Cory Riverside Energy:
A Carbon Case

CORY
RIVERSIDE ENERGY

Carbon Trust Peer Review

Cory Riverside Energy: A Carbon Case

The Carbon Trust has conducted a peer-review on the report Cory Riverside Energy: A Carbon Case.

The scope of this study was to run a comparison between two alternative scenarios for waste management and its goal being to demonstrate which has the lower impact: the conversion of waste into electricity within Cory Riverside Energy's operations, with waste transport by road and river; and the disposal of the same waste to a UK landfill site with waste transport by road only. This was accepted as suitable for the goal of the study and to be in line with the UK Government 2014 Defra study, Energy from Waste: A Carbon Based Modelling Approach.

The main findings of the peer-review were:

- The carbon footprint study is based on an appropriate methodology and identifies the key carbon impact categories for Cory Riverside Energy's own Energy from Waste activities and an alternative scenario of the waste being sent off to Landfill.
- The study also supports Cory Riverside Energy's results regarding the comparative analysis of their own Energy from Waste operations to the alternative scenario of Landfill.

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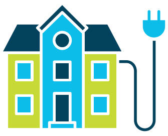
"Cory Riverside Energy's mission is to provide London with a safe, secure, affordable and sustainable energy supply and to continue to do so into the future."

Who we are

Cory Riverside Energy ('Cory') is one of the leading waste management companies in London with 275 employees across a network of sites and facilities. Established in 1896, Cory has served London for over 120 years. Working closely with local authorities, Cory manages over 750,000 tonnes of London's waste. Uniquely, the business operates a 'green highway' on the River Thames, using a fleet of tugs and barges to sustainably transfer London's municipal and commercial waste and recyclable by-products to/from Riverside EfW facility. The energy from waste facility at Riverside generates circa 525,000 MWh of baseload electricity, powering the equivalent of 160,000 homes per year. Cory Riverside Energy's mission is to provide London with a safe, secure, affordable and sustainable energy supply and to continue to do so into the future.



160,000

Households powered with the c.525,000 MWh energy we generate

10,000

Up to 10k tonnes of Air Pollution Control Residue recycled to create building blocks for use in construction

100,000

Vehicle journeys saved using our carbon efficient fleet of tugs and barges to move waste along the Thames

200,000

Up to 200k tonnes of ash recycled as construction aggregate

149,000

Tonnes of carbon saved by not sending waste to landfill

750,000

Up to 750k tonnes of London's waste turned into electricity and recycling product

Abstract

In the UK and across Europe, strategies on waste management have shifted from traditional waste disposal in landfills to increased recycling and waste treatment in energy recovery facilities[1]. A consensus has emerged that diversion of waste from landfill is fundamental to reaching a circular economy and reducing carbon emissions. The purpose of this paper is to capture the impact Cory Riverside Energy has on reducing UK carbon emissions, with respect to alternative energy generation and waste management pathways. Results of this paper highlight that Cory Riverside Energy's operations in London provide substantial carbon benefits over alternatives through:

- *Utilisation of an R1 rated[2] efficient energy recovery facility that recovers more energy from waste than traditional landfill gas generation;*
- *Preventing methane gas escaping to the atmosphere at landfills, which has a much higher global warming potential than carbon dioxide;*
- *Advantages over alternatives on all three aspects of the UK energy trilemma: security of energy supply; cost-effectiveness; and low carbon generation;*
- *Operation of 'green highway' on River Thames. Using tugs and barges to transfer waste and recyclables, reducing lorry movements and congestion on London's roads.*

1 See Energy from waste, A guide to the debate, Department for Environment, Food & Rural Affairs, 2014 here

2 See Guidance on R1 Status here

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Glossary

APCR
Air pollution control residue – residue from treatment of exhaust gas from energy recovery.

Biogenic waste
Waste from biological material from living or recently living organisms.

Calorific Value
Calorific Value (CV) – is a measure of the amount of energy contained within waste that could potentially be released when it is completely combusted.

CHP
Combined Heat and Power (CHP) – is the use of a heat engine or a power station simultaneously to generate both electricity and useful heat.

Fossil waste
Material within the waste stream that has come from sources such as coal, oil and natural gas which have been locked underground for millions of years.

Greenhouse Gas (GHG) Protocol
The Greenhouse Gas (GHG) Protocol, developed by World Resources Institute (WRI) sets the global standard for how to measure, manage, and report greenhouse gas emissions.

Global warming potential
The Global Warming Potential (GWP) is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2).

IBA
Incinerator bottom ash - ash that is left over after waste is burnt in an incinerator.

kWh
Kilowatt hour – i.e. a measure of electrical energy equivalent to a power consumption of one thousands watts for one hour. The common unit of electricity.

R1 Status
The definition in the revised Waste Framework Directive for a 'recovery' operation. For municipal waste incinerators this is based on a calculation of a plant's efficiency in converting tonnages of municipal waste to energy.

Residual waste
Residual waste is waste that cannot be recycled for economic, environmental or practical reasons.

Waste Hierarchy
In an ideal world all waste would be prevented. In reality, for a range of social, economic and practical reasons, this does not happen. Where waste does exist it is usually best to reuse it if possible, and if not, to recycle it. What can't be recycled, the residual waste, could either go to energy recovery or as a last resort, landfill. This general order of preference is known as the waste hierarchy.

Context

Carbon reduction is widely recognised in existing literature as the primary tool for justifying different approaches relating to energy and waste policy[3]. The flagship UK policy, the 2008 Climate Change Act[4] sets out a legally binding target of at least an 80% cut in UK greenhouse gas emissions by 2050 against a 1990 baseline. In addition, the UK also has a legally-binding target of achieving 15% of its total energy (electricity, heat, transport) from renewables by 2020[5]. Within this policy context, energy from waste must play a major role in reducing waste to landfill and reducing UK carbon emissions[6].

WHAT IS ENERGY FROM WASTE?

Energy from Waste (EfW) is the recovery of energy, by various different technologies, from residual waste. It plays a valuable role in reducing the environmental impacts of waste management[7]. This role is core to the UK waste hierarchy[8]. Priority is given to waste prevention, re-use and recycling/composting. For waste that remains, energy recovery is preferable to disposal at landfill.

WHY IS IT IMPORTANT?

