Programme Area: Bioenergy

Project: Energy From Waste

Title: Executive Summary - Technology System Improvement Opportunity Report

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

Purpose: **Arising IP**
Restrictions: **No additional restrictions**

ETI Executive Summary

Programme: Distributed Energy

Project Name: Energy from Waste

Deliverable: DE2001 / WP3.3: Technology System Improvement Opportunity 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.

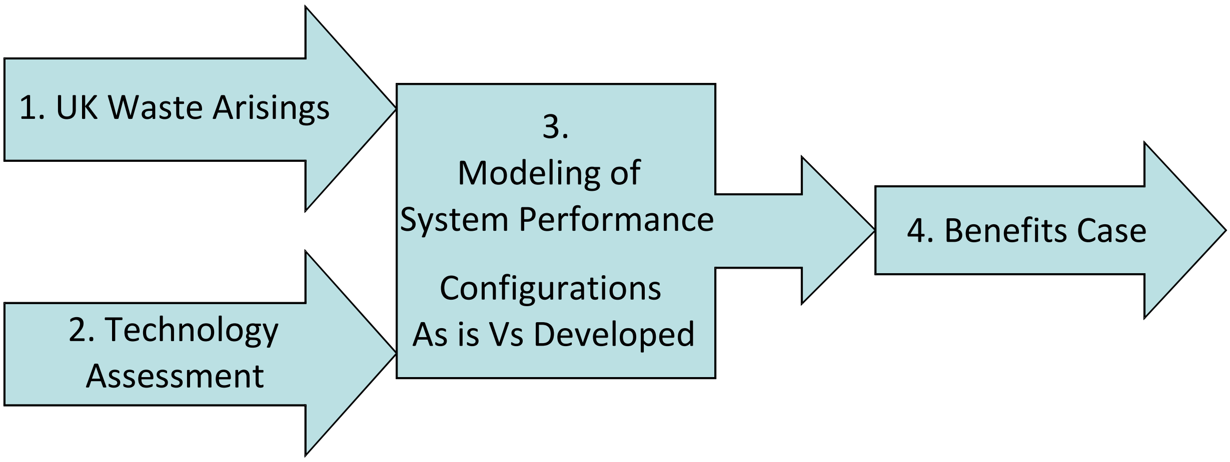

Fig 1 : Energy from Waste Project Structure

This report is the final report in work package 3. It presents the results from the system modelling work carried out by the consortium, drawing heavily on inputs from WP1 – Waste Assessment and WP2 – Assessment of EfW Technologies. It combines the arising data from each Work Package into an economic, mass and energy model that takes into account the changing availability of wastes in the UK and aligns technology choices with the likely waste arisings.

This assessment is important since population growth in the UK is creating increasing amounts of waste that have to be stored for a long period of time. In many cases the wastes have a calorific value and could be used as energy feed stocks. There are significant opportunities to reduce emissions and fossil fuel use by developing effective strategies to generate energy from waste. This has the multiple benefits of:

1) Decreasing the need for landfill,
2) Reducing the consumption of fossil fuels,
3) Reducing emissions of greenhouse gases,

4) Improving energy security,
5) Creating more localised distributed energy systems.

By modelling the performance of Energy from Waste systems then the potential impact of technology acceleration in these areas can be quantified and commissioned as appropriate.

Basis of Designs

This report draws on the waste analysis and technology work in WP 1 and 2. It combines these data in an economic, mass and energy model that takes into account the changing availability of wastes in the UK and aligns technology choices with the likely waste arisings.

The data are combined to create models for each of four community scenarios (detailed below in table 1) to identify the most appropriate feedstock and technology options for EfW systems at each scale. The scenarios analyse potential throughputs, product yields, profitability and emissions to describe potential operating regimes for the communities. The model outputs have been used to identify technology development opportunities for each scenario.

	Population	% of UK Population	Number in the UK	Activity
City	500k	34	5 cities over 500k 26 between 200k and 500k e.g. Leeds	Residential, industrial and service
Town	50k	43	A few hundred towns e.g. Corby	Residential and commercial with light industrial
Village	5k	21	Over 1 thousand villages of this size	Mainly residential
Rural Agricultural	500	2	Very large number of communities of 500 or less	Mixed farming and residential

Table 1 : Community Scenarios

The objective of creating the population scenarios is to:

1) Develop the waste scenario for each case;
2) Assess the technology options that can be used to process the wastes in a way that delivers the most effective financial and environmental contribution to the community's energy requirement;
3) Identify the technology developments that can improve the waste to energy supply;

4) Bring the data together into a potential technology development plan with options for future funding.

