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WRATE Modelling of IAWAREs

Report prepared for IEA Bioenergy Task 36

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IEA Bioenergy

A Report for IEA BioEnergy

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Change of Ownership of AEA

On 8 November 2012, Ricardo plc acquired the assets and goodwill of AEA Technology plc. A new company, Ricardo-AEA Ltd, has been constituted to operate the continuing business. All AEA Technology plc employees were transferred to Ricardo-AEA Ltd as part of the acquisition.

This proposal is therefore presented in the name of Ricardo-AEA Ltd

All the employees referred to in this proposal therefore remain available for the execution of the project, via the new company Ricardo-AEA Ltd, as does the entire capability and resources previously represented by AEA Technology plc. All individuals remain at their current locations, all offices being retained.

The financial track record is therefore that of Ricardo plc, the parent company of Ricardo-AEA Ltd

Background to the Change from AEA Technology plc to Ricardo-AEA Ltd
AEA Technology plc was an Energy and Environmental consultancy with 400 highly qualified employees, and had a track record of delivering and providing services to the UK public sector, the European Commission, international customers, and the private sector for many years. Many of its assignments were very high-profile.

In November 2011 its parent company, AEA Technology Group plc (AEAG), decided on a financial restructuring to deal with long-standing balance sheet issues, one of which is a deficit in its defined benefit pension scheme. Although this legacy scheme was closed to new members in 2003, and existing members in 2009, it became increasingly difficult to fund the scheme. The result is that on 8 November 2012 it was announced that Ricardo plc had bought the assets and goodwill of AEA Technology plc, and that the employees had transferred to Ricardo as well.

Ricardo plc
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Robert Bell, MD Ricardo-AEA

Customer:
IEA Bioenergy Agreement

Customer reference:
Task 36, Topic 4

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Executive summary

The concept of “Integrated Advanced WAste REfineries", or I-AWAREs, was originally raised by SP Technical Research of Sweden[1]. The idea is to co-locate waste treatment facilities and integrate their utilities, to optimise efficiency. In particular, the fundamental issue SP’s team sought to address is the excess heat that is lost during waste processing. The goal of the research was to determine how much energy could be saved by co-locating a number of waste treatment facilities, and linking their power and heat supplies and demands, to maximise overall energy efficiency.

The initial study investigated the energy efficiency of the I-AWAREs concept. In this study, the focus was broadened using Life-Cycle Assessment (LCA) to six environmental indicators – namely Global Warming Potential, Abiotic Resource Depletion, Human Toxicity Potential, Freshwater Aquatic EcoToxicity, Acidification Potential and Eutrophication Potential. In this case, the England and Wales Environment Agency’s WRATE software was used to establish the environmental impacts of alternative scenarios, embracing the I-AWARE concept to varying extents. Three initial scenarios were designed, using the Borås waste treatment facility in Sweden as a template:

- Separate treatment of food waste in an AD plant, and residual waste in a fluidised bed incinerator, with no sharing of energy;
- Treatment of food waste in AD plant, and residual waste in the fluidised bed incinerator, with heat and electricity shared between the facilities; and
- A control scenario, in which all the food and residual waste is sent to a conventional incinerator.

As an intermediate step in the modelling, mass and energy balances were completed describing the scenarios, with input from SP. This was a pivotal step towards building the user-defined process models in WRATE that represented the existing and potential future waste treatment facilities. Once these were also finalised, the actual modelling of the scenarios in WRATE was relatively straightforward.

The analysis demonstrated that sharing heat and electricity produced a beneficial result for all six environmental criteria, though the extent of the benefit varied.

Our principal conclusion is therefore that the concept of I-AWAREs, in which multiple waste streams are treated in co-located facilities with shared heat and electricity, is environmentally as well as energetically favourable.

A further set of scenarios was also modelled, in which the residual waste was pretreated to produce a refuse-derived fuel (RDF) that was gasified and upgraded to Synthetic Natural Gas (SNG), with efficiencies, in separate scenarios, of 40%, 50% and 60%. It was acknowledged that such facilities do not exist currently, and that they would face significant technical difficulties, in particular associated with the preparation of the RDF and the upgrading and conversion of the waste syngas into SNG.

The results showed that such an I-AWARE facility, if it could be realised even with the lowest conversion efficiency of 40%, would out-perform the other scenarios, often by some margin. In fact, its clear superiority raised serious questions about the validity of the modelling, and, in particular, whether the pathway “Residual Waste -> RDF -> Gasification -> SNG” is even possible. This cuts right to heart of the debate about gasification. At the moment, no operational facility is even close to managing this, so we conclude that this process chain remains a mere theoretical possibility. More information on the actual performance of large scale gasification of RDF is vital before we can have confidence that the situation in reality would be as modelled in theory.

In the meantime, given that the SP team also investigated fuel cells, it would be interesting to attempt to build a model of such a system in WRATE along similar lines to the work described herein. Although the study would again be theoretical, this would still provide an indication of how environmentally favourable that sort of technology might be, in comparison with operational facilities.

[1] See their report for IEA Bioenergy Task 36 Topic 2 entitled, “Integration of processes for optimizing resource recovery from waste streams”.

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1 Introduction

This work was supported by IEA Bioenergy Task 36 as part of two projects examining options for recovery of resources from waste. It complements the report by SP Technical Research of Sweden on "Integrated Advanced WAste REfineries", or I-AWAREs, investigating how to increase resource recovery from waste. The fundamental issue SP's team sought to address is the excess heat that is lost during waste processing. The goal of the research was to determine how much energy could be saved by co-locating a number of waste treatment facilities, and linking their power and heat supplies and demands, to maximise overall energy efficiency.

The work reported here widened the analysis of the I-AWAREs scenarios performed by the SP team, beyond overall energy efficiency to six environmental indicators, using Life-Cycle Assessment (LCA). LCA is used to establish the environmental (and sometimes social) impacts of a product, service, policy or process – referred to as the functional unit. The ideal approach is to assess a system from cradle to grave, to ensure no environmental burdens are shifted along the life cycle or between impact categories when changes are introduced to a product or service.

Streamlined LCAs simplify the rigorous nature of a full LCA, often by restricting the system boundary, not considering the full life cycle or using existing data instead of generating new empirical data. For this study, a dedicated streamlined LCA package, WRATE, was used.

In this report we discuss how WRATE works in the section below and then present the methodology for the work and the results obtained.

2 WRATE

2.1 Introduction

The England and Wales Environment Agency's Waste and Resources Assessment Tool for the Environment (WRATE) software allows waste specialists in the public and private sector to measure and improve the environmental performance of their operations, by modelling current, planned and hypothetical waste management scenarios, from collection to final disposal, thereby identifying more environmentally preferable routes for the management of their wastes.

2.1.1 How WRATE Works

WRATE is a specialist LCA tool for the management of municipal solid waste (MSW), and therefore the system boundary is from "gate to grave". The model starts at the point when materials are discarded into a waste management system (the gate), assuming they arise at no environmental cost, and follows those materials until they are recycled, composted, recovered, "lost" (such as gaseous emissions from a thermal process or water evaporation from a biological process) or disposed in landfill (the grave). The main implication of this streamlined approach is that WRATE is not easily adapted for modelling waste prevention.

WRATE Datasets

A process can range from a simple process, such as a bin, to a much more complex process, such as a thermal treatment plant. For each process, the Environment Agency compiled data on the resources used to operate the process and the emissions that occur to the environment when the process is operated. The Environment Agency also defined a series of allocation algorithms that link the feedstock inputs to the outputs of a process (recovered product or residual waste). These algorithms can be dependent on the waste composition input (fractional or elemental composition) the total quantity of the waste, or the properties of the treatment plant.

In this way, the WRATE developers produced over 120 standardised process datasets, or allocation tables, as presented in Table 1 below.

Table 1: WRATE Default Process Datasets

Containers (34)

Sacks, bins, recycling banks…

Transport (26)

RCVs, ship, barge, train, car

Intermediate Facilities (14)

Transfer Stations, HWRC, Intermodal, MRF

Recycling Processes (24)

Ferrous, PAS100 Compost, Glasphalt etc.

Treatment & Recovery…

Composting (8)	**Autoclave (2)**
Anaerobic Digestion (4)	**Incinerators (6)**
MBT-Aerobic (6)	**Pyrolysers (2)**
MBT-AD (4)	**Gasifiers (2)**
MBT-Biodrying (4)	**Cement Kiln (1)**
RDF Production (2)	

Landfill (6)

Clay Liner, Clay cap, etc. etc.

As well as using default processes, the WRATE user has the option of creating user-defined processes (UDPs), in order to model as accurately as possible the particular waste process or facility of interest. UDPs are created by duplicating a default process's allocation table and then modifying, adding and deleting relevant parameters. For thermal treatment plants, the most common parameters adjusted are the energy input and output, the metals recovered, the principal air emissions and the raw materials used (including air pollution control additives, such as urea and activated carbon).

Project Details

A "project" in WRATE may constitute several scenarios, all of which apply to one particular year in a particular country, handle the same amount of waste with the same composition, and use the same electricity mix. This means that any study on different waste compositions, or with different electricity mixes, must be conducted in multiple WRATE projects that cannot be compared within the software.

