**Programme Area:** Bioenergy

**Project:** Energy From Waste

# Title: Executive Summary - Benefits Case


## 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 / WP4.2: Energy from Waste: UK Benefits Case

## 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.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.

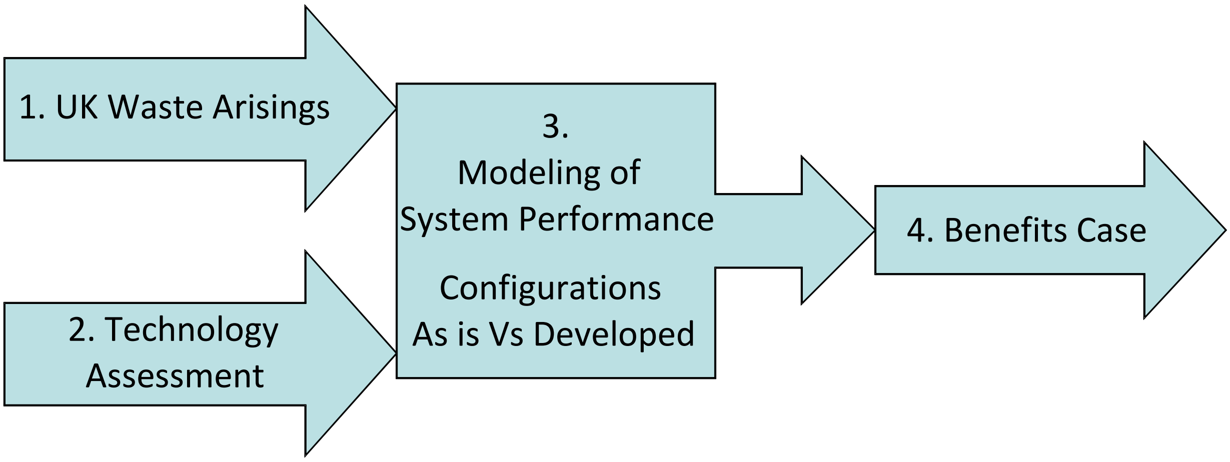


Fig 1: Energy from Waste Project Structure

The UK government's approach to waste management is driven by the adoption of the waste hierarchy in the EC Waste Framework Directive:

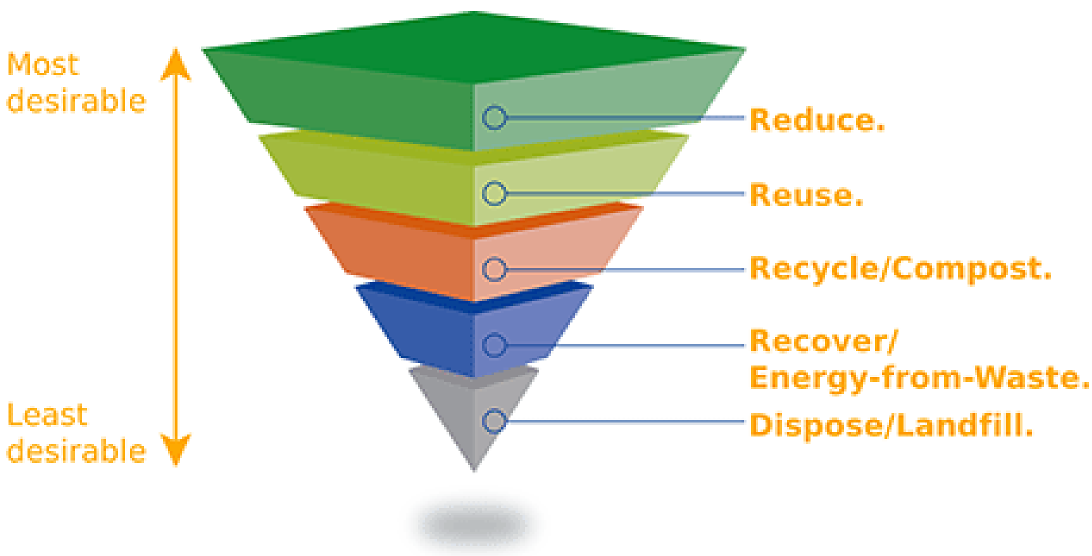


Figure 2: The Waste Hierarchy

Adoption of the waste hierarchy approach is leading to a reduction in the generation of wastes and an increase in the extraction of materials with an alternative commercial value. This means that the amount and nature of waste generated over time is changing, consequently any generic energy from waste conversion system much has the ability to cope with the future changes.

