Infrastructure, environment, facilities

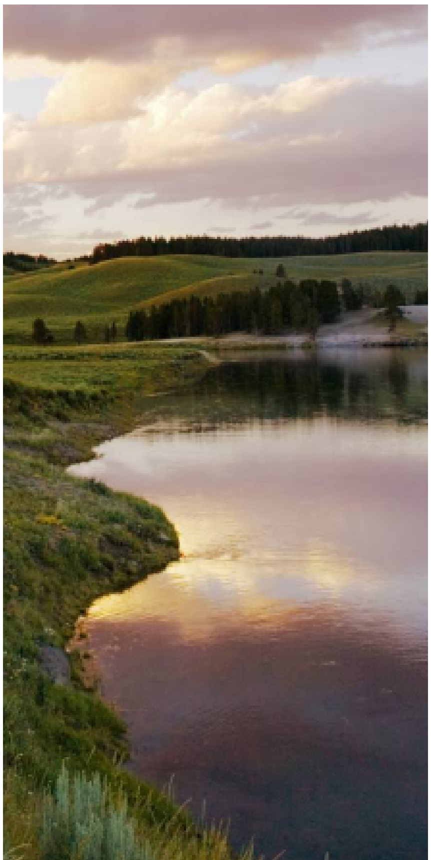
Imagine the result

FINAL REPORT

ASSESSMENT OF THE OPTIONS TO IMPROVE THE MANAGEMENT OF BIO-WASTE IN THE EUROPEAN UNION
ANNEX E: Approach to estimating costs

STUDY CONTRACT NR 07.0307/2008/517621/ETU/G4

EUROPEAN COMMISSION DG ENVIRONMENT
ARCADIS Project number – 11/004759 | Version A | 30-11-2009



CLIENT	**European Commission Directorate-General Environment Mr. Bartosz Zambrzycki Unit G.4 – BU – 5 05/118 B-1049 Brussels**

ASSESSMENT OF THE OPTIONS TO IMPROVE THE MANAGEMENT OF BIO-WASTE IN THE EUROPEAN UNION

ARCADIS
Infrastructuur, milieu, gebouwen

CONSULTANTS	**ARCADIS Belgium nv Clara Snellingsstraat 27 2100 Deurne Belgium EUNOMIA Research & Consulting 62 Queen square Bristol, BS1 4JZ United Kingdom**
Contact	**Laurent Franckx**
Telephone	**+32 3 328 62 73**
Telefax	**+32 3 328 62 87**
E-mail	**l.franckx @arcadisbelgium.be**
Website	**www.arcadisbelgium.be**

Revision				
Version	Date	Remark		
Final	30/11/2009			
Issued by				
Department	Function	Name	Signature	Date
ARCADIS, Strategic Policy Advice	Team leader and senior economist	Laurent Franckx		
ARCADIS, Strategic Policy Advice	Senior waste specialist	Mike Van Acoleyen		
Eunomia		Dr Dominic Hogg		
Eunomia		Dr Adrian Gibbs		
Eunomia		Tim Elliott		
Eunomia		Chris Sherrington		
Eunomia		Ann Ballinger		
Eunomia		Siobhan O'Brien		
Eunomia		Debbie Lister		
Eunomia		Catherine Beswick		
Verified by				
Department	Function	Name	Signature	Date
Approval by client				
Department	Function	Name	Signature	Date

TABLE OF CONTENTS

A FINANCIAL MODELLING 7

A.1 Cost Metrics 7

A.2 Costs and Gate Fees 8

A.3 The Nature of Switches 9

A.4 Key Variables 9

A.5 Weighted Average Cost of Capital 10

A.6 Revenue from Electricity Sales 13
- A.6.1 Revenues from Heat Sales 15
- A.6.2 Revenues from Biogas to Grid Sales 17
- A.6.3 Revenues from Biogas to Vehicle Fuel Sales 18
- A.6.4 Levels of Support for Renewable Electricity 20
- A.6.5 Levels of Support for Renewable Heat 23
- A.6.6 Levels of Support for Biogas to Grid 23
- A.6.7 Levels of Support for Biogas to Vehicle Fuel 23
- A.6.8 Landfill Tax, Standard Rate 24
- A.6.9 Landfill Tax, Lower Rate 24
- A.6.10 Incineration Tax 25
- A.6.11 Landfill Gate Fee, Hazardous 25
- A.6.12 Landfill Gate Fee, Non-hazardous 25

A.7 Process-specific Assumptions 25
- A.7.1 Open Air Windrow Composting 26
- A.7.2 In-vessel Composting (IVC) 28
- A.7.3 Anaerobic Digestion 29
- A.7.4 Landfill 38
- A.7.5 Incineration 39
- A.7.6 Mechanical Biological Treatment (MBT) 45

B VARIATIONS IN CAPEX AND OPEX BETWEEN MEMBER STATES 47

B.1 Labour Costs for Landfill 52
- B.1.1 Landfill Capex 52
- B.1.2 Landfill Opex 52

B.2 Labour Costs for Incineration 52
- B.2.1 Incineration Capex 52
- B.2.2 Incineration Opex 52

B.3 Labour Costs for MBT 53
- B.3.1 MBT Capex 53
- B.3.2 MBT Opex 54

B.4 Labour Costs for AD 54
- B.4.1 AD Capex 54

B.4.2 AD Opex 54

B.5 Labour Costs for Windrow 55
B.5.1 Windrow Capex 55
B.5.2 Windrow Opex 55

B.6 Labour Costs for IVC 55
B.6.1 IVC Capex 55
B.6.2 IVC Opex 56

LIST OF GRAPHS

Figure A-1: Adjustments Made to Average Cost of Capital Estimates 11
Figure A-2: Investment Cost for Biogas Clean-up as a Function of Capacity (m^3/hr) 35
Figure A-3: Cost per kWh of Cleaned Biogas as a Function of Plant Capacity 35
Figure A-4: Biogas injection to grid 37
Figure A-5: Variation in Capital Cost with Scale 41
Figure A-6:Range of Unit Capital Costs Reported in German Tenders for MBT Facilities (by capacity) 45

LIST OF TABLES

Table A-1: Different Cost Metrics 8
Table A-2: Weighted average cost of capital for specific processes by country banding 12
Table A-3: Revenue from Electricity Sales within each Member State 14
Table A-4: Assumed Electricity Revenues for Generators in each Member State 15
Table A-5: Revenue from Heat Sales within each Member State 16
Table A-6: Revenue from Biogas to Grid Sales within each Member State 18
Table A-7: Revenue from Biogas to Vehicle Fuel Sales within each Member State 20
Table A-8: Levels of Support for Renewable Electricity for each Member State 22
Table A-9: Standard Rate Landfill Tax for Member States 24
Table A-10: Incineration Taxes in EU Member States 25
Table A-11: Average Market Prices for Compost in Different Sectors (€/t per t f.m.) 28
Table A-12: Key Financial Data for Digestion Plant (rounded to the nearest €) 32
Table A-13: Costs of Anaerobic Digestion Facilities 36
Table A-14: Publicly Quoted Sources of Incinerator Cost Information 40
Table A-15: Capex and Opex Assumptions for 400kt/yr Incinerator with CHP Plant 43
Table A-16: Investment Costs for CHP in Finland (in €, year 2000 base) 44
Table B-1: Average Hourly Labour Costs in EU 27 47
Table B-2: Country-specific Capex (€/t) 49
Table B-3: Country-specific Opex (€/t) 50
Table B-4: Proportion of Labour associated with Capex and Opex 50
Table B-5: Percentage Labour associated with Opex for an Electricity only plant 53

LIST OF ABBREVIATIONS

AD	Anaerobic digestion
MBT	Mechanical biological treatment
ABPR	Animal By-Products Regulation
ACR+	Association of Cities and Regions for Recycling and Sustainable Resource management
BAT	Best available techniques
BIR	Bureau of International Recycling
BMW	Biodegradable municipal waste
BREF	BAT Reference Documents
CEWEP	Confederation of European Waste-to-Energy Plants
EEA	European Environment Agency
EEB	European Environmental Bureau
ETC/SCP	European Topic Centre on Sustainable Consumption and Production
FEAD	European Federation of Waste Management and Environmental Services
FGW	Fruit and garden waste
IPPC	Integrated Pollution Prevention and Control
ITT	Invitation to tender
LCA	Life cycle analysis
MSW	Municipal solid waste
VFG	Vegetable fruit and garden waste

A Financial Modelling

The cost modelling has been undertaken with a view to:

- Seeking to preserve some 'reality' in the modelling of the costs of switches in management; and
- Seeking to ensure that flexibility to changes in the parameters which DG Environment may seek to vary is preserved.

The cost modelling focuses upon those 'switches' which are examined in the context of this report.

A.1 Cost Metrics

We propose to model using three different cost metrics:

- The **social metric,** which makes use of the European Commission's standard discount rate approach for use in Impact Assessments[1].
- The **private metric,** which applies a private Weighted Average Cost of Capital (WACC) valuing the opportunity cost of capital investments – either the cost of capital charges, or the opportunity cost of not reinvesting capital in an alternative project [in addition a private sector annualisation would factor in retail prices/taxes that private agents face (transfers which are excluded when taking a social resource cost perspective)].
- The **hybrid metric**, which recognises capital costs as a resource cost (this hybrid approach is contrary to conventional EU project appraisal).

Further detail on these different cost metrics is given in Table A-1.

The costs will be presented in real 2009 Euros. Where estimates are based on figures from earlier years, these will be inflated by the relevant GDP deflator. Where costs have been converted to € from £ Sterling, a long term exchange rate of €1.25 = £1 has been used. Where costs have been converted from other currencies, the exchange rate applied will be indicated in the text.

---

[1] European Commission (2009) Impact Assessment Guidelines, 15th January 2009. This discount rate is expressed in real terms, taking account of inflation, and is therefore applied to costs and benefits expressed in constant prices. The rate broadly corresponds to the average real yield on longer-term government debt in the EU over a period since the early 1980s. For impacts occurring more than 30 years in the future, the Guidelines state that a declining discount rate could be used for sensitivity analysis if this can be justified in the particular context.

Table A-1: Different Cost Metrics

Metric	Discount Rate	Resource cost v. retail price?
Pure Social metric (Conventional NPV approach)	NPV using European Commission's standard 4% discount rate for inter-temporal comparisons within Impact Assessments.[1] No cost of capital.	Value resource cost only, i.e. no taxes included
Pure Private metric (private agents' perspective)	Annuitisation applying private weighted average cost of capital (WACC) discount rate (assumed to range from 10-15% for this study).	Value costs as retail prices including taxes, subsidies etc.
Hybrid metric (social metric but which cost of capital included)	NPV using EU Impact Assessment 4% discount rate but also include costs of capital at relevant sectoral WACC – recognising private costs of capital as a true resource cost.	Value resource cost only (but include capital costs which are by this cost metric defined as resource costs)

A.2 Costs and Gate Fees

Where matters of cost are concerned, the waste sector is typically used to dealing with the issue in terms of 'gate fees'. Gate fees are not 'costs', and there are various reasons why the gate fee at a facility may differ from average costs, or marginal costs, as they might be conventionally understood. Gate fees may, depending upon the nature of the treatment, be affected by, *inter alia*:

- Local competition (affected by, for example, haulage costs);
- Amount of unutilised capacity;
- The desire to draw in, or limit the intake of, specific materials in the context of seeking a specific feedstock mix;
- Strategic objectives of the facility operator; and
- Many other factors besides.

Any one of these can influence the market price, or gate fee, for a service offered by a waste management company.

Another feature of the waste treatment market at present is the use of long-term contracts in the municipal waste market to procure services. The nature and length of these contracts, and the nature and extent of the risks which the public sector may wish to transfer to the private sector, influences the unitary payment, or gate fee, offered under any given contract. The nature of risk transfer may relate, for example, to technology and its reliability, or to specific outputs which a contract seeks to deliver, and these may, in turn, relate to existing policy mechanisms.

The key point is that the nature of the risk transfer associated with a given contract affects gate fees. In the municipal waste sector, contract prices may typically be wrapped up in the form of a single payment, which may be composed of a number of different elements associated with the delivery of the contract against the specified outputs. This 'unitary payment' is typically determined on a contractual basis, and so is somewhat different to gate fees which might be realised at facilities operating in a more openly competitive market. In the approach used in this study, issues of risk transfer are not considered.

It should also be noted that whilst much of the major infrastructure for municipal waste has, in the past, been financed using project finance, it remains possible that corporate finance could be used to support projects in future. This would have the effect of changing the cost of capital used to support any given project.

Generally, therefore, the costs we have used may be different from ‘gate fees’ or payments which may be experienced in a given contractual agreement, or spot market transaction, though they will approximate to them. In general, the calculated costs might be lower than gate fees / payments agreed under local authority contracts, except in those cases where, locally, either markets are very competitive, or strategic actions of operators have the effect of depressing gate fees in the area.

If operating in a truly competitive market with shorter term contracts, the gate fees charged by merchant plant should be closer to the true marginal costs of the treatment process. However, while merchant plants are typically developed to serve the commercial and industrial sectors, they operate in a market that is influenced by the workings of the municipal waste treatment sector and may price accordingly. Indeed, the distinction is not clear cut as some merchant plant will also handle municipal waste.

It should also be recognised that different treatments are more and less sensitive to variables which underpin the analysis of costs. For example, changes in the cost of capital (see Section A.5) affect the unit (per tonne) cost of more capital intense treatments in a more significant way than they do for those with lower unit capital costs. Similarly, assumptions concerning landfill taxes, and levels of support for renewable energy outputs will affect different treatments in different ways.

A.3 The Nature of Switches

The nature of switches we are looking at varies in the profundity of the change in waste management system that they imply. For example, some merely imply the direction of waste away from one management route (e.g. landfill) into another (e.g. MBT). However, others imply a switch from one management route (e.g. landfill) to another (e.g. recycling) which may imply a change in collection system *as well as* the management of the material. These might be referred to as ‘treatment switches’, and ‘system switches’, respectively. The latter are far more difficult to model.

Where additional waste is being collected for composting, for example, the costs of doing this depend on a whole host of factors, not least of which is how that additional material is being obtained (i.e. what combination of change in system, change in participation, change in capture rate, change in relative collection frequency of kitchen waste and refuse, etc.), and the costs of this change relative to a given baseline. In the general case, these costs could be positive or negative, depending upon the assumptions one was to use concerning how the additional material is collected, and the nature of any counterpart changes in the collection system.

Below, we outline the key assumptions behind our approach.

A.4 Key Variables

As is apparent from the following sections describing the approach to the financial modelling, many of the policy mechanisms contributing to the financial costs under the private metric are underdeveloped across the EU as a whole, and the levels of support available to the technologies under consideration are not always unclear. In addition, for many Member States it is likely that new support mechanisms will be developed, and existing mechanisms altered, in response to the challenging targets set under the Renewable Energy Directive. [2] Along with the possibility that some taxes and subsidies may act as 'perverse incentives', encouraging behaviour that is not positive from a societal point of view, it must be borne in mind that the modelled private perspective does not allow for the most appropriate assessment of costs and benefits either within or between Member States.

The social metric, whereby taxes and subsidies are ignored, enables a more direct comparison of the costs and benefits attributable to the switches. This metric also provides the most robust analysis in terms of guiding actions that provide the greatest net benefit in societal terms.

However, this metric is less familiar to people in industry, for whom gate fees may be considered as costs (see 0), and one still has to make assumptions about revenue streams such as for electricity and gas. In an ideal 'first best' world there would be no market failures, and energy markets in Europe would function perfectly, enabling the clear identification of one price. However, there are a number of problems such as a lack of interconnection between national grids, and the fact that some major operators are still owned by the state and receive implicit state aid. Therefore, for the social metric, we are modelling a second best situation where some market and policy imperfections have to be taken as given.