Before building the scenario details, the user has to enter project-wide details on three parameters:

Project information various textual details about the project, including the local authority covered, the year of study, and any peer reviewer's comments;

Waste composition WRATE has almost 150 waste fractions from which to select, so most MSW compositions can be modelled accurately;

Electricity mix WRATE allows the user to choose a country and a year for the electricity mix. Using waste to produce electricity with offset a very different mix of alternative processes, depending on whether the process is in (for example) England or Norway, in 2002 or 2020.

Once these details are fixed, WRATE has a user-friendly interface for the entry of process data. A screenshot of the workspace is presented below in *Figure 1*.

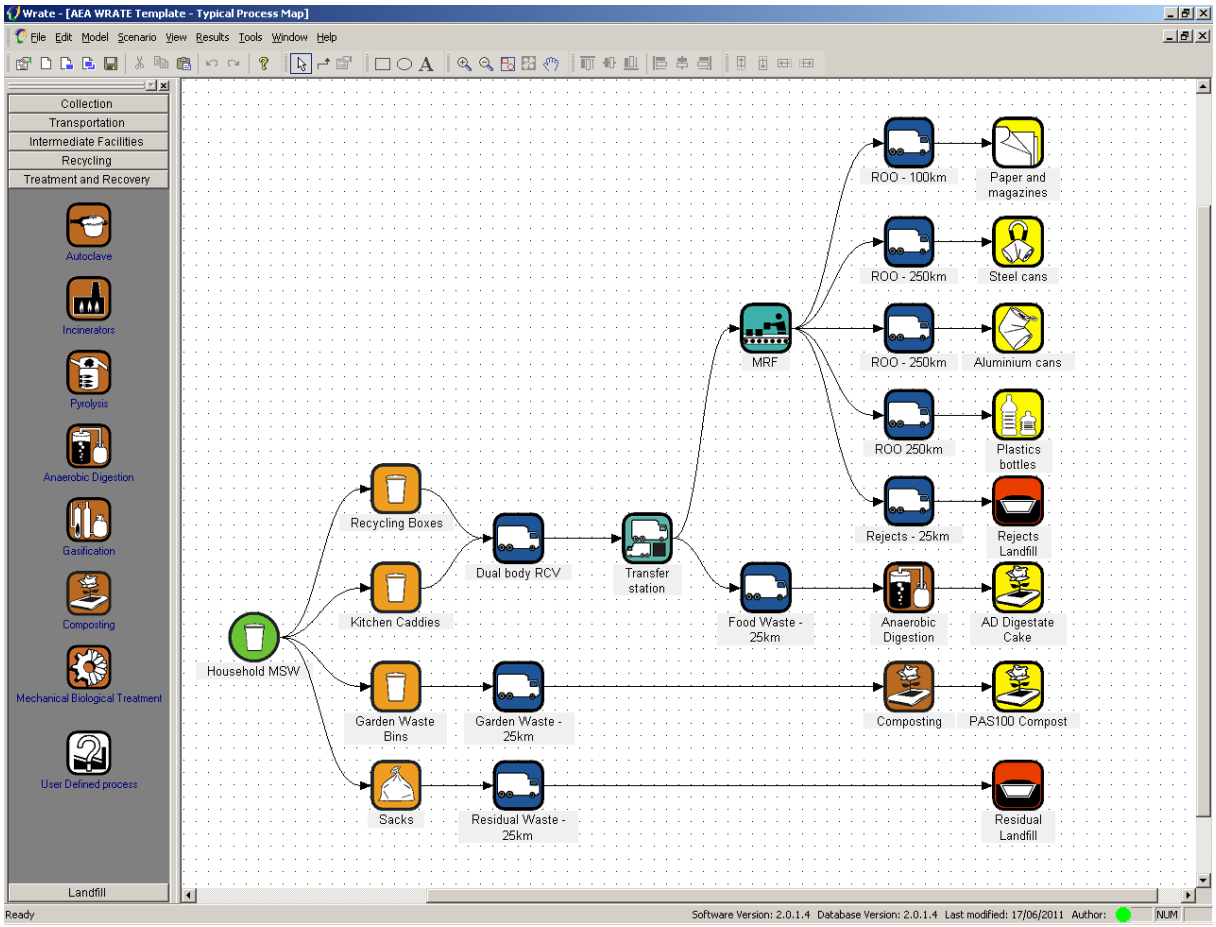
Scenario Building

A scenario is a collection of processes that together describe how a set waste is taken from point of arising to its end of life (either as a recyclate, compost, digestate, landfilled material or a loss in a process (such as combusted waste).

Building a scenario is a simple task to understand. Processes can be selected from the palette on the left hand side of the screen and dragged onto the screen (see Figure 1 below). A linking tool allows the user to pass waste from one process to the next, until all the required processes and flows have been described.

Things become more complex when one process has more than one output. The most obvious example, in the case of household waste, is the separation that occurs in the household, putting (in some instances) dry recyclables, garden waste, food waste and residual waste in different receptacles. In these cases, as well as creating the links, the user must stipulate how each waste fraction is distributed between the next processes. Once this is completed, the scenario design is finished. WRATE shows a green light if it finds no errors in the data entry. Otherwise, a red light appears, and this can be clicked to learn more about the source of the error.

Figure 1: WRATE's Workspace Interface



Results

WRATE calculates an environmental burden for the modelled system by using this information on process behaviour and a series of databases on the environmental cost of using resources or recovering materials and energy. The software compiles a life cycle inventory (LCI) which represents the environmental burden as the inputs and outputs that occur to and from the environment due to the existence and operation of the waste management system.

As described above, WRATE assumes that all the waste arises at no environmental cost. If the process produces recyclates, these are credited with whatever environmental impacts are avoided by not needing to create equivalent materials from virgin sources (minus any rejects). Similarly, any generated energy (heat or electricity) is credited in comparison to the heat or marginal electricity mix that is offset.

WRATE's results are presented as environmental burdens (such as the additional global warming potential created). The main implication of the offsetting described above is that overall results are frequently negative, reflecting the fact that, starting with "environmentally free" waste, the waste management process has a net benefit on the environment, reducing overall environmental impacts by offsetting the need to make materials or energy from virgin materials. This means that negative and low values are the most preferred.

WRATE reports against six default environmental indicators:

+ **Global Warming Potential** (GWP) is an assessment of the amount of carbon dioxide and other gases emitted into the atmosphere and liable to cause global warming. Apart from CO_2, the other major greenhouse gas for waste management tends to be methane, which is 23-times more potent than CO_2. WRATE also weights emissions of other greenhouse gases according to the climate change potency to produce a carbon footprint expressed in CO_2 equivalents.

- **Abiotic Resource Depletion** (ARD) is related to extraction of scarce minerals and fossil fuels. The abiotic depletion factor is determined for each extraction of minerals and fossil fuels based on the remaining reserves and rate of extraction.
- **Human Toxicity Potential** (HTP) is a measure of the impacts on human health. Characterisation factors describe the fate, exposure and effects of toxic substances over an infinite time horizon.
- **Freshwater Aquatic EcoToxicity Potential** (FAETP) is a measure of the adverse effects to aquatic organisms that result from being exposed to toxic substances. It is well known that fish can 'bioaccumulate' concentrations of mercury and other toxins. Mobile heavy metals are extremely toxic to aquatic life, so activities that reduce releases of heavy metals will be favourable in this assessment.
- **Acidification Potential** (AP) relates to the release of acidic gases, such as sulphur dioxide, which have the potential to react with water in the atmosphere to form 'acid rain' and causing ecosystem impairment.
- **Eutrophication Potential** (EP) is a reflection of released nitrate and phosphate levels. Nitrates and phosphates are essential for life but increased concentrations in water can encourage excessive growth of algae, reducing the oxygen within the water and damaging ecosystems.

The results from the six criteria can be expressed as a single normalised unit of measurement so they can be partially compared against each other. This unit is "European person equivalents", which represents the lifestyle impact one person has in Western Europe on the various criteria in a year. The number calculated is then equal to the effect an increase/decrease in population has against the six criteria. WRATE calculates results on an annual basis and for one given year only.

Results from WRATE can be provided at the process and scenario levels. Scenarios can be compared and a number of results formats are produced, suitable for communicating to non-technical audiences.

3 Methodology

In this project, the requirement was to reproduce the scenarios developed by the SP team, and to investigate the differences in the environmental impacts of the scenarios. The first task was to agree which scenarios to model.

3.1 Choice of Scenarios to be Modelled

The SP team derived its data for the energy balance modelling largely from operational information from the Borås waste treatment facility in Sweden. On this site, there is an anaerobic digestion facility and a fluidised bed incineration plant. The principal aim of the SP team's study was to understand the benefits of sharing energy between those facilities. However, there was also a round of work investigating future possibilities, around advanced gasification techniques and fuel cells.

It was agreed that three scenarios would be modelled in WRATE, as follows:

0a Separate treatment of food waste in AD plant, and residual waste in the fluidised bed incinerator, with no sharing of energy;

1 Treatment of food waste in AD plant, and residual waste in the fluidised bed incinerator, with heat and electricity shared between the facilities; and

0b A control scenario, in which all the food and residual waste is sent to a conventional incinerator.

