The Bioeconomy Consultants

NNFCC

Review of BEIS assumptions underlying estimates of power generation costs for ACT and EfW with CHP

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Disclaimer

NNFCC is a leading international consultancy with expertise on the conversion of biomass to bioenergy, biofuels and biobased products.

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1 Acknowledgement

NNFCC and 2gb Consulting wish to acknowledge the input by the following who provided review and comment on the emerging findings and suggestions for revision. However, the conclusions drawn are those of the authors taking account of comments received, sources of information reviewed and experience in similar or related projects:

Kevin Chown, Kew Technology Ltd
Philip Cozens, Progressive Energy Limited
Paul Winstanley, EXETI
Plus, comments in review from BEIS (Clean Electricity, Energy Security and Networks and Markets)

2 Executive Summary

The Department for Business, Energy and Industrial Strategy (BEIS) is undertaking a review of the department's assumptions around the cost of generating electricity through energy from waste (EfW) with combined heat and power (EfW with CHP) and advanced conversion technologies (ACT) with and without CHP. BEIS commissioned NNFCC, with support from Consulting Engineer 2gb Consulting, to conduct a short formal review of BEIS analysis and financial assumptions. These currently draw on previous definitions of technologies eligible to apply for CfD contracts under the 'ACT' technology heading. BEIS provided an Excel spreadsheet containing the key modelling parameters, which includes high/medium/and low values for some key parameters, plus additional worksheets addressing other particular modelling values or parameters. The data provided draws predominantly on previous analysis by ARUP (2016)[1] with updates by BEIS. BEIS now wish to understand which, if any, of this data needs to be updated and or amended to reflect both current project developments and to ensure costs listed under 'ACT' headings reflect technologies meeting current eligibility criteria for ACT's within the CfD.

Analysis and feedback are based on a mix of existing knowledge in the team, review of publicly available data sources or reference material and through exposure of data to a very limited number of project developers and one expert on ACT technologies for further comment. NNFCC wish to highlight that there are an extremely limited number of relevant ACT projects and limited examples of EfW with CHP projects from which to draw data, but best attempts have been made to draw on the available data, external expertise and knowledge from related sectors to highlight where existing BEIS data and assumptions should or may need to be revised. The results therefore should be treated with some caution. Costs can vary widely both between scales of plant and even for the same scale of plant.

The key areas where amendments were deemed to be significant included:

- estimates for gate fee ranges, where an uplift was recommended for both EfW feedstock and RDF.
- ACT projects with and without CHP - an increase in the electrical capacity (net power) was recommended as a proportion of more recent projects have been larger than the original capacity range considered

More minor recommended amendments included:

ACT projects (with or without CHP)

- a small increase in expected useful plant lifetime
- increasing the upper value for net efficiency of ACT technologies to reflect more efficient technologies
- reducing capital costs for ACT projects
- a small reduction in availability to reflect the need for annual maintenance
- consideration to include a higher heat to power ratio (0.78 (heat as a fraction of power output)) for situations where an ACT is coupled to a CHP unit using steam cycle technology

[1] Arup_Renewable_Generation_Cost_Report, 2016 (copy provided by BEIS)

EfW projects with CHP

- expanding the net power (electrical capacity) to reflect larger plants in the development pipeline
- minor extension to construction period
- recommendation to reduce the active lifetime
- a recommendation to increase the lower value for net efficiency to reflect drives to greater efficacy
- a small reduction in availability to reflect the need for annual maintenance
- consideration towards reducing the qualifying biogenic content of residual waste fed to EFW plants, to reflect increased food wastes segregation over time (but NOT to amend the biogenic content of RDF typically used in ACT's, where the additional waste sorting and refining processes will tend to maintain biogenic content over time).

There is little new in the way of new technology development in the EFW sector, but some refinement to improve process efficacy. In the ACT sector, there is differentiation occurring to serve the advanced transport fuels sector but there is little difference in basic ACT technology function or examples to consider expanding on the range of costed examples.

3 Background

The Department for Business, Energy and Industrial Strategy (BEIS) is undertaking a review of the department's assumptions around the cost of generating electricity through energy from waste with combined heat and power (EfW with CHP) and advanced conversion technologies (ACT). The department's generation costs estimates are key assumptions behind its power sector analysis, and in helping to ensure appropriate support is provided to generators and value for money obtained for consumers via the Contracts for Difference scheme.

BEIS commissioned NNFCC, with support from Consulting Engineer 2gb Consulting, to conduct a short formal review of BEIS analysis and assumptions concerning the generation costs for EfW with CHP and ACT ('Advanced ACT +/- CHP), ensuring that these align with estimates for ACT technologies current deemed to be eligible for support under the CfD mechanism, following revision of eligibility parameters in 2018.

3.1 Key areas of focus for the review

(Directed by BEIS)

- Applicability of high, medium and low values used in key modelling parameters (i.e., are they reflective of current status and possible emerging technologies performance)
- Gate fees and renewable qualifying multipliers: future projections and variations between technologies and locations.
- Scope for extending on (and need for) the current analysis to include other drivers of cost differentiation between projects (for instance, different process types), based on pipeline projects that may be brought forward.
- Heat to power ratios for CHP implementation

And also, to comment on:

- relevance of current BEIS technology archetypes 'Standard', 'Advanced' and 'CHP' to ascertain whether these still reflect the current state of the technology and CfD eligibility.
- modelling approaches used to generate cost assumptions
- decommissioning cost provision
- alternatives or improvements wherever assumptions or approaches are found to be inadequate.

3.2 Exclusions

Review of financing costs or hurdle rate estimates were specifically excluded from the analysis by BEIS.

4 Approach

BEIS provided an Excel spreadsheet containing the key modelling parameters, and high/medium/and low values for some key parameters. The data provided draws predominantly on previous analysis by

ARUP (2016) with updates by BEIS. These values feed into models of levelised cost of electricity (LCOE), for which one worked scenario example was provided to demonstrate how the assumptions and data were utilised/applied.

NNFCC were provided with data and assumptions made for the following technologies (with no further subdivision):

- Standard ACT (pre 2018 definition)
- ACT Advanced (pre 2018 definition)
- ACT Advanced + CHP (pre 2018 definition)
- EFW + CHP

Along with additional tables for

- Opex adjustments (for each technology) for date of commissioning (reducing to account for learning rate and improved efficacy)
- Heat revenue estimates (ACT CHP and EfW CHP) and underlying assumptions
- Fuel costs and gate fees (for EfW and ACT) (currently amended by scaling from earlier values due to uncertainty over calorific values of feedstock)
- Decommissioning costs (for each technology – all currently assumed to be the same)
- Renewable Qualifying Multiplier – currently assumed to be 50% for all technologies (i.e., 50% of fuel is bio-derived)

BEIS provided its assumptions for the modelling parameters described in Table 1. BEIS wish to identify which, if any, of these parameters need revision (to individual numbers or ranges) to ensure the dataset is representative of current conventional EfW technologies and innovative technologies meeting the ACT definition derived in 2018, used to define eligibility for support under the CfD mechanism from allocation round 3 (see Section 4.1).

The project team gave initial feedback based on existing internal knowledge, gained through discussions on key parameters with project developers, or from review of publicly available data sources or reference material. In each case where any amendment is suggested the rational and source of any underpinning evidence is provided.

As a secondary check, under Non-Disclosure Agreements, the datasets and NNFCC's opinions and suggestions for amendment were passed to 2 project developers of ACT projects and to one expert advisor on ACT technologies for further review and comment.

The result of the review outcome is presented in tables, one for each technology type and combination, along with a 'red/orange/green' flagging system to indicate whether the values currently being use by BEIS are within expected ranges or:

- require minor modification in some cases (Green flag),
- require some minor modification that may have a small impact on outcomes (orange flag) or
- require modification which may have a significant impact on modelled cost outputs (red flag).

Table 1. Modelling parameters defined and used by ARUP and subject to review in this study

Parameter	Description
Pre-Development Period	Pre-development period. The time period required by a generation project to achieve technical design, planning permission and regulatory compliance. Reported as a value to one decimal place (e.g., 1.5 years).
Construction Period	The time period required by a generation projects to bring it to operational readiness. Reported as value to one decimal place.
Plant operating period	Operation period. The expected time period over which a generation project can operate and produce electricity.
Net Power	Net power - maximum available electricity generation capacity considering parasitic load requirements. Capacity is reported as a MW figure.
Net efficiency	Efficiency (Lower heating value) - used to calculate fuel required (MWh) for electricity generation (expressed as % efficiency)
Availability	Maximum potential time that a generation plant is available to produce electricity annually. Reported as a % value (reflecting down time required for maintenance).
Load Factors	The ratio of average annual output to its total potential output if a plant were to operate at full capacity over its lifetime. Reported as a %.
Pre-development and construction phasing	Pre-development and construction 1) total costs and 2) phasing of spend (for both pre-development and construction). % of costs are phased annually, according to a typical expenditure profile and project timing assumptions. With phasing (as % of total cost per annum) reported on a % basis.
Capital costs range	Low, Medium and High capex costs £/kW, with Capex cost learning rates factor reducing costs over time
Infrastructure Cost	Infrastructure cost. Assumed to comprise grid connection cost (e.g., underground cable costs), local substation and substation cost. The boundary of cost is assumed to include the site where the generator is located, associated electrical infrastructure and connection to the nearest point on the electricity grid. Reported as a total cost in £'000.
Opex costs	Low, Medium and High OPEX costs £/kW (for fixed and variable elements) (OPEX costs assumed to remain static)
Insurance Cost	Ongoing annual cost of insuring a generation asset. Reported on a £/MW basis.
Use of System (UoS)	Network Use of System (UoS) charges. Costs of connecting to and using the transmission network. Calculated as a £/kW/per annum.
Gate fees	Fees charged for disposal/treatment of waste - a revenue stream for EfW/ACT technologies.
Renewable Qualifying Multiplier (RQM)	The proportion of electrical output relating to qualifying, low-carbon generation - based on monthly fuel data provided by the generator. For CfD modelling, BEIS assume a flat 50% (i.e., 50% of output deemed to be from eligible feedstock).
Heat revenue	Heat revenues from selling heat to an offtaker
Decommissioning costs	Cost of decommissioning the project at end of life, plus any revenue from scrappage value. Modelled as a proportion (%) of construction costs.

