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The Bioeconomy Consultants

Energy from Waste: Efficiency based measurement

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Executive Summary

This briefing paper discusses the potential for introducing an efficiency based measurement to categorise advanced Energy from Waste (EfW) processes. Biomass, whether specially grown or originating from wastes, is a limited resource and it is important to maximise the value extracted from each tonne processed. In power generation, this means maximising the amount of power exported to the National Grid per tonne of biomass processed. Hence, DECC's policy aims look to drive energy efficiency and value. However, measuring efficiency of an ACT on a consistent basis from plant to plant is challenging and complex. A one size fits all efficiency measure will not be straight forward to set up and will be complex and expensive to implement and manage.

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1   Energy Balances and Energy Efficiency

Energy balances are used to demonstrate and account for the flows of energy through processes. They account all energy inputs and outputs within defined system boundaries, in a common reporting unit. Energy can be converted into different forms, e.g. mechanical energy to heat energy, but due to the first law of thermodynamics, there can be no accumulation of energy, and therefore the sum of energy inputs must equal the sum of energy outputs and energy storage.

Energy balances can be used to determine the energy efficiency of a conversion process, usually defined as the useful energy out (for example MWh of electricity) divided by the energy inputs:

Energy efficiency (%) = useful energy produced x100 / energy input

For Energy from Wastes (EfW), the main energy input is the chemical energy content of the fuel, measured as the calorific value (Lower heating value, LHV or Higher heating value, HHV). Other energy inputs include, but are not limited to, any energy used to process the feedstock prior to gasification (depending on the system boundary chosen), any energy used to produce any oxygen used by the gasifier (again depending on the system boundary chosen). Energy outputs include electricity, heat, chemical energy content of carbon left in ash, heat losses etc.

One of the key challenges in calculating energy efficiency is in defining the boundaries of the energy inputs and the energy outputs in a <u>consistent</u> manner. For coal fired processes, this is relatively straight forward as there are set standards available and years of experience to draw on. For waste processes, however, this is not straight forward, in particular when it comes to defining the boundaries of the energy inputs to a system.

2   Challenges – Pros and Cons of using efficiency to categorise waste ACTs

Energy efficiencies are already required by regulators for some projects. Energy efficiency is reported to the Environment Agency under Environmental Permitting Regulations and in application for R1 status. This defines an energy from waste plant either as recovery (R1) or a disposal operation (D10). This categorisation is based on a modified efficiency calculation, calculated using the R1 formula. For these purposes, the system boundaries comprise only the essential parts of the incineration and energy recovery process, including combustion chambers, boilers, flue gas cleaning systems, and often energy transformation and recovery equipment. The energy contained in the waste refers to waste after pretreatment since the purpose of R1 is to differentiate the EfW plant itself from landfill, regardless of the waste type being combusted (i.e. rMSW[1], RDF or SRF).

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[1] Defined here as "residual MSW"; "residual Municipal Solid Waste"

For the RO banding sub categorisation and the future EMR, the aim would be to differentiate between different technology types so that the more efficient can be more strongly incentivised. To be robust, therefore, the variety of technology types and their differing requirements need to be considered in the energy efficiency calculation in a consistent way. Otherwise, some developers will be advantaged and others disadvantaged and unintended consequences may arise.

When calculating an energy balance (or energy efficiency calculation), it is essential to define the boundaries of what is included and what is excluded when accounting for total energy inputs and total energy outputs. When calculating the energy balance around a single plant where the aim is to understand the performance of that plant only, perhaps to compare performance over one day against another, these can be defined as required, providing that the same boundaries are used each time a balance is calculated to allow comparison between balances.   However, where the objective is to compare single energy balances from a number of plants, all of different design and using, for example, different feedstocks, then choosing the boundaries becomes critical to enabling inter-plant comparison and highly complex.