3.2 Waste Composition

In order to match the work in the two studies, a critical requirement was to use comparable feedstocks. The SP team provided an elemental analysis (C, Cl, S, H, N, O) of the Borås residual waste, as well as its calorific value, ash value and moisture content. Moreover, the tonnages of the organic and residual waste were provided.

Some time was spent modelling various waste composition mixes in WRATE and checking how well their elemental analyses and other parameters matched those from the SP team. This was made more difficult because the Borås waste includes some C&I waste, which rather skewed its parameters.

Eventually, it was decided to start with WRATE's "English MSW" waste composition. Data from a confidential recent waste collection project was used to estimate the likely levels of dry recyclables and organics that might be diverted by a competent waste collection authority, leading to a 50% diversion rate (27% recycling, 8% garden and 15% food). The figures looked realistic, and, encouragingly, this yielded a final residual waste CV of 10.8 MJ/kg, close enough to the target CV of 11 MJ/kg.

The full manipulation of the waste is presented in Table 3, below. The resulting parameters for the residual waste, versus the targets from Borås, are presented in Table 2.

Table 2: Final Residual Waste Parameters, versus Boras Targets

Parameter	Target from Boras	Final Value in WRATE Model
Calorific Value	11.0	10.8
Ash	11.3	14.5
Moisture	33.3	27.1
C	30.5	28.7
Cl	0.8	1.1
S	0.3	0.1
H	7.7	3.9
O	15.5	22.1
N	0.6	0.8

3.3 Creation of Mass and Energy Balances

With the scenarios and waste agreed, the next step was to create and agree mass and energy balances. Inherent in this work was the need to agree the efficiency of each technology stage, and its heat and energy demands.

Several iterations were required to complete this work, while the details of the energy recovery as a function of the incoming waste CV were finalised. The results are the three mass balances presented in Appendix 1:

- Figure 4: Mass and Energy Balance for Scenario 0a – Isolated AD and BFB Facilities
- Figure 5: Mass and Energy Balance for Scenario 0b – Incineration Only
- Figure 6: Mass and Energy Balance for Scenario 1 – Integrated AD and BFB Facilities

Table 3: WRATE Waste Composition Modelling Results

			%	Tonnage		27.4%		7.9%		14.8%			%	49.8%
	Waste Fraction	**CV**	**English MSW**			**Recycling**		**Green Composting**		**Kitchen Waste**			**Residual Waste**	
1	Paper and card	10.7	24.0%	47,980	69%	**33,138**					31%	14.9%	**14,842**
2	Plastic film	21.3	3.8%	7,620							100%	7.6%	**7,620**
3	Dense plastic	24.7	6.2%	12,340	20%	**2,468**					80%	9.9%	**9,872**
4	Textiles	14.3	2.8%	5,580	15%	**837**					85%	4.8%	**4,743**
5	Absorbent hygiene products	5.5	2.3%	4,680							100%	4.7%	**4,680**
6	Wood	16.8	3.6%	7,200							100%	7.2%	**7,200**
7	Combustibles	14.6	6.1%	12,180							100%	12.2%	**12,180**
8	Non-combustibles	2.6	2.7%	5,320							100%	5.3%	**5,320**
9	Glass	1.4	7.9%	15,780	90%	**14,202**					10%	1.6%	**1,578**
10	Organic	3.8	31.6%	63,180			25%	**15,886**	47%	**29,580**	28%	17.8%	**17,714**
11	Ferrous metal	0.0	3.1%	6,120	50%	**3,060**					50%	3.1%	**3,060**
12	Non-ferrous metal	0.0	1.3%	2,640	45%	**1,188**					55%	1.5%	**1,452**
13	Fine material <10mm	3.5	2.0%	3,960							100%	4.0%	**3,960**
14	WEEE	7.1	2.2%	4,460							100%	4.5%	**4,460**
15	Specific hazardous household	7.5	0.5%	960							100%	1.0%	**960**
			8.5		8.2		4.2		3.5			10.8	
	Total			200,000		**54,893**		**15,886**		**29,580**			**99,641**

Key

Red = Calorific Values

Green = Waste Composition %s

Pink = Input Tonnages

Purple = % Split of Fates

3.4 WRATE Modelling

With the above research completed, the WRATE modelling was performed, in three stages, as described below.

3.4.1 Project Parameters

The three principal project parameters were previously introduced in Section 2.1.1. The waste composition has already been presented (see Table 3). For this study, the electricity mix was chosen to be the anticipated 2020 electricity mix for the UK, as follows:

Table 4: Anticipated Project Electricity Mix (UK, 2020)

Energy Source	Baseline Fuel Mix	Generating Efficiency	Marginal Fuel Mix
Coal	26.4%	35.7%	33.8%
Oil	0.3%	33.1%	
Gas	3.4%	34.9%	4.2%
Gas CCGT	43.2%	47.6%	62.0%
Nuclear	9.7%	38.6%	
Waste	0.2%	20.6%	
Thermal other	0.8%	18.7%	
Renewables thermal	2.4%	25.8%	
Solar PV	0.3%	15.5%	
Wind	11.3%	25.0%	
Tidal	0.3%	82.0%	
Wave	0.3%	82.0%	
Hydro	1.4%	82.0%	
Geothermal		82.0%	
Renewable other		82.0%	

3.4.2 Creation of UDPs

Several of the facilities presented in the mass and energy balances are not directly available in WRATE. For each of these, it was necessary to develop user-defined processes (UDPs).

Anaerobic Digestion Plant

For all facilities, the first decision was on which default system to base the UDPs. Four AD plants are available in WRATE (shown in the left hand column in Table 5). The decision to select Cambi is detailed in Table 5.

Table 5: Selection of AD Default Process

AD Plant	Description of Suitability
Strabag (previously Linde) dry process (large scale)	Quite different - horizontal PFR
BiogenGreenfinch wet process (small scale)	Unsuitable: small tank, and pasteurisation post digestion
Dranco dry process (large scale)	Misses pre-sanitisation, right temperature level (thermophilic AD, 25-40% TS), but dry instead of wet process

AD Plant	Description of Suitability
Cambi thermal hydrolysis (medium scale)	Mesophilic operation not ideal. However, Cambi is the only known provider of thermal hydrolysis AD of source-segregated MSW. It is felt that this plant is representative of technology used at Boras.

Having selected the Cambi plant, it was necessary to modify the incoming waste, energy input and output, and process outputs and emissions. The modifications made are presented in Table 6. The reasons for these changes were to convert the waste input to 100% food waste, and to match the mass and energy balances agreed.

Table 6: Amendments to the Cambi AD Process

		Original Process	Isolated	Integrated
Incoming Waste Composition (kg)	Garden waste	2,091,417	0	0
	Paper and card	1,284,132	0	0
	Absorbent hygiene products	590,808	0	0
	Fine material <10mm	1,251,887	0	0
	Food waste	7,541,745	12,759,989	12,759,989
	Total	**12,759,989**	**12,759,989**	**12,759,989**
Energy Input	Electricity Grid (MJ)	3,144,427	0	0
Process Output	Other Compost [†]	1,651,200	30.5%	30.5%
	Compost PAS 100	3,440,000	0	0
Process Energy Production (MJ)	Electricity to the Grid	4,208,316	0	0
	Natural Gas	0	*[1]	*[2]
Process Emissions (to sewer)	Water [†]	13,000,000	2.8%	2.8%
	Dry Solids	247,000	0	0

[*] These values are defined by allocation formulae, as follows, where [UWFT] and [UTNCV] represent, respectively, [USER_WASTE_FRACTIONS_TOTAL] and [USER_TOTAL.NET_CV].

1 $= 3{,}564{,}000 \times \left[\frac{[UTNCV]}{7{,}486{,}724} - \left[\frac{[UWFT]}{7{,}501{,}875} + 0.120266 \times \left[\frac{[UTNCV]}{7{,}486{,}724} - \frac{[UWFT]}{7{,}501{,}875} \right] \right] \right]$

2 $= 476.04 \times [UTNCV]$

[†] Percentages here are applied to the [USER_WASTE_FRACTIONS_TOTAL].

Borås Bubbling Fluidised Bed (BFB)

The choice of WRATE standard process on which to model the Borås BFB was relatively simple, as only the Dundee plant in WRATE uses fluidised bed technology. Again, it was necessary to modify the incoming waste, energy output, and process and waste outputs. The modifications made are presented in Table 7.

Table 7: Amendments to the Dundee EfW Process

		Original Process	Isolated	Integrated
Incoming Waste Composition (kg)	Waste Electrical & Electronic Equipment	0	1	1
	Non-combustibles	0	1	1
Process Outputs	Non-Ferrous Metal	11.5%	0.0%	0.0%

		Original Process	Isolated	Integrated
(metals as % of metals in)	Ferrous Metal	55.0%	55.0%	55.0%
	Bottom Ash Ferrous	45.0%	20.0%	20.0%
	Bottom Ash Non-Ferrous	83.5%	50.0%	50.0%
	Bottom Ash (as % of all input)	[†]	2.06%	2.06%
Waste Outputs	Air Pollution Control Residue (as % of all input)	[‡]	7.9%	7.9%
Process Energy Production (MJ) [*]	Electricity to the Grid	125,146,800	15.0%	13.7%
	External Heat	0	70.1%	68.2%

[†]=([USER_TOTAL.ASH]*0.91)+(([USER_WASTE_FRACTIONS.NON_FERROUS]+[USER_WASTE_FRACTIONS.RDF_1_12])*0.05)+0.2*((([USER_WASTE_FRACTIONS.FERROUS_METAL]+[USER_WASTE_FRACTIONS.RDF_1_11])*(1-0.55))+([USER_TOTAL.ASH]*0.91)+(([USER_WASTE_FRACTIONS.NON_FERROUS]+[USER_WASTE_FRACTIONS.RDF_1_12])*0.885))

[‡]=([USER_TOTAL.ASH]*0.09+[USER_WASTE_FRACTIONS_TOTAL]*0.025)

[*] Percentages here are applied to the [USER_TOTAL.NET_CV].

