on collection rates and efficiency gains]. Government legislation seeks to incentivise the diversion of waste from landfill through the existing landfill tax and landfill diversion targets. In parallel the UK is committed to reducing its GHG emissions by 80% by 2050 and supplying 15% of its energy demands from renewable sources by 2020. These drivers lead to a requirement for technology solutions which enable wastes to be used as a cost effective, low carbon and indigenous energy resource for the UK.

The Energy from Waste FRP was commissioned to address these requirements and identify potential opportunities for a large scale demonstration project in this area.

The objective of the project is to provide the following outputs:

- Detailed analysis, characterisation and mapping of UK waste arisings to be used as the basis for the subsequent technology assessment and economic analysis within this Project.
- Assessment of the available Energy from Waste technologies for the whole energy value chain from waste input to power and/or heat output and identification of gaps / opportunities in this value chain.

- Identification of combinations of technologies for development and related technology improvement opportunities to fill gaps in the value chain.
- Clear UK benefits case for development and deployment of the identified technologies. The benefits will be judged against criteria agreed with the consortium at the beginning of the project under the headings of Affordability / GHG Reduction / Energy Security / Robustness

The project is split into 4 work packages, represented schematically below.

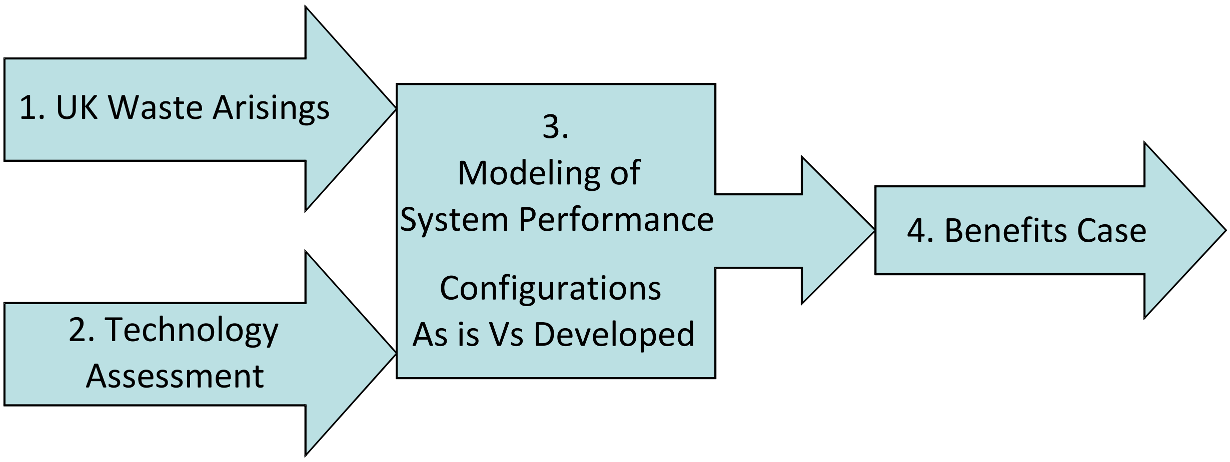

Fig 1 : Energy from Waste Project Structure

Waste materials are generally regarded as being life-cycle carbon neutral as their raw resources have already been extracted. Recovering their energy content in an 'Energy from Waste' (EfW) plant offsets

i) the methane that would be generated through their degradation in landfill (21x more active as a GHG than CO2) and

ii) ii) The CO2 emissions associated with fossil-fuel energy generation displaced by EfW plants. However, these carbon reductions can only be realised if the energy is recovered at a price that is competitive with other forms of generation to enable market deployment.

Currently, waste materials can be processed using mass burn incineration to reduce waste volumes, and hence subsequent landfill costs. Energy is mainly recovered from such systems with a low temperature steam cycle to avoid excessive superheater corrosion at an efficiency of around 20 – 30% (depending on technology), compared to ~45% for state-of-the-art coal power plants, leading to relatively high CO2 emissions per KWh. The challenge is to find technology options which can exploit the synergy between growing needs to solve the problems of environmentally-friendly waste disposal (when re-use and recycling are not options) and the generation of clean affordable power and heat.

To achieve the carbon benefits from this synergy, technologies are needed which can recover the energy in waste materials at a higher efficiency, close to source, with comparable or lower generation costs than other competing energy technologies.

This report is the final report in work package 2. It presents the results from the testing carried out within the project into the Anaerobic Digestion (AD) and thermal processing (pyrolysis and gasification) of selected waste feeds, i.e. competing technologies against which mass incineration should be assessed.

Basis of Designs

The overall project is aimed at improving the definition of the opportunity for significant levels of primarily electricity and heat generation (with other outputs such as by-products and chemicals where markets exist) from the waste available in the UK, both today in coming decades.

The focus of Work Package 2 (WP2) was to explore the suitability of the likely distributed energy technology choices to handle a large fraction (e.g. 80%) of the waste arisings in any particular location. The intention was to focus on technologies which are best placed to handle the widely variable waste feeds which will be seen over the period of a year in any particular location. The objective being to process such waste streams reliably and with flexibility in matching the heat and power demands of the surrounding local communities.