3   Inputs Boundaries

3.1   Waste Feedstocks

The proposed UK ACT projects include a wide variety of configurations and feedstocks. Some projects will process rMSW, some RDF or SRF and some a mixture of feed materials. Some projects will receive RDF or SRF made by another company, receiving a gate fee of the order of £20-40/tonne; others will receive rMSW with a gate fee of the order of £75/tonne and will process it in their own on site MRF/MBT/MHT[2] before gasifying the resulting RDF/SRF. Hence, there is an issue here as to whether to define the energy balance boundary at the gasifier or further upstream in the waste processing chain:

Option 1. Define the feedstock input chemical energy at the gasifier feed hopper. In this case, any energy expended in preparing the feedstock is not counted in the energy balance and any credits which may arise for recovering recyclates are not assigned. Hence:

1.   Energy expended upstream of the gasifier feed hopper will not be manifested in the efficiency calculation leading to the possibility that excessive energy will be used upstream (e.g. drying very wet wastes) to enhance ROC yields.

2.   Downdraft fixed bed gasifiers will be advantaged as they require a briquetted feedstock – the energy used in briquetting (up to 10% of the energy in the feedstock) will not be counted.

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[2] MRF – Materials Recycling Facility; MBT – Mechanical Biological Treatment plant; MHT – Mechanical Heat Treatment plant.

3. Gasifiers that can process rMSW such as plasma gasifiers and grate-type gasifiers may be disadvantaged as they do not require any waste pre-processing. Such gasifiers could though also process rMSW and RDF/SRF in campaigns or even blends of rMSW and RDF/SRF. As well as being disadvantaged, efficiencies of these plants may therefore fluctuate, perhaps across any set banding cut-off. As a result, a plant may switch between being an advanced system and a standard system as feedstock changes occur.

4. Where gasifiers are able to switch between using rMSW and, for example, RDF, the different embedded energy contents[3] of the different types of wastes will not be taken into consideration. A system for monitoring and auditing these changes will need to be put in place, perhaps using carbon 14. This could potentially add large costs across all projects including those where switching to rMSW processing is not an option.

5. There is less incentive to increase recycling rates upstream of the gasifier. Additional revenue through increased power sales and increased ROCs will be obtained by maximising input energy levels. If enhanced recycling can be achieved and is a realistic option, then this may reduce the ACT input energy levels and hence reduce the power available for sale and the ROC income.

A variant on option 1 is to combine C14 measurement of biogenic content with MWh output to provide a measure of MWh produced per kg of fossil (or biogenic) carbon. This measure would, though, not highlight the different embedded energy contents of the different types of wastes that could be processed. It might, therefore, drive excessive feedstock preparation activities to yield an enhanced ROC value. If the volume of biogenic plastics in the wastes to be processed[4] was to increase, backing out an equivalent volume of fossil derived plastics, then fossil GHG emissions per tonne of waste processed, assuming constant total plastics content would reduce. However, it should be noted that the optimal processing pathway for bioplastics recovery (advanced gasification versus say recycling) is not yet clear.