Of the energy remaining in the waste stream, the proportion of this that can be converted to energy is dependent on a number of factors including the amount of residual waste available for energy conversion and the efficiency which the embodied energy is converted to useful heat, electricity and other energy vectors.

Understanding the potential benefits of converting the available waste produced in the UK into energy is needed to guide future investment in technology development in this area. This report is the final report for the ETI Energy from Waste FRP and as such it seeks to quantify the benefits to the UK energy system associated with Energy from Waste.

## Basis of Designs

The structure of the Benefits Case for the Energy from Waste FRP was agreed early in the project so as to give clear goals for the consortium to deliver against. The details are contained in deliverable D4.1. The benefits case has 2 distinct elements:

1. UK Benefits Case
    a. A holistic assessment of the program area (energy from waste), in terms of its overall potential to impact on the ETI core focus areas i.e. greenhouse gas reduction, energy security, affordability, robustness and additionality
2. Benefits and Costs of Technology Development Opportunities
    a. The benefits and costs associated with the development and implementation of the system improvements at either the individual component technology level or at the end-to-end system level. Individual component technologies fall into different categories (i.e. pre-processing, waste processing, post-processing and power & heat conversion). The system level comprises of all these four categories.

The evaluation criteria for the benefits and costs of the system improvements and the UK Benefits case have been broadly developed around the ETI Objectives, i.e.

- *Affordability*: Does a technology have the potential to be commercially viable?
- *CO2 Reduction*: What scale of CO2 abatement is likely to be achieved through mass deployment of a particular technology?
- *Energy Security*: What is the likely impact on UK energy security?
- *Robustness*: How resilient are technologies under different scenarios?
- *ETI Leverage:* Can the skills and capabilities of the ETI contribute to a step-change in technology improvement?

The creation of the Benefits Case (Work Package 4) is dependent upon the preceding 3 work packages, presented schematically in figure 1 above.

To develop both the UK Benefits Case and identify potential Technology Development Opportunities (TDOs) the consortium created a $CO_2$ and financial assessment model which builds upon the System Performance Model developed in Work Package 3. To simplify the analysis process, the assessment of opportunities has been carried out at 4 scales, namely:

- City
    - 34% of UK population live in cities
    - 500k people taken as scenario scale
    - UK has 5 cities over 500k people and 26 between 200k and 500k
    - Mixed economy of residential, industrial and service
    - No agricultural
- Town
    - 43% of UK population live in towns
    - 50k people taken as scenario scale
    - Residential and commercial (with surrounding agricultural).
- Village
    - 21% of UK population live in villages
    - 5k people taken as scenario scale
    - Residential, little commercial
- Rural Agricultural
    - 2% of UK population live in a rural setting
    - 500 people taken as scenario scale
    - Mainly farming and light industrial (arable or livestock)

Further details regarding each of these community scales and associated waste arisings can be found in table 1.

At each of these scales the consortium has evaluated a number of potential scenarios around waste availabilities and conversion efficiency to allow the available energy from waste to be estimated for a 2030 timeframe.

The graph below summarises all the potential energy from waste scenarios developed by the consortium during the project. The following should be noted:

- Scenarios at the low end of the chart assume low waste production, high recycling, low accessibility of waste and low conversion efficiencies
- Scenarios at the high end of the chart assume high waste volumes, low recycling and easy accessibility of waste which can be converted with high efficiencies.

- DECC 2050 pathways are included the chart for reference.