3.4.3 Creation of Scenarios

With the waste composition, project parameters and user-defined processes completed, the final stage of the modelling was to create the scenarios in WRATE. Based on the mass balance in Table 3, percentages of the dry recyclables, garden and food waste were diverted to separate recycling, composting and AD fates, with the residual waste going to BFB. The flowcharts for the three scenarios modelled are presented in Appendix 2, as follows:

- Figure 7: Scenario 0a – Isolated AD and BFB Facilities (i.e. no energy link between facilities)
- Figure 8: Scenario 0b – Incineration Only
- Figure 9: Scenario 1 – Integrated AD and BFB Facilities

4 Results

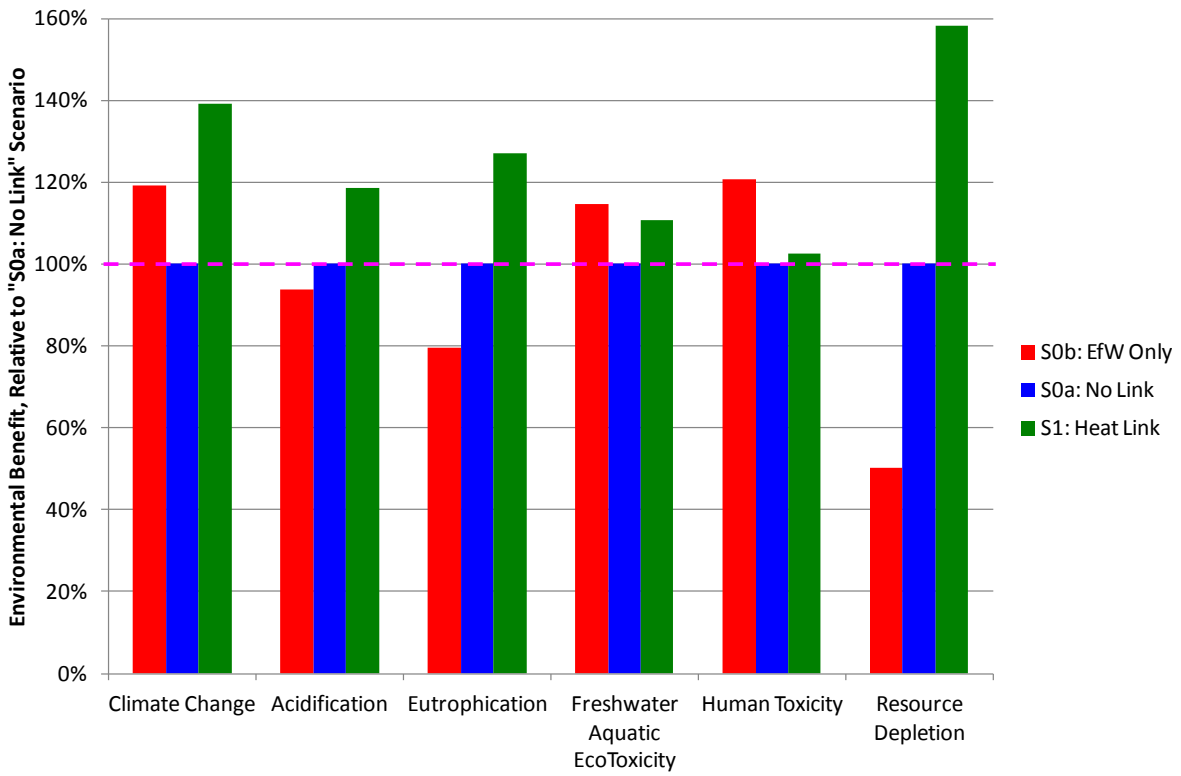
The environmental impacts calculated by WRATE for the three scenarios are presented in Table 8 below. Note first that, as all the figures are negative, the scenarios actually result in net benefits to the environment. By using the waste as a source of recyclates, organic soil improvers and energy, the need to use virgin and fossil materials is reduced, yielding a net environmental benefit in all the scenarios.

Table 8: WRATE Results (Environmental Impacts)

Indicator	Units	S0b: EfW Only	S0a: No Link	S1: Heat Link
Climate Change	te CO_2-eq	-44,600	-37,400	-52,000
Acidification	te SO_2-eq	-250	-267	-316
Eutrophication	te PO_4-eq	-9	-11	-14
Freshwater Aquatic EcoToxicity	te 1,4-DCB-eq	-10,900	-9,500	-10,500
Human Toxicity	te 1,4-DCB-eq	-131,000	-108,000	-111,000
Resource Depletion	te antimony-eq	-740	-1,480	-2,340

The results are presented in another format in Figure 2 below. Here, the benefits are compared relative to the “S0a: No Link” scenario (in blue bars, consistently 100%).

Figure 2: WRATE Results, Relative to "S0b: No Link" Scenario



The principal result from the analysis is that the “S1: Heat Link” scenario consistently out-performs the unlinked scenario, although the extent of the improvement varies. The benefits are most noticeable for resource depletion and climate change, where the use of fossil fuel alternatives is significant.

The conclusion from this analysis is that co-locating waste technologies, so that their heat and electricity supplies and demands can be balanced, yields not only energy benefits but is generally more favourable for the environment.

Interestingly, the plot shows that the "S0b: EfW Only" also performs better than the unlinked scenario for some of the criteria, including climate change. This is because the EfW Only scenario produces more electricity, which, in the UK in 2020, is still otherwise heavily dependent on fossil fuel. Changing the project location to Sweden reversed this particular result, with the No Link scenario then twice as beneficial as the EfW Only option. This demonstrates the significance of the chosen project location.

5 Gasification Scenario

5.1 Discussion of Scenario Design

The SP team went somewhat further than the scenarios already discussed, investigating more advanced I-AWAREs, using combinations of technologies such as mechanical pre-treatment, gasification, syngas upgrading and even fuel cells. In theory, these scenarios could also be modelled in WRATE to investigate their environmental credentials. The issue is that the analysis comes to rely increasingly on technical assumptions and estimates, rather than actual plant data.

To see what WRATE results might arise, it was agreed that one possible future scenario would be investigated:

S2 Treatment of food waste in anaerobic digestion (AD) plant; residual waste through a mechanical pre-treatment (MPT) plant to produce a refuse-derived fuel (RDF) for gasification and upgrading to Synthetic Natural Gas (SNG), with residues from that going to the fluidised bed incinerator, with heat and electricity shared between all four facilities.

It should be noted immediately that this scenario is not reflected (yet) in reality. There are no plants taking residual waste through an MPT process and then a gasifier and upgrader to provide SNG. We are aware of significant technical difficulties with this chain of processes, in particular associated with the preparation of mixed waste for gasification and the upgrading and conversion of the waste syngas into SNG. Experience to date points to issues with contaminants in the waste feedstock, which can be at low concentrations, but which nevertheless can inhibit the correct operation of the facilities. Another concern is that the most reliable process model in WRATE for gasification, on which our modelling was based, is Energos technology, which is designed not to produce syngas but as a two-stage combustion process.

These genuine technical issues mean that we must treat any results from the modelling with great caution, but do not fundamentally interfere with the theoretical modelling of how such a chain of facilities might perform, if the issues could be overcome.

Once again, it was important to get the waste composition right, with the performance of the MPT plant the key additional composition issue for this scenario. Table 9 shows how the residual waste from Table 3 (now split between a dry and a moisture fraction) is diverted to the RDF fraction, depending on whether it was targeted for the RDF (with a diversion rate of 45.9%) or accidentally brought across into the RDF (at a rate of 4.7%). These deliberate and accidental diversion rates were determined in two stages:

1. By adjusting their relative ratio until (at 10.2%) the desired RDF calorific value of 15.5 MJ/kg was achieved; and then
2. By adjusting their total values until the amount of RDF generated reached 25,000 tonnes.

The dry fractions, totalling 19,767 tonnes, were the amounts of RDFs 1.1 to 1.15 produced, the total moisture (5,233 tonnes) the RDF 1.16, and the residue (74,641 tonnes) was sent to the BFB process. Appendix 3 provides the WRATE scenario map (Figure 10) and the mass and energy balance used for this scenario (Figure 11).