A variation on the above is to set an input feed material biogenic content cut off, for example at 90%. This can have the unintended consequence of driving plant operators to blend wastes with wood to achieve the set biogenic content incurring not only extra costs but also perhaps unnecessary GHG emissions (through transportation, extra processing etc.). There will be an element of diminishing returns beyond a certain biogenic content which perhaps needs to be identified. It should also be noted that the biogenic power will be "blended" with non-biogenic power in the national grid. This point is recognised in the Renewable Transport Fuels Obligation which now permits "partially renewable" fuels.
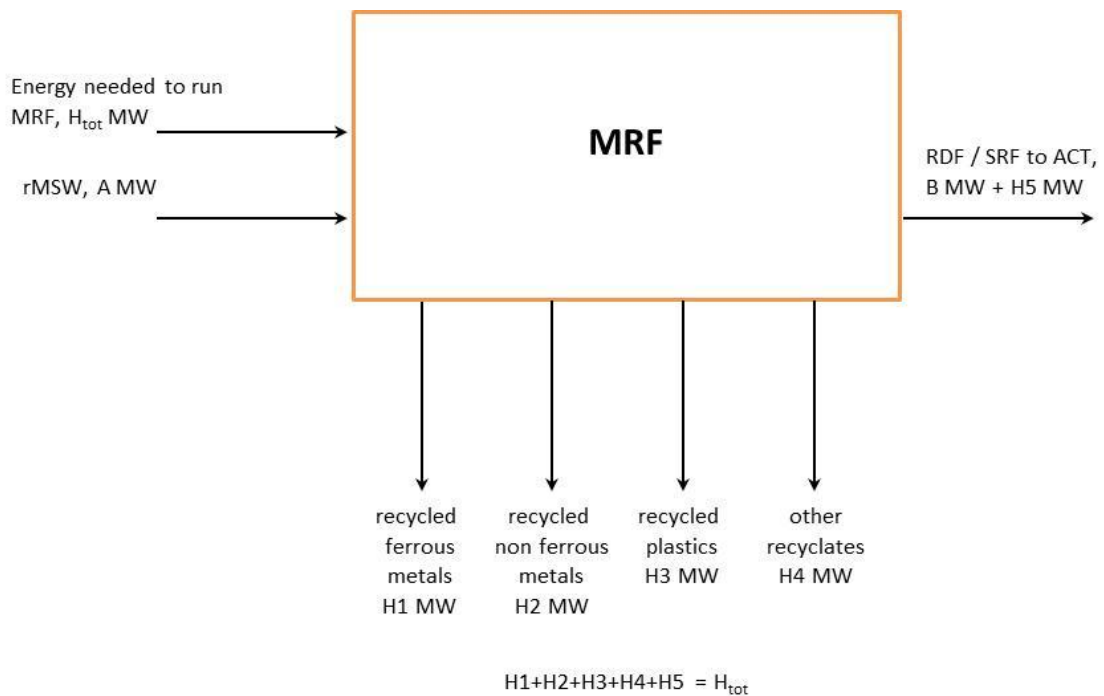
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[3] The energy used to process rMSW to produce, say, RDF in a MRF
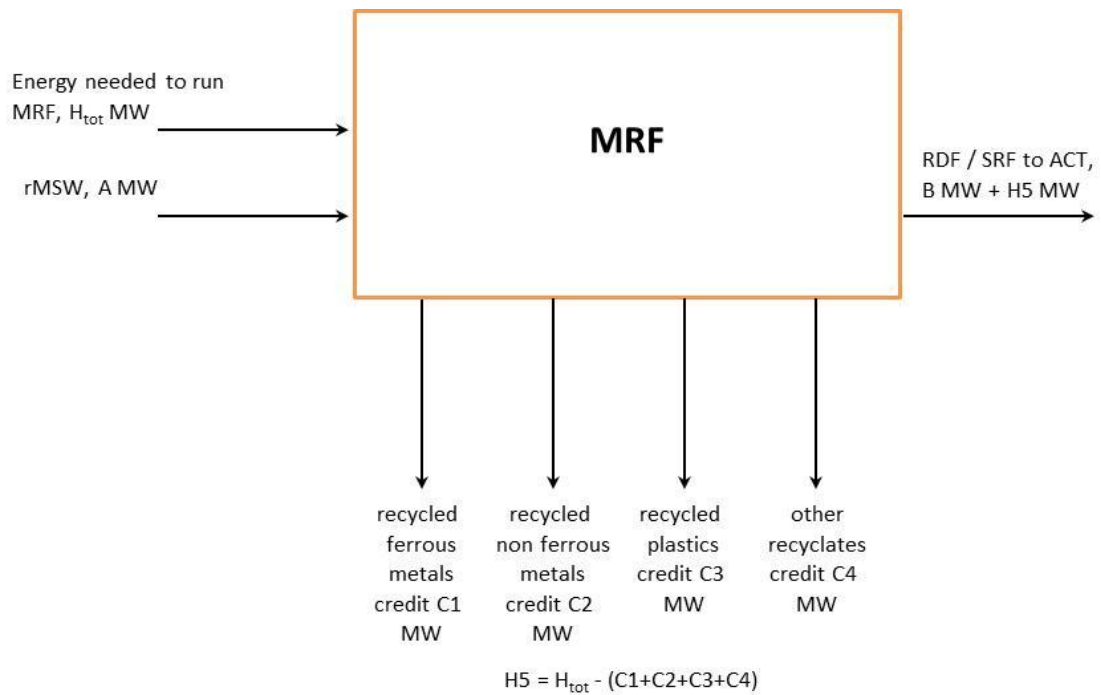[4] For example, by gasification

Option 2. Define the feedstock input chemical energy at a point prior to waste pre-treatment in a MRF/MBT/MHT. Issues arising from this option are:

1. The definition of the "start" of pre-treatment is difficult to define, particularly as the systems used for waste collection and treatment differ across the UK.

    a. For example, in some regions, wet and hence low calorific food waste may be source segregated while in other regions not. Where not pre-segregated, then this will lower the calorific value of the waste stream and hence impact the ACT's efficiency. An ACT in one region may end up with a different efficiency to an identical plant in another.