These scenarios are a generalisation but are an acceptable route for simplifying the modelling of a complex problem. The scenarios are used to assess technology options. For the purposes of modelling it was assumed that:

1) The technologies will be taken up by communities that can use them;
2) The transportation of wastes to a very large regional facility does not occur;
3) There will be no planning constraints affecting the EFW developments.

Before the scenario modelling was carried out a set of guiding principles were developed based on the waste analysis and technology testing carried out in WP 1 and 2. These principles are:

1) Wastes that can be sorted should be sorted where economic;
2) Segregated wastes should go to recycling in closed loops that feed waste back to reuse - There are a wide range of established processes;
3) Wet (> 80% water) bio-organic wastes will go to anaerobic digestion;
4) Incineration is used where there is a need to reduce waste to landfill and where electricity and heat can be used within the community;
5) Advanced thermal processes, particularly gasification, are attractive where there are opportunities to use the syngas in a range of processes such as: heat and power, chemicals or fuels;
6) Pyrolysis is difficult with mixed wastes and its use would be limited to segregated wastes in most cases.

To facilitate the analysis of each potential scenario the consortium created a simple process model which integrates technologies at the community scale and is then used to identify development opportunities. The overall technology system flow is represented schematically in figure 1 below:

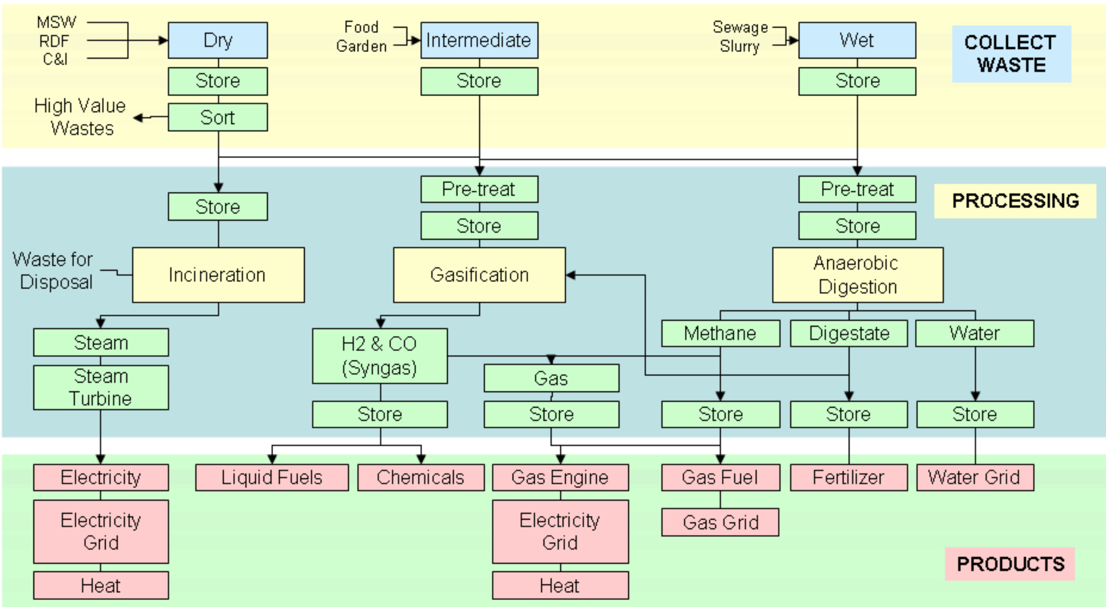

Figure 1 : Schematic Technology Flow Sheet

The inputs to the model for each community scenario are derived from the following data sources

a. Knowledge of waste arisings and compositions (WP1);

b. The background technology understanding (WP2);

c. Results from the experimental technology testing work (WP2);

d. Detailed modelling of specific identified processes and technologies (WP3).

