Towards a better exploitation of the technical potential of waste to energy

(Draft) Final Report

20 June 2016

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Executive Summary

[The executive summary will provided with the published final report]

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1 Preface

The information and views set out in this Initial Report are those of the authors and do not necessarily reflect the official opinion of the Commission. The Commission does not guarantee the accuracy of the data included in this study. Neither the Commission nor any person acting on the Commission's behalf may be held responsible for the use which may be made of the information contained therein.

2 Glossary

Abbreviation	Terminology
ABP	Animal By Products
ACT	Accelerated Carbonation Technology
AD	Anaerobic Digestion
ADR	Advanced Dry Recovery
Al_2O_3	Aluminium Oxide
APC	Air Pollution Control
APCr	Air Pollution Control Residues
ASR	Auto Shredder Residue
ATT	Advanced Treatment Technology
BFB	Bubbling Fluidised Bed
CaO	Calcium Oxide
CBM	Compressed Biomethane
CCU	Carbon Capture and Utilisation
C&I	Commercial & Industrial Waste
CFB	Circulating Fluidised Bed
CHP	Combined Heat and Power
CO	Carbon Monoxide
CO2	Carbon Dioxide
CoP	Coefficient of Performance
CV	Calorific Value
DHN	District Heating Network
DMS	Direct Melting System
DS	Dry Solids
ECS	Eddy Current Separation
EfW	Energy from Waste (combustion)
ELP	End of Life Plastic
Fe_2O_3	Iron Oxide

Abbreviation	Terminology
FGT	Flue Gas Treatment
FGR	Flue Gas Recirculation
GHG	Greenhouse Gas
GtG	Gas to Grid
H2	Hydrogen
H2S	Hydrogen Sulphide
HCl	Hydrogen Chloride
HF	Hydrogen Fluoride
IBA	Incinerator Bottom Ash
IED	Industrial Emissions Directive
IGCC	Integrated Gasification Combined Cycle
ISWA	International Solid Waste Association
ITHP	Intermediate Thermal Hydrolysis Process
LBM	Liquefied Biomethane
MBT	Mechanical and Biological Pre-treatment
MCA	Multi Criterion Analysis
MHT	Mechanical Heat Treatment
MSW	Municipal Solid Waste
MTHW	Medium Temperature Hot Water
NCV	Net Calorific Value
NO	Nitrogen Oxide
NOx	Nitrogen Oxides
NO2	Nitrous Oxide
NTP	Non-Thermal Plasma
PCDD/F	Polychlorobenzodioxins and Furans
PE	Polyethylene
PP	Polypropylene
PVC	Polyvinylchloride
PWN	Private Wire Network
RED	Renewable Energy Directive
RDF	Refuse Derived Fuel
RFB	Revolving Fluidised Bed
ROCs	Renewable Obligation Certificates
SCR	Selective Catalytic Reduction
SiO_2	Silicon Dioxide
SNCR	Selective Non-Catalytic Reduction

Abbreviation	Terminology
SOx	Sulphur Oxides
SO2	Sulphur Dioxide
SRF	Solid Recovered Fuel
TDP	Thermal Depolymerisation
THP	Thermal Hydrolysis Process
TIF	Twin Interchanging Fluidised Bed
TOC	Total Organic Carbon
TRL	Technology Readiness level
UCO	Used Cooking Oil
WHPG	Waste Heat Power Generation
WID	Waste Incineration Directive
WtE	Waste to Energy

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3 Introduction

In 2016, as part of the Energy Union Package, the Commission plans to issue a Communication on Waste-to-Energy (WtE). The aim of the Communication is to maximise the potential of WtE, by facilitating a joined-up approach in both energy and resource efficiency policies, and the transition to a Circular Economy.

Member States are obliged under the EU's revised Waste Framework Directive (Directive 2008/98/EC) to apply as a priority the waste hierarchy, which ranks waste management options in order of environmental preference. Energy recovery can represent a sustainable option for waste that is genuinely residual, that is, that cannot be prevented, reused or recycled, by diverting it from landfill with resultant lower greenhouse gas emissions and economic, social and environmental benefits (e.g. avoided methane emissions).

It is also recognised that efficient energy recovery from residual waste can enhance environmental benefits compared to landfill disposal, make an important contribution to the EU's renewable energy targets, and help provide energy security throughout Member States. However, there is currently a gap between the potential for, and delivery of, WtE that is resulting in valuable resources going to landfill.

The waste hierarchy options of prevention, reuse, recycling and recovery are not mutually exclusive and recovering energy from waste is not incompatible with increasing recycling rates. However, a wide range of pre-treatment and thermal treatment technologies exist that are technically proven and commercially available in the EU and globally, and many others are available at different stages of their development cycle around the world. The selection of the most environmentally and commercially sustainable technology for a defined set of circumstances can be challenging and represent a perceived barrier to investment.

Energy recovery technologies include conventional technologies (both direct combustion and the combustion of waste-derived fuel) and advanced conversion technologies (ACT). ACT technologies are broadly categorised into:

- Pyrolysis;
- Gasification processes (including emerging waste treatment technologies such as plasma arc gasification and a combination of pyrolysis and gasification); and
- Liquefaction processes to produce fuels.

Whilst energy recovery from municipal solid waste (MSW) is well established, there are now an increasing range of commercial and industrial waste streams from which energy recovery is being considered as an alternative to landfill. Developments in WtE technologies have also led to an increased flexibility in how the intermediate products of energy recovery can be used, i.e. the conversion of biogas in to a vehicle fuel or injection to a gas grid, or the conversion of products of pyrolysis in to chemical commodities.

Previous work has provided extensive data for the production and use of waste-derived-fuels within the European Union, mainly for the year 2008. However a more dynamic approach is now required to provide more contemporary data up to 2014, to identify trends in the development of WtE in each Member State, provide an outlook on the future of WtE techniques and provide a more comprehensive analysis on the generation of different forms of energy and other outputs from WtE.

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Whilst WtE is prevalent in some Member States, less than 5% of all waste was used for energy recovery across the EU28 in 2012. Landfill still dominates waste management in many EU countries.

4 Purpose of the Study

This study is aimed at supporting the forthcoming 2016 Communication by delivering a robust and up-to-date examination of the current landscape of WtE in the EU, whilst also investigating how proven and innovative technologies may play a role in increasing the potential of WtE operations. This is split into four tasks:

- Task 1: Provide an analysis of the current use of waste streams for energy recovery in the EU-28:
    - Sub-task 1.1: Produce a comprehensive database for the generation, use and energy production from 20 waste streams for the EU-28 over the period 2009 to 2014; and
    - Sub-task 1.2: Identify the main trends in the deployment of WtE in each Member State and provide an explanation as to why WtE has evolved differently across the EU-28.
- Task 2: Provide an analysis of the technical improvement potential for Waste-to-Energy.
    - Task 2.1: This task identifies techniques that demonstrate the greatest potential to improve current WtE operations, without resulting in a negative impact on the environment or human health when compared to existing WtE operations.
    - Task 2.2: For each of the techniques identified in Task 2.1, an evaluation has been performed. This evaluation considers two key criteria: net annual average energy efficiency and applicability. This process has identified the WtE techniques with the highest potential, which will be subject to a more detailed analysis in the next phase of the study.
    - Task 2.3: Detailed analysis of WtE techniques. The approach for the detailed analysis of the techniques identified as having the highest potential will be validated at the expert workshop.
- Expert Workshop: An expert workshop was held on 09 March 2016 to obtain input to the study from key stakeholders. The feedback from the workshop and subsequent written feedback from stakeholders has been incorporated into the methodology and content of the report.
- Task 3: The objective of this final task is to draw together the current status and use of waste streams which are appropriate for the production of energy (from Task 1) with the WtE technical improvement potential identified in Task 2.

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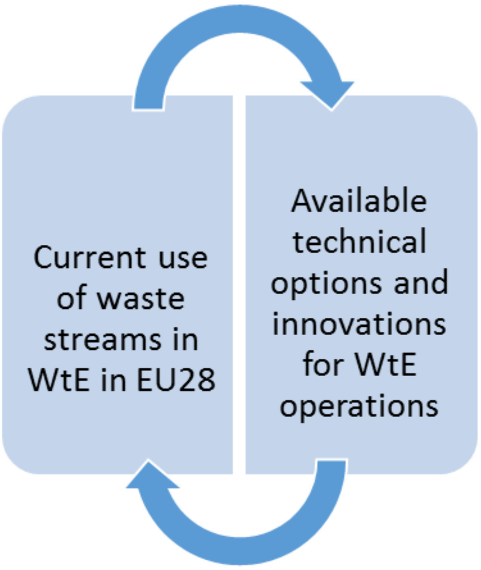

This report and its conclusions will help inform the JRC-IPTS' input to the 2016 Communication by DG Environment, highlighting how industry and governments can improve the WtE landscape by providing guidance, improving knowledge and understanding to remove barriers to WtE technologies by ensuring information is available and readily understood, and to provide guidance to communicate the full range of technologies available for a wide range of wastes and waste derived fuels.

4.1 Purpose of the study in relation to ongoing BREF work

This JRC-IPTS is currently updating the Waste Incineration Best available techniques REFerence document (the WI BREF) which was first published in 2006 and is due for revision in 2016. This objective of the updated WI BREF is to establish new benchmarks for the environmental performance of waste incineration plants over the next decade but does also include a consideration of energy performance.

The authors of this study have consulted with the BREF Working Groups to ensure that this study does not conflict with the updated WI BREF (or any other BREF for that matter) and it is confirmed that this study is not intended to take the place of the BREF document.

4.2 Study constraints

This study is solely focussed on identifying opportunities to better exploit the technical potential of WtE when a waste cannot be prevented, recycled or reused. Therefore, the study does not include:

- Analysis of non-waste fuels (e.g. virgin biomass);
- Analysis of techniques for landfill gas capture to produce biogas for power generation;
- Techniques focussed on recycling;
- A consideration of commercial aspects which may restrict the implementation of the technical potential of WtE; or
- A detailed analysis of the mass / energy balance for each technique or for any pre-treatment which is required to implement a technique.

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5 Task 1 - Analysis of the current use of waste for energy recovery in the EU-28

Task 1 aims at providing an analysis of the current use of combustible wastes in Waste-to-Energy operations in the EU-28.

5.1 Scope of the study

5.1.1 Scope of combustible wastes studied

Definition of waste as part of this study

As part of this study, waste definition is based on the Waste Framework Directive (WFD) (2008/98/EC) as any substance or object which the holder discards or intends to or is required to discard.

Substances and materials, which are residues of production or consumption processes, may or may not be waste, and a distinction between residue, and waste should be made.

In particular, the WFD includes in Article 5 a definition of by-products and the main conditions which must be met by a substance or object to be classified as a by-product. A substance or object, resulting from a production process, the primary aim of which is not the production of that item, may be regarded as not being waste but as being a by-product only if the following conditions are met:

(a) Further use of the substance or object is certain;

(b) The substance or object can be used directly without any further processing other than normal industrial practice;

(c) The substance or object is produced as an integral part of a production process; and

(d) Further use is lawful, i.e. the substance or object fulfils all relevant product, environmental and health protection requirements for the specific purpose and will not lead to overall adverse environmental or human health impacts.

Type of wastes included in the scope of the study

The scope of the study includes solid, liquid and gaseous combustible wastes that can be used as energy sources. They can be divided in two categories:

- Combustible wastes that are always waste-derived, but not necessarily transformed into fuels (e.g. wood waste, waste oil, sorted residues), called “waste streams” in this report;
- Combustible wastes that are always used as fuels, but which can also be derived from non-waste feedstock (e.g. biodiesel, bioethanol, biogas), called “waste-derived fuels” in this report. For this category the scope of the study is limited to the share of fuel that is waste-derived. Note that waste-derived fuels such as biodiesel and biogas can be produced from waste streams within the scope of this study. This problem is further discussed in paragraph 5.1.3 in relation to the risk of double counting.

In this study, “combustible wastes” is a generic expression used to refer to “waste streams” **and** “waste-derived fuels”.

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In addition, energy from combustible waste that has already been subjected to treatment and disposal is out of the scope of the present study. Therefore, landfill gas and urban mining won't be discussed in the present study.

Scope of the study in accordance to the hierarchy for waste management

The scope of the study is in line with the hierarchy for waste management as defined by the Waste Framework Directive. Therefore, it focuses on combustible wastes that are non-preventable, non-reusable and non-recyclable in an economically and environmentally sound way. As a consequence, it should not be seen as a stimulus for more energy recovery when options are available that are ranked higher in the waste hierarchy.

However, considering that the technical, economic and environmental feasibility of waste material recovery changes with time and geography, the scope of the study also includes combustible wastes that are currently recycled in some parts of Europe, such as plastic wastes, waste oil, etc.

List of combustible wastes studied

The list of combustible wastes studied is partially based on the scope of the Waste Framework Directive. According to the provisions of WFD Article 2[1], this excludes in particular straw and woodchip. In addition, this study also includes animal faeces and sludge that are not considered in the WFD.

The constitution of this list is based on two main sources of information (see Table 1.1):

1) The list of the main combustible wastes sent for incineration (with and without energy recovery). This information comes from Eurostat Waste Statistics.
2) The list of 18 combustible wastes studied in the 2011 second interim report from Umweltbundesamt (UBA) called "Waste-derived fuels: Characterisation and suitability for end-of-waste" (referred as "UBA 2011 report" in the rest of the document).

List of 18 combustible wastes studied in this report:

- Waste streams
    1. Wood waste
    2. Plastic waste
    3. Paper waste
    4. Textile waste
    5. Waste tyres and waste rubber
    6. Waste oil (used oils)
    7. Waste solvents
    8. Chemical waste
    9. Household and similar waste
    10. Mixed and undifferentiated materials
    11. Sorting residues
    12. Animal and vegetal waste

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[1] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0098

13. Dried/dewatered municipal sewage sludge

- Waste-derived fuels:
  14. Biogas
  15. Biodiesel
  16. Bioethanol
  17. Gaseous output from gasification
  18. Gaseous, liquid and solid output from pyrolysis

Production and treatment of Solid Recovered Fuels (SRF) is addressed in paragraph 5.3.11 on sorting residues.

According to Table 1.1, the list of 18 studied combustible wastes account for 97% of the total maximum energy potential of all combustible wastes sent for incineration (with and without energy recovery) in EU-28 in 2012.

<u>Using the "maximum energy potential" to compare the waste-to-energy potential for several combustible wastes</u>

In Table 1.1, the maximum energy potential is calculated by multiplying the amount of combustible wastes sent for (co)incineration[2] by their average lower heating values (based on various sources detailed in Annex 1). This calculated data does not take into account technology energy efficiencies. Therefore, it does not provide an estimate of the current energy produced from waste, but it can be used to compare the potential for waste-to-energy production from various combustible wastes.

Table 1.1: Total energy potential from waste incineration (D10 +R1) in the EU-28 in 2012 (Source: Eurostat Energy Statistics and Deloitte from calculations) – in blue, waste categories included in the list of 18 combustible wastes

	Total incinerated (R1 + D10) 1000 tonnes or million Nm^3	Lower Heating Value MJ/kg or MJ/Nm^3	Total maximum energy potential		Related combustible wastes category(4)
			PJ	%	
Waste streams					
Animal and vegetal wastes (1)					
Animal and mixed food waste	2 080	28	35	2%	12
Animal faeces, urine and manure	1 030	12	12	1%	
Vegetal wastes	1 750	17	28	1%	
Chemical and medical wastes (1)					
Acid, alkaline or saline wastes	130	n.a.	0	0%	
Chemical wastes	3 740	25	93	5%	8
Health care and biological wastes	1 150	24	28	1%	
Industrial effluent sludges	2 700	10	26	1%	
Sludges and liquid wastes from waste treatment	370	10	4	0%	

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[2] Based on Eurostat Waste Statistics, Eurostat Water Statistics and Eurostat Energy Statistics databases, and other information provided by European experts and federations.

	Total incinerated (R1 + D10) 1000 tonnes or million Nm^3	Lower Heating Value MJ/kg or MJ/Nm^3	Total maximum energy potential		Related combustible wastes category(4)
			PJ	%	
Spent solvents	1 110	28	29	2%	7
Used oils	470	31	32	2%	6
Common sludges (3)					
Common sludges	3 260	10	22	1%	14
Equipment (1)					
Batteries and accumulators wastes	0	n.a.	0	0%	
Discarded equipment	40	15	1	0%	
Discarded vehicles	0	n.a.	0	0%	
Waste containing PCB	10	15	0	0%	
Mineral and solidified wastes (1)					
Combustion wastes	630	15	0	0%	
Dredging spoils	0	n.a.	0	0%	
Mineral waste from construction and demolition	1 460	5	8	0%	
Mineral wastes from waste treatment and stabilised wastes	220	n.a.	0	0%	
Other mineral wastes	230	n.a.	0	0%	
Soils	50	11	1	0%	
Mixed ordinary wastes (1)					
Household and similar wastes	52 180	9	470	25%	9
Mixed and undifferentiated materials	11 480	13	149	8%	10
Sorting residues	22 280	15 [3]	334	18%	11
Recyclable wastes (1)					
Glass wastes	0	n.a.	0	0%	
Metal wastes, ferrous	40	n.a.	0	0%	
Metal wastes, mixed ferrous and non-ferrous	0	n.a.	0	0%	
Metal wastes, non-ferrous	10	n.a.	0	0%	
Paper and cardboard wastes	340	17	6	0%	3
Plastic wastes	1 700	36	61	3%	2
Wastes tyres	1 090	29	35	2%	5
Textile wastes	140	17	2	0%	4
Wood wastes	27 960	13	375	20%	1
Waste-derived fuels (2)					
Waste-derived biogas	8 470	26	108	6%	15
Waste-derived biodiesel	381	37	19	1%	16

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[3] The calorific value of sorting residues depends on the waste treated and the degree of sorting. Good sorting can produce a residue with a calorific value higher than 15 MJ/kg

	Total incinerated (R1 + D10) 1000 tonnes or million Nm^3	Lower Heating Value MJ/kg or MJ/Nm^3	Total maximum energy potential		Related combustible wastes category(4)
			PJ	%	
Waste-derived bioethanol	~0	n.a.	~0	0%	17
Gaseous output from gasification	~0	n.a.	~0	0%	18
Gaseous, liquid and solid output from pyrolysis	~0	n.a.	~0	0%	19
Total	138 156 (5)		1 878	100%	

(1) Categories used in Eurostat Wastes Statistics (see descriptions in following paragraphs).
(2) Categories not included in Eurostat Wastes Statistics, but used in the UBA 2011 report (see descriptions in following paragraphs).
(3) Category used in Eurostat Water Statistics (see descriptions in following paragraphs).
(4) The numbers refer to the above list of 18 combustible wastes
(5) Total in 1000 tonnes excluding biogas
(6) n.a. = not applicable

5.1.2 Scope of the data

5.1.2.1 Period for data collection

Data has been collected for the period 2006-2016. The Eurostat waste statistics database is the main source of information and it provides information at two years intervals. 2014 waste statistics were not available at the moment this project was elaborated, so 2012 is the most recent year for which waste statistics data could be used.

5.1.2.2 Type of data to be collected

For each EU-28 country data collection focused on the following information:

- Amount of combustible waste generated.
- Import/export outside of EU-28 is also studied whenever relevant.
- Amount of waste treated, for the following categories[4]:
    - Incineration / Energy recovery (R1)
    - Incineration on land/ Disposal (D10)
    - Disposal (D1, D2, D3, D4, D5, D6, D7, D12)
    - Recovery other than energy recovery (R2 to R11)
- Amount of energy produced, for the following categories:
    - Conversion into heat with direct use: mostly relevant for cement kilns
    - Conversion into heat for steam production
    - Conversion into electricity
    - Biogas conversion into biomethane

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[4] Definitions of waste treatment methods and related categories (R1, D10, etc.) are provided in the Eurostat Manual on waste statistics

Waste treatment categories should be understood as follows[4]:

- Recovery other than energy recovery means any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy.

  Note, that recycling is a subset of recovery and means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material (e.g. composting, anaerobic digestion etc.) but excludes the use as fuels and the use for backfilling operations.

  In this report, "material recovery" is used to refer to "recovery other than energy recovery".

- Disposal means any operation which is not recovery even where the operation has as a secondary consequence the reclamation of substances or energy.

Annex 2 also provides the definition of all treatment methods for recovery (R1 to R10) and for disposal (D1 to D12).

5.1.3 Risk of double counting

To provide an overview of the combustible waste generation and treatment in the EU-28, it is necessary to add the figures for the 18 combustible wastes studied (see Table 1.1). However, the result is not correct as some wastes and counted more than once. As part of the present study, double counting mostly occur in the following situations:

- Eurostat data on waste generation: for consistency reasons, the current methodology for the estimation of combustible waste generation use, as much as possible, data from the Eurostat Waste Statistics database. As explained in further details in paragraph 5.5.1, Eurostat data on waste generation shall cover all waste (primary and secondary waste) generated by the statistical units which means that double counting of waste is part of the concept. This means that "sorting residues" are already accounted for as part of other waste streams.

- Eurostat data on waste treatment: only waste sent to final treatment should be reported to Eurostat; treated waste should thus be counted only once. However, there is also evidence of double counting for MSW sent to MBT (Mechanical Biological Treatment) plants.

- Waste-derived biogas production: in Eurostat Waste Statistics the fermentation of biodegradable wastes for biogas production is not accounted for under the categories "incineration" or "energy recovery", but under the category "recovery other than energy recovery" along with other treatment methods (such as composting). Therefore, it is not possible to estimate the production of waste-derived biogas for each organic waste streams studied (in particular for "Animal and vegetable waste" (A&VW) and "Municipal sewage sludge" (MSS)). Waste-derived biogas is studied separately, which represents double counting of a kind. However, waste-derived biogas is expressed in Nm^3 (whereas other waste-derived biogas feedstocks (A&VW, MSS) are in tonnes), and energy production from these feedstocks is only accounted once, because Eurostat Waste Statistics database does not provide it.

- Waste-derived biodiesel: most of waste-derived biodiesel production in the EU-28 comes from waste edible oil and fat, which are also included in the waste category "Animal and vegetable wastes". However, data on edible oil and fat generation and treatment are difficult to find and most data provided by Member States to Eurostat does not account for it. Considering that waste-derived biodiesel represents a

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growing market for energy recovery it was decided to study it as a separate combustible waste.

5.2 Methodology for task 1

5.2.1 Methodology for creation of the database

The figure below describes the 4 steps methodology used to create the database.

Step 1: draft database

In order to ensure harmonised and consistent results with the 2011 study from UBA, for combustible wastes that are in common to both studies, data collection started with the methodology and key assumptions used by UBA. The construction of the draft database was completed with up-to-date bibliographic research.

Step 2: discussion with European federations

Key EU federations were contacted to discuss the main assumptions of the draft methodology. The draft database is then updated according to their feedbacks.

Step 3: workshop with national and European experts

The updated database and first elements of data analysis were presented in a background document. This document was sent to national and European experts invited to attend a one day stakeholder workshop organized in Seville. Following this workshop, numerus inputs were received. Methodological inputs (assumptions, ratios used, other existing databases) were implemented. Inputs related to specific national data were not used in the calculations for consistency reasons. They were taken into account to analyse the robustness of the results.

Step 4: final database

Final database compilation.

5.2.2 Analysis of the trends at European and national level

The analysis is based on compiled databases for the years 2006 to 2012 (or later whenever available). For trends related to waste treatment method, a specific focus was made on the waste hierarchy. In addition, Member States were asked to provide inputs to explain unexpected past evolutions or outlook on developments of waste management practices. Whenever provided, these explanations are included in the analysis of the trends.

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5.3 Results of waste streams data collection and analysis

5.3.1 Wood wastes

Generation of wood wastes

Data on the generation of wood wastes comes from Eurostat Waste Statistics.
In Eurostat, the EWC-Stat category “07.5 Wood wastes” contains hazardous and non-hazardous wastes.

Description of the category and main NACE sectors that produce wood wastes according the Eurostat Manual on waste statistics[5]:

"Wood wastes (07.5): These wastes are wooden packaging, sawdust, shavings, cuttings, waste bark, cork and wood from the production of pulp and paper; wood from the construction and demolition of buildings; and separately collected wood waste. They mainly originate from wood processing, the pulp and paper industry and the demolition of buildings but can occur in all sectors in lower quantities due to wooden packaging. Wood wastes are hazardous when containing hazardous substances like mercury or tar-based wood preservatives."

Table 1.2: Evolution of the generation of wood wastes per Member State (Source: Eurostat Waste Statistics)

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	Wood waste generation (1000 tonnes/yr)			
	2006	2008	2010	2012
Austria	6 300	6 232	1 295	888
Belgium	1 797	1 573	2 779	4 193
Bulgaria	161	327	115	201
Croatia	199	195	174	97
Cyprus	33	17	24	14
Czech Republic	638	248	303	238
Denmark	864	892	304	232
Estonia	1 791	1 288	871	816
Finland[6]	13 338	12 477	12 281	11 941
France	7 478	8 682	8 945	6 051
Germany	8 835	10 271	10 812	11 713
Greece	745	830	350	121
Hungary	482	336	287	242
Ireland	401	147	508	201
Italy	2 469	3 448	3 760	3 901
Latvia	240	87	87	56
Lithuania	220	231	300	182
Luxembourg	85	74	111	87
Malta	1.0	0.4	8.2	13.3
Netherlands	1 944	2 272	2 561	2 572
Poland	2 808	3 367	3 508	3 949
Portugal	1 233	736	905	824
Romania	1 466	1 806	2 340	2 058
Slovakia	768	629	239	401
Slovenia	1 154	470	334	339
Spain	1 909	1 932	1 624	1 247
Sweden	4 689	4 508	1 863	1 171
United Kingdom	7 607	4 398	2 827	3 742
Total EU-28	69 656	67 476	59 515	57 489

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[5] Additional information can be found in the "Guidance on classification of waste according to EWC-Stat categories" document.

[6] Since 2013, Finland has changed its methodology of the reporting of woos wastes to Eurostat and data for 2013 will be around 3Mt instead of 12Mt for 2012

Table 1.2 shows that EU-28 wood waste production has been consistently decreasing between 2006 and 2012 with a very significant decrease by 13% between 2010 and 2008.

Based on data from Table 1.2, Figure 1.1 shows the evolution of the generation of wood wastes for the 14 Member States responsible for more than 96% of the overall generation in 2012.

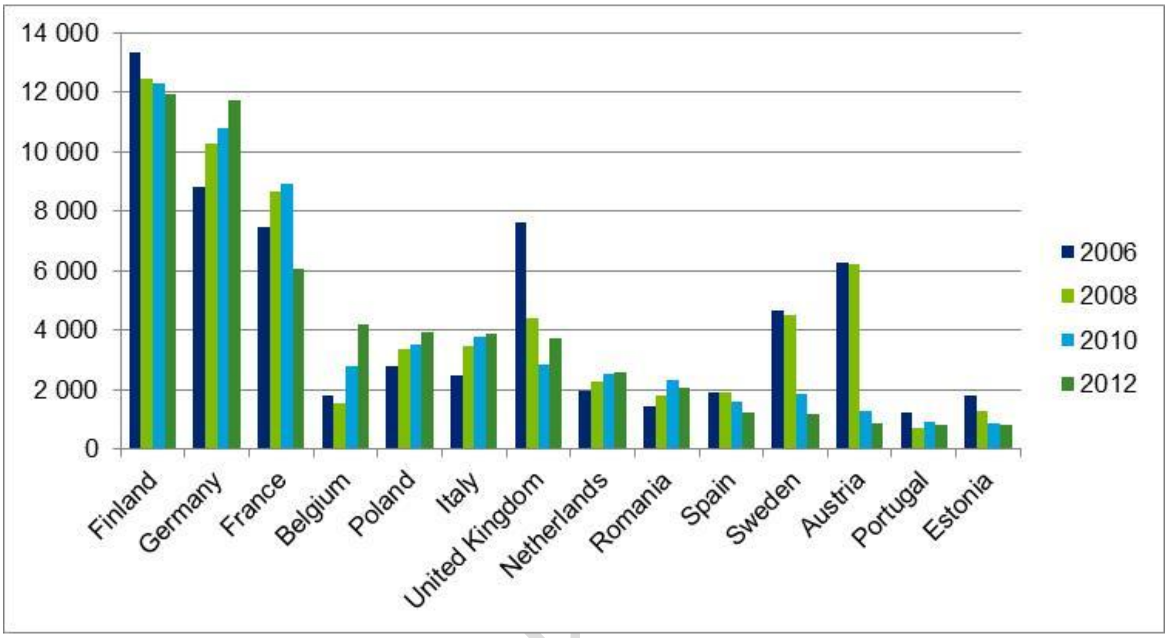

Figure 1.1: Evolution of the generation wood wastes for the 14 main EU-28 producers in 2012 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr)

Looking at the main EU-28 producers, we can see different trends among countries from 2006 until 2012. While it appears that wood waste generation is decreasing in Finland, Sweden and Austria, it is increasing in Germany and Belgium.
In the case of Spain the decrease in wood waste generation can be due to the fall of the construction sector since 2008, which demanded a significant amount of wood products. No further information was provided by Member States that might explain the figure.

Please note that wood waste reporting is extremely difficult, subject to interpretation, and sometimes evolution in the reporting methodology (see Finland in Table 1.2). Indeed, it is difficult to distinguish between virgin and pretreated wood, wood waste used in production processes and wood waste used for energy recovery. Further difficulties may arise due to the fact, that wood waste is often recovered internally. Therefore, Eurostat data for wood waste generation should be used carefully.

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<u>Import/export outside of EU-28</u>

Quantities of exported and imported wood waste outside the EU-28 were collected on Eurostat COMEXT Database. Quantities are available on a monthly and yearly basis from 1988 to 2008. For the purpose of the study, yearly imported and exported quantities from 2006 to 2008 were considered. Relevant data were identified based on their CN8 code. According to the methodology used in the UBA 2011 study, the following CN8 codes were used for wood wastes:

WDF	CN8 Code	Description
Waste wood	44013090	Wood waste and scrap, whether or not agglomerated in logs, briquettes, pellets or similar forms (excl. sawdust)
	45019000	Cork waste; crushed, powdered or ground cork

Table 1.3 shows that the EU-28 has a growing negative trade balance which represented 2% of EU-28 wood wastes generation in 2006 and 3% in 2008.

Table 1.3: Evolution of wood wastes trade outside of EU-28 (Source: Eurostat COMEXT Database)

	Import/export outside of EU-28 (1000 tonnes/yr)		
	Import	Export	Trade balance
2006	1 390	137	-1 252
2008	1 917	168	-1 748
2010	NA	NA	NA
2012	NA	NA	NA
2014	NA	NA	NA

Unfortunately no data is available for the years after 2008.

Treatment of wood waste

Wood waste treatment data comes from Eurostat Waste Statistics. Eurostat provides data on material recovery for the years 2006, 2008, 2010 and 2012, but data on other treatments (energy recovery, incineration on land, and landfill) are only available for the years 2010 and 2012.

Table 1.4: Evolution of the wood wastes sent for energy recovery per Member State (Source: Eurostat Waste Statistics)

	2010 (1000 tonnes/yr)		2012 (1000 tonnes/yr)	
	Energy recovery (R1)	Incineration/ Disposal (D10)	Energy recovery (R1)	Incineration/ Disposal (D10)
Austria	330	3.8	446	0.0
Belgium	732	314.6	136	785.9
Bulgaria	89	0.2	79	0.1
Croatia	71	1.0	21	0.0
Cyprus	2	2.5	0	0.0
Czech Republic	36	0.4	26	1.3
Denmark	25	0.0	30	0.0
Estonia	265	0.0	289	0.0
Finland	7 649	15.5	8 426	44.4
France	1 601	266.5	1 614	92.5
Germany	6 915	158.5	8 260	5.2
Greece	39	0.0	11	0.0
Hungary	36	0.9	29	0.3
Ireland	73	17.0	18	0.0
Italy	867	44.8	776	12.8
Latvia	4	0.0	6	0.5
Lithuania	101	0.0	85	0.1
Luxembourg	0	0.0	0	0.0

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	2010 (1000 tonnes/yr)		2012 (1000 tonnes/yr)	
	Energy recovery (R1)	Incineration/ Disposal (D10)	Energy recovery (R1)	Incineration/ Disposal (D10)
Malta	0	0.0	0	0.0
Netherlands	904	17.5	1 043	10.8
Poland	2 582	2.8	2 286	1.6
Portugal	490	1.1	585	0.8
Romania	1 173	0.2	1 039	0.2
Slovakia	67	0.3	56	5.0
Slovenia	172	0.8	202	0.1
Spain	3	0.3	3	0.0
Sweden	1 373	1.6	1 191	2.5
United Kingdom	248	0.0	347	0.0
Total EU-28	25 840	850.0	27 000	960.0

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Between 2010 and 2012 the amount of wood wastes sent for energy recovery has increased by 4% at EU-28 level. While in most EU-28 countries this amount has been stable or slightly decreasing, the two main energy producers, Finland and Germany, have increased their amount sent for energy recovery by 10% and 19% respectively.

Figure 1.2 shows the repartition of wood waste treatment methods for the 14 EU-28 countries representing 99% of wood wastes sent to incineration and energy recovery in 2012.

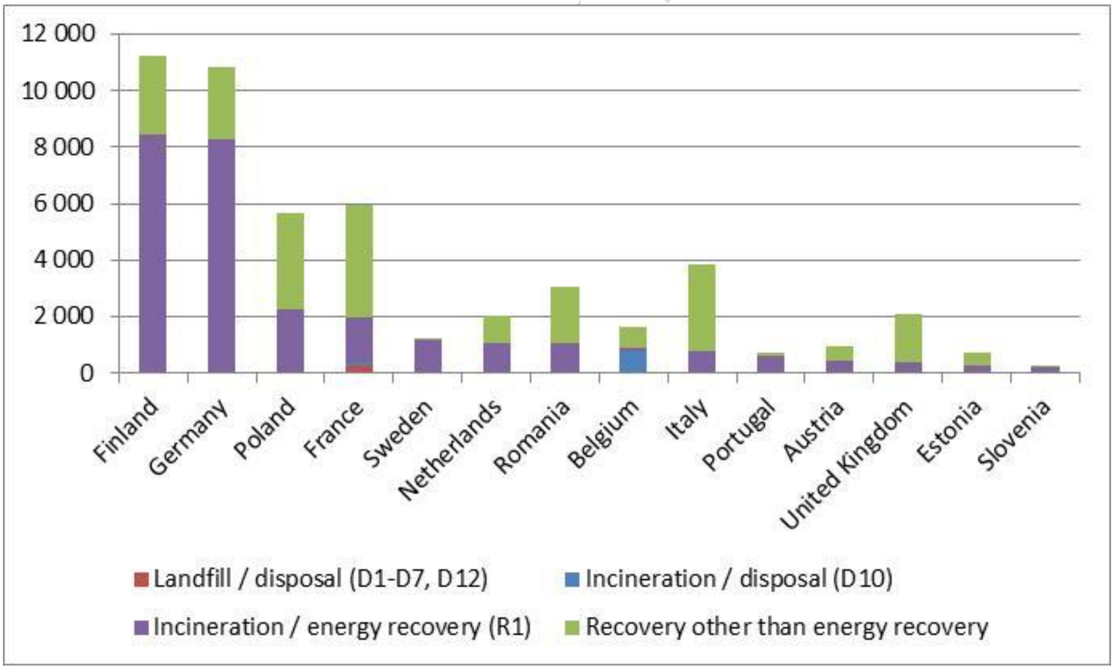

Figure 1.2: Treatments of wood wastes for the 14 EU-28 main contributors to energy production from wood waste in 2012 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr).