A.5 Weighted Average Cost of Capital

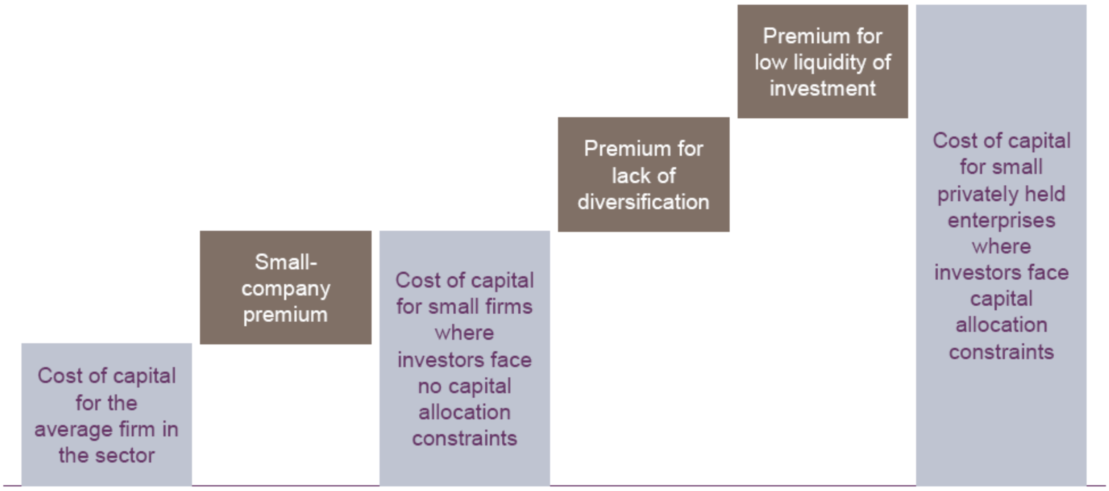
The cost of capital for similar treatment processes will vary between and indeed within Member States depending on a number of factors such as the regulatory structure in respect of the national waste treatment market, the perceived credit-worthiness of the institutions seeking to attract (what might typically be) international finance, and the way in which projects are financed. An example of the factors that might affect the cost of capital based on the characteristics of the project developer are shown in Figure A-1.[3]

---

[2] Directive 2009/28/EC. Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF

[3] Oxera Consulting (2007) *Economic Analysis for the Water Framework Directive: Estimating the Cost of Capital for the Cost-Effectiveness Analysis, Financial Viability Assessment and Disproportionate Costs Assessment—Phase II,* Report for Defra, DfT and the Collaborative Research Programme, June 20th 2007. It should be re-emphasised that these are intended to represent the WACC in real terms. As such, the implied nominal rates would be higher owing to the effects of inflation.

Figure A-1: Adjustments Made to Average Cost of Capital Estimates



Source: Oxera

The waste sector's weighted average cost of capital is affected by the risk associated with the investment being made. As the waste sector in Europe shifts away from 'traditional ways' of doing things, and to the extent that contract structures seek to ensure risk is borne, where appropriate, by the private sector, so the cost of capital appears to have increased. Many investments in the municipal sector are financed using project finance, with Special Purpose Vehicles (SPVs) set up for the purpose of delivering a specific service, or range of services. SPVs are financed using debt and equity, with the equity investors expecting greater returns on their investment. The ratio of debt:equity will therefore have an influence on the effective cost of capital to the company concerned. It may well be that in the future, more investments are financed corporately, with associated impacts on the weighted cost of capital. In the UK, Ernst & Young, advisers on many Private Finance Initiative (PFI) projects in the waste sector, assumed a 15% real pre tax cost of capital for gasification, pyrolysis and anaerobic digestion, and a 12% cost of capital for incineration with CHP. These figures seem to reflect risks experienced in the context of municipal contracts.

It seems possible that the average cost of capital may be lower in 'merchant' transactions (where plant are developed to treat waste on the open market rather than as part of a local authority contract) where the transfer of risk is not explicitly priced in to the cost of capital. However, obtaining financial support for a given project may be more difficult owing to the issues associated with securing supply of waste into the project. Moreover, for fixed-throughput infrastructure, such as incinerators, investors would expect a higher rate of return than for a municipal contract where the supply is secure.[4]

We have taken the following approach:

- We have used Ernst & Young's figure of 15% for large capital items of infrastructure (incineration and MBT);
- We have used a figure of 12% for items of infrastructure where the quantum of capital required is lower (IVC and AD plants). This reflects the fact that treatment

---

[4] Audit Commission (2008) *Well disposed: Responding to the Waste Challenge.* Local Government National Report, September 2008.

facilities are likely to be constructed outside of public contracts on a more commercial basis; and

- We have used a lower figure of 10% for collection and sorting systems, as well as for landfill and open air windrow composting facilities.

This reflects, we believe, a reasonable assessment of the opportunity cost of capital going forward. It seems reasonable to suggest, however, that there might be variations in the cost of capital across technology types, and between contract (and risk-sharing) structures. For example, local authorities in the UK might well be more inclined to have recourse to Prudential Borrowing where the quantum of capital associated with a given treatment project is relatively small. [5]

It is worth stating that the current environment is one in which the availability of credit is constrained, leading to a worsening in the terms upon which credit is made available. This would be expected to increase the cost of capital. However, the analysis here is forward looking, and extends beyond the short-term so we consider the above figures to be reasonable.

In considering whether to amend these figures to reflect country-specific circumstances, we have investigated applying an approach based on that used in a recent report for the UK Government on the costs for Member States of complying with the EU's 20% renewable energy target in 2020.[6] This places countries into one of three risk bands, Low. Medium and High.

- Low - Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, The Netherlands, Portugal, Spain, Sweden, United Kingdom
- Medium – Cyprus, Greece, Malta
- High – Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia

The weighted average cost of capital applied for each process technology in the respective country banding, adapting the approach to the waste sector is shown in Table A-2.

Table A-2: Weighted average cost of capital for specific processes by country banding

Risk Band	Landfill	Incineration	MBT	AD	IVC	Windrow
Low	10%	15%	15%	12%	12%	10%
Medium	12%	17%	17%	14%	14%	12%
High	14%	19%	19%	16%	16%	14%

There are a number of difficulties in the application of such an approach. In general terms, the risk banding of countries is intended to reflect the perceived credit-worthiness of the organisations who might be seeking finance, along with the institutional nature of waste collection and treatment. For countries such as Bulgaria and Romania, where one might reasonably expect that international finance would require a higher level of return, such a broad-brush approach does not, however, take account of the structural funds that

---

[5] Prudential Borrowing is a method of financing the development of waste infrastructure in the UK, where the capital cost of the facility falls below the Treasury's recommended threshold (£20 million), below which the use of private finance is not considered likely to offer value for money. It is considered most suitable for low risk assets.

[6] Poyry (2008) Compliance Costs for Meeting the 20% Renewable Energy Target in 2020: A Report to the Department for Business, Enterprise and Regulatory Reform, March 2008.

are available. The impact of these funds is likely to be a reduction in the perceived risk for other financiers, thus reducing the overall cost of capital.

In addition, the ownership structures are very different for individual Member States. For example, in Austria, landfills are all in public ownership due to the long term nature of the liabilities. Elsewhere, for the same reason, full privatisation is the preferred approach.

Assuming a country specific cost of capital is further complicated by the fact that we are not just considering new build. There are many fixed assets such as incinerators, that are at various points in their operational life, and the age of facilities tends to have a bearing on the costs of capital and hence gate fees. If construction costs tend to run ahead of general inflation measures, such as the Harmonised Index of Consumer Prices (HICP), then a facility built in the early 1990s, with gate fees indexed to inflation, will have lower costs, and therefore lower gate fees, than an equivalent new build facility.

It's not possible to take into account all of these factors in a country specific way. Therefore we have decided not to vary the costs of capital by country, but have instead varied the costs by technology for as the quantum of capital involved increases, more complex procurement approaches and risk structures are brought into play. The figures we use are therefore:

- 15% for large capital items of infrastructure (incineration and MBT);
- 12% for items of infrastructure where the quantum of capital required is lower (IVC and AD plants).
- 10% for collection and sorting systems, as well as for landfill and open air windrow composting facilities.

It must be noted that this is an approximation, and a simplifying assumption that must be treated with some caution.

A.6 Revenue from Electricity Sales

Ideally it would be possible to accurately establish, for each Member State, the wholesale prices that generators would receive for the electricity they produce. However, this process is complicated by a number of factors. The first of these is the lack of properly developed and integrated wholesale markets within the EU. Ultimately, there may be a single European energy market with a single wholesale price at any one time, but currently the market is fragmented, and in a number of cases, such as Romania and Bulgaria, prices are set by the Government regulator. Where wholesale markets do exist, and data is available, it is not clear what proportion of this price would be received by the generator, and how much might be taken by the supplier.

As a proxy, as a first step, we have used Eurostat's most recent half-yearly electricity prices, without taxes, for Band IF industrial consumers, with annual consumption of between 70,000 MWh and 150,000 MWh. [7] These are shown in Table A-3.

---

[7] Eurostat (2009) Energy Statistics Database. Available at http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/data/database

Table A-3: Revenue from Electricity Sales within each Member State

Member State	Revenue from Electricity Sales (€/MWh)	Member State	Revenue from Electricity Sales (€/MWh)
AT	€ 73.50	IT	€ 96.70
BE(Flanders)	€ 66.60	LV	€ 68.40
BE(Wallonia)	€ 66.60	LT	€ 72.45
BE(Brussels)	€ 66.60	LU	€ 75.50
BG	€ 45.00	MT	€ 132.30
CY	€ 153.00	NL	€ 82.00
CZ	€ 84.10	PL	€ 66.70
DK	€ 84.50	PT	€ 50.50
EE	€ 36.20	RO	€ 54.80
FI	€ 53.60	SK	€ 93.70
FR	€ 46.50	SI	€ 74.10
DE	€ 75.50	ES	€ 69.00
EL	€ 66.40	SE	€ 61.80
HU	€ 87.40	UK	€ 96.70
IE	€ 100.40		

In using prices for one of the larger groups of industrial users (country specific prices become increasingly sparse when looking at the largest consumers), and stripping out taxes, it is expected that the prices are a reasonable, if slightly elevated, approximation of the wholesale prices. While these figures may not be entirely accurate, they have the benefit of having been gathered using a standard methodology, and they do reveal the variations in prices between Member States. We then adjust these figures to represent an assumed differential between wholesale prices and prices for industrial consumers, and a further differential between wholesale prices and the prices that a generator would receive. We assume the price received by generators to be 60% of the price for large industrial consumers.

There are a number of pieces of missing data, so alternative values have been included in the following cases. For Belgium there is no price given for the second half of 2008, so we have used the price as for the first half. While in general there has been an increase in the cost of electricity for industrial customers in EU Member States from the first to the second half of 2008, for Belgium's immediate neighbours, France, Germany and the Netherlands, there has been a slight decline. Holding the prices constant from early 2008 for Belgium would appear to be a reasonable assumption in this case.

For Lithuania, the price for the first half of 2008 has been increased by 15%. In the absence of alternative data, this assumption is based on the stated price increases in neighbouring countries of Poland and Latvia of 9% and 32% respectively between the first and second halves of 2008. Luxembourg has been assigned the same price as the neighbouring country of Germany, and Italy has been assigned the same price as the UK. In the absence of other data this is based on a report by Vattenfall suggesting that spot prices on the Italian electricity exchange (IPEX) were comparable to those in the UK during 2008. [8]

For Malta, there is no data available for the second half of 2008 for industrial users in Band IF. The price applied reflects the price paid by industrial consumers in Band ID, with consumption between 2,000 MWh and 20,000 MWh per annum. The values used for the modelling are shown in Table A-4

Table A-4: Assumed Electricity Revenues for Generators in each Member State

Member State	**Revenue from Electricity Sales (€/MWh)**	**Member State**	**Revenue from Electricity Sales (€/MWh)**
AT	€ 44.10	IT	€ 58.02
BE(Flanders)	€ 39.96	LV	€ 41.04
BE(Wallonia)	€ 39.96	LT	€ 43.47
BE(Brussels)	€ 39.96	LU	€ 45.30
BG	€ 27.00	MT	€ 79.38
CY	€ 91.80	NL	€ 49.20
CZ	€ 50.46	PL	€ 40.02
DK	€ 50.70	PT	€ 30.30
EE	€ 21.72	RO	€ 32.88
FI	€ 32.16	SK	€ 56.22
FR	€ 27.90	SI	€ 44.46
DE	€ 45.30	ES	€ 41.40
EL	€ 39.84	SE	€ 37.08
HU	€ 52.44	UK	€ 58.02
IE	€ 60.24		

A.6.1 Revenues from Heat Sales

The use of heat, typically for district heating systems, is, for many countries, an underdeveloped market sector. As a result, there are no readily available, up-to-date figures for revenues from the sale of heat for all the Member States. However, looking forward, it is likely that there will be a greater push for the development of renewable heat in Member States following of adoption of plans to meet the targets identified in the

---

[8] Vattenfall (2008) Annual Report: Wholesale Electricity Prices. Available at http://report.vattenfall.com/annualreport2008/Menu/Wholesale+prices/wholesale_electricity_prices.pdf

Renewable Energy Directive (RED).[9] Development of this market should therefore lead to greater availability of price information.

Countries such as Denmark, Sweden and Austria have made investments over a number of years, and for these countries, for our modelling, including a price for heat has more relevance than for warmer southern European countries. For example, Cyprus, Greece, Spain, Portugal and Malta have no identified heating sales, but realistically, it is not likely that the use of biowaste for generating heat will seriously be considered in these Member States.

Country specific revenues from heat sales for most EU member states can be found in a report published by Euroheat and Power for the Ecoheatcool project.[10] Prices for the purpose of this modelling are taken from Table 17, which lists district heat prices for most current EU member states in 2003. These data were originally sourced from a study gathering national average district heat prices for 1999-2003.[11] The figures provided exclude VAT. We have therefore updated these prices by HICP in order to adjust to 2009 price levels. It could reasonably be expected that prices might follow that of gas, which for all member states has increased at a level greater than general inflation between 2003 and 2009. However, the ownership structure of many district heating systems, whereby there is historical and significant levels of public ownership, albeit moving towards private involvement, should lead to a reduced fluctuation in prices.[12] This public ownership does, however, make it less certain that the prices identified are at all close to the true market price that would be achieved in a perfect market for renewable heat.

Where no price information has been identified, but it is considered likely that demand for heating might exist, prices for neighbouring countries are used as follows. For Belgium, we apply the price for The Netherlands, while for Ireland we use the UK price.

In the absence of a well developed market for renewable heat, and the associated lack of up-to-date figures, we note that caution must be exercised in the interpretation of the figures applied in relation to renewable heat sales. The values used for the modelling are shown in Table A-5.

Table A-5: Revenue from Heat Sales within each Member State

Member State	Revenue from Heat Sales (€/MWh)	Member State	Revenue from Heat Sales (€/MWh)
AT	€ 62.04	IT	€ 69.42
BE(Flanders)	€ 47.93	LV	€ 36.16
BE(Wallonia)	€ 47.93	LT	€ 38.40
BE(Brussels)	€ 47.93	LU	€ 57.59
BG	€ 25.34	MT	€ 0.00
CY	€ 0.00	NL	€ 47.94

---

[9] Directive 2009/28/EC. Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF

[10] Euroheat & Power (2006) *Ecoheatcool Work package 1: The European Heat Market*, Final Report

[11] Werner, S., Brodén, A., (2004) *Prices in European District Heat Systems*, Proceedings of the 9th International Symposium on District Heating and Cooling, August 30-31, 2004, Esbo, Finland.

[12] DHCAN (2003) District Heating System Ownership Guide. Available at http://www.euroheat.org/workgroup4/KN1507%20Owners.ip%20Management.pdf

Member State	Revenue from Heat Sales (€/MWh)	Member State	Revenue from Heat Sales (€/MWh)
CZ	€ 41.67	PL	€ 32.05
DK	€ 72.49	PT	€ 0.00
EE	€ 25.25	RO	€ 24.42
FI	€ 34.32	SK	€ 36.20
FR	€ 49.31	SI	€ 37.45
DE	€ 57.60	ES	€ 0.00
EL	€ 0.00	SE	€ 56.60
HU	€ 38.98	UK	€ 27.53
IE	€ 27.53		

A.6.2 Revenues from Biogas to Grid Sales

On a European scale, the injection of biogas into the grid is a very small scale and relatively recent technological development. There are a number of technical and (related) regulatory barriers to the diffusion of this approach to the use of biogas, not least of which are the challenges in upgrading to meet the strict (but varying) quality requirements of the network operators. As there is very little information as to the revenue that would be received for the sale of biogas to grid operators, we model on the assumption that the revenue would be equivalent to the price of natural gas.

As for wholesale electricity prices, ideally it would be possible to accurately establish, for each Member State, the wholesale prices that plant operators would receive for the gas they produce. However, this process is complicated by a number of factors including the lack of properly developed and integrated wholesale gas markets within the EU.

As a proxy, we have used Eurostat's most recent half-yearly gas prices, without taxes, for Band I4 industrial consumers, with annual consumption of between 100,000 GJ and 1,000,000 GJ. [13]

Again, in using prices for one of the larger groups of industrial users (country specific prices become increasingly sparse when looking at the largest consumers), and stripping out taxes, it is expected that the prices are a reasonable, if slightly elevated, approximation of the wholesale prices. While these figures may not be entirely accurate, they have the benefit of having been gathered using a standard methodology, and they do reveal the variations in prices between Member States.

These prices are given in GJ so in order to convert them to MWh the figures are multiplied by 3.6.

There are a number of pieces of missing data, so alternative values have been included in the following cases. In the absence of current data, Austria and Luxembourg have been assigned the same gas price as neighbouring Germany.