Energy generation in the UK faces complex challenges: delivering security of energy supply; in a cost-effective manner; through low carbon technology; thereby reducing dependency on imported fossil fuels. The challenge of meeting these core policy objectives has been coined the "UK energy trilemma" *(see Figure 1)*. This trilemma dominates energy policy discussion. This paper aims to demonstrate Cory Riverside Energy's performance in managing waste in line with the waste hierarchy alongside being a solution to the "energy trilemma". To achieve this a model was utilised to quantify; the overall carbon[9] emissions arising from the waste management processes of Cory Riverside Energy. This includes waste transport; treatment; energy recovery; and aggregate recycling. The overall carbon emissions attributable to Cory are compared against an average landfill disposal route representative of the UK. In this way, the net carbon saving of Cory's processes can be quantified. The metric chosen is tonnes CO_2 saved per annum.

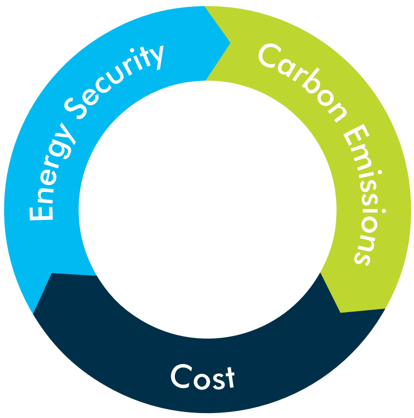


Figure 1 *UK Energy Trilemma Schematic*

3 See Energy recovery for residual waste, Department for Environment, Food & Rural Affairs, 2014 here

4 See UK Climate Change Act 2008 here

5 See EU Renewable Directive 2009/28/EC here

6 See Climate Change Mitigation Potential of the Waste Sector, German Federal Environment Agency here

7 See *UK Green Investment Bank, Residual Waste Report, 2014* here

8 See Defra Guidance on waste hierarchy here

9 Carbon; CO_2 and CO_2e are used interchangeably throughout report to represent greenhouse gas emissions

Aims

The purpose of the study was to investigate Cory Riverside Energy's contribution in reducing UK carbon emissions by providing safe, secure, affordable and sustainable energy. It focused on following aims:

1.

Investigate the carbon impacts of Cory Riverside Energy's transport of waste and recyclables via the 'green highway' on the River Thames.

2.

Demonstrate the sustainability credentials of Cory Riverside Energy's processes against UK landfill.

3.

Measure Cory Riverside Energy's annual contribution to the UK generation mix.

4.

Evaluate Cory Riverside Energy with respect to the UK Energy Trilemma: providing an affordable; low carbon; secure energy source.

Scope and Boundary

The scope of study was to compare carbon emissions resulting from Cory Riverside Energy's operations with UK landfill disposal. Two carbon models were developed to incorporate emissions profiles: energy from waste and landfill[10].

The boundary of the Cory energy from waste model begins when residual waste enters the management responsibility at its transfer stations. From here, carbon (or CO_2) emissions are calculated throughout the process. Energy generated at Riverside EfW was assumed to offset fossil fuels and thereby replace CO_2 emissions that would have stemmed from an alternative generating source. This is in line with UK Government guidance on the appraisal of electricity generation options[11]. The reprocessing of incinerator bottom ash (IBA) and air pollution control residue (APCR) into recycled aggregate is contracted out by Cory Riverside Energy. Downstream CO_2 savings from IBA and APCR recycling are not included as being attributable to Cory Riverside Energy in this paper but a wider discussion on the use of recyclable products is included in *Section 2.6*. A baseline scenario of waste disposal to UK landfill was utilised as a benchmark to contrast the performance of Cory Riverside Energy's process. This approach is in line with other studies of this kind[12]. To achieve a like-for-like comparison, assumptions have been made. CO_2 and methane (CH_4) emissions which would otherwise have arisen from diverting waste processed at Riverside EfW to landfill are estimated. In similar fashion to the boundary set for Cory Riverside Energy, transport of waste, emissions from landfill, and total fossil fuel energy generation offset are all incorporated in CO_2 emissions assessment from landfill.

10 Principles laid down by *ISO 14064-1: 2006* and the *Greenhouse Gas Protocol*[10] were employed. Data in the models is representative of 2015.

11 *DUKES Guidance: Valuation of energy use and greenhouse gas emissions for appraisal*, see here

12 See *Energy recovery for residual waste, Department for Environment, Food & Rural Affairs, 2014* here

1.0 Carbon in Waste

The chemical content of residual waste impacts how CO_2 emissions are calculated from EfW; or separately from a landfill processes. The key science underpinning calculations of CO_2 emissions from EfW or landfill is developed below.

1.1 NATURE OF RESIDUAL WASTE

Waste going to EfW or landfill is assumed to be residual waste. A typical black bag of residual waste contains a mixture of diverse items, including paper, food, plastics, clothes, glass and metals. The mixture of different items comes from different sources (e.g. food) will have originated from biological sources. This waste is classified as biogenic carbon. Some of the waste materials (e.g. plastics) will have originated from fossil fuels such as oil. Carbon in this type of waste is known as non-biogenic (fossil) carbon. Some of the waste (e.g. clothes), will contain both biogenic and fossil carbon, while others will contain little or no carbon (e.g. metals). Waste combustion or landfill produces CO_2 emissions proportional to carbon content of waste.

1.2 CALCULATION OF CARBON EMISSIONS FROM EFW PROCESS

In EfW plants, the calculation of CO_2 process emissions includes non-biogenic (fossil) carbon in waste only. Any release of biogenic CO_2 emissions discounted. The United Nations governing body, the Intergovernmental Panel on Climate Change (IPCC), have agreed conventions for doing this[13]. This avoids double counting of carbon only relatively recently absorbed by biogenic matter and not to be considered from fossil fuels.