4.1 Cautionary note

This review is undertaken based on estimates for costs for projects expected to be compliant with BEIS' 2018 definition for ACTs (see Table 2). It should be recognised that this definition covers a very limited number of project examples from which to draw information and experience.

4.2 Price base

Unless otherwise stated, the base year for all derived costs is 2020 and these represent developer estimates of up-front costs for the highlighted cost elements, derived from experience based on UK development projects and disaggregated from other cost elements. Given the lack of clarity in published data, it is not always possible to ascertain what elements have been included or excluded for example within a generic CAPEX or OPEX cost. Such values are therefore used as comparators to sense check that estimate look to be within an expected range.

5 Relevant projects supported by the CfD mechanism to date and project numbers and scale in the development pipeline

There have been 3 CfD allocation rounds held to date with a fourth planned for 2021.

5.1 EFW

EfW with CHP was only eligible in round 1. Two projects were successful, with generating capacities of 45-49.8 MWe. These represent projects that are towards the larger end of EFW+CHP projects identified in the Renewable Energy Planning database[2] (REPD) as either currently under construction or in planning, where 88% of planned EfW+CHP plants are below 45MWe. However, there are also a few exceptionally large plants >70MWe in large urban areas, with potential for large heat offtakes when sited near existing heat networks.

5.2 ACT technologies

ACT has been eligible in all 3 allocation rounds to date (though with differing definitions of eligibility between rounds which have been increasingly restrictive over time (see Section 6). This has supported 11 projects to date, only 2 of which (supported in the last allocation round (AR3)) would fit with current eligibility criteria and these plants are currently in development. The technology capacity scale of existing projects is relatively small compared to competitor EfW or biomass+CHP technologies reflecting the low maturity of the technology and moves to focus on modular deployment to reduce risks (costs already reflect this common practice of a modular approach to scaling).

Review of the ACT project development pipeline evidenced through the Renewable Energy Planning Database (REPD, June 2020) suggests that the capacity of new ACT plants is generally increasing. The

[2] BEIS Renewable-Energy-Planning-Database-june-2020-update

exception to this is where ACT technology is deployed with CHP, where the capacity is typically <15 MWe. This reflects the difficulty in securing contracts for consistent high heat offtake.

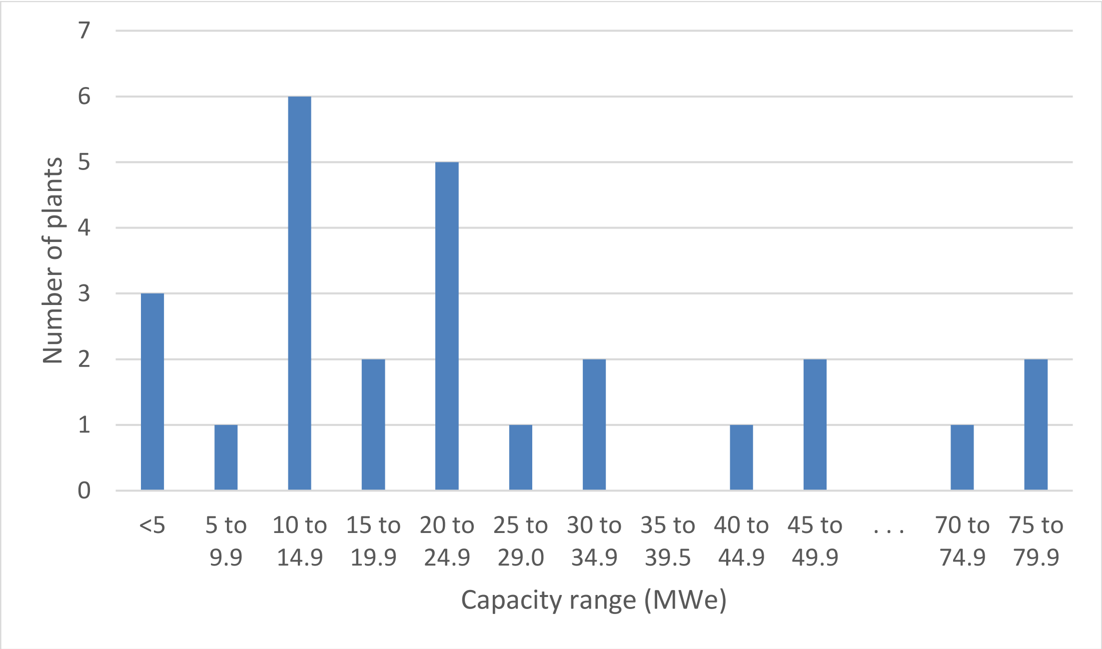

Figure 1. EFW + CHP plant numbers by capacity range (MWe) for developments classed as 'in planning[3] or under construction' listed in the REPD (26 cases)

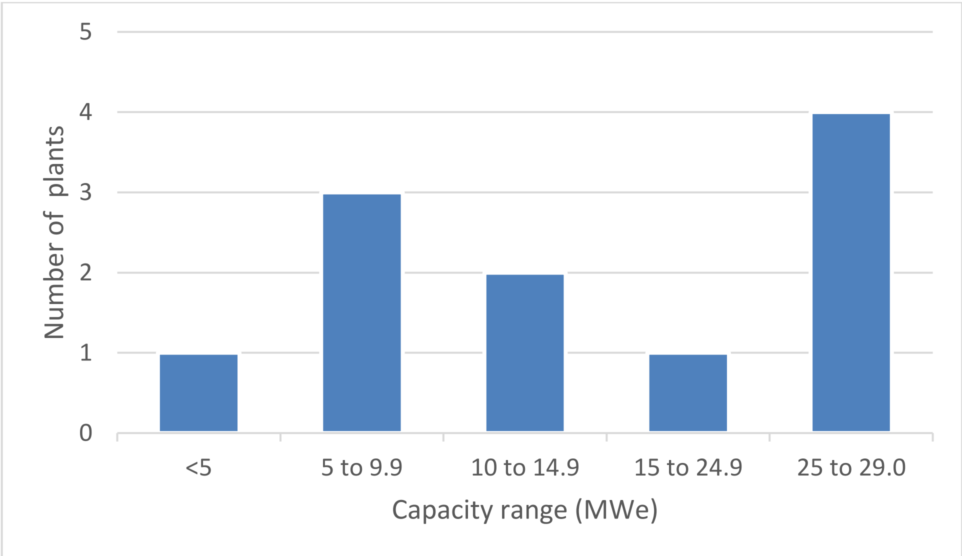

Figure 2. ACT plant numbers by capacity range (MWe) supported under the first three CfD allocation rounds (for 11 ACT plants)

[3] In all cases 'in planning' excludes plants where plans have been rejected, withdrawn or planning has expired.

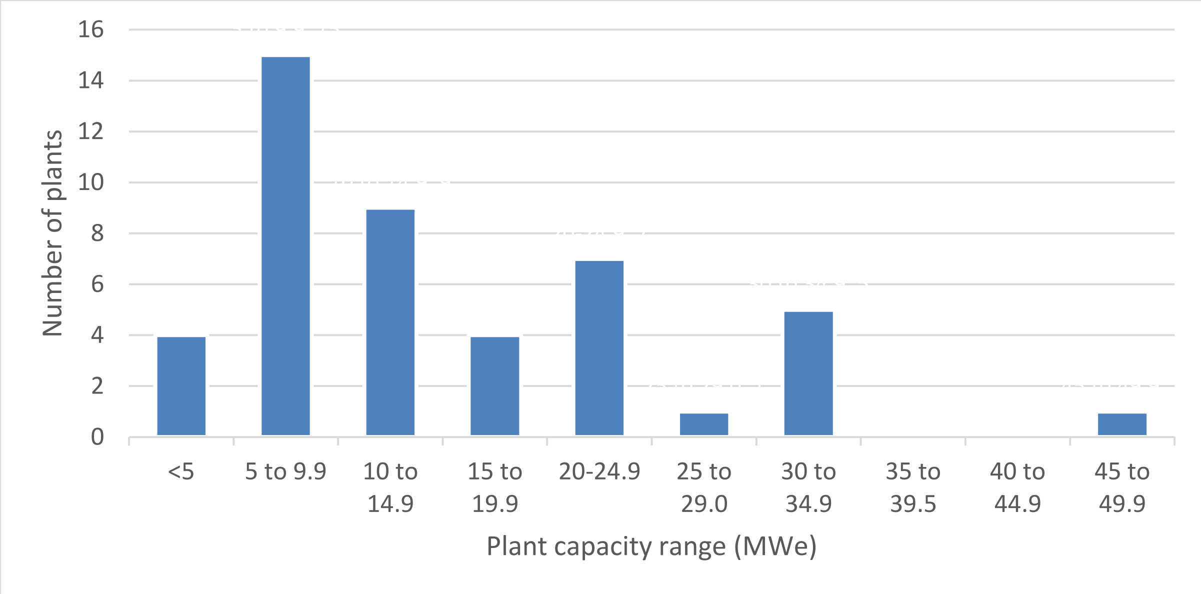

Figure 3. ACT plant numbers by capacity range(MWe) for developments classed as 'in planning or under construction' listed in the REPD (46 cases)