The first deliverable in WP2 (D2.1 – Technology Assessment Report) identified the technology types which the consortium believed could be employed at each stage of an advanced Energy from Waste system. The current development state of each technology with respect to its use with typical mixed wastes was assessed and operational information collated where available. This identified data gaps which needed further investigation to facilitate the system modelling activities to be carried out in WP3.

Specifically only limited data was available on:

1) Anaerobic Digestion
2) Gasification Technologies
    a. Up-draft
    b. Down-draft
    c. Fluidised bed
3) Slow pyrolysis

In all cases this was with respect to the mixed wastes identified as part of the work conducted in WP1 (Waste Assessment). For reliable system operation, it is necessary to have an understanding of the properties of the fuel gases produced and the contaminants arising from the use of mixed wastes. From the available literature, it was impossible to make fair comparisons between the candidate technology options as each report/paper understandably focused on specific trials either with restricted feedstocks or only dealt with single technologies.

To fill the data gaps a test programme comprising of a series of tests in AD and thermal processes (pyrolysis and gasification) was conducted using appropriate waste feedstocks. In addition synthetic gases similar to those expected as outputs from AD and thermal processes were used to assess the impact on combustion engine performance. The outcome of this testing is presented in the accompanying D2.2 report.

Results summary

A summary of the main findings for each of the technologies operating with mixed waste materials is presented in table 1 below

Technology	**General Considerations**		**Findings from Testing Programme**	
	For	**Against**	**For**	**Against**
AD	Wet biodegradable wastes; right scale	Limited fuel options.	Good with food waste; possible to include paper/card	H_2S levels
Updraft Gasification	Simple technology; right scale	High tar levels; operation dependent on fuel properties	Problems with some fuels	Low/medium CV gas; high tar levels
Downdraft Gasification	Simple technology	Small scale only; operation dependent on fuel properties	Few operational problems	Low CV gas;
FB Gasification	Flexible medium scale technology	More complex equipment & operation	Fuel flexible; moderate tar levels; few operational problems	Low CV gas; high NH_3; risk of agglomeration
Slow Pyrolysis	Simple technology;	Operation dependent on fuel properties	High gas CV – high CH_4 and H_2; some operational problems	High tar levels

Table 1 : Summary findings from the Test Programme

Details of the test methodologies and a detailed interpretation of the results may be found on page 9 of the report “Testing Programme Summaries”

Key findings

Key findings from the test programme are as follows:

1) Directing ‘wet’ waste (food/agriculture-derived) to suitably-sized AD plants is a logical approach, although the addition of some bio-degradable paper and card may also be acceptable.
2) On its own, paper and card provide only 40% of the biogas derived from food waste alone, and so any feedstock blending will reduce the overall output of biogas, which at best is around 29% of the energy content of the feed materials (i.e. >70% of the energy content of the waste is left in the AD residue). However, the use of a blend of paper & card with food waste is expected to be beneficial in terms of system stability and reduced H2S production, if confirmed for continuously-fed systems and at larger scales.
3) The benefits of adding components, other than food waste, into the AD blend is directly influenced by the choice between maximising the output of cleanest biogas and the overall gas output, if the biogas production is in a combined system with syngas production from a parallel pyrolysis/gasification process, in which the AD residue is used as a feedstock
4) For any proposed EfW system it is necessary to compare the capital costs of combined plants where there will be the option of directing the more digestible, non-food wastes to either an AD plant or to a pyrolysis/gasification plant which would be using the remainder of the waste fractions along with the AD residues
5) The thermo chemical tests carried out with mixed food waste-paper & card were generally successful, after the food waste had been dried, as such this provides an alternative option where an AD plant is inappropriate.
6) As shown in the engine tests, gases with compositions/CVs similar to those produced in the AD and thermo chemical testing (but following clean-up) are suitable for engine use. The range of gas compositions resulting from extremes of likely waste fuel feed blends suggests that all the gases will be combustible, but care will have to be taken to ensure that stable combustion in the engine can be maintained, e.g. as influenced by varying hydrogen levels
7) The pyrolysis studies for the wide range of materials gave the expected high levels of H_2 and CH_4 in the gas produced, as well as significant tar levels as expected (noting the issue of accuracy of the tar measurements), although tar levels were high in the gasification tests as well. Tar recycling and further treatment/use (e.g. burning to provide process heat) remains a key issue moving forward

8) The gasification tests proved that similar levels of gas could be produced for all waste feedstocks, and so variability of the waste blend with time should not be a major issue, provided the technology chosen and the associated ancillaries are sufficiently flexible to handle this variability.

9) Gas compositions correspond well with waste fuel analyses and so an elemental approach to predicting gas compositions, and hence CV should be possible.