1.3 CALCULATION OF CARBON EMISSIONS FROM A LANDFILL PROCESS

In landfill operations, CO_2 emissions stem primarily from the methane constituent of landfill gases escaping to atmosphere. Methane is a very potent greenhouse gas, estimated to have 25 times the global warming potential of CO_2[14]. Small quantities of methane that escape to the atmosphere produce large amounts of CO_2 equivalent emissions. To understand methane and CO_2 emissions from landfill, four main processes are relevant:

1. *A large proportion of waste (thus carbon content) does not degrade to produce gas: instead remains trapped in the landfill. This is termed sequestration. It is beneficial for environment as it traps carbon of fossil origin from converting to landfill gas and escaping to atmosphere;*
2. *A smaller proportion of waste comprised of both organic and non-organic matter biodegrades: this produces a landfill gas comprising of CO_2 and methane;*
3. *The majority of landfill gas is collected and used as fuel in landfill gas combustion engines and turbines that generate electricity; and*
4. *A percentage of landfill gas escapes directly to the atmosphere and contributes to climate change. Landfill gas is converted to CO_2e to quantify the carbon impact.*

1.4 ADDITIONAL GREENHOUSE GASES

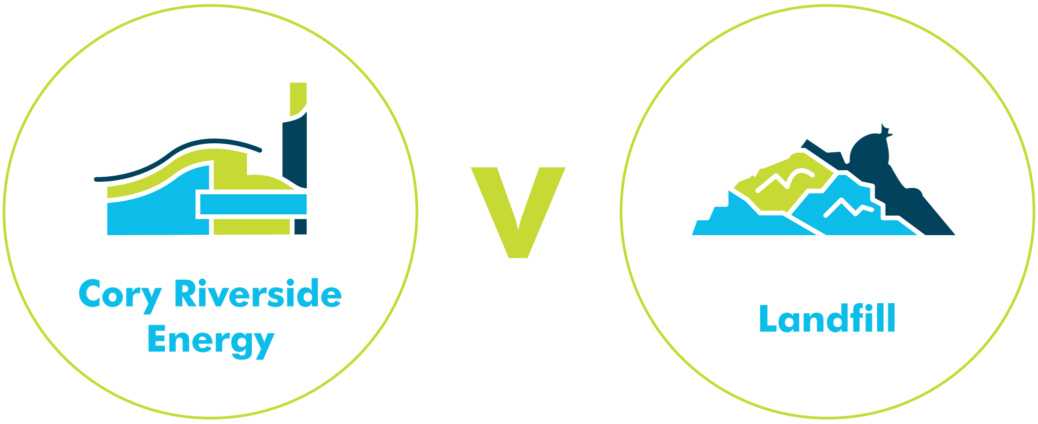
Both EfW facilities and landfills emit small quantities of other greenhouse gases, alongside carbon dioxide (CO_2) and methane (CH_4), such as nitrous oxide (N_2O). The inclusion of N_2O would result in a small disbenefit from energy from waste over landfill. However, the impact of these additional greenhouse gases is classified as de-minimis on the outcome of the study; it would impact the results by <0.1% and is therefore excluded. It is more suited to detailed life-cycle analysis outwith of this study.

13 See IPCC: Emissions from Waste Incineration: Good practise guidance (reference on page 1) here

14 See global warming potential of Methane here

2.0 Carbon Models

The models compare two scenarios:



These are summarised in *Table 1* across four energy consuming boundaries:

1. Transfer Stations
2. Transport
3. Process
4. Avoided Fossil Fuels

The input into the carbon models is 700,138 tonnes residual waste. Output from the models is the comparison of energy generation (MWh) and CO_2 emissions (tCO_2) associated with waste treatment from energy from waste or landfill.

Boundary	1 Transfer Stations	2 Transport	3 Process	4 Avoided Fossil Fuels
Cory Riverside Energy	Energy consumption at waste transfer stations	Transport of waste to EfW via the River Thames waterway	CO_2 emissions to produce energy from waste	CO_2 benefits from avoided fossil fuel power generation
Landfill	Conservatively excluded from landfill model	Transport of waste via road to landfill	CO_2 emissions from landfill	CO_2 benefits from avoided fossil fuel power generation

Table 1: *Cory Riverside Energy vs Landfill Carbon Models*

2.1 Transfer Stations

CORY RIVERSIDE ENERGY

Cory Riverside Energy's electricity, natural gas and gas oil (red diesel) consumption at the transfer stations and management buildings are recorded in the model. Total energy consumption (kWh) and carbon emissions (tCO_2) are presented in *Table 2*, with *Figure 2* itemising it by energy sources. Electricity consumption at transfer stations is the main activity that produces carbon emissions.

LANDFILL

At all times, CO_2 emissions from landfill have been estimated on a conservative basis. This provides a defensible counter-factual comparison with Cory processes. In landfill model energy consumption (hence CO_2 emissions) at transfer stations has been excluded. It is assumed that the transport section accounts for all energy to collect and transport waste to landfill.

Energy Sources	kWh	tCO_2
Electricity	7,490,256	3,871
Natural gas	847,871	177
Gas oil	407,379	112
Total	**8,745,506**	**4,160**

Table 2 *Transfer Stations: Energy and CO_2 emissions*

TRANSFER STATIONS
(% OF CARBON FOOTPRINT)

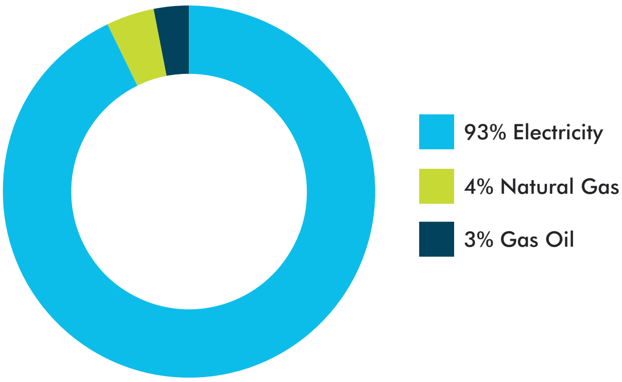


Figure 2 *Cory Riverside Energy: Transfer Stations*

2.2 Transport

CORY RIVERSIDE ENERGY
RIVER AND ROAD

Cory is the largest barge (or lighterage) operator in London, operating on River Thames for over 110 years. Cory uniquely use the River Thames as a *green highway* to transport waste to Riverside EfW plant by lighterage. Residual waste is transported in sealed containers on barges that can transport up to 300-tonnes at a time. Cory operates 5 "Damen Shoalbusters" tug boats. Total fuel consumed on these tugs to transport waste in 2015 was 1,013,445 litres. This equates to 1.60 litres of fuel to transport one tonne of waste via the *green highway.*

Alongside river operations, a smaller percentage (9.7%) of waste reaches Riverside EfW via road transport. This fuel consumption is estimated based on Waste Collection Vehicle Fuel Efficiency Report, 2010[15]; this report states 8.41 litres of fuel are used to transport one tonne of waste to landfill. This equates to 574,272 litres overall. Associated CO_2 emissions are included in Cory's transport carbon footprint discussed in *Table 3*. This allows comparison with standard landfill transportation systems.