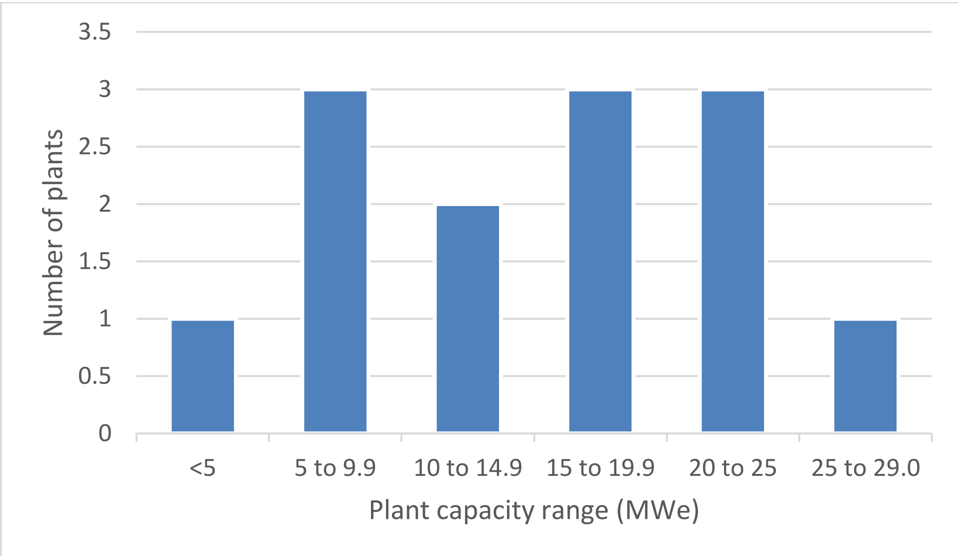

Figure 4. ACT+CHP plant numbers by capacity range (MWe) for developments, classed as 'in planning or under construction' listed in the REPD (13 cases)

In the REPD, the majority of ACT projects in planning and under construction (46 plants) lie within the 5 to 25 MWe capacity (see Figure 3). Thirteen of these developments plan to adopt CHP, with capacity between 5 and 29 MWe (see Figure 4). The success of the larger plants will rest on securing a large heat offtake.

6 Evolution of ACT definitions within the Contacts for Difference mechanism and preceding support schemes

The categorisation of ACT technologies and more importantly eligibility criteria for what is defined as an 'Advanced ACT', have evolved over time. BEIS and its predecessor DECC have striven to try to differentiate between 'standard' and 'advanced' ACT technologies, to restrict ACT eligibility to the most innovative and efficient technologies.

ACT's were first supported under the Renewable Obligation (from 2002) where Advanced Gasification was defined as:

> *"Electricity generated from a gaseous fuel which is produced from waste or biomass by means of gasification, and has a gross calorific value when measured at 25ºC and 0.1 megapascals at the inlet to the generating station of at least 4 megajoules per metre cubed"*

and Advanced Pyrolysis as

> *"Electricity generated from a liquid or gaseous fuel which is produced from waste or biomass by means of pyrolysis, and (a) in the case of a gaseous fuel, has a gross calorific value when measured at 25ºC and 0.1 megapascals at the inlet to the generating station of at least 4 megajoules per metre cubed, and (b) in the case of a liquid fuel, has a gross calorific value when measured at 25ºC and 0.1 megapascals at the inlet to the generating station of at least 10 megajoules per kilogram"*

Meeting the above criteria provided access to increased support under the RO at 2 ROC/MWh.

The first two allocation rounds of the CfD did not differentiate between 'standard' and 'advanced' ACT, but by round three (2019), additional criteria had been introduced to more tightly define eligibility criteria for support under the 'ACT' technology heading (see Table 2).

These criteria were introduced to address applications for the CfD by less innovative close-coupled combustion gasification processes, where syngas is generated and passed to a boiler with no cooling or clean-up. This form of ACT does not result in syngas output that is usable in gas engines, turbines or other high value fuel or chemical applications.

Table 2. Technology eligibility under the 'ACT' technology heading within the CfD support scheme

Pre 2018 categorisation	Post 2018 eligibility
'Standard' ACT technologies with or without CHP	Standard ACT is no longer differentiated from conventional EfW technologies and as an established technology is grouped in CfD allocation 'pot 1'
'Advanced' ACT technologies with or without CHP	The only permitted ACT configuration, which must deliver a minimum of 60% energy conversion efficiency and physical separation of the gasification/liquification and subsequent combustion units. Relevant technologies fall into CfD allocation 'pot 2'

7 ACT cost assumption review

Data provided by BEIS for 'ACT' aligns most closely with the previous (pre-2018) definition of 'Standard ACT' and as such this data was not considered further in relation to technologies eligible for 'pot 2'. Data provided by BEIS as 'Advanced ACT' has been used as the basis for an assessment of need for amendment for ACTs defined as eligible under the under the post 2018 categorisation.

There are currently no known operational examples of this technology in the UK, though there are a small number of developments in progress. The basis for the revisions proposed draws on a small set of data for non-UK projects (these are listed in Section 17) along with use of expert input from UK projects currently in development. With such a small data set it is inappropriate to state precise figures for many of the parameters (e.g., for scale, efficiency etc) or to provide reliable data on planning costs and timeframes for what are a limited number of examples of early development projects. Therefore, the assumptions on such factors at present are reliant on comparable conventional technology implementations and best available technical and practical knowledge.

Issue highlight warning

Parameter 1	(green)	*Little or no issue or v minor adjustment recommended*
Parameter 2	(amber)	*Minor issue where amendment recommended*
Parameter 3	(red)	*Issue where amendment is recommended which may have significant impact or consequence*
Parameter 3		*No amendment required or anticipated*

Parameter	Issue ranking	Comment
Pre-Development Period		The current BEIS assumptions are realistic. In practice the LCOE is unlikely to be very sensitive to this figure. (current assumption 1-5 years)
Construction Period		Currently stated timeframes seem reasonable for a production plant. (current assumption 1.8-2.8 years) (smaller plants are quicker to build within this time range)
Plant operating period	(green)	Currently stated timeframes are within reasonable range of expectation (current assumption 25 years). However, comments in review from developers suggest plants could be active for up to 30 years so suggest the values are amended to **25, 27, 30 years (L,M,H))**
Net Power	(red)	The range (currently 5.9-13 MW) needs broadening. Modular, packaged technology could support a threshold of 1.5MW (which would also address current smaller plants targeting fuels and chemicals) and [non-UK] examples exist of plants as high as 46MWe (see section 14). The recommended values are therefore : **1.5, 15, 30 (MW)**
Net efficiency (electrical efficiency)	(amber)	This range (currently 22.8-27.6%) needs broadening. A higher efficiency is achievable based on existing ACT implementations (see annex 1). The recommended values are **22.8%, 27%, 30% (L,M,H),** 30% would be stretching. 25% was set previously by the ETI as a target minimum standard for ACT, but not all may be capable of achieving that so suggest retaining current minimum value.
Availability	(green)	The current assumptions (1.0 = 100%) are unreasonable as ACT's require downtime for maintenance, with single train processes this would equate to availability of 0.85 (15%

		downtime) or 0.9 at best. The recommended values would be **0.85 (L&M) 0.9 (H)**
Load Factors		These are reasonable (0.79 (stabilising at 0.8) to 0.91 (stabilising at 0.9). There is insufficient operational data to justify changing these values..
Pre-development and construction phasing		The current figures (Pre-licensing costs, Technical and design £61.2-£685/kW, Regulatory + licensing + public enquiry £32.3-£362.3/kW) and their phasing (from 1 year to an even spread over 5 years) appear reasonable. The LCOE is also not very sensitive to these figures.
Capital costs range		Based on a very limited number of example plants that conform to the 2018 BEIS definition for an ACT (see annex 1), a modest reduction is proposed **3,500, 7,000 10,000 (£/kW) (L,M,H)**. The previous range was £4,632-£13,307/kW. The authors accept that the evidence base for this change is weak.
Capital costs - learning rates		Price adjustment for learning rates are in line with industry standard figures and similar to gasifier learning rates previously derived by NNFCC for ACT's (0.78 to 0.9[4]) So no change advised (current rates range from 0.8 to 1.0)
Infrastructure Cost		The current figures (£1,025K-£1,699K) are reasonable. The LCOE is also not very sensitive to these figures
Opex costs		Little information is available on OPEX given the very limited number of relevant plants globally. However, limited calculations provided by developers based on advised staffing levels and associated cost are consistent with current figures. (£125K-£217K/MW for fixed elements and £33-£55/MWh variable elements)
Insurance Cost		Little information is available. There is no clear reason to reconsider the figures (currently £66K-115K/MW/year). Insurance is a risk for ACT projects and it takes time to secure. Developers report costs are typically increasing towards the upper end of the indicated range.[5]
Use of System (UoS)		Little information is available. There is no clear reason to reconsider the figures (currently £13,4K-13,9K/MW/year)