The outputs from the modelling work are used to define a number of potential Technology Development Opportunities (TDOs) which are explored in greater detail in Work Package 4 to ultimately deliver D4.2 – The UK Energy from Waste Benefits Case.

The report concludes by combining the technology opportunities to identify technology development opportunities that could form the basis of practical development and demonstration work that the ETI could pursue in the next stages of its Distributed Energy Programme.

Results summary

1) Most of the current effort in EFW is targeted at conurbations on the scale of a city. However, 64% of the population lives in towns or villages. EFW developments at this level provide a significant opportunity for technology and system development. They can provide a significant percentage of their total energy requirement. Hence the need for town and village solutions to be part of an integrated low carbon energy supply system. Table 2 below quantifies the levels of waste (both wet and dry)

produced annually for each scenario and the potential energy available from this waste.

Scenario	Population	Dry Waste (kt/yr)	Dry Waste Energy Content (MJ/yr)	Wet Waste (kt/yr)	Wet Waste Energy Content (MJ/yr)	Comment
City	500k	490 (306-673)	$4.8x10^9$ ($4x10^8$-$5.6x10^9$)	408 (255-560)	$9.2x10^8$ ($7.7x10^8$-$1.1x10^9$)	Urban with little agriculture
Town	50k	49 (31-67)	$4.8x10^8$ ($4x10^8$-$5.6x10^8$)	41 (25-56)	$1.0x10^8$ ($8.7x10^7$-$1.2x10^8$)	Residential and commercial
Village	5k	4.9 (3.1-6.7)	$4.8x10^7$ ($4x10^7$-$5.6x10^7$)	4.1 (2.5-5.6)	$1.1x10^7$ ($9.7x10^6$-$1.3x10^7$)	Residential with little commercial
Rural Community	500	0.49 (0.31-0.67)	$5.1x10^6$ ($4.3x10^6$-$5.6x10^6$)	20	$6x10^7$	Mainly farming with residential

Table 2 : Summary of Waste Scenarios (2030 range of wastes in brackets)

2) For each of the community scenarios and analysis of the capital investment for EfW systems, the CO2 emissions and the profitability was carried out, the results are presented below. Sensitivity analysis was also conducted, details of which may be found in sections 6, 7, 8 and 9 of the report

Scenario	Capital Investment (£m)	Base Case Simple Profit (£m/yr)	Carbon Dioxide Emissions (kt/yr)	Comments
City (Incineration)	272	10.5	940	All dry waste to incineration All wet waste to anaerobic digestion
City (Gasification and Chemicals)	307	37.9	445	All dry waste to gasification. Syngas split 33/33/33 between electricity, chemicals and liquid fuels All wet waste to anaerobic digestion
City (Gasification for Electricity)	232	8.2	662	All dry waste to gasification. All syngas to electricity All wet waste to anaerobic digestion

Table 2 : City Operational Summary

Scenario	Capital Investment (£m)	Base Case Simple Profit (£m/yr)	Carbon Dioxide Emissions (kt/yr)	Comments
Town (Incineration)	27.7	1.1	96	All dry waste to incineration All wet waste to anaerobic digestion
Town (Gasification)	17	1.7	67	All dry waste to gasification. Syngas used 100% for electricity generation All wet waste to anaerobic digestion

Table 3 : Town Operational Summary

Scenario	Capital Investment (£m)	Base Case Simple Profit (£m/yr)	Carbon Dioxide Emissions (kt/yr)	Comments
Village (Incineration)	2.7	0.03	9.4	All dry waste to gasification and electricity All wet waste to anaerobic digestion
Village (Gasification)	1.2	0.2	6.6	All dry waste to gasification and electricity All wet waste to anaerobic digestion

Table 4 : Village Operational Summary

Scenario	Capital Investment (£m)	Base Case Simple Profit (£m/yr)	Carbon Dioxide Emissions (kt/yr)	Comments
Rural	1.4	0.2	1.2	All dry waste to gasification and electricity All wet waste to anaerobic digestion

Table 5 : Operational Summary

3) The modelling work carried out led to the identification of the following Technology Development Opportunities