LANDFILL
ROAD

Road based waste collection dominates the landfill sector and therefore provides the best comparison with Cory's processes. Standard refuse collection vehicles (RCVs) are predominantly diesel in the UK. The *Waste Collection Vehicle Fuel Efficiency Report, 2010* was the best available report to represent fuel consumption in UK landfill fleet. This specified that 8.41 litres of diesel are consumed to transport one tonne of waste to landfill in the trail that was undertaken. Using this calculus, it takes 5,888,161 litres of diesel to transport 700,138 tonnes to landfill. See *Table 3* and *Figure 3* on following page for comparison between Cory Riverside Energy and UK landfill transport processes. The Cory 'green highway' is responsible for substantial annual carbon savings.

15 See WRAP 2010 Report here

Energy Sources	Diesel *(litres)*	Marine Oil *(litres)*	CO_2 Emissions *(tonnes)*
Cory Riverside Energy	574,272	1,013,445	5,163
Landfill	5,888,161	–	18,642

Table 3 *Transport: Cory Riverside Energy Vs Landfill*

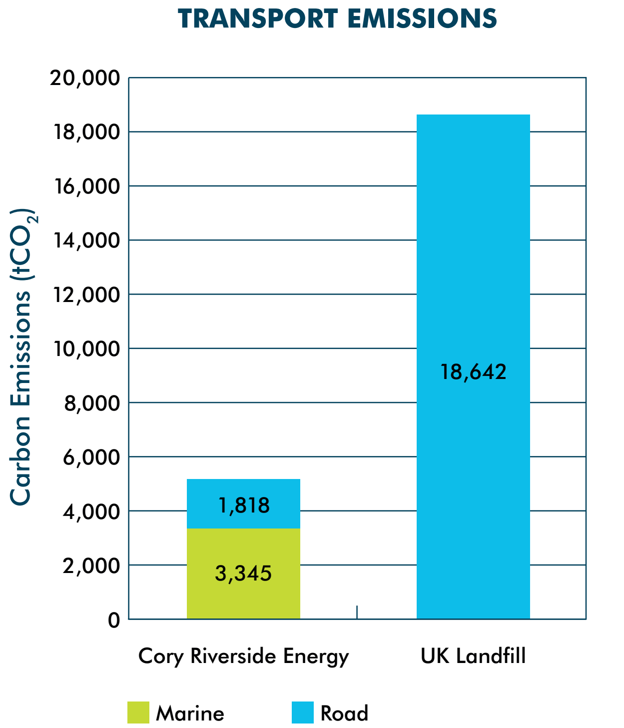


Figure 3 *Cory Riverside Energy vs Landfill*

WHAT BENEFITS DOES CORY'S 'GREEN HIGHWAY' BRING TO LONDON?

CARBON REDUCTION

The use of the River Thames by Cory to transport waste and aggregates has major carbon savings when benchmarked against typical road transport to landfill; we estimate fuel savings totalling millions of litres. The absolute saving of circa 13,500 tCO_2 equates to 19.25 kg CO_2 per tonne of waste or aggregate transported. It equates to removing 100,000 truck journeys from London's road every year or taking 6,000 cars off London's roads[16]. To put this in context, the transport sector is widely regarded as being one of the most difficult areas to achieve substantial long-term CO_2 reductions. Cory's river operations are playing a leading role in reducing CO_2 in London.

100,000

Vehicle journeys saved using our carbon efficient fleet of tugs and barges to move waste along the River Thames

LOCAL AIR POLLUTION IMPROVEMENTS

The essential transportation of waste inevitably creates side effects (external impacts). External impacts are not borne by one individual or business in itself. They affect society at large[17]. It is widely recognised that road based transport has higher external impacts than other forms of transport. Examples of external impacts from road transportation include:

- *Accident costs;*
- *Costs of congestion (delay costs); and*
- *Air pollution and human health costs*

Furthermore, the Greater London Authority has placed great emphasis on improving air quality in London[18]. A recent study by the Royal College of Physicians and the Royal College of Paediatrics and Child Health concluded that exposure to particulate matter and nitrogen oxide pollution is responsible for the equivalent of 40,00 deaths each year in the UK[19]. Furthermore, it imposes a cost to society between £15 billion and £20 billion per year. For reference, this is greater than the sum associated with obesity (£10 billion)[20].

Cory Riverside Energy contributes to reducing local air pollution by taking refuse collection vehicles off congested roads in central London and using the River Thames instead. Cory is proud of its contribution in reducing impacts from road transport in the Greater London Area and fully supports initiatives for a cleaner, greener, safer London.

16 Average CO_2 emissions from UK car is 2.33 tonnes per annum

17 See External Costs of Transport, European Commission Report here

18 See Mayor of London public consultation launch July 2016 here

19 See Royal College of Physicians Report, 2016 here

20 See Defra, Air Pollution action in a changing climate, 2010 here

2.3 Energy from Waste

2.3.1 WASTE COMPOSITION

The composition of waste received by Riverside EfW is measured annually via sample data taken from waste stream. This reporting is conducted by a third party on behalf of Cory. Reporting uses Ofgem's methodology to calculate the percentage of waste entering Riverside that is derived from biogenic sources.

CARBON CONTENT

In 2015, chemical analysis revealed 27% of the waste entering Riverside EfW contains carbon (C) by weight. This result is higher than the 23% used in the Defra carbon modelling study, but within the typical range of municipal solid waste in the UK (20-30%)[21]. Calorific value and therefore energy produced is highly correlated to carbon content; this model uses calorific value as a proxy for carbon content.

BIOGENIC CONTENT

Table 4 summarises the composition of waste by: % weight of total sample; % of CV of energy recovery process; biogenic content; non-biogenic content. This allows quantification of the biogenic and non-biogenic proportion in the waste stream. Results highlight: 54.10% of the waste is biogenic in origin; 45.90% of waste is of fossil fuel origin. For the purpose of calculating CO_2 emissions from EfW, only emissions from waste of fossil fuel are considered.