2. This option is often used to indicate that the best energy efficiency is obtained by those processes that burn or gasify raw, untreated waste (e.g. rMSW). This is made on the assumption that all the energy inputs to the MRF are assigned to the RDF/SRF output. However, MRF energy inputs must be fairly allocated across each of the MRF output streams, in a similar way to Life Cycle Analysis calculations. This, though, brings added complication and challenge as there are different, equally valid, ways to allocate:

    a. By mass. The MRF energy inputs are allocated by mass flow rates. This would result in the densest materials (e.g. steel) receiving an excessive share of the energy input while the least dense products (e.g. RDF) receiving the least. i.e. H1 in the figure below (Figure 1) would be disproportionally large.

    b. By energy content. The MRF energy inputs are allocated by energy flow rates (this is the allocation process used by the RED). In this case, MRF outputs having no calorific value such as steel and aluminium (H1 and H2 in the Figure 1) would receive no energy allocation. H3 for plastics would receive an unfairly high allocation as plastics have an high energy content per kg.

    c. By price. The MRF energy inputs are allocated according to market price (this is the allocation process used by Publicly Accessible Standard PAS2050). This can often be the most robust allocation procedure available for life cycle analysis calculations across all applications (not just energy applications). However, in the case of a MRF, the RDF/SRF product, in having a negative monetary value, will receive either an energy credit for having been processed or will receive no allocation of MRF energy inputs. i.e. H5 in Figure 1 could be negative which would yield a higher gasifier efficiency.

Energy needed to run MRF, H_{tot} MW

rMSW, A MW

MRF

RDF / SRF to ACT, B MW + H5 MW

recycled ferrous metals $H1$ MW

recycled non ferrous metals $H2$ MW

recycled plastics $H3$ MW

other recyclates $H4$ MW

$$H1+H2+H3+H4+H5 = H_{tot}$$

Figure 1 Allocating energy flows by mass, energy or price

d. By substitution credits. This is the most complex allocation procedure and is the process that was used by the RTFO before RED alignment in December 2011. Substitution credits calculate a credit for the energy that would have been used to produce, for example, steel which has not now been produced because recycled steel has been recovered (see Figure 2 below). The credits for each of the recyclate streams are then added to the RDF/SRF stream from which the MRF energy input is deducted. Hence, if the credits are greater than the MRF energy input, then the RDF/SRF stream energy value "could" be improved. The key challenge in using substitution credits is again one of boundaries when calculating the energy credit. However, substitution credits do best represent real life operations.

3. The option to include feedstock pre-treatment within the boundaries of the ACT efficiency calculation while fairly allocating the MRF energy demand across the full range of recyclates should encourage higher recycling rates as ACT operators will be encouraged to maximise the amount of MRF energy demand allocated to recyclates.

4. By including feedstock pre-treatment within the boundaries of ACT efficiency, the energy required for specialist pre-treatment such as briquetting should be properly accounted for.

Energy needed to run MRF, H_{tot} MW

rMSW, A MW

MRF

RDF / SRF to ACT, B MW + H5 MW

recycled ferrous metals credit C1 MW

recycled non ferrous metals credit C2 MW

recycled plastics credit C3 MW

other recyclates credit C4 MW

$H5 = H_{tot} - (C1+C2+C3+C4)$

Figure 2 Allocating energy flows by substitution credits

3.2   Oxygen

Gasifiers require an oxidant which can be air (often described as air blown), steam, oxygen or a mixture of 2 or 3 of these. Oxygen is typically used when:

1.   A gas turbine is to be used. Gas turbines require the input syngas to be compressed. It is uneconomic to compress the nitrogen that is a feature of air blown gasification systems' syngases (around 50% of syngas).

2.   Where a fuel or other chemical is to be produced from the syngas. The nitrogen, which is large constituent of air blown syngases, does not take any part in the fuel/chemical synthesis reactions, but takes space in the reactors which is costly.

2.   Where a specific syngas CV is needed (e.g. for RO 2009 definition). If there is a drive to reduce waste fossil content, then the waste CV will reduce. The CV of the output syngas will then also reduce. One way to increase that syngas CV is to use oxygen or oxygen enriched air to reduce the syngas nitrogen content and hence increase its CV. The extra costs to a project developer of doing this would need to be balanced against the increase ROC income.