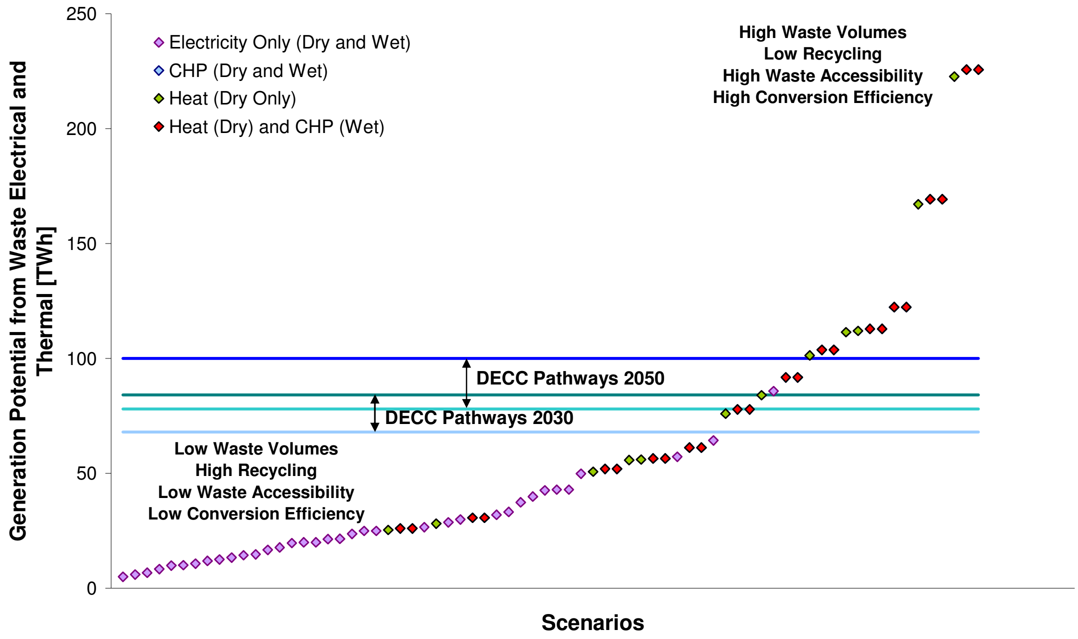


Figure 3: Potential Energy from Waste Availability 2030

The emissions benefits that may result from energy from waste are dependent on the emissions intensity of the energy source which is offset by the energy from waste system, and the emissions intensity of the waste itself.

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Purpose – Governance
No additional restrictions

| Scale | UK Context | | | | Waste Arisings | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Population | Percentage of UK population | Number in the UK | Activity | Dry Waste (kT/yr) | Dry Waste Energy Content (MJ/yr) | Wet Waste (kT/yr) | Wet Waste Energy Content (MJ/yr) | Commentary |
| City | 500K | 34 | 5 cities over 500k<br>26 between 200k and 500k e.g. Leeds | Residential, industrial and service | 490<br>(306-673) | $4.8x10^9$<br>($4x10^9$-$5.6x10^9$) | 408<br>(255-560) | $9.2x10^8$<br>($7.7x10^8$-$1.1x10^9$) | Urban with little agriculture |
| Town | 50K | 43 | A few hundred towns<br>e.g. Corby | Residential and commercial with light industrial | 49<br>(31-67) | $4.8x10^8$<br>($4x10^8$-$5.6x10^8$) | 41<br>(25-56) | $1.0x10^8$<br>($8.7x10^7$-$1.2x10^8$) | Residential and commercial |
| Village | 5K | 21 | Over 1 thousand villages | Mainly residential | 4.9<br>(3.1-6.7) | $4.8x10^7$<br>($4x10^7$-$5.6x10^7$) | 4.1<br>(2.5-5.6) | $1.1x10^7$<br>($9.7x10^6$-$1.3x10^7$) | Residential with little commercial |
| Rural Agriculture | 500 | 2 | Very large number of communities | Mixed farming and residential | 0.49<br>(0.31-0.67) | $5.1x10^6$<br>($4.3x10^6$-$5.6x10^6$) | 20 | $6.0x10^7$ | Mainly farming with little residential |

Table 1: Community Scales and Waste Arisings

As stated earlier, the energy when can be extracted from waste is governed by the efficiency of the conversion technology employed, to allow an analysis to be performed to identify optimum conversion technologies the consortium created table 2 which quantifies conversion efficiency (feedstock in to usable energy out) for both wet and dry waste. These values were reviewed with the ETI technical advisory group (made up of representatives of E.ON, Aston University, Sheffield University, Carbon Trust, WRAP and DEFRA) to confirm they were both realistic and indicative of what could be achieved

| Conversion Efficiency Values | Thermal (Dry Waste) | Biological (Wet Waste) |
|---|---|---|
| Representative of low conversion efficiency | 15% | 5% |
| Representative of current best practice | 20% | 10% |
| Representative of potential high conversion efficiency | 30% | 15% |
| Representative of CHP conversion | 80% | 20% |
| Representative of primarily heat recovery with CHP of wet wastes | 80% | 30% |