	Community Scenario			
Technology	City	Town	Village	Rural Community
Biogas for vehicle use	+++	+++	+++	+++
Biogas for injection into the gas grid	+++	+++	+++	+++
Development of low cost gas clean-up technology	+++	+++	+++	+++
Low cost heat network	+++	+++	+++	+
Integrated gasification, incineration and AD technology systems that integrate innovative technologies	+++	+++	++	+
Develop small and micro scale AD plants below 5kt/yr		++	+++	++
Development of low cost processes to convert syngas into chemicals and fuels	+++			
50kt/yr advanced thermal technology		+++		
5kt/yr gasification or incineration technology			+++	
10t/yr gasification, advanced thermal or incineration technology				+++

Table 6 : Technology Development Opportunities

4) The ranking of each of the TDO's is based on feedback obtained at an ETI run workshop in November of 2010. The drivers for technology development are divided into two groups, those that are generic to all technology scales and types and those that are technology specific. In all cases there is a need to develop technology that:

   a. Reduces the capital cost per unit of investment. This could be through the economies that come from large scale plants or through long production runs of similar units leading to economies from repetition. It should be noted that currently all plants require some support mechanism through either the landfill tax at the supply end or the feed in tariff (FIT) or renewable obligations certificate (ROC) system to be economically viable. A capital cost reduction of over 30%/tonne of feed would be required to remove the need for public sector support mechanisms;

   b. Improves the yield of higher value products and making use of all by-product streams would be of great value. The technology study and experimental work indicates that all technologies studied have low conversion efficiencies for the transformation of feedstock into energy. In many cases the electricity yield is up to 50% lower than the conventional fossil fuel alternatives;

   c. Increase the efficiency of energy conversion both electrically and thermally. Pure thermal systems that convert gas into heat for local use can reach conversion efficiencies as high as 85%. This requires a different approach to gas use either in grid or in local heat networks;

d. Can handle variable feedstock form and moisture content. This is essential to the successful operation of waste to energy plants. The evidence from the work to date also indicates that mixed wastes have similar elemental composition, but differ widely in form and moisture content;

e. Can produce homogenised feedstocks through mechanical, biological or thermal pre-treatment;

f. Can meet legislative and regulatory requirements for safe and beneficial operation;

g. Are robust, flexible, and reliable and are easy to operate.

5) The other overarching feature of the conclusions that come from the modeling work is that viable solutions for cities are currently available so should not be included in further work. There is a need to develop smaller scale technologies that are appropriate to town or village communities and these should be included in further work. These technologies will need to flexible enough that they can be:

   a. Turned-up and turned-down without damage to the plant and uneconomic decreases in operational efficiency;

   b. Turned-on and turned-off as required dependent on season and the amount of waste arisings.

Key findings

Key findings from the test programme are as follows:

6) The evidence is that the amount of residual MSW and C&I waste produced each year is reducing as recycling rates increase and the mix of materials within the MSW is changing. This reduction is linked to a combination of: the commodity value of recyclable materials and increased efficiency in material use.

7) Elemental analysis of MSW and C&I waste indicates that, although it contains different mixtures of materials, the elemental composition of the dry waste is consistent. However, it is noted that it changes in its form (shape) and its moisture content.

8) It is concluded that MSW composition will continue to change in both volume and mix over time, but that the elemental composition is likely to remain the same.

9) Any energy from waste technologies must be able to cope with wastes in various forms and with a moisture content of up to 40%. The number of technology options

is reduced based on this requirement for flexibility of the range of feedstock materials and the production of readily useable products that can be consistently produced. These are most likely to be medium to high temperature thermal processes.

10) Gasification is the preferred technology as pyrolysis is a complex process in the treatment of highly variable MSW and C&I waste. It is more appropriate for use with consistent feedstock streams. However, pyrolysis routes that produce gas or are combined with gasification steps are appropriate technologies.

11) The project modelling, using a number of community scenarios to define waste arisings shows that most UK communities produce tonnages of MSW that are less than the current economic scale for incineration and gasification plants. EfW – including CHP - technologies that work economically on the scale of a town or village are a major development opportunity.

12) As the electricity production from current thermal technologies is of the order of 20% to 25%, a significant amount of the energy content of the waste is lost.

13) It is concluded that distributed energy from waste plants of an appropriate size to local communities could bring significant benefits in efficiency and reductions in transport costs.