The issues which arise with respect to energy balance boundaries and oxygen are:

1.   Whether to include the oxygen plant within the energy balance at all. For example, the oxygen plant may be an existing plant used to supply

a variety of other customers and the extra oxygen being supplied to the ACT may be "spare".

2. How to allocate the energy input to the oxygen plant across a variety of oxygen applications. For example, one oxygen plant factory could supply a range of end users on the same site.

3.3 Other inputs

Some ACTs require other inputs such as olivine for bed material in fluidised beds while others do not. A decision would have to be made as to whether an energy debit is applied for such inputs to ensure consistency. Adding such debits would increase complexity.

4 Outputs Boundaries

ACTs can be used to produce a variety of useful outputs including electricity, fuels, chemicals and biochar. An issue can arise when calculating energy efficiencies when one or more co-products are produced which do not have an energy application. Examples are

- Gasification plants producing ammonia plus power

- Pyrolysis plants producing biochar plus power

In these cases, if the efficiency is defined as the MWh of power produced divided by the energy inputs, then what is a valuable and efficient plant might be "downgraded" due to an apparently low efficiency to power.

The "energy value" or "exergy" of the outputs should also be considered. Electricity has high exergy since it can be used in a wide variety of highly valued energy applications such as lighting, heating, cooking, powering motors. Biochar can be used as a solid fuel but is more difficult to use – to convert it into high exergy and useable power would cost a further efficiency loss (say 60-70%). Hence a decision would have to be made as to whether lower energy values are assigned to non-electricity co-products such as biochar, fuels and chemicals.

A separate issue is how to treat CHP process efficiencies and how to compare these with power only projects. Total CHP efficiencies will typically be over 50% compared to power only projects which will have a maximum efficiency of the order of 40%. Hence, a poorly performing CHP plant may appear more efficient than a strongly performing and technologically advanced power only plant.

It should also be recognised that to produce heat from Rankine cycle (steam) systems, high exergy electricity needs to be sacrificed to yield low exergy heat. Hence, the efficiency to power drops. There is no loss of power by extracting heat from an engine or gas turbine generating system.

5   Other

Some companies have stronger engineering/science expertise than others. The complexity required to set up an energy efficiency monitoring system may introduce excessive costs to some companies who are not set up to manage the accumulation of data needed.

There may also be an issue for companies buying RDF or SRF in from a variety of companies including from abroad. RDF supply companies may not be in a position to, or have a desire to, produce accurate and robust energy balance information.

6   Conclusions: Use of an Efficiency Cut off for Advanced and Standard ACTs.

In principle, the use of an efficiency cut off measure could be applied to any energy conversion process including existing incinerators. The above issues, particularly around setting consistent energy balance boundaries would still apply.

Such a system should be expected to drive innovation in incineration technologies with heat recovery for power generation to achieve higher efficiencies.

6.1   Implementation Costs

To calculate and report the whole system efficiency, where the system includes fuel pre-treatment and upstream processes, would require a reporting tool similar to the Biomass GHG Lifecycle Assessment Tool.

The cost of developing this tool was around £80,000 not including cost of project management and the cost of hosting and maintaining the tool once developed.

The Biomass GHG Lifecycle Assessment Tool incorporates a credit (albeit a little awkwardly) for digestate from AD. The credits arising in a MRF would be more numerous and difficult to calculate. Hence, a pre-study would be required to assess and define the best way to allocate MRF energy inputs. We estimate that this would cost of the order of £50,000. This kind of project might best be delivered with a LCA practitioner.

We estimate therefore a total cost of £130,000 minimum and a timescale of 10-12 months to implement a system, modelled on the Biomass GHG Lifecycle Assessment Tool.

Additionally, Ofgem would require initial set up costs for IT and staffing of the order of £1million. Whether this full cost would need to be incurred depends on the precise scheme design and any savings from learning with doing that could be made.

Costs of compliance would, we estimate, require a half full time equivalent (FTE) having an estimated annual cost of £20,000-30,000/year. If a much more limited

requirement is placed on small operators such as for the Biomass GHG Lifecycle Tool scheme, then these could be of the order of £2,000-3,000 /year.

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