21 See Carbon Balances 2006, Energy Impacts of the Management of UK Waste Streams, here

Waste Composition	By Weight %	By CV %	Biogenic Content %	Non Biogenic %	Qualifying Renewable %	Fossil Carbon %
Paper and card	27.83	27.80	100	0	27.8	0
Plastic film	8.51	18.67	0	100	0	18.67
Dense plastic	7.77	17.28	0	100	0	17.28
Textiles	3.43	5.25	50	50	2.625	2.62
Misc. Combustible	9.55	12.26	50	50	6.13	6.13
Misc. Non-Combustible	5.39	0.00	50	50	0	0
Glass	4.52	0.00	0	100	0	0
Putrescibles	26.44	16.35	100	0	16.35	0
Ferrous Metal	1.58	0.00	0	100	0	0
Non-ferrous Metal	1.00	0.00	0	100	0	0
Hazardous	1.21	0.00	0	100	0	0
Fines	2.77	2.39	50	50	1.195	1.19
Total	**100%**	**100%**	–	–	**54.10%**	**45.90%**

Table 4 *Waste Composition*

2.3.2 RIVERSIDE EFW PROCESS EMISSIONS

This section discusses CO_2 emissions from the energy recovery process at Riverside EfW. It follows principles laid down in other studies and reports[22]. As waste is combusted, all carbon (biogenic and fossil) is converted to CO_2. As per IPCC convention[23], only fossil CO_2 is considered derived from fossil fuels and counted towards emissions. CO_2 emissions from Riverside EfW are summarised in *Table 5*. A further circa 350 tonnes of CO_2 are emitted at Riverside covering: grid electricity; gas oil and mains water. This is incorporated into the final calculation in results section.

22 See Energy recovery for residual waste, Department for Environment, Food & Rural Affairs, 2014 here

23 See IPCC: Emissions from Waste Incineration: Good practise guidance (reference on page 1) here

317,914
tonnes of CO_2

Derived from fossil fuels; emitted from the energy recovery process at Riverside whilst treating 700,138 tonnes of waste

454
kg CO_2

Derived from fossil fuels; emitted per tonne of waste treated

Mass of Waste *(tonnes)*	x	Carbon *(%)*	x	Fossil Carbon *(%)*	=	*Mass of Fossil Carbon (tonnes)	x	Carbon to CO_2 *(44/12)*	=	**Total Fossil CO_2
700,138		27		45.90		86,704		3.667		317,914

*Mass of waste x Percentage Carbon in waste x Fossil Carbon = Mass of Fossil Carbon (tonnes) in waste

**Mass of Fossil Carbon x 44/12 (C to CO_2 conversion) = Total Fossil CO_2 from energy recovery (tCO_2)

Table 5 *CO_2 Emissions from Riverside EfW*

2.3.3 ENERGY GENERATION

Table 6 summarises the 2015 energy generation and export to grid. Energy generation is a function of the thermal efficiency of the process. Each process in the EfW system: burning waste; producing heat; generating steam; and driving a turbine, results in energy losses affecting efficiency. By maximising thermal efficiency, the overall environmental benefit of the plant is consistently maintained. Riverside EfW is at the top performing end of electricity only EfW facilities in the UK and this ensures classification as an R1 recovery facility. Riverside EfW generated 574,385 MWh in 2015. 515,166 MWh was exported. This energy is considered to substitute for displaced fossil fuel generation and results in CO_2 savings which is discussed in *Section 2.5*. In 2015, the electricity exported from Riverside EfW would be enough to power over 160,000 homes[24]. 54% of this energy can be considered renewable generation, contributing to UK renewable energy targets. Riverside has the potential and is planned to operate as a combined heat and power (CHP) plant in the future. This increases the carbon reduction benefits from waste to energy recovery as the utilisation of excess heat from the process does not produce any additional CO_2.

Mass of Waste *(tonnes)*	Energy Generated *(MWh)*	Energy Exported *(MWh)*
700,138	574,385	515,166

Table 6 *Riverside EfW Energy Generation (MWh) 2015*

2.3.4 AIR QUALITY CONTROL

Local air pollution is taken very seriously at Cory. Energy from waste plants are tightly controlled under the Waste Incineration Directive (2000/76/EC)[25]. These requirements have been recast into the Industrial Emissions Directive (2010/75/EU)[26]. This sets stringent limits for a number of potential pollutants. It also sets demanding operating requirements which help to minimise pollution. Cory Riverside EfW monthly emissions records are available to publically download from the Cory Riverside Energy website. Cory reports emissions data to the Environment Agency on a daily basis and has an excellent emissions record.

160,000

Households powered with the c.525,000 MWh energy we generate

24 Annual UK domestic energy consumption at 3,300 kWh per annum in medium household, see reference here

25 See Waste Incineration Directive here

26 See Industrial Emissions Directive here

2.4 Landfill

This section models the methane emissions that would result in diverting the residual waste mass treated at Riverside EfW to a typical UK landfill. It converts methane emissions to CO_2 equivalent (CO_2e). Estimates of methane produced by a landfill site are subject to considerable uncertainty. The rate of methane production varies: as a function of time; climatic conditions; waste stream composition; and management.

In order to model a meaningful comparison with EfW processes, data assumptions are applied. Firstly, residual waste destined for landfill is considered to have the same carbon and biogenic content as waste that was treated at Riverside EfW. This allows an all else being equal comparison. Variable data sources and fixed data sources laying behind assumptions are summarised in *Table 7* and *Table 8*.

Variable Landfill Assumptions	Value	Data source
Total percentage Carbon (by weight)	27%	Compositional and Chemical Analysis of Waste Entering Riverside EfW, January 2015
Carbon that is sequestered as ground deposit and does not degrade to landfill gas	73%	Adapted from 2014 Defra Study
Carbon that will decompose landfill gas	27%	Adapted from 2014 Defra Study
Landfill gas capture rate	66%	Adapted from 2014 Defra Study
Total Methane oxidised	3%	Adapted from Defra 2014 Study. Of the 30% of landfill gas not captured, 10% will be oxidised to CO_2 in the landfill cap (3% total)
Methane released to atmosphere	27%	The remaining 27% of methane is released to atmosphere
Electrical conversion efficiency	41%	Adapted from Defra 2014 Study

Table 7 *Variable Landfill Assumptions*

Fixed Landfill Assumptions	Value	Data source
Methane – Global Warming Potential CO_2e	25	IPCC default value[27]
Landfill Gas: Used to generate energy	50%	IPCC default value
Landfill Gas: CO_2 to Methane Ratio	50%	IPCC default value
Calorific value of methane	50	Mj/tonne

Table 8 *Fixed Landfill Assumptions*

27 See GWP of Methane here

Carbon emissions from landfill come from methane in landfill gas escaping to atmosphere. Following the assumptions laid down in *Table 7* and *Table 8*; 27% of the methane generated as a result of the landfilling of 700,138 tonnes waste will create CO_2e emissions. *Table 9* summarises this result.