Table 9: Waste Component Mass Balance for Scenario 2 (values in tonnes)

	Waste Fraction	Dry	Moisture	Total	To RDF	Dry	Moisture	Residue
1	Paper and card	11,211	3,631	14,842	45.9%	5,151	1,668	8,023
2	Plastic film	5,491	2,129	7,620	45.9%	2,523	978	4,119
3	Dense plastic	8,837	1,035	9,872	45.9%	4,060	476	5,337
4	Textiles	3,836	907	4,743	45.9%	1,762	417	2,564
5	Abs. hygiene products	1,737	2,943	4,680	4.7%	82	138	4,460

6	Wood	6,509	691	7,200	4.7%	306	33	6,861
7	Combustibles	10,278	1,902	12,180	45.9%	4,722	874	6,584
8	Non-combustibles	5,024	296	5,320	4.7%	236	14	5,070
9	Glass	1,550	28	1,578	4.7%	73	1	1,504
10	Organic	7,007	10,707	17,714	4.7%	330	504	16,881
11	Ferrous metal	2,657	403	3,060	4.7%	125	19	2,916
12	Non-ferrous metal	1,259	193	1,452	4.7%	59	9	1,384
13	Fine material <10mm	2,337	1,623	3,960	4.7%	110	76	3,774
14	WEEE	4,009	451	4,460	4.7%	189	21	4,250
15	Specific haz household	860	100	960	4.7%	40	5	915
	Total	**72,603**	**27,038**	**99,641**		**19,767**	**5,233**	**74,641**

Conversion Efficiency

Initial results revealed that this new scenario was more favourable for every environmental criterion, and sometimes by quite a margin. Further inspection revealed that this was entirely down to the model of the gasifier. The particular driving force for the favourable results was the synthetic natural gas produced the gasification process, which was initially reckoned to be produced with an efficiency of 60% (i.e. 60% of the calorific value of the incoming RDF is converted to SNG energy).

For pure biomass feedstocks, figures of 65% are quoted, so 60% did not seem unreasonable. However, given the results, it was decided to also try modelling the gasifier at efficiencies of 50% (Scenario S2b) and 40% (Scenario S2c).

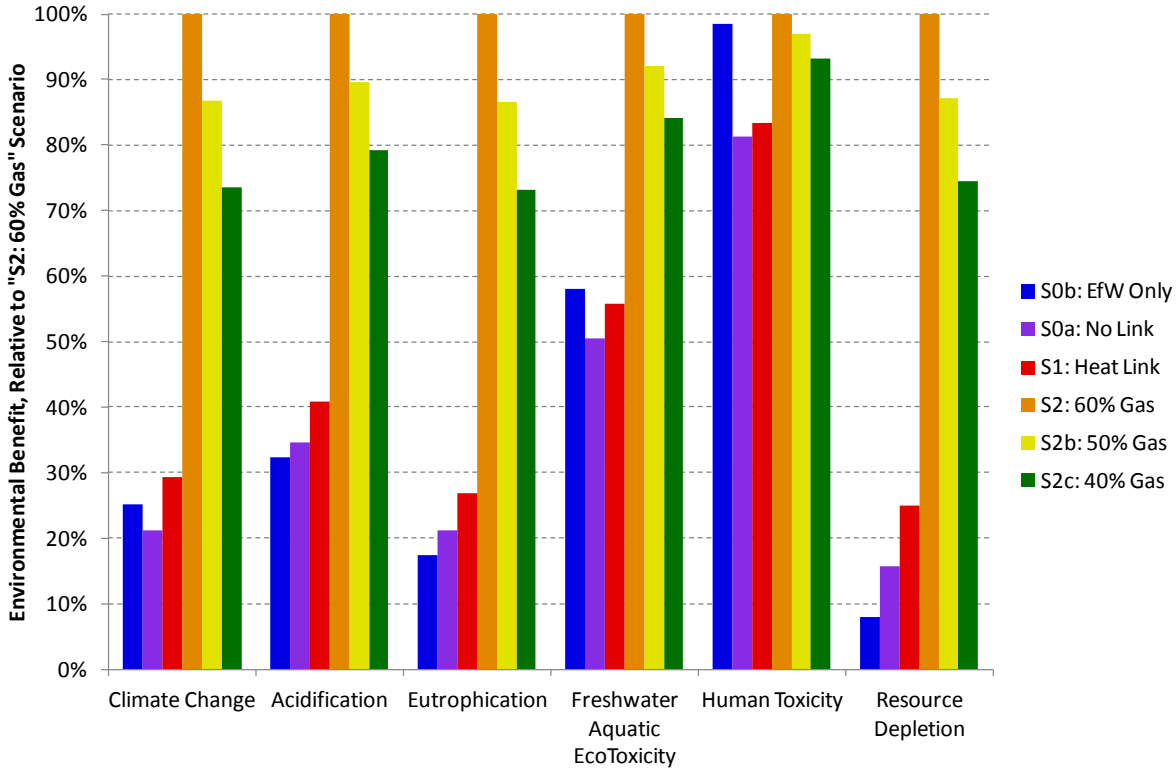
5.2 Results

The results for the new scenarios are presented, together with the original results, in Table 10. In Figure 3, the performance is compared to the environmental benefits of Scenario 2, with Gasification converting 60% of the incoming RDF energy to SNG.

Table 10: WRATE Results (Environmental Impacts)

Indicator	Units	S0b: EfW Only	S0a: No Link	S1: Heat Link	S2: 60% Gas	S2b: 50% Gas	S2c: 40% Gas
GWP	te CO_2-eq	-44,600	-37,400	-52,000	-177,100	-153,700	-130,200
AP	te SO_2-eq	-250	-267	-316	-772	-692	-612
EP	te PO_4-eq	-9	-11	-14	-52	-45	-38
FAETP	te 1,4-DCB-eq	-10,900	-9,500	-10,500	-18,800	-17,300	-15,800
HTP	te 1,4-DCB-eq	-131,000	-108,000	-111,000	-133,000	-129,000	-124,000
ARD	te antimony-eq	-740	-1,480	-2,340	-9,390	-8,190	-7,000

Figure 3: WRATE Results, Relative to "S2: 60% Gas" Scenario



The extra round of sensitivity analysis on the efficiency of the gasifier shows that even a 40% efficient gasifier (green bars) would out-perform the basic heat-linked scenario.

5.3 Analysis

Ricardo-AEA staff are highly experienced in WRATE modelling. In our experience, it is rare for one scenario (or group of scenarios) to comprehensively out-perform alternatives across the board in the fashion shown above. For one thing, if such differences were commonplace, councils and waste management companies would demonstrate much greater consistency in their choices of plant technology. The fact that such a range of technologies persists suggests that the answers are not so clear cut.

This leads us to challenge the modelling we have done for this project, and suspect that something is not right. We believe to be valid our conclusions about linking the heat of the EfW and AD plants in Scenario 1, but conclude that we must challenge our modelling for Scenario 2, which involved three critical modelling assumptions:

1. to base the gasification model on the Energos WRATE model;
2. to assume that 40%(-60%) SNG could be recovered; and
3. to assume that the pathway “Residual Waste -> RDF -> Gasification -> SNG” is possible.

These factors merit further investigation, and this is done in turn below.

5.3.1 Energos Model

The first assumption is that the Energos WRATE model is a reasonable starting point for the modelling. In one sense, this is hard to challenge, since we are confident that there is no better starting point, since WRATE’s only gasification options are Energos or Novera, and the latter was never built. There is a valid question about whether simply changing the energy and process material flows of the Energos process was adequate. Ideally, more comprehensive changes would have been made, to reflect the different capital equipment required, the different operational materials and the different emissions.

However, our intuition, from having used WRATE extensively, is that a more accurate set of modifications would be unlikely to nullify the improvements depicted above. The benefits might be diminished, but we suspect that they would endure.

5.3.2 40-60% SNG Conversion

The question about the possible efficiency of conversion, from calorific value in the RDF to embodied energy in the SNG, has been addressed to some extent in the sensitivity analysis presented above. As already discussed, for pure biomass feedstocks, figures of 65% efficiency are quoted, so 60% did not seem unreasonable. Even if it were, though, dropping this efficiency to 40% appears to be a significant drop and suitable to test the robustness of the results to uncertainties about this efficiency. The fact is that, even at 40%, the gasification scenario remains most preferred, and this suggests that uncertainty about this efficiency is not a key factor.

5.3.3 Validity of the Process Pathway

The final assumption is more overarching, and it is that the process pathway is practicably possible. The pathway starts with residual waste, which is passed through a mechanical pre-treatment process capable of separating, to some extent, a light and combustible RDF fraction (paper, plastics, textiles) from a denser, wetter fraction. The RDF is then passed to the advanced gasification process, whose syngas is upgraded to produce SNG.

We consider that the unit operations are plausible, given that each of these individual process steps has been demonstrated, though the production of SNG has only been done using biomass, rather than waste. However, there remains a genuine question about whether the chain of processes can successfully be run sequentially. The closest operational plant to date, Lahti Energy's Kymijärvi II power plant[2], gasifies RDF to produce syngas, but then combusts that gas in an ordinary natural gas boiler. The new Air Products waste facility in the Tees Valley[3] aims to take the next step, by burning its syngas in a combustion gas turbine. In the longer term, they also envisage using the water gas shift reaction to produce hydrogen.

For the time being, this technology remains a mere theoretical possibility. The modelling performed for this report demonstrates why there continues to be interest in such possibilities. However, the fact remains that no-one has managed to deliver a full-scale operational plant, despite numerous attempts over many years.