Table 2: Technology Energy Conversion Efficiency Projections

These differing conversion efficiencies were combined with an analysis of the percentage of waste which could be considered to be $CO_2$ neutral based on its biogenic content, this is described in table 4 below. It should be noted that when calculating $CO_2$e emissions it is important to consider the accounting protocol. The $CO_2$e emissions from the degradation of waste are commonly accounted for in one of three ways

- All emissions are counted as being $CO_2$ neutral
- Emissions from biogenic portion of waste is counted as being $CO_2$ neutral
- No emissions are counted as being $CO_2$ neutral

| $CO_2e$ Emissions Intensity (g/kWhr) | Conversion Efficiency | % of Waste Counted as CO2e Neutral | | |
|---|---|---|---|---|
| | | 0% | 50% | 100% |
| Advanced Thermal Conversion/Treatment (Dry Waste) | 15% | 540 | 324 | 108 |
| | 20% | 516 | 305 | 95 |
| | 30% | 427 | 254 | 81 |
| | 80% (CHP) | 225 | 144 | 63 |
| | 80% (Heat) | 225 | 144 | 63 |
| AD (Wet Waste) | 5% | 4,181 | 2,156 | 132 |
| | 10% | 3,768 | 1,944 | 120 |
| | 15% | 3,755 | 1,931 | 107 |
| | 20% | 1,944 | 1,032 | 120 |
| | 30% | 1,931 | 1,019 | 107 |

Table 3: Emissions Intensities of Technology Development Scenarios

These assumptions were then used to form 8 scenarios to allow the emissions savings from differing energy from waste systems to be combined with forecasts around potential future waste arisings to be estimated. The 8 scenarios are defined in table 8 below.

| Scenarios - all at 50% arisings accessibility | | | | |
|---|---|---|---|---|
| Scenario | Conversion Efficiency | | Arising Projection | |
| | Dry Waste | Wet Waste | Dry | Wet |
| 1 | 15 % | 5 % | Low | Low |
| 2 | 20 % | 5 % | Mid | Mid |
| 3 | 20 % | 20 % (CHP) | Mid | Mid |
| 4 | 30 % | 5 % | Mid | Low |
| 5 | 30 % | 20 % (CHP) | Low | High |
| 6 | 80 % (CHP) | 10 % (CHP) | Mid | Mid |
| 7 | 80 % (CHP) | 5 % | High | Low |
| 8 | 80 % (Heat) | 30 % (CHP) | High | High |

Table 4: Emissions Modelling Scenarios

An analysis was then carried out for each of the scenarios above to estimate the $CO_2$ emissions, this was applied in three cases:

- 0% counted, i.e. all emissions are assumed to be $CO_2$ neutral
- 50% counted. This aligns with the situation in work package 1 (Waste Assessment) where 66% of waste was found to be biogenic
- 100% are counted

The output for the analysis with 50% of waste counted as $CO_2$e neutral is presented below in figure 6. It should be noted that the calculated total emissions benefit for the UK incorporated an offset against the forecast UK electricity and heat emission intensities for each generation scenario. The following projection and sources of the offset emissions intensities were used:

- 2015 (EDF): 494 g/kWhr
- 2015 (Committee on Climate Change, CCC) : 450 g/kWhr
- 2020 (Committee on Climate Change, CCC) : 300 g/kWhr
- 2030 (Committee on Climate Change, CCC) : 50 g/kWhr
- 2050 (Committee on Climate Change, CCC) : 10 g/kWhr
- Heat at all years: gas intensity in domestic boiler: 191g/kWhr