Landfill emissions - calculation	Tonnes	%
1. Total Waste Input	700,138	–
2. Total Percentage Carbon	–	27%
3. Percentage Carbon Sequestered	–	73%
4. Decomposable Carbon Proportion	–	27%
5. *Mass of Decomposable Carbon (1 x 2 x 4 = 5)	51,002 (C)	–
6. Mass of Methane (5) x 0.5 x 16/12 (Methane in Landfill Gas)	34,002 (CH_4)	100%
7. Mass of Methane Captured (6) x 0.66	22,441 (CH_4)	66%
8. Mass of Methane Oxidised (6) x (1 – 0.7)*(0.1)	1,156 (CH_4)	3%
9. **Mass of Methane Released to Atmosphere	10,404 (CH_4)	31%
10. ***CO2e from Methane released (9) x 25	260,111 (CO_2e)	–

*Calculate mass decomposable carbon (C) in the waste stream.
**Calculate the mass of methane released to atmosphere.
***Calculate the CO2 equivalent from this methane release.

Table 9 *Carbon emissions from landfill*

260,111
tonnes of CO_2e
Assumed to represent emissions from UK landfill to treat 700,138 waste

2.4.1 LANDFILL – ENERGY GENERATION

Based on a 66% landfill gas capture rate, 700,138 tonnes waste at a UK landfill would generate 63,716 MWh (see *Table 10*). This energy is considered to substitute for displaced fossil fuel generation and results in CO_2 savings which are discussed in *Section 2.5*.

Mass of Methane Captured	Proportion Used for Generation	Calorific Value (MJ/t)	Electrical Conversion Efficiency	Energy Generated (Gj)	*Energy Generated (MWh)
22,441	50%	50.00	41%	230,020	63,716

*Mass of methane captured x Proportion used for generation x Calorific value of waste x Electrical efficiency = **Energy Generation (Gj): convert to MWh**

Table 10 *Energy Generation from Landfill*

2.5 Avoided Fossil Fuels

HOW DOES ENERGY FROM WASTE OR LANDFILL REDUCE FOSSIL FUEL USE?

The most significant factor when assessing CO_2 savings from EfW or landfill is how much fossil fuels are used for conventional power generation. When energy derived from either EfW or landfill is available, conventional power (hence fossil fuels) will be displaced. When estimating carbon reductions, the UK government position is that electricity produced by combined cycle gas turbine (CCGT) is displaced; CCGT represents the current trend in new plant commissioning. Therefore, generating electricity from waste offsets CO_2 emissions from CCGT plants producing an equivalent amount of energy at that time. An equation summarises this:

Energy Generated (MWh) x Carbon Intensity of CCGT (tCO_2/MWh) = Total CO_2 offset (tCO_2e)

The accepted life-cycle carbon intensity for UK CCGT in 2015 was 0.385 tCO_2/MWh generated[28]. This number is used to quantify carbon offset from Riverside EfW (576,569 MWh) and UK landfill (63,716 MWh). *Figure 4* highlights a key finding of this study. Riverside EfW outperforms landfill by producing greater carbon savings through generating more energy.

512,853 MWh

the extra energy generated at Cory Riverside Energy over a landfill gas operation treating the same amount of waste

AVOIDED CARBON EMISSIONS AND ENERGY GENERATION

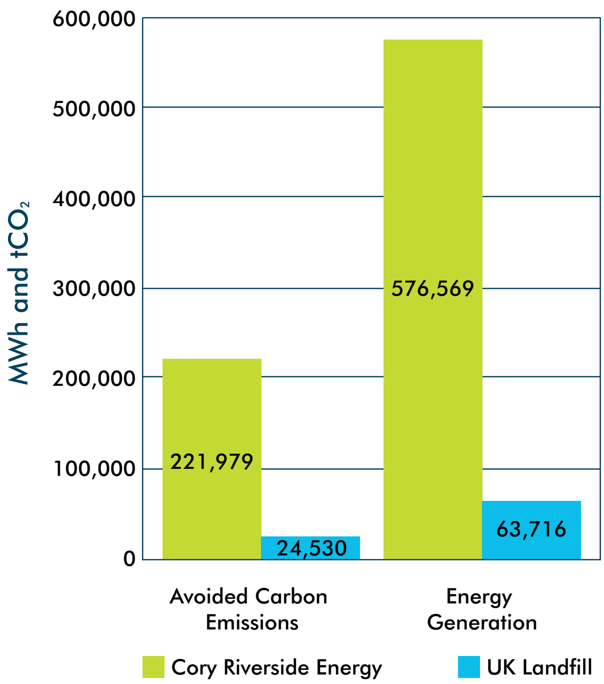


Figure 4 *Cory Riverside Energy vs Landfill*

28 See GOV.UK Electricity Grid Emissions Factors here

2.6 Aggregate Replacements

Aggregate replacement using both recycled Incinerator Bottom Ash (IBA) and Air Pollution Control Residues (APCR) can have significant carbon and wider environmental benefits. The Riverside EfW facility produces circa 200,000 tonnes of IBA and 17,500 tonnes of APCR per annum. IBA is used as a construction aggregate. APCR is used to make building blocks.

The benefits of this recycling has been assessed in many academic papers with varying but substantial levels of positive support for CO_2 emissions savings from aggregate recycling[29]. Cory Riverside Energy choses to work with third party aggregate recyclers such as Ballast Phoenix, Carbon8 and Castle Environmental to ensure that these by-products of the EfW process are turned back into a reusable aggregate. CO_2 savings from IBA and APCR are not directly claimed by Cory Riverside Energy in the carbon model utilised in this study. Furthermore, the carbon footprint from transport under the operations control of Cory is excluded from this model. Given its small percentage (<0.1 %) we consider it de-minimis to overall report and its findings.

10,000

tonnes of Air Pollution Control Residue recycled to create building blocks for use in construction

200,000

tonnes of ash used as aggregate to build roads

29 See aggregate recycling papers (Burnley et al., 2015; Grosso et al., 2011 and Rigamonti et al., 2012)

"Using the River Thames as a 'green highway', the Cory fleet of five tugs, more than 50 barges and in excess of 1,500 containers transport c.1 million tonnes of residual waste and aggregate per year. In doing so, the 'green highway' saves carbon and removes 100,000 vehicles movements from London's congested roads."

3.0 Results

Through our 'green highway' and efficient energy generation, this study has demonstrated that the Cory Riverside Energy operation is a significantly more environmentally beneficial method of managing residential municipal waste than landfill. The results from the carbon models are provided below. A net carbon footprint is set out for both models: Cory Riverside Energy and Landfill (see *Table 11* and *Figure 5*).