---

[13] Eurostat (2009) Energy Statistics Database. Available at http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/data/database

According to Eurostat, due to the limited sizes of the gas markets, prices are not applicable for Greece, Cyprus and Malta. [14] The values used for the modelling are shown in Table A-6

Table A-6: Revenue from Biogas to Grid Sales within each Member State

Member State	Revenue from Biogas to Grid Sales (€/MWh)	Member State	Revenue from Biogas to Grid Sales (€/MWh)
AT	€ 36.83	IT	€ 36.78
BE(Flanders)	€ 29.70	LV	€ 38.10
BE(Wallonia)	€ 29.70	LT	€ 38.40
BE(Brussels)	€ 29.70	LU	€ 36.83
BG	€ 24.78	MT	€ 0.00
CY	€ 0.00	NL	€ 31.89
CZ	€ 35.57	PL	€ 29.84
DK	€ 29.12	PT	€ 26.07
EE	€ 27.90	RO	€ 22.93
FI	€ 30.24	SK	€ 42.83
FR	€ 34.04	SI	€ 39.02
DE	€ 36.83	ES	€ 30.38
EL	€ 0.00	SE	€ 38.00
HU	€ 36.41	UK	€ 28.77
IE	€ 32.65		

A.6.3 Revenues from Biogas to Vehicle Fuel Sales

The upgrading of biogas for use as vehicle fuel is currently a niche market if considering the EU as a whole, although there is considerable experience in Sweden and to a certain extent in France, where Lille runs the municipal bus fleet on biogas, and in Italy where waste trucks in Rome are run on biogas. [15]

It is therefore not possible to identify revenues for the sale of biogas for vehicle fuel for all Member States, as it simply does not yet take place on an appropriate scale.

We model on the basis that the main use for biogas, at least for the next few years, is likely to be for captive vehicle fleets with refilling stations at their home depots. This reflects a continuation of recent experience.

The presumption is that these fleets would be switching away from conventional of ultra-low sulphur diesel (ULSD) operation. In this case, one might ask what assumptions should one use regarding a) the costs of the switch in vehicles and b) the value of the biogas derived. A report on vehicle use of biogas for the National Society for Clean Air (NSCA) considers the additional costs of switching vehicles to either spark ignition or dual

---

[14] Eurostat (2009) Natural gas prices for second semester 2008. Available at http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-QA-09-026/EN/KS-QA-09-026-EN.PDF

[15] European Commission (2007) Report on Technological Applicability of Existing Biogas Upgrading Processes. Report commissioned under the BioGasMax Project, Contract Number 019795

fuel as compared to the use of ultra-low sulphur diesel (ULSD) from the point of view of a fuel user.[16]

The analysis indicates that compressed biogas is competitive relative to ULSD, more especially so where the vehicle is a dual fuel one. The suggestion is that from a vehicle user's point of view, the higher cost of vehicles (the capital involved in the purchase of dual fuel vehicles and their maintenance) is offset by the lower cost of biogas as fuel. Consequently, we have taken the view that, from the perspective of the biogas generator, one would either assume that one needed to equip the vehicles, but impute a shadow value for the fuel equivalent to that of diesel, or simply assume that the implied revenue generated equates to that of compressed natural gas. We have followed the latter approach for the sake of simplicity.

Data on fuel prices were taken from European National Gas Vehicle Association (NGVA) statistics.[17] The values provided in the document correspond to compressed natural gas prices for the majority of the member states and are inclusive of VAT. For each, VAT has been stripped out at the appropriate country specific rate to give prices before tax.

Data is, however, unavailable for the following countries: Cyprus, Denmark, Estonia, Greece, Hungary, Ireland, Lithuania, Malta and Romania. Subsequent searches have failed to uncover data. An attempt was made to identify any correlation between pre-tax CNG prices and pre-tax industrial gas prices, but there was no significant relationship from the data available. Therefore, for these member states a value equal to the lowest observed price (€0.18 per cubic metre) was assigned. The values used for the modelling are shown in Table A-7.

---

[16] Sustainable Transport Solutions (2006) *Biogas as a Road Transport Fuel: An Assessment of the Potential Role of Biogas as a Renewable Transport Fuel*, Report for the National Society for Clean Air, June 2006.

[17] NGVA Europe (2009) *Comparison of fuel prices in Europe*, April 2009

Table A-7: Revenue from Biogas to Vehicle Fuel Sales within each Member State

Member State	Revenue from Biogas to Vehicle Fuel Sales (€/cubic metre)	Member State	Revenue from Biogas to Vehicle Fuel Sales (€/cubic metre)
AT	€ 0.74	IT	€ 0.57
BE(Flanders)	€ 0.42	LV	€ 0.19
BE(Wallonia)	€ 0.42	LT	€ 0.18
BE(Brussels)	€ 0.42	LU	€ 0.33
BG	€ 0.42	MT	€ 0.18
CY	€ 0.18	NL	€ 0.43
CZ	€ 0.53	PL	€ 0.18
DK	€ 0.18	PT	€ 0.42
EE	€ 0.18	RO	€ 0.18
FI	€ 0.65	SK	€ 0.63
FR	€ 0.53	SI	€ 0.18
DE	€ 0.58	ES	€ 0.42
EL	€ 0.18	SE	€ 0.84
HU	€ 0.18	UK	€ 0.59
IE	€ 0.18		

A.6.4 Levels of Support for Renewable Electricity

While the principle of support mechanisms for renewable electricity has long been established within the European Union, there is a remarkable level of variation in the type and levels of support structures across the Member States. For the purposes of our modelling, we have sought to identify a figure, in €/MWh for renewable electricity generated by the relevant technology for each Member State. Interestingly, despite the various pieces of work to support the Renewable Energy Directive, there has been no attempt to produce such a figure for each country at the European level. [18]

Typically schemes within the EU are based on a fixed level of price support (e.g. feed-in tariffs) or a quantity based scheme, where the price obtained will fluctuate according to the level of compliance with the targets.

Feed-in tariffs are the most commonly employed support scheme in the EU. In certain Member States, producers can choose whether to opt for a feed-in tariff system or a premium tariff (e.g. Slovenia). Premium tariffs are paid in addition to the market price.

---

[18] Directive 2009/28/EC. Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF

Quota obligation systems are typically coupled with tradable green certificates. Tax reductions or exemptions are used in some Member States to incentivise renewable electricity generation (e.g. Finland).

Values for the different support schemes (e.g. feed-in tariffs, premium tariffs, green certificates) were extracted from a DG TREN funded study on renewable energy markets.[19] Most of the tariffs are differentiated according to categories such as plant capacity and input material. However, due to the variation in both approach and terminology between support schemes for individual member states, a certain level of interpretation has been required. [20] For the purposes of this modelling we have attempted to establish a general level of support per MWh of output for each technology (where applicable), within each Member State. This is not a straightforward task as data is not presented in a consistent manner through the report.

Where the FIT represents the complete price paid for the supply of renewable electricity, we have to make an attempt to differentiate, for the purposes of our modelling (of both social and private metrics), between the element that is considered to be the standard price received for the electricity, and the element that is the support mechanism. To do this, we take the overall FIT, and strip out what we assume to be the wholesale price of electricity as described in A.6. Therefore, the remainder is treated for modelling purposes as the level of support. In a number of cases, however, the modelled price of electricity is greater than the stated feed-in tariff. In these instances, we model on the assumption that there is no extra support mechanism in addition to the price.

For the reasons outlined above, it is necessary to apply a certain amount of caution in the interpretation of the results in respect of renewable support mechanisms. In addition to the difficulties in interpreting the data, the very nature and level of support mechanisms in EU countries is in a considerable state of flux. The impact of the Renewable Energy Directive, setting even more ambitious targets for the proportion of electricity to be generated by renewables is sure to promote a revision of schemes across the EU.[21] The values used for the modelling are shown in Table A-8.

---

[19] ECOFYS, Fraunhofer ISI, EEG, Lithuanian Energy Institute and Seven (2008) *Renewable Energy Country Profiles*, February 2008

[20] It should be noted that effective quantification of support schemes for each EU Member State in terms of €/MWh for specific technologies would be a useful and not-insignificant research project.

[21] Directive 2009/28/EC. Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF

Table A-8: Levels of Support for Renewable Electricity for each Member State

Member State	**Renewable Electricity Support – Landfill Gas (€/MWh)**	**Renewable Electricity Support – Anaerobic Digestion (€/MWh)**	**Renewable Electricity Support – Combined Heat & Power (€/MWh)**	**Renewable Electricity Support – Incineration (€/MWh)**
AT	€ 0.00	€ 69.00	€ 0.00	€ 0.00
BE(Flanders)	€ 0.00	€ 0.00	€ 0.00	€ 0.00
BE(Wallonia)	€ 0.00	€ 0.00	€ 0.00	€ 0.00
BE(Brussels)	€ 0.00	€ 0.00	€ 0.00	€ 0.00
BG	€ 0.00	€ 0.00	€ 0.00	€ 0.00
CY	€ 0.00	€ 0.00	€ 0.00	€ 0.00
CZ	€ 0.00	€ 34.90	€ 0.00	€ 42.90
DK	€ 0.00	€ 0.00	€ 0.00	€ 0.00
EE	€ 38.00	€ 38.00	€ 38.00	€ 38.00
FI	€ 4.20	€ 4.20	€ 4.20	€ 4.20
FR	€ 0.00	€ 66.00	€ 29.75	€ 0.00
DE	€ 0.00	€ 69.60	€ 39.60	€ 0.00
EL	€ 0.00	€ 12.40	€ 0.00	€ 0.00
HU	€ 0.00	€ 10.33	€ 0.00	€ 0.00
IE	€ 0.00	€ 0.00	€ 0.00	€ 0.00
IT	€ 83.30	€ 83.30	€ 234.00	€ 0.00
LV	€ 0.00	€ 80.10	€ 0.00	€ 0.00
LT	€ 0.00	€ 0.00	€ 0.00	€ 0.00
LU	€ 27.10	€ 27.10	€ 0.00	€ 0.00
MT	€ 0.00	€ 0.00	€ 0.00	€ 0.00
NL	€ 0.00	€ 0.00	€ 0.00	€ 0.00
PL	€ 0.00	€ 0.00	€ 0.00	€ 0.00
PT	€ 0.00	€ 66.50	€ 0.00	€ 3.50
RO	€ 0.00	€ 0.00	€ 0.00	€ 0.00
SK	€ 0.00	€ 0.00	€ 0.00	€ 10.30
SI	€ 0.00	€ 0.00	€ 0.00	€ 0.00
ES	€ 49.00	€ 12.00	€ 0.00	€ 0.00
SE	€ 30.00	€ 30.00	€ 30.00	€ 30.00
UK	€15.42	€123.36	€ 0.00	€ 0.00

A.6.5 Levels of Support for Renewable Heat

As for renewable electricity, the approach to the support of renewable heat, where it exists, varies between Member States. Currently most national schemes to support renewable heat generation are in the form of investment subsidies rather than a production subsidy that could be expressed in terms of €/MWhth.[22] The available data is too sparse to provide any meaningful set of figures on an EU-wide level. However, for modelling purposes, it is arguably more important to understand the level of support in countries where there is existing relatively widespread use of heat, and where we might be seeking to model switches away from CHP incineration of biowaste. Even in these cases, however, it is not clear whether the price support is implicit in the price received for heat.

In Denmark, biomass based heat is exempt from CO_2 duty, which is set at a rate of €12/tCO_2. Therefore, for modelling purposes we assume a credit based on the carbon intensity of the displaced heating source, taken in this case to be the average heat generation mix in Denmark. This has a carbon intensity of 0.22 kg CO_2/kWhth, or 0.22 tCO_2./MWhth. This gives a credit of €2.64/MWhth. While these tax based incentives exist, a report for the UK Government considered that the key to Denmark's success lies in a well-designed legal framework (Heat Act 772) around which heat supply is mandated. [23]

In Sweden, there are no revenue incentives for renewable heat, but capital grants are available for extending district heating schemes and biogenic fuels are not subject to VAT. The success of the market is arguably due to the abundance of the wood resource and a planning regime that developed district heating schemes from the 1970s. [24]

A.6.6 Levels of Support for Biogas to Grid

The injection of biogas to the grid is a relatively new technological development, and the policy mechanisms have not yet been developed to any significant extent across the EU-27. It is expected that over the next few years there may be a significant increase in interest in this use of biogas, and that support mechanisms may well be forthcoming.

For direct injection of biogas to the grid, certain EU countries currently offer exemptions from excise taxes (e.g. Finland), while in other Member States, biogas is subject to the same degree of taxation as natural gas (e.g. France).[25] However, because of the relative novelty of this technology, it is not possible to provide any meaningful amount of data on support mechanisms.

A.6.7 Levels of Support for Biogas to Vehicle Fuel

As detailed in A.6.3 the upgrading of biogas for use as a vehicle fuel is a niche market, with operational examples in only a small number of EU Member States. Support mechanisms have generally not yet been developed to any meaningful extent, beyond the inclusion of biogas within broader tax exemptions for 'biofuels'. Accordingly, due to the sparcity of available data, we have not been able to include support for biogas as a vehicle fuel in the modelling.

---

[22] ECOFYS, Fraunhofer ISI, EEG, Lithuanian Energy Institute and Seven (2008) *Renewable Energy Country Profiles*, February 2008

[23] Ernst & Young (2007) Renewable Heat Support Mechanisms. A Report for Defra/BERR, 23 October 2007. Available at http://www.berr.gov.uk/files/file42043.pdf

[24] Ernst & Young (2007) Renewable Heat Support Mechanisms. A Report for Defra/BERR, 23 October 2007. Available at http://www.berr.gov.uk/files/file42043.pdf

[25] Eurogas Group of Experts in Energy Taxation (2008) *Energy Taxation in the European Economic Area*, as of 1st September 2008

A.6.8 Landfill Tax, Standard Rate

Landfill taxes have been introduced in a number of EU Member States. Most values were taken from previous research undertaken by Eunomia.[26] Further information was gathered from a variety of sources: EIONET;[27] CEWEP;[28] ETC/RWM;[29] and EEA.[30]

Lowest values correspond with Slovakia, Estonia and Catalonia (Spain), at 10 Euros or less. The Netherlands and Flemish/Walloon regions of Belgium have the highest landfill taxes, at 85 and 60 Euros, respectively.

These sources of information also highlighted certain countries that have not imposed a landfill tax. These are: Germany; Greece; Hungary; and Luxembourg. Information on countries such as Bulgaria, Cyprus, Lithuania, Malta, Poland and Romania is limited; their respective central governing bodies for the environment gave no indications that landfill taxes exist. The rates used in the modelling are shown in Table A-9.

Table A-9: Standard Rate Landfill Tax for Member States

Member State	Landfill Tax (€/tonne)	Member State	Landfill Tax (€/tonne)
AT	€ 8	IT	€ 26
BE(Flanders)	€ 60	LV	€ 0
BE(Wallonia)	€ 60	LT	€ 0
BE(Brussels)	€ 60	LU	€ 0
BG	€ 0	MT	€ 0
CY	€ 0	NL	€ 85
CZ	€ 16	PL	€ 0
DK	€ 50	PT	€ 19
EE	€ 8	RO	€ 0
FI	€ 30	SK	€ 8
FR	€ 9	SI	€ 19
DE	€ 0	ES	€ 0
EL	€ 0	SE	€ 43
HU	€ 0	UK	€ 50
IE	€ 15		

A.6.9 Landfill Tax, Lower Rate

In some Member States there is a lower rate of Landfill Tax for materials considered to be inert. For example, in the UK bottom ash from incinerators is currently considered to be inert and subject to a lower rate of tax. However, this is currently subject to a

---

[26] As per the Irish review of policy disposal taxes and bans document.

[27] EIONET website (2006) *Country specific factsheets*

[28] CEWEP (2006) *Landfill taxes and bans*

[29] ETC/RWM (2008) *Evaluation of waste policies related to the Landfill Directive*

[30] EEA (2007) *The road from landfill to recycling: common destination, different routes*

consultation, with the anticipated result being that the ash is liable to pay standard rate tax in the future. For the purposes of this modelling we work on the basis of a single, standard rate of landfill tax where applicable.

A.6.10 Incineration Tax

There are a small number of Member States where incineration taxes are imposed. These are listed in Table A-10

Table A-10: Incineration Taxes in EU Member States

Member State	Incineration Tax (€/tonne)
AT	€ 7
BE(Flanders)	€ 7
BE(Wallonia)	€ 3
DK	€ 44
SE	€ 49

A.6.11 Landfill Gate Fee, Hazardous

Some facilities generate a residue which is classified as hazardous. For the purpose of this study, we have not included a model, as such, of a hazardous waste landfill site. We have assumed, however, a cost per tonne of landfilling hazardous waste of €180 for all Member States.

A.6.12 Landfill Gate Fee, Non-hazardous

Where a treatment sends residues to non-hazardous waste landfill, the costs used are those modelled for the landfill as per the relevant price metric for the specific country.

A.7 Process-specific Assumptions

There are considerable challenges involved in determining representative capital and operating costs for all of the specific processes in one particular country. These difficulties are compounded when trying to establish representative costs for each of the EU-27. When making such inter-country comparisons it is not always clear whether different reports are actually comparing identical cost elements, and using these figures can therefore introduce large errors into the modelling.