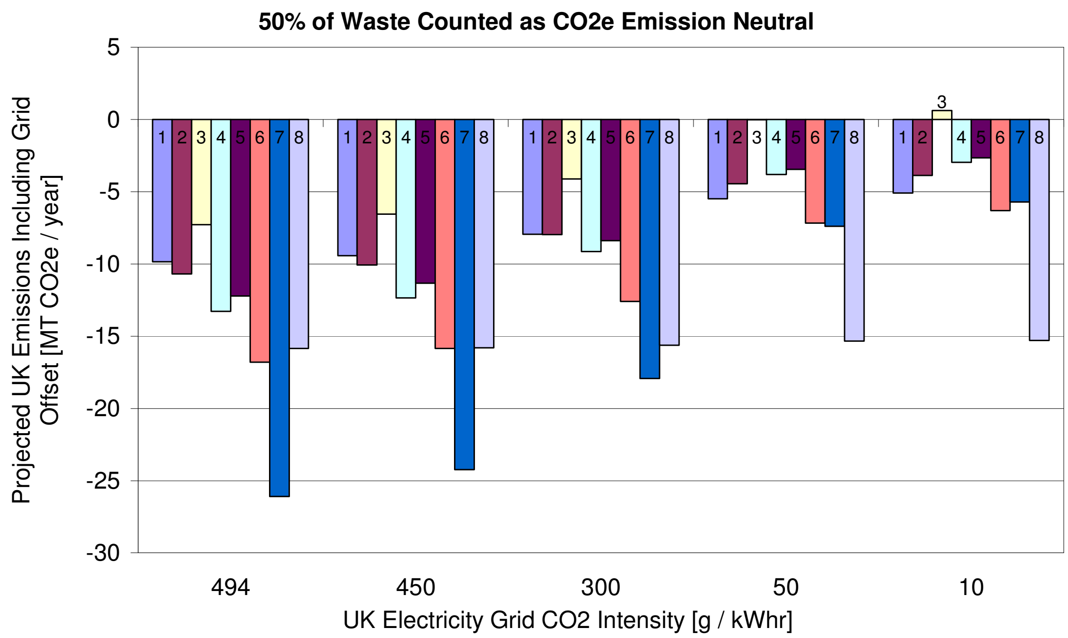


Figure 4: UK Emissions: 50% of Waste Counted as $CO_2$e Neutral

The projection of $CO_2$e emissions shown in figure 6 is felt to be the most representative, due to the alignment of biogenic content in the assumptions with that found imperially in WP1

(Waste Assessment). Across the 8 scenarios considered an emission reduction of 15MT$CO_2$e/year is projected to be achievable with modest technology conversion efficiency. This benefit is driven largely by offsetting (negating) $CO_2$e emissions from the landfilling of wastes, and from offsetting from based electrical generation. Figure 6 also show the benefit of using "waste" heat in CHP facilities (see scenario 6) and reiterates the importance of facilities at scales where the heat can be used effectively.

## Results and Key Findings

As a result of the scenario analysis and modelling work carried out by the consortium the following key points can be made:

1) Applying forecast values for low to high waste availability and conversion efficiencies, the amount of useful energy from waste (both heat and power) which may be generated ranges from **5 to 230TWhrs**.
2) Projected achievable electrical generation is approximately **25TWhrs** per year
3) This equates to between **5% and 8% of the UK's electricity demand**
4) For each of the technology and waste arisings scenarios, the deployment of advanced energy from waste technologies is projected to contribute to a net decrease in UK $CO_2$e emissions of between **5 and 10 MT$CO_2$e/year** at midpoint technology conversion and waste arisings scenarios
5) Greater emissions reductions are associated with high total conversion efficiency technologies, both to electricity and from utilising heat.

The consortium have forecast that if the total wastes arising in the UK (both wet and dry waste) are divided by the number of communities at each scenario scale, the number of possible energy from waste plant opportunities would be up to the number identified in table 1 below.

| City | Town | Village | Rural |
|---|---|---|---|
| 500kt/yr | 50kt/yr | 5kt/yr | 500t/yr |
| 76 | 946 | 4,544 | 4,544 |

Table 5: Maximum Number of UK EfW Plants at Each Community Scale

## Further work

A key step to fulfilling the opportunities described above is technology development in a number of key areas. Based on the testing, modelling, technology assessment and integration work carried out by the project consortium, the following Technology Development Opportunities (TDOs) have been identified:

1) The development of integrated advanced thermal (gasification and/or pyrolysis) systems for energy from waste at the community scale. City scale technology is well served by incineration and the focus on the development work should be on town and village scale technologies.
2) Cost effective gas clean-up is essential to the development of community scale advanced thermal systems.
3) Low cost, high efficiency distributed scale anaerobic digestion (AD) plants that can be integrated with advanced thermal technologies.
4) The development of community scale integrated distributed energy from waste facilities link thermal and AD technologies into highly efficient systems that can maximise resource efficiency.