Carbon Models	1 Transfer Stations	2 Transport	3 Process	4 Avoided Fossil Fuels	Total
Scenario	tCO_2e	tCO_2e	tCO_2e	tCO_2e	Total tCO_2e
Cory Riverside Energy	4,160	5,163	318,269	(221,979)	**105,613**
UK Landfill	-	18,642	260,111	(24,530)	**254,223**
Net Carbon Saving (tCO_2e)	(4,160)	13,478	(58,157)	197,449	**148,610**

Table 11 *Carbon Model Comparison*

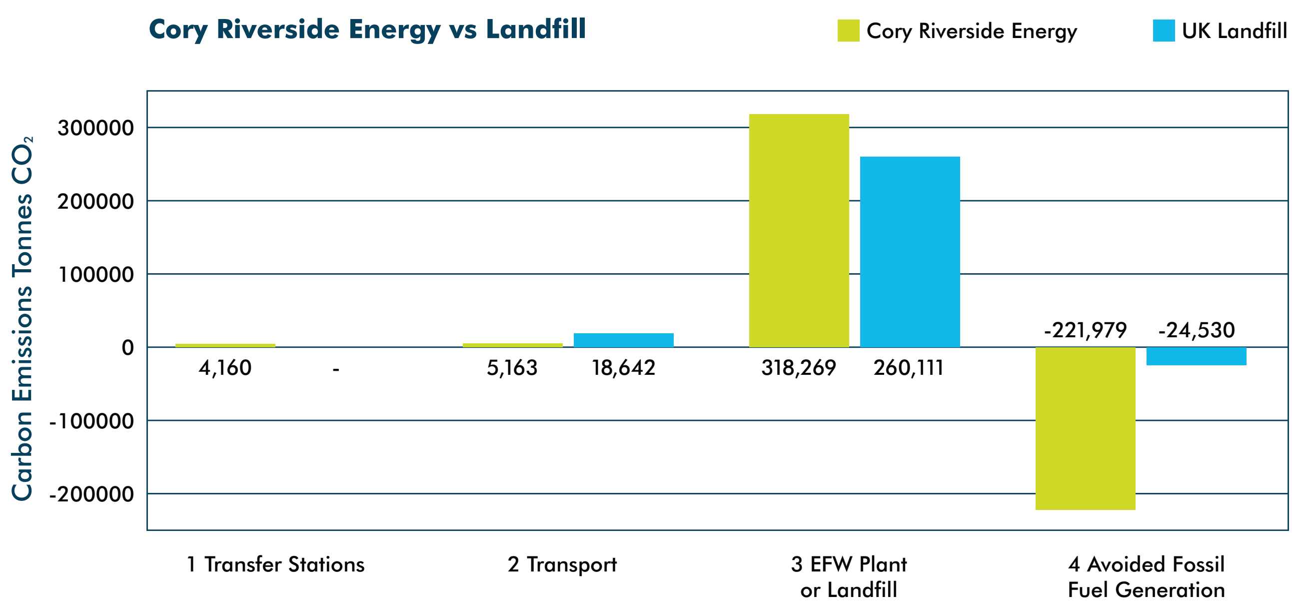


Figure 5 *Carbon Model Results: Cory vs Landfill*

3.1 Findings

Findings indicate a strong carbon case, and associated wider benefits from the Cory Riverside Energy process:

1. POSITIVE ENVIRONMENTAL IMPACT

Cory's holistic process resulted in a net reduction of approximately 149,000 tonnes CO_2 when compared to disposing the same quantity of waste in a landfill. This is a carbon saving of circa 212 kg CO_2 per tonne of waste handled.

2. RENEWABLE ENERGY

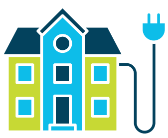
Riverside EfW produces over 9 times the amount of exportable electricity in comparison to landfill processing the same amount of residual waste.

3. EFFICIENT PROVEN TECHNOLOGY

The Riverside EfW facilities R1 recovery status demonstrates an efficient modern operation. Riverside EfW maximises energy generation supplied to UK National Grid while minimising environmental impacts.

4. 'GREEN HIGHWAY' ON RIVER THAMES

The Green Highway on River Thames has large carbon benefits; it saves circa. 13,500 tonnes CO_2 per annum when compared with standard road based waste transport. It reduces up to 100,000 lorry movements on London's roads.



5. ENERGY SECURITY

Riverside EfW powers the equivalent of 160,000 homes per annum with reliable, locally sourced baseload electricity from UK citizens waste. This creates less dependence on imported fossil fuels. It complements other renewable energy sources such as wind and solar.

6. COST EFFECTIVE

Energy from waste reduces costs to consumers through reductions in landfill taxes and dependency on the price volatility of imported fossil fuels.

3.2 Sensitivity Analysis

To further enhance this study, the sensitivity of the model output to the input assumptions in energy from waste and landfill was tested. It was found to be highly sensitive to changes in:

- Carbon intensity of displaced energy source;
- Proportion of decomposable carbon going to methane at landfill; and
- Landfill gas capture rates

To assess how variations in inputs affect overall carbon benefits from EfW over landfill, the unit of comparison used is kilograms CO_2 saved by EfW over landfill in treating one tonne of waste. For reference, a 2014 Green Investment Bank analysis has this saving across their portfolio at 200 kg CO_2 per tonne residual waste[30].

CARBON INTENSITY OF DISPLACED ENERGY SOURCE

Comparison with other energy generation methods gives different results due to the differing carbon intensity of the energy source being offset. This study has adopted UK Government guidance and compared output to CCGT. However, there is acknowledgement in academic literature that this may be a flawed approach[31 32]. If Riverside EfW and landfill were assumed to offset energy generated from the UK grid emissions factor, or a CCGT: Coal mix, this would significantly increase the carbon benefit of energy from waste over landfill due to the increased electricity produced by EfW over landfill from same amount of waste. *Table 12* describes the influence that changes to carbon intensity of displaced energy source has on the performance of EfW over landfill.