8 ACT+CHP cost assumption review

The following table refers to the BEIS 2018 definition of ACT. Very few large-scale ACTs with CHP capability have been identified (see Section 17). Separate evidence indicates the cost of adding heat capture to a thermal plant is less than 5%, which has been corroborated by feedback from 3rd party experts. In practice all thermal plants require cooling systems; the addition of plant to make the heat available for external use is not a major addition. Most of the cost is in the use of that heat, not its capture. As such the numbers for ACT+CHP closely follow those for ACT. As noted in the section on Heat Revenue, whilst some ACTs may be able to load-follow technically, this is unlikely to be

[4] NNFCC 2012. Estimated gasifier learning rates out to 2050, Report for DECC

[5] Previous problems with ACT projects have led many insureres to no longer providing support for ACT projects, which means securing insurance takes longer and it is costly.

economically viable in most cases. The assumption here is that all ACT+CHP operates on base load with heat used when demanded.

Parameter	Issue ranking	Comment
Pre-Development Period		The current BEIS assumptions (1, 2.8 and 5 years) reflect a pessimistic 'high' end which probably reflects multiple public challenges and review rounds and difficulty experienced in securing funding. A relatively smooth run would be 2.7 years (12 months in data preparation, 6-18 months in reporting to planning committee, further 3 months to respond to challenges raised). In practice the LCOE is unlikely to be very sensitive to this figure. Advise no change to current range.
Construction Period		Currently stated timeframes seem reasonable for a production plant. (Current assumption 1.8-2.8 years), the smaller the plant the quicker it is typically to build.
Plant operating period		Currently stated timeframes seem reasonable for a production plant. (Current assumption 25 years)
Net Power		The range (currently 0.4-1.6 MW) needs broadening, in particular the upper figure as plants in development are typically expected to be at a higher net power output capacity (Figure 4). The recommended values are: **0.5,7,15 (MW) (L,M,H)** It is difficult to gain insight on plants expected to operate at below 1MWe as these are not captured within the REPD dataset, but few of these are expected to be residual waste fed.
Net efficiency		This range (currently 22.8-27.6%) needs increasing. A higher efficiency is achievable based on existing ACT implementations (see annex 1). The recommended values are **22.8%, 25%, 30% (L,M,H)**. 25% has been set previously by the ETI as a target minimum standard for ACT, but not all may be capable of achieving that so suggest retaining current minimum value.
Availability		The current assumptions (1.0 = 100%) are unreasonable as developers advise ACT's require downtime for maintenance, with single train processes this would equate to availability of 0.85 (15% downtime) or 0.9 at best. The recommended values would be **0.85 (L&M), 0.9 (H).**
Load Factors		These are reasonable (0.79 (stabilising at 0.8) to 0.91 (stabilising at 0.9). Electrical output can be impacted by heat demand, especially where this fluctuates between winter and summer demand, but again insufficient data exists to quantify this and it would not apply to plants with a consistent base heat demand. There is therefore insufficient data to justify changing these values.
Pre-development and construction phasing		The current range (Pre-licensing costs, Technical and design £61.2-£685/kW, Regulatory + licensing + public enquiry £32.3-£362.3/kW) and their phasing (from 1 year to an even spread over 5 years) are reasonable. The LCOE is also not very sensitive to these figures.

Capital costs range		Based on limited example plants that conform to the 2018 BEIS definition for an ACT (see annex 1), the incremental cost of adding heat capture to a conventional EfW plant is less than 5%. Heat capture from an ACT that conforms to the 2018 BEIS definition is more complex and a premium of 10% over the cost of the basic ACT is realistic. More than this would be difficult to justify as it has to be supported by the additional heat revenue. CAPEX should thus be aligned with ACTs (previous table) making a provision for the additional cost of heat capture. On this basis a modest reduction is proposed: **4,000, 8000, 12,000 (£/kW) (L,M,H)** (previously ranged from £5,313-£18,021 £/kW). **Note – as this draws on the data for ACT, the same caveats apply to this data**
Capital costs – learning rates		Price adjustment for learning rates are in line with industry standard figures and similar to gasifier learning rates previously derived by NNFCC for ACT's (0.78 to 0.9). So, no change advised (current rates vary from 0.8 to 1.0)
Infrastructure Cost		The current range (1,025K-1,699K) is reasonable. The LCOE is also not very sensitive to these figures
Opex costs		Little information is available on OPEX. There is, therefore, no clear reason to reconsider the current figures (£126K-£218K/MW (fixed elements) £32.6-£55.4/MWh (variable elements))
Insurance Cost		Little information is available. There is no clear reason to reconsider the current figures (£66.4K-£114.9K/MW/year). Insurance is a risk for ACT projects and it takes time to secure. costs are typically increasing towards the upper end of the indicated range.
Use of System (UoS)		Little information is available. There is no clear reason to reconsider the figures (currently £13.4K-£13.9K/MW/year)

9 EFW+CHP cost assumption review

Parameter	Issue	Comment
Pre-Development Period		The current BEIS assumptions are realistic, reflecting long planning and appeals process. In practice the LCOE is unlikely to be very sensitive to this figure. (current assumption 2.3-6.4 years)
Construction Period		Currently stated timeframes (2.7-3.4 years) are reasonable but at 'high 'end can extend up to **4 years** for larger plants. <3 years possible for smaller plants. suggested range **2.7, 3.4, 4.0 years (L,M,H)**
Plant operating period		Currently stated operating lifetimes seem long (current assumption 30-40 years) given that EfW will increasingly become one of the most GHG intensive means of power generation unless linked to CCS. The financial models for most EfW plants are evaluated on an operational lifetime of 25 years. Suggested range is therefore **25, 27, 30 years (L,M,H)** with any life extension requiring further investment in CCS
Net Power		The current range (11.4-38.2 MWe) would cover around 60% of plants currently under construction or in planning (Figure 1), widening this slightly would address a larger number of potential plants and reflect that plants supported under the CfD to date have been above the current range max. The recommended values are: **10,25,45 MWe (L,M,H)** (while

		noting that there are a very small number of very large EFW+CHP projects (70MWe+) that could come forward)
Net efficiency		The current range (currently 18-28%), reflects poor to best operations in the sector. Typical net energy efficiency (power generation) from waste feed energy is around 20%, typically limited by low boiler temperatures to reduce boiler corrosion risk from chlorine and other contaminants in the waste stream. More modern efficient systems operating with super-heated steam (the norm for most EfW facilities) should be able to achieve 28% or even slightly higher efficacy in some circumstances, but this would be tempered in CHP systems. Plants with modern boilers and flue treatments should at least achieve 20%. The recommended values are therefore **20%, 24%, 28% (L,M,H).**
Availability		The current assumptions (88% to 100% (0.88-1.0)). Most modern plants are more robust and are anticipated to operate at 90%+ availability. The lower figure should be raised to 90% The suggested range is therefore , **0.9, 0.93, 0.95 (L,M,H)**
Load Factors		Existing values are reasonable (0.80 to 0.90). Heat-led CHP would tend to drive load factor to lower end of range compared to situation with baseload heat offtake and conversely where power led values are typically estimated to be closer to 0.9.
Pre-development and construction phasing		The current figures (Pre-licensing costs, Technical and design £132-£203/kW, Regulatory + licensing + public enquiry £7.2-£114.4) and their phasing (relatively even spread over 3 years) are reasonable. The LCOE is also not very sensitive to these figures.
Capital costs range		Current estimate of £11.0K to 16.9K/kW. High end is representative of relatively small scale EFW+CHP development costs. At higher end (+20MWe) figures closer to 7.7 to 8.7k/kW have been reported (Table 7) So, suggest amending range to **£8,000, 14,000,£16,959/kW (L,M,H)**
Capital costs – learning rates		Price adjustment for learning rates (0.99 falling to 0.96) (i.e., relatively slow falls in costs of next of a kind plant) are reasonable for what, in the main, are widely established technologies with known risk and operational profiles. So, no change advised.
Infrastructure Cost		The current range values (3,152K-9,031K) are reasonable. The LCOE is also not very sensitive to these figures
Opex costs		Currently £87K-£226K/MW (fixed elements) High end is close to values seen for smaller developments (<10 MWe scale). Some values of £300K+/MW seen for larger plants (ca 18MWe), but all values are highly sensitive to what has been included within the estimate. Currently £31-£82/MWh (variable elements) This range encompasses typical variable costs ranges seen for EFW+CHP. No justification to change existing values.
Insurance Cost		Little information is available. There is no clear reason to reconsider the figures (currently £48.2K-£126.0K/MW/year) .
Use of System (UoS)		Little information is available. There is no clear reason to reconsider the figures (currently £6.5K-£30.7K/MW/year).