[2] http://www.lahtigasification.com/
[3] http://www.airproducts.co.uk/teesvalley/

6 Conclusions

The work reported here looked to widen the analysis of the I-AWAREs scenarios performed by the SP team, beyond overall energy efficiency to six environmental indicators, using the WRATE LCA software.

Matching the WRATE input parameters – in particular, the waste composition – to the figures used by the SP team proved to be difficult but was ultimately achieved. By creating mass and energy balances, the Ricardo-AEA team was able to reproduce the data used by the SP team.

Completing the mass and energy balances was also a pivotal step towards building the user-defined process models in WRATE that represented the existing and potential future waste treatment facilities. Once these were also finalised, the actual modelling of the scenarios in WRATE was relatively straightforward.

Three initial scenarios were modelled, representing the two treatment processes (AD and BFB) either with or without heat and electricity sharing, and a control in which all the material went to a standard incinerator.

The analysis demonstrated that sharing heat and electricity produced a beneficial result for all six environmental criteria, though the extent of the benefit varied.

Our principal conclusion is therefore that the concept of I-AWAREs, in which multiple waste streams are treated in co-located facilities with shared heat and electricity, is environmentally as well as energetically favourable.

A further set of scenarios was also modelled, in which the residual waste was pretreated to form an RDF that was gasified and upgraded to SNG, with efficiencies, in separate scenarios, of 40%, 50% and 60%. It was acknowledged that such facilities do not exist currently, and that they would face significant technical difficulties, in particular associated with the preparation of the RDF and the upgrading and conversion of the waste syngas into SNG.

The results showed that such an I-AWARE facility, if it could be realised even with the lowest conversion efficiency of 40%, would out-perform the other scenarios, often by some margin. However, these results need validation. More information on the actual performance of large scale gasification of RDF is vital before we can have confidence that the situation in reality would be as modelled in theory.

Future Work

Given the favourable results of the gasification scenarios, it would good to investigate these options more thoroughly. This would involve collecting actual plant data to the extent that it is available, and investigating the SNG conversion technologies more closely.

Given that the SP team also investigated fuel cells, it would be interesting to attempt to build a model of such a system in WRATE. Although the work would be largely theoretical, this would still provide an indication of how environmentally favourable that sort of technology might be, in comparison with operational facilities.

Ricardo-AEA

June 2013

Appendices

Appendix 1: Scenario Mass & Energy Balances

Appendix 2: WRATE Scenario Maps

Appendix 3: Gasification Scenario Details

Appendix 1 – Scenario Mass & Energy Balances

Figure 4: Mass and Energy Balance for Scenario 0a – Isolated AD and BFB Facilities

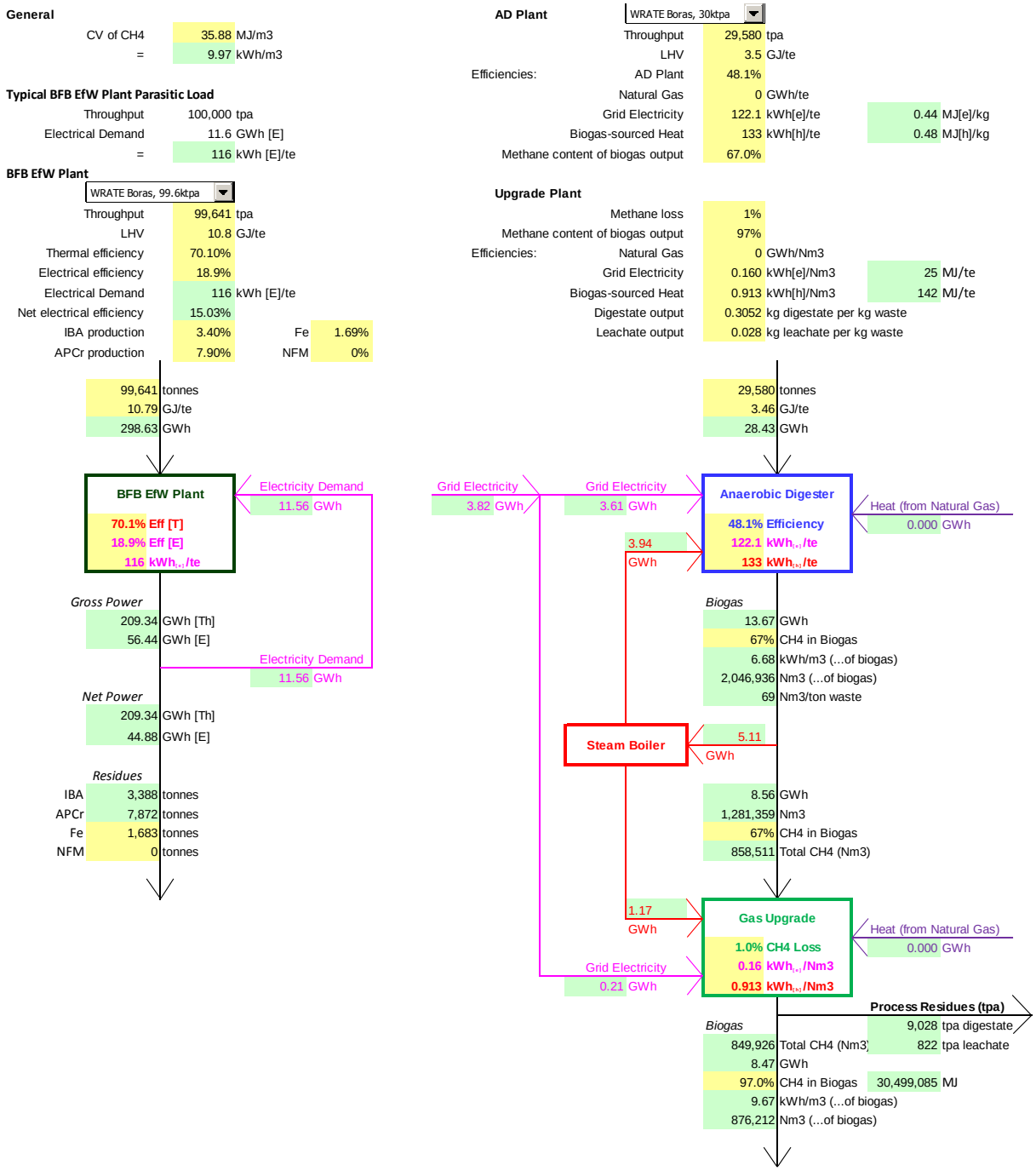


Figure 5: Mass and Energy Balance for Scenario 0b – Incineration Only

RDF Feed **Organic Feed**

General

CV of CH4	35.88	MJ/m3
=	9.97	kWh/m3

Typical BFB EfW Plant Parasitic Load

Throughput	100,000	tpa
Electrical Demand	11.6	GWh [E]
=	116	kWh [E]/te

BFB EfW Plant

WRATE Boras, 99.6ktpa

Throughput	99,641	tpa
LHV	10.8	GJ/te
Thermal efficiency	20.10%	
Electrical efficiency	0.0%	
Electrical Demand	116	kWh [E]/te
Net electrical efficiency	-3.87%	
IBA production	16.07%	
APCr production	3.70%	

Fe	1.30%
NFM	0%

WRATE Boras, 30ktpa

Throughput	29,580	tpa
LHV	3.5	GJ/te

99,641	tonnes	
10.79	GJ/te	
298.63	GWh	

29,580	tonnes	
3.46	GJ/te	
28.43	GWh	

129,221	tonnes
9.11	GJ/te
327.06	GWh

Generic EfW Plant (Chineham)