10) Of the gasification technologies explored, both the fluidised bed and downdraft gave the best overall performance in terms of the practical issues associated with operation and the consistency of products produced and so are recommended for inclusion in future developments. The updraft testing did give useful results but these were more variable than those for fluidised bed gasification (partly due to the batch approach to the testing which may have shown the technology in a poor light). The industrially recognised versatility of the fluidised bed option, both in this testing and in the open literature, means that this is preferred for the medium-scale operation over the updraft option

11) In addition to the process data generated from the testing, one of the most valuable aspects of this project has been the lessons learned in using real waste materials in the tests. The waste materials tested were sourced from waste transfer sites and were pre-processed to a suitable physical form for the size of test rigs used. This pre-processing and the subsequent feeding into the reactors revealed important learnings which are also highly applicable to commercial energy from waste systems. These pre-processing problems and their solutions developed during this project may be viewed as provisional guidelines for future applications; the key areas of focus should be:

    a. Fuel Preparation
    b. Fuel Blending
    c. Fuel Feeding
    d. Fuel Bridging

    Details of the key findings for each of the above may be found on pages 23 and 24 of the report

12) Considering the above issues, it is possible to rank the waste materials subjectively in terms of their generic ease of feeding, with 5 being the easiest and 1 the most difficult:

a.	Demolition wood	5
b.	Paper/card	4
c.	Dense plastics	3
d.	Film plastics	2

e.	Food waste	2
f.	Textiles	1

Standards for ranking the feeding behaviour waste materials would be beneficial, leading to new monitoring and control approaches

Further work

This deliverable is the final deliverable in Work Package 2, it is used as an input into the WP3 (Modelling of System Performance) and WP4 (Benefits Case).Table 2 below provides a summary of the key findings and implications, and also provides preliminary options/recommendations for further consideration

Issue/Parameter	Findings	Technology Impacts	Technology Options/Recommendations
Waste Mixes	AD gave good performance as expected with food waste; the addition of paper/card may offer some process benefits. All pyrolysis/gasification technologies were able to process all feeds, but with varying performance – so all options are possible for waste mixes.	L - AD needs further technical development and should be focused on food waste, with or without paper/card as necessary to achieve the required products. M – Selected gasification/pyrolysis technologies also need optimisation/ development – choice will depend on other parameters and required scale of operation. M – Variable performance could require gas buffer storage to even out output variability.	H – Optimisation of operation and definition of safe/reliable operating envelopes with selected technologies should be examined. H – Development of AD for waste feeds H – Further consideration of slow pyrolysis technologies needed as some variants should perform better than shown in test work. M – Consider the need/scale of gas storage required (also helps to de-couple gas production from electricity/heat demand).
Gas CV	Calculated gas CVs were broadly in line with expectations and reflected the C/H/O balance of the waste fuels. The CV of AD biogas depends on the mix of CH_4/CO_2.	H – Consistency of gas CV within a specified is essential for reliable system performance.	H – Need to define CV boundary conditions for different engine types. M - For the thermal processes, gas CVs can be improved through process changes if not suitable for current combustion engine use.
Gas Composition	Gas compositions varied between the thermal processes, with high CH_4/H_2 from pyrolysis and mixed H_2/CO from the gasification options. AD gave expected CH_4/CO_2 mix.	H – Variable gas compositions could lead to operational problems, e.g. high H_2 could cause flame speed problems/combustion instability.	H – Need to define safe envelope of gas compositions and compare with expected ranges from variable waste feeds. M - Gas compositions can be modified through process changes if needed to meet downstream process and engine requirements
Solid Residues	Gasification/pyrolysis residues likely to comprise unburned waste/unconverted carbon in all cases, the	M - Disposal issues will remain as they will probably be classified as hazardous – due to trace	M - Consider residue recycling to improve carbon utilisation. Char residues from mixed waste feeds unlikely

	exact levels being process technology dependent. AD residues will be very wet.	metals (should be low in sulphides). M – Carbon levels in residues may reflect significant energy loss M - Wet AD residues may lead to problems with use/disposal	to be suitable for soil improvement etc. M - If insufficient, consider post-processing/ combustion to extract lost energy and minimise disposal problems. M – Drying or blending of AD residues with the dry wastes for gasification/pyrolysis should be further explored.
Tars	High tar levels found in all pyrolysis/gasification cases, in particular for pyrolysis and updraft gasification as expected. FB and downdraft gasification gave the lower amounts.	H - Tars present a disposal problem as well as reflecting lost energy potential. FB and downdraft are the preferred technologies re tar levels.	H - Tar recycling or post-processing prior to disposal will need consideration. Could be used to provide process heat.
NH_3/HCN in gas	NH_3 measured/estimated in all pyrolysis/gasification tests. Levels were moderate in many tests, in particular FB gasification where higher than equilibrium values are common.	H - Resulting engine NO_x emissions if no reduction measures may be a problem.	H - Depending on standards, consider the impact on engine NO_x emissions. H - If needed, process changes should be explored to reduce NH_3/HCN levels. Alternatively, wet/dry scrubbing of the fuel gas will be needed. Low cost process improvements/gas cleaning essential for commercial viability.

Note: H = High, M = Medium and L = Low

Table 2 : Key Issues from AD and Thermal Testing

References

Knoef H. A. M., “Handbook of Biomass Gasification”, Gasnet/Btg, 2005

Lettner F, Timmerer H, Haselbacher P “Biomass gasification – State of the Art Description”

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