The approach taken here is to establish the different process specific capital and operating costs for a baseline plant in a country that we consider to best represent the situation in Europe. From this baseline of process specific costs, the proportion represented by labour costs for both capex and opex is established. This element is then varied on a country by country basis according to the local wage levels, while the 'technology cost', i.e. the cost of purchasing the capital equipment is held constant for all countries, as these are traded within the European market.

The same approach is applied to the operational expenditure, with the technology element being held constant, and the labour element varied according to local wage relativities. Full details on this approach are given in Section B.

It must be noted that the following operating costs do not include the revenues from sales of compost or energy.

A.7.1 Open Air Windrow Composting

Open-air windrow composting schemes are relatively low-cost processes.

Eunomia suggested, in 2002, costs for open-air windrow facilities of €20 - €40 per tonne (net of compost sales) for low- and high-specification windrow facilities.[31] These figures are only marginally higher today.

AEA Technology examined the effects of scale on gate fees for open air windrow composting. These figures seem high, with gate fees supposedly never dropping below around £23 (€28.75) per tonne, even at a scale of 200,000 tonnes (which is more or less unprecedented for such facilities).[32] The AEA study gave no information on unit capital costs, even though the study sought to demonstrate economies of scale at different plant sizes.

Eunomia[33] has studied the capital and operational costs related to OAW facilities across Europe. Capital costs vary less across the plants than operating costs. France, for example, has reported operating costs between €4-€13 for a 12,000 tonne plant. The cost in Ireland is considerably higher at between €16 - €23. From this it is clear that there is a variation of operating costs across the EU 27. We have accounted for this by varying the cost of labour through indexation of labour costs (Section B.5).

We have modelled on the basis of a facility of the order 20,000 tonnes and have taken figures from previous studies undertaken by ourselves,[34] and inflated these to give a unit capital cost, including land, of €105 per tonne of throughput. We have tested this with industry representatives who have confirmed this as a sensible figure. We assume a lifetime of capital of 15 years.

Operating costs have been estimated at €6.50 per tonne of throughput before disposal of rejects. Annual maintenance costs are modelled as 3% of unit capital cost per tonne, which equates to €3.15/tonne.

For rejects, we have assumed 5% of input material has to be landfilled.[35] This is assumed to attract landfill tax at a standard rate.

The revenues from sales of compost are frequently ignored in studies assessing treatment costs. However, revenues from compost sales have the potential to increase in significance as energy prices increase. In most countries with more mature compost markets, as more material becomes available, so there tends to be more effort spent in marketing products, and refining them for specific end-use markets. This does not always translate into higher revenues. However, the revenues are likely to be higher as the costs of gas (and other energy sources) increases, with gas being a feedstock for synthetic nitrogen fertilisers.

ADAS reports a figure for the value of nutrients of the order £10 (€12.50) per tonne of compost.[36] A report for the Joint Research Centre shows average values for composts

---

[31] Eunomia (2002) *The Legislative Driven Economic Framework Promoting MSW Recycling in the UK*, Final Report to the National Resources and Waste Forum.

[32] AEA Technology (2007) *Economies of Scale – Waste Treatment Optimisation Study* by AEA Technology, Final Report, April 2007

[33] Eunomia (2002), *Costs for Municipal Waste Management in the EU: Annexes, Final Report to DG Environment, European Commission,* http://europa.eu.int/comm/environment/waste/studies/pdf/eucostwaste.pdf

[34] Eunomia (2002) *The Legislative Driven Economic Framework Promoting MSW Recycling in the UK*, Final Report to the National Resources and Waste Forum;

[35] In theory, one might suggest that this type of material could be used for other purposes. In practice, rejects from garden waste facilities tend to consist more of grit and stones, and to a lesser degree, materials associated with garden implements which find their way into the facility. The potential for, for example, energy recovery is less obvious with such reject streams.

obtained in different countries (see Table A-11). All of these are positive with median EU figures being between €0.6-€15.30 per tonne of fresh matter, adjusting for the anomalies of higher priced small bags. We have assumed a value of €3.50 per tonne of waste input for compost (equivalent to around €7 per tonne of compost, towards the mid range suggested in Table A-11.)

---

[36] See *'Compost lowering costs for farmers'*, accessed from letsrecycle.com, 10 July 2007, http://www.letsrecycle.com/do/ecco.py/view_item?listid=37&listcatid=217&listitemid=10069

Table A-11: Average Market Prices for Compost in Different Sectors (€/t per t f.m.)

Sector	**BE/FI**	**CZ**	**DE**	**Fi**	**ES**	**GR**	**HU**	**IE**	**IT**	**NL-bio**	**NL green**	**SE**	**SI**	**UK**	**EU Mean**
Agriculture (food)	1.1		14.0	0.0	27.0*	-	15.0	-	3.0	-4.0	2.0	0.0	-	2.9	**6.1**
vineyards, orchards	1.1	-	-	-	-	-	-	-	12.0	-	-	-	-	2.9	**5.3**
Organic farming	1.1	-	-	-	-	42.0	-	-	-	-	-	-	-	2.9	**15.3**
Horticulture & green house production	1.1	-	15.0	-	-	42.0	-	-	-	-	-	-	-	2.9	**15.3**
Landscaping	2.5	4.5	15.0	2.0	-	-	18.0	-	25	4.0	-	-	-	6.5	**9.7**
Blends	1.1$^{2)}$	-	-	2.0	-	-	-		-	3.5	-	-	-	2.9	**2.4**
Blends (bagged$^{1)}$)	-	-	-	-	-	-	-	90.0	200.0	-	-	-	-	-	**(145)**
Soil mixing companies	1.1	-	-	2.0	-	-	-	-	-	-	-	-	-	6.5	**3.2**
Wholesalers	1.1	-	-	-	-	-	-	-	-	-	-	-	12.0	-	**6,6**
Wholesalers (bagged$^{1)}$)	-	-	160.0	-	-	-	-	-	-	-	-	-	-	-	**(160)**
Hobby gardening	7.2	4.5	-	10.0	-	-	20.0	-	13.0	0.3	-	-	21.0	20	**12.0**
Hobby gardening (bagged$^{1)}$)	-	-	-	-	-	300.0	-	-	-	-	-	-	-	-	**(300)**
Mulch	-	-	-	-	-	-	-	-	-	-	-	-	-	3.6	**3.6**
Land restoration, landfill covers	1.1	-	-	0.7	-	0.0	-	-	-	-	-	-	-	0.7	**0.6**

$^{1)}$ High prices because sold in small bags (5 to 20 litres)

$^{2)}$ Price for compost when sold to the substrate producer!

Source: J. Barth, F. Amlinger, E. Favoino, S. Siebert, B. Kehres, R. Gottschall, M. Bieker, A, Löbig and W. Bidlingmaier (2008). Compost Production and Use in the EU. Report for the European Commission DG/JRC.

A.7.2 In-vessel Composting (IVC)

IVC systems come in various shapes and sizes. They can be vertical or horizontal. Unit capital costs depend upon, for example:

- Scale of facility;

- Nature of process used (and the degree to which the process is managed through 'fixed capital' rather than mobile equipment);
- Materials treated;
- Nature of exhaust air treatment; and
- Time spent in the intensive and maturation phases.

Typically capital costs have been relatively low (of the order €190 per tonne of capacity). However, there might be reasons to expect these to be somewhat higher in cases where:

- The food waste component is higher, giving rise to a need for more thorough management of the input materials (notably to ensure adequate structural material is present through mixing), requiring more expensive treatment of exhaust air;
- Concerns regarding odour are expected to be significant, again affecting exhaust air treatment.

Jacobs suggest a figure for capital costs of £146 (€182.50) per tonne for a 30,000 tonne plant.[37] An EEA report[38] from 2002 indicates that capital costs will vary significantly as the scale increases. For a 30,000 tonne plant a capital cost of €100 per tonne is estimated. This, however, is low as the study includes open air and enclosed composting facilities. We have used a figure of €205 per tonne. It should be noted that some systems are relatively more costly (in terms of capital commitment) than others. We assume a lifetime of capital of 20 years.

For operating costs, Jacobs suggest a figure of £18 (€22.50) per tonne at a 30,000 tonne plant. This is considered to be higher than the industry average. We have used a figure of €12.50 per tonne. Maintenance is taken to be 5% of capital costs, at €10.25/tonne.

We assume rejects are 5% of input material and that these are sent to landfill where they attract landfill tax at the standard rate.

As with open-air facilities, we have attributed to compost a revenue of €3.50 per tonne.

A.7.2.1 Ammonia Scrubbing

There is potential for GHG abatement through the use of scrubbers before biofilters at in-vessel compost plants

The costs of the scrubber relate to the volume of air-flow through the scrubber. For a 20,000 tonne per annum plant, the airflow would be, at a maximum, around 40,000 m^3/hr. A suitable scrubber with circulation pump, tank for sulphuric acid and tank for ammonium sulphate would cost of the order €125,000 including additional piping (somewhat less – €87,500 or so - for the scrubber alone). We therefore model on the basis of a capital cost of €6.25/tonne. Operating costs associated with electricity use, use of concentrated sulphuric acid, use of water, maintenance, and management of residue (ammonium sulphate) have been estimated at €1.55 per tonne of waste input.

A.7.3 Anaerobic Digestion

Like IVC systems, AD facilities come in different shapes and sizes. Most digesters have vertical tanks, but some are horizontal. Mechanisms vary considerably and a number of patented processes exist. Processes may:

---

[37] Jacobs (2008) *Development of a Policy Framework for the Tertiary Treatment of Commercial and Industrial Wastes: Technical Appendices*, Report for SNIFFER / SEPA, March 2008.

[38] EEA (2002) *Biodegradable municipal waste management in Europe: Part 3 Technology and market issues*, available at: http://www.eea.europa.eu/publications/topic_report_2001_15

- Operate at high or low solids content;
  Wet digestion processes are carried out at a Total Solids (TS) content of no more than 15% by weight, most commonly within the range of 7-12% TS. Usually, water must be added to the feedstock at the slurrying stage to dilute the waste (organic materials range from 10-30% TS). Mixing in process tanks can be achieved by mechanical mixers within the tanks, or by gas mixing, using recirculated biogas, if TS in the digester is below 10%. Most wet digestion processes use a completely mixed reactor.
  Dry digestion processes are carried out at a Total Solids (TS) content of over 15%, with 25-40% being the most common TS range. This material is too thick for liquid-handling pumps, and therefore dry digestion technologies use concrete pumps and screw conveyors. Mechanical and gas mixing equipment cannot usually handle the high solids concentrations of dry digestion, and therefore mixing is achieved by the configuration of the digester and recirculation of waste through the digester. The tank is usually a plug flow reactor, rather than a completely-mixed reactor as normally used in wet digestion.
- Operate at mesophilic or thermophilic temperatures;
  AD can function over a large range of temperatures from so-called psychrophilic temperatures (around 10 ^{o}C) to extreme thermophilic temperatures (>70^{o}C). Temperature influences the speed (kinetics) of anaerobic reactions. In particular, methanogenesis is affected by temperature, with rates and yields increasing with temperature. Reactor temperature affects not only the reaction velocities of physico-chemical processes, but also, biochemical conversion rates.
  The average value of temperature over a long time period fixes the bacterial population thus defining the two major groups of micro organisms. These are usually classified in association with two temperature ranges, around 35^{o}C in the mesophilic range (25^{o}C-40^{o}C), and around 55^{o}C (45^{o}C-65^{o}C) in the thermophilic range. A variation of reactor temperature within the specified ranges can change reaction velocity.
  The vast majority of digestion, especially of OFMSW, is carried out in these two temperature ranges. In the year 2000, more than 60% of capacity for treating municipal-type waste was in the mesophilic range with thermophilic accounting for just less than 40%;[39]
- Be one- or two- stage in nature;
  As investigations concerning anaerobic digestion have proceeded, concerns regarding inhibitors of the reaction process, and as to what might be the rate-limiting step in the process have given rise to processes which, rather than occurring in one tank, are carried out in separate reactors in more than one stage. The rationale for this is that the conversion of organic wastes to biogas is mediated by a sequence of reactions which are not necessarily optimized under the same conditions. Typically, two stages are used in which the first harbours the liquefaction-acidification reactions (with a rate limited by the hydrolysis of cellulose) and the second harbours the acetogenesis and methanogenesis, the rate of which is limited by the slow microbial growth rate. If the stages occur in separate reactors, the rate of methanogenesis can be enhanced through biomass retention schemes (or other means) whilst the rate of hydrolysis can be speeded up through

---

[39] L. De Baere (2000) State of the art of Anaerobic Digestion of Solid Waste in Europe, *Water Science and Technology*, Vol.41, No.3, pp.283-90.

using microaerophilic conditions.
Various reactor designs have emerged over time. However, although in theory, the design of multi-stage systems should improve performance, in practice, the main advantage appears to be reliability in treating wastes which exhibit unstable performance in single-stage systems. Amongst these more problematic materials are those with very low C/N (Carbon/Nitrogen) ratios, such as market / wet kitchen wastes. Hence, Bernal et al observed that, under thermophilic conditions, if the feedstock has high biodegradability (as with market wastes), the rate of acidogenesis may create more acids than can be converted by methanogenesis, affecting the stability of the process.[40] This problem could be overcome by using separate reactors. Yet the comparative disadvantage which single stage systems have in this regard can be overcome by co-digesting these more problematic wastes with other materials, biological reliability being improved by buffering and mixing. Hence, multi-step processes still account for only 10% or so of the market for digesters dealing with solid wastes; and

- Be continuous or batch processes.
  Most systems are continuous systems. Batch systems are usually simply filled with fresh wastes (with or without seed material) and are allowed to go through all stages of degradation in the dry phase. Sometimes described as being akin to 'landfill in a box', these systems generate much more biogas than landfills because of the continuous recirculation of leachate (effecting a partial mixing through distribution of inoculant, nutrients and acids) and the higher temperature of operation.

For all configurations detailed below, we assume a lifetime of capital of 15 years.

A.7.3.1 AD with Electricity Only

This technology is not prevalent across the EU member states. There have, however, been some reviews of the costs of anaerobic digestion in Europe. A recent study found considerable variation in costs across different technology suppliers. The reader is referred to the full report for details and to our earlier review.[41]

Greenfinch gave figures for capital costs of £4 (€5) million for 20kt, and operating costs of £20 (€25) per tonne including rejects, but before revenues.[42] These are likely to be lower costs than would be realizable under a contractual situation. Capital costs for AD facilities used to deal with household, or industrial food wastes (and other biowastes) tend to be of the order €312 - €437 per tonne depending upon scale and the nature of the facility.

In a feasibility study for Northern Ireland, suppliers were asked about the capital costs for facilities of given sizes.[43] The results are shown in Table A-12. It can be seen that the capital costs vary enormously, rather more for a given scale plant than the operating costs. This, combined with the different ways of treating capital costs, makes it difficult to generalize concerning the costs of digestion plants. Particularly when dealing with source segregated fractions of municipal waste, digesters tend to be more or less heavily

---

[40] O. Bernal, P. Llabres, F. Cecchi and J. Mata-Alvarez (1992) A Comparative Study of the Thermophilic Biomethanization of Putrescible Organic Wastes, *Odpadny vody / Wastewaters,* Vol. 1, No.1, pp.197-206.

[41] Leif Wannholt (1999) *Biological Treatment of Domestic Waste in Closed Plants in Europe - Plant Visit Reports*, RVF Report 98:8, Malmo: RVF. Hogg et al (2002) *Costs for Municipal Waste Management in the EU*, Final Report to DG Environment, European Commission.

[42] Greenfinch (2003) *Presentation by Greenfinch Ltd Based on Anaerobic Digestion: City Solutions Day*, New & Emerging Technologies for Waste, February 2003.

[43] Eunomia (2004) *Feasibility Study Concerning Anaerobic Digestion in Northern Ireland,* Final Report for Bryson House, ARENA Network and NI2000.

engineered to deal with potential contraries. In addition, post-digestion processes vary across suppliers.

Table A-12: Key Financial Data for Digestion Plant (rounded to the nearest €)

CAPACITY	10,000	20,000	25,000	50,000	50,000	50,000	75,000	165,000
Total Investment Cost	4	4	16	8	22	20	20	25
Unit Investment Cost	391	188	634	150	440	400	267	152
Unit Operating Cost	34	25	25	23	20	35	28	28

A Juniper report invited offers for a mock facility treating 30,000 tonnes of food waste and 10,000 tonnes of slurry. The figures obtained from respondents using extensive pre-treatment were, adjusting for recent movements in the exchange rate, of the order €5.25-€6.25 million (or €175 – 209 per tonne capex if one considers the food only[44]). The operating costs were quoted as €425,000, or around €14 per tonne. We assume these are net of revenues from energy sales since they are so low.[45]

One can see, therefore, a very wide variation in the capital cost figures being quoted, and the variation cannot be explained by appeal to factors such as scale alone, partly because of the variety of technical designs on offer.