0.0%	Eff [T]
20.1%	Eff [E]
0	$kWh_{(E)}$/te

Electricity Demand
0.00 GWh

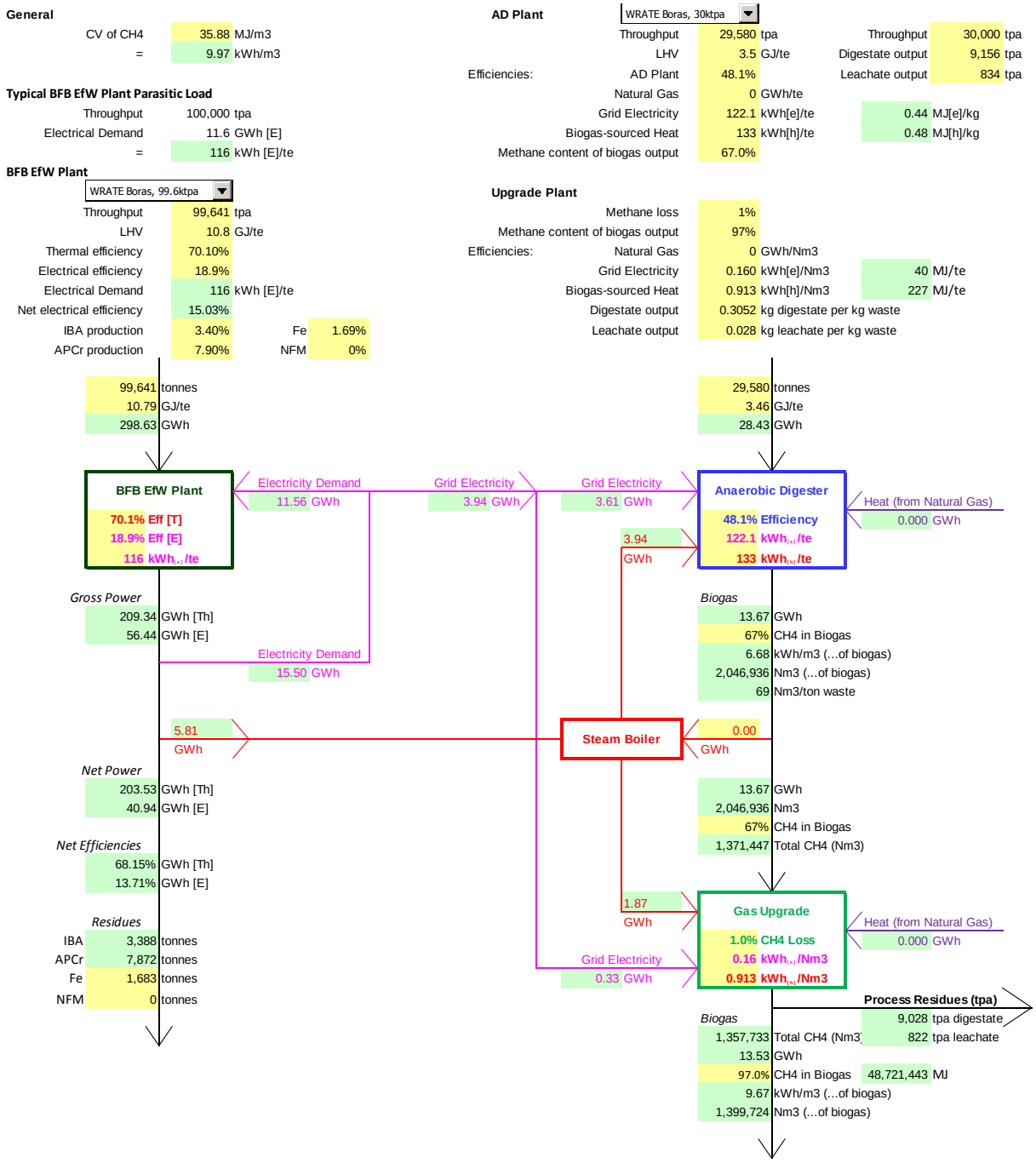
Gross Power

0.00	GWh [Th]	0.00	MJ[Th]
65.74	GWh [E]	236,658,564	MJ[E]

Residues

IBA	20,761	tonnes
APCr	4,779	tonnes
Fe	1,683	tonnes
NFM	0	tonnes

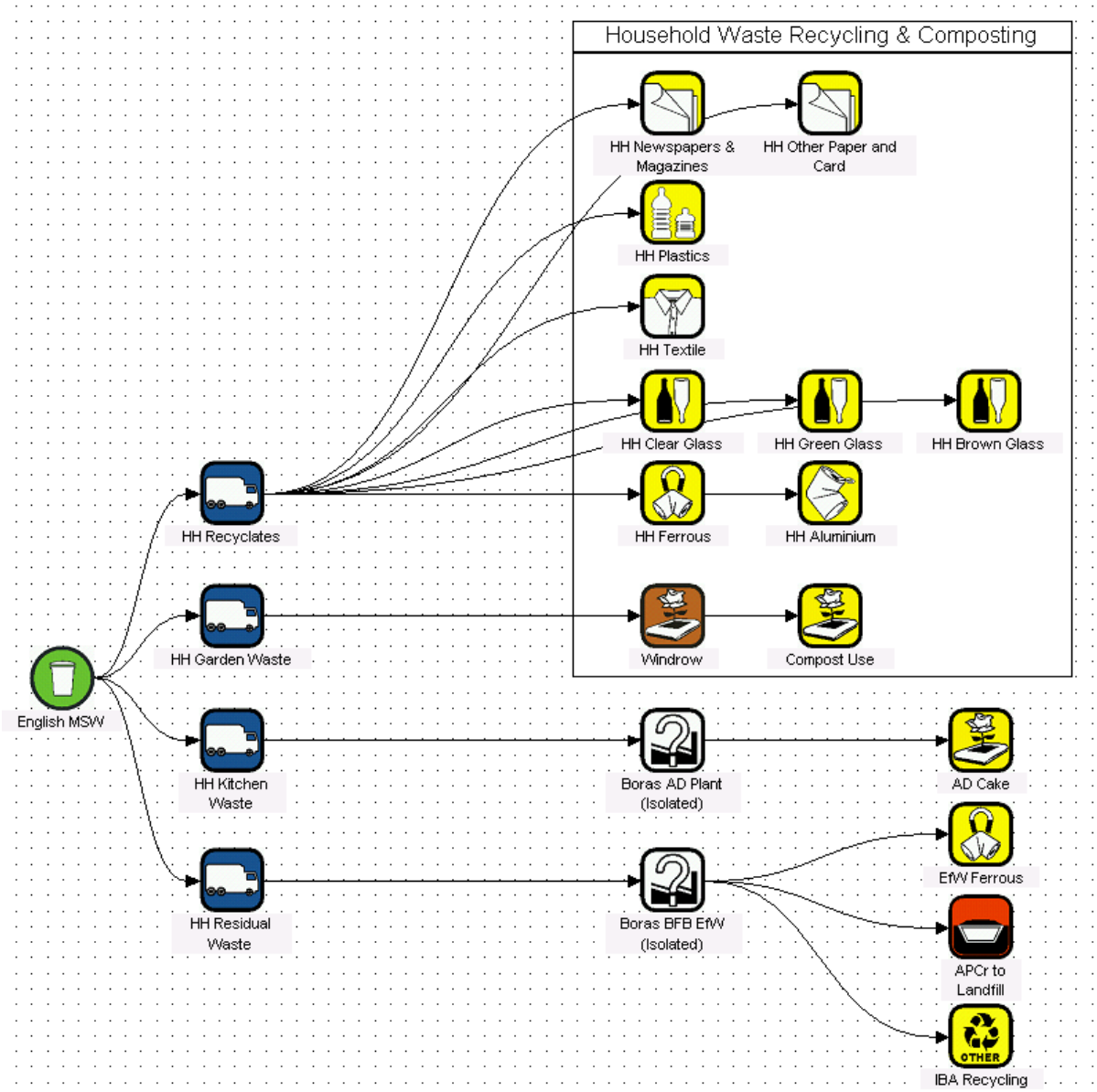
Figure 6: Mass and Energy Balance for Scenario 1 – Integrated AD and BFB Facilities



Appendix 2 – WRATE Scenario Maps

The following figures present the WRATE process maps for the four scenarios modelled.

Figure 7: Scenario 0a – Isolated AD and BFB Facilities



All four scenarios treated the Household (HH) Recyclates and HH Garden Waste in the same way. For this reason, only the HH Kitchen and Residual Waste streams are shown.

Figure 8: Scenario 0b – Incineration Only

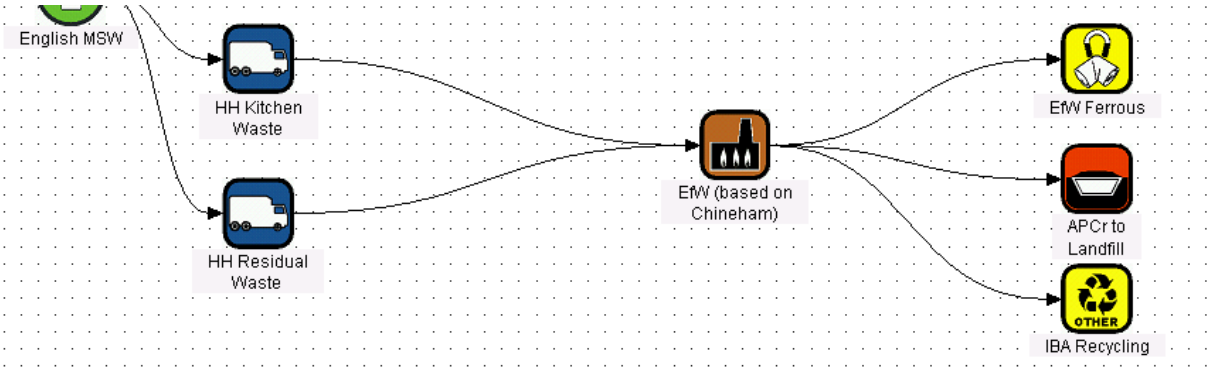
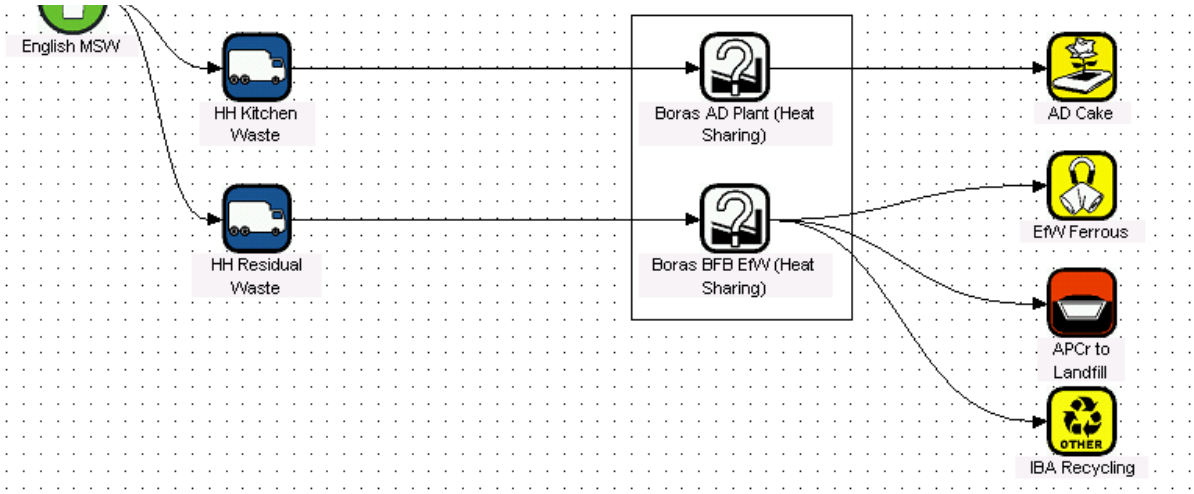


Figure 9: Scenario 1 – Integrated AD and BFB Facilities



Appendix 3 – Gasification Scenario Details

The following figures present the mass and energy balance and the WRATE process map for the theoretical gasification scenario.