10 Gate fees

Gate fees are influenced by a wide range of parameters including contract terms and length, with gate fees tending to be lower for supply under long term contracts (which can be up to 25 years in length) and newer and renegotiated contracts tend to be at a higher rate through tracking of the cost of alternative disposal routes primarily via landfill. The degree of competition between waste processing facilities in a region can also influence gate fees, as such gate fees are very variable in character.

The cost of waste disposal is primarily driven by the Landfill tax which makes up the bulk of the cost of disposal to landfill. Introduced in 1996, the tax has gradually increased the cost of using landfill (see Figure 5) as a mechanism to encourage diversion via recycling or other routes of disposal. The tax rate is set in government Budget statements addressing the near term, so there is little long-term clarity. However, in recent years the tax has been increased in line with the Retail Price Index. There is currently no indication that this is likely to change.

Figure 6 shows how the cost of landfill operational costs plus landfill tax have set a ceiling on gate fees. EfW gate fees have followed this general trend with a marginal saving of between £17-£32/tonne on the cost of disposal via landfill, with newer plants on new and shorter contracts most responsible for driving an upward trend in cost, particularly at the bottom end of the EfW gate fee range. This reflects the increasing move towards merchant plants and away from very long-term contracts with local authorities originally used to underpin plant development. Smaller plants also tend to require higher gate fees.

The key factors influencing future gate fees for EfW options are therefore RPI increases in the landfill tax, which will cap the cost of alternative routes of disposal. Gate fees are therefore expected to narrow in range and stabilise at rates which track increases in the cost of disposal via landfill.

Refuse Derived Fuel (RDF), is shredded, sorted waste, with fewer inert materials, produced for use in EFW and more importantly ACT applications (which are more feedstock demanding). RDF is also the main form of waste exported to Europe (to fill underutilised EfW capacity) and thereby influences UK RDF gate fees.

UK export of RDF to Europe started due to lack of treatment infrastructure in the UK and as an alternative to increasingly costly landfill. RDF exports have risen significantly since 2010 to reach over 3 million tonnes in 2017, fuelled by increases in landfill tax and the over-capacity of EfW facilities in Europe driving low gate fees, particularly in the Netherlands a key destination for UK RDF export (responsible for accepting 44% of UK waste export in recent years).

However, it is expected exports have now peaked with European EfW facilities now closer to their operating capacities. In addition, in January 2020, the Netherlands imposed a tax of £32/tonne on the import of all foreign waste for incineration. Costs of disposing of RDF have been increasing in recent years, driven by gate fees offered previously by European plants, but may now stabilise.

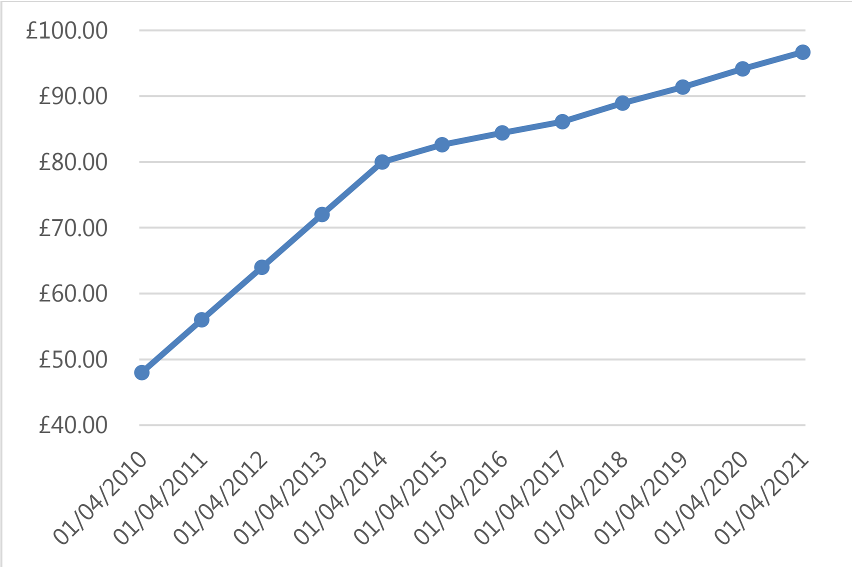

Figure 5. Landfill tax rate (Standard rate) £/tonne (based on actual budget announced rate in years indicated)

Current costs for RDF reflect prices that have been developed through the RDF export market. RDF plant gate costs effectively represent the costs that exporters are likely to levy at the plant gates to dispose of the residual waste stream. This cost covers a number of items including, shipping and transport costs, handing costs and gate fees at recipient plants. RDF plants typically expend £10-15/tonne in RDF preparation and baling. UK transport costs are likely to be around £5-£10/tonne. So, to compete with export opportunities a UK ACT plant using RDF would need to be prepared to accept gate fees of between £63-83/tonne or lower to compete at current RDF gate prices. While the export market for RDF has peaked, there remains a steady demand, but the impact of the new Netherlands tax may temper this, particularly if other countries cannot take up the released waste volumes. Countering this, UK waste treatment capacity is also rising which could increase competition domestically. In light of this it is anticipated that gate fees for RDF are likely to remain at current estimates and increase in line with inflation.

It is difficult to obtain insight on gate fees, and there is reliance on published figures by WRAP and Lets recycle.com. The former tends to lag in time while the latter provides monthly updates based on declared values in the market, primarily by local authorities and through interviews with industry interests. These provide indicative values to work with.

Values for EfW gate fees and RDF costs were obtained from lets recycle.com. Values for the last 12 months were used to calculate £/MWh value ranges based on typical calorific values (see Table 3). These were compared with the original values provided by BEIS (which date back to 2014 with inflationary uplifts).

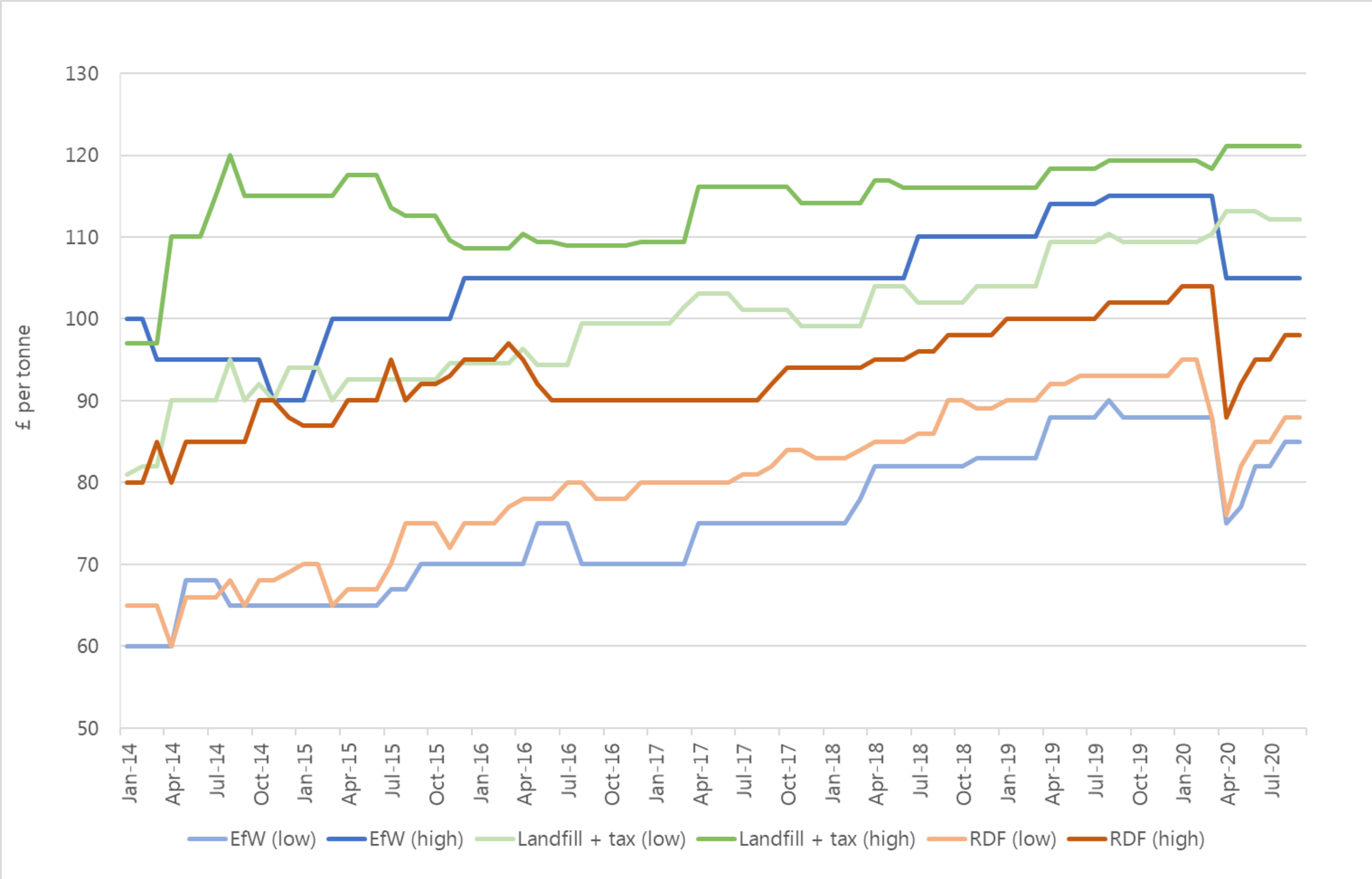

Figure 6. Range of monthly gate fees (high and low values) (£/tonne), reported through local authority and waste industry survey (actual market price on dates indicated) (from Letsrecycle.com[6]) for landfill (operating cost plus landfill tax) and EfW options (Efw gate fee = fee for mixed waste) and costs at plant gate for RDF disposal