Figure 1.3 gives an overview of the repartition of wood waste treatment methods in EU-28 and its evolution between 2010 and 2012. While at EU-28 level similar amounts of wood wastes are sent for energy recovery and material disposal, Figure 1.2 shows that some member states have focused their treatment strategy on energy recovery while other countries send more wood wastes to material recovery.

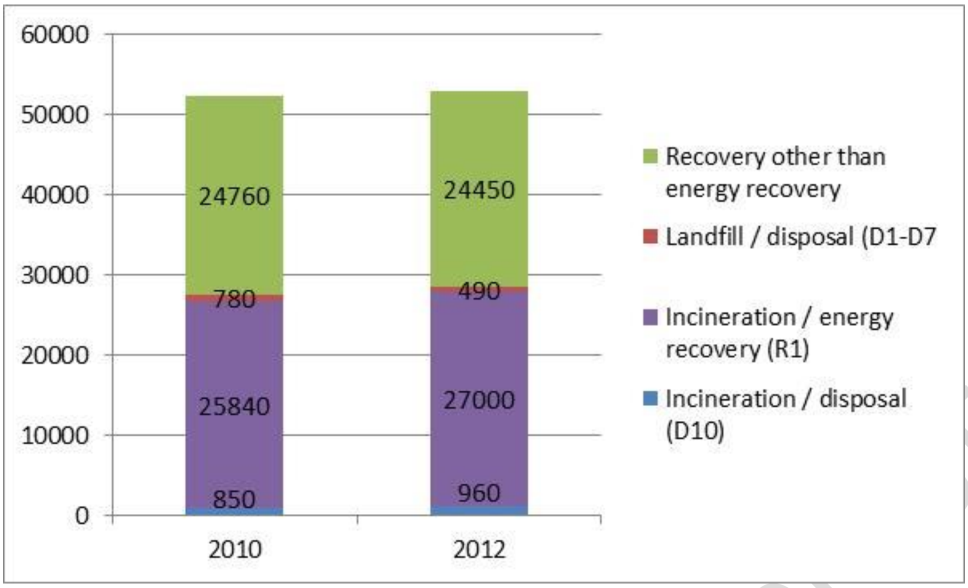

Figure 1.3: Evolution of wood waste treatment methods in EU-28 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr)

It is important to highlight that according to Eurostat, around 2Mt of wood waste is hazardous waste. Hazardous waste may contains impurities and hazardous compunds which may not be suitable to be used in co-incineration plants or additional energy consumption is required for pre-treatment of waste and emission abatement systems.

5.3.2 Plastic wastes

Generation of plastic wastes

Data on the generation of plastic wastes comes from Eurostat Waste Statistics. PlasticsEurope, the European Association of Plastic Manufacturers, provides annual data on plastic production, consumption and plastic wastes management in the EU-28. However, it is difficult to confront it with Eurostat data, because the scope is not the same: the scope of PlasticsEurope' data is broader as it represents all post-consumer plastics generated. For instance, in 2012 in the EU-28, collected post-consumer plastics wastes reached 25Mt[7], while 17Mt of plastic wastes were reported by Member States to Eurostat (see Table 1.5). PlasticsEurope data, is however useful to comment on plastic wastes trends in the EU-28.

In Eurostat, the EWC-Stat category "07.4 plastic wastes" contains only non-hazardous wastes. Description of the category and main NACE sectors that produce plastic wastes according the Eurostat Manual on waste statistics[8]:

"*Plastic wastes (07.4): These are plastic packaging; plastic waste from plastic production and machining of plastics; plastic waste from sorting and preparation processes; and separately collected plastic waste. They originate from all sectors as packaging waste, from sectors producing plastic products and from separate sorting by businesses and households. All plastic wastes are non-hazardous. A distinction*

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[7] http://www.plasticseurope.org/Document/plastics-the-facts-2012.aspx

[8] Additional information can be found in the "Guidance on classification of waste according to EWC-Stat categories" document.

should be made between plastic wastes and mixed packaging that belongs to the category 'mixed and undifferentiated materials'."

Table 1.5: Evolution of the generation of plastic wastes per Member State (Source: Eurostat Waste Statistics)

	Plastic waste generation (1000 tonnes/yr)			
	2006	2008	2010	2012
Austria	350	641	565	358
Belgium	632	1 075	698	611
Bulgaria	26	73	60	100
Croatia	186	30	25	39
Cyprus	57	68	84	74
Czech Republic	214	232	254	326
Denmark	54	73	79	107
Estonia	90	94	25	23
Finland	125	87	71	91
France	1 166	1 551	1 437	1 647
Germany	1 414	1 936	2 288	2 530
Greece	755	673	227	133
Hungary	147	150	151	186
Ireland	358	39	335	126
Italy	1 564	1 609	2 141	2 733
Latvia	12	9	8	22
Lithuania	30	31	40	51
Luxembourg	32	20	27	26
Malta	1	2	4	4
Netherlands	378	410	518	610
Poland	325	407	863	970
Portugal	996	193	224	214
Romania	580	419	564	649
Slovakia	75	94	111	108
Slovenia	43	47	56	48
Spain	1 617	1 904	1 465	1 143
Sweden	188	223	219	176
United Kingdom	3 447	2 489	3 660	3 986
Total EU-28	**14 863**	**14 578**	**16 201**	**17 091**

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Table 1.5 shows that EU-28 plastic waste production is increasing since 2008 after a small decrease from 2006 to 2008.

PlasticsEurope data for 2012 to 2014 is in line with the small increase shown in Table 1.5: the five countries (Germany, Italy, France, UK, and Spain) representing two thirds of plastics demand show a small upward trend on the period[9]. This increase is however, much smaller than the evolution presented in Figure 1.4.

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[9] http://www.plasticseurope.org/Document/plastics---the-facts-2015.aspx

Based on data from Table 1.5, Figure 1.4 shows the evolution of the generation of plastic wastes for the 14 Member States responsible for more than 94% of the overall generation in 2012.

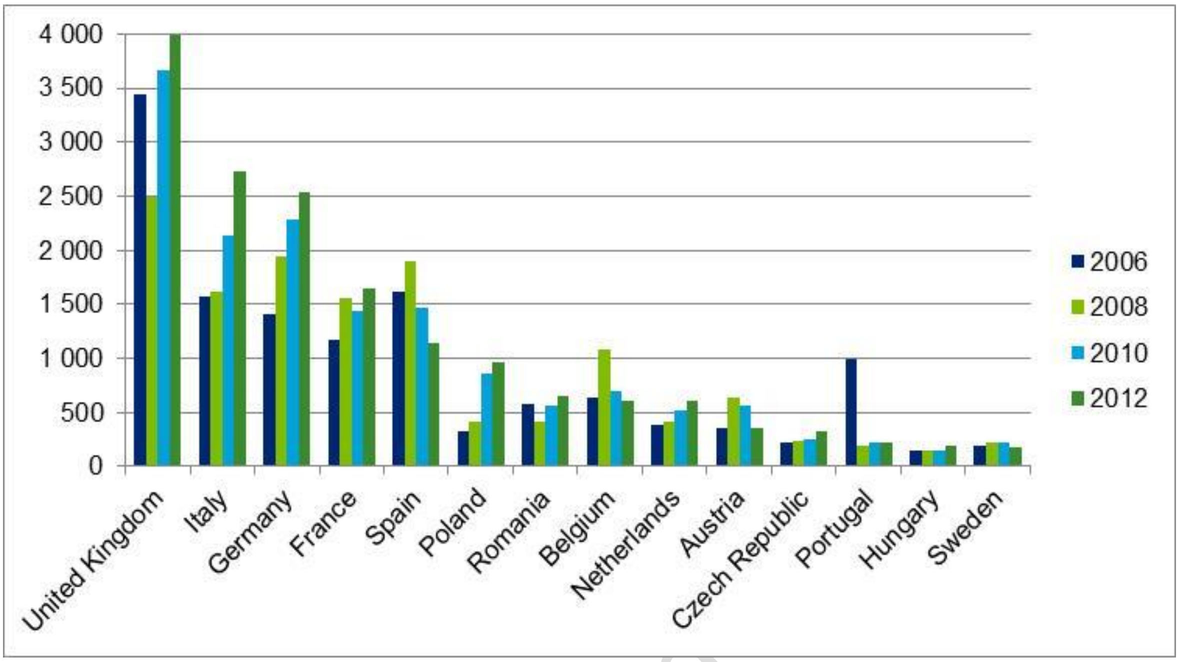

Figure 1.4: Evolution of the generation plastic wastes for the 14 main EU-28 producers in 2012 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr)

The three biggest producers (UK, Italy, and Germany) represent 54% of total plastic wastes generated. According to Figure 1.4, the amount of plastic wastes generated has increased by 60% in UK from 2008 to 2012 and by 75% and 79% in Italy and Germany resp. from 2006 to 2012.

On the contrary, Greece ranks as the 15th biggest EU-28 producer in 2012 with around 130 000 tonnes of plastic wastes, while it ranked as the 7th biggest producer in 2006 with more than 750 000 tonnes of plastic wastes.

In the case of Spain, the decrease can be due to both the effect of the economic crisis on consumption and a change in methodology in order to avoid double counting. No further information was provided by Member States that might explain the figure.

PlasticsEurope data for plastic packaging waste generation in countries presented in Figure 1.4 show close figures for UK, Italy and France, but higher figures for Germany. In addition, Eurostat data should be considered with caution because there no explanation could be found to the fact that UK generates much more waste than Italy, Germany and France.

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<u>Import/export outside of EU-28</u>

Quantities of exported and imported plastic wastes outside the EU-28 were collected on Eurostat COMEXT Database. Quantities are available on a monthly and yearly basis from 1988 to 2014. For the purpose of the study, yearly imported and exported quantities from 2006 to 2014 were considered. Relevant data were identified based on their CN8 code. According to the methodology used in the UBA 2011 report, the following CN8 codes were used for plastic wastes:

WDF	CN8 Code	Description
Waste plastics (production residues)	39151000	Waste, parings and scrap of polymers of ethylene
	39152000	Waste, parings and scrap of polymers of styrene
	39153000	Waste, parings and scrap of polymers of vinyl chloride
	39159011	Waste, parings and scrap of polymers of propylene
	39159018	Waste, parings and scrap, of addition polymerization products (excl. that of polymers of ethylene, styrene and vinyl chloride and propylene)
	39159090	Waste, parings and scrap, of plastics (excl. that of addition polymerization products)

Table 1.6 shows that the EU-28 has a positive trade balance, which represented around 13% of EU-28 plastic waste generation in 2010 and 12% 2012. This trade balance increased slightly between 2010 and 2012, then decreased over the year 2012 and increased significantly again over the year 2013 until 2014.

Table 1.6: Evolution of plastic wastes trade outside of EU-28 (Source: Eurostat COMEXT Database)

	Import/export outside of EU-28 (1000 tonnes/yr)		
	Import	Export	Trade balance
2006	252	2 105	1 853
2008	238	2 243	2 005
2010	75	2 129	2 053
2012	79	2 191	2 111
2014	108	2 194	2 086

Treatment of plastic wastes

Plastic waste treatment data comes from Eurostat Waste Statistics. Eurostat provides data on material recovery for the years 2006, 2008, 2010 and 2012, but data on other treatments (energy recovery, incineration on land, and landfill) are only available for the years 2010 and 2012.

Table 1.7: Evolution of the plastic wastes sent for energy recovery and incineration per Member State (Source: Eurostat Waste Statistics)

	2010 (tonnes/yr)		2012 (tonnes/yr)	
	Energy recovery (R1)	Incineration/ Disposal (D10)	Energy recovery (R1)	Incineration/ Disposal (D10)
Austria	126 192	338	39 845	0
Belgium	10 259	4 487	17 028	3 497
Bulgaria	585	40	3 388	76
Croatia	652	132	0	0
Cyprus	3	5	0	0
Czech Republic	44 676	118	28 248	253
Denmark	1 275	0	4 343	0
Estonia	719	0	0	0
Finland	19 724	15 381	32 047	10 031
France	750 000	0	776 211	0
Germany	304 122	44 996	435 955	30 659

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	2010 (tonnes/yr)		2012 (tonnes/yr)	
	Energy recovery (R1)	Incineration/ Disposal (D10)	Energy recovery (R1)	Incineration/ Disposal (D10)
Greece	0	0	601	0
Hungary	5 496	3 121	7 526	2 815
Ireland	0	0	13	0
Italy	12 034	23 372	44 405	31 624
Latvia	0	0	0	0
Lithuania	0	0	72	0
Luxembourg	22 225	0	6 000	0
Malta	0	0	0	0
Netherlands	86 610	8 969	86 900	2 994
Poland	17 675	116	9 312	236
Portugal	4 050	23	3 347	40
Romania	16 414	1 856	18 837	538
Slovakia	2 756	65	1 010	22
Slovenia	3 998	1 043	117	1 643
Spain[10]	0	15 238	0	0
Sweden	84 718	0	105 011	0
United Kingdom	0	0	0	0
Total EU-28	1 514 183	119 300	1 620 216	84 428

Between 2010 and 2012 the amount of plastic wastes sent for energy recovery has increased by 7% at EU-28 level. Looking at Table 1.7, it appears that plastic wastes sent to incineration have decreased by 35 000 tonnes while during the same period plastics sent to energy recovery have increased by 100 000 tonnes.

Figure 1.5 shows the repartition of plastic waste treatment methods for the 14 EU-28 countries representing 99% of plastic wastes sent to incineration and energy recovery in 2012. France is both the main producer of energy from plastics wastes and the country sending the most plastics for landfilling.

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[10] “Plastic waste Management in European countries 2012-Facts and Figures. Consultic” provides complementary data for post-consumer plastic waste treatment in 2012 in Spain: generation (2 065kt)/ recycling (584-28%)/ energy recovery (345-17%)/ landfill (1136-55%).

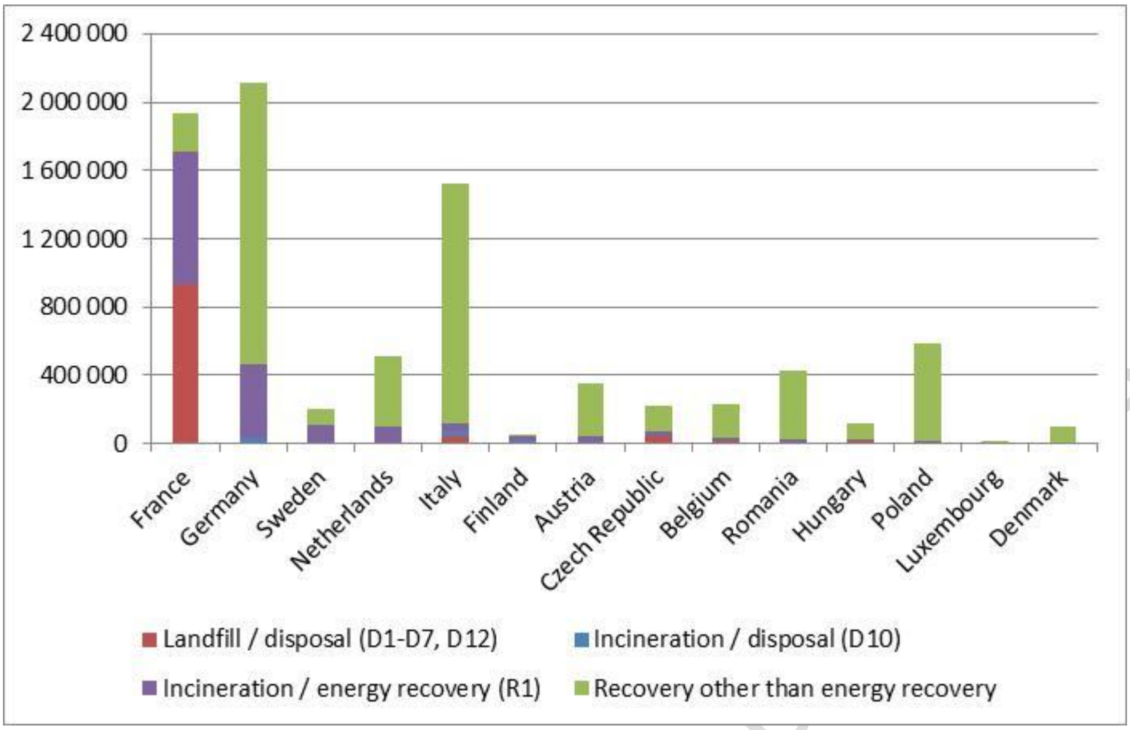

Figure 1.5: Treatments of plastic wastes for the 14 EU-28 main contributors to energy production from plastic waste in 2012 (Source: Eurostat Waste Statistics – in tonnes/yr).

Figure 1.6 gives an overview of the repartition of plastic waste treatment methods in EU-28 and its evolution between 2010 and 2012. Looking at Figure 1.6, it appears that the European hierarchy for waste treatment is not applied in EU-28 globally because plastic wastes sent for landfilling have increased the most between 2010 and 2012.

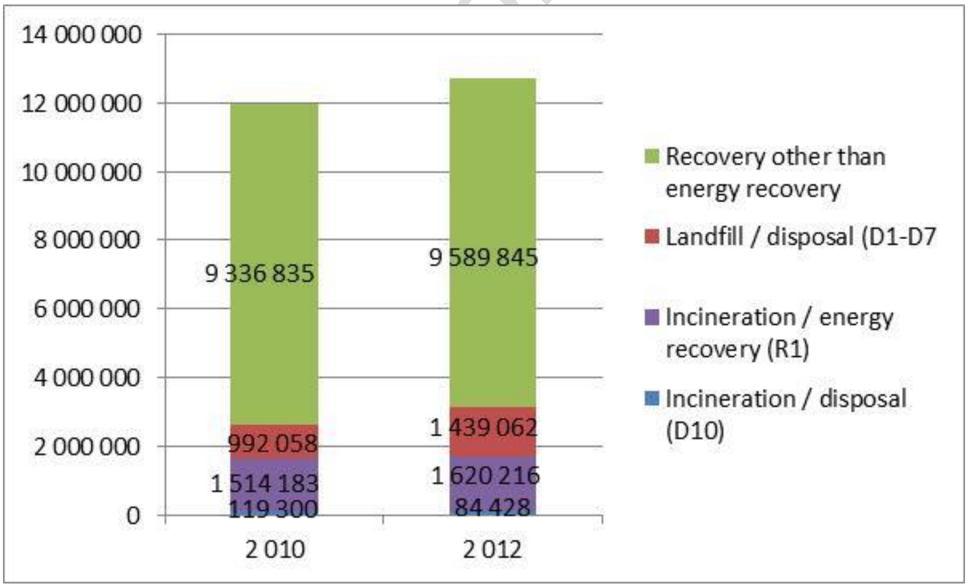

Figure 1.6: Evolution of plastic waste treatment methods in EU-28 (Source: Eurostat Waste Statistics – in tonnes/yr)

According to PlasticsEurope, the evolution of the waste management of the 25 Mt of post-consumer plastics produced annually in the EU-28, is in line with the waste hierarchy: from 2006 to 2014, a decrease by 38% of landfill, and an increase by 46% and 64% of wastes sent to energy recovery and recycling respectively[11].

The potential of plastic as an energy source depends on several issues: the polymer considered (HDPE, PET, PP), the source (packaging, agriculture, EEE, vehicles), the existence of pollutants as metals and their way of collection and treatment (separated, mixed, crushing the product, etc). For instance, according to the waste hierarchy, separated plastic packaging should be recycled instead of incinerated.

5.3.3 Paper wastes

Generation of paper wastes

Data on the generation of paper wastes comes from Eurostat Waste Statistics.
In Eurostat, the EWC-Stat category "07.2 Paper and cardboard wastes" contains only non-hazardous wastes.

Description of the category and main NACE sectors that produce paper wastes according the Eurostat Manual on waste statistics[12]:

"*Paper and cardboard wastes (07.2): These wastes are paper and cardboard from sorting and separate sorting by businesses and households. This category includes fibre, filler and coating rejects from pulp, paper and cardboard production. These wastes are largely generated by three activities: separate collection, mechanical treatment of waste and pulp, and paper and cardboard production and processing. All paper and cardboard wastes are non-hazardous*."

Table 1.8: Evolution of the generation of paper wastes per Member State (Source: Eurostat Waste Statistics)

	Paper waste generation (1000 tonnes/yr)			
	2006	2008	2010	2012
Austria	2 020	1 525	1 937	1 841
Belgium	4 524	3 543	4 214	3 870
Bulgaria	317	110	160	202
Croatia	703	103	144	200
Cyprus	173	153	146	137
Czech Republic	637	698	690	702
Denmark	788	782	1 038	1 025
Estonia	439	159	80	95
Finland	1 231	806	767	649
France	7 611	6 899	7 005	7 348
Germany	9 334	9 982	8 062	8 184
Greece	474	729	652	522
Hungary	574	591	585	538
Ireland	1 101	34	746	396
Italy	5 612	5 161	5 352	5 148
Latvia	28	10	45	106
Lithuania	95	109	105	124
Luxembourg	97	105	125	109

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[11] http://www.plasticseurope.org/Document/plastics---the-facts-2015.aspx

[12] Additional information can be found in the "Guidance on classification of waste according to EWC-Stat categories" document.

	Paper waste generation (1000 tonnes/yr)			
	2006	2008	2010	2012
Malta	4	4	12	11
Netherlands	2 691	2 940	2 652	2 313
Poland	769	1 134	1 009	1 135
Portugal	2 380	1 150	1 249	987
Romania	1 099	548	585	928
Slovakia	199	219	192	222
Slovenia	175	200	134	130
Spain	4 648	4 733	3 843	3 599
Sweden	2 405	2 292	1 280	744
United Kingdom	14 242	12 803	5 760	5 680
Total EU-28	**64 370**	**57 518**	**48 567**	**46 945**

According to Eurostat Manual on waste statistics, between 2008 and 2010, the significant decrease in paper wastes generation shown in Table 1.8 is for one part due to the evolution of waste categories. Indeed, two codes on production waste and unspecified wastes were removed from this category during that period.

This downward trend also results from a structural evolution due to the dematerialization, which impacts mostly paper consumption and to a lesser extent the cardboard industry. In addition, since 2008, there is a global conjectural evolution due to the reduction in the consumption since 2008.

Based on data from Table 1.8, Figure 1.7 shows the evolution of the generation of paper wastes for the 14 Member States responsible for more than 93% of the overall generation in 2012.

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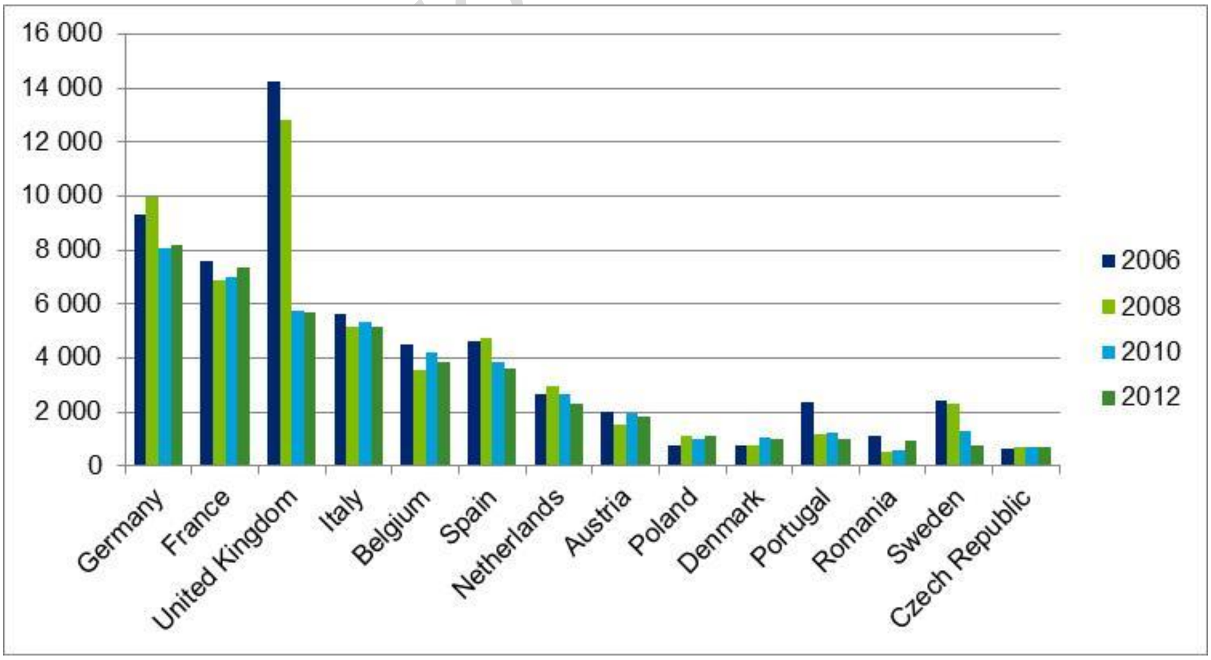

Figure 1.7: Evolution of the generation paper wastes for the 14 main EU-28 producers in 2012 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr)

Figure 1.7 shows that most of the main EU-28 paper wastes generators display a generally downward trend in generation.

The sudden drop observed for the UK in Figure 1.7 between 2008 and 2010 is due to the adoption in 2012 of improved methodology for collecting data on paper wastes. The data for 2010 was revisited using the new methodology as a basis but the figure for 2008 reflects the existing methodology that was applied.

Import/export outside of EU-28

Quantities of exported and imported paper wastes within the EU-28 were collected on Eurostat COMEXT Database. Quantities are available on a monthly and yearly basis from 1988 to 2014. For the purpose of the study, yearly imported and exported quantities from 2006 to 2014 were considered. Relevant data were identified based on their CN8 code. According to the methodology used in the UBA 2011 report, the following CN8 codes were used for paper wastes:

WDF	CN8 Code	Description
Waste paper	47071000	Unbleached craft paper or paperboard or corrugated paper or paperboard
	47072000	Other paper or paperboard made mainly of bleached chemical pulp, not coloured in the mass
	47073010	Old and unsold newspapers and magazines, telephone directories, brochures and printed advertising material
	47073090	Other paper or paperboard made mainly of mechanical pulp (for example, newspapers, journals and similar printed matter)
	47079010	Other, including unsorted waste and scrap of paper
	47079090	Other, including sorted waste and scrap of paper

Table 1.9 shows that EU-28 has a positive trade balance which represented 20% of EU-28 waste generation in 2010 and 18% in 2012.

Table 1.9: Evolution of paper wastes trade outside of EU-28 (Source: Eurostat COMEXT Database)

	Import/export outside of EU-28 (tonnes/yr)		
	Import	Export	Trade balance
2006	1 007 054	8 628 412	7 621 358
2008	1 164 381	11 575 483	10 411 101
2010	1 362 876	10 183 107	8 820 230
2012	1 456 710	11 201 506	9 744 796
2014	1 293 907	9 913 960	8 620 052

Treatment of paper wastes

Paper waste treatment data comes from Eurostat Waste Statistics. Eurostat provides data on material recovery for the years 2006, 2008, 2010 and 2012, but data on other treatments (energy recovery, incineration on land, and landfill) are only available for the years 2010 and 2012.

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Table 1.10: Evolution of the paper wastes sent for energy recovery and incineration per Member State (Source: Eurostat Waste Statistics)

	2010 (tonnes/yr)		2012 (tonnes/yr)	
	Energy recovery (R1)	Incineration/ Disposal (D10)	Energy recovery (R1)	Incineration/ Disposal (D10)
Austria	13 709	570	10 546	0
Belgium	2 785	1 218	0	155
Bulgaria	24	213	10	15
Croatia	56	86	6	0
Cyprus	0	48	0	0
Czech Republic	9 450	377	9 324	368
Denmark	3 351	0	4 012	0
Estonia	3	3	13	0
Finland	34 702	15 069	34 053	13 062
France	345 000	0	203 732	0
Germany	47 646	19 235	38 223	4 434
Greece	0	0	0	0
Hungary	952	501	846	282
Ireland	6	0	0	0
Italy	748	1 373	54	1 828
Latvia	13	0	30	0
Lithuania	101	0	73	0
Luxembourg	0	0	0	0
Malta	0	84	0	4
Netherlands	44 943	136	9	0
Poland	2 962	93	2 561	89
Portugal	429	89	166	254
Romania	19 056	2 244	10 349	58
Slovakia	2 050	92	395	145
Slovenia	21	40	17	26
Spain	0	0	0	0
Sweden	12 228	0	5 956	0
United Kingdom	74	468	0	334
Total EU-28	540 309	41 939	320 375	21 054

Between 2010 and 2012 the amount of paper wastes sent for energy recovery has decreased by 40% at EU-28 level. France is one of the main country responsible for this evolution because the amount of paper wastes sent to energy recovery has dropped from 345 000 tonnes in 2010 to 204 000 tonnes in 2012. The Netherlands are also responsible for this evolution but to a lesser extent.

Figure 1.8 shows the repartition of paper waste treatment methods for the 14 EU-28 countries representing nearly 100% of paper wastes sent to incineration and energy recovery in 2012. Material recovery is not included in this figure because it represents 99% of paper wastes treated (see Figure 1.9 below). Looking at Figure 1.8, we can see that France alone represents 60% of paper wastes sent to energy recovery.

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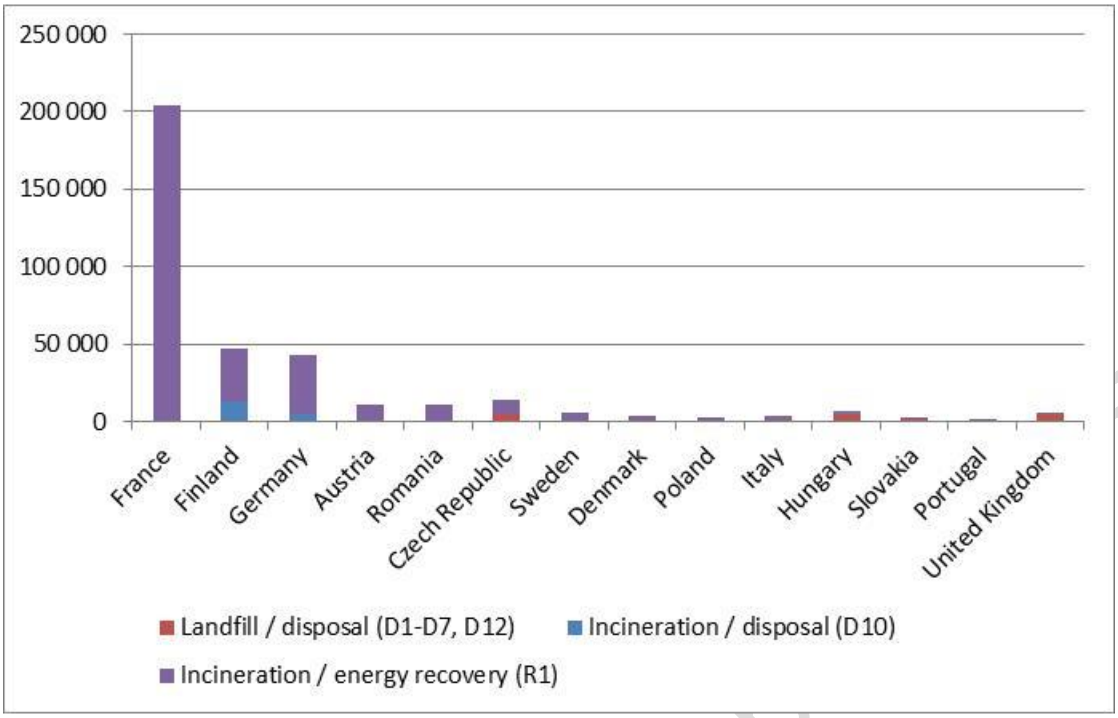

Figure 1.8: Treatments (excl. material recovery) of paper wastes for the 14 EU-28 main contributors to energy production from paper wastes in 2012 (Source: Eurostat Waste Statistics – in tonnes/yr).

Figure 1.9 gives an overview of the repartition of paper waste treatment methods in EU-28 and its evolution between 2010 and 2012.
The waste management system in the EU-28 is in line with the waste hierarchy because more than 99% wastes are recovered.

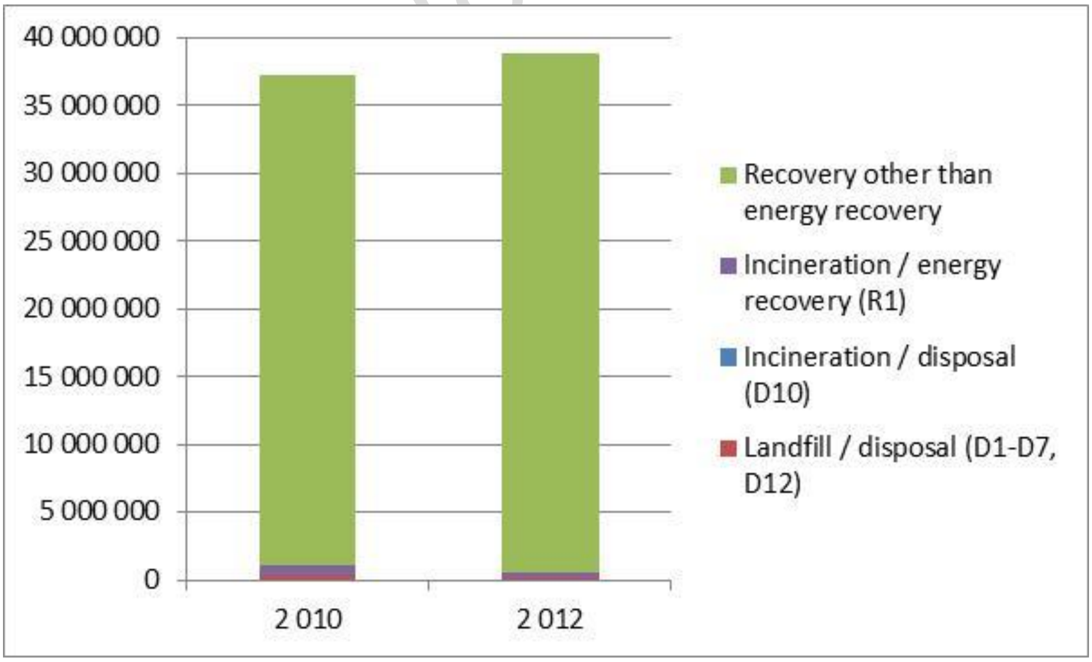

Figure 1.9: Evolution of paper waste treatment methods in EU-28 (Source: Eurostat Waste Statistics – in tonnes/yr)

With the exception of heavily contaminated wastes, in compliance with the waste hierarchy, paper and cardboard wastes should be recycled.

5.3.4 Textile wastes

Generation of textile wastes

Data on the generation of textile wastes comes from Eurostat Waste Statistics. In Eurostat, the EWC-Stat category "07.6 textile wastes" contains only non-hazardous wastes. Description of the category and main NACE sectors that produce textile wastes according the Eurostat Manual on waste statistics[13]:

"*Textile wastes (07.6): These wastes are textile and leather waste; textile packaging; worn clothes and used textiles; waste from fibre preparation and processing; waste tanned leather; and separately collected textile and leather waste. They originate from only a small number of activities: the leather and fur industry, the textile industry, the mechanical treatment of waste and separate collection. All textile wastes are non-hazardous.*"

According to this definition textile waste generation only takes into account the wastes that are collected.

Table 1.11: Evolution of the generation of textile wastes per Member State (Source: Eurostat Waste Statistics)

	Textile waste generation (1000 tonnes/yr)			
	2006	2008	2010	2012
Austria	35	142	54	46
Belgium	627	166	246	173
Bulgaria	13	11	6	7
Croatia	21	9	17	3
Cyprus	24	42	31	28
Czech Republic	78	77	62	63
Denmark	0	0	1	3
Estonia	7	5	2	2
Finland	7	8	8	16
France	432	391	380	440
Germany	182	213	238	310
Greece	16	5	5	2
Hungary	50	13	27	20
Ireland	182	5	5	19
Italy	823	541	434	396
Latvia	0	0	0	0
Lithuania	6	5	5	9
Luxembourg	6	5	6	6
Malta	0	0	0	0
Netherlands	125	129	107	114
Poland	73	84	83	94
Portugal	476	96	125	61
Romania	254	19	19	15

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[13] Additional information can be found in the "Guidance on classification of waste according to EWC-Stat categories" document.

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	Textile waste generation (1000 tonnes/yr)			
	2006	2008	2010	2012
Slovakia	19	15	8	9
Slovenia	13	10	7	7
Spain	92	138	100	77
Sweden	20	20	19	6
United Kingdom	247	275	1 101	1 182
Total EU-28	3 826	2 425	3 097	3 108

According to Table 1.11 the generation of textile wastes has decreased by 37% from 2006 to 2008 and has increased by 28% from 2008 to 2010.

Based on data from Table 1.11, Figure 1.10 shows the evolution of the generation of textile wastes for the 14 main EU-28 producers representing 97% of total EU-28 generation in 2012.

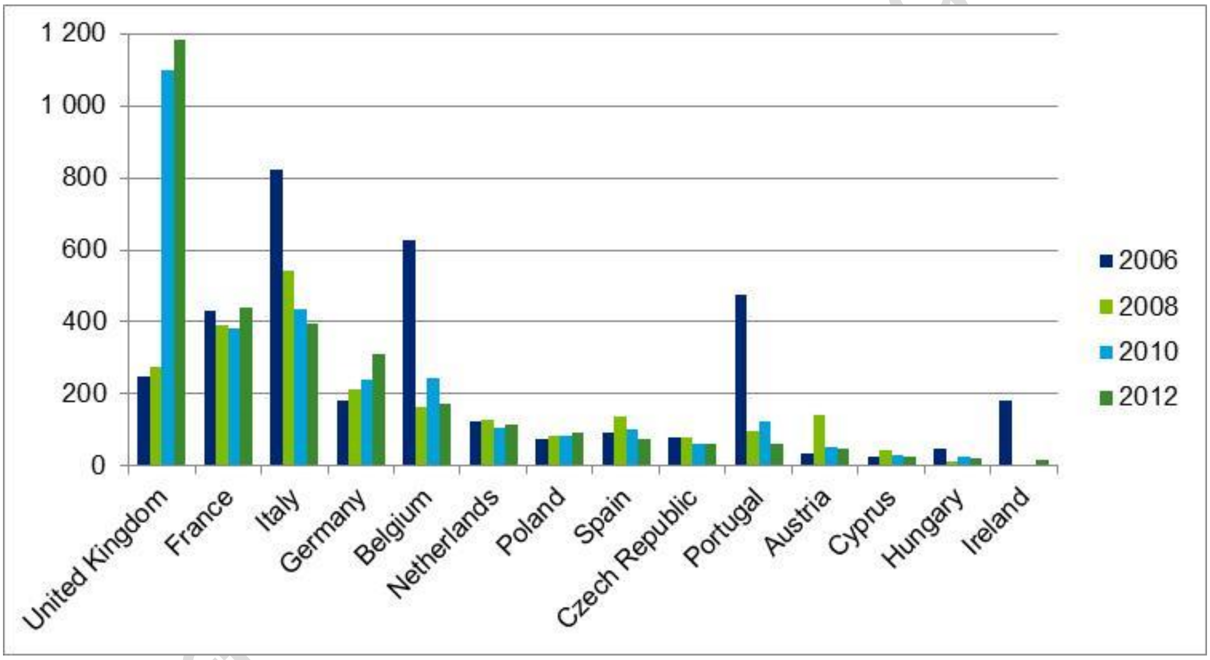

Figure 1.10: Evolution of the generation of textile wastes for the 14 main EU-28 producers in 2012 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr)

As shown in Figure 1.10, there is a sudden drop in textile wastes generation from 2006 to 2008 in 4 countries (Italy, Belgium, Portugal and Ireland). On the same figure, we can see that between 2008 and 2010 UK has increased by 400% the amount of textile waste generated. These differences might be due to evolution in reporting methodology for the 5 Member States. No further information was provided by Member States that might explain the figure.

Import/export outside of EU-28

Quantities of exported and imported textile wastes within the EU-28 were collected on Eurostat COMEXT Database. Quantities are available on a monthly and yearly basis from 1988 to 2014. For the purpose of the study, yearly imported and exported quantities from 2006 to 2014 were considered. Relevant data were identified based on

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their CN8 code. According to the methodology used in the UBA 2011 report, the following CN8 codes were used for textile waste:

WDF	CN8 Code	Description
Waste textiles	41152000	Parings and other waste of leather or of composition leather, not suitable for the manufacture of leather articles; leather dust, powder and flour
	50030000	Silk waste (including cocoons unsuitable for reeling, yarn waste and garnetted stock)
	51031010	Noils of wool or of fine animal hair, non-carbonised (excl. garnetted stock)
	51031090	Noils of wool or of fine animal hair, carbonised (excl. garnetted stock)
	51032010	Yarn waste of wool or of fine animal hair
	51032091	Waste of wool or fine animal hair not carbonized
	51032099	Waste of wool or fine animal hair carbonized
	51033000	Waste of coarse animal hair
	52021000	Cotton waste (yarn waste)
	52029100	Cotton waste (garnetted stock)
	52029900	Other cotton waste
	53013090	Flax waste, incl. yarn waste and garnetted stock
	55051010	Waste (including noils, yarn waste and garnetted stock) of manmade fibres of nylon or other polyamides
	55051030	Waste of polyesters
	55051050	Waste of acrylic or modacrylic
	55051070	Waste of polypropylene
	55051090	Waste of other synthetic fibres
	55052000	Waste off artificial fibres
	63090000	Worn clothing and other worn articles
	63101010	Used or new rags, scrap twine, cordage, rope and cables and worn out articles of twine, cordage, rope or cables, of wool or fine or coarse animal hair, sorted
	63101030	Rags of flax or cotton, sorted
	63101090	Rags of other textile materials, sorted
	63109000	Rags, unsorted

Table 1.12 shows that the EU-28 has a growing positive trade balance which represented 29% of EU-28 textile waste generation in 2010 and 32% in 2012. This trade balance is increasing since 2006 onwards.

Table 1.12: Evolution of textile wastes trade outside of EU-28 (Source: Eurostat COMEXT Database)

	Import/export outside of EU-28 (tonnes/yr)		
	Import	Export	Trade balance
2006	334 770	864 379	529 609
2008	295 794	1 006 198	710 404
2010	232 696	1 116 694	883 998
2012	239 730	1 228 421	988 691
2014	262 880	1 301 043	1 038 163

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Treatment of textile wastes

Textile waste treatment data comes from Eurostat Waste Statistics. Eurostat provides data on material recovery for the years 2006, 2008, 2010 and 2012, but data on other treatments (energy recovery, incineration on land, and landfill) are only available for the years 2010 and 2012.

For the years 2010 and 2012 not all countries provide data for all treatments, and for some countries like UK and Portugal there are sudden increases and drops in the amount of wastes sent for material recovery.

Finally, it is important to consider that a significant amount of collected textile wastes are re-used. Unfortunately there is no data available to estimate the share of collected textile wastes that are re-used.

Table 1.13: Evolution of the textile wastes sent to incineration and energy recovery per Member State (Source: Eurostat Waste Statistics)

	2010 (tonnes/yr)		2012 (tonnes/yr)	
	Energy recovery (R1)	Incineration/ Disposal (D10)	Energy recovery (R1)	Incineration/ Disposal (D10)
Austria	20 334	61	22 767	0
Belgium	231	101	0	87
Bulgaria	80	1	117	0
Croatia	149	0	0	0
Cyprus	0	1	0	0
Czech Republic	14 156	147	20 701	74
Denmark	48	0	150	0
Estonia	0	0	0	0
Finland	60	1	12	0
France	4 984	192	0	0
Germany	36 122	5 482	41 489	5 452
Greece	0	0	0	0
Hungary	3 526	53	2 229	113
Ireland	0	0	17	0
Italy	0	1 252	1	1 509
Latvia	5	0	1 302	0
Lithuania	0	0	44	0
Luxembourg	0	0	0	0
Malta	0	0	0	0
Netherlands	6 599	3 472	20 193	151
Poland	1 946	21	1 957	48
Portugal	244	26	529	12
Romania	4 023	109	2 110	505
Slovakia	26	63	856	52
Slovenia	0	13	0	0
Spain	0	0	2 277	0
Sweden	0	0	0	0
United Kingdom	0	7 417	0	9 723
Total EU-28	92 533	18 412	116 751	17 726

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According to Table 1.13, the amount of textile wastes sent to incineration (D10) and energy recovery (R1) represents around 4% of total textile wastes generated and collected. This estimate is in line with the estimated 5% of generated and collected textile wastes from the UBA report from 2011 (based on literature review and interviews with experts).

Figure 1.11 shows the repartition of textile waste treatment methods for the 14 EU-28 countries representing nearly 100% of textile wastes sent to incineration and energy recovery in 2012. Recovery (other than energy recovery) is not included in this figure because it represents nearly 90% of textile wastes treated (see Figure 1.11 below). As shown by Figure 1.11, Germany, Austria, Czech Republic and the Netherlands represent 82% of textile wastes sent to incineration (with and without energy recovery).

Figure 1.11: Treatments (excl. material recovery) of textile wastes for the 14 EU-28 main contributors to energy production from textile wastes in 2012 (Source: Eurostat Waste Statistics – in tonnes/yr).

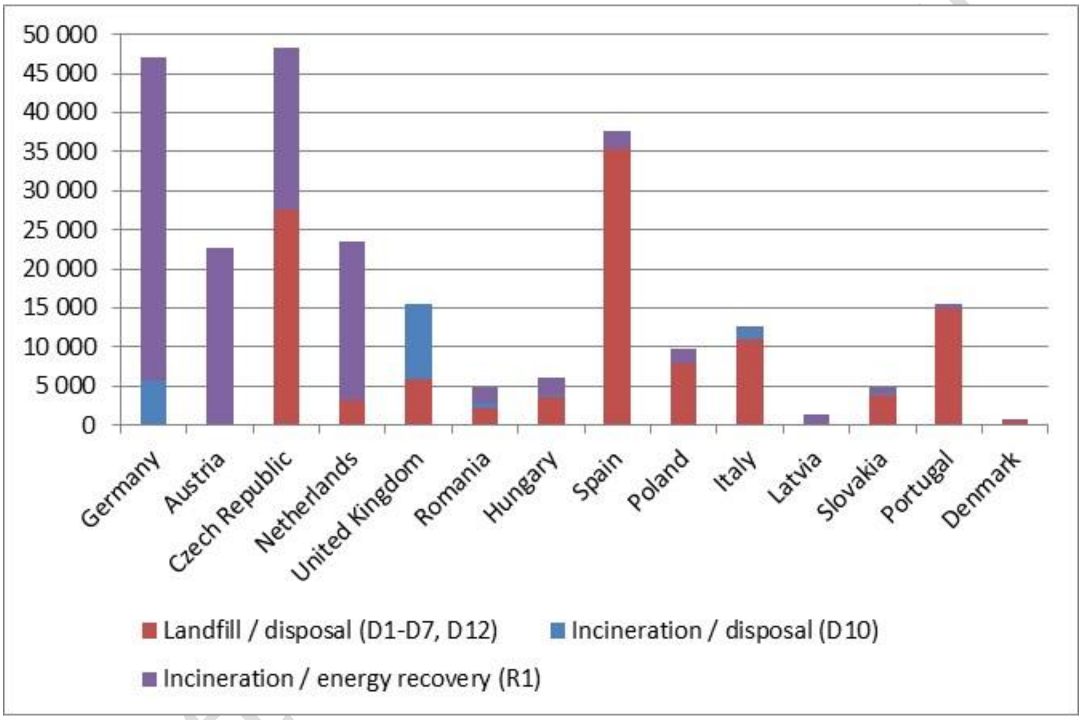

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Figure 1.12 provides an overview of the repartition of textile waste treatment methods in EU-28 and its evolution between 2010 and 2012.

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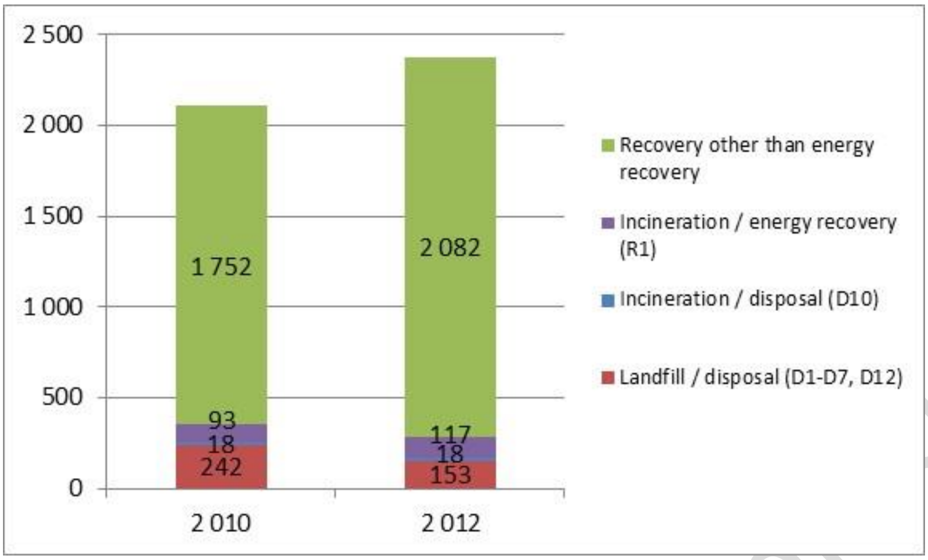
Figure 1.12: Evolution of textile waste treatment methods in EU-28 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr)



The waste management system in the EU-28 is in line with the waste hierarchy because nearly 90% wastes are recovered. However, considering the evolution in data reported by some Member States (including UK), and the difficulty to estimate the share of textile wastes re-used, these data should be used with caution.

The European Textile Service Association is doing a study on the end of life of textiles. The results should be ready by mid-2016. It could provide useful information to understand the evolutions observed in the previous graphics, to understand the trends in the EU-28 and to identify outlook to better comply with the waste hierarchy.

5.3.5 Waste tyres and waste rubber

Generation of waste tyres and waste rubber

There are two main sources of information for generation of waste tyres and waste rubber:

- Eurostat Waste Statistics collects data on the generation of the EWC-Stat category "07.3 Rubber wastes". It provides data every 2 years, 2012 being the latest available, for each of EU-28 countries. Description of the category and main NACE sectors that produce textile wastes according the Eurostat Manual on waste statistics: "*Rubber wastes (07.3): item 19. These wastes are only end-of-life tyres which come from the maintenance of vehicles, and end-of-life vehicles. All rubber wastes are non-hazardous. They can be generated in all sectors*.". According to this definition, rubber production waste (hose, gloves, technical rubber goods) should not be included in the category "07.3 Rubber wastes". However, looking at the origin of the rubber waste we see that 230 kt of the total rubber waste originates from the NACE sectors C20-C22 "Manufacture of chemical, pharmaceutical, rubber and plastic products". This might indicate that a significant amount of rubber production waste is included in this category.
- ETRMA - European Tyre & Rubber Manufacturers Association collects annual data from on the industry on the amount of waste tyres generated. It provides annual data, 2013 being the latest available, for each of EU-28 countries.

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In this study the data from ETRMA shall be used because it seems to be more in line with real figures. For instance in 2009, Eurostat Statistics estimate that 3 750 000 tonnes of wastes have been produced, Portugal being responsible for the generation of 1 million tonnes of these wastes. According to the UBA 2011 report and the Portuguese collection scheme (Valorpneu), this figure should be around 90 000 tonnes. The same year, ETRMA estimates that 3 121 000 tonnes of wastes have been produced, among which 89 000 tonnes come from Portugal.

ETRMA has developed a personal 2 steps methodology to estimate the share of waste tyres:

- Step 1- estimation of used tyres generation = new tyres (replacement market) + retreaded tyres (national market) + import of second-hand tyres;
- Step 2- estimation of waste tyres generation = used tyres generation – reuse – export – retreating.

In some counties like France and Italy, waste tyres generation also includes historical stocks that are collected and treated. Data collected by ETRMA come from a wide range of sources including:

- National statistics reported to public authorities (for ex. ADEME in France, UK UTWG, DK, BG, SK, CZ);
- National statistics from other sources (Germany);
- End of life tyres management companies (14 operational; 16 created) in the ETRMA network;
- Other end of life tyres management companies (such as FRP, TNU, EcoTyre, ...);
- Tyre industry.

Data for generation of waste tyres are presented in Table 1.14 below.

Table 1.14: Evolution of the generation of wastes tyres per Member State (Source: ETRMA)

	Waste tyres generation (1000 tonnes/yr)			
	2008	2010	2012	2013
Austria	49	50	60	60
Belgium	73	69	66	55
Bulgaria	27	20	22	25
Croatia	n.a.	n.a.	n.a.	n.a.
Cyprus	8	8	5	5
Czech Republic	57	55	54	55
Denmark	41	37	36	38
Estonia	9	10	11	15
Finland	42	40	46	50
France	297	302	323	352
Germany	432	475	424	413
Greece	52	47	36	32
Hungary	43	29	36	36
Ireland	38	28	24	25
Italy	323	371	330	354
Latvia	9	10	11	9

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	Waste tyres generation (1000 tonnes/yr)			
	2008	2010	2012	2013
Lithuania	11	11	13	23
Luxembourg	n.a.	n.a.	n.a.	n.a.
Malta	0	0	0	0
Netherlands	44	50	62	62
Poland	195	219	185	158
Portugal	72	71	64	66
Romania	53	33	46	34
Slovakia	23	22	23	23
Slovenia	15	11	10	15
Spain	250	234	219	228
Sweden	67	78	76	79
United Kingdom	368	335	282	419
Total EU-28	**2 598**	**2 615**	**2 464**	**2 631**

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According to Table 1.14 the generation of wastes tyres is stable (+1.3%) from 2008 to 2013.

Based on data from Table 1.14, Figure 1.13 shows the evolution of the generation of waste tyres for the 14 main EU-28 producers representing 91% of total EU-28 generation in 2013.

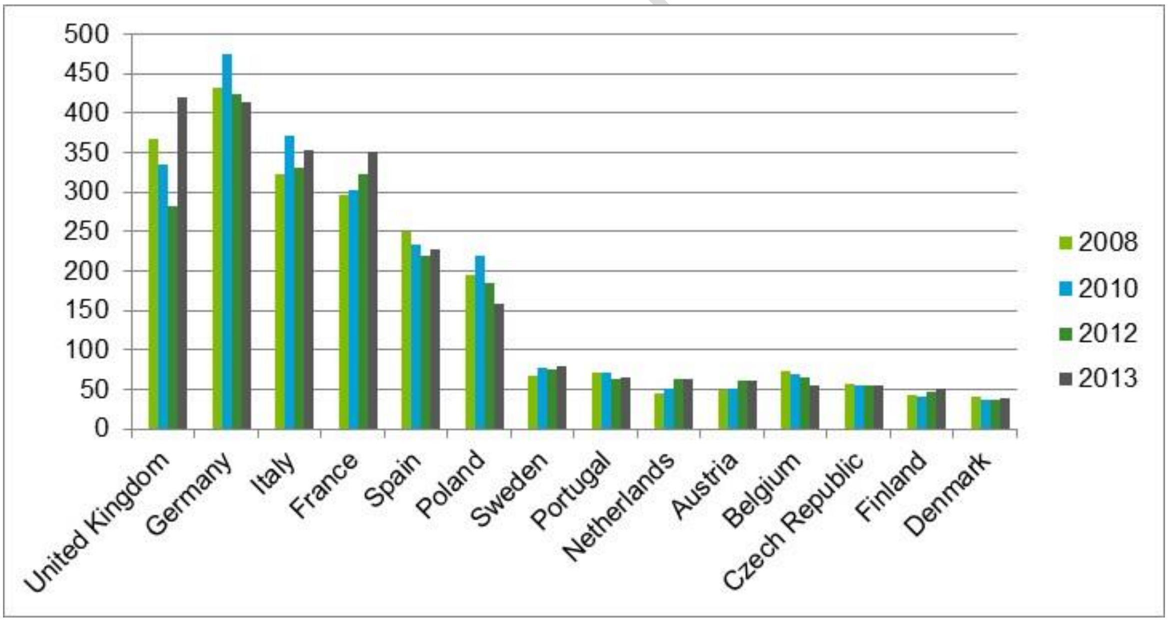

Figure 1.13: Evolution of the generation of waste tyres for the 14 main EU-28 producers in 2013 (Source: ETRMA – in 1000 tonnes/yr)

In 2013, the 6 main EU-28 producers of waste tyres (UK, Germany, Italy, France, Spain and Poland) represent 73% of the wastes generated. The global waste generation stability observed at European level (see Table 1.14) hides significant evolutions for some Member States: a decrease in Poland (-28%) and Germany (-13%) since 2010, and an increase in France (+17%) and UK. In UK, the increase by

48% of waste generation in UK from 2012 to 2013 has not been explained and may be due to methodological changes in the estimation.

Import/export outside of EU-28

Quantities of exported and imported waste tyres and waste rubber outside EU-28 were collected on Eurostat COMEXT Database. Quantities are available on a monthly and yearly basis from 1988 to 2014. For the purpose of the study, yearly imported and exported quantities from 2006 to 2014 were considered. Relevant data were identified based on their CN8 code. According to the methodology used in UBA 2011 report, the following CN8 codes were used for waste tyres and waste rubber:

WDF	**CN8 Code**	**Description**
Waste tyres, waste rubber	40040000	Waste, parings and scrap of soft rubber and powders and granules obtained therefrom
	40170010	Hard rubber, e.g. ebonite, in all forms, incl. waste and scrap
	40122000	Used pneumatic tyres of rubber

Table 1.15 shows that EU-28 has positive trade balance that has kept increasing since 2006.

Table 1.15: Evolution of waste tyres and waste rubber trade outside of EU-28 (Source: Eurostat COMEXT Database)

	Import/export outside of EU-28 (tonnes/yr)		
	Import	Export	Trade balance
2006	94 578	212 749	118 171
2008	96 638	271 772	175 133
2010	96 836	322 782	225 945
2012	84 082	484 632	400 549
2014	79 594	611 467	531 872

Data in Table 1.15 include waste tyres (CN8 Code 40122000) and other rubber waste (CN8 Codes 40040000 and 40170010). For comparison, Table 1.16 provides figures from ETRMA on the export of waste used tyres.

Table 1.16: Evolution of export of used tyres outside of EU-28 (Source: ETRMA)

	Export of used tyres (tonnes/yr)
2008	154 000
2010	179 000
2012	194 000
2013	244 000

Treatment of waste tyres

There are two main sources of information for treatment of waste tyres and waste rubber:

- Eurostat provides data on material recovery for the years 2006, 2008, 2010 and 2012, for EU-28 member states. Data on other treatments (energy recovery, incineration on land, and landfill) are only available for the years 2010 and 2012,

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and the quality of this data is uncertain because many countries have declared 0 tonne regarding quantities sent for landfill disposal and incineration on land.

- ETRMA possesses annual data (for EU-28 member states and for the years 2006 to 2012) on the waste tyres treatment methods. According to ETRMA statistics, since 2008, at least 95% of used tyres in Europe are recovered. This includes re-use of used tyres, recycling and energy recovery of end-of-life tyres. The management of the remaining 5% wastes is uncertain. Some of it is lost to the ground and sent to landfill.

With regard to the treatment of end-of-life tyres (see Figure 1.14):

- 1.2 million tonnes are being sent to material recovery (latest data: 2013).
- about 1.3 million tonnes of ELTs are sent annually to energy recovery (including co-incineration in cement kilns). On average 92% of the tonnage of ELTs sent to energy recovery is sent to co-processing (cement kilns) and the remainder is used in district heating plants/ boilers.

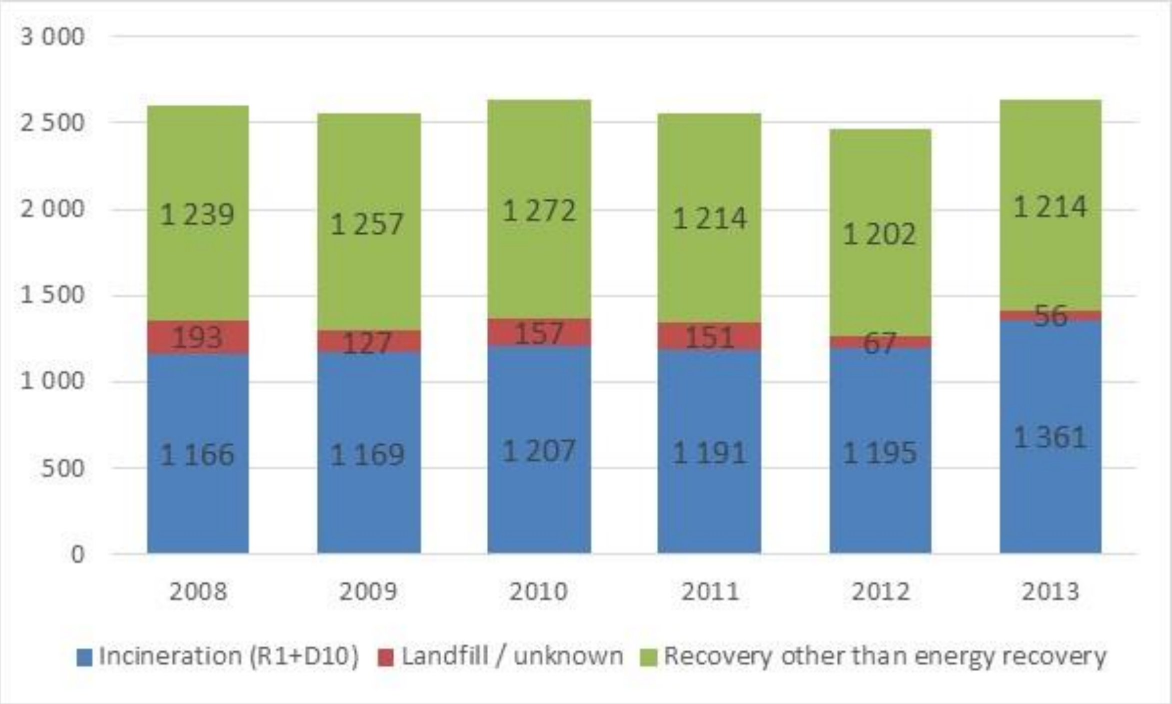

Figure 1.14: Evolution of waste tyres treatment methods in EU-28 (Source: ETRMA – in 1000 tonnes/yr

According to ETRMA, under current market conditions the economic viability of Pyrolysis, thermolysis and gasification has yet to be proved as there are few or no large-scale plants currently in operation. In 2013, the estimated quantity of ELT pyrolysis in Europe was about 11,000t in the EU28.

5.3.6 Waste solvents

Generation of waste solvents

Data on the generation of waste solvents comes from Eurostat Waste Statistics.
In Eurostat, the EWC-Stat category "01.1 spent solvents" contains only non-hazardous wastes.

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"*Spent solvents (01.1): These are hydrocarbons, fluorocarbons, chlorinated carbons; organic halogenated, non-halogenated solvents, including organic washing liquids; and organic fluorinated refrigerants. They are used in chemical industries as reaction agent and in extraction processes, cleaning processes in mechanical engineering and surface treatment and appear almost exclusively in the manufacture of chemicals, chemical products, basic pharmaceutical products and preparations, and rubber and plastic products (item 9 of Section 8 of Annex I of the Waste Statistics Regulation). To a lesser extent, this type of waste can also be generated during the fabrication of metal products and during recycling. Separately collected fractions of spent solvents can be generated by almost all economic activities, including private households*."

Table 1.17: Evolution of the generation of waste solvents per Member State (Source: Eurostat Waste Statistics)

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	waste solvent generation (1000 tonnes/yr)			
	2006	2008	2010	2012
Austria	24	34	48	29
Belgium	208	75	176	302
Bulgaria	0	0	0	0
Croatia	5	1	0	1
Cyprus	0	0	0	0
Czech Republic	13	12	13	9
Denmark	15	14	19	22
Estonia	0	0	0	0
Finland	20	16	20	19
France	413	264	431	440
Germany	714	741	723	734
Greece	0	0	0	0
Hungary	36	29	22	36
Ireland	140	130	606	159
Italy	282	236	244	279
Latvia	0	0	1	1
Lithuania	0	0	0	0
Luxembourg	1	1	1	2
Malta	3	3	1	1
Netherlands	211	155	154	114
Poland	14	6	6	8
Portugal	61	12	10	9
Romania	1	2	3	1
Slovakia	9	3	3	3
Slovenia	10	12	21	19
Spain	218	257	182	190
Sweden	44	68	62	63
United Kingdom	417	308	206	251
Total EU-28	**2 863**	**2 382**	**2 952**	**2 694**

According to Table 1.17 the production of wastes solvents has decreased by 17% from 2006 to 2008 and has increased by 24% from 2008 to 2010.

Based on data from Table 1.17, Figure 1.15 shows the evolution of the generation of waste solvents for the 14 main EU-28 producers representing 99% of total EU-28 generation in 2012.

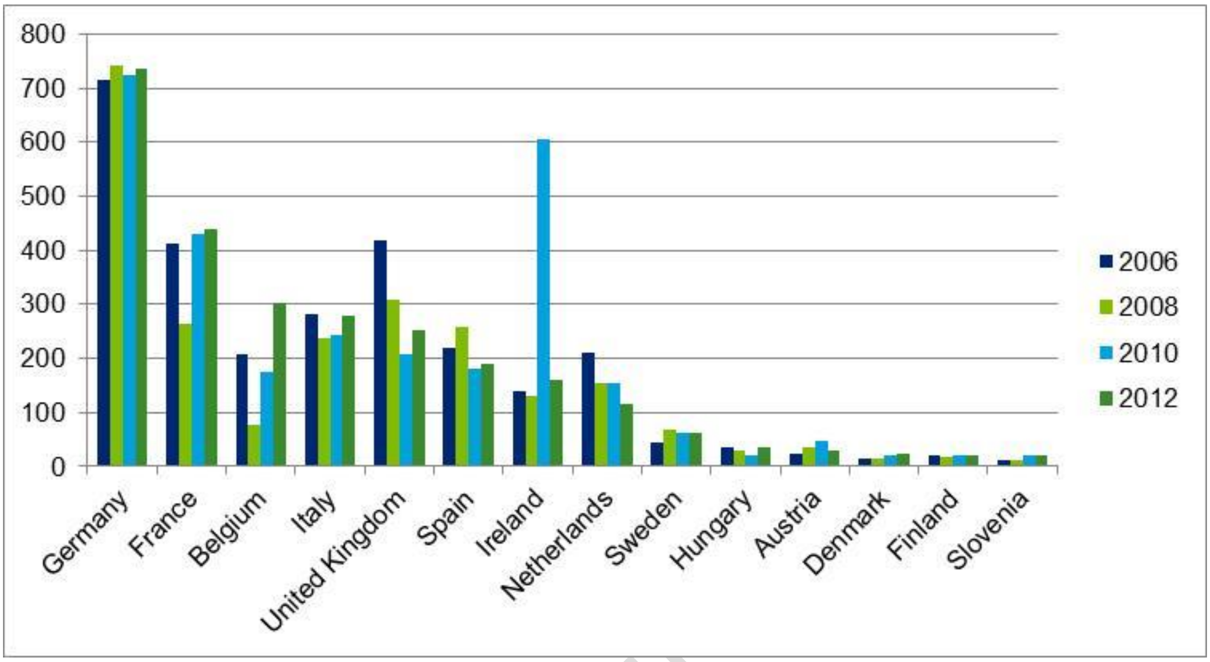

Figure 1.15: Evolution of the generation of waste solvents for the 14 main EU-28 producers in 2012 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr)

Several trends shown in Figure 1.15 are difficult to explain: the sudden drops in waste solvents generation in 2008 in France and Belgium and the sudden spike in Ireland in 2010, where generation was about 400% higher than other years. No information was provided by Member States that might explain the figure.

Import/export outside of EU-28

Quantities of exported and imported waste solvents outside EU-28 were collected on Eurostat COMEXT Database. Quantities are available on a monthly and yearly basis from 1988 to 2014. For the purpose of the study, yearly imported and exported quantities from 2006 to 2014 were considered. Relevant data were identified based on their CN8 code. According to the methodology used in UBA 2011 report, the following CN8 codes were used for waste solvents:

WDF	CN8 Code	Description
Waste solvents	38254100	Waste organic solvents, halogenated
	38254900	Waste organic solvents, non-halogenated

Table 1.18 shows that the EU-28 has had a fluctuating and negative waste solvents trade balance since 2006, which reached a low in 2014. This trade balance represented around -0.12% of the EU-28 annual production of waste solvents in 2010 and -0.16% in 2012.

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Table 1.18: Evolution of waste solvents trade outside of EU-28 (Source: Eurostat COMEXT Database)

	Import/export outside of EU-28 (tonnes/yr)		
	Import	Export	Trade balance
2006	6 065	1 782	-4 283
2008	5 933	253	-5 679
2010	8 322	4 926	-3 395
2012	4 543	121	-4 421
2014	12 948	2 119	-10 829

Treatment of waste solvents

Waste solvent treatment data comes from Eurostat Waste Statistics. Eurostat provides data for all treatments but only for the years 2010 and 2012.

Table 1.19: Evolution of the waste solvents sent for energy recovery and incineration per Member State (Source: Eurostat Waste Statistics)

	2010 (tonnes/yr)		2012 (tonnes/yr)	
	Energy recovery (R1)	Incineration/ Disposal (D10)	Energy recovery (R1)	Incineration/ Disposal (D10)
Austria	22 520	34 539	31 599	0
Belgium	42 212	34 700	3	37 994
Bulgaria	0	0	0	0
Croatia	32	0	0	0
Cyprus	0	4	0	2
Czech Republic	2 296	3 016	1 547	5 477
Denmark	14 261	0	14 277	0
Estonia	0	0	98	1
Finland	42	19 972	0	20 856
France	136 332	109 426	164 328	101 990
Germany	285 915	236 419	305 734	215 206
Greece	11	0	0	0
Hungary	72	14 728	0	18 042
Ireland	13 586	19 314	8 005	12 889
Italy	5 374	42 124	0	42 976
Latvia	0	200	0	0
Lithuania	0	12	0	49
Luxembourg	192	0	341	6
Malta	0	0	0	0
Netherlands	25 477	39 146	34 181	13 192
Poland	38	1 543	82	1 484
Portugal	3	2	13	0
Romania	57	2 330	15	106
Slovakia	12	189	11	150
Slovenia	2 000	10 933	917	6 645
Spain	44 796	836	30 103	0
Sweden	431	3 884	1 393	5 000
United Kingdom	8 581	0	0	0

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	2010 (tonnes/yr)		2012 (tonnes/yr)	
	Energy recovery (R1)	Incineration/ Disposal (D10)	Energy recovery (R1)	Incineration/ Disposal (D10)
Total EU-28	604 240	573 317	592 647	482 065

According to Table 1.19, nearly as much waste solvents are sent for incineration as for energy recovery, and the two treatment methods represent 40% of waste solvent generation in the EU-28 in 2010 and 2012.

According to a report from JRC in 2010[14], energy recovery represented about 35% of the treatment and disposal pathways for waste solvents in the EU-28.

Figure 1.16 shows the repartition of waste solvent treatment methods for the 14 Member States responsible for nearly 100% of waste solvent sent to incineration and energy recovery in the EU-28 in 2012.

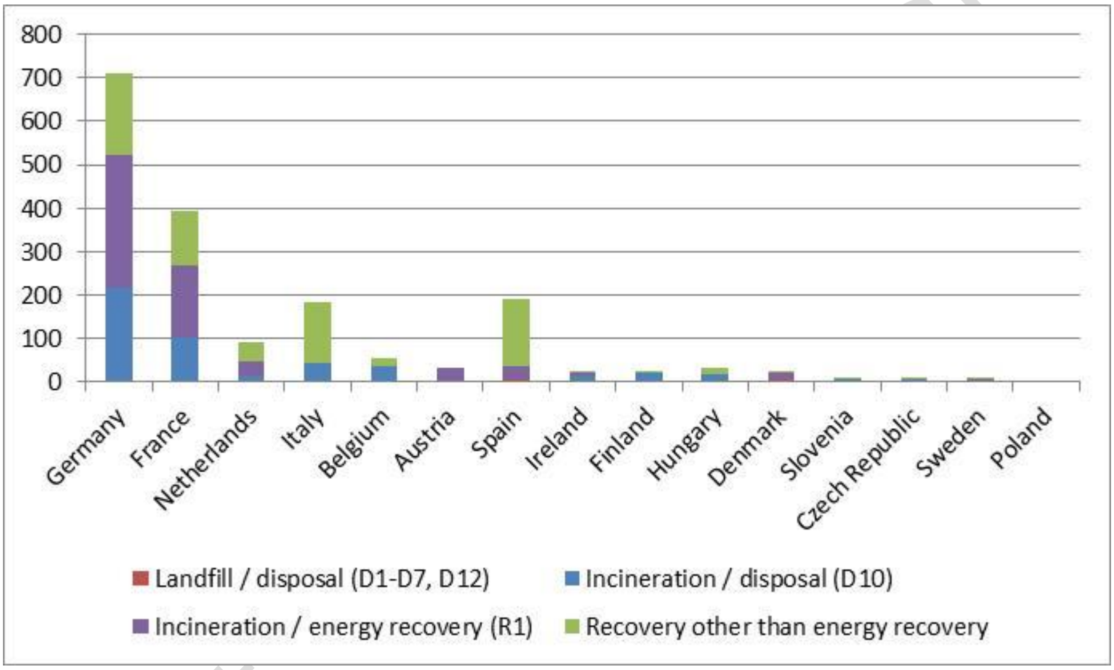

Figure 1.16: Treatments of waste solvents for the 14 EU-28 main contributors to energy production from waste solvents in 2012 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr).

According to Figure 1.16, Germany and France are by far the main contributors to energy production from waste solvents. Energy generation could still increase because nearly 1/3 of wastes are still sent to incinerators in these countries.

Figure 1.17 gives an overview of the repartition of waste solvent treatment methods in the EU-28 and its evolution between 2010 and 2012. Looking at Figure 1.17, it appears that in accordance with the European hierarchy for waste treatment, wastes sent for material recovery are increasing by 15 000 tonnes while those sent for energy recovery and incineration without energy recovery are decreasing by 12 000 tonnes and 90 000 tonnes, respectively. Even though wastes sent for landfilling represent less than 1% of total wastes, it is important to note that this amount has doubled between 2010 and 2012.

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[14] Source: JRC 2010: "Study on the selection of waste streams for end-of-waste assessment". Seville

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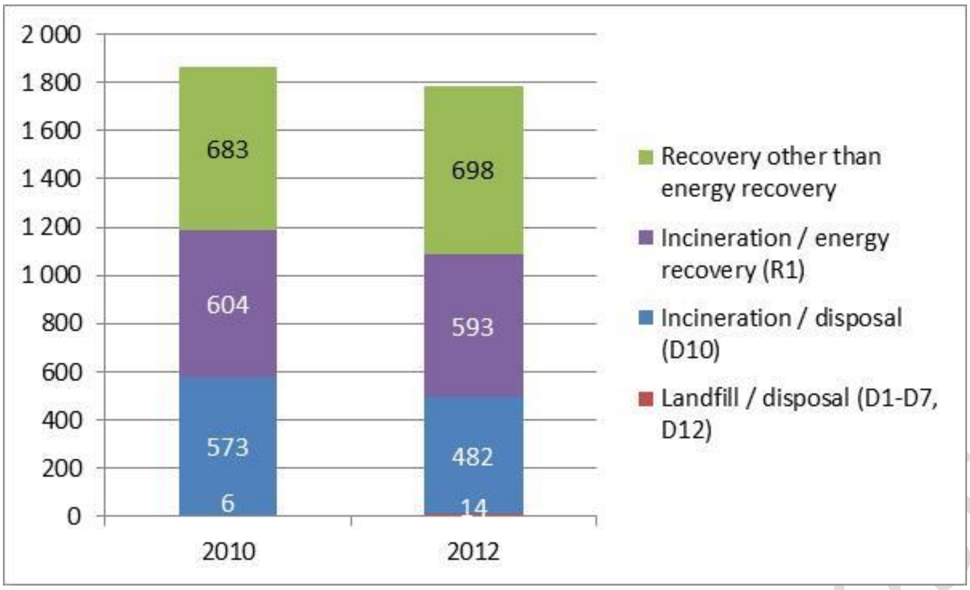

Figure 1.17: Evolution of waste solvent treatment methods in EU-28 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr)

5.3.7 Waste oil (mineral and synthetic)

Generation of waste oil

The methodology used to estimate generation of waste oil is to make assumptions on the amount of collected used oil based on information on the consumption of lubricants.

Eurostat waste statistics database has information on the consumption of used oil. However this database is not used because, according to the UBA 2011 report the waste category used oil also contains waste types not suitable to be used as combustible waste (e.g. desalter sludge).

Data on generation of waste oil comes from the United Nations Statistics Division. Assumption on the amount of used oil collected comes from GEIR (Groupement Européen de l'industrie de la Régénération). They estimate that 47% of total used oils consumed are collected the rest is lost to the nature (e.g. lubricants used in car motors, lubricants on saw chains, etc.). This estimation is in line with the assumption used in UBA 2011 report of 50%.

Table 1.20: Evolution of the generation of waste oils per Member State (Source: UN Database and assumptions from GEIR)

	Waste oils generation (1000 tonnes/yr)				
	2006	2008	2010	2012	2013
Austria	37	34	31	38	23
Belgium	49	43	25	24	20
Bulgaria	22	15	21	16	12
Croatia	18	18	16	14	14
Cyprus	3	3	3	2	2
Czech Republic	90	73	74	70	76
Denmark	29	26	24	24	24

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	Waste oils generation (1000 tonnes/yr)				
	2006	2008	2010	2012	2013
Estonia	2	2	2	1	1
Finland	37	41	35	31	31
France	346	323	292	282	273
Germany	551	521	475	486	486
Greece	57	32	19	16	18
Hungary	46	43	37	25	8
Ireland	15	16	13	14	14
Italy	305	228	205	266	252
Latvia	12	12	7	10	10
Lithuania	12	11	9	9	10
Luxembourg	6	4	4	3	4
Malta	2	2	2	2	2
Netherlands	86	99	74	49	47
Poland	105	112	110	104	96
Portugal	39	36	31	23	22
Romania	37	30	34	45	42
Slovakia	32	21	14	21	25
Slovenia	14	8	6	10	9
Spain	236	228	207	169	171
Sweden	195	216	55	22	21
United Kingdom	336	242	273	194	196
Total EU-28	2 718	2 441	2 097	1 972	1 908

According to Table 1.20 the production of waste oil decreases on average by 10% every two years from 2006 to 2013.

Based on data from Table 1.20, Figure 1.18 shows the evolution of the generation of waste oil for the 14 main EU-28 producers representing 92% of total EU-28 generation in 2013.

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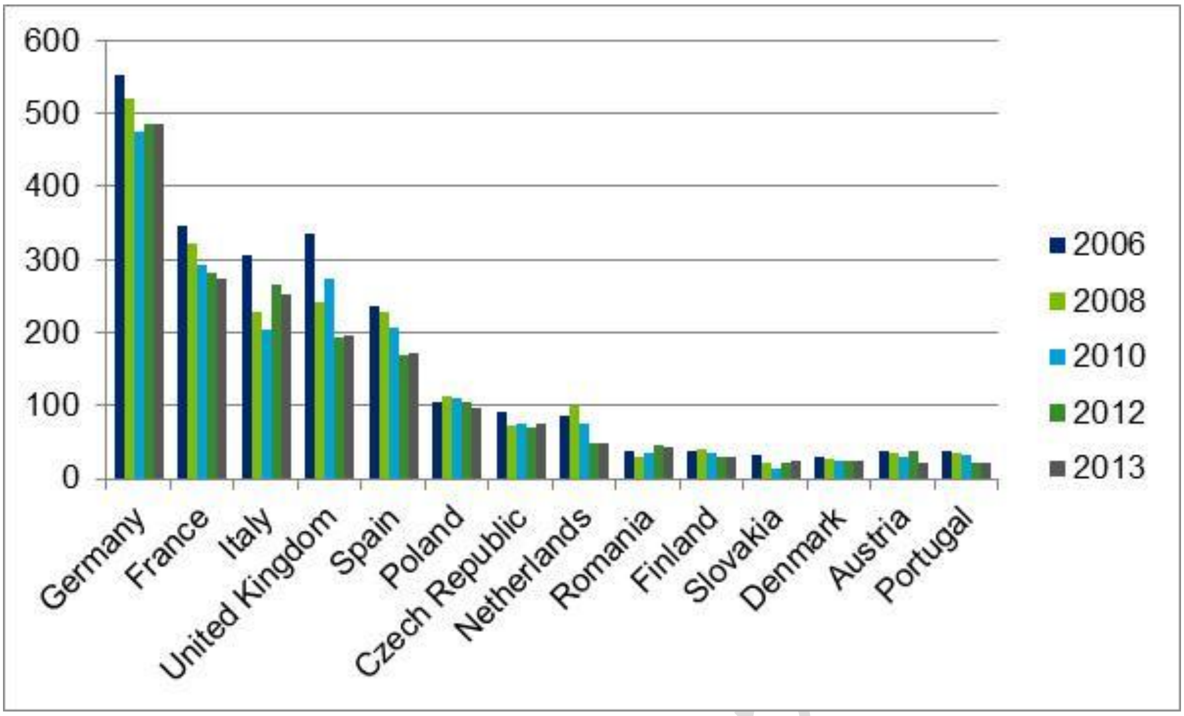

Figure 1.18: Evolution of the generation waste oil for the 14 main EU-28 producers in 2013 (Source: UN Database – in 1000 tonnes/yr)

Most EU-28 main producers of waste oil also follow a downward trend from 2006 to 2013.

<u>Import/export outside of EU-28</u>

Quantities of exported and imported waste oil outside EU-28 were collected on Eurostat COMEXT Database. Quantities are available on a monthly and yearly basis from 1988 to 2014. For the purpose of the study, yearly imported and exported quantities from 2006 to 2014 were considered. Relevant data were identified based on their CN8 code. According to the methodology used in UBA 2011 report, the following CN8 codes were used for waste oil:

WDF	CN8 Code	Description
Waste oil	27109100	Waste oils containing polychlorinated biphenyls [PCBs], polychlorinated terphenyls [PCTs] or polybrominated biphenyls [PBBs]
	27109900	Waste oils containing mainly petroleum or bituminous minerals (excl. those containing polychlorinated biphenyls [PCBs], polychlorinated terphenyls [PCTs] or polybrominated biphenyls [PBBs])

Table 1.21 shows that the EU-28 has a negative oil waste trade balance yet that it has been fluctuating since 2006. In 2010 this trade balance represented around 1% of the EU-28 annual production of waste solvents in 2010 and -2% in 2012.

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Table 1.21: Evolution of waste oil trade outside of EU-28 (Source: Eurostat COMEXT Database)

	Import/export outside of EU-28 (tonnes/yr)		
	Import	Export	Trade balance
2006	16 913	21 813	4 899
2008	45 054	3 585	-41 468
2010	47 573	65 381	17 808
2012	94 392	64 010	-30 382
2014	66 273	32 194	-34 078

Treatment of waste oil

There is no available database on the treatment of waste oil. In a previous report from 2011, UBA estimated the amount of used oil sent to energy recovery based on the following assumptions:

- In Western European countries the share being combusted was assumed to be 45 % of the collected amount (cf. EC, 2006[15]).
- For the newest Member States, it is assumed that 95% of the amount collection is used as a waste-derived fuel.

Even though there is no publically available data, based on expert interviews, it is estimated that most waste oils that are not sent to energy recovery are recycled.

Table 1.22: Evolution of the waste oils sent to energy recovery per Member State (Source: calculations based on UN Database – in 1000 tonnes/yr)

	Waste oils sent to energy recovery (1000 tonnes/yr)				
	2006	2008	2010	2012	2013
Austria	17	15	14	17	10
Belgium	22	19	11	11	9
Bulgaria	21	14	20	16	12
Croatia	17	17	15	13	13
Cyprus	1	1	1	1	1
Czech Republic	86	69	71	67	72
Denmark	13	12	11	11	11
Estonia	2	2	2	1	1
Finland	17	18	16	14	14
France	156	145	131	127	123
Germany	248	235	214	218	218
Greece	54	31	18	16	17
Hungary	43	41	35	24	7
Ireland	7	7	6	6	6
Italy	137	103	92	120	113
Latvia	12	11	6	10	9
Lithuania	11	11	9	9	9

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[15] Source: EC – European Commission (2006): Report from the commission to the council and the European Parliament on implementation of the community waste legislation Directive 75/442/EEC on waste, Directive 91/689/EEC on hazardous waste, Directive 75/439/EEC on waste oils, Directive 86/278/EEC on sewage sludge, Directive 94/62/EC on packaging and packaging waste and Directive 1999/31/EC on the landfill of waste for the period 2001–2003, SEC(2006)972.

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	Waste oils sent to energy recovery (1000 tonnes/yr)				
	2006	2008	2010	2012	2013
Luxembourg	3	2	2	1	2
Malta	1	1	1	1	1
Netherlands	38	45	33	22	21
Poland	100	106	105	99	91
Portugal	18	16	14	10	10
Romania	35	29	32	42	40
Slovakia	30	20	13	20	24
Slovenia	13	7	5	9	8
Spain	106	103	93	76	77
Sweden	88	97	25	10	9
United Kingdom	151	109	123	87	88
Total EU-28	**1446**	**1287**	**1118**	**1059**	**1018**

According to Table 1.22, waste oils sent to energy recovery is on a downward trend from 2006 to 2013.

Even if, no recent aggregated data on waste oil management in the EU-28 could be found, it is deemed that results in Table 1.22 represent high range estimates. As an example, in 2014 in Spain[16], 32% of waste oil were energetically recovered and 68% was regenerated into lubricant oil bases. More recent data on waste oil treatment methods should be soon available from GEIR.

Figure 1.19 shows the repartition of waste oil treatment methods for the 14 EU-28 countries representing nearly 91% of waste oil sent to energy recovery in 2013. As explained above, according to European experts, estimated amount of waste oils recycled in Figure 1.19 is considered as a low range estimate of the current situation. In addition, results from Figure 1.19 should be used with caution, because the 45% and 95% ratios used to estimate the share of waste sent to energy recovery correspond to averages at European level, and are not country specific ratios.

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[16] Source: SIGAUS (The Waste Oils Management System)

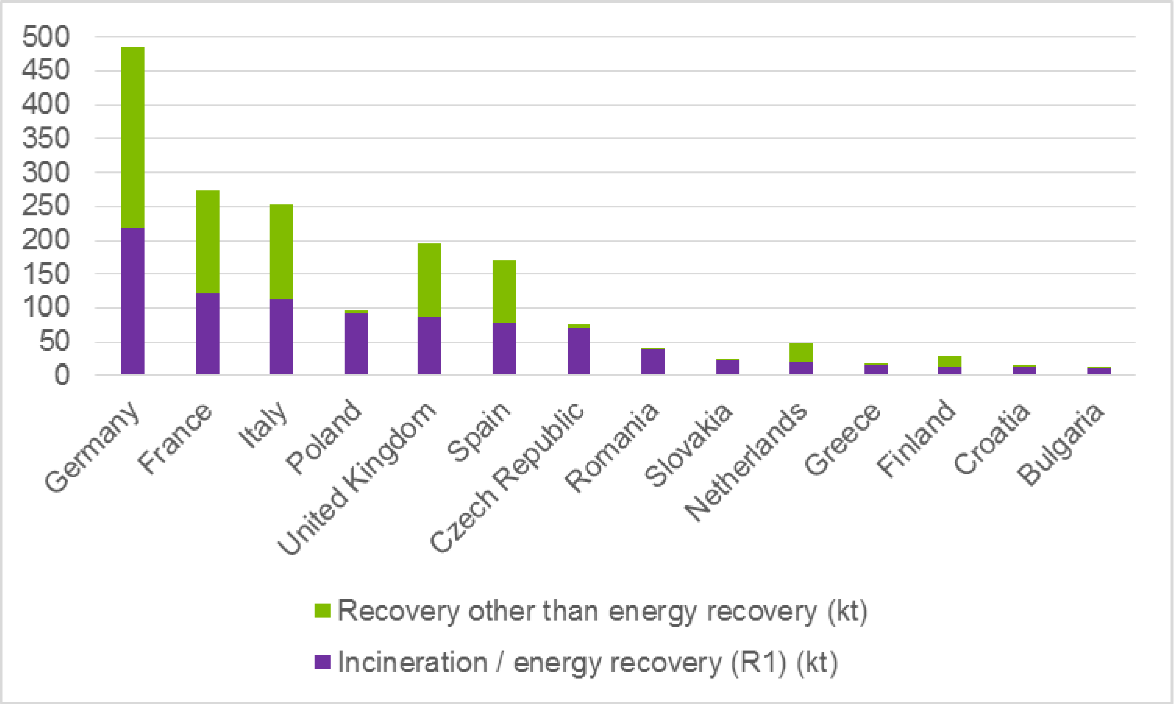

Figure 1.19: Treatments of wastes oils for the 14 EU-28 main contributors to energy production in 2013 (Source: calculations based on UN Database – in 1000 tonnes/yr).

Based on federations and expert inputs, it appears that waste oil is a 100% recyclable material. Following the waste hierarchy, waste management should therefore focus on reaching high quality recycling rate.

5.3.8 Chemical waste

Generation of chemical wastes

Data on the generation of chemical wastes comes from Eurostat Waste Statistics. In Eurostat, the EWC-Stat category "*Chemical wastes*" comes from the fusion of three categories after 2008:

- Spent chemical catalysts (01.4)
- Chemical preparation wastes (02)
- Chemical deposits and residues (03.1)

This category contains non-hazardous wastes.

Description of the category and main NACE sectors that produce chemical wastes (HSW) according the Eurostat Manual on waste statistics[17]:

"*Chemical wastes (01.4, 02, 03.1): These are solid or liquid spent chemical catalysts; off specification products and wastes like agro-chemicals, medicines, paint, dyestuff, pigments, varnish, inks and adhesives, including related sludges; chemical preparation waste like preservatives, brake and antifreeze fluids, waste chemicals; tars and carbonaceous waste like acid tars, bitumen, carbon anodes, tar and carbon waste; fuels, emulsions, sludges containing oil, like bilge oil, waste fuels oil, diesel, petrol, waste from oil water separator; aqueous rinsing and washing liquids, aqueous mother*

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[17] Additional information can be found in the "Guidance on classification of waste according to EWC-Stat categories" document.

liquors; spent filtration and adsorbent material like activated carbon, filter cakes, ion exchangers. They mainly originate from the chemical industry and from various industrial branches producing and using chemical products. They are hazardous when containing toxic chemical compounds, oil, heavy metals or other dangerous substances."

Table 1.23: Evolution of the generation of chemical wastes per Member State (Source: Eurostat Waste Statistics)

	Chemical waste generation (1000 tonnes/yr)			
	2006	2008	2010	2012
Austria	673	472	230	225
Belgium	960	722	708	888
Bulgaria	161	135	84	51
Croatia	547	456	26	20
Cyprus	0	0	0	0
Czech Republic	320	365	311	234
Denmark	30	35	125	109
Estonia	1 123	1 402	1 450	1 518
Finland	456	675	280	254
France	1 569	1 392	1 527	1 595
Germany	4 482	5 081	3 642	3 061
Greece	58	17	13	41
Hungary	186	184	156	184
Ireland	183	167	812	219
Italy	2 573	2 518	2 224	2 197
Latvia	13	10	8	10
Lithuania	2 026	1 963	43	37
Luxembourg	17	20	22	19
Malta	30	34	14	11
Netherlands	938	1 225	1 241	1 221
Poland	3 287	2 551	1 946	1 523
Portugal	2 795	230	230	214
Romania	360	209	140	61
Slovakia	133	113	91	100
Slovenia	63	75	27	50
Spain	1 541	1 536	1 012	861
Sweden	816	748	735	558
United Kingdom	3 144	2 342	1 285	1 786
Total EU-28	28 483	24 676	18 382	17 048

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According to Table 1.23, the generation of chemical wastes has decreased by 40% from 2006 to 2012.

Based on data from Table 1.23, Figure 1.20 shows the evolution of the generation of chemical waste for the 14 main EU-28 producers representing 95% of total EU-28 generation in 2012.

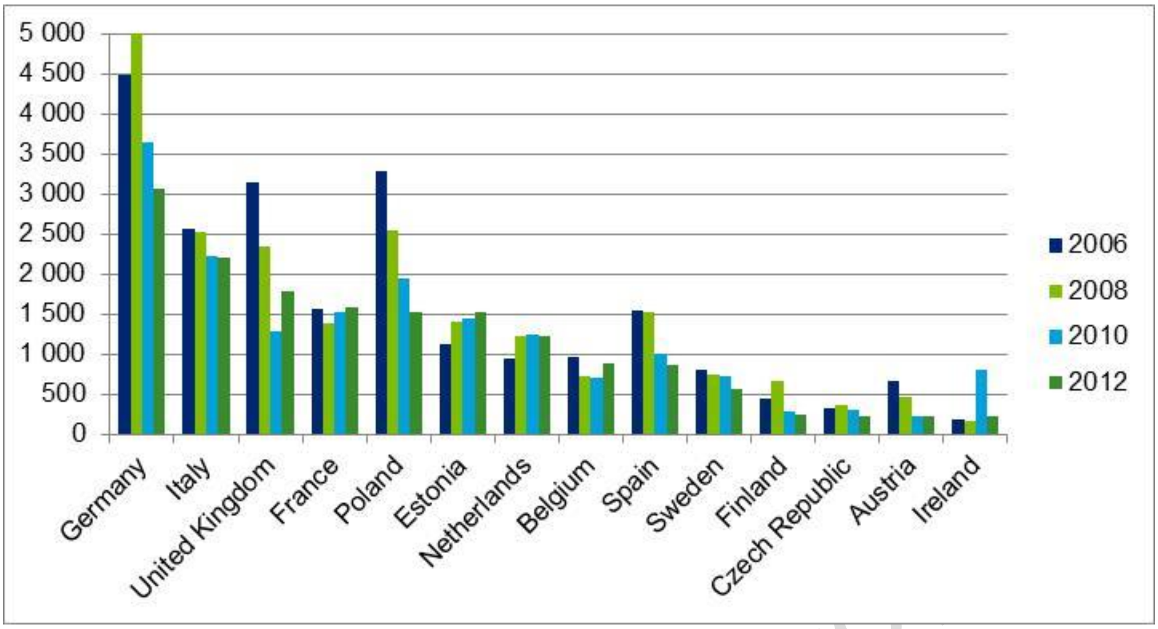

Figure 1.20: Evolution of the generation chemical waste for the 14 main EU-28 producers in 2012 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr)

As shown by Figure 1.20, from 2006 to 2014, four of the five main EU-28 chemical waste producers follow a downward trend (Germany, Italy, UK, and Poland), while the generation of waste is stable in France on the same period. No information was provided by Member States that might explain the figure.

Import/export outside of EU-28

No information on import/export of chemical waste outside of EU-28 has been identified.

Treatment of chemical waste

Chemical waste treatment data comes from Eurostat Waste Statistics. Eurostat provides data for all treatments (energy recovery, incineration on land, landfill, and material recovery) but only for the years 2010 and 2012.

Table 1.24: Evolution of the chemical wastes sent for energy recovery and incineration per Member State (Source: Eurostat Waste Statistics)

	2010 (1000 tonnes/yr)		2012 (1000 tonnes/yr)	
	Energy recovery (R1)	Incineration/ Disposal (D10)	Energy recovery (R1)	Incineration/ Disposal (D10)
Austria	61	30	79	0
Belgium	92	69	1	111
Bulgaria	0	0	0	0
Croatia	11	3	2	0
Cyprus	0	0	0	0
Czech Republic	28	21	11	31
Denmark	92	0	66	0
Estonia	5	0	3	0
Finland	6	59	2	55
France	474	574	409	626
Germany	511	498	601	448

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	2010 (1000 tonnes/yr)		2012 (1000 tonnes/yr)	
	Energy recovery (R1)	Incineration/ Disposal (D10)	Energy recovery (R1)	Incineration/ Disposal (D10)
Greece	2	0	2	0
Hungary	22	39	26	41
Ireland	31	0	5	0
Italy	54	178	73	159
Latvia	0	0	0	0
Lithuania	0	1	0	0
Luxembourg	0	0	0	0
Malta	0	0	0	0
Netherlands	105	420	82	510
Poland	10	31	2	46
Portugal	3	12	1	14
Romania	35	50	10	8
Slovakia	1	2	1	4
Slovenia	0	3	11	3
Spain	120	5	65	0
Sweden	47	68	49	24
United Kingdom	0	8	0	131
Total EU-28	**1 710**	**2 070**	**1 500**	**2 213**

Between 2010 and 2012, the amount of chemical waste sent for energy recovery has decreased by 12%, while on the same period the amount sent for incineration/disposal has increased by 7%.

Figure 1.21 shows the repartition of chemical waste treatment methods for the 14 EU-28 countries representing 98% of chemical wastes sent to incineration and energy recovery in 2012. The repartition of chemical wastes is very different from one country to another, some countries sending most of their wastes to incineration/disposal (France and the Netherlands), while others send most of their wastes to material recovery (Germany, Spain, Poland).

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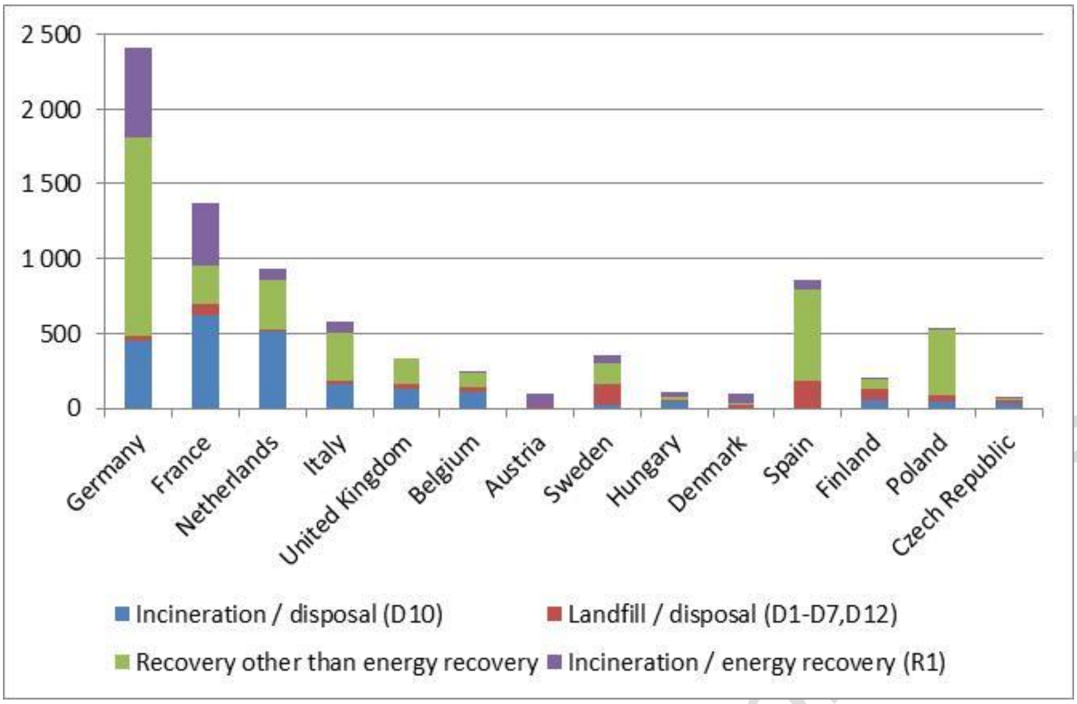

Figure 1.21: Treatments of chemical wastes for the 14 EU-28 main contributors to energy production from chemical waste in 2012 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr)

Figure 1.22 gives an overview of the repartition of chemical waste treatment methods in EU-28 and its evolution between 2010 and 2012. Looking at Figure 1.22, it seems that EU-28 Member States tend to follow the European waste management hierarchy because, between 2010 and 2012, wastes sent to landfill show the biggest decrease while wastes sent for incineration/disposal increase and those sent for material recovery are stable on the same period.

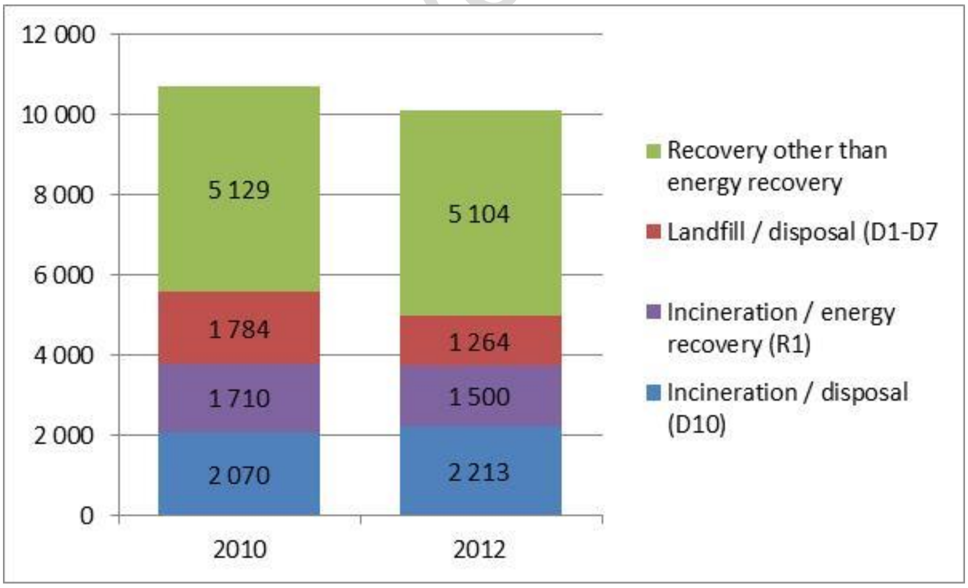

Figure 1.22: Evolution of chemical waste treatment methods in EU-28 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr)

5.3.9 Household and similar wastes

Generation of household and similar wastes

Description of the category and main NACE sectors that produce household and similar wastes (HSW) according the Eurostat Manual on waste statistics[18]:

"*Household and similar wastes (10.1): These wastes are mixed municipal waste, bulky waste, street-cleaning waste like packaging, kitchen waste, and household equipment except separately collected fractions. They originate mainly from households but can also be generated by all sectors in canteens and offices as consumption residues. Household and similar wastes are non-hazardous*".

Every two years, Members States provide Eurostat specific information on municipal waste. As explained in the above definition, the scope for "household and similar wastes" and "municipal waste" are different, the latter including separately collected wastes for instance. Even though the database on municipal waste is very reliable, it could not be used, because it is not possible to provide specific data for household and similar wastes.

Data on the generation of household and similar wastes (HSW) comes from Eurostat Waste Statistics. In Eurostat, the EWC-Stat category "10.1 Household and similar wastes" contains non-hazardous wastes.

Table 1.25: Evolution of the generation of household and similar wastes per Member State (Source: Eurostat Waste Statistics)

	Household and similar wastes generation (1000 tonnes/yr)			
	2006	2008	2010	2012
Austria	2 459	1 876	3 664	2 624
Belgium	5 020	3 608	2 570	2 837
Bulgaria	4 102	3 747	3 107	3 110
Croatia	1 320	1 677	1 337	1 396
Cyprus	253	183	173	166
Czech Republic	3 189	3 281	3 309	3 100
Denmark	3 141	3 172	2 806	2 733
Estonia	655	466	305	294
Finland	1 931	1 705	2 031	1 594
France	25 527	23 921	22 179	22 371
Germany	20 933	20 806	21 376	20 955
Greece	4 927	5 077	4 771	4 305
Hungary	4 111	3 494	3 195	2 897
Ireland	342	145	3 265	2 737
Italy	25 063	26 190	21 378	18 043
Latvia	957	752	563	727
Lithuania	1 286	1 253	1 065	1 016
Luxembourg	198	212	210	208
Malta	241	261	218	206
Netherlands	8 208	7 878	7 432	7 185

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[18] Additional information can be found in the "Guidance on classification of waste according to EWC-Stat categories" document.

	Household and similar wastes generation (1000 tonnes/yr)			
	2006	2008	2010	2012
Poland	7 195	6 784	8 638	8 774
Portugal	6 651	6 830	6 024	4 661
Romania	4 152	5 504	4 464	5 343
Slovakia	1 437	1 533	1 458	1 382
Slovenia	727	861	777	560
Spain	23 236	22 604	21 120	19 584
Sweden	2 671	2 523	2 511	2 587
United Kingdom	47 745	43 701	28 956	28 261
Total EU-28	207 675	200 044	178 896	169 655

According to Table 1.25 the production of household and similar wastes (HSW) has increased by 18% from 2006 to 2012.

Based on data from Table 1.25, Figure 1.23 shows the evolution of the generation of HSW for the 14 main EU-28 producers representing 89% of total EU-28 generation in 2012.

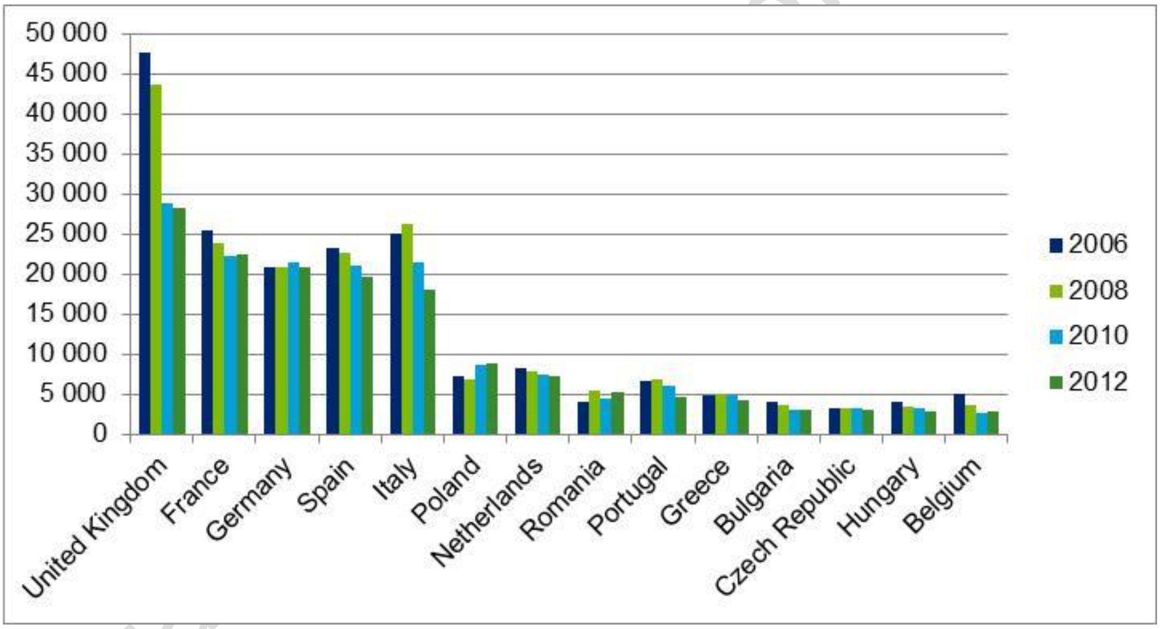

Figure 1.23: Evolution of the generation of household and similar wastes for the 14 main EU-28 producers in 2012 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr)

Figure 1.23 shows that the main EU-28 producers follow the general downward trend observed at European level. The sudden drop observed for the UK between 2008 and 2010 is due to the adoption in 2012 of an improved methodology for collecting data on paper wastes. The data for 2010 was revisited using the new methodology as a basis, but the figures for 2008 and 2006 reflect the previous methodology.

Import/export outside of EU-28

No information on import/export of HSW outside of EU-28 has been identified.

Treatment of household and similar wastes

HSW treatment data comes from Eurostat Waste Statistics. Eurostat Waste Statistics provides data on material recovery only for the years 2010 and 2012, and data on other treatments (energy recovery, incineration on land, and landfill) are available for the years 2006, 2008, 2010 and 2012.

Table 1.26 presents the mass balance between generation and treatment of HSW. The detail of the mass balance per country is available in Annex 3.

Table 1.26: Mass balance between household and similar wastes generation and treatment in EU-28 in 2010 and 2012 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr)

	2010	2012
Waste generation (1000 tonnes)	178 896	169 655
Waste treatment (1000 tonnes)	153 150	137 343
Difference[19] (%)	-14%	-19%

There appears to be a discrepancy between the waste generation and the amount of waste treated in the EU-28. Import/export outside of EU-28 could be responsible for the observed difference of 14% to 19%. Some Member States explained that the difference between MSW generation and treatment could be explained by different interpretations for complying with the Waste regulation for treatment. For instance, in the Netherlands, MSW that is sorted will get a new LoW code, this might be as sorted waste and then it will be incinerated of recycled. Only MSW that is directly incinerated will keep the LoW as MSW.

Table 1.27 presents the evolution of the amount of household and similar wastes sent for energy recovery and incineration per Member State in 2010 and 2012.

Table 1.27: Evolution of the household and similar wastes sent for energy recovery and incineration per Member State (Source: Eurostat Waste Statistics)

	2010 (1000 tonnes/yr)		2012 (1000 tonnes/yr)	
	Energy recovery (R1)	Incineration/ Disposal (D10)	Energy recovery (R1)	Incineration/ Disposal (D10)
Austria	0	1 191	1 069	0
Belgium	1 294	372	1 479	569
Bulgaria	0	0	0	0
Croatia	2	4	0	0
Cyprus	0	0	0	0
Czech Republic	452	0	586	0
Denmark	2 299	0	2 232	0
Estonia	0	0	0	0
Finland	340	101	902	2
France	6 333	5 388	6 728	5 058
Germany	6 580	8 286	7 474	6 905
Greece	0	0	0	0
Hungary	408	0	366	0
Ireland	0	0	134	0
Italy	18	3 028	33	2 595
Latvia	0	0	0	0

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[19] Difference (%) = (Use-Generation)/Generation

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	2010 (1000 tonnes/yr)		2012 (1000 tonnes/yr)	
	Energy recovery (R1)	Incineration/ Disposal (D10)	Energy recovery (R1)	Incineration/ Disposal (D10)
Lithuania	0	0	0	0
Luxembourg	0	116	0	122
Malta	0	0	0	0
Netherlands	3 208	2 091	5 705	25
Poland	0	102	17	51
Portugal	1 053	46	923	42
Romania	2	0	6	0
Slovakia	167	2	163	4
Slovenia	0	0	0	0
Spain	1 567	9	1 496	7
Sweden	2 268	0	2 296	0
United Kingdom	16	4 107	0	5 190
Total EU-28	**26 007**	**24 845**	**31 610**	**20 570**

According to Table 1.27, between 2010 and 2012 the amount of HSW sent for energy recovery has increased by 22% at EU-28 level, while on the same period the amount sent for incineration disposal has decreased by 17%. According to Eurostat Waste Statistics, wastes sent for energy recovery represent about 20% of HSW generation in the EU-28.

Figure 1.24 shows the repartition of HSW treatment methods for the 14 EU-28 countries representing 99% of HSW sent to incineration and energy recovery in 2012. The repartition of HSW is very different across Member States:

- Italy is the only country in which material recovery is the main treatment pathway;
- Four countries (France, UK, Italy and Spain) sent more than 5 million tonnes of wastes to landfill;
- Germany and France are the only countries sending significant amounts of wastes to both incineration disposal and energy recovery.

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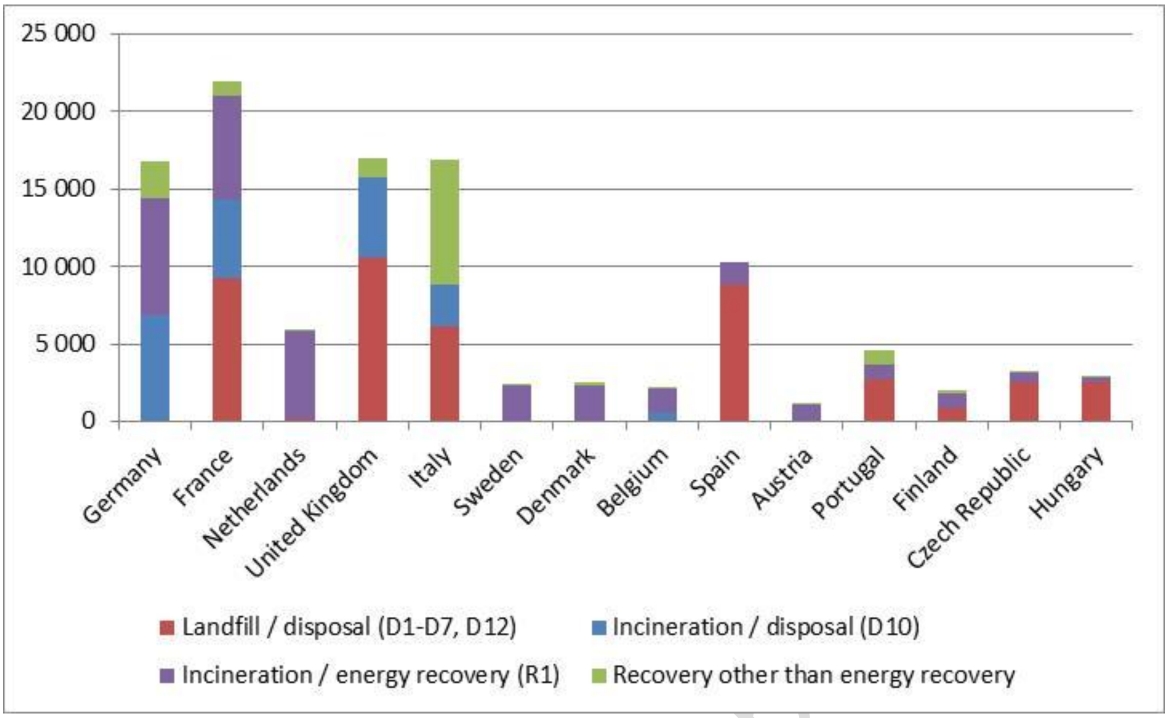

Figure 1.24: Treatments of household and similar wastes for the 14 EU-28 main contributors to energy production from household and similar wastes in 2012 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr).

Information provided in Figure 1.24 reflects the HSW management practices in Member States:

- In the case of Spain, landfilling is higher due to the low cost of this treatment. This might change in the future as a few regions, such as Catalonia, have established taxes for landfilling to encourage separate collection and recycling.
- In Germany, a landfill ban on organic substances has been implemented several years ago and prove to be efficient.

Figure 1.25 shows the evolution of household and similar wastes treatment methods in EU-28. Looking at Figure 1.25, it appears that the trends between 2006 and 2012 are in line with the European hierarchy for waste treatment: reduction of wastes sent for landfill and incineration disposal, and increase of the amount sent for material and energy recovery.

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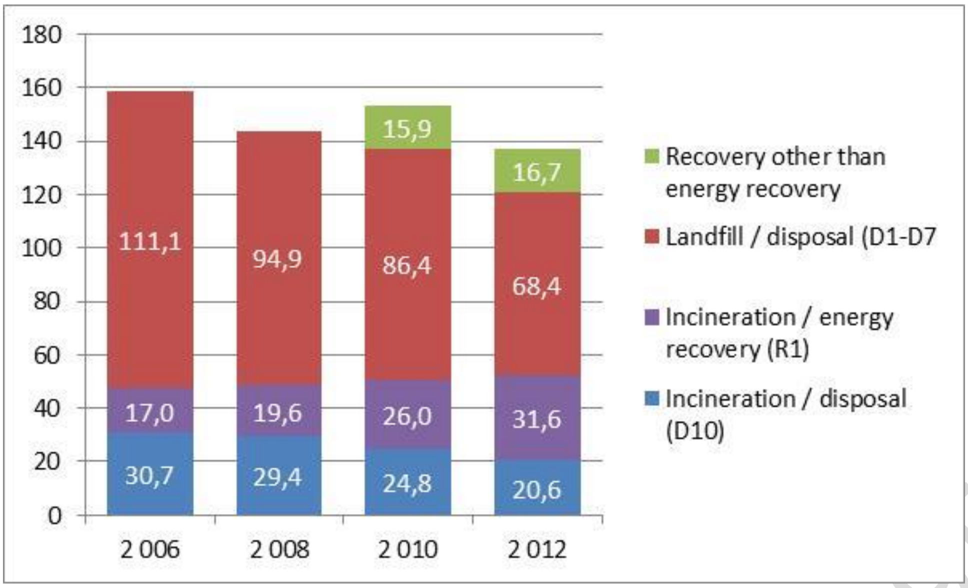

Figure 1.25: Evolution of household and similar wastes treatment methods in EU-28 (Source: Eurostat Waste Statistics – in million tonnes/yr)

Note: As explained above, the amount of HSW sent to material recovery is missing for the years 2006 and 2008.

Please note that, according to interviews with experts, data on recovery (other than energy recovery) should be used carefully. Indeed, in this category some countries report wastes entering Mechanical Biological Treatment (MBT) plants to Eurostat. But, only part of the wastes sent to MBT plants is really recovered, some of the rest being sent to landfill after sorting.

5.3.10 Mixed and undifferentiated materials

Generation of mixed and undifferentiated materials

Data on the generation of mixed and undifferentiated materials (M&UM) comes from Eurostat Waste Statistics.
In Eurostat, the EWC-Stat category “10.2 mixed and undifferentiated materials” contains non-hazardous wastes.

Description of the category and main NACE sectors that produce mixed and undifferentiated materials (M&UM) according the Eurostat Manual on waste statistics[20]:

“*Mixed and undifferentiated materials (10.2): These are unspecified and mixed waste without any general waste source. This category covers not only mixed packaging but also mainly residual categories from different branches of industry (food production, textile industry, combustion plants, surface treatment of metals and plastics, etc.). These residual categories are often used for nation-specific waste codes. Mixed and undifferentiated materials are hazardous when containing heavy metals or organic pollutants*.”

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[20] Additional information can be found in the “Guidance on classification of waste according to EWC-Stat categories” document.

The Eurostat manual also indicates that as of 2010 the category summarises all unspecified LoW-codes; the amount of category 10.2, non-hazardous, should be higher than before.

Table 1.28: Evolution of the generation of mixed and undifferentiated materials per Member State (Source: Eurostat Waste Statistics)

	Mixed and undifferentiated materials (1000 tonnes/yr)			
	2006	2008	2010	2012
Austria	1 137	32	86	140
Belgium	3 340	1 132	4 641	3 061
Bulgaria	61	49	87	167
Croatia	45	20	258	59
Cyprus	99	62	89	78
Czech Republic	200	177	288	348
Denmark	1 080	939	961	1 039
Estonia	33	27	53	81
Finland	553	192	1 884	993
France	12 523	12 628	12 258	9 869
Germany	4 503	4 813	6 861	6 996
Greece	83	61	998	989
Hungary	234	197	392	380
Ireland	339	128	466	741
Italy	3 414	3 729	6 429	5 859
Latvia	12	2	13	307
Lithuania	8	22	82	51
Luxembourg	6	5	92	33
Malta	15	6	11	11
Netherlands	326	243	894	905
Poland	339	479	2 056	3 631
Portugal	778	532	369	387
Romania	3 316	2 105	2 610	288
Slovakia	83	82	130	130
Slovenia	18	29	86	134
Spain	1 134	1 587	2 068	2 021
Sweden	2 433	831	1 093	835
United Kingdom	7 404	4 392	7 117	7 408
Total EU-28	**43 518**	**34 500**	**52 372**	**46 941**

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According to Table 1.28, the production of M&UM has decreased by 21% and 10% from 2006 to 2008, and from 2010 to 2012 resp., whereas the production has increased by 52% between 2008 and 2010. Considering that the evolution between 2008 and 2010 is for one part due to the evolution of the perimeter (as explained above), then the generation of M&UM follow a downward trend between 2006 and 2012.

Based on data from Table 1.28, Figure 1.26 shows the evolution of the generation of waste M&UM for the 14 main EU-28 producers representing 95% of total EU-28 generation in 2012.

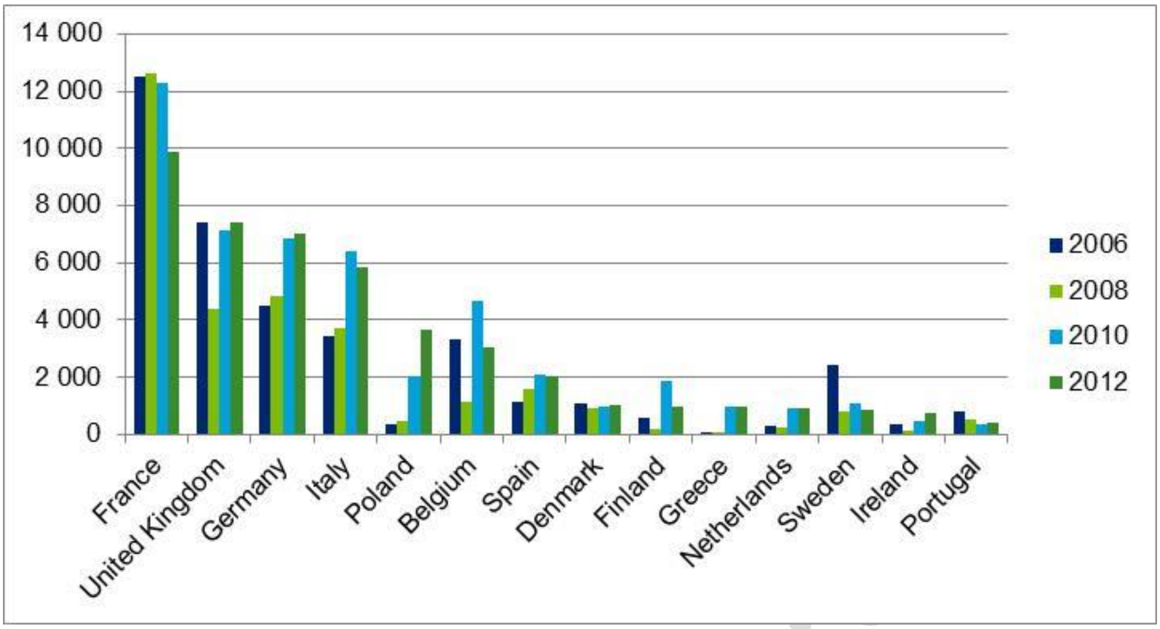

Figure 1.26: Evolution of the generation of mixed and undifferentiated materials for the 14 main EU-28 producers in 2012 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr)

Looking at Figure 1.26, most of the Member States included in this figure show a significant increase in the generation of mixed and undifferentiated materials between 2008 and 2010. This can probably be explained by evolution of the perimeter of the definition.

As explained in the above definition, M&UM is mostly a left-over category with unspecified and country specific waste streams. It is therefore, very difficult ton confront Eurostat data with any other database. No further information was provided by Member States that might explain the figure.

<u>Import/export outside of EU-28</u>

Comprehensive trade-data was not identified.

<u>Treatment of mixed and undifferentiated materials</u>

Treatment data for mixed and undifferentiated materials comes from Eurostat Waste Statistics. Eurostat Waste Statistics provides data on material recovery only for the years 2010 and 2012, and data on other treatments (energy recovery, incineration on land, and landfill) are available for the years 2006, 2008, 2010 and 2012.

Table 1.29 presents the mass balance between generation and treatment of M&UM. The detail of the mass balance per country is available in Annex 3.

Table 1.29: Mass balance between generation and treatment of mixed and undifferentiated materials in EU-28 in 2010 and 2012 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr)

	2010	2012
Waste generation (1000 tonnes)	52 372	46 941
Waste treatment (1000 tonnes)	34 948	33 123
Difference[21] (%)	-33%	-29%

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[21] Difference (%) = (Use-Generation)/Generation

There appears to be a discrepancy between the waste generation and the amount of waste treated in the EU-28. Import/export outside of EU-28 could be responsible for the observed difference of about 30%.

Table 1.30: Evolution of the mixed and undifferentiated materials sent for energy recovery and incineration per Member State (Source: Eurostat Waste Statistics)

	2010 (1000 tonnes/yr)		2012 (1000 tonnes/yr)	
	Energy recovery (R1)	Incineration/ Disposal (D10)	Energy recovery (R1)	Incineration/ Disposal (D10)
Austria	45	4	103	0
Belgium	558	242	2 882	617
Bulgaria	10	0	9	0
Croatia	8	2	0	0
Cyprus	0	0	0	0
Czech Republic	9	1	14	2
Denmark	300	0	356	0
Estonia	1	0	0	0
Finland	1 275	10	436	61
France	620	305	304	231
Germany	1 717	350	1 925	319
Greece	2	0	1	0
Hungary	17	1	208	2
Ireland	0	0	29	0
Italy	782	260	679	202
Latvia	52	0	2	0
Lithuania	0	0	3	0
Luxembourg	0	0	0	0
Malta	0	0	0	0
Netherlands	79	47	117	33
Poland	50	6	91	8
Portugal	28	1	13	1
Romania	27	5	69	1
Slovakia	3	1	2	2
Slovenia	1	0	7	0
Spain	0	3	194	0
Sweden	1 383	5	2 354	3
United Kingdom	1	153	65	131
Total EU-28	**6 967**	**1 394**	**9 863**	**1 613**

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According to Table 1.30, between 2010 and 2012 the amount of M&UM sent for energy recovery has increased by nearly 3 million tonnes at EU-28 level, while on the same period the amount sent for incineration disposal has increased by 0.2 million tonnes. According to Eurostat Waste Statistics, in 2012, wastes sent for energy recovery represent about 20% of waste generation in the EU-28.

Figure 1.27 shows the repartition of M&UM treatment methods for the 14 EU-28 countries representing 99% of M&UM sent to incineration and energy recovery in 2012.

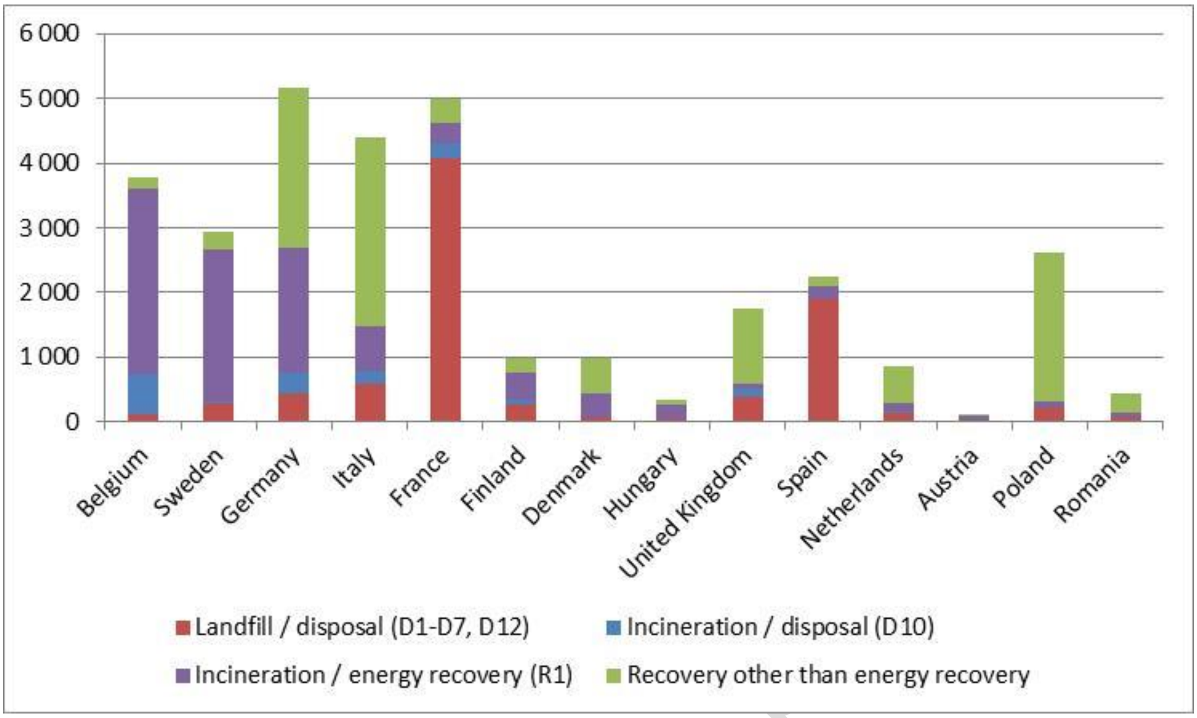

Figure 1.27: Treatments of the mixed and undifferentiated materials for the 14 EU-28 main contributors to energy production from mixed and undifferentiated materials in 2012 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr).

Figure 1.28 shows the evolution of M&UM treatment methods in EU-28. As explained above, because of the evolution of the definition of M&UM between 2008 and 2010, it seems more relevant to study the trends for the years 2010 and 2012 only. Focusing on these years in Figure 1.28, it appears that the trends are in line with the European hierarchy for waste treatment: reduction of wastes sent for landfill and increase of the amount sent for energy recovery.

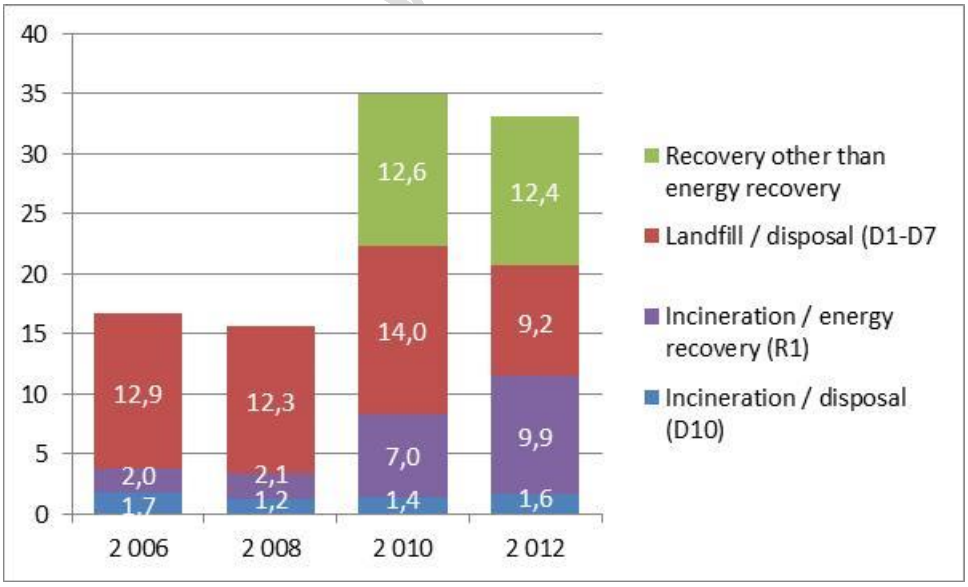

Figure 1.28: Evolution of mixed and undifferentiated materials treatment methods in EU-28 (Source: Eurostat Waste Statistics – in million tonnes/yr)

Note: As explained above, the amount of M&UM sent to material recovery is missing for the years 2006 and 2008.

Based on this data, it appears that M&UM has a significant potential for material and energy recovery. However, considering the great heterogeneity of the category and the lack of clear definition of the type of wastes included, it is difficult to provide a robust analysis of generation and waste management trends. It is also difficult to provide an accurate estimate of its potential for material and energy recovery, in accordance with the treatment hierarchy.

5.3.11 Sorting residues

Generation of sorting residues

Data on the generation of sorting residues comes from Eurostat Waste Statistics. In Eurostat, the EWC-Stat category "10.3 Sorting residues" contains hazardous and non-hazardous wastes.

Description of the category and main NACE sectors that produce sorting residues according the Eurostat Manual on waste statistics[22]:

"*Sorting residues (10.3): These wastes are sorting residues from mechanical sorting processes for waste; combustible waste (refuse derived fuel); and non-composted fractions of biodegradable waste. They mainly originate from waste treatment and separate collection. Sorting residues from demolition activities are excluded. They are hazardous when containing heavy metals or organic pollutants."*

Table 1.31: Evolution of the generation of sorting residues per Member State (Source: Eurostat Waste Statistics)

	Sorting residues generation (1000 tonnes/yr)			
	2006	2008	2010	2012
Austria	568	534	1 395	1 611
Belgium	1 118	884	1 538	1 700
Bulgaria	61	105	56	323
Croatia	22	33	8	29
Cyprus	0	0	2	3
Czech Republic	315	228	295	352
Denmark	0	0	490	510
Estonia	15	39	35	144
Finland	409	529	683	293
France	3 617	4 151	6 193	5 857
Germany	11 182	12 902	13 972	16 396
Greece	252	21	155	253
Hungary	137	166	148	228
Ireland	41	8	501	491
Italy	7 878	10 831	9 971	13 536
Latvia	5	5	4	11
Lithuania	6	5	36	219
Luxembourg	21	12	41	34

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[22] Additional information can be found in the "Guidance on classification of waste according to EWC-Stat categories" document.

	Sorting residues generation (1000 tonnes/yr)			
	2006	2008	2010	2012
Malta	17	7	8	50
Netherlands	3 204	2 787	2 336	1 412
Poland	1 354	2 862	4 664	5 651
Portugal	424	94	166	357
Romania	26	172	602	695
Slovakia	136	166	24	78
Slovenia	49	49	17	81
Spain	995	1 101	6 080	7 505
Sweden	1 276	2 298	1 278	1 656
United Kingdom	4 782	7 621	4 181	5 944
Total EU-28	37 910	47 610	54 877	65 417

According to Table 1.31 the production of sorting residues has increased on average by 20% every two years from 2006 to 2008.

According to CEPI, the Confederation of European Paper Industries, the increasing trend in sorting residues is also noticed in pulp & paper industry. Factories using waste paper as raw material are receiving lower waste paper qualities which is resulting in more pulping rejects (sorting residues).

Based on data from Table 1.31, Figure 1.29 shows the evolution of the generation of sorting residues for the 14 main EU-28 producers representing 97% of total EU-28 generation in 2012.

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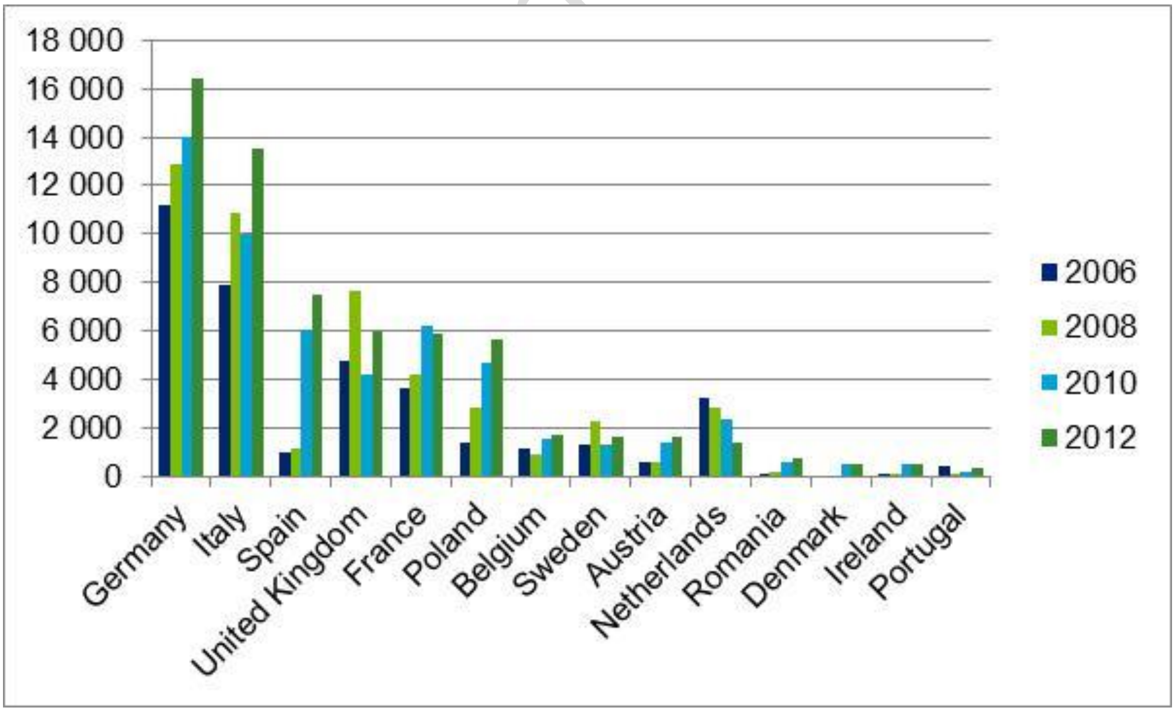

Figure 1.29: Evolution of the generation of sorting residues for the 14 main EU-28 producers in 2012 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr)

According to data provided in Table 1.31 and the information shown in Figure 1.29, Germany and Italy which represent nearly half of EU-28 production in 2012 are on a strong upward trend between 2006 and 2012.

In the case of the Spanish data, the tendency of the generation data could be due to a change in the methodology. In 2010, waste from MBT plants formerly included in 09.1 category (Animal and vegetable wastes) were classified under 10.3 "sorting residues" category. Therefore, data from 2010 and 2012 are more accurate. No further information was provided by Member States that might explain the figure.

Import/export outside of EU-28

Comprehensive trade-data was not identified.

Treatment of sorting residues

In its 2011 report, UBA made the assumption that all sorting residues were used for energy recovery. However, Eurostat Waste Statistics provides data on material recovery only for the years 2010 and 2012, and data on other treatments (energy recovery, incineration on land, and landfill) are available for the years 2006, 2008, 2010 and 2012.

Therefore, data from Eurostat Waste Statistics has been used. Table 1.32 presents the mass balance between generation and treatment of sorting residues. The detail of the mass balance per country is available in Annex 3.

Table 1.32: Mass balance between generation and treatment of sorting residues in EU-28 in 2010 and 2012 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr)

	2010	2012
Waste generation (1000 tonnes)	54 877	65 417
Waste treatment (1000 tonnes)	53 860	62 994
Difference[23] (%)	-2%	-4%

The difference between the waste generation and the amount of waste treated in the EU-28 is below 4%. Import/export outside of EU-28 could be responsible for the observed difference.

Table 1.33: Evolution of sorting residues sent to incineration and energy recovery per Member State (Source: Eurostat Waste Statistics)

	2010 (1000 tonnes/yr)		2012 (1000 tonnes/yr)	
	Energy recovery (R1)	Incineration/ Disposal (D10)	Energy recovery (R1)	Incineration/ Disposal (D10)
Austria	411	346	1 151	0
Belgium	771	350	50	509
Bulgaria	30	0	52	0
Croatia	0	0	2	0
Cyprus	0	0	0	0
Czech Republic	45	2	114	2
Denmark	169	0	133	0
Estonia	19	0	52	0
Finland	135	24	41	15
France	847	126	394	148

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[23] Difference (%) = (Use-Generation)/Generation

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	2010 (1000 tonnes/yr)		2012 (1000 tonnes/yr)	
	Energy recovery (R1)	Incineration/ Disposal (D10)	Energy recovery (R1)	Incineration/ Disposal (D10)
Germany	7 495	2 167	9 606	1 952
Greece	1	0	0	0
Hungary	132	2	117	1
Ireland	49	0	178	0
Italy	284	2 239	573	2 479
Latvia	0	0	127	0
Lithuania	0	0	0	0
Luxembourg	6	7	12	11
Malta	0	0	0	0
Netherlands	533	498	1 337	13
Poland	734	78	958	85
Portugal	67	0	148	0
Romania	73	0	248	0
Slovakia	1	0	30	0
Slovenia	13	17	17	20
Spain	537	0	956	0
Sweden	486	0	442	0
United Kingdom	208	12	302	6
Total EU-28	13 045	5 868	17 040	5 242

According to Table 1.33, between 2010 and 2012 the amount of sorting residues sent for energy recovery has increased by 31% at EU-28 level, while on the same period the amount sent for incineration disposal has decreased by 11%. According to Eurostat Waste Statistics, wastes sent for energy recovery represent about 26% of sorting residues generation in the EU-28.

Figure 1.30 shows that landfilling of sorting residues is still very common in the EU-28 in 2012. For five of the main producers of sorting residues (UK, Spain, Italy, Poland and France), landfilling was the main treatment for sorting residues in 2012. Germany is the only country among the main producers to use energy recovery as the principal treatment method for sorting residues.

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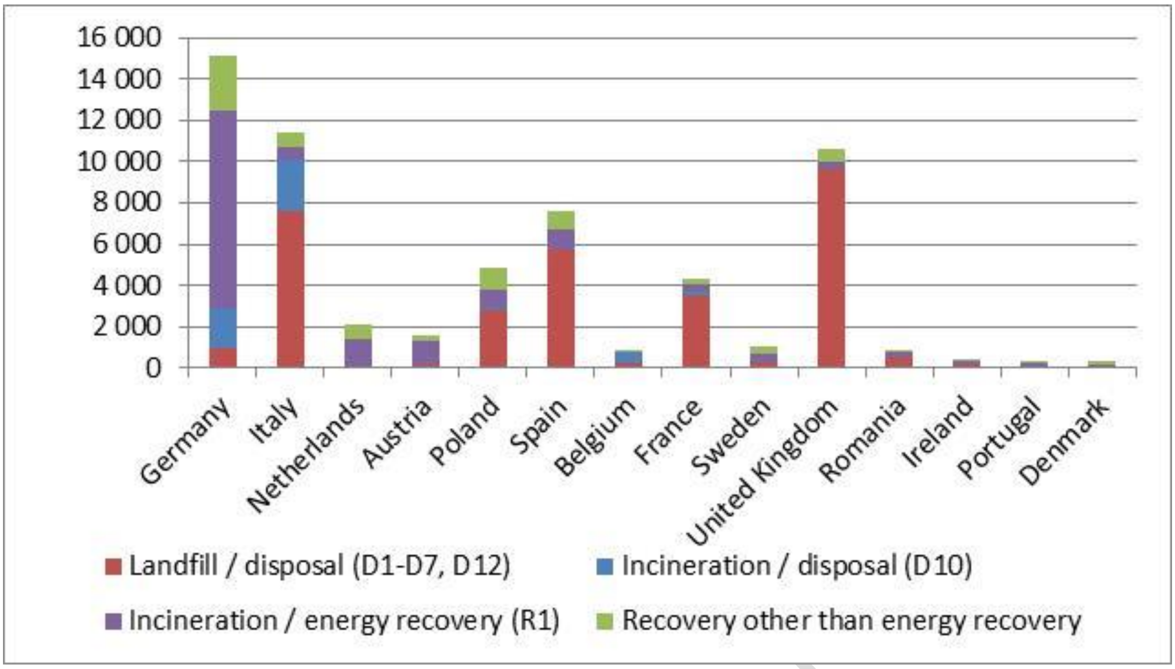

Figure 1.30: Treatments of sorting residues for the 14 EU-28 main contributors to energy production from sorting residues in 2012 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr).

According to European experts, the difference of treatment methods between member states for treating sorting residues, is based on local regulations. Germany, Austria, Netherlands have forbidden landfilling many years ago while landfilling is still very common in countries like France and UK.

Figure 1.31 shows the evolution of sorting residues treatment methods in EU-28 (NB: material recovery was not estimated in 2006 and 2008).

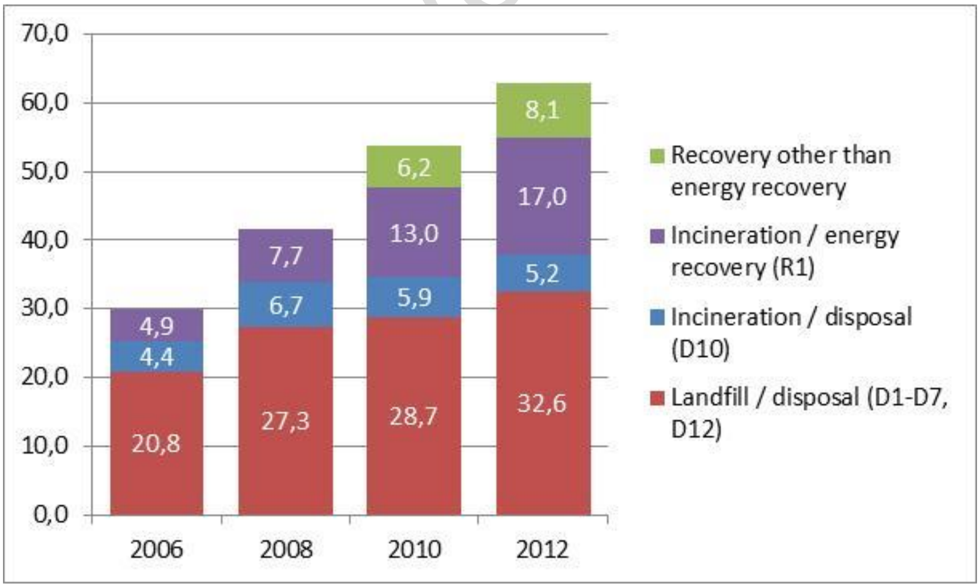

Figure 1.31: Evolution of sorting residues treatment methods in EU-28 (Source: Eurostat Waste Statistics – in million tonnes/yr)

Looking at Figure 1.31, it appears that since 2006 the amount of sorting residues sent for incineration is quite stable whereas wastes sent to energy recovery has been multiplied by 3.5 on the same period. However, the trend from 2006 until 2012 does not seem to follow the European waste management hierarchy because the amount of wastes sent to landfill in on an upward trend on the same period.

In relation to the potential of this waste as an energy source, it should be taken into account the European waste policy and the waste management models implemented accordingly by Member States. The implementation of more efficient separate collection systems should increase the separated collection fractions, but with higher quality separation at households rejects of these fractions will be lower. Besides the mixed residual waste fraction will be lower too and as well as its sorting residues. All of it entail a decrease in sorting waste. To conclude, sorting waste depends on the model of waste management established in the countries and should vary in the future.

Sorting residues and Solid Recovered Fuels

As mentioned above, according to Eurostat, sorting residues are defined as: "*sorting residues from mechanical sorting processes for waste; combustible waste (refuse derived fuel); and non-composted fractions of biodegradable waste. They mainly originate from waste treatment and separate collection".* Based on this definition, sorting residues represent the main source for the production of solid recovered fuels (SRF), with the exception of construction and demolition wastes which can be used to produce SRF but are excluded from sorting residues.

A 2015 study[24] estimates that 13.5 million tonnes of SRF/RDF[25] are currently being used in the EU-28. 12 million tonnes are burnt in cement plants and dedicated waste-to-energy plants. It is therefore considered that a significant part of the 17 million tonnes of sorting residues sent to energy recovery are in fact, wastes prepared according to European standard for SRF, and then burnt in cement plants and dedicated waste-to-energy plants.

5.3.12 Animal and vegetable wastes

Generation of animal and vegetable wastes

Data on the generation of animal and vegetable wastes (A&VW) comes from Eurostat Waste Statistics. According the Eurostat Manual on waste statistics, this category is composed of 3 sub-categories:

- Animal and mixed food wastes (09.1): "*These wastes are animal and mixed wastes from food preparation and products, including sludges from washing and cleaning; separately collected biodegradable kitchen and canteen waste, and edible oils and fats. They originate from food preparation and production (agriculture and manufacture of food and food products) and from separate collection. Animal and mixed waste of food preparation and products are non-hazardous.*
- Vegetal wastes (09.2): "*These wastes are vegetal wastes from food preparation and products, including sludges from washing and cleaning, materials unsuitable for consumption and green wastes. They originate from food and beverage production, and from agriculture, horticulture and forestry. Vegetal wastes are non-hazardous*".
- Animal faeces, urine and manure (09.3): "*These wastes are slurry and manure including spoiled straw. They originate from agriculture. Animal faeces, urine and manure are non-hazardous*".

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[24] Study from 2015 "Markets for Solid Recovered Fuel - Data and assessments on markets for SRF" from CEMBUREAU and ERFO.

[25] Solid Recovered Fuel (SRF) / Refused Derived Fuel (RDF)

As explained in paragraph 5.1.3 "Risk of double counting", edible oil and fat represents a market of growing importance for waste-to-energy. However, this combustible waste is difficult to estimate based on Eurostat Waste Statistics, and it was decided to study it separately.

Even though the perimeter of the category animal and vegetable wastes (A&VW) has not changed since 2006, the sub-categories 09.1 and 09.2 were restructured as of 2010. Therefore, it is possible to provide detailed data by subcategory for the years 2010 and 2012, but only aggregated data are available for the previous years.

Table 1.34: Repartition of the generation of animal and vegetable waste by subcategories in 2012

	Total	Animal and mixed food waste	Vegetal wastes	Animal faeces, urine and manure
EU-28 (1000 tonnes)	110 060	37 240	56 730	16 090
EU-28 (%)	100%	34%	52%	15%

Table 1.35: Evolution of the generation of animal and vegetable wastes per Member State (Source: Eurostat Waste Statistics)

	Animal and vegetable wastes generation (1000 tonnes/yr)			
	2006	2008	2010	2012
Austria	2 018	3 712	1 661	1 893
Belgium	4 390	4 266	4 588	4 891
Bulgaria	984	977	731	1 130
Croatia	284	110	120	133
Cyprus	181	200	201	221
Czech Republic	684	541	450	443
Denmark	187	166	973	890
Estonia	300	287	280	84
Finland	1 074	1 243	900	988
France	6 226	7 591	9 406	11 281
Germany	12 052	12 231	12 933	14 087
Greece	4 779	138	445	492
Hungary	3 360	1 379	808	791
Ireland	1 274	523	2 079	1 243
Italy	9 346	9 406	9 490	9 976
Latvia	204	145	166	137
Lithuania	901	1 062	536	578
Luxembourg	97	91	88	85
Malta	12	15	16	16
Netherlands	12 289	13 255	14 588	14 545
Poland	8 291	7 124	6 356	5 930
Portugal	1 188	526	392	203
Romania	22 655	19 838	18 895	18 212
Slovakia	1 229	1 225	904	863
Slovenia	297	256	264	310
Spain	20 665	15 647	9 763	8 297
Sweden	1 754	1 788	1 684	1 842

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	Animal and vegetable wastes generation (1000 tonnes/yr)			
	2006	2008	2010	2012
United Kingdom	12 025	12 842	9 187	10 497
Total EU-28	**128 744**	**116 581**	**107 904**	**110 057**

The decline is due to a two methodological changes:

- The exclusion of manure when used as by-product.
- The reclassification of organic waste from MBT plants, that was included in sorting waste category.

Based on data from Table 1.35, Figure 1.32 shows the evolution of the generation of A&VW for the 14 main EU-28 producers representing 95% of total EU-28 generation in 2012.

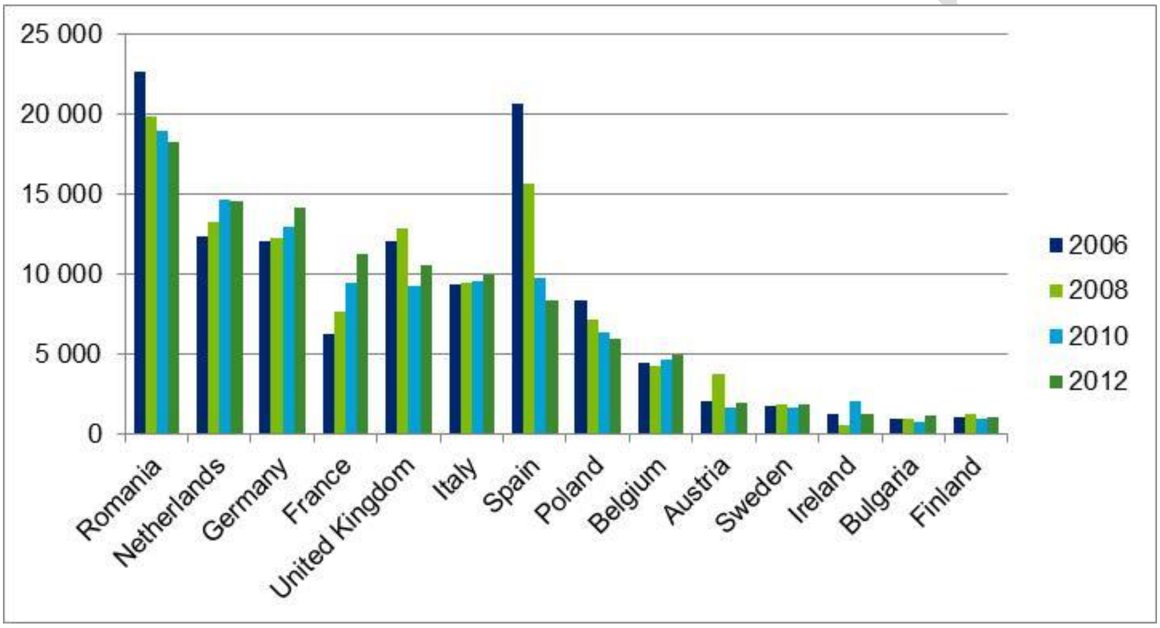

Figure 1.32: Evolution of the generation of animal and vegetable wastes for the 14 main EU-28 producers in 2012 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr)

Looking at Table 1.35 and Figure 1.32, it appears that at the EU-28 level, generation of A&VW followed a downward trend from 2006 to 2010 (with an average decrease by 8% every two years) and was stable (slight increase by 2%) from 2010 to 2012. Some of EU-28 Member States follow a downward trend from 2006 to 2012 (Romania, UK, Spain, and Poland), while others (The Netherlands, Germany, and France) follow an upward trend on the same period.

Import/export outside of EU-28

No information on import/export of A&VW outside of EU-28 has been identified.

Treatment of animal and vegetable wastes

A&VW treatment data comes from Eurostat Waste Statistics. Eurostat provides data on material recovery and landfill for the years 2006, 2008, 2010 and 2012, but data on other treatments (energy recovery, and incineration on land) are only available for the years 2010 and 2012.

Table 1.36: Evolution of animal and vegetable wastes sent for energy recovery and incineration per Member State (Source: Eurostat Waste Statistics)

	2010 (1000 tonnes/yr)		2012 (1000 tonnes/yr)	
	Energy recovery (R1)	Incineration/ Disposal (D10)	Energy recovery (R1)	Incineration/ Disposal (D10)
Austria	81	2	14	0
Belgium	80	33	16	43
Bulgaria	5	0	11	0
Croatia	2	9	2	0
Cyprus	0	4	2	7
Czech Republic	46	4	53	2
Denmark	75	0	63	0
Estonia	41	0	0	0
Finland	145	32	61	152
France	501	17	325	15
Germany	1 226	34	1 403	32
Greece	14	18	57	18
Hungary	200	1	167	1
Ireland	1	4	29	0
Italy	242	26	187	15
Latvia	0	0	3	0
Lithuania	2	0	9	0
Luxembourg	0	0	0	0
Malta	0	7	0	5
Netherlands	382	467	352	484
Poland	100	40	42	46
Portugal	103	7	15	11
Romania	17	0	100	40
Slovakia	6	17	5	28
Slovenia	7	0	6	0
Spain	21	29	100	0
Sweden	377	0	26	0
United Kingdom	78	907	589	312
Total EU-28	**3 752**	**1 656**	**3 637**	**1 213**

According to Table 1.36, between 2010 and 2012 the amount of A&VW sent for energy recovery is stable (-3% on the period), while the amount sent to incineration/ disposal has dropped by 27%.

Figure 1.33 shows the repartition of A&VW treatment methods for the 14 EU-28 countries representing 96% of A&VW sent to incineration and energy recovery in 2012.

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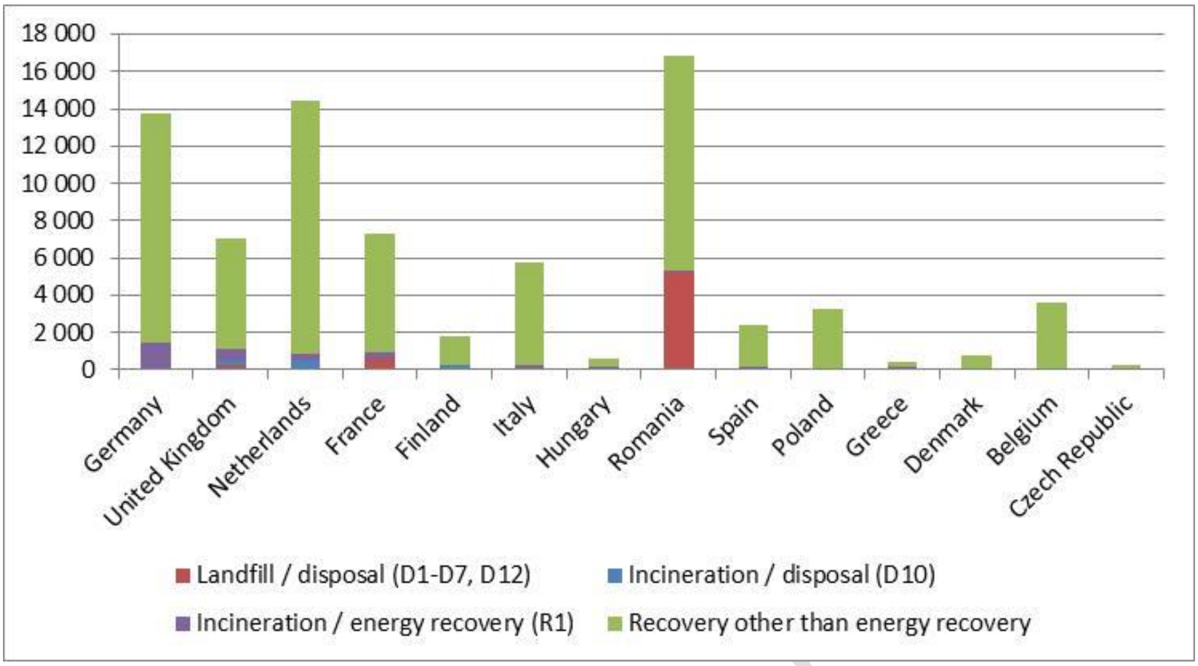

Figure 1.33: Treatments of animal and vegetable wastes for the 14 EU-28 main contributors to energy production from animal and vegetable wastes in 2012 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr).

Looking at Figure 1.33, it appears that material recovery is by far the main treatment method used for animal and vegetable wastes. Even if it is not possible to detail the amount of wastes sent to each recovery operation, it is probable that a significant share of these wastes are sent to R3 "*Recycling/reclamation of organic substances which are not used as solvents (including composting and other biological transformation processes)*".

Figure 1.34 gives an overview of the repartition of animal and vegetable waste treatment methods in EU-28 and its evolution between 2010 and 2012. Considering that around 85% wastes are sent for material recovery, the scale of the axis has been cut on purpose at 30 million tonnes to be able to analyse trends for other waste treatments. Looking at Figure 1.34, it appears that at European level, the evolution of A&VW treatment pathways follows the waste management hierarchy: between 2010 and 2012, the wastes sent to landfill and to incineration/ disposal have decreased by 600 000 and 400 000 tonnes respectively, while on the same period, the amount of wastes sent for material recovery and energy recovery have decreased by 100 000 tonnes.

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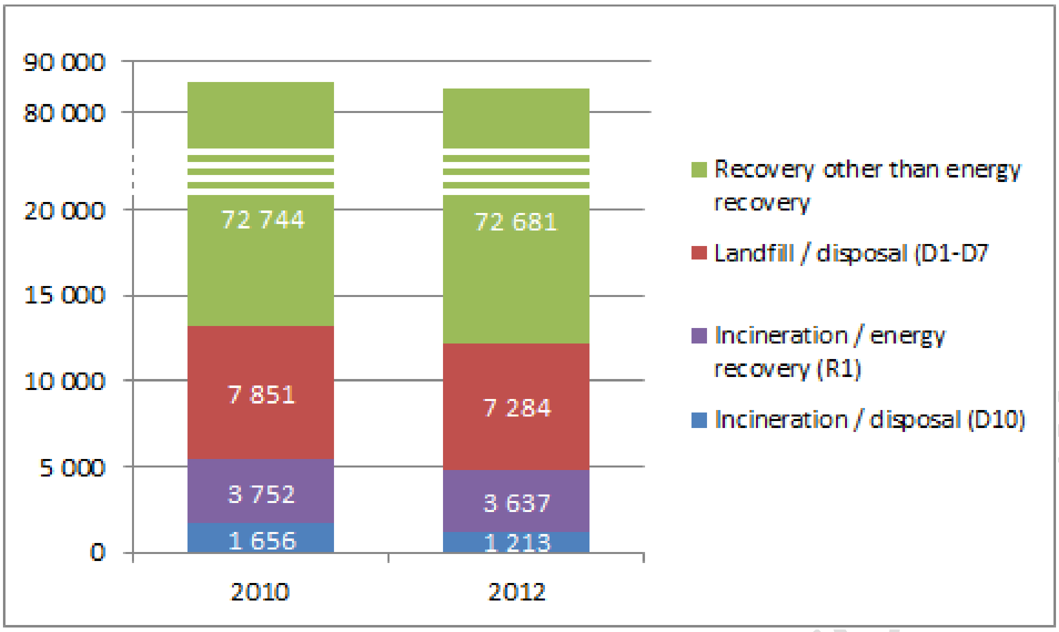

Figure 1.34: Evolution of animal and vegetable waste treatment methods in EU-28 (Source: Eurostat Waste Statistics – in 1000 tonnes/yr)

As explained above, several waste treatment methods are included in the category "recovery other than energy recovery" among which composting and anaerobic digestion. In paragraph 5.6 you can find a discussion on the use of composting or anaerobic digestion for biomass.

5.3.13 Dried/dewatered municipal sewage sludge

Generation of municipal sludge

Specific data on generation and treatment of municipal sewage sludge are not available from Waste Statistics.

Data on the generation of municipal sludge comes from Eurostat Water Statistics for urban wastewater treatment plants which is based on OECD/Eurostat Joint Questionnaire - Inland Waters. In OECD/Eurostat, sewage sludge is generally defined as the residual of wastewater treatment, and more specifically:

"*The accumulated settled solids separated from various types of water either moist or mixed with a liquid component as a result of natural or artificial processes*." In principle all NACE sectors and private households are covered by the data set produced.

Considering the definition of the waste stream, it is clear that industrial sludges are excluded from the scope.

According to the information provided by OECD/Eurostat[26], data are collected for each Member State of the EU. However, EU-28 totals or averages are not yet calculated by OECD/Eurostat as there are too many gaps in the data due to the voluntary nature of reporting. For some countries annual data is available.

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[26] http://ec.europa.eu/eurostat/cache/metadata/en/env_nwat_esms.htm

Table 1.37: Evolution of municipal sewage sludge generation from urban wastewater treatment plants per Member State. Data expressed in dry matter (Source: Eurostat Water Statistics)

	Municipal sewage sludge production (1000 tonnes DM/yr)			
	2006	2008	2010	2012
Austria	255	254	263	266
Belgium	128	140	176	157
Bulgaria	38	43	50	59
Croatia	:	:	30	42
Cyprus	:	8	8	7
Czech Republic	203	220	196	263
Denmark	:	108	141	141
Estonia	28	22	19	22
Finland	149	144	143	141
France	:	1 087	966	987
Germany	2 100	2 053	1 911	1 849
Greece	126	136	:	119
Hungary	238	172	170	162
Ireland	78	103	90	72
Italy	:	:	1103	:
Latvia	24	19	21	20
Lithuania	:	:	:	45
Luxembourg	15	13	10	8
Malta	0	0	1	10
Netherlands	373	353	351	346
Poland	501	567	527	533
Portugal	:	:	:	339
Romania	226	79	82	85
Slovakia	55	58	55	59
Slovenia	19	20	30	26
Spain	1 065	1 156	1 205	2 757
Sweden	207	214	204	207
United Kingdom	1 809	1 814	1 419	1 137
Total EU-28	7 635	8 783	9 172	9 860

“:” not available in Eurostat

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Taking into account missing data and the heterogeneity of information provided it seems that municipal sewage sludge production is slightly increasing in the EU-28 from 2006 to 2012.

Import/export outside of EU-28

No information on import/export of municipal sewage sludge outside of EU-28 has been identified.

Treatment of municipal sewage sludge

Data on municipal sewage sludge treatment for the period 2006-2012 comes from Eurostat Water Statistics. This database provides details for 5 subcategories:

"Incineration", "agricultural use", "compost and other applications", "landfill", and "other"[27].

Considering that sewage sludge often has a high water content and therefore usually requires drying, or the addition of supplementary fuels to ensure stable and efficient combustion[28], the total net energy production often does not reach the threshold to be considered as "R1 incineration". Therefore, sewage sludge incineration is considered as "D10 incineration" even if it is not specified in Eurostat Water Statistics database. Data on the incineration of municipal sludge from Eurostat Water Statistics are presented in Table 1.38.

Table 1.38: Evolution of municipal sewage sludge incineration per Member State. Data in dry matter. (Source: Eurostat Water Statistics)

	Municipal sewage sludge incineration (1000 tonnes DM/yr)			
	2006	2008	2010	2012
Austria	98	91	115	139
Belgium	68	72	113	89
Bulgaria	0	0	0	0
Croatia	:	:	:	:
Cyprus	:	2	0	0
Czech Republic	0	3	5	8
Denmark	:	36	34	34
Estonia	0	0	:	:
Finland	0	2	0	32
France	:	206	181	207
Germany	965	1078	1004	1009
Greece	0	24	:	39
Hungary	5	9	20	24
Ireland	0	0	0	0
Italy	:	:	37	:
Latvia	0	0	0	0
Lithuania	:	:	:	0
Luxembourg	1	1	1	1
Malta	0	0	0	0
Netherlands	325	336	330	321
Poland	4	6	20	57
Portugal	:	:	:	0
Romania	:	:	0	0
Slovakia	0	0	0	3
Slovenia	5	7	13	13
Spain	41	:	62	100
Sweden	0	0	2	1
United Kingdom	:	:	260	229

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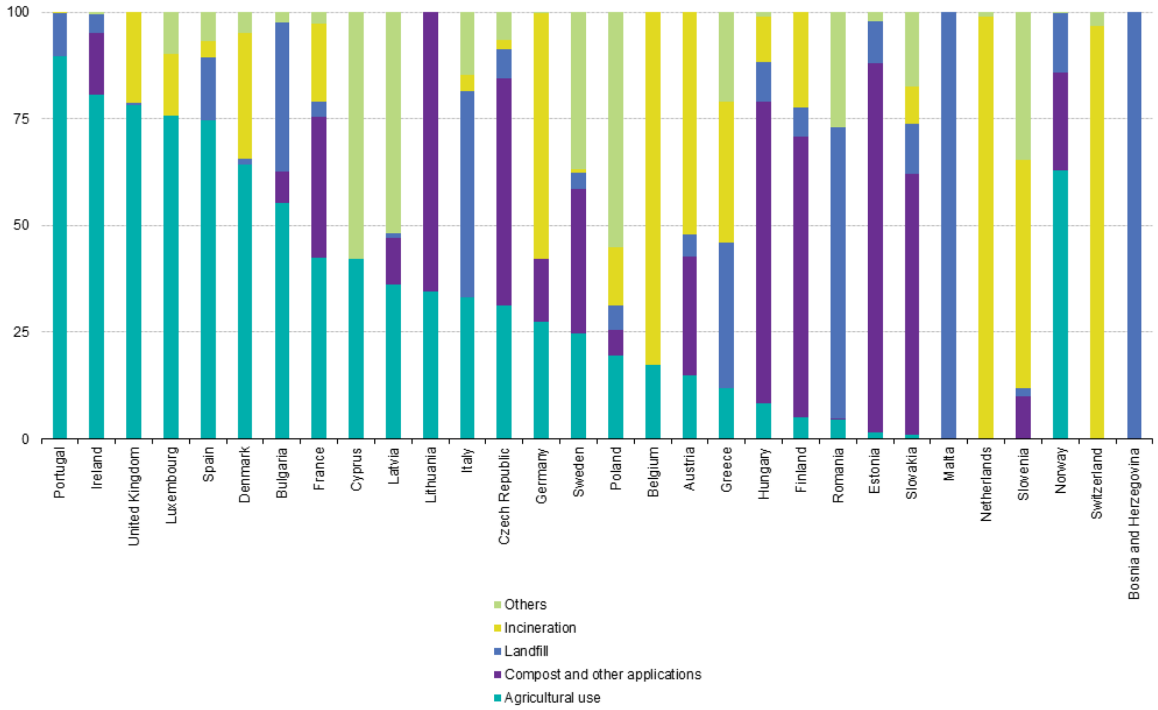
[27] The document "Data Collection Manual for the OECD/Eurostat Joint Questionnaire on Inland Waters" (Version 3.0 – September 2014) does not provide additional information on the treatments considered under the category "Other".

[28] Bref Waste Incineration, 2006

	Municipal sewage sludge incineration (1000 tonnes DM/yr)			
	2006	2008	2010	2012
Total EU-28	1 513	1 873	2 195	2 306
n.a.: not available in Eurostat				

On its website[29], Eurostat Water Statistics provides graphics (see Figure 1.35) and explanations on the treatments of municipal sewage sludge in Europe in 2012.



(¹) Belgium, Denmark, Greece, Spain, Cyprus, Lithuania, Luxembourg, the Netherlands, Austria, Portugal, Finland, Sweden and the United Kingdom: 2012.
Italy: 2010. Croatia: not available.
Source: Eurostat (online data code: env_ww_spd)

Figure 1.35: Treatments of municipal sewage sludge in Europe in 2013[1] (Source: Eurostat Water Statistics).

Looking at Figure 1.35 it appears that municipal sewage sludge treatment pathways are different across Member States. This is for one part due to variations in the composition of municipal sewage sludge: nutrients content, and concentrations of pollutants such as heavy metals[30]. Agricultural use and composting is the main treatment for several countries including Portugal, Ireland, the United Kingdom, Luxembourg and Spain. According to Eurostat Water Statistics, alternative forms of sewage disposal may be used to reduce or eliminate the spread of pollutants on agricultural or gardening land; these include incineration and landfill. While the Netherlands, Belgium, Germany, Slovenia and Austria reported incineration as their principal form of treatment for disposal, discharge into controlled landfills was practised as the principal type of treatment in Malta (where it was the sole form of treatment), Romania and Italy.

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[29] http://ec.europa.eu/eurostat/statistics-explained/index.php/Water_statistics#Wastewater_treatment

[30] Source : http://ec.europa.eu/eurostat/statistics-explained/index.php/Water_statistics#Wastewater_treatment

Please note that reporting issues for sludge land-spreading might arise across Member States: land-spreading should be coded as R10 (Land treatment resulting in benefit to agriculture or ecological improvement) but often it might be reported as D2 (Land treatment, e.g. biodegradation of liquid or sludgy discards in soils)

Figure 1.36 shows the evolution of municipal sewage sludge treatment methods in the EU-28 on the period 2006- 2012.

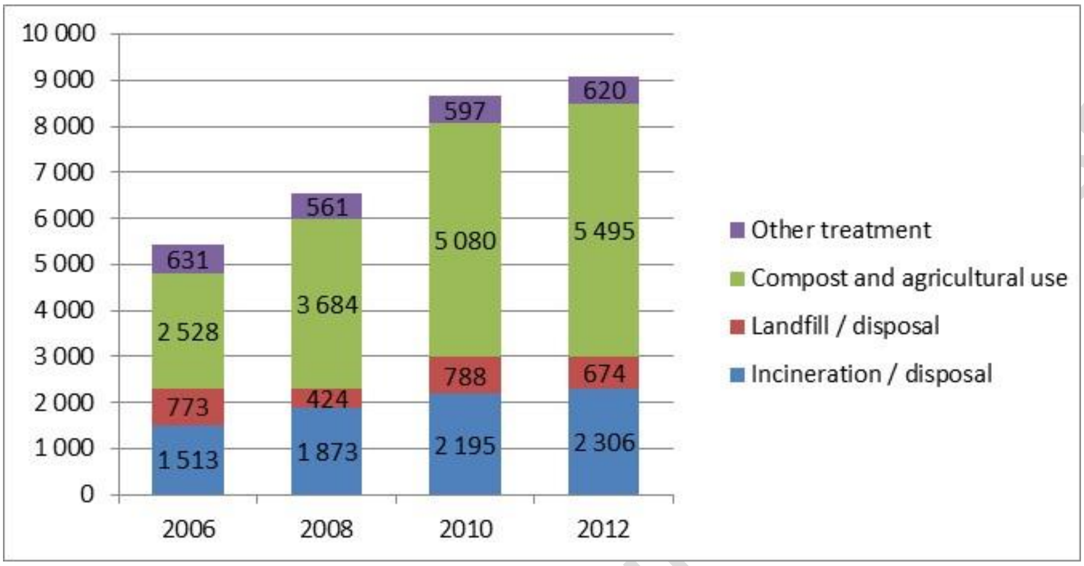

Figure 1.36: Evolution of municipal sewage sludge treatment methods in EU-28 (Source: Eurostat Water Statistics – in 1000 tonnes/yr)

On Figure 1.36, the upward trend from 2006 to 2010 for incineration can most probably be explained by an increase in the number of countries responding to the OECD questionnaire. Between 2006 and 2012, the share of sewage sludge sent to incineration was nearly constant at 25% of total waste treated. As explained above, the net energy (taking into account the energy used for drying the sludge) recovered from sludge combustion is very low, which makes sewage sludge less interesting for incineration.

5.4 Results of waste-derived fuels data collection and analysis

5.4.1 Waste derived biogas

Generation of biogas

In Eurostat Waste Statistics the treatment of biodegradable wastes for biogas production is considered as a recovery operation taken into account in the code R3 “R3 Recycling/reclamation of organic substances which are not used as solvents (including composting and other biological transformation processes)”. Therefore, it is not possible to estimate the amount of biogas produced from wastes using the Eurostat Waste Statistics database.

In this context, data on the generation of biogas comes from Eurostat Energy Statistics and the European Biomass Association (EBA).

In Eurostat, the category “09 biogas” is defined as: “*gases composed principally of methane and carbon dioxide produced by anaerobic fermentation of biomass, or by thermal processes*”.

As explained in paragraph 4.2 and 5.1.1 related to the scope of the study, energy from combustible waste that has already been subjected to treatment and disposal is out of the scope of the present study. Thus, landfill gas isn't discussed in the present study, even though it represents a significant amount of total biogas produced in the EU-28.

Biogas can be produced from waste biomass and non-waste biomass such as energy crops. Eurostat Energy Statistics provides data on biogas production from two sub-categories representing the main sources of biogas production:

- Sewage sludge gas: produced from the anaerobic digestion of sewage sludge; and
- Other biogases from anaerobic digestion of agricultural residues (animal slurries) and industrial wastes (waste in abattoirs, breweries and other agro-food industries).

To estimate the share of waste-derived biogas, it is assumed that sewage gas is 100% waste-derived biogas, and that 17% of the other biogas from anaerobic digestion comes from wastes. For comparison, in its report from 2011, UBA used a ratio of 15% for "Other biogas".

The methodology used to estimate the 17% ratio is based on installed capacities (see Table 1.39) and estimated biogas yield (see Table 1.40) for:

- industrial waste biogas plants: 100% waste-derived biogas production; and
- agricultural plants: 13% biogas from agricultural waste and 87% from energy crops (not considered as waste-derived biogas).

The 13% ratio was estimated using the average feedstock composition for 7 Member States representing 87% of installed agricultural plants capacities in Europe: France, Germany, Hungary, Italy, Latvia, Poland, and the United Kingdom.

Table 1.39: Repartition of anaerobic digestion plants in Europe in 2014 (source: EBA "Biomethane & Biogas report 2015")

	Sewage	Industrial waste	Agricultural
Installed capacity (MWe)	663	285	5 546
Number of plants	2 861	827	11 670
Average capacity (MWe/plant)	0.23	0.34	0.48

Table 1.40 presents the biogas yields used to estimate the 17% ratio of waste-derived biogas production from agricultural, and industrial waste biogas plants in combination with data on average feedstock composition for agricultural waste, energy crop and industrial residues. These data are only averages[31], and do not represent the large variety of feedstocks and biogas yields used for biogas production:

- agricultural wastes: from 20 to 30 m^3/t FM for cattle manure, to 130 to 270 m^3/t FM for poultry manure;
- energy crops: from 120 to 140 m^3/t FM for sugar beets, to 170 to 230 m^3/t FM for maize silage;
- industrial residues: from 60 to 75 m^3/t FM for sugar beets pulp, to 290 to 340 m^3/t FM for molasses.

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[31] Source: interviews with EBA experts

Table 1.40: Average biogas yields used for calculations (source: EBA from various sources)

	Agricultural wastes	Energy crop	Industrial residues
Biogas yield (m^3/t FM)	30	200	180

Results of calculations per Member states are presented in Table 1.41 at two year intervals.

Table 1.41: Evolution of the generation of waste-derived biogas per Member State (Source: Deloitte calculation based on Eurostat Energy Statistics and EBA data)

	Waste-derived biogas production (million Nm^3/yr)				
	2006	2008	2010	2012	2014
Austria	63	76	71	81	95
Belgium	10	13	43	58	79
Bulgaria	0	0	4	0	5
Croatia	0	7	6	7	10
Cyprus	0	1	2	4	4
Czech Republic	53	63	89	148	214
Denmark	52	51	53	58	66
Estonia	2	1	2	1	2
Finland	19	20	23	26	28
France	91	93	101	122	129
Germany	776	1 253	1 598	2 239	2 617
Greece	16	9	14	27	27
Hungary	14	16	22	43	36
Ireland	13	15	17	14	14
Italy	18	23	55	280	499
Latvia	3	4	6	15	21
Lithuania	3	3	6	6	13
Luxembourg	3	4	5	6	7
Malta	0	0	0	1	0
Netherlands	91	115	137	144	156
Poland	71	98	106	139	167
Portugal	2	3	3	3	7
Romania	0	0	1	8	5
Slovakia	11	16	16	35	34
Slovenia	2	6	10	13	10
Spain	98	40	75	134	199
Sweden	34	96	103	131	141
United Kingdom	281	340	431	482	594
Total EU-28	**1 726**	**2 364**	**3 000**	**4 223**	**5 181**

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Table 1.41 shows that EU-28 waste-derived biogas production has been increasing by 20% to 40% every two years between 2006 and 2014. Based on Table 1.41, Table 1.42 presents the repartition of waste-derived biogas production from sewage sludge and other biogas from anaerobic digestion in the EU-28. Since 2006, the share of sewage sludge gas has decreased continuously, representing less than half of the total waste-derived biogas production after 2012. Based on this downward trend, sewage sludge might represent less than 40% in the future compared to other waste-derived biogas produced from agricultural and industrial residues.

Table 1.42 Evolution of the production of waste-derived biogas for sewage sludge gas and other biogas (Source: calculation based on Eurostat Energy Statistics)

		2006	2008	2010	2012	2014
Sewage sludge gas	million m^3/yr	1 399	1 499	1 664	1 954	2 220
	%	81%	63%	55%	46%	43%
Other biogas	million m^3/yr	328	865	1 336	2 269	2 960
	%	19%	37%	45%	54%	57%

Based on data from Table 1.41, Figure 1.37 shows the evolution of the generation of wastes-derived biogas for the 14 main EU-28 producers representing 96% of total EU-28 generation in 2014.

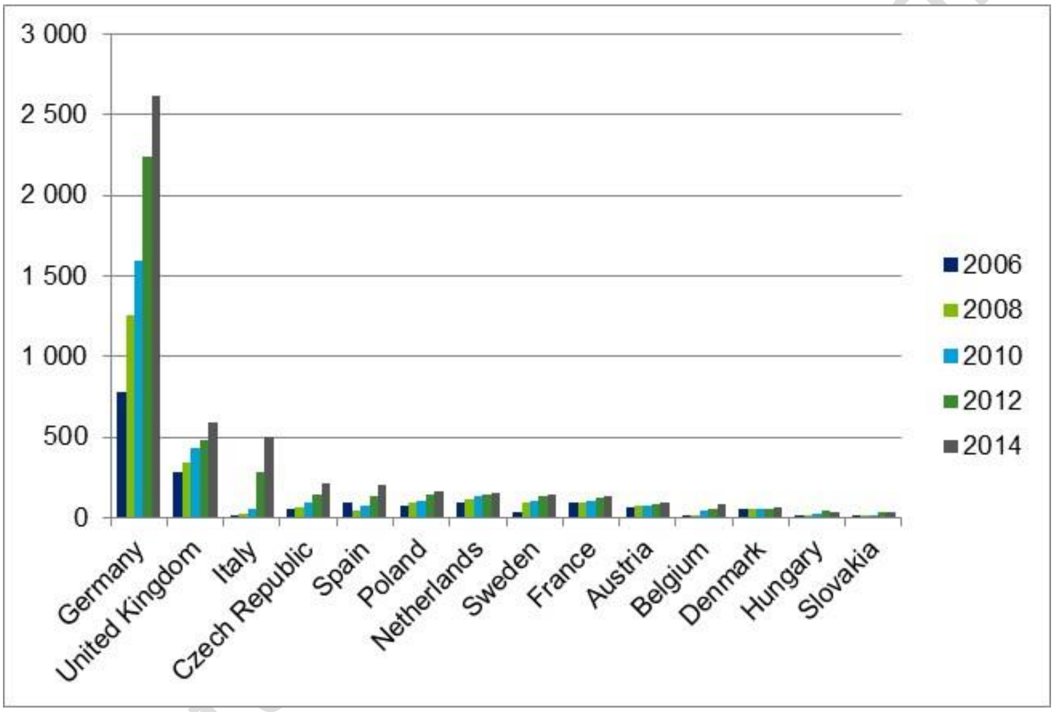

Figure 1.37: Evolution of the generation of waste-derived biogas for the 14 main EU-28 producers in 2014 (Source: Eurostat Waste Statistics – in million Nm3/yr)

According to Figure 1.37, in 2014, Germany represents more than 50% of the EU-28 production, and the production continues to increase in this country.

<u>Comments on data calculation</u>:

In Spain, national data from the Ministry of environment are in line with results, and in Finland, national data for sewage sludge are 20% below data from Eurostat. In addition, in its 2015 biogas report, EBA estimated that in 2014, 140 567 GWh of biogas (including landfill gas and non-waste derived biogas) was produced in the EU-28, which is 20% below the Eurostat estimate on the period.

Based on this, it is considered that calculated data represents a high range estimate of the current situation.

In 2014, agricultural plants using agricultural wastes and energy crops are dominating the market under the impulsion of Germany and to a lesser extent Italy[32]. However, in 2015, the share of agricultural plants decreased in Europe, due to new installations in the water sector as well as the food and drink sector and waste management industries. This evolution might continue and change the landscape of biogas plants in coming years.

Some feedstocks can be either sent to anaerobic digestion plants or composting plants. In paragraph 5.6, you can find a discussion on the use of composting or anaerobic digestion for biomass.

Finally, it is important to remember that, as explained in paragraph 5.1.1, the definition of "waste" vs "by-product" for industrial and agricultural residues is provided by the Waste Framework Directive, but remains subject to interpretation. Therefore, all countries do not apply the same rules. This should be kept in mind when looking at the methodology and results on waste-derived biogas.

Import/export outside of EU-28

No information on biogas import/export outside of EU-28 has been identified. Historically biogas has been produced and used locally, but more countries are allowing biomethane injection in the gas network making it possible to sell biomethane to other countries.

Treatment of biogas

Except for leakage of biogas that could not be estimated, biogas is used at 100% for energy production.

Energy production from biogas

Biogas is used to produce electricity, heat and biomethane. Biomethane can then be used for transportation, grid injection, and industrial processes.

Data from the European Biogas Association has been used to estimate the amount of waste-derived heat, electricity and biomethane produced in the EU-28. Results are considered as low range estimates, because EBA has collected data from the main biogas producers, but all Member States did not provide information. Considering data gaps, it is only possible to provide estimates for 2014 at EU-28 level.

Description of the methodology used to calculate the amount of heat, electricity and biomethane from waste-derived biogas (see Table 1.43):

- At the end of 2014, there were 367 biomethane plants in the EU-28, representing an overall upgrading capacity of 199 204 Nm^3/h[32]. The estimation of waste-derived biomethane production is based on biomethane production data for 2014[32], and an estimate of the share of waste-derived biomethane at national level[33]. For Germany and Sweden (representing 84% of total biomethane produced in the EU-28), it represents respectively 13% and 100% of the total production. Using this approach, it was calculated that in 2014, 12 PJ of waste-derived biomethane were produced in the EU-28. Germany and Sweden represent respectively 37% and 39% of waste-derived production in the EU-28.
- At the end of 2014, there were 17 240 biogas plants in the EU-28, representing an overall installed capacity of 8 293MW_{el}. The estimation of waste-derived utilised heat production (after exclusion of internal use) is based on the production of

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[32] Information from the EBA 2015 annual biogas report and from personal communication with EBA

[33] For Germany and Sweden, the estimation of the share of waste-derived biomethane is based on the feedstock repartition, and for other Member States, a conservative estimate of 50% has been used.

utilised heat for agricultural, sewage and other (biowaste and industrial biogas) plants at national level. It was considered that 100% of the heat produced from sewage, biowaste and industrial biogas is waste-derived. For agriculture, a ratio of 13% has been applied[34]. Using this approach, it was estimated that in 2014, 33 PJ of waste-derived utilised heat were produced in the EU-28. Germany and Italy represent respectively 39% and 53% of waste-derived production in the EU-28.

- Data on the production of electricity for agricultural, sewage and other (biowaste and industrial biogas) plants was not available. Therefore, the share of waste-derived electricity was estimated using the total amount of electricity produced in Europe, multiplied by the share of waste-derived heat (26%, see Table 1.43). Using this approach, it was estimated that in 2014, 70 PJ of waste-derived electricity were produced in the EU-28.

Table 1.43: Production of heat, electricity and biomethane production from anaerobic digestion plants in Europe in 2014 (source: Deloitte estimate based on EBA "Biomethane & Biogas report 2015")

	Utilised heat	Electricity	Biomethane
Total production (PJ)	108	229	44
Waste-derived production (PJ)	33	70	12
Waste-derived production (%)	31%	31%	26%

The amount of biogas converted into biomethane should increase in coming years, because, since 2011, the number of biomethane plants follow an upward trend and 2014 represents the highest increase with 83 new biogas upgrading units commissioned in Europe[32].

5.4.2 Bioethanol

Eurostat Energy Statistics database provides annual data on the production of biogasoline (including bioethanol) for all EU-28 countries for the period 2006 to 2014. Description of biogasoline according the Eurostat "Renewables annual questionnaire 2014"[35]:

"Biogasoline: This category includes bioethanol (ethanol produced from biomass and/or the biodegradable fraction of waste), biomethanol (methanol produced from biomass and/or the biodegradable fraction of waste), bioETBE (ethyl-tertio-butyl-ether produced on the basis of bioethanol; the percentage by volume of bioETBE that is calculated as biofuel is 47%) and bioMTBE (methyl-tertio-butyl-ether produced on the basis of biomethanol: the percentage by volume of bioMTBE that is calculated as biofuel is 36%).

− Of which Bioethanol: this category includes ethanol produced from biomass."

From this definition, it appears that Eurostat Energy Statistics database does not provides specific information for bioethanol production nor does it make the distinction between bioethanol produced from waste or from biomass. Therefore, this database cannot be used in this study.

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[34] Refer to the aforementioned methodology for calculation of waste-derived biogas production.

[35] The "Annual renewable questionnaire 2014" provides Member States information on how to complete the questionnaire as part of their annual obligation of reporting to Eurostat energy statistics. http://ec.europa.eu/eurostat/documents/38154/6935814/AQ2014-RENEWABLES-instructions.pdf/e16338f5-bbed-4c13-bdbf-903307420d45

In Europe (Finland, Spain, etc.) there are several industrial and demonstration plants producing bioethanol from process residues (bakery waste, residues from enzyme production, from brewery, etc.) and by enzymatic hydrolysis of organic fraction from household and similar waste. In 2009, the share of wastes in feedstock materials for the production of bioethanol was considered negligible (Gaupmann, 2009)[36]. In Finland, 5 plants producing 10 million litres of bioethanol from process residues (wastes and by-products) are in operation. It is therefore considered that waste-derived bioethanol production has increased since 2009. However, it was not possible to estimate the growth of the market in the EU-28 since 2009 for the following reasons:

- the lack of waste-related data at European level;
- the reluctance of plant operators to provide detailed information on feedstocks for confidentiality reasons;
- difference across Member States on the classification of by-products vs wastes (see discussion in paragraph 5.1.1).

In this context, waste-derived bioethanol techniques are studied in this report as part of the emerging WtE techniques.

5.4.3 Waste Derived Biodiesel

Generation of biodiesel

Eurostat Energy Statistics database provides annual data on the production of biodiesel for all EU-28 countries for the period 2006 to 2014. Description of biodiesel according the Eurostat "Renewables annual questionnaire 2014"[37]:

"Biodiesels: This category includes biodiesel (a methyl-ester produced from vegetable or animal oil, of diesel quality), biodimethylether (dimethylether produced from biomass), Fischer Tropsch (Fischer Tropsch produced from biomass), cold pressed biooil (oil produced from oil seed through mechanical processing only)."

However, this database only refers to "biomass" and does not make the distinction between biodiesel produced from waste or from by-products (see discussion in paragraph 5.1.1 for the difference between waste and by-products).

It is difficult to get a precise estimation of the share of biodiesel produced from wastes because Member States do not agree on how to determine whether a biomass feedstock used for biodiesel production is a waste or a by-product. In addition, it is impossible to base this estimate on the number and capacity of existing plants because most of them produce biodiesel from wastes and non-waste animal fat and vegetable oils, and for confidentiality reasons they are not willing to provide detailed information (type and quantity) on their feedstock.

In this context, it was estimated that waste derived biodiesel represents around 5% of total generated biodiesel (UBA, 2011). This is considered as a low range estimate.

The results of the calculations are presented below in Table 1.44 at two year intervals.

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[36] Source Gaupmann (2009): Setting the scene – Bioethanol production in the EU. RSB Consultation (Version Zero). Europe stakeholder outreach meeting. Brussels, 19 March 2009

[37] The "Annual renewable questionnaire 2014" provides Member States information on how to complete the questionnaire as part of their annual obligation of reporting to Eurostat energy statistics. http://ec.europa.eu/eurostat/documents/38154/6935814/AQ2014-RENEWABLES-instructions.pdf/e16338f5-bbed-4c13-bdbf-903307420d45

Table 1.44: Evolution of the generation of waste-derived biodiesel per Member State (Source: Eurostat Energy Statistics)

	Waste-derived biodiesel production (tonnes/yr)				
	2006	2008	2010	2012	2014
Austria	6 583	12 543	13 835	10 399	13 408
Belgium	0	14 392	16 323	15 390	19 424
Bulgaria	0	500	629	409	3 119
Croatia	0	177	698	1 987	1 782
Cyprus	0	342	282	333	0
Czech Republic	5 568	3 876	10 008	8 731	11 086
Denmark	3 596	5 072	3 928	0	0
Estonia	0	0	0	0	0
Finland	0	4 801	16 995	14 524	20 257
France	30 066	89 672	101 470	111 231	118 655
Germany	118 181	127 923	156 492	142 534	174 029
Greece	2 400	3 598	6 434	7 108	8 101
Hungary	0	7 018	7 242	7 373	6 719
Ireland	126	2 168	3 626	1 370	1 382
Italy	11 272	33 765	40 384	14 505	29 293
Latvia	342	1 429	2 208	4 597	3 809
Lithuania	523	3 265	4 507	5 394	6 051
Luxembourg	0	0	0	0	0
Malta	0	0	31	56	58
Netherlands	934	4 195	19 309	59 493	86 940
Poland	4 677	13 583	19 911	31 754	37 349
Portugal	4 578	8 264	15 998	15 376	16 387
Romania	0	4 666	618	5 075	5 542
Slovakia	2 423	5 765	6 387	5 680	5 305
Slovenia	101	402	944	54	0
Spain	3 232	11 338	43 165	25 428	61 248
Sweden	2 483	7 431	10 148	19 170	6 111
United Kingdom	13 039	14 470	7 895	12 656	7 251
Total EU-28	210 124	380 656	509 467	520 628	643 305

Table 1.44 shows that EU-28 waste-derived biodiesel production has been increasing since 2006.

Comparison with estimations based on edible oil and fat generation:

- Edible oil and fat comprises various waste fractions of vegetable and animal origin, such as used cooking oil from restaurants and households or fat arising in the food industry. No database on generation of waste edible oil and fat at EU-28 level has been identified. Available information from literature review and experts show significant differences at national level for edible oil and fat generation and collection efficiency: 0.44 kg/capita in Germany (Statistiches Bundesamt 2009) and 1 kg/capita in Slovenia (EPA Slovenia 2010) to 3.3 kg/capita in the Austrian province of Burgenland (AMT Der Burgenländischen Landesregierung 2006).
- In 2011, UBA estimated that on average in the EU-28, 1kg of edible oil and fat are collected per capita. This represents 500 000 tonnes of wastes collected and an

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equivalent amount of biodiesel produced. This value is in line with data from Table 1.44 considering that edible oil and fat is the main feedstock for waste-derived biodiesel production in the EU-28.

Based on data from Table 1.44, Figure 1.38 shows the evolution of the generation of waste-derived biodiesel for the 14 main EU-28 producers representing 95% of total EU-28 biodiesel production in 2014.

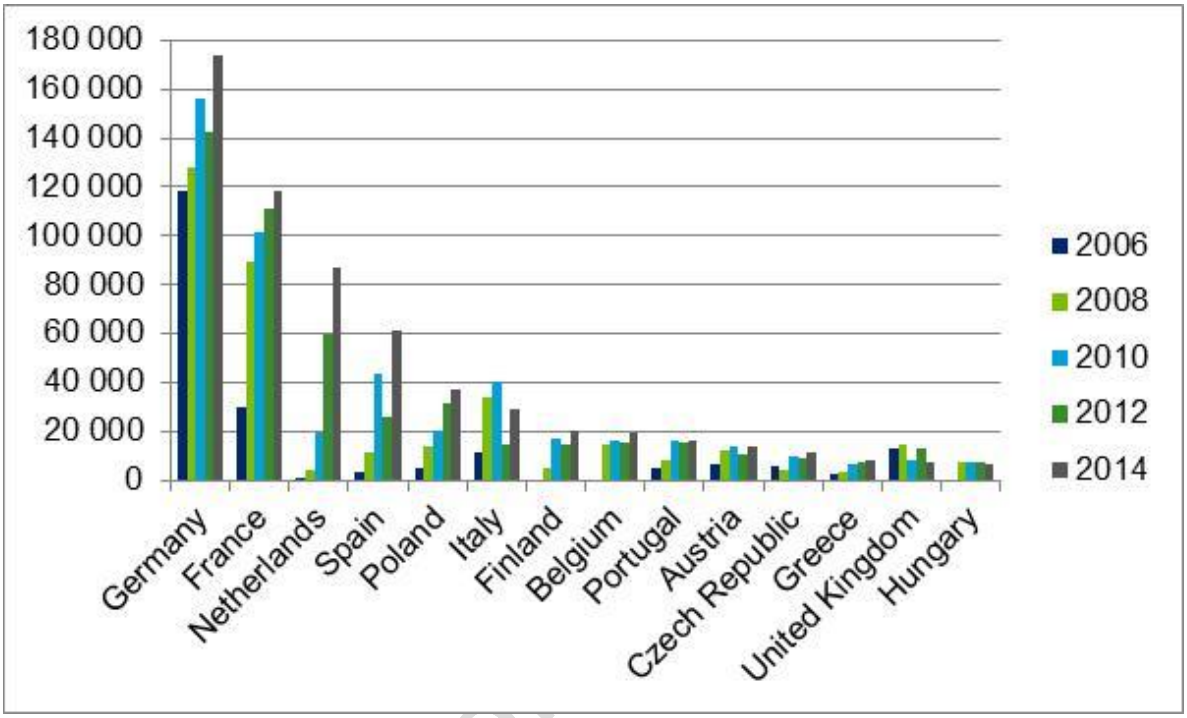

Figure 1.38: Evolution of the generation of waste-derived biodiesel for the 14 main EU-28 producers in 2014 (Source: Eurostat Waste Statistics – in tonnes/yr)

Looking at Figure 1.38 it appears that between 2006 and 2014, all main biodiesel producing EU countries have increased their production significantly.

Finland reported that national data are in line with Eurostat data for biodiesel production. However, for confidentiality reasons they cannot estimate the share of waste-derived biodiesel produced.

The downward trend for UK (Figure 1.38 is not in line with expert's observation of the national market. Indeed, according to UK experts, most UK biodiesel producers have moved to nearly 100% waste based production over the period.

Comments on calculations:
There are two main limits in the current methodology applied:

- The 5% ratio for waste-derived biodiesel production, and the 1kg/capita ratio for edible oil and fat collection in the EU-28 are based on the UBA study from 2011. The Renewable Energy Directive (RED 2009/28/CE) establishes the "double-counting" system[38], an incentive for the production of waste-derived biodiesel. This has led to "*important and continuous progress during the past 5 years* (2010-2015)*, including the opening of commercial production facilities*"[38]. In addition, according to Fediol,

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[38] European Commission, SWD(2015) 117 final, *Technical assessment of the EU biofuel sustainability and feasibility of 10% renewable energy target in transport*

because of the double counting for biodiesel, the trade in edible oil and fat as raw material for biodiesel has increased dramatically in the past years. Therefore, the two ratios provide the best available estimates, but represent a low range estimate of the current situation.

- The 5% average is applied to all Member States, while it is to be expected that the share of waste-derived biodiesel varies significantly across Member States. Indeed, feedstock used for biodiesel production is country specific, and ratios for edible oil and fat collection per capita are different across Member States. In addition, a few Member States[38] (such as Belgium, France, Malta, Spain) have implemented the double-counting system in their legislation, which provides further incentives for waste-derived biodiesel production. Therefore, country specific data in Figure 1.38 should be used carefully.

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Import/export outside of EU-28

There is no specific data for import/export of waste-derived biodiesel. Eurostat COMEXT Database, only provide trade data for biodiesel.

Quantities are available on a monthly and yearly basis from 1988 to 2014. For the purpose of the study, yearly imported and exported quantities from 2006 to 2014 were considered. Relevant data were identified based on their CN8 code. According to the methodology used in the UBA 2011 study, the following CN8 codes were used for biodiesel:

WDF	CN8 Code	Description
Biodiesel	15162091	Vegetable fats and oils and their fractions, partly or wholly hydrogenated, inter-esterified, re-esterified or elaidinised, whether or not refined, in immediate packings of <= 1 kg (excl. hydrogenated castor oil "opal wax" and further prepared)
	15162095	Rapeseed, colza, linseed, sunflower-seed, illipe, karite, makore, touloucouna or babassu oils and their fractions, partly or wholly hydrogenated, inter-esterified, re-esterified or elaidinised, whether or not refined, for technical or industrial uses, in immediate packings with a net content of > 1 kg or otherwise prepared (excl. for the manufacture of foodstuffs for human consumption)
	15162098	Vegetable fats and oils and their fractions, partly or wholly hydrogenated, inter-esterified, re-esterified or elaidinised, whether or not refined, in immediate packings of > 1 kg or in another form (excl. fats and oils and their fractions, further prepared, hydrogenated castor oil and subheading 1516.20.95 and 1516.20.96)

Table 1.45 shows that the EU-28 has a positive biodiesel trade balance.

Table 1.45: Evolution of biodiesel trade outside of EU-28 (Source: Eurostat COMEXT Database)

	Import/export outside of EU-28 (tonnes/yr)		
	Import	Export	Trade balance
2006	16 438	40 326	23 888
2008	27 657	36 145	8 488
2010	26 232	37 035	10 803
2012	24 086	39 564	15 478
2014	20 510	40 095	19 584

Treatment of biodiesel

Biodiesel is used at 100% for energy production.

5.4.4 Gaseous output from gasification

According to UBA (2011), coal, petroleum and gas are the dominating feedstock to gasification plants. Extracting data from the NETL/DOE 2010 World Gasification Database (NETL/DOE 2010), UBA (2011) estimated that around 1.5% (215 MW_{th}) of total European syngas is produced annually from wastes. This amount is negligible compared to the calculated annual EU-28 energy potential of 2.3 million TJ of waste-derived energy (see Table 1.1).

European experts have divergent opinions on gasification projects outlook: while some experts consider that the current small-scale pilot operations in the UK could lead to commercial scale project, other experts think that waste-based gasification projects are not economically viable.

Therefore, it was decided not to study this technique further in this report.

5.4.5 Gaseous, liquid and solid output from pyrolysis

According to UBA (2011) and interviews with European experts from ETRMA and GEIR, the number of pyrolysis plants in Europe has been decreasing in recent years and there are now very few plants remaining in activity. However, for some countries the situation depart from the current trend at European level. For instance, in Spain several pyrolysis-gasification plants of tyres and plastic waste have been authorized in the last two years. Also in the UK, several companies seem to be willing to develop pyrolysis infrastructure, particularly in respect of the flash pyrolysis of high calorific value mixed wastes. This remains a niche area, but there is considerable interest from innovators in the UK.

It is difficult to know exactly how many plants remain active in EU-28 or to estimate how much energy they produce and from which feedstock. However, information gathered tend to prove that these amounts are low. European experts have divergent opinions on the possible development of the technology for wastes-to-energy production.

Therefore, it was decided not to study this technique further in this report.

5.5 Discussion on data collection and trend analysis

5.5.1 Eurostat methodology for data collection

This paragraph provides details on Eurostat methodology for data collection on waste generation and waste treatment. Restrictions in the scope can explain some differences with data provided by Member States of European federations.

Eurostat Manual on waste statistics provides, in its chapter 2.1, a definition of waste entering the scope of Eurostat waste statistics database in accordance with the Waste Statistics Regulation (WStatR), including consequences on double counting.
The WStatR covers substances and materials which are defined as wastes in accordance with the EU legislation, and which are covered by the Waste Framework Directive.

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Waste included:

The Waste Statistics Regulation makes a clear distinction between 'waste generation' and 'waste treatment'. Waste generation includes all wastes generated by economic activities and by households. Because economic activity includes activities of treatment facilities, waste generated by these facilities (secondary waste) should also be reported under waste generation.

This includes both residues of waste treatment and consumption residues that are produced by these facilities.

Waste treatment includes all waste entering treatment facilities for final treatment (this includes both public and private waste treatment facilities).

Please note: The different concepts of the WStatR for the handling of secondary waste have consequences with regards to the double counting of waste:

- Data on waste generation shall cover all waste (primary and secondary waste) generated by the statistical units which means that double counting of waste is part of the concept.
- Data on waste treatment refer to the final treatment; treated waste should thus be counted only once. The only exemption[39] is the double counting of combustion residues from waste incineration and energy recovery.

Waste excluded:

Some waste streams are however not covered by the WStatR. These are:

- wastes excluded from the scope of the Waste Framework Directive;
- wastes that are internally recycled (see paragraph below for further details).

However, waste streams excluded from the scope of the Waste Framework Directive because they are covered by other Community legislation however fall within the scope of the Waste Statistics Regulation. This applies in particular to animal carcasses and animal by-products covered by Regulation (EC) No 1069/2009.

Exclusion of some recovery and disposal operations, pre-treatment:

Disposal and recovery operations defined as preparatory operations are excluded from reporting on waste treatment. Among others, it excludes biological treatment (D8): operations which use aerobic or anaerobic biological processes in order to prepare the waste for subsequent disposal, e.g. by reducing the amount of biodegradable components, or by degradation of organic pollutants. This includes, in particular:

- biological-mechanical treatment of municipal waste;
- biological treatment of contaminated soil, sludges or mineral wastes, if followed by disposal.

The following operations are also excluded from reporting on waste treatment:

- Blending, mixing and repackaging of waste (D13 and D14)
- Exchange of wastes (R12)
- Temporary storage (D15 and R13)

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[39] As explained in paragraphs 5.3.9 and 7.1.2.1 there is also evidence of double counting for MSW sent to MBT plants. However, this is not discussed in the Eurostat Manual on waste statistics

Exclusion of co-incineration plants using specific biomass wastes:

Excluded from the Waste Statistics Regulation are co-incineration plants[40] that use as a fuel **only** the following biomass wastes:

- vegetable waste from agriculture and forestry;
- vegetable waste from the food processing industry;
- fibrous vegetable waste from virgin pulp production and from the production of paper from pulp;
- uncontaminated wood waste (excluding wood from construction and demolition or other wood waste that may contain halogenated organic compounds or heavy metals);
- cork waste.

Therefore, no statistics are compiled in Eurostat Waste Statistics on the amount of waste treated in such facilities.

It is important to emphasize that the exemptions refer only to co-incineration plants that use no other wastes than the biomass wastes listed above. Statistics have to be compiled for:

- all co-incineration plants that use as a fuel other wastes than those listed above;
- all incineration plants dedicated to the thermal treatment of waste, with or without energy recovery.

Exclusion of internal recycling:

No statistics have to be compiled for waste that is recycled on the site where the waste is generated; i.e. internal recycling. Enterprises which recycle waste internally may also receive waste from other companies for recycling. In these cases, statistics should include recycling of external waste and exclude recycling of internal waste.
Internal recycling excludes:

- any disposal operation, such as the disposal of waste at a company's own landfill;
- energy recovery operations.

5.5.2 Quality of the Eurostat data and resulting limits in data interpretations

5.5.2.1 Evolution in the Eurostat Waste Statistics methodology and trend analysis

Significant evolutions in the Eurostat Waste Statistics methodology occurred after 2010. These evolutions have an impact on some waste category definitions, such as mixed and undifferentiated materials. For those wastes, the scope of the data is different before and after 2010. Also for 7 waste streams (among which: wood, plastics, papers, textiles, solvents, chemicals, and animal and vegetable wastes), waste treatment data for landfill, incineration (D10) and energy recovery (R1) is only available for the years 2010 and 2012. In addition, Eurostat Waste Statistics does not provide data for the year 2014 at the time this report is published. As a consequence, some trends are only based on data from 2010 and 2012, which makes the observation less robust.

Fortunately, Eurostat Waste Statistics provides in his User Manual a guidance on methodological changes, and resulting evolutions in Eurostat data. Thanks to this

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[40] Co-incineration plants in the meaning of Directive 2000/76/EC on the incineration of waste

manual, it is possible to use and analyse Eurostat Waste Statistics with all necessary caution.

Furthermore, Member States improve their own reporting methodologies. For instance, Spain considers that data from 2010 and 2012 are more accurate, due to improved methodology and more quality control on the data.

As a conclusion, some experts consider that Eurostat data does not reflect the current situation for all waste streams studied. However, most experts also agree that, for most waste streams, there is no better database available to provide an overview on waste generation and treatment at European and national level. Some inconsistency in Eurostat data was noted during the project. Such inconsistencies are well known (see discussion on double-counting in paragraph 5.1.3), but are already subject to significant efforts at European and Member State levels to rectify them.

5.5.2.2 Discussion on trends from 2006 to 2012 and after 2012

The crisis in Europe since 2008 may explain some downward trends for several waste streams including plastics and papers and cardboards.
In addition, the period 2006 to 2012 corresponds to the latest information available from Eurostat Waste Statistics at the time of the project, but significant evolutions have occurred since then. Based on feedbacks from Member States and industry experts, some of them have been taken into account from a qualitative point of view during the analysis of the graphics. For instance, in Finland since 2012, the waste-to-energy capacity has more than doubles, and MSW sent to incinerators have followed the same evolution as a consequence.

5.5.2.3 Discussion on incineration disposal (D10) and incineration with energy recovery (D10)

The distinction incineration disposal (D10) and incineration with energy recovery (D10) is based on the R1 factor calculation explained whithin a guideline published in June 2011. Data on R1/D10 referring to years before that are thus not comparable.
According to Member States and industry expert feedbacks, the approach on implementing the formula is different between the member states. As a results, several Member States including Germany (only one waste-to-energy plant not achieving the R1 status) and the Netherlands (all waste incinerator plants being R1), indicated that data from Eurostat are not representative of the current situation.

In addition, most D10 treatment of waste produce a certain amount of energy. Also R1-plants waste can be treated as D10, as some waste does not fulfil the criterion for incinerations as R1. This criterion is that waste must have a lower content of water and inert then of 50% m/m. Such waste can be sludges and solvents. This makes the distinction between R1 and D10 difficult, some plants shifting from D10 to R1 from one year to another depending on the waste used, and possible technical issues faced periodically and reducing the overall energy efficiency of the plant.

As a conclusion, most experts consider that using data from 2006 to 2012, it is not relevant to make a distinction between R1 and D10, whereas the sum of both gives a more correct estimate. As a consequence, in task 3, calculation are based on total waste incinerated (D10 and R1).

For more information on the R1 formula and its implementation in the EU-28, please have a look at the JRC report from 2014 "*Report on the impact of R1 climate correction factor on the Waste-to-Energy (WtE) plants based on data provided by*

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Member States". This report provides a good overview on the consequences of the R1 formula, and discuss the opportunity of changing the R1 formula to integrate a climate factor aiming at taking into account the impact of climate conditions on R1 formula.

5.5.2.4 Discussion on reporting for industrial/agricultural "waste" vs "by-product"

Finally, it is important to remember that, as explained in paragraph 5.1.1, the definition of "waste" vs "by-product" for industrial and agricultural residues is provided by the Waste Framework Directive, but remains subject to interpretation. Therefore, all countries do not apply the same rules. In addition, for confidentiality reasons, many plants producing energy from wastes are reluctant to provide detailed information (type and quantity) on their feedstock, which makes it impossible to decide whether it is a waste or a by-product. This is mostly significant for "Animal and vegetable wastes" treatment, and for waste-derived fuels production (biogas, biodiesel, bioethanol).

This should be kept in mind when looking at the methodology and results for these combustible wastes.

5.5.2.5 Information on hazardous waste

According to Hazardous Waste Europe (HWE), the European association for hazardous waste (HW), 50 million tonnes of HW are generated in the EU-28, a third of which is produced by France and Germany. On these 50 million tonnes, the association estimates that 20 to 25 million tonnes contains an organic part and should therefore not be sent to landfill. Approximately 5 million tonnes are sent to incineration and co-incineration: 3 to 4 million tonnes in dedicated hazardous waste incinerators, 1 to 2 million tonnes in co-incineration in cement kilns, and 1 to 2 million tonnes burnt in small percentage in co-incineration in non-hazardous waste incinerators (especially in Germany, Italy and Sweden).

In comparison, Eurostat estimates that 75 million tonnes of HW were produced in the EU-28 in 2012, nearly 28 million tonnes of which being non inert. Unfortunately, it was possible to identify neither the reason for the 50% difference between the estimations made by the European association and Eurostat, nor the main waste streams impacted by this difference.

5.6 Identification of combustible waste with significant potential for energy production

This selection is based on the current amount (in PJ) of waste sent for incineration (with or without energy recovery), and the amount (in PJ) sent to landfill because of part of it (that cannot be recycled) could be sent to energy recovery in coming years. In accordance with the waste management hierarchy, the amount (in PJ) of wastes sent to energy recovery should not increase at the expense of material recovery.

Table 1.46 presents, for the 15 most significant combustible wastes studied, the amount of wastes sent to incineration and landfill in 2012 in the EU-28.

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Table 1.46: Amount of wastes sent to incineration and landfill in 2012 in the EU-28 (Source: Deloitte) – in blue, waste categories with significant potential for energy production

	Incineration (D10+R1) - PJ		Landfill / disposal (D1-D7-D12) – PJ	
Wood wastes	375	21%	7	0%
Plastic wastes	61	3%	51	4%
Paper and cardboard wastes	6	0%	3	0%
Textile wastes	2	0%	3	0%
Wastes Tyres	35	2%	2	0%
Spent solvents	29	2%	0	0%
Waste oils	32	2%	0	0%
Chemical wastes	93	5%	31	2%
Household and similar wastes	470	26%	616	43%
Mixed and undifferentiated materials	149	8%	120	8%
Sorting residues	334	18%	489	34%
Animal and vegetal wastes[1]	76	4%	103	7%
Dried/dewatered municipal sewage sludge[1]	22	1%	7	0%
Waste-derived biogas[2]	108	6%	0	0%
Waste-derived biodiesel[2]	19	1%	0	0%
Total	**1 812**	**100%**	**1 432**	**100%**

1- For “Animal and vegetable wastes” and “Municipal sewage sludge”, energy produced from anaerobic digestion is taken into account within “waste-derived biogas”
2- Biogas and biodiesel are used only for energy purpose, so data for “Incineration (D10+R1) – PJ” is the same as the amount of waste-derived biofuel produced.

According to Table 1.46, the 6 following combustible wastes appear to have significant potential for energy production because, for the 16 combustible wastes studied, they represent 83% (in TJ) of wastes sent to incineration in Table 1.46, and 93% (in TJ) of wastes sent to landfill:

- Animal and vegetal wastes
- Household and similar wastes
- Mixed and undifferentiated materials
- Sorting residues
- Wood wastes
- Waste-derived biogas

In accordance to the waste hierarchy, waste currently sent to landfill should be sent to energy recovery only if recovery other than energy recovery is not possible.

In addition, Figure 1.39 shows the evolution of the amount of wastes sent to incineration (with and without energy recovery) in the EU-28. Considering that for a large number of wastes studied data on incineration is only available as of 2010, Figure 1.39 is limited to those years.

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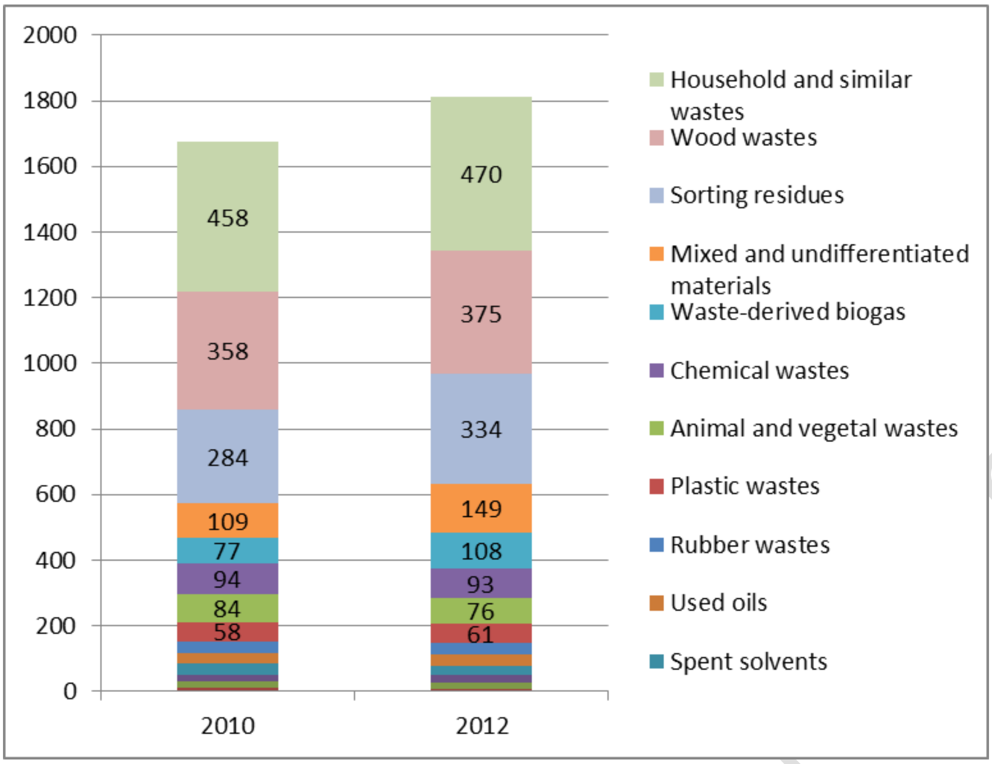

Figure 1.39: Evolution of the amount (in PJ) of wastes sent to incineration (with and without energy recovery) in the EU-28 (Source: Deloitte)

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Discussion on the waste hierarchy for composting and anaerobic digestion

The evolution of waste-derived biogas production depends, among other things, to the choice between sending relevant feedstock toward composting or anaerobic digestion. The waste hierarchy doesn't say which of the two treatment methods should be chosen in priority.

In its report from 2011 "Supporting Environmentally Sound Decisions for Bio-Waste Management - A practical guide to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA)", JRC provides some information to help prioritise between the two treatment methods. The report provides a decision tree to help the user make the right decision, which depends on the characteristics of the feedstock (water content, methanogenic potential, etc.), on the technology available and their efficiency. However, as main guidance, the report states that "*As Anaerobic Digestion (AD) (including composting of digestate) allows combining both benefits, it is likely to be the preferable environmental option in many instances*."

5.7 Main outlets for waste-to-energy

5.7.1 Identification of the main outlets for waste-to-energy

The identification of the main outlets for the production of energy from waste is a prelude for task 2 "Analysis of the technical improvement potential for Waste-to-Energy". Therefore, the list of outlets should include installations that produce most of the energy from waste in Europe, and for each outlet it should be possible to compare techniques and identify technical improvement potential for waste-to-energy.

Based on the current situation, 5 main outlets were identified:

- **Group 1 - Combustion plants**: Combustion plants which utilise waste as a secondary energy source in combination with other types of fuels (these installations include all kinds of conventional power plants used for the generation of mechanical and/or electrical power generation and heat, as well as recovery boilers). CL plants are excluded;
- **Group 2 – Waste Incineration plants**: waste incineration plants dedicated to the thermal treatment of waste, with recovery of the combustion heat generated, through the direct incineration by oxidation of waste;
- **Group 3 - CL plants**: Cement and Lime production plants;[41]
- **Group 4 - AD plants**: Anaerobic Digestion plants;
- **Group 5 - Other WtE plants**: other Waste to Energy plants (including pyrolysis, gasification, plasma treatment and hazardous waste incinerators).

In the report the 5 main outlets will be referred to as:

- Group 1 - Combustion plants
- Group 2 – Waste Incineration (WI) plants
- Group 3 - CL plants
- Group 4 - AD plants
- Group 5 - Other WtE plants

Hazardous waste incinerators are studied separately from combustion plants because it was considered that their techniques should not be compared when trying to identify technical improvement potential for waste-to-energy.

5.7.2 Waste-derived energy production per main outlet

Overview of waste-to-energy plants in the EU-28

The European Commission published in March 2016 the “WID implementation final report” (EC, 2016). This report provides information (see table below) on the amount of incineration and co-incineration plants in Europe and per Member State (excluding Croatia), according to the definition of art (3) of the WID (2000/76/EC). Data comes from the reports submitted by Member States for the third and last reporting period under the WID which covered the period 2012-2013.

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[41] The current report focuses on Cement plants. We are waiting data from Eula (the European Lime Association) on Lime production plants. This will be updated in the final report

	WI plants[1]	Co-incineration[1]				AD plants
		Cement kilns	Combustion plant	Other industrial facilities[2]	Total	
Total number of plants	939	176	305	207	688	15 725
Plants recovering heat	562	not available			469	15 725

(1) Definition according to art (3) of the WID (2000/76/EC) including also thermal treatment processes such as pyrolysis, gasification or plasma processes
(2) 95 facilities not covered by Annex II.1 or II.2 of the WID (2000/76/EC) and 112 uncategorized

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Heat and electricity production from waste in the EU-28

Miscellaneous sources provide information on the amount of heat and electricity produced from combustible waste in Europe.

- Waste-to-electricity production: CEWEP, the Confederation of European Waste-to-Energy Plants, estimates that in 2013 in the EU-28, 110 PJ of electricity was produced from the incineration of 76.5 M tonnes of MSW and similar waste in 411 WI plants. The same year, Eurelectric, the association of the electricity industry in Europe, estimated that 86 PJ[42] of electricity were produced from renewable waste in the EU-28. It represented 4% of total renewable electricity production.
- Waste-to-heat production: in 2012-2013, 79% of total incineration and co-incineration plants reported recovering heat in Europe (EC, 2016). 54% of the plants without heat recovery were located in two Member States: France (34%) and Germany (20%). On the same period, CEWEP estimated that 275 PJ of waste-derived heat were produced from 411 WI plants. For cement kilns, waste-derived thermal energy conversion was estimated at 176 PJ in 2013 (see figure below).

Table 1.47 presents the estimation of waste-to-energy production in the EU-28 by outlet.

Table 1.47 Estimation of the waste-derived energy production in the EU-28 for the 5 outlets studied

	Combustion plants	WI plants[1]		CL plants[2]	AD plants[3]			Other WtE plants[4]
		Heat production (PJ)	Electricity production (PJ)	Thermal energy conversion (PJ)	Utilised heat production (PJ)	Electricity production (PJ)	Biomethane production (PJ)	
2006	n.a.	180	81	127	n.a. (not available)			n.a.
2007		165	89	141				
2008		183	92	149				
2009		177	97	154				
2010		199	105	165				
2011		228	106	184				
2012		265	106	177				
2013		275	110	176				
2014		n.a.	n.a.	n.a.	33	70	12	

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[42] 24 TWh. Source: Eurelectric 2015, "A sector in transformation: Electricity industry trends and figures"

1- source: CEWEP
2- no information for Lime production plants. Information for cement kilns from CEMBUREAU
3- source: Deloitte calculation based on Eurostat Energy Statistics and EBA data
4- information only for hazardous waste plants from Hazardous Waste Europe

Table 1.48 shows that in the period 2006-2013, the amount of energy produced from waste has increased by 39% for cement kilns, by 36% for electricity from WI plants, and by 53% for heat from WI plants. The latter can be explained by the significant increase in the number of WI plants having a CHP.

Estimation of waste consumption for energy production

The amount of wastes consumed by cement kilns and waste-to-energy plants has been analysed in order to assess whether it is its representative compared to the total waste-derived energy produced in the EU-28.

Table 1.48: Amount of waste consumed by waste-to-energy plants and cement kilns in the EU-28 in 2013

	Amount of wastes treated in 2013 – 1000 tonnes	Source
WI plants	76 500	CEWEP
Cement Kilns	8 000	CEMBUREAU
Total	84 500	

Looking at both Table 1.1 and Table 1.48, it appears that waste-to-energy plants and cement kilns account for only 63% of the 138 million tonnes of wastes sent for incineration in the EU-28[43]. There are several explanations for this difference of 51 million tonnes of wastes:

- A number of plants producing energy from wastes are not accounted for in Table 1.49, especially combustion plants and to a lesser extend other WtE plants such as hazardous waste plants. Although it was not possible to estimate the amount of wastes used by combustion plants, it might represent a significant amount of the 26 million tonnes of wood wastes reported by Eurostat. A more in-depth analysis based on data from all industries using process residues in co-incineration should provide a better understanding on this aspect. Also, according to Hazardous Waste Europe, 5 million tonnes of hazardous wastes are sent for incineration, instead of the 10.5 million tonnes provided by Eurostat Waste Statistics database, in 2012.
- As explained in previous paragraphs, the definition of “waste” and “by-products” is open to interpretations. It is, however, impossible to estimate how much of the difference could be explained by this.
- Based on Eurostat Waste Statistics database, in 2012, 36.5 million tonnes of wastes were sent for incineration/disposal (D10). It was not possible to estimate the share which goes to incineration plants without any kind of energy recovery and the share that goes to energy plants with low energy efficiency (according to the R1 formula) and which are therefore no considered as energy recovery.
- Finally some experts interviewed consider that Eurostat Waste Statistics data represent a high range estimate.

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[43] Wastes sent for anaerobic digestion are not taken into account in the 138 million tonnes

6 Task 2 - Analysis of the technical improvement potential for Waste-to-Energy

The objective of Task 2 is to provide an analysis of the technical improvement potential for Waste-to-Energy with respect to energy production.

6.1 Identification of techniques

Task 2 commences with the identification of WtE techniques. The three step data collection strategy used for this task is illustrated in the figure below.

In Task 1, the main waste treatment outlets were defined and arranged into five Groups as follows:

Group	WtE Outlet
Group 1	Combustion plants: Combustion plants which utilise waste as a secondary energy source in combination with other types of fuels (these installations include all kinds of conventional power plants used for the generation of mechanical and/or electrical power generation and heat, as well as recovery boilers)
Group 2	WI plants: Waste incineration plants dedicated to the thermal treatment of waste, with recovery of the combustion heat generated, through the direct incineration by oxidation of waste
Group 3	CL plants: Cement and Lime production plants
Group 4	AD plants: Anaerobic Digestion plants
Group 5	Other WtE plants: Other Waste to Energy plants (including pyrolysis, gasification and plasma treatment)

Within each group, the techniques are split into two sub groups: the first sub group lists techniques which are considered to be proven techniques which could be implemented immediately in any Member State to improve the deployment of WtE with respect to energy generation. They will have a Technology Readiness Level (TRL) of at least 9, for further discussion of TRL, please refer to section 6.2.2 below.

The second sub group lists emerging WtE techniques which are considered as 'Technologies to watch'. These technologies all have a TRL level of 8 or less. This TRL level indicates that they are currently not commercially mature but may offer potential in the future.

An evaluation of all techniques was performed according to the methodology described below in section 6.2.

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6.2 Technique evaluation methodology

The approach to the evaluation of the improvement techniques is described in the following sections.

6.2.1 Evaluation definitions

Table 2.49 below describes the two key criteria assessed for each technique and a descriptor of how a 'Red, Amber, Green' rating was applied to each of the two criteria.

Table 2.50: Evaluation and rating definitions

Criteria		**Rating**		
		🟥	🟨	🟩
1. Net **annual average** energy efficiency		Reduced efficiency:	No change in efficiency:$^{+}$	Increased efficiency:
		Net electrical efficiency[44] less than 22%	Net electrical efficiency between 22% and 29%	Net electrical efficiency above 29%
		Net heat only energy efficiency^{++} below 70%	Net heat only energy efficiency^{++} approx 75%	Net heat only energy efficiency^{++} above 80%
		Net CHP energy efficiency^{+++} below 68%	Net CHP energy efficiency^{+++} of approx 71%	Net CHP energy efficiency^{+++} of above 76%
		Net gas network / liquefaction energy efficiency of below 35%	Net gas network / liquefaction energy efficiency between 35% and 40%	Net gas network / liquefaction energy efficiency of above 40%[45]
2. Applicability		🟥	🟨	🟩
	Location	High location dependence	Some restrictions on location which may restrict deployment	Independent of location
	Waste stream	Only applicable to waste streams with low total energy potential	Applicable to waste streams with medium total energy potential	Applicable to waste streams with high total energy potential
	Retrofit potential	New installations only	Can be retrofitted in some instances	Can be retrofitted in the majority of installations

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[44] ISWA CE Report 5 Table 5 – Based on gross efficiencies corrected to net efficiencies. It is assumed that in electricity only mode, electrical parasitic load is 10% of power produced. Available at: http://www.iswa.org/fileadmin/galleries/Task_Forces/Task_Force_Report_5.pdf

[45] ISWA CE Report 5, Table 2 – Methane output represents increased efficiency.

6.2.1.1 Net annual average energy efficiency

$^{+}$ This middle column (No Change in Efficiency) represents the base-line, or in other words the average value in the range that we are encountering in practice today. Reduced Efficiency applies to techniques which are below the expected level of energy efficiency (there are limited numbers of these techniques) and at the other end of the spectrum, Increased Efficiency represents techniques which deliver above average performance.

$^{++}$ In the calculation of annual average heat only energy efficiency, it is assumed that this category applies to cement / lime kilns, waste heat boilers combusting hazardous / non-hazardous waste and industrial boilers where the heat producing plant only runs when it is required and therefore **all the heat produced is sold.** It should also be noted that cement / lime kilns included in this category consume the heat energy produced (rather than recovering heat via a steam boiler), pre-treatment is required to produce the SRF fuel and the process produces a material product as a result of combustion[46].

$^{+++}$ In the calculation of net annual average CHP energy efficiency, it is assumed that **80% of the heat produced per annum can be sold** for heating or cooling purposes[47]. This is calculated as shown in Annex 4[48]. It should be noted that electrical output is reduced when a thermal plant is run in CHP mode (80% of the time) and that electrical output will improve again during periods when heat is not supplied (the remaining 20% of the time). This is reflected in the calculation.

6.2.1.2 Applicability

A key aim of this study is to understand how the technical potential of waste to energy can be further exploited. In order to do this, an evaluation of the applicability of different techniques has been made. The applicability of each technique has been considered in three different ways:

- Location dependence;
- Waste streams; and
- Opportunity for retrofitting to existing installations.

Location

In general, the main restrictions on the location of techniques is the viability of district heating/cooling. Other factors relating to location will remain the same across member states. Therefore the location criterion has been evaluated in a qualitative way. Some examples of location dependence are shown below:

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[46] CEMBUREAU interviews, January - April 2016

[47] ESWET estimate, May 2016

[48] ISWA CE Report 5 Table 5 - Based on ISWA gross efficiencies corrected to net efficiencies. It is assumed that in electricity only mode, electrical parasitic load is 10% of power produced. In CHP mode, electrical parasitic load is 20% of power produced. Parasitic heat load is around 1% in both cases.

High location dependence	Some restrictions on location which may restrict deployment	Independent of location
Techniques delivering heating will be highly dependent on location. For example, northern Europe have a longer heating season, whereas there may be little or no demand for district heating in southern Europe.	There may be some restrictions on techniques delivering cooling, for example, a shorter cooling season in N. Europe, or dependent on proximity to another user of a cooling network, i.e. data centre	Techniques delivering power only will be applicable to a wide range of location types.

Waste stream applicability

This has been assessed using a quantitative method, based on the amount of energy (in PJ) currently being recovered from each waste stream; this assessment takes account of both the quantity and calorific value of the waste stream. For example, for the wastes that already contribute higher amounts of energy, there is more potential here to increase the efficiency of the energy recovery from these waste streams. For smaller waste streams, or those that generate a lower amount of energy, there is less potential. Each technique was assessed as to which of the waste streams in the table below the technique was applicable to, and therefore the % of potential energy in PJ that was also applicable.

Waste	PJ	%
Household and similar wastes	757	34%
Wood wastes	375	17%
Sorting residues	345	16%
Waste-derived biogas	217	10%
Mixed and undifferentiated materials	166	7%
Animal and vegetal wastes	100	4%
Chemical wastes	93	4%
Plastic wastes	46	2%
Rubber wastes	32	1%
Spent solvents	31	1%
Dried/dewatered municipal sewage sludge	15	1%
Waste oils	14	1%
Waste-derived biodiesel	14	1%
Paper and cardboard wastes	6	0%
Textile wastes	2	0%
Edible oil and fat	3	0%

The scoring assigned is set out below.

Applicable to <33% of total potential energy	Applicable to 34-66% of total potential energy	Applicable to 67% of total potential energy

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Opportunity for retrofitting to existing installations

To enable the WtE landscape to be changed in the short to medium term, it is important to identify techniques which can be more easily retrofitted to existing WtE installations. Scoring was assigned as follows:

New installations only	Can be retrofitted in some instances	Can be retrofitted in the majority of installations

Combining the applicability sub-criteria.

As there are three sub-criteria which are used to evaluate the overall applicability of each technique, to get an overall score, the RAG scores (R=1, A=2, G=3) for location, waste streams and retro-fitting are multiplied together. The rounded cube root of each score is then calculated to determine the overall score of Red, Amber, or Green. This process is line with guidance set out by the EC-JRC for aggregating non-numerical indicators[49].

This will result in the lowest score being 1 (i.e. Red in each applicability sub-criteria) to the maximum of 27 (i.e. Green in each applicability sub-criterion).

Multiplied scores of 1,2 or 3 = rounded root value of 1	Multiplied scores of 4,6,8,9 or 12 = rounded root value of 2	Multiplied scores of 18 or 27 = a rounded root value of 3

Two red sub-scores automatically lead to a red overall score, whereas at least two sub-scores of green and one orange are needed for an overall green score.

The overall applicability score will still be a qualitative indicator, rather than a quantitative indicator, but gives a good idea of how much of the actual market can be affected by the energy efficiency gain delivered by a given technique. The most relevant techniques today will be those that can be implemented in existing installations, without geographical limitations and for an important fraction of waste materials.

6.2.1.3 Other considerations

In addition to the two rated criteria, for each technique further comment is provided on:

- Exclusion criteria – the technique could be excluded from further deployment if it causes possible conflicts with the waste hierarchy, has a negative effect on emissions or for other specific reasons.
- Technology Readiness Level – each technique is rated for Technology Readiness Level as described in section 6.2.2 below.

6.2.2 Approach and Technology Readiness Level

Where possible, each technology and system has been assigned a Technology Readiness Level (TRL) as shown below in Table 2.50. The TRL indicates how close the technique is to commercial deployment, this has been recorded in the scoring notes for each technique. A technique with a high TRL should have low residual risks and good availability of operational data. Many highly innovative techniques have a low TRL and there likely to be very little operational data.

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[49] Available at: https://ec.europa.eu/jrc/en/coin/10-step-guide/step-7

2676 **Table 2.51: Technology Readiness Level**

Technology Readiness Level	Description
1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or proof of concept
4	Technology basic validation in laboratory environment
5	Technology basic validation in a laboratory environment, where basic technological components are integrated together with realistic supporting elements
6	Technology model or prototype demonstration verified in a relevant environment
7	Technology prototype demonstrated in an operational environment
8	Actual technology completed and qualified through testing and demonstration
9	Actual technology qualified through successful commercial operation
9 +	More than one commercial scale plant and over 5 years operational experience

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6.3 Task 2 – Technique dashboard

This report is not intended to be read from cover to cover (although it can be), but to present techniques in each of the six groups. Readers can select groups of interest by selecting them from the dashboard below.

1		Combustion plants co-incinerating waste
2		Waste incineration plants
3		Cement and Lime (CL) plants
4		Anaerobic Digestion plants
5		Other Waste to Energy plants

6.4 Combustion plants (other than CL plants) co-incinerating wastes

This section considers combustion plants (other than CL plants) co-incinerating wastes. In this group, waste is a secondary fuel and the primary fuel is a non-waste such as coal or biomass.

6.4.1 Overview of waste as a secondary fuel in large combustion plants

Besides incineration in specially designed and operated waste incineration plants, certain wastes such as contaminated biomass, sewage sludge and SRF may also be co-incinerated in regular combustion installations such as power plants. The waste fraction in co-incineration is termed as the secondary fuel with the majority fossil (or biomass) fuel known as the primary fuel.

Combustion plant operators may find co-incineration of certain wastes attractive as it offers economic benefits where a gate fee may be charged and waste with a high biogenic content can help offset GHG emissions from fossil fuel combustion. A barrier to co-incineration of waste is the requirement for the plant to conform to all legislation concerning the incineration of waste, including WID compliance and environmental permitting; both of these carry risk and a high administrative burden which may not outweigh the achieved economic and carbon reduction benefits. Other technical issues for an LCP plant considering co-combustion of waste include:

- fuel quality and characteristics
- boiler design
- fuel handling and feeding
- slagging, or bed sintering (fluidised bed boiler)
- fouling of heat transfer surfaces
- hot corrosion
- effects on emission levels compared to the emissions that occur when only a conventional primary fuel is used
- ash properties, bottom ash removal
- storage of waste fuel
- utilisation and/or disposal options for solid waste/residues from co-combustion.

The main types of secondary fuel that have been used for co-incineration in large combustion plants are shown below where the most important ones on this list are sewage sludge, paper sludge and biomass/wood.

Type of secondary fuel	Examples of secondary fuel
Animal (by-) products	Animal meal, tallow, meat and bone meal Cattle manure and chicken litter
Chemicals	Organic acids and liquid solvents Phosphor oven gas
Municipal waste	Waste paper Waste packing materials Waste plastics

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Type of secondary fuel	Examples of secondary fuel
	Mixed wastes
Oily materials	Tar Waste oil
Recovered fuels	Fuels derived from different high calorific waste fractions (SRF)
Sludge	Sewage Paper sludge (such as de-inking, bio and primary sludge)
Tyres	Shredded tyres
Vegetables	Energy crops such as willow Agricultural residues such as straw, cereal plants, pasture from landscape cultivation
Wood	Wood residues, demolition wood, waste wood, forest residues, wood chips Biomass pellets/briquettes

The range of energy efficiency in existing combustion plants is shown below in Table 2.51[50]. It is assumed that co-incineration will be applied to existing plants, it is noted that new combustion plants will be more energy efficient.

Table 2.52: Net annual average energy efficiency of combustion plants

	Net annual average energy efficiency (%)
Plant fuel	Electricity only
Coal / lignite pulverised combustion [+]	36 – 40
Biomass fluidised bed combustion [++]	28 -30
Gas Turbine	32 – 35
CCGT power only	50 - 54
CCGT with CHP	< 35

[+] Pulverised combustion is the most likely form of lignite / coal fired LCP for the addition of waste

[++] Fluidised bed combustion is the most likely form of biomass fired LCP for the addition of waste

The highest plant efficiencies are found in those plants which operate on a combined cycle gas turbine (CCGT) and where a combustion plant also has the ability to operate in CHP mode. Biomass fired plants have a markedly lower energy efficiency.

6.4.2 Combustion plants co-incinerating wastes - Proven improvement techniques

A list of proven improvement techniques for the co-incinerating of wastes in combustion plants is provided below in Table 2.52.

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[50] LCP - Reference Document on Best Available Techniques - July 2006 Pgs. vii to viii

Table 2.53: List of proven improvement techniques for co-incinerating wastes in combustion plants

#	Technique title
a	Mixing of waste with a primary fuel prior to incineration
b	High efficiency Circulating Fluidised Bed gasification and co-firing of syngas in combustion plant
c	Special grate for co-incineration of waste
d	Feeding secondary fuels into a fluidised bed combustion plant

Note on Methanisation: To avoid repetition, it should be noted that the production of biomethane through Anaerobic Digestion and injection to the gas grid for use in natural gas fired combustion plant is described under Group 4.

A full description of each technique and the evaluation is shown below.

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6.4.3 Large combustion plant techniques evaluation

<table>
<tr><th>Technique Title:</th><th colspan="2">Mixing of waste with a primary fuel prior to combustion</th></tr>
<tr><td>Description</td><td colspan="2">The easiest way to introduce a secondary (waste) fuel into a combustion process is by mixing it with the primary fuel[51]. In a coal or lignite-fired boiler, the following locations for fuel mixing are possible:
1. On the coal conveyor belt
2. In the coal bunker
3. In the coal feeder
4. At the coal mill
5. On the pulverised coal lines
In the first three situations, the secondary fuel is spread over the primary fuel (coal). In this way an adequate mixing of the fuel streams occurs. This results in a grinding of the secondary fuels together with the primary fuel in the coal mill to create a pulverised dust.
It is only possible to apply this technique when the grinding behaviour of both fuels are more or less the same or when the amount of secondary fuels is very small compared with the main fuel flow. Secondary fuels that are pulverised separately from the main fuel can be injected into the coal mill or into the pulverised coal pipelines between the coal mill and boiler (situations 4 and 5).
Other secondary fuels, such as biomass