14) The modelling also shows that the economics of waste to energy plants are very highly geared to the cost of the feedstock, the capital cost of the plants, the efficiency of conversion of the waste to useful energy, the product value and the local use of waste heat. It is concluded that any future energy from waste development project must address the operational efficiency of the process plants with a major focus on the conversion efficiency of the processes to electricity or fuels and the local use of heat produced by the plant.

15) The emissions of energy from waste plants are driven by the transport costs of bringing wastes to the plant, distribution loses once energy is produced, the efficiency of heat use and the conversion efficiency of the plants themselves. It is concluded that the best way to reduce emissions from energy from waste is to have local plants that are of an appropriate size and scale to the local community with high conversion efficiencies and local use of heat.

16) It is concluded that there is a need to develop gasification and incineration plants of an appropriate size and scale for local communities with high energy from waste conversion efficiencies.

17) Anaerobic digestion plants have been identified as the best route to process wet wastes. Although AD technology is well established it has low efficiency for the size of plant. It is concluded that AD for energy production should be targeted with a view

to increasing the yield of gas per unit of feedstock and increasing process intensity to reduce plant size.

18) AD plants produce methane rich gas that is akin to natural gas and in the UK this is typically burnt to produce electricity. It is concluded that lower emissions will result if AD plant conversion efficiency is increased and if the biogas produced is injected into the UK national gas grid or used locally for high efficiency CHP systems.

19) It is concluded that although SRF plants and autoclaves are becoming increasingly common there is a continuing need for all technologies identified to improve technologies that prepare feedstock to a consistent shape and moisture content.

20) The gas produced by gasification and AD contains contaminants and it is concluded that there is a need to clean-up technologies before these gases can be used effectively. In the case for gasification, there has been little evidence that indicates the industry has resolved the issue of gas cleaning for use in downstream processes beyond boilers.

21) Feedstock cost, feedstock quality, product value, capital investment and process efficiency as the major variables driving business profitability and emissions production. These variables split into to two groups: Controllable and uncontrollable variables. These are summarised in the table below.

Variable	Controllable/ Uncontrollable	Effect on Profitability	Effect on Emissions	Comments
Feedstock cost	Uncontrollable	Higher price lowers profitability	None	Set by a combination of legislation and market conditions
Product value	Uncontrollable	Higher price increase profitability	None	Set by regulation and market conditions
Feedstock quality	Controllable	Balance quality and price to manage returns	Higher yields of products lowers emissions	Blending of feedstocks and feedstock flexibility allows this to be managed both to reduce cost and improve process yield
Capital investment	Controllable	Lower capital increases profitability	None	Need to guard against loss of function as capital reduced
Process efficiency	Controllable	High conversion to high value products increases profitability	High conversion to high value products reduces emissions	

Table 7 : Controllable Vs Uncontrollable Variables

Clearly controllable variables offer the best opportunity for successful technology development.

Further work

1) The modeling work undertaken in WP 3.3 is based on the current available waste data. Additional work could be undertaken to create further data sets that assess the effect of changing composition and changing recycling levels on energy from waste generation. This work could be undertaken in follow-on projects and draw on the outputs of WP 3.2. However, this additional modelling will not affect the technology development ideas generated from this work package.

2) Within the scope of work of the project around the generation of heat and power from waste the consortium has identified a number of potential Technology Development Opportunities which can be pursued in a subsequent EfW demonstration project, these are:

   a. Integrated gasification / advanced thermal, incineration and AD technology systems

   b. Medium, small and micro scale advanced thermal processes for wastes

   c. Small and micro scale AD plants

   d. Low cost gas clean up

   These TDOs are described in section 5 of the report, their feasibility in terms of energy security, affordability and CO2 reduction is quantified in deliverable D4.2 – The UK EfW Benefits Case.

3) In addition further opportunities around the opportunities presented by the generation of fuels and chemicals from waste have been identified, namely:

   a. Low cost heat networks (already addressed via the ETI Macro DE project)

   b. Biogas for use in vehicles and the national grid

   c. Low cost processes to convert syngas to chemicals or fuels

   To this end the ETI has commissioned a number of small scale, exploratory pieces of work to quantify the opportunity for the latter 2 options and ultimately feed into the shaping for a follow-on demonstration project.

References