[6] https://www.letsrecycle.com/prices/efw-landfill-rdf-2/efw-landfill-rdf-2020-gate-fees/

Table 3. Gate fee calculation £/kWh (2020 cost basis)

Technology and technology cost band	Cost of RDF at plant gate (£/t RDF)[1]	Preparation and transport cost (£/t)	Gate fee[1] £/tonne	Calorific Value (MJ/kg (LHV))[2]	Gate fee range (£/MWh)
EFW					
Low (high gate fee)			£110.00	9-12	£33.00-£44.00
Med (mod gate fee)			£97.25	9-12	£29.18-£38.90
High (low gate fee)			£84.50	9-12	£25.35-£33.80
RDF (for ACT)			(cost minus prep costs)	(High grade)	
Low (high gate fee)	£98.00	£20	£78.00	11-15	£18.72-£25.53
Med (mod gate fee)	£93.54	£20	£73.54	11-15	£17.65-£24.07
High (low gate fee)	£88.41	£20	£68.41	11-15	£16.42-£22.39

1) Average of last 12 months data (Oct 2019 to Sept 2020) from letsrecycle .com
2) Typical calorific range values specified in purchase contracts

Table 4. Suggested gate fees (2020 cost basis) for EfW and ACT cost bands, comparison with current BEIS values and assessment of impact on power costs

Technology	Technology and technology cost band	Suggested gate fee range (£/MWh)	*Current (BEIS) Gate fee range (£/MWh)*	Impact rating
EFW	**Low (high gate fee)**	**£44.00**	*£36.53*	Significant impact on costs
	Med (mod gate fee)	**£34.04**	*£30.66*	Significant impact on costs
	High (low gate fee)	**£25.35**	*£20.22*	Significant impact on costs
ACT	**Low (high gate fee)**	**£18.72 (high CV)[1]**	*£14.44*	Significant impact on costs
	Med (mod gate fee)	**£17.65 (high CV)[1]**	*£12.96*	Significant impact on costs
	High (low gate fee)	**£16.42 (high CV)[1]**	*£11.11*	Significant impact on costs

1) Assumes fuel with high CV specification in contracts for RDF for ACT plants

The new figures suggest that the BEIS estimates for gate fee receipts are a little low and that higher gate fees for EfW operations could typically be obtained in the current market. These calculations are very sensitive to assumptions around calorific value. It is assumed that ACT operators would preferentially secure higher quality RDF with a CV closer to 15 MJ/kg, so gate fee estimates were based on this value which gives slightly higher gate fees for ACT technologies than the original values derived by ARUP for BEIS.

The gate fees identified for EfW are comparable to those derived by WRAP in its latest gate fee assessment report for 2019[7] (which addresses gate fees for 2018/19) when considering gate fees for post-2000 EfW plants looking to secure new contracts (which would be typical of a new developer looking to secure feedstock). WRAP figures (after accounting for 3% inflation) indicated mode (most commonly encountered) EfW gate fee values ranging from £92.70-£97.8/tonne, and a typical range of 94.76-£113.30. The modal values are in line with the estimates derived from letsrecycle.com and there is significant overlap in range estimates between the two datasets. This gives some confidence in the use of the letsrecycle.com gate fees, which result from more recent industry survey than the WRAP data. The suggested gate fees derived from these on a £/MWe basis are shown in Table 4.

11 Renewable Qualifying Multiplier (RQM)

BEIS currently assumes 50% (on a mass basis) of the waste stream is renewable and will remain so into the future. However, there are a number of issues currently likely to influence the composition of municipal, commercial and industrial waste streams going forward, by diverting renewables from the 'general' waste stream, these include pressure to:

- increase recycling rates and moves to increase segregated waste collections
- divert biologically active materials from land fill
- instigate separated food waste collections
- reduce use of fossil plastics in packaging applications

In terms of recycling rates, the UK has hit a plateau at around 45% in recent years[8], the target for 2020 was to hit 50%. In addition, less than 40% of UK household waste is segregated at source – so without further drives to change waste collection and segregation practices, the composition and material flows to waste processing facilities (typically Material Recycling Facilities (MRF's)) will remain relatively unchanged in the near future. However, one area that has seen change albeit from a small base, is food waste collection. Only half of Local Authorities in England provide separated food collection, but segregated collection has been slowly increasing, typically by around 0.2% per annum in recent years[8]. This will have a small but negative impact on the biogenic content of the UK waste stream over time

[7] WRAP gate fees report 2018/19. Comparing the cost of alternative waste treatment options. Available to view (Nov 2020) at: http://www.wrap.org.uk/sites/files/wrap/WRAP%20gate%20fees%20report%202019.pdf

[8] Statistics on waste managed by local authorities in England in 2018/19
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/918853/201819_Stats_Notice_FINAL_accessible.pdf

as illustrated below (Figure 7), extrapolating from current trends and with food waste accounting for around 14% of the biogenic content of residual waste streams currently[9].

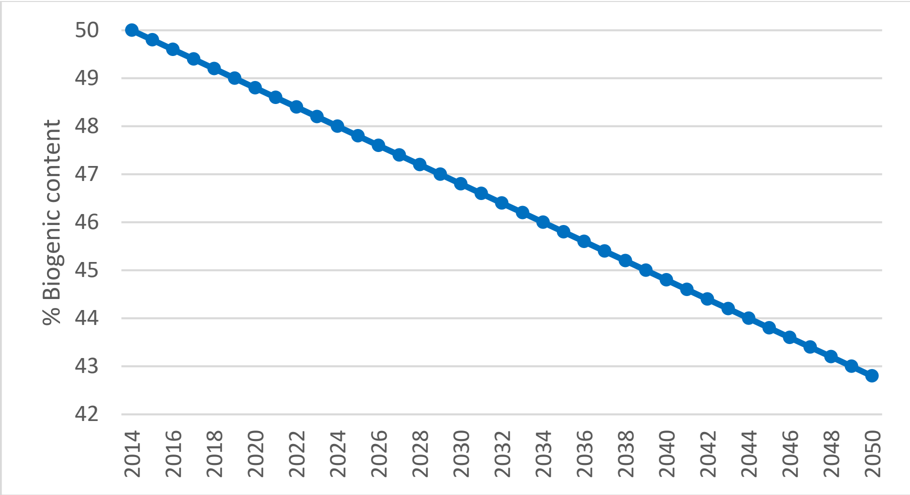

Figure 7. Extrapolated decline in % biogenic content of residual waste stream over time if segregated food collection continues to grow at current rates.

The only waste derived fuel with a specific standard designation is solid recovered fuel (SRF). SRF is strictly defined as according to the stipulations of the standard EN 15359, which can be produced from materials recovered from MSW, C&I wase or CDW waste streams. SRF can typically be characterised by an energy content in the range of 10–25 MJ kg^{-1} as received (Net CV is used to break down SRF into quality classes), Typical biogenic content is around 50–65% on an energy basis[10] (as SRF contains plastics with a higher CV than biomass, the biogenic percentage measured on a mass basis is likely to be toward the higher end of this range). In terms of less defined residual MSW streams used for EfW and RDF, composition reflects local collection and sorting practices, hence composition is more variable.

In responses to a 2014 call for evidence by Defra on the RDF market[11] four waste management respondents indicated the biogenic content of RDF generally ranged between 50-60% (Question 2, part v response), dependent on the ratio of paper, card, food waste and plastic. Clearly there is a wide degree of variation in biogenic content of EfW and RDF, so use of a starting value of 50% for RDF is a pragmatic approach. For RDF, contract specifications drive the degree of processing required, so processors are likely to at least maintain a 50% biogenic content going forward.

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[9] Defra, Energy recovery for residual waste - A carbon based modelling approach (2014) http://randd.defra.gov.uk/Document.aspx?Document=11918_WR1910Energyrecoveryforresidualwaste-Acarbonbasedmodellingapporach.pdf

[10] Iacovidou E, et Al., 2018. Technical properties of biomass and solid recovered fuel (SRF) co-fired with coal: Impact on multi-dimensional resource recovery value. Waste Management 73, p535-545. Available to view at (29/10/2020): https://www.sciencedirect.com/science/article/pii/S0956053X17304932

[11] Defra, Refuse derived fuel market in England. Summary of responses to the call for evidence (2014) Available to view at (31/10/2020): https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/381621/rdf-market-sum-response-201412.pdf

Technology	Current RQM	**Proposed RQM**	
ACT Advanced with and without CHP	50%	**No change**	
EfW with CHP	50%	**2020 to 2030: 48.8%** **2030 to 2040: 46.8%** **From 2040: 44.8%**	

12 Heat revenue

A waste-to-energy plant's primary purpose is to dispose of waste with the majority of revenue from gate fees. If such a plant were to follow heat demand it would be operating only part of the time and be much less economic. Waste-to-energy technologies are also, operationally, not designed to load-follow. As such EfW or ACT with CHP operate primarily on baseload which means that either a continuous heat demand is needed, or not all heat will be used.