We have used a figure of €375 for unit capital costs. For operating costs, we have good reason to believe that if one is seeking a figure before revenue generation from energy sales, and disposal of rejects, the figures above are all too low. We have used a figure of €37.50 per tonne. We believe this to be representative of facilities of scale 20-30,000 tonnes capacity, with appropriate post-treatment of the digested biowaste.

A.7.3.2 AD with CHP

The issue of CHP is discussed in this document with regard to both thermal facilities and AD facilities. Where thermal facilities are concerned, and where steam turbines are used to generate energy, there is a trade-off between the generation of electricity and the generation of heat. AD systems usually generate energy using gas engines. Where gas engines are concerned, the generation of heat incurs little penalty in terms of electricity generation, and the majority of facilities operate CHP engines, partly to ensure the provision of free heat which is needed to keep the feedstock at the required (mesophilic or thermophilic) temperature, as well as providing heat for hygienisation of the feedstock in the wake of the EU Animal-by Products Regulations.

The likelihood that:

- AD facilities will be operated at smaller scale than incinerators;
- the total heat delivered is likely to be less than in what may be larger incinerators; and
- the fact that CHP units are likely to be used to generate energy anyway,

---

[44] The slurry was deemed to have only 5% solids content so only 5% or so of the solids would be in the slurry.

[45] Juniper (2007) *Commercial Assessment: Anaerobic Digestion Technology for Biomass Projects*, Report for Renewables East, June 2007.

makes it more likely that, where AD is concerned, heat use may be more possible, and may be possible on a more opportunistic basis. It also implies that at least as far as generation equipment is concerned, the incremental costs are low (close to zero). In addition, the associated costs of infrastructure for delivering heat may be lower in a given area (as fewer end users would need to be served).

The relatively small number of publicly available studies that have looked at the issue of CHP generation have tended to support the view that where thermal facilities are concerned, effective utilization of CHP is likely to be predicated upon district or community heating schemes. Where AD is concerned, this is less likely to be necessary. AEA argue that where sewage treatment works are concerned:[46]

> *'the option of heat recovery for additional heat (over and above what is required for the process) is generally not implemented as the value is low, there are limited opportunities for use on site (occasionally there are some works offices) and the cost of sale to other customers is too high as they will seldom be in close proximity to the water treatment works.'*

They estimate the cost of the pipes and trenching to be of the order £1 (€1.25) million per mile of trench.

For AD, an indication of the sort of differential between CHP and non-CHP configurations was given by Jacobs, who suggest that for a 40,000 tonne plant, the capital costs increase from £10.62 (€13.68) million to £11.48 (€14.35) million, or from €332 to €359 per tonne of annual throughput. The operating costs were estimated to remain constant.[47]

In this study, we have estimated capital costs for the useful deployment of CHP of an additional €2.06 million in capital terms for a 20,000 tonne per annum facility. This lies between the Jacobs estimate and that implied by Ilex[48] (see Section A.7.5.2) for a heat network. We have also added €1.50 per tonne to the operating costs. Evidently, this must be treated as an estimate, and the specifics will vary with the location and local opportunities for heat use of any given plant.

Therefore we have modelled a capital cost of €478 per tonne, and an operating cost of €38.75 per tonne.

A.7.3.3 AD with Gas Upgrading for Use as Vehicle Fuel

The costs of gas upgrading tend to be expressed relative to the flow rate of biogas into the cleaning process. A number of different processes exist for cleaning up biogas (mainly for CO_2 removal, but also for scrubbing of H_2S), including chemical absorption, pressure swing adsorption, water scrubbing, and membrane separation. These processes are developing in terms of their energy use per unit of gas cleaned, and the extent to which methane is lost in the process. The aim, evidently, is to improve process efficiency without adding significantly to cost.

Much of the information offered is in terms of the cost per unit of gas cleaned, or per unit of energy in biogas delivered. However, this is not especially useful for this study as we are seeking information of the change in capital cost at the AD plant, as well as in the operating cost. It is important in this regard to note that biogas upgrading is not simply an additional cost. If the intention is to make use of biogas as vehicle fuel, there are savings

---

[46] AEA Energy and Environment (2008) *The Evaluation of Energy from Biowaste Arisings and Forest Residues in Scotland*, Report to SEPA, April 2008.

[47] Jacobs (2008) *Development of a Policy Framework for the Tertiary Treatment of Commercial and Industrial Wastes: Technical Appendices*, Report for SNIFFER / SEPA, March 2008.

[48] Ilex Consulting (2005) *Eligibility of Energy from Waste – Study and Analysis*, Final Report to the DTI, March 2005.

to be made in terms of the avoided cost of CHP generation, and of connection to the electricity grid.

SLR estimate costs for a packaged gas engine generator set, up to about 1MWe, installed in a container ready for connection to the site switchboard, at about €750/kW (with costs per kW falling thereafter to €562-€625/kW).[49] For a 20-30,000 tonne plant, the generation is of the order 1MW, with associated capital costs of around €750,000. However, as the facility would still make use of a gas engine for heat and power, albeit a smaller gas engine, to power the process and keep the feedstock at the required temperature, any saving on CHP generation would be a proportion of the €750,000 figure. We estimate an avoided cost of €250,000 for a 20,000 tonne plant.

AEA notes:

The costs of connection local to the generation project will be borne by the developer of the biowaste project. These costs will include:

- Works on the site of the generation (e.g. new transformers, switchgear etc).
- *Any new or upgraded cable (over or underground) from the biowaste site to the nearest suitable connection point on the network.*
- *Additional or upgraded transformers and switchgear at the connection point.*

The size of the generator, the distance to the connection point and the voltage level at which the connection for connection will determine the scale of costs for the local connection. The costs of additional or upgraded transformers and switchgear at the connection point will depend on the level (if any) of unused capacity on the existing grid equipment.

For grid connection, the costs of connection and overhead lines will be specific to a given project. SLR suggests the following figures for 11, 33 and 132kV connections and overhead lines, in thousands of pounds, converted to euro using the long term exchange rates:

- 11kV Grid connection equipment: €25 - €75;
- overhead line: €18.72 - €37.5/km;
- 33 kV Grid connection equipment: €150 - €187.5;
- overhead line: €25 - €43.75/km;
- 132 kV grid connection equipment: €1,000 - €1,250.

They also note that in addition to these figures, the time taken to get permission to connect to the grid can be important.

Small generation projects will be connected to the lower voltage distribution network. For a 20,000 tonne plant, generating some 0.5-0.75 MW electricity, an 11kV connection should suffice. Taking into account cabling costs (which are variable depending upon distance from the grid), we estimate a total fee to be of the order €187,500.

For gas upgrading, the unit costs fall as the flow rate into the clean-up system increases. This is shown in Figure A-2. The implications for unit costs (under specific assumptions regarding the cost of capital and the investment life-time) are shown in Figure A-3.

In our estimation, a 20,000 tonne plant, operating for around 7,500-8,000 hours per annum, would be expected to generate around 400m^3 of biogas per operating hour.

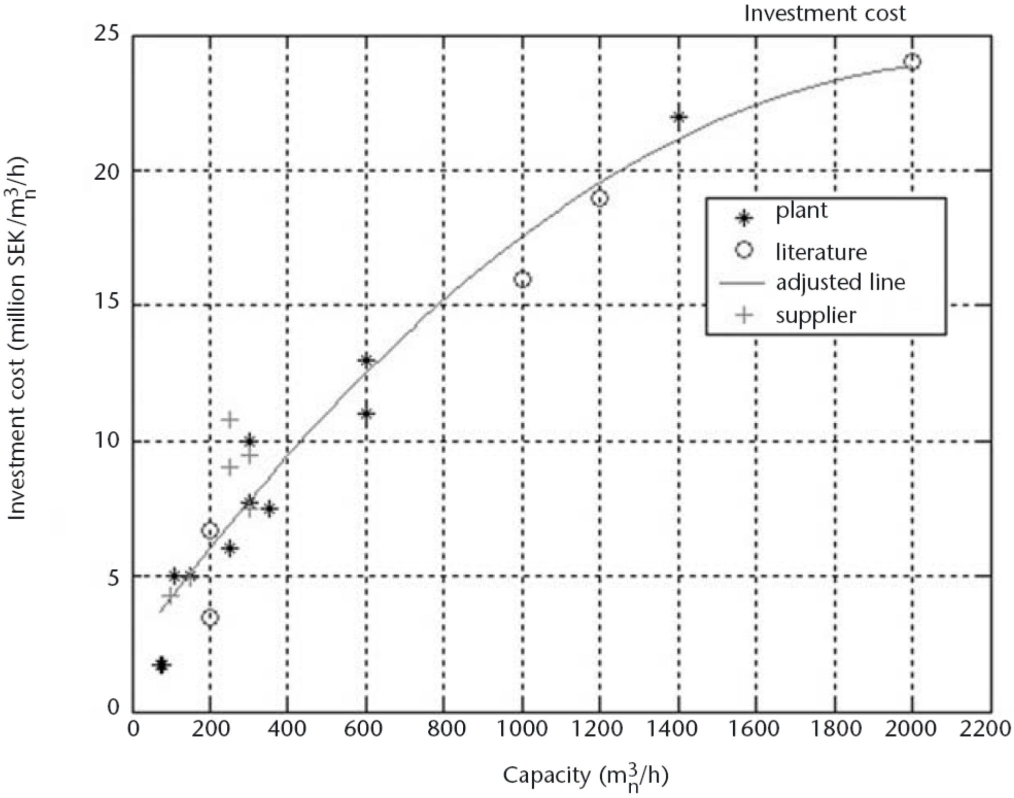
---

[49] SLR (2008) *Cost of Incineration and Non-incineration Energy-from-waste Technologies*, Report to the Mayor of London, January 2008.

A report by the Institut Catala d'Energia (ICAEN) gave figures, which appear to be 2004 figures, of €600,000 for capital costs, and operating costs of €80,000 per annum, for pressure swing adsorption processes.[50] More recent figures from a Fraunhofer UMSICHT report gives figures for gas cleaning for different processes. At the throughputs we are interested in, investment costs are of the order €1.32 – €1.4 million. Operating costs were €327,000 – €336,000.[51]

We use an average of the Fraunhofer figures. This results in a capital cost of €1.36 million euro (around €68 per tonne) and operating costs of €331,500 million (around €16.50 per tonne). In addition to these costs, we have added a cost for pipework of €375,000 (€18.75 per tonne). This reflects figures for 5km of pipework given by Schulz[52] and for a plant in Uppsala reported in an earlier study by Eunomia et al Table A-13.

Figure A-2: Investment Cost for Biogas Clean-up as a Function of Capacity (m^3/hr)



Source: O. Jonsson and M Persson (2003) Biogas as a Transportation Fuel, Session 1, FVS Fachtagung 2003

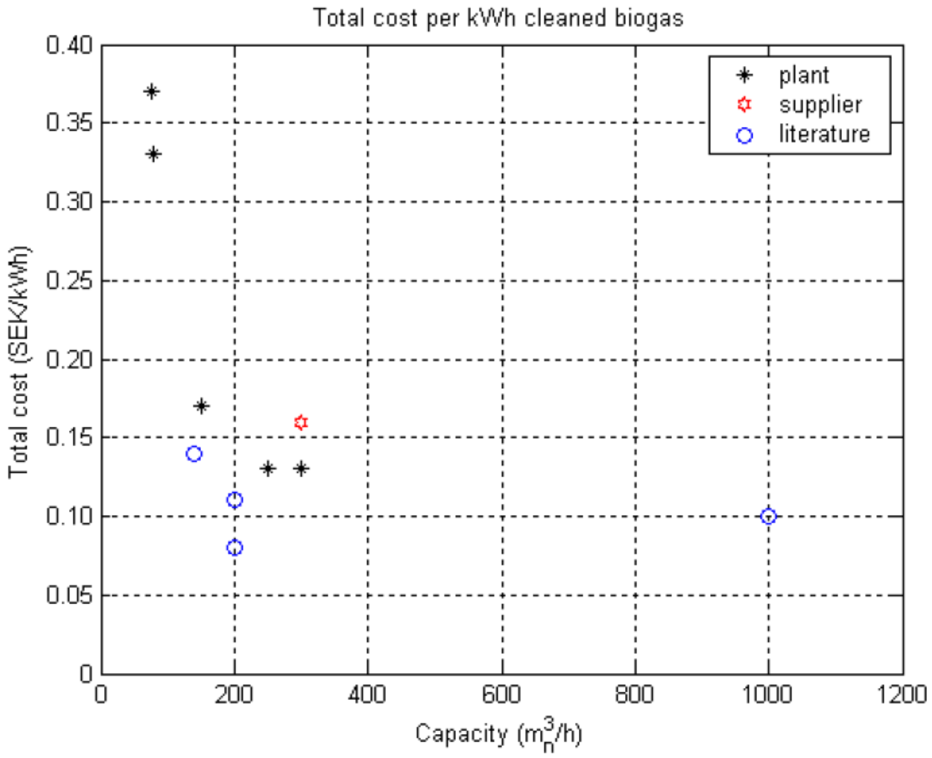
Figure A-3: Cost per kWh of Cleaned Biogas as a Function of Plant Capacity

---

[50] ICAEN (2004) Economic Framework Report, Deliverable for the Altener Project Regulation Draft of Biogas Commercialisation in Gas Grid – BIOCOMM, 2004.

[51] Fraunhofer UMSICHT (2008) Technologien und Kosten der Biogasaufbereitung und Einspeisung in das Erdgasnetz. Ergebnisse der Markterhebung 2007-2008, report for the Bundesministerium fur Bildung und Forschung, April 2008.

[52] W. Schulz (2004) *Untersuchung zur Aufbereitung von Biogas zur Erweiterung der Nutzungsmöglichkeiten*, Bremer Energie-Konsens GmbH



Source: Margaretta Persson (2007) Biogas Upgrading and Utilization as a Vehicle Fuel, Paper presented to the European Biogas Workshop, The Future of Biogas in Europe III, 14th June 2007

Table A-13: Costs of Anaerobic Digestion Facilities

	Uppsala	**Linköping**
	30 000 tons/year	100 000 tons/year
Capital cost – digestion plant	€ 6 000 000 (1997)	€5 900 000 (1996)
Capital cost – gas cleaning and compression	€ 850 000 (1997)	€2 800 000 (1996)
Capital costs –piping	€ 330 000 (1997)	€550 000 (1996, 5 km piping)
Variable costs/year	€ 220 000	€ 200 000 – 400 000

Source: Uppsala municipality and Linköping municipality, cited in Eunomia et al (2002)

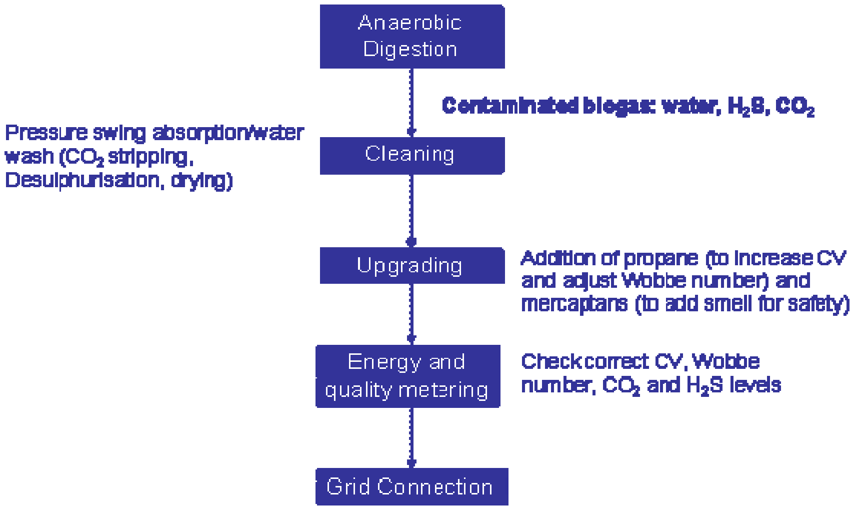
The additional capex, relative to generation of electricity only, for a 20,000 tpa plant is €1.36 million plus €375,000, giving £1.73 million. Savings associated with avoided costs of grid connection and a smaller gas engine are £187,500 and €250,000 respectively, totalling €437,500. Net increase in capital cost is therefore €1,297,500, which for a 20,000 tpa facility gives an increased unit capex of €65/tonne. This gives a total capital cost of €440 per tonne.

For operational costs we have added €16.50 per tonne, but subtracted €8 to take account of maintenance costs that we understand are included in the Fraunhofer figures. As for all processes, we calculate maintenance separately based on a proportion of the capital cost. For AD with gas upgrading for vehicle fuel these total €22 per tonne per annum. We have subtracted a further €2 to account for a reduction in opex for the smaller CHP plant. This gives total opex of €45.25/tonne.

A.7.3.4 AD with Gas Upgrading for Use in Grid

To inject gas into the gas grid the gas must be cleaned, upgraded, metered and then connected to the grid. Figure A-4 explains the pathway of biogas to grid injection.