Scenario	EfW Carbon Saving *(kg)*
Per tonne waste	
CCGT (used in model) (0.385 kg CO_2 per kWh)	212
UK Grid Emissions Factor (0.412 kg CO_2 per kWh)	232
CCGT 70%: Coal 30% (0.539 kg CO_2 per kWh)	325

Table 12 *Influence of energy mix used in calculating savings*

30 Green Investment Bank, 2014: UK Residual Waste Market. See here

31 Burnley, Stephen; Coleman, Terry and Peirce, Adam (2015). Factors influencing the life cycle burdens of the recovery of energy from residual municipal waste. Waste Management, 39 pp. 295–304. See here

32 Lund, H., Mathiesen, B.V., Christensen, P. et al. Int J Life Cycle Assess (2010) See here

CHANGES IN DECOMPOSABLE CARBON GOING TO METHANE AT LANDFILL

The study is highly sensitive to the level of sequestration assumed, especially at high biogenic content. In the modelling the assumed proportion of decomposable C going to methane is 27%. This is in line with Defra 2014 study. By reducing the level of carbon sequestration at landfill; hence increasing the DDOC proportion, the amount of methane released to atmosphere is increased. This results in a significant increased carbon benefit of EfW over landfill. Similarly, if more carbon is sequestered at the landfill, less escapes to atmosphere at methane reducing carbon savings (see *Table 13*).

Scenario	Landfill Emissions	EfW Carbon Saving *(kg)*
Per tonne waste		
DDOC 21%	202,309	139
DDOC 27% (used in model)	260,111	212
DDOC 33%	327,548	299

Table 13 *Influence of Decomposable Carbon proportion (DDOC)*

Scenario	Landfill Emissions	EfW Carbon Saving *(kg)*
Per tonne waste		
Landfill (60% gas capture)	306,014	281
Landfill (66% gas capture)	260,111	212
Landfill (75% gas capture)	229,510	109

Table 14 *Landfill Gas Capture Rates*

LANDFILL GAS CAPTURE RATES

The modelled level of methane release from landfill is dictated by the landfill gas capture rate. In the Defra 2014 study, three scenarios are analysed to represent landfill gas capture: high methane emissions (50 % gas capture); central methane emissions (60% gas capture) and low methane emissions (75% capture). Level of landfill gas capture is a controversial debate in this area. A 2006, Eunomia Report[33] indicates that there is very little in the way of field measurements to substantiate the use of the Defra high gas capture rate (75%). It also notes that field measurement from The Netherlands gives figures of between 10-55% for instantaneous gas capture and average rates of 25%. Default values for reporting to the IPCC are specified around 20%. The modelled assumption used in our analysis was 66% gas capture. Using a higher value for landfill gas capture is a defensible way of being conservative and not over-estimating the benefits from EfW over landfill. It should be clearly stated that lifetime gas capture rates from a landfill are unlikely to reach 66%. *Table 12* compares the carbon emissions that arise from landfill all else being equal at 60% capture, 66% capture and 75% gas capture (see *Table 14*).

Reducing the proportion of landfill gas captured significantly increases the carbon emissions associated with treating residual waste at landfill; this significantly increases the carbon benefit of Riverside EfW over landfill. Similarly increasing the landfill gas capture rate to 75%, over the level modelled in this report would result in a lower carbon saving from EfW over landfill. There are overall carbon benefits for EfW over landfill across all the variable scenarios that were looked at in this sensitivity analysis. Furthermore, following investigation in this sensitivity analysis, the results used in this reports' carbon model are conservative.

32 See Eunomia 2006 Report here

Summary

The results from this study indicate a strong carbon saving by sending residual waste for EfW treatment at Cory Riverside Energy as opposed to landfill disposal.

The general trends exemplified by all modelling supports this statement. The level of carbon saving is very dependent on the level of landfill gas capture and undoubtedly more research is required to estimate this in an accurate manner. Much more work is also required to better understand the level of sequestration; subsequently DDOC proportion in landfills to remove the present considerable uncertainty. The biogenic content of waste has an influence on the results of this study. The higher the biogenic content of waste, the better performance of Riverside EfW against landfill. Cory Riverside Energy are already taking steps to actively understand and maintain their highest possible biogenic content in waste treatment process. This includes quarterly monitoring of composition of waste entering the facility. As with all modelling results, the above should be interpreted with a suitable degree of caution. One limitation of comparing energy recovery to landfill is different time scales. In energy recovery CO_2 is emitted during incineration; at landfill CO_2 emissions occur over a much longer time frame. This is an inevitable limitation in any study of this nature, however it does not invalidate the findings or conclusions.

"By minimising waste to landfill and maximising energy generation through our efficient plant operation, we provide a unique waste management solution that generates a secure supply of affordable, low carbon renewable energy."

4.0 Conclusions

The key conclusions of this study mirror the research aims:

1.

The 'green highway' saves circa. 13,500 tCO_2 per annum. This is the equivalent to removing 100,000 lorry movements from London's roads. The 'green highway' has other wider benefits to the people of London.

2.

Cory Riverside Energy's local waste disposal solution reduces UK carbon emissions. Circa.149,000 tonnes CO_2 are saved annually by diverting waste from landfill and generating energy at Riverside EfW plant. This equates to 212 kg CO_2 saved per tonne of waste handled.

3.

The Riverside EfW plant uses proven, reliable technology to generate baseload electricity that complements other renewable power sources. The facility produces enough electricity to power 160,000 homes every year.

4.

Riverside EfW is a cost effective, low carbon solution that reduces dependence on imported fossil fuels and strengthens UK energy independence.

"Cory's river based, local waste disposal and energy generation solution, has substantial carbon savings compared to road based transport and landfilling of waste."

ABOUT THE AUTHORS

Ethan O Brien is a Carbon Management Advisor at Cory Riverside Energy. Ethan graduated with an MSc from the University of Edinburgh Business School in 2014. Ethan has international work experience, developing renewable energy projects in East Africa, alongside consulting on carbon management and energy efficiency for a range of UK businesses across the manufacturing, retail, agricultural and commercial sectors. Ethan is a member of the Energy Managers Association and in the process of becoming a Chartered Energy Manager (CEM) and Member of the Energy Institute (MEI).

Nicola Topliss is the Group Environmental Manager at Cory Riverside Energy and has over 10 years' experience in the waste management industry. Nicola has always had a keen interest in the environment and has a BSc in Environmental Science from the University of East Anglia, where her interest in carbon management first started, in the Tyndall Centre for Climate Change Research. She represents the company on the Environmental Service Association's Regulations working group and the Environmental Industries Commission's Waste Management and Resource Efficiency working group. In 2010 she successfully worked on a number of carbon saving initiatives for the London Mayors' Green 500 Awards scheme, which resulted in a Platinum and Gold award for the group.

CREDITS

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LEGAL STATEMENT

CORY
RIVERSIDE ENERGY

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