Heat demand is mainly seasonal. CHPQA Standard Issue 7 reference typically 7 months of heating in a year. CHPs are also frequently supplemented by and/or backed up by conventional boilers and connected to the grid to export excess power. The assumption below is that revenue will only be gained for heat used, i.e.

- heat offtake would apply for 7 months of the year (based on CHPQA assumptions), and
- heat actually used in this period would be 80% of that available as the plant cannot load follow and only so much heat can be economically stored.

Therefore, heat used would be 7/12 x 0.8 = 46%. This reduces the heat ratios to 0.8 & 0.9. Optimistically the heat ratio could be ~ 1, i.e., the amount heat sold would be the same as the power sold.

BEIS' Methodology wraps the above factors in a single figure called 'Heat to Power' ratio: the assumed ratio of used (rather than useful) heat to power generated (which will all be used).

According to the CHPQA Standard Issue 7, generation plant efficiency varies between 25% - 50% (a typical EfW plant is likely to be 20% or less; a modern Combined Cycle Gas Turbine (CCGT) can exceed 50%) with the balance of energy being 'dumped' as heat. Operating in CHP mode, the heat is largely used and efficiencies increase to 60%~ 80% (possibly more).

EfW's are less efficient largely because the direct combustion of feedstock results in gases that are at a lower temperature than that which would be obtained from syngas (from gasification) and includes contaminants that cause corrosion at high temperatures. The boiler thus operates at a lower temperature leading to lower thermodynamic efficiencies.

EfW plants can be assumed to use a steam cycle. ACT plants can use a steam cycle or Internal Combustion (IC) engine. Steam and IC engine implementations will deliver different efficiencies. The calculated ratio for an IC engine is very close to the 'legacy assumptions' in the BEIS model. **However, it may also appropriate to include a further option for ACT CHP based on a steam cycle and a heat to power ration of 0.783** (78.3% see Table 5).

Table 5. Heat to power ratio calculation

			% of energy used		Energy used	Heat to Power Ratio
ACT CHP	**IC Genset**					
power	35%	*1*	100%	*7*	35.0%	
heat	40%	*2*	47%	*8*	18.7%	**0.53 (BEIS 0.52 currently)**
CHP Net thermal efficiency	75%	*3*				
ACT CHP	**Steam cycle**					
power	30%	*9*	100%		30.0%	
heat	50%	*9*	47%		23.5%	**0.78 (BEIS =0.52 currently**
CHP Net thermal efficiency	80%					
EfW CHP	**Steam cycle**					
power	20%	*4*	100%	*7*	20.0%	
heat	50%	*5*	47%	*8*	23.3%	**1.17 (BEIS=1.18 currently)**
CHP Net thermal efficiency	70%	*6*				

Notes

1	*Does depend on the syngas composition and therefore the type of gasifier / pyrolyser. If the gasifier is air-blown the syngas will have a lower CV due to nitrogen dilution which will reduce the efficiency of the gas engine*	https://genelco.gr/index.php?cPath=30#:~:text=Syngas%20can%20be%20used%20to,power%2C%20hot%20water%20and%20steam.&text=The%20use%20of%20syngas%20in,heat%20produced%20are%20renewable%20energy.
2	*Net efficiency of ~ 75% implies usable heat of 40%*	https://www.ge.com/news/press-releases/integrated-gasified-biomass-power-plant-will-use-ge-gas-engine-technology-help
3	*Biomass gasifier + Jenbacher projected net efficiency > 70%*	https://www.ge.com/news/press-releases/integrated-gasified-biomass-power-plant-will-use-ge-gas-engine-technology-help
4	*Calculation based on quoted gross waste consumption, derived CV and quoted net power generation - e.g., Peterborough EfW; Hooton Biopower*	
5	*Back calculation from multiple sources stating steam cycle CHP efficiency of ~ 70%*	
6	*Multiple sources stating steam cycle CHP efficiency of ~ 70%*	
7	*All power will be used or sent to the grid*	
8	*From CHPQA (and other) sources, heat demand is seasonal - 7 months per year; also assume that 80% of available heat is used (also varies during day and from day to day)*	
9	*The figure presented here is based on a data from 2 ACT CHP projects based on a steam cycle.*	

13 Decommissioning costs

BEIS account for plant decommissioning costs for all technologies as 5% of base capex cost for estimate of cost of decommissioning plus 2% of base capex for estimate of scrappage value. Based on experience this is deemed to be a fair starting point, but with increasingly strict rules from the Environment Agency, for all technologies, if the land has to be cleaned up and the site cannot be repurposed, a further 5% of capex costs could be required for land recovery.

In contrast, for a small-scale ACT with a smaller footprint the costs could be a little lower at 4% of base capex cost for decommissioning plus 2% of base capex for scrappage value.

	Current BEIS assumptions		Proposed Values	
	Assumed decommissioning costs as % of base capex	Assumed scrappage value as % of base capex	Assumed decommissioning costs as % of base capex	Assumed scrappage value as % of base capex
EfW CHP	5%	2%	L+M both 5%, H 10%	2%
ACT	5%	2%	L 4%, M 5%, H 10%	2%
ACT CHP	5%	2%	L 4%, M 5%, H 10%	2%

14 Approach to modelling of levelized costs of electricity production

No issues were found with the method adopted for calculation of LCOE, but as BEIS is aware the outputs are sensitive to, and dependent on the quality of inputs. In the case of ACT technologies and even EfW with CHP, inputs are based on a few samples. ACT's are highly diverse both in terms of technology and scale of deployment, and in either case with very few examples. The redefining of eligibility in 2018 invalidated use of much of the historic data as a basis for future projections. Deriving specific CAPEX and OPEX, and learning rates is therefore difficult and has relatively low confidence statistically speaking and compared to other technologies such as solar and wind where there has been a large number of projects and a smooth and continuous path towards cost reduction.

15 Technology development

15.1 ACT

A review of the projects defined as 'ACT' technologies within the REPD database, classed as 'in planning' and 'under construction' identified 46 plants, around 28% of which planned to adopt CHP. Review of associated gasification technology suggest few would meet the current CfD definition of ACT. The added complexity required to meet the current ACT eligibility criteria which requires gas cleaning and use of a gas engine for power generation to deliver the highest energy efficiency values appears to have discouraged development of ACT's over simpler EfW gasification projects.

15.2 EfW

The majority of EfW facilities developed in the UK over the last 20 years have been those procured by Local Authorities in order to meet landfill diversion targets and provide affordable, long term residual waste solutions[12]. These were developed with investment under the Public Private Partnership (PPP)/Public Finance Initiative (PFI) regime and were secured under long term contract agreements for waste management. These are no longer being seen as appropriate or economically favourable. The focus of new EFW developments has shifted to opportunities to develop merchant facilities targeting commercial and industrial waste in the absence of any form of government support for anything other than EFW+CHP and eligible ACT plants. As a result, there has been little drive to innovate EFW technologies, but there have been significant improvements in EfW performance. Plants are more robust with most operating at higher than 90% availability. More heat is being recovered with initiatives such as flue gas heat recovery and lower parasitic loads are also improving overall energy efficiency, particularly in EfW-CHP plants.

Extracting steam from the turbine to drive CHP processes does have an energy penalty, though the overall process may be close to 70% energy conversion efficiency. Extraction of heat via a CHP system will typically reduce electricity generation. This has an impact on the overall economics, which coupled with higher CAPEX, and need to secure an 'anchor' heat demand explains why EFW+CHP has not been a popular development choice. However more important is the cost of developing the heat networks to utilise a large quantity of low-grade heat, which has little value to industrial users. Small scale ACT's offer a potential solution to such problems.

16 Summary of key areas for attention

To reiterate, both the original data and the revised data are based on a very limited number of project examples and should be treated with caution. Costs can vary widely both between scales of plant and even for the same scale of plant.

ACT technologies

A broadening of the range net power capacity is advised to reflect the increasing size of some pipeline developments.

A small change in net efficiency is also advised to reflect evidence of improving technology performance.

A small reduction in capital costs is suggested across the range to reflect wider recent international experience, however the paucity of data under pinning such suggestions is highlighted

Very minor amendments to operating lifetime and plant availability are advised, the latter to reflect the need for annual maintenance.

[12] Ricardo Energy and Environment. https://www.recyclingwasteworld.co.uk/in-depth-article/uk-challenges-of-efw-facilities/157645/

ACT+CHP technologies

A broadening of the net power capacity range is advised to reflect projects in the pipeline (with power increasingly being the focus over and above heat output).

In line with the suggestion to increase capital costs for ACT, this feeds into a linked increase for ACT+CHP.

A small amendment to broaden net efficiency is also proposed

A minor amendment to plant availability is advised to reflect the need for annual maintenance.

EfW+CHP technologies

A modest increase to construction period is suggested to reflect recent project experience.