Figure A-4: Biogas injection to grid



Source: Enviros (2008) Barriers to Renewable Heat: Analysis of Biogas Options, prepared for BERR

The capital cost of upgrading an anaerobic digestion plant for use in the national grid as electricity from a 2008 Canadian study[53] suggests that total capital costs are in the region of $2.130 (€1.52) million, €275 per tonne. Eight operational anaerobic digesters that transfer biogas to the national grid for use as electricity were examined and an average of these has been assessed. The result applies to a plant which produces 240 nm3/h (approx 6,000 tonne capacity). The operating expenditure for the average plant is assumed to be $322,492 (€230,000) per year, including debt service. The Swedish sewage treatment facility, Bromma, is estimated to have an operational expenditure at €260,000 in 2006 prices[54].

The upgrading and cleaning of biogas for use in the national grid has different requirements related to the cleaning of the gas in each of the EU 27, and occasionally these requirements vary within a country. The variation applies to the standard of the gas that is required in a gas network. Standards for injection into the gas grid are not agreed across the E.U. Within France, for example, there are two types of gas. In the South H gas is available, with an energy content similar to that in Swedish upgraded biogas. The North of France, B gas is available which comes from the Netherlands network and has a higher energy content[55].

The standards applied to the injection of biogas to the grid are expected to drive the cost of the upgrade. In Sweden the cleaning required for biogas is the same for vehicle fuel

---

[53] Electrigaz Technologies Inc. (2008) Feasibility Study – Biogas upgrading and grid injection in the Fraser Valley, British Columbia

[54] Persson, Wellinger. A., and Hugosson, B (2007) *Report on Technological Applicability of Existing Biogas Upgrading Processes,* available at:

[55]

and injection into the grid, as the same standard applies to both[56]. In the UK a regulatory barrier exists due to the oxygen content of pipeline gas which is currently too low to include renewable gas[57]. Propane is also added to the gas in order to improve the Wobbe index[58] rating of the gas. France also has similar restrictions relating to the level of oxygen in the gas injected into the grid. In Germany the hydrogen must be <5% volume, as opposed to <12% in natural gas[59]

We have assumed that the cost of upgrading for use in the grid is similar to that of upgrading for vehicle fuels. This is due to insufficient data to assume otherwise as it has the technology is not yet available in many of the EU 27 countries.

A.7.4 Landfill

The landfill model is broken down into:

- The capital costs for the site.

  Evidently, these may vary in unit (i.e. per annual tonne treated) terms depending upon the size of the site. We have modelled on the basis, broadly, of:

  - A fill rate of 250,000 tonnes per annum and a lifetime of 12 years;
    Of course, fill rates and life times vary, as will the total available void of a given site. This was felt to be broadly representative of a modern site, or extension;
  - Capex, including site assessment, acquisition, site development, restoration and aftercare, is modelled at €145 per tonne of material accepted at the site each year (in other words, the landfill is being treated as a facility with a 250,000 tonne throughput, with capex of €145per tonne of that annual throughput);
  - We acknowledge that site acquisition is a large factor in determining the capital cost of a landfill, and that these costs vary across the EU. In order to vary the capital expenditure of landfill we have examined the labour element, which has been indexed across the EU. This was deemed not to be possible for land costs.
- Operating costs are estimated at €8.75 per tonne, before revenues from energy generation, whilst restoration, post-closure and aftercare are estimated to cost a further €8.75 per tonne;
- Landfill tax is included or excluded depending upon the cost metric being used. In the social cost metric, it is not included in the costs.

It should be noted that where a *specific* material is being ‘switched’ from landfill to another process, the model picks up the relevant energy generation associated with that material.

---

[56] Persson, M., Jonsson, O. And Wellinger, A. (2007) *Biogas Upgrading to Vehicle Fuel Standards and Grid Injection,* IEA Bioenergy

[57] National Grid (2009) *The potential for Renewable Gas in the UK,* available at: http://www.nationalgrid.com/NR/rdonlyres/9122AEBA-5E50-43CA-81E5-8FD98C2CA4EC/32182/renewablegasWPfinal1.pdf

[58] The Wobbe index is a performance standard that refers to the quality of a fuel gas and measures the interchangeability of gases when used as fuel

[59] Altener (2002) *Regulation Drafe of Biogas Commercialisation in Gas Grid*, BIOCOMM Project 4.1030/C/02-082/2002

A.7.5 Incineration

Quotes from public sources are given in Table A-14. This table has been converted to euro prices at the relevant exchange rate. It can be seen that even the same source quotes different costs in public. This merely serves to highlight the paucity of good, publicly available information, as well as the dependence of costs on issues unrelated to the plant itself. The costs of such facilities are sensitive to planning risks, and the nature of the procurement process.

There are three incinerators modelled in this study. These are:

- An incinerator delivering electricity only;
- An incinerator delivering combined heat and power (CHP);and
- An incinerator delivering heat only.

We begin by describing the basic configuration which is the first one above. We then comment on changes from this baseline model. For all configurations we assume a lifetime of capital of 20 years.

Table A-14: Publicly Quoted Sources of Incinerator Cost Information

	Capacity (kt)	**Capex (€ mn)**	**Capex Average (€ mn)**	**Opex (€/t)**	**Opex Average (€/t)**	**Gate Fee (indicative) (€/t)**
McLanaghan (SU)	63	16-24	20	44-67	56	
	125	31-45	35			
	188	48-56	51			
	250	50-73	59			
	500	91-125	109			
	625	100-131	116			
AEAT (North London)	563	104				31
	338	77				38
AEAT (EA) (elec only)	125	44		30		
	250	66		28		
	500	113		21		
AEAT (EA) (CHP)	125	51		33		
	250	79		30		
	500	133		23		
Enviros (London Costings)						63-75

Note: AEAT capex figures exclude costs of land, and gate fees exclude costs of dealing with residues.

Sources: S. McLanaghan (2002) Delivering the Landfill Directive: The Role of New and Emerging Technologies, Report for the Strategy Unit, 0008/2002; AEAT (1999) Waste Pre-treatment: A Review, Agency R & D Report Reference No PI-344/TR; Enviros (2003) Costing the Mayor's Waste Strategy for London, Report for the GLA, September 2003.

A.7.5.1 Electricity Only

The incineration model is broken down into:

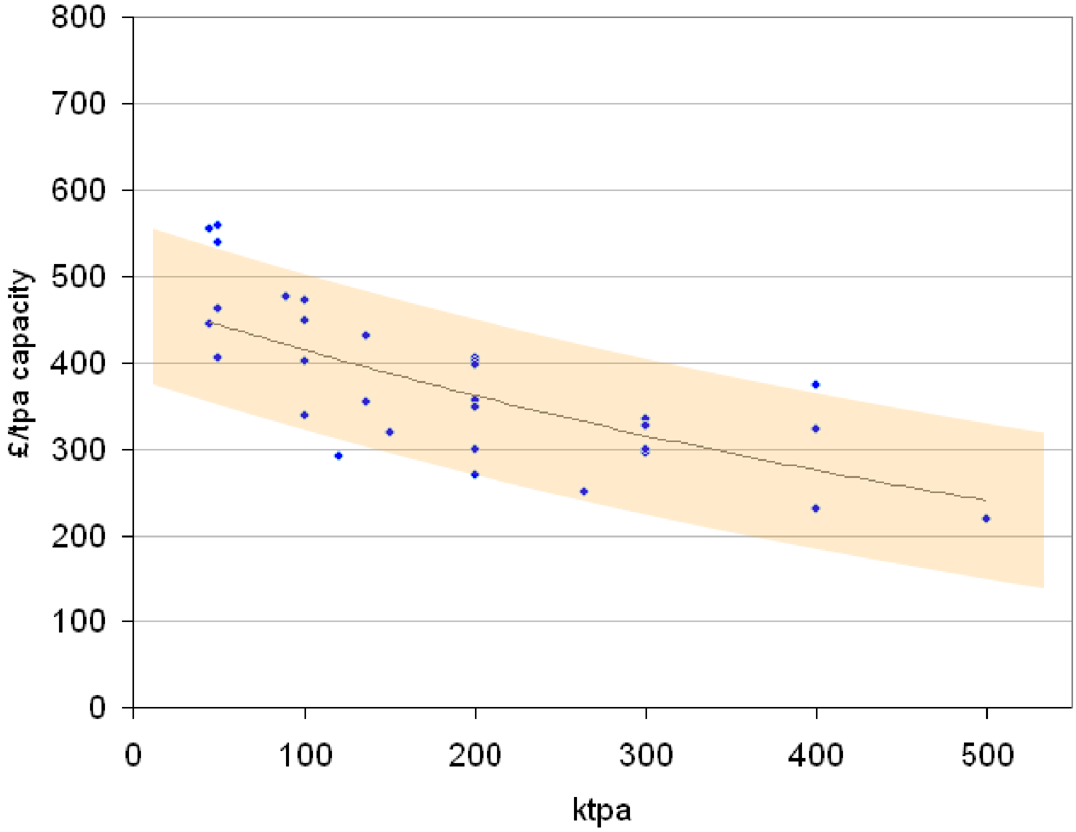
- A capital cost element:
  Unit capital costs could be quite variable in any given situation and would depend upon scale, the nature of risk transfer, the detailed plant design, the requirements in terms of architecture, the nature of the flue gas cleaning technology etc. Quoted figures do not always include the costs of land, especially now that local authorities are encouraged to acquire sites. The figure we have chosen is felt to be broadly representative of a plant of the order 200,000 tonnes capacity. There are likely to be some larger facilities constructed, but some smaller ones also. Ilex used a figure, in 2004 prices, of €73.25 million for a 200kt plant.[60] SLR looked at plants already built and found that capital costs varied with scale as in Figure A-5. Jacobs suggest a figure of £86.5 (€108.1) million for a 250,000 tonne facility, though this seems low relative to the same company's estimates in the context of a recent procurement in Leeds (see below). [61] Given the recent cost inflation in construction projects, these figures are probably rather low for new-build facilities.

---

[60] Ilex Consulting (2005) *Eligibility of Energy from Waste – Study and Analysis*, Final Report to the DTI, March 2005.

[61] Jacobs (2008) *Development of a Policy Framework for the Tertiary Treatment of Commercial and Industrial Wastes: Technical Appendices*, Report for SNIFFER / SEPA, March 2008.

Figure A-5: Variation in Capital Cost with Scale



Note: £/tpa refers to the "capital cost per tonne of waste treated"; ktpa refers to "thousands of tonnes of waste treated per annum

Source: SLR (2008) Cost of Incineration and Non-incineration Energy-from-waste Technologies, Report to the Mayor of London, January 2008.

Fichtner, looking at a one-line 182kt plant, considered that capital costs would be of the order £77.2 (€96.5) million, excluding land acquisition, costs of grid connection, and legal and advisory services, increasing to £98.6 (€123.25) million where the plant had two lines. For all costs, including contingency, but excluding land acquisition, the figure was £87.25 (€109.1) million. However, a key factor for incinerators and other capital projects, is the effect of inflation. Particularly in recent years, the costs of construction and of material have run ahead of conventional indices of inflation. The indexation cost implied for this project owing to inflation over the construction period was £26.5 (€33.1) million.[62] This inflation figure appears to be a figure quoted for increases in prices in nominal, terms rather than real terms. For the purposes of the analysis, we have assumed capital costs today would be of the order €118.75 million, with the real effects of indexation likely to be of the order €18.75 million. Examination of a Dutch facility shows a capital cost of €436 million euro for a 648kt plant[63]. We have used a figure of €137.5 million capex, or €625 per tonne;

- Operating costs:
  For operating costs, before revenues from electricity generation and costs of dealing with residues, we have used a figure of €25 per tonne ;

---

[62] Fichtner (2007) *Jacobs Leeds Energy-from-Waste: Validation of EFW Costs*, 7 September 2007.

[63] Dijkgraaf, E., Aalbers, R.F.T., Varkevisser, M. (2001) *Effects of open national borders on wast incineration: The Netherlands*, Prepared for the 2nd Annual International Management Waste-to-Energy 2002

- Revenues from electricity generation are estimated on the basis of net delivered energy (calculated from the environmental analysis);
- Revenues from energy subsidies are examined in Sections A.6.4 to A.6.7.
- Costs of dealing with residues:
  These are estimated as follows:
  - For fly ash, the waste is assumed to be landfilled at a hazardous waste landfill. As discussed in Section A.6.11, we have not modelled this explicitly but have used a fixed pre-tax figure for the costs of landfilling, inclusive of haulage.
  - For bottom ash, we assume that on average, around two-thirds of material is put to some form of use in the construction industry. The remaining third is assumed to be landfilled at non-hazardous waste sites, and attracting lower rate landfill tax.[64]

A.7.5.2 Incineration with CHP

It is difficult to estimate, with any degree of accuracy, exactly what could be the costs of a CHP system given that so many variables exist. Costs will depend upon the specific design of a given CHP scheme. Not only are there differences related to the nature of the infrastructure required, but also, there will be differences in the impact on the plant itself, depending upon whether the intention is merely to use low grade heat for district heating, or medium or high pressure steam extraction. The former will have little impact on power generation; the latter will have a more significant effect.

Ilex estimated the costs of a CHP system on behalf of BERR.[65] The estimated costs of CHP were based around the development of a 400,000 tone per annum plant, partly because a previous report had suggested that larger plants of this size were likely to be developed.

Costs of CHP relate to:

- Costs of providing heat from the facility (relative to costs of providing electricity only)
- Costs of securing a market for the heat
- Loss of revenue from power sales

The first of these includes the costs of tapping into the steam turbine where the initial design allowed for this (and several have done so, or are planning to do so), provision of heat exchangers, and (depending on the nature of the recipients) provision of back-up boilers. In addition, the infrastructure for heat supply to the users has to be put in place if it does not already exist. The nature of the heat consumer(s) is likely to be a key determinant of these network-related costs. It is difficult to generalise these costs, given the wide variation in the possible networks. In principle, co-location alongside a major industrial heat user would be likely to give lower costs, but in practice, the likelihood of this occurring at conventional incinerators may be low. There might be a higher likelihood of merchant facilities being developed for the off-take of solid recovered fuel (SRF), especially where the heat user is involved in the project itself.

Ilex estimated costs for different CHP plant as shown below in Table A-15. These figures were intended to be indicative of costs. The 43 MW capacity relates to a heat generation

---

[64] We note that recent sampling by the Environment Agency suggests that in a relatively large minority of samples, bottom ash fails to meet some of the limit values. Bottom ash may, in future, have to be treated as hazardous waste dependent upon the outcomes of tests.

[65] Ilex Energy Consulting (2005) *Extending ROC Eligibility to Energy from Waste with CHP*, a supplementary report to the DTI, September 2005.

efficiency of around 24%. This is the only CHP option considered by Ilex which seems likely to qualify as 'good quality CHP' as the net efficiency, however measured, is relatively low for the other options considered. The figures in Table A-15 show that the main costs are related to the provision of the network and customer connections, and that in the Ilex assumptions, these show some clear increase with scale, which might not be the case depending upon the nature of customers.

In reviewing the Leeds scheme, Fichtner comments on Jacobs' costs associated with a CHP system which, it is claimed, have been taken directly from a scheme considered for a 250,000 t/a EfW facility.[66] The capital costs for the CHP scheme were £33.8 million and the annual operating cost is £320,951 per annum. The 250 ktpa facility is, in fact, a 400ktpa facility, and one with a power efficiency of 20% and a heat efficiency of 12%. This would imply efficiency of heat generation of the order 20% for a 250ktpa facility, which is quite a low figure (and would, arguably, imply a very poor use of capital in the investment in the heat network).

Table A-15: Capex and Opex Assumptions for 400kt/yr Incinerator with CHP Plant

Thermal Capacity	**Capex (€m)**			**Annual Opex (€m/year)**			
	Heat Exchan -ger	Heat Network	Customer Connections	Pumping	Heat Exchan -ger	Heat Network	Customer Connections
3	0.24	2.99	1.19	0.01	0.00	0.01	0.03
11	0.78	8.50	3.85	0.03	0.01	0.04	0.08
20	1.10	18.54	6.99	0.04	0.01	0.09	0.14
23	1.13	19.76	8.04	0.05	0.01	0.10	0.16
28	1.13	24.06	9.79	0.06	0.01	0.13	0.20
30	1.19	25.78	10.49	0.06	0.01	0.13	0.21
34	1.19	29.21	11.89	0.08	0.01	0.15	0.24
43	1.23	36.95	15.04	0.09	0.01	0.19	0.30
66	1.25	56.71	23.08	0.14	0.01	0.29	0.46

Note: Costs for heat networks, to a lesser extent, customer connections, will be very site specific and these numbers are intended only to be illustrative

Source: Ilex Energy Consulting (2005) Extending ROC Eligibility to Energy from Waste with CHP, a supplementary report to the DTI, September 2005.