Figure 10: Scenario 2 – Integrated AD, MBT, BFB and Gasification Facilities

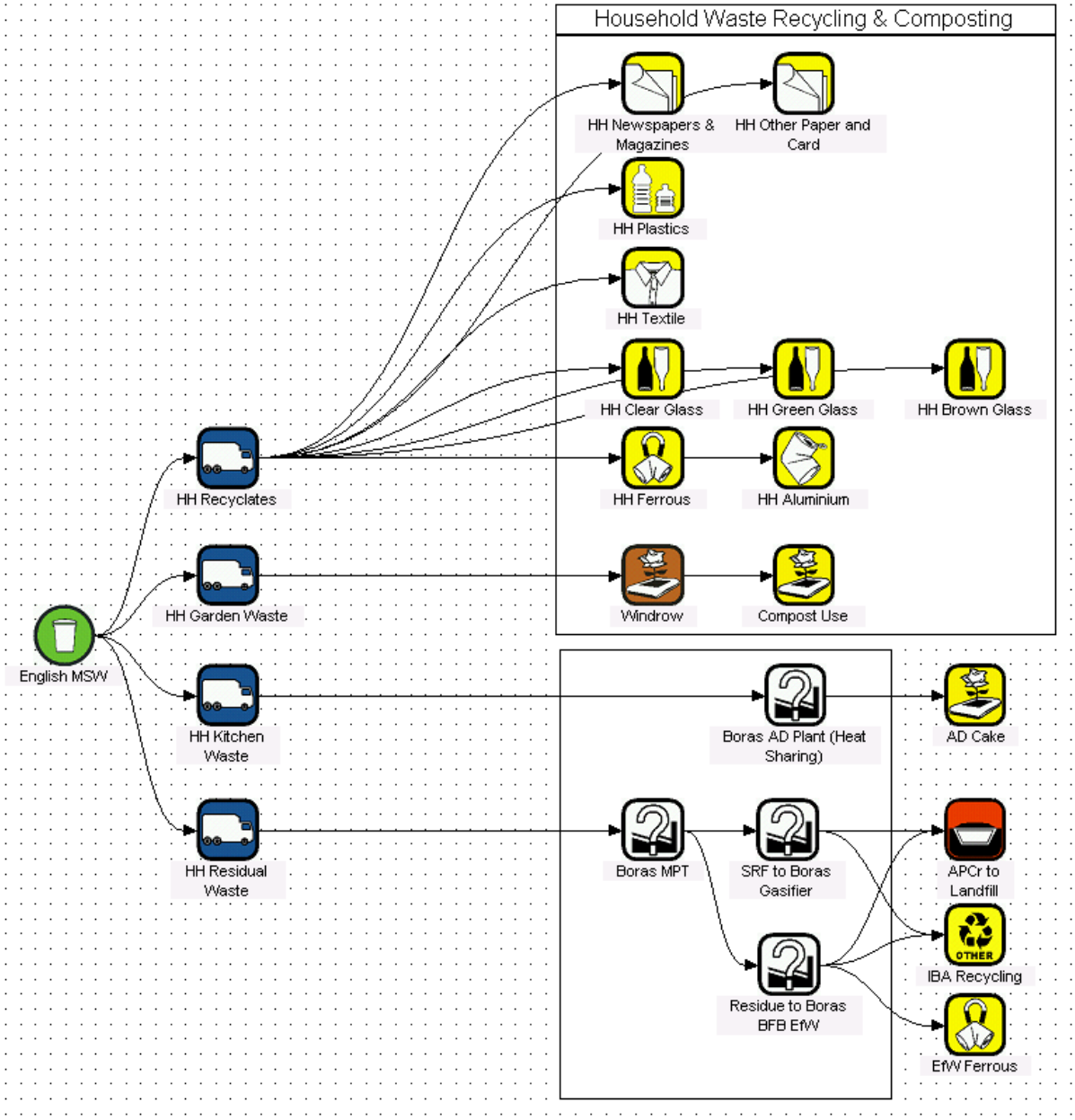
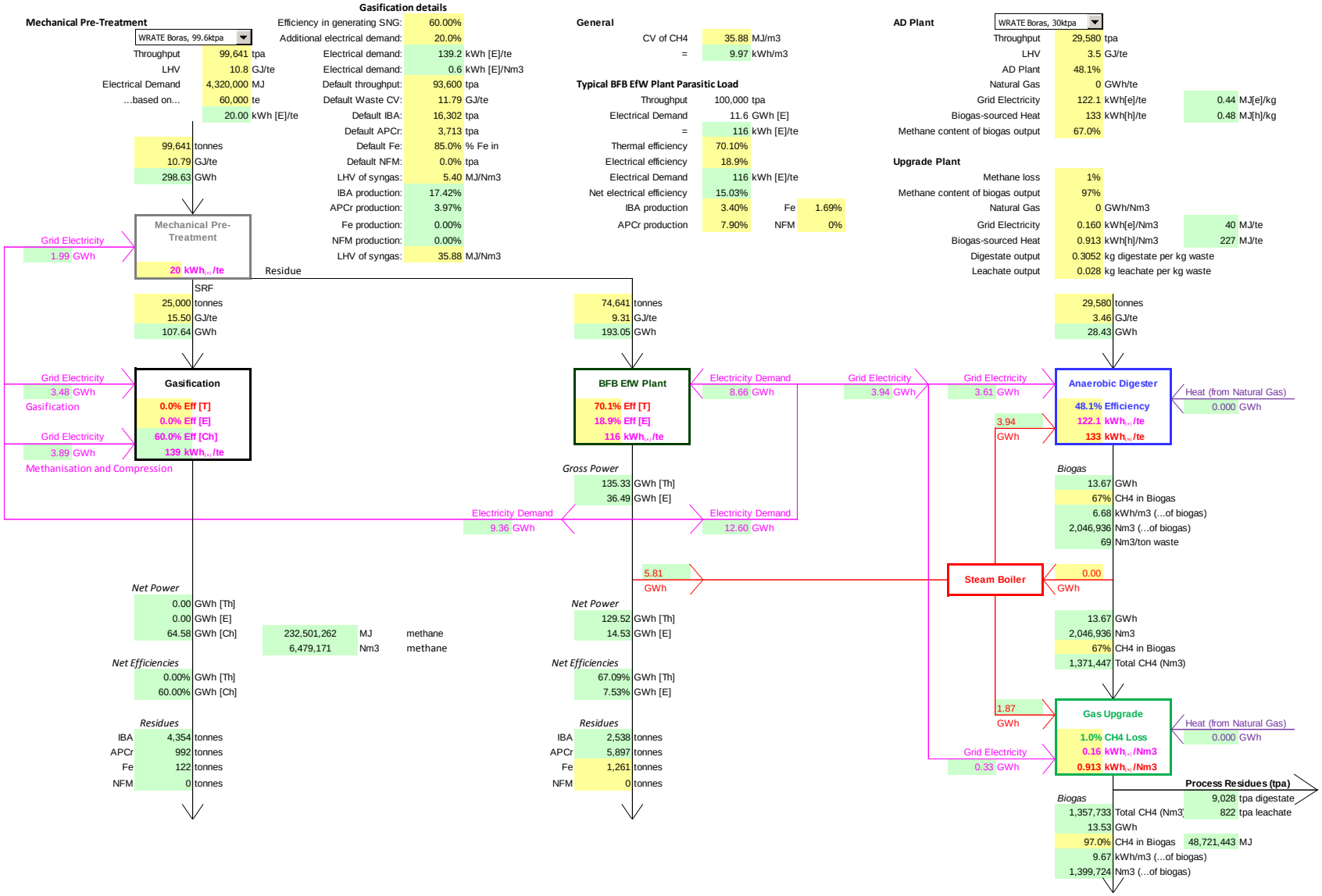


Figure 11: Mass and Energy Balance for Scenario 2 – Integrated AD, MBT, BFB and Gasification Facilities



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