Current BEIS estimates are for project operating lifetimes of 30-40 years. This may be optimistic for new plants unless these can be retrofitted to capture CO2 emissions in future. Typically, a minimum of 25 years would be guaranteed, with perhaps an extension to 30 at the 'high' end.

A broadening of the range in net power capacity is advised to reflect that there are a few large plants coming forward in the pipeline.

A small increase in minimum net efficiency to 20% to reflect expected minimum performance.

Conventional EfW technology is well developed and exploited, so plants tend to be robust and have a high availability of>90%, so it is suggested the low end of the plant availability range is lifted to this value.

A small reduction in the low end of capital costs is advised to reflect falling cost of larger projects with established EfW technologies.

Gate Fees

Latest data suggest the current BEIS estimates for gate fees (EFW and RDS (for ACT)) are lower than might be expected in the current market. This results from ongoing inflationary increase in the landfill tax which drives up treatment costs in the market and newer plants tending to contract at higher than historic rates on shorter and merchant contracting terms. Gate fees provide a significant income stream and any increase in revenue (from increases in gate fee receipts per tonne) will influence overall plant economics. It is advised that the illustrated revised gate fee structure is used.

RQM

Without further incentives to increase recycling rates, the main factor influencing waste composition for conventional EfW plants will be the success achieved in driving segregated food waste collections. Based on current progress rates, a gradual but small decrease in renewable content of residual waste streams is envisaged, to around 44.8% by 2040. This will have a small negative impact on plant revenues over time.

In contrast, as RDF fuels used in ACT plants are from a more refined fuel channel, with the degree of sorting and refinement tailored to match client needs, no significant change in biogenic content from current estimates (50%) is advised.

Heat Ratios

The existing heat ratios derived by BEIS are compatible with most technologies and no change is advised for EFW with CHP of ACT coupled with an Internal Combustion engine. However, it is advised that provision should be made to include a higher heat ratio (0.78) for situations where an ACT is coupled to a CHP unit using steam cycle technology.

Decommissioning costs

Minor amendments to decommissioning costs were advised at the high end of the range to address situations where additional land clean up costs are specified, and also at the lower end a small reduction in decommissioning costs is recommended to reflect the typically smaller relative size and footprint of such developments.

Technology innovation

There is little new in the way of technology development in the EFW sector, but some refinement occurs to improve process efficacy. In the ACT sector, there is differentiation occurring to serve the advanced transport fuels sector but there is little differentiation in basic ACT technology function or examples to consider expanding on the range of examples costed by BEIS.

17 Annex 1 - ACT Example Projects

Even worldwide there are very few examples of ACTs that conform to the revised BEIS definition. A key source has been the IEA Bioenergy Report 'Gasification of Waste for Energy Carriers', Task 33: 2018.[12] (GWEC).

ACTs have the potential to increase the overall energy efficiency (heat plus power) generated from wastes, driven by the CfD requirement to achieve at least 60% energy efficiency, but also, when using oxygen blown gasifiers, to convert wastes into fuels and chemicals. This potential requires ACTs to produce a high-quality clean syngas.

The GWEC report endorses these objectives and provides examples that support the feasibility and costs of achieving them. The report draws on project implementations worldwide and thus provides a much larger dataset. It was originally aimed at biomass gasification for power generation; however, it also addresses wastes and fuel production as the core technologies are common to these areas.

The data and conclusions presented in the report are consistent with both 2GBC's experience in this area and the broad conclusions of the ARUP data and reports used in previous BEIS modelling.

Those ACTs where the GWEC report provides sufficient data are summarised below.

Table 6. Example ACT project from IEA Task 33 GWEC report.

Summary of Data									
Project		**Input**		**Output**		**Efficiency**[13]		**CAPEX**	
	t/hr	MJ/kg	MWt	MWe	MWt	Power	total	£M	£M/MWe
Kew*	1.7	13	7.0	1.8		25%		15	8.3
Synnov Déchets**	5.7	16	23.6	7	12	28%	75%	31	4.4
CHO Power Tiper	8	16	36	11		31%		54	4.9
CHO Power, Locminé	8	16	36	11		31%		43	3.9
Lahti / Kymijärvi II & III*	36	~17	165	46	88	31%	88%	145	3.2

* Prototype project so capex will be higher than on subsequent deployment
** CHP Enabled

[13] A difficulty with such numbers is the lack of clarity on exactly what is inlcuded within such numbers, for example whether an allowance for feedstock preparation is included or parasitic energy demand (e.g. for plasma gasification). Efficiency figures therefore need treating with some caution.

Notes:

- In broad terms this data illustrates that the smaller the plant, the higher the specific CAPEX. For the same technology, the effect of changes in scale can be roughly calculated using the formula Cost 2 = Cost 1 x (Scale 2 / Scale 1) ^ 0.6. A rule-of-thumb is that doubling the size leads to a CAPEX increase of 50%.
- The GWEC report states that if the Lahti plant were to operate in power only mode, instead of CHP, its electrical efficiency has been estimated to be close to 35% (*though this appears high if utilising relatively unrefined syngas*).
- The GWEC report also cites other ACT implementations' efficiency but without CAPEX. Thermoselect fits the BEIS syngas segregation and net energy efficiency requirement along with several Japanese implementations and one in Karlsruhe. However, in the latter case the net efficiency was 10%. The report suggests this could be doubled by implementing a power island based on an engine and steam cycle, but even so would only just match the efficiency of a modern mass-burn EfW plant.

A review of UK projects defined as 'ACT' technologies within the REPD database identified three projects fitting the new ACT definition:

Project	Ref ID	
JCB Broadcrown / Kew Sustainable Energy Centre	5299	based on technology currently being developed by a former ETI funded project by Kew.
Advanced Plasma Power	6209	Advanced Plasma Power had switched focus from power generation to SNG production prior to going into receivership in December 2018. It was revived as Advanced Bio-Fuels in 2019, but with the same focus.
4Evergreen Technologies	4959	This is an advanced process proposition based on pyrolysis, an IC engine-based power island and use of organic rankine cycle to utilise residual heat. However, development is still at an early stage and both cost and performance information has yet to be validated.

17.1 Small Scale ACT with CHP

Modular small-scale technologies do exist based on a simple gasifier and wood chip or pellet down-draft gasifier (e.g., Holz Kraft, Helec, Fröling). Currently these are very small-scale units at 49kWe. Down-draft gasifiers do not scale-up well and are problematic as they approach 1MWe (equivalent). Holtz Kraft has designed plants up to 600kWe, but there are no reference installations above 49KWe (except multiples of 49kWe).

Based on Holz, Kraft and Helec's data, typical performance is:

- Generation efficiency: 23%-26%
- Gross efficiency: 73%-80%

- Heat Rate: 2-2.25

Note that the heat from one of these examples was delivered at 85 degrees Centigrade which limits applications, however this is highly suitable for local heating requirements. Implementation is most likely where there is a constant heat demand.

18 Annex 2 – EFW+CHP example projects

Table 7. Example EFW+CHP project costings and operational parameters

	MW_e	MW_{th}	CAPEX[14] £	£/kW_e	Variable cost £	£/MWh_e	Fixed OPEX £	£/MW_e	Net electrical efficiency	Load	Construction period	Min Op life	Ref
Aberdeen (plan 1)	2.4	16	£52m	£21.6K	£1.14m	£65.5	£1.28m	£534K	15%	91%	-	25yrs	1
Aberdeen (plan 2)	8	40	£135m	£16.8K	£2.86m	£49.1	£1.49m	£186K	20%	91%	-	25yrs	1
Runcorn I	28	51	£218m	£7.79K	-		-		-	-	48 mths	25yr	2
Dunbar	23	17	£200m	£8.70K	-		-		-	-	36 mths	25yr	2
Power only examples													
Generic EU EfW	18			£9.40K	£335/MW_e (total opex value)				-	-	-	25yr	3
Lakeside EfW	37		£160m	£4.32K	-		-		-	-	-	23yr	2
Runcorn II EfW	42		£214m	£5.10K	-		-		-	-	45-48 mths	25yr	2
Exeter EfW	3		£46m	£15.3K	-		-		-	-	33 mths	25yr	2
Ardley EfW	24		£205m	£8.54K	-		-		-	-	36-38 mths	25yr	2
Cardiff EfW	28		£218m	£7.70K	-		-		-	-	36-38 mths	25yr	2
Cornwall (AEAT)	16.7		£88m	£5.33K	£7.23m	£60.3	-		-	-	-	-	4

1) AMEC Foster Wheeler report for Aberdeen City Council (EFW Business case) https://committees.aberdeencity.gov.uk/mgConvert2PDF.aspx?ID=61677
2) Pennon Group Presentation, EfW Plants https://www.pennon-group.co.uk/system/files/uploads/financialdocs/pennon_efwplantsandlakeside_presentation_181011.pdf
3) Eunomia "Costs for municipal Waste management in the EU" Final report to DG Environment European Commission (2001 but costs updated to 2020 and converted to sterling (£0.9 per €).
4) Appendix 2 Residual waste treatment in Cornwall: Assessment of costs and environmental impacts of single or multiple facilities. https://www.cornwall.gov.uk/media/3633071/Appendix-2-Residual-Waste-treatment-in-Cornwall.pdf

[14] Capex values for CHP plants do not include costs of associated heat networks

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