The CHP option which most closely reflects our technical options are those with the higher thermal capacity (even though we are considering a smaller plant). The heat network and the customer connections would, using Ilex's figures, imply additional capital costs of the order €53.8-€81.3 million. Perhaps unsurprisingly, in Ilex's analysis, these scenarios – where the heat generation is greatest – are those which appear least favourable from a financial perspective given the power penalty implied by the increase in heat demand. Interestingly, the bottom row of the Table implies a heat generation efficiency of only 24%, with power generation at 17%, implying a much higher power to heat ration than might be expected in many CHP systems which had what one might call a 'serious' focus on heat provision.

In a report carried out at the turn of the decade for the European Commission, investment costs for power and CHP schemes in Finland were as set out in Table A-16. What this shows is the relative costs of power only schemes to those generating heat and power. The differentials are not trivial. Given that these figures are expressed in Euros in 2000,

---

[66] Fichtner (2007) Jacobs Leeds Energy-from-Waste: Validation of EFW Costs, 7 September 2007.

then accounting for exchange rate movements and for inflation over the last eight years, the figures do not seem so different to those provided by Ilex.

Table A-16: Investment Costs for CHP in Finland (in €, year 2000 base)

	Heating	Power / heating	Heating	Power / Heating
Capacity, tons/year	40,000	40,000	300,000	300,000
Investment	13,336,000	24,248,000	52,490,000	95,437,000

Source: Eunomia (2002), Costs for Municipal Waste Management in the EU: Annexes, Final Report to DG Environment, European Commission, http://europa.eu.int/comm/environment/waste/studies/pdf/eucostwaste.pdf.

In another report, Jacobs suggest that at 25,000 tonnes capacity, unit capital cost figures increase by £135 (€169) per tonne (or around a 40% increase in costs relative to their power only estimate).

In our analysis, we have used Ilex's figures at the 43 MW size, for a 400,000 tonne per year plant, implying heat generation at around 30% of input energy. For such a scheme, the following applies:

- Additional capital costs of €53.75 million;
- Additional operating costs of €0.58 million;

We therefore model on the basis of additional capex of €134 per tonne, and additional opex of €1.45 per tonne. This gives a total capex of €759 per tonne and total opex of €26.45

A.7.5.3 Incineration with Heat Only

Incineration with heat only is popular technology. In Germany most recently constructed EfW plants have tended to be heat-only facilities. This is due to power generation being less lucrative as a result of the price regulation of direct supply.

Many of the cost impacts related to a heat only incinerator are discussed in Section A.7.5.2. The main costs relate to:

- Costs of providing heat from the facility (relative to costs of providing electricity only)
- Costs of securing a market for the heat

The ILEX study assumes that district heating networks need to be established to accommodate this technology. This is true for some EU member states, though a number of member states have extensive pre-existing district heat networks (for example Sweden and Germany). The actual cost of this process is difficult to assess.

Fitchner notes that the estimated cost of grid connection and enabling works is £3.5 million. This is a cost which would not be borne by the proposed technology. This cost does not fully represent the cost differential between CHP and heat-only incineration. Estimations made by Eunomia in the 2002 review of waste management costs suggest that the capital cost of a heat-only facility will be significantly less than that of a CHP plant (Table A-16). The difference in operating costs is not as great as shown in Table A-15.

We have modelled a capital cost of €735 per tonne for a heat only facility. We have assumed that operating costs for a heat only facility will be lower than that of a CHP facility and equal to those of an electricity only facility at €25 per tonne.

A.7.6 Mechanical Biological Treatment (MBT)

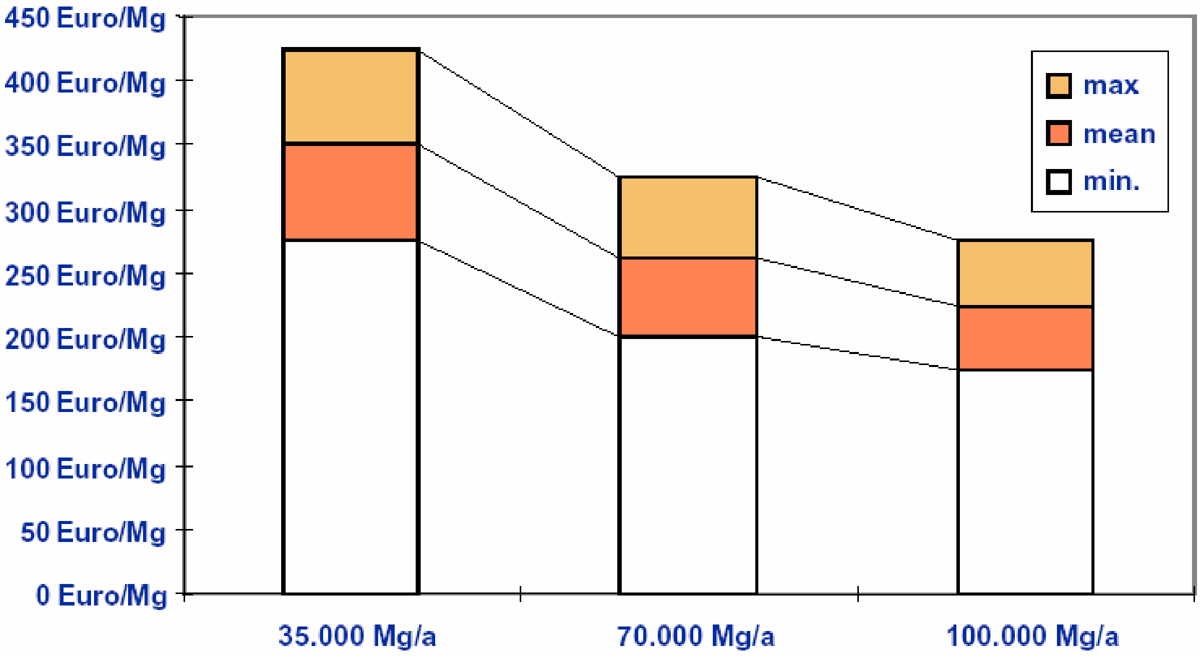
MBT facilities can be configured in various different ways. Generally, outputs include more than one of the following:

- Recyclables;
- A stabilised biowaste, which may find use as a 'compost like output', but which may have to be landfilled;
- A fraction to be sent to landfill;
- A refuse derived fuel.

For some facilities of this nature, particularly lower capital cost MBT processes based on aerobic treatment, 60,000 tonnes or so is believed to be a near-optimum scale from a *technical* (if not a project) perspective. Figure A-1, showing the results of analysis of tenders for German plants over one year, suggests that economies of scale may already be limited at a capacity of 100,000 tonnes.

It should also be noted that this review covered a range of plant sizes with 60,000 tonne facilities falling in the middle of this range. Figure A-1 shows that this type of capacity is far from unusual for MBT plants. Indeed, the average size for the German facilities listed is around 70,000 tonnes.

Figure A-6: Range of Unit Capital Costs Reported in German Tenders for MBT Facilities (by capacity)



Our analysis assumes essentially three types of biological treatment process, and in two of them, the equipment used is similar:

- Aerobic stabilisation system with the output being delivered to landfill;
- Aerobic biodrying system to produce an SRF; and
- A splitting system.

In the second of the systems, the SRF is used either in a gasifier, a cement kiln or a power station, or a 'dedicated waste combustion facility, such as a fluidised bed incinerator, or possibly, an incinerator with a water-cooled grate. For our modelling we have assumed that the SRF is sent to an electricity generating incinerator.

In all cases, flows of materials to landfill are costed using the relevant cost and tax from the landfill modelling, depending upon the cost metric being used

A.7.6.1 Aerobic Stabilisation System

Stabilisation technologies are low capital cost treatments for residual waste. We have used a figure of €230 per tonne, and an operating cost of €19 per tonne before disposal costs. A French study into the cost of MBT found that a 30,000 tpa stabilisation system with residues to landfill will cost €4.5 million in 2005 prices. This suggests a cost of €150 per tonne.[67] This is considered to be quite a low cost. In the UK an examination of various MBT configurations from 2005 has suggested that for a stabilisation facility of this nature would incur a capital cost of €201 per tonne.[68]

These costs are similar to those for in-vessel composting, reflecting similarities in technology, though scale will usually be larger, and there are costs of residue disposal to be considered. We have assumed all residues are landfilled except in the case where a ‘compost like output’ is deemed capable of being used on land.

A.7.6.2 Aerobic Biodrying Facility Preparing SRF

In principle, the costs of this type of system will be different depending upon whether the SRF which is being prepared is to be of higher or lower quality. The waste is unloaded into a reception pit where it is transferred to a shredder to reduce the size. The waste is then transferred to a biodrying area. The aerobic fermentation occurs in windrows. We have used figures for the capital cost of €250 per tonne, with operating costs of €21 per tonne before residue disposal. [69] These estimates are supported by the data gathered by Juniper Consulting in 2003. [70] It should be noted that the reality is that both the capital costs and the costs of dealing with residues will depend upon the detailed configuration of the system and the specification to which SRF is being produced. We have assumed that the SRF produced is used in at an electricity generating incinerator.

A.7.6.3 Split System Preparing SRF

In this MBT process residual waste is received at the plant. Following the initial separation process the remaining waste is divided into dense and organic waste. The dense fraction is destined to be used as RDF and the organic material is treated through aerobic composting. A UK demonstration project for a 25,000 tonne facility suggests that capital costs would be £3.9 million (2004 prices). Operating costs for this facility are estimated at between £465,000 and £767,000 per annum. The capital cost of a similar plant of 42,000 tonne capacity is estimated at £9.6 million, with an operational cost of £1.4 million per annum. The costs of these facilities will vary based on the quality of the

---

[67] ENGREF (2006) Mechanical biological treatment of waste : advantages, drawbacks, costs and stakeholders, Technical Synthesis

[68] Milton Keynes (2005) Costings, mass balances and BMW mass balances for various MBT concepts, Report for Milton Keynes Coucil

[69] Cllr Eddy Alcock (2006) *Study Tour of Selected German Waste Processing Plants*, available at: http://www.suffolk.gov.uk/NR/rdonlyres/056D566A-5B88-4F3C-928F-D4CDEF5BD4C0/0/NotesofGermanVisitMemberDirectorFINAL.pdf

[70] Juniper consulting (2003) Annexe D: The Process Review, available at: http://www.juniper.co.uk/Publications/mbt_report.html

SRF produced and the configuration. We have modelled a capital cost of €320 with an operational cost of €45 per annum.

B Variations in Capex and Opex between Member States

There are notable variations in labour costs between member states. [71] Table B-1 lists the average hourly costs, and an index of these costs relative to the UK's labour costs (where the UK=100)

Table B-1: Average Hourly Labour Costs in EU 27

Country	Average Hourly Labour Costs (€)	Indexed relative to UK labour costs (UK =100)	Country	Average Hourly Labour Costs (€)	Indexed relative to UK labour costs (UK =100)
AT	24.53	100.25	**IE**	24.47	100.00
BE	30.73	125.58	**IT**	24.53	100.25
BG	1.55	6.33	**LV**	2.77	11.32
CY	8.35	34.12	**LT**	3.56	14.55
CZ	6.63	27.09	**LU**	31.1	127.09
DK	31.98	130.69	**MT**	8.35	34.12
EE	4.67	19.08	**NL**	27.41	112.01
FI	26.39	107.85	**PL**	5.55	22.68
FR	29.29	119.70	**PT**	10.6	43.32
DE	26.43	108.01	**RO**	2.33	9.52
EL	8.35	34.12	**SK**	4.8	19.62
HU	6.14	25.09	**SI**	10.76	43.97
SE	26.39	107.85	**UK**	24.47	100.00

Source: Eurostat 2008; Poyry 2008.

For each process technology, for both capital and operational expenditure, an element will be comprised of labour costs. For this study it is assumed that general technology costs, such as the cost of purchasing large capital items, will be consistent across

---

[71] Eurostat (2008) Europe in Figures: Eurostat Yearbook 2008, Table 1.11: Labour costs (average hourly labour costs in industry and services of full-time employees in enterprises with 10 or more employees) for 2005; Poyry (2008) Compliance Costs for Meeting the 20% Renewable Energy Target in 2020: A Report to the Department for Business, Enterprise and Regulatory Reform, March 2008. Labour costs are the total expenditure borne by employers for the purpose of employing staff. They include employee compensation (including wages, salaries in cash and in kind, employer's social security contributions), vocational training costs, other expenditure such as recruitment costs, spending on working clothes and employment taxes regarded as labour costs, minus any subsidies received. The Eurostat data is incomplete for some countries, so the following assumptions have been made: Austria and Italy are taken to equal the average of EU-12 countries. Cyprus and Greece are taken to equal Malta. Ireland taken to equal the United Kingdom. Sweden taken to equal Finland.

member states. However, the labour element will vary according to the index shown in Table B-1.[72]

The proportion of capital and operational costs that is related to labour for each process technology is identified. This then allows country specific *total* capital expenditure and operational expenditure figures to be generated for each technology. We have assumed that the labour costs will not vary significantly across the modelled configurations of the technologies. There is an element of the labour cost that may not change, as technology providers supply their own staff to meet the standards they require as part of a new facility. We have accounted for this by adjusting the proportion where necessary.

Table B-2 summarises the calculated capital expenditure per tonne for each of the treatment technologies in each of the EU 27. These figures are in 2009 terms and stated in euros. Table B-3 provides a summary of the operational expenditure per tonne, for each technology in each country. Table B-4 details the assumptions made with regard to the proportion of capital and operating costs attributed to the treatment technologies.

---

[72] The cost of land for each facility will also vary both between and, importantly, within countries. It is felt that this cost element is much more site specific than the labour element to the extent that making 'reasonable' estimates would involve considerable uncertainty. Obtaining accurate figures for capital and operating costs for each technology in each of the EU-27 is fraught with difficulty. Intuitively, costs will vary between member states, and it is felt that the approximation of labour costs is an appropriate and transparent method of dealing with this variation.

Table B-2: Country-specific Capex (€/t)

Country	Landf-ill	MBT (Stabilisation)	MBT (Biodrying)	Incineration (Electricity Only)	Incinerat-ion (CHP)	Incinera-tion (Heat Only)	AD (Elec Only)	AD (CHP)	AD (Gas Upgrad-ing)	Windrow	IVC
AT	145 €	230 €	250 €	625 €	759 €	735 €	375 €	478 €	440 €	105 €	205 €
BE (F)	152 €	248 €	269 €	651 €	790 €	765 €	399 €	509 €	468 €	110 €	218 €
BE (W)	152 €	248 €	269 €	651 €	790 €	765 €	399 €	509 €	468 €	110 €	218 €
BE (B)	152 €	248 €	269 €	651 €	790 €	765 €	399 €	509 €	468 €	110 €	218 €
BG	118 €	165 €	180 €	531 €	645 €	625 €	287 €	366 €	337 €	88 €	157 €
CY	126 €	185 €	201 €	559 €	679 €	658 €	313 €	399 €	368 €	93 €	171 €
CZ	124 €	180 €	195 €	552 €	670 €	649 €	307 €	391 €	360 €	92 €	168 €
DK	154 €	251 €	273 €	656 €	796 €	771 €	404 €	515 €	474 €	110 €	221 €
EE	122 €	174 €	189 €	544 €	661 €	640 €	299 €	381 €	351 €	91 €	164 €
FI	147 €	235 €	256 €	633 €	769 €	744 €	382 €	487 €	449 €	106 €	209 €
FR	151 €	244 €	265 €	645 €	783 €	758 €	393 €	502 €	462 €	109 €	215 €
DE	147 €	236 €	256 €	633 €	769 €	744 €	383 €	488 €	449 €	106 €	209 €
EL	126 €	185 €	201 €	559 €	679 €	658 €	313 €	399 €	368 €	93 €	171 €
HU	123 €	178 €	194 €	550 €	668 €	647 €	305 €	388 €	358 €	92 €	167 €
IE	145 €	230 €	250 €	625 €	759 €	735 €	375 €	478 €	440 €	105 €	205 €
IT	145 €	230 €	250 €	625 €	759 €	735 €	375 €	478 €	440 €	105 €	205 €
LV	119 €	169 €	183 €	536 €	651 €	631 €	292 €	372 €	342 €	89 €	160 €
LT	120 €	171 €	186 €	540 €	655 €	635 €	295 €	376 €	346 €	90 €	161 €
LU	153 €	249 €	270 €	652 €	792 €	767 €	400 €	510 €	470 €	110 €	219 €
MT	126 €	185 €	201 €	559 €	679 €	658 €	313 €	399 €	368 €	93 €	171 €
NL	148 €	238 €	259 €	637 €	774 €	749 €	386 €	492 €	453 €	107 €	211 €
PL	123 €	177 €	192 €	548 €	665 €	644 €	303 €	386 €	355 €	91 €	165 €
PT	129 €	191 €	207 €	568 €	690 €	668 €	322 €	410 €	378 €	95 €	176 €
RO	119 €	168 €	182 €	535 €	649 €	629 €	290 €	370 €	340 €	89 €	159 €
SK	122 €	175 €	190 €	545 €	661 €	640 €	300 €	382 €	352 €	91 €	164 €
SI	129 €	191 €	208 €	569 €	691 €	669 €	322 €	411 €	378 €	95 €	176 €
ES	134 €	204 €	222 €	587 €	713 €	691 €	340 €	433 €	398 €	98 €	186 €
SE	147 €	235 €	256 €	633 €	769 €	744 €	382 €	487 €	449 €	106 €	209 €
UK	145 €	230 €	250 €	625 €	759 €	735 €	375 €	478 €	440 €	105 €	205 €

Table B-3: Country-specific Opex (€/t)

Country	Landf-ill	MBT (Stabilisation)	MBT (Biodrying)	Inciner-ation (Electr-icity Only)	Incine-ration (CHP)	Incine-ration (Heat Only)	AD (Electr-icity Only)	AD (CHP)	AD (Gas Upgrading)	Windrow	IVC
AT	9 €	19 €	21 €	25 €	26 €	25 €	38 €	39 €	45 €	7 €	13 €
BE (F)	10 €	21 €	23 €	26 €	28 €	26 €	40 €	42 €	49 €	7 €	13 €
BE (W)	10 €	21 €	23 €	26 €	28 €	26 €	40 €	42 €	49 €	7 €	13 €
BE (B)	10 €	21 €	23 €	26 €	28 €	26 €	40 €	42 €	49 €	7 €	13 €
BG	5 €	13 €	14 €	20 €	21 €	20 €	27 €	28 €	33 €	5 €	11 €
CY	6 €	15 €	16 €	21 €	23 €	21 €	30 €	31 €	36 €	6 €	11 €
CZ	6 €	14 €	16 €	21 €	22 €	21 €	29 €	30 €	35 €	6 €	11 €
DK	10 €	21 €	23 €	27 €	28 €	27 €	41 €	42 €	49 €	7 €	13 €
EE	5 €	14 €	15 €	20 €	22 €	21 €	28 €	29 €	34 €	5 €	11 €
FI	9 €	20 €	22 €	25 €	27 €	25 €	38 €	40 €	46 €	7 €	13 €
FR	10 €	20 €	22 €	26 €	28 €	26 €	40 €	41 €	48 €	7 €	13 €
DE	9 €	20 €	22 €	25 €	27 €	25 €	38 €	40 €	46 €	7 €	13 €
EL	6 €	15 €	16 €	21 €	23 €	21 €	30 €	31 €	36 €	6 €	11 €
HU	5 €	14 €	16 €	21 €	22 €	21 €	29 €	30 €	35 €	5 €	11 €
IE	9 €	19 €	21 €	25 €	26 €	25 €	38 €	39 €	45 €	7 €	13 €
IT	9 €	19 €	21 €	25 €	26 €	25 €	38 €	39 €	45 €	7 €	13 €
LV	5 €	13 €	15 €	20 €	21 €	20 €	28 €	28 €	33 €	5 €	11 €
LT	5 €	13 €	15 €	20 €	22 €	20 €	28 €	29 €	34 €	5 €	11 €
LU	10 €	21 €	23 €	27 €	28 €	26 €	41 €	42 €	49 €	7 €	13 €
MT	6 €	15 €	16 €	21 €	23 €	21 €	30 €	31 €	36 €	6 €	11 €
NL	9 €	20 €	22 €	26 €	27 €	26 €	39 €	40 €	47 €	7 €	13 €
PL	5 €	14 €	15 €	21 €	22 €	21 €	29 €	30 €	35 €	5 €	11 €
PT	6 €	15 €	17 €	22 €	23 €	22 €	31 €	32 €	38 €	6 €	11 €
RO	5 €	13 €	15 €	20 €	21 €	20 €	27 €	28 €	33 €	5 €	11 €
SK	5 €	14 €	15 €	20 €	22 €	21 €	28 €	29 €	34 €	5 €	11 €
SI	6 €	15 €	17 €	22 €	23 €	22 €	31 €	32 €	38 €	6 €	11 €
ES	7 €	17 €	18 €	23 €	24 €	23 €	33 €	34 €	40 €	6 €	12 €
SE	9 €	20 €	22 €	25 €	27 €	25 €	38 €	40 €	46 €	7 €	13 €
UK	9 €	19 €	21 €	25 €	26 €	25 €	38 €	39 €	45 €	7 €	13 €

Table B-4: Proportion of Labour associated with Capex and Opex

Treatment	**Labour Proportion of Capex**	**Labour Proportion of Opex**
Landfill	20%	50%
Incineration (Electricity Only)	16%	23%
Incineration (CHP)	16%	21%
MBT	30%	34%
AD	25%	30%
Windrow	17%	21%
IVC	25%	15%

B.1 Labour Costs for Landfill

B.1.1 Landfill Capex

Capital costs for landfill are discussed in Section A.7.4. The capex of landfill will vary widely throughout the EU 27 as the cost of land is a key variable which can only realistically be assessed on a site-specific rather than country specific basis[73].

Site assessment represents a significant proportion of civils costs associated with landfill capex. We have assumed this to be at 1% based on the landfill extension detailed by Eunomia[74] and summary of landfill costs produced by Enviros[75]. Other components of the civils cost relate to site development and the engineering requirements. Figures provided for these costs are not conclusive. Enviros note that engineering costs could increase to 15% of the capital expenditure in future years.

Based on the facility outlined in Section A.7.4, the Eunomia study of 2002, and from our experience of the landfill market we have estimated the percentage of capex associated with labour to be 20%.

B.1.2 Landfill Opex

The operating cost of landfill is essentially composed of labour costs and the cost of operating equipment. We have assumed that approximately 50% of the operating cost is comprised of labour. This assumption accounts for the labour intensive nature of landfill operation.

B.2 Labour Costs for Incineration

B.2.1 Incineration Capex

A 2002 report for the UK's Environment Agency suggests that civil engineering costs represent 16% of the capital costs of a 200kt/yr electricity only incineration plant.[76] Therefore technology costs are taken to be 84% of the total capital cost of an electricity only incinerator. This holds true for a CHP incinerator also. Adjusting the civils cost element, taken to best reflect the labour input to the capital expenditure, by the varying labour costs across the EU 27, we can derive country specific capital costs for incineration. Total capital cost of incineration technologies are discussed in Section A.7.5.

To derive country specific total capital costs, we hold the technology capex constant and vary the labour capex according to the index in Table B-1.

B.2.2 Incineration Opex

The labour cost element of an incinerator is also shown to vary dependant on the size of the incinerator. The opex per tonne discussed in Sections A.7.5.1 and A.7.5.2 refers to a

---

[73] E. Dijkgraaf, HRJ (2004) *Burn or Bury? A social cost comparison of final waste disposal methods*, Ecological Economics, 50 pp 233-247

[74] Eunomia (2002), *Costs for Municipal Waste Management in the EU: Annexes, Final Report to DG Environment, European Commission,* http://europa.eu.int/comm/environment/waste/studies/pdf/eucostwaste.pdf

[75] Enviros Consulting Ltd. (2003) *Landfill Financing and Contracts*, available at: http://www.landfill-site.com/Landfill_Costs_Paper_Sardinia_2003.pdf

[76] Environment Agency (2002) Waste Pre-Treatment: A Review, R&D Technical Report P1-344. Report by AEA Technology for the Environment Agency.

200,000 tonne incinerator. Fichtner[77] provides a breakdown of the operational expenditure associated with a 182,000 tonne plant. Table B-5 examines the variation between these estimates. It is clear that the capacity of the plant is correlated to the labour element of the operational cost.

Table B-5: Percentage Labour associated with Opex for an Electricity only plant

	Opex (€ millions)	Labour (€ millions)	%
EA (100 kt)	3	1	33%
EA (200 kt)	5.50	1.25	23%
EA (400 kt)	8.25	1.50	18%
Fichtner (180 kt)	6.58	1.30	20%

From the Environment Agency analysis of the cost of an incineration plant we have assumed that 23% of the operational cost of an incinerator can be attributed to the cost of labour. For a CHP plant we have assumed that this figure will be slightly lower at 21%, based on the EA evaluation of a 200,000 tonne plant.

B.3 Labour Costs for MBT

B.3.1 MBT Capex

As discussed in Section A.7.6 a variety of MBT processes are available. For this modelling we have chosen to examine

- Stabilisation;
- Biodrying;
- Splitting with SRF output

Labour costs are not readily available for all MBT processes in their various forms and combinations. Juniper Consulting carried out an extensive survey of current MBT processes and technologies.[78] The civil works for two plants are provided. The reference plant produces bio-stabilised output which is used as a soil improver or landfilled. Some of the processes produce SRF as an output. The cost figures from this study were compared to a seperate system - a SRF producing 'reverse air flow' MBT proposed for the DEFRA New Technologies Demonstrator Programme. 79 For the proposed DEFRA facility, 37% of the capex was attributed to labour cost. The Juniper study suggests that between 41% and 45% of the capex will be allocated to labour costs. Other examples have suggested that a lower labour cost, at 29% of total capex, is to be expected. It was deemed prudent that a mid-range estimate of 30% be taken as the civils cost associated with the capex of an MBT facility. We have assumed that the labour costs associated with capital expenditure will not vary significantly across the variety of MBT process that are available.

---

[77] Fichtner (2007) *Leeds Energy from Waste Validation of EfW Costs*, report for

[78] Juniper Consulting (2005) *Mechanical-Biological-Treatment: A Guide for Decision Makers Processes, Policies and Markets (Annexe D: Process Reviews),* Report for SITA Environmental Trust 2005

[79] DEFRA (2005), *New Technology Demonstrator Programme: Catalogue of Applicants,* available at: http://www.urbanmines.org.uk/assets/files/n/newtechnologescataloguepdffile_288.pdf

B.3.2 MBT Opex

Operating costs for an MBT facility were determined from a Defra New Technologies proposal. 24% of the operational cost for this plant are attributable to labour. The operational cost was calculated from the total yearly estimated cost of operating the plant, with the labour element calculated as a proportion. It has been assumed for both the capital and labour costs that the proportion of labour required for the operation of a stabilisation plant applies to all the configurations of MBT plant that we have modelled. This assumption has been made as the variety of MBT facilities that are available are far more numerous than those we have chosen to model. The variations that will affect the operational expenditure, such as maintenance, will vary with the complexity and output of the plant. This is accounted for in the per tonne unit cost attributed to each technology as discussed in Section A.7.6

The labour cost per tonne is expected to remain constant throughout the process. An ILEX study[80] expects the labour element of operating costs to be higher, at 34%. Other operational MBT facilities indicate a higher labour element. We have, therefore, used a figure of 34% for each configuration of an MBT facility in the absence of better information.

B.4 Labour Costs for AD

B.4.1 AD Capex

As discussed in section A.7.3.1 capital costs for AD facilities vary significantly depending on the size and configuration of a facility. It is difficult to generalise the cost of digestion plants across one country, and even more so across the EU 27.

McLanaghan[81] presents a detailed study of the alternative waste treatment options available in the U.K. The paper notes that the capex costs for a separate digestion facility (dry plants as discussed in Section A.7.3) in the UK are comparable to similar plants in Europe.

A Canadian feasibility study notes that a separate digestion facility has an associated labour cost of 51%[82], this is considered to be high and may include the cost of materials. Eunomia (2002) examined the cost of building and operating several AD plants in Europe. The labour element of the capital cost ranges from 25% to 35%. Due to the potential for labour to be transferred from one country to another, and thus less likely to vary across member states we have deemed it prudent to assume that 25% of the capital cost can be attributed to labour.

B.4.2 AD Opex

The operating costs of an anaerobic digestion facility vary depending on the size of the plant and on the type of digester. [55] A 10,000 tpa facility with gas compression for use in vehicles was found to utilise 72% of its operating costs on labour, but staffing levels can

---

[80] ILEX Consulting (2005) *Extending ROC eligibility to Energy from Waste with CHP,* Report to the Department of Trade and Industry

[81] S. McLanaghan (2002) *Delivering the Landfill Directive: The Role of New and Emerging Technologies, Report for the Strategy Unit*, 0008/2002

[82] Electrigaz Technologies Inc. (2008) Feasibility Study – Biogas upgrading and grid injection in the Fraser Valley, British Columbia

vary significantly across facilities and technologies[83]. This figure is net of revenues from sale of electricity. In order to maintain consistency it is important to assess the operating expenditure prior to revenues.

We expect that the operating costs involved in an AD plant will be significantly higher than any other composting process, such as IVC or Open Air Windrow. We have made what we feel to be a reasonable assumption that 30% of operational costs will be allocated to labour in the financing of an AD plant.

B.5 Labour Costs for Windrow

B.5.1 Windrow Capex

Estimating the level of capital expenditure for open air windrow faces a number of difficulties that apply equally to other methods of composting (IVC and AD). Eunomia[84] examine the cost of composting across the European Union (which at the time of reporting consisted of 12 countries). The study references a Swedish composting plant similar to an open air windrow and a UK based open air windrow facility accepting green waste from Civic Amenity sites. The cost of a windrow composting facility is heavily dependant on:

- The choice of technology, and;
- Legal and quality constraints applied to the output.

In order to extract the civil costs of an open air windrow facility we have taken the example previously used by Eunomia. We have assumed that civil costs are the portion of capital costs that are not related to the actual construction of the facility. In this instance this includes:

- Surface Improvements and Hardstanding;
- Landscaping; and,
- Services.

17% of the capital expenditure can be attributed to civil costs, which is taken to represent the labour element of the capital cost.

B.5.2 Windrow Opex

The operational cost of an open air windrow has been taken from the Eunomia 2002 study. The per tonne operating cost is assumed to have an associated labour cost of 21%. The labour costs detailed refer to three full time employees operating the plant.

B.6 Labour Costs for IVC

B.6.1 IVC Capex

In-vessel composting cost assumptions are described in A.7.2. McLanaghan[85] notes that the capital expenditure associated with IVC can vary significantly. This is supported by

---

[83] S. Last (2008) *An Introduction to Waste Technologies,* Waste Technologies UK Associates 2006-2008

[84] Eunomia (2002) *Costs for Municipal Waste Management in the EU: Annexes, Final Report to DG Environment, European Commission,* http://europa.eu.int/comm/environment/waste/studies/pdf/eucostwaste.pdf

[85] S. McLanaghan (2002) *Delivering the Landfill Directive: The Role of New and Emerging Technologies, Report for the Strategy Unit*, 0008/2002

the analysis performed by the European Environment Agency (EEA)[86]. The levels of UK costs are considered to reflect similar capital expenditure in the area covered by the EEA study. Eunomia (2002) shows that between 20 and 30% of the total investment cost will be reflected in labour. This labour cost includes the development of the site and technical installations. Therefore we have assumed that 25% of the capital expenditure will relate to the civils costs.

B.6.2 IVC Opex

The proportion of operating cost that can be related to labour costs has been assumed to be slightly lower than that of an open air windrow[87]. A 40,000 IVC facility in Germany is estimated to attribute 14% of yearly operating costs to labour. We have modelled the percentage of labour cost related to operational expenditure at 15%.

---

[86] European Environment Agency (2002) *Biodegradably municipal waste management in Europe, Part 3:Technology and market issues*

[87] FEC Services Ltd. (2003) *Anaerobic digestion, storage, oligolysis, lime, heat and aerobic treatment of livestock manures*, available at: http://www.scotland.gov.uk/Resource/Doc/1057/0002224.pdf

ARCADIS

Kantoren ARCADIS Belgium

Kantoren ARCADIS Engineering & Consulting

Deurne-Antwerpen Clara Snellingsstraat 27 B-2100 Deurne-Antwerpen T +32 3 360 83 00 F +32 3 360 83 01	Berchem-Antwerpen Roderveldlaan 3 B-2600 Berchem T +32 3 328 62 86 F +32 3 328 62 87	Kortrijk Sint-Jorisstraat 21 B-8500 Kortrijk T +32 56 24 99 20 F +32 56 24 99 21
Gent Kortrijksesteenweg 302 B-9000 Gent T +32 9 242 44 44 F +32 9 242 44 45	Haaltert Bruulstraat 35 B-9450 Haaltert T. +32 53 83 04 80 F.+32 53 83 59 54	Leuven Vaartkom 31/8 B-3000 Leuven T +32 16 63 95 00 F +32 16 63 95 01
Hasselt Eurostraat 1 bus 1 B-3500 Hasselt T +32 11 28 88 00 F +32 11 28 88 01	Oostende Archimedesstraat 7 B-8400 Oostende T +32 59 27 38 00 F +32 59 27 39 00	Bruxelles Avenue Louise 500 B-1050 Bruxelles T +32 4 349 56 00 F +32 4 349 56 10
Luik Rue des Guillemins 26, 2e verd. B-4000 Luik T +32 4 349 56 00 F +32 4 349 56 10	Charleroi 119, Avenue de Philippeville B_6001 CHARLEROI T.. +32 71 298 900 F. +32 71 298 901	Bastogne Rue Thier De Luzéry 6 B-6600 Bastogne T +32 61 21 38 85 F +32 61 21 52 28

Iso gecertificeerd voor:
Adviesverlening, studie en ontwerp van gebouwen, infrastructuur, milieu en ruimtelijke ordening