The consortium has identified four project stages to address the above TDOs, which are identified below in table 6. The costs at this stage are rough order of magnitude and would be refined during the definition phase of any follow on project:

| Project | Capital | Project Costs | Timescale | Priority |
|---|---|---|---|---|
| Advanced Thermal Processes | £10m - £15m | £10m | 3-5 years | 1 |
| Gasification Gas Cleaning | £5m | £3m | 2-3 years | 2 |
| Anaerobic Digestion | £3m | £2m | 3-5 years | 3 |
| Integrated Facility | £15m - £20m | £5m - £10m | 3-6 years | 4 |
| Total | £33m - £43m | £20m - £25m | | |

Table 6: Elements of Energy from Waste Development Programme

Figure 5 below shows how the four projects integrate into a development programme for the demonstration of an integrated system approach to energy from waste.

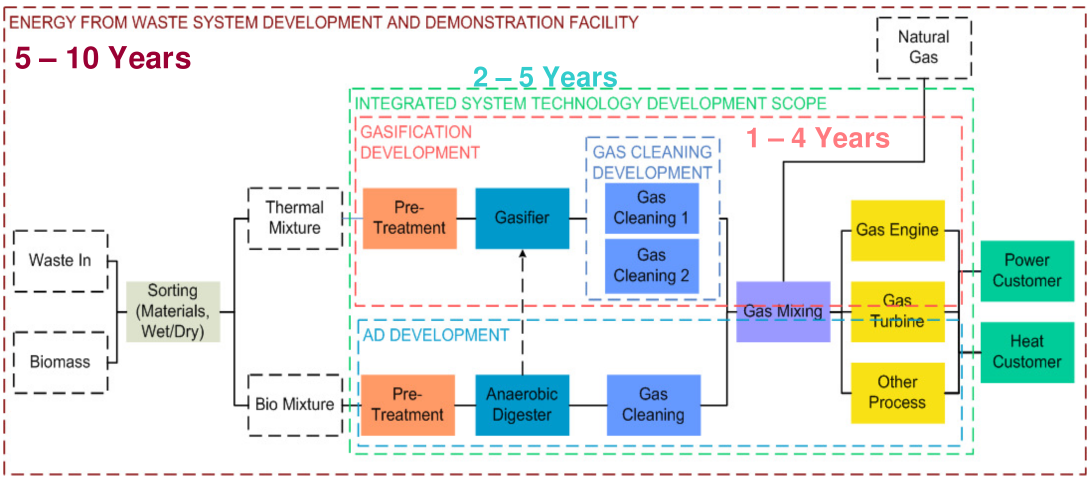


Figure 5: Structure for Integrated Energy from Waste Programme

**The preferred approach advocated by the ETI's DE SAG and by the external reviewers** consulted is for a demonstration project to focus on projects 1 and 2 highlighted above, namely **an advanced thermal conversion process with integrated gas clean up**.

To achieve the benefits described above, considerable technical development and demonstration is required, particularly around the end-to-end waste to power generation system integration of advanced thermal conversion technologies. The collaborative structure and ability to bring together a range of cross disciplinary skills would uniquely position the ETI to enable the successful development and demonstration of an advanced thermal conversion process with integrated gas clean up.

It should be noted that the scope of the Energy from Waste FRP is focused on the generation of heat and power from waste, looking outside this scope the consortium identified a number of additional areas that could add value in the future. These are:

1) Low cost heat networks
2) The use of syn-gas generated from EfW technologies to create fuels / chemicals
3) The use of pyrolysis to create transport fuels
4) The injection of bio-gas and syn-gas from EfW technologies into the gas grid
5) The injection of bio-gas and syn-gas from EfW technologies into the gas grid with CCS

The issue of heat networks is being addressed in the ETI Macro DE project. Additional work was commissioned to explore opportunities 2 to 5 as counterfactual and / or complementary to the technology development approach advocated. It is critical that these areas be evaluated prior to the definition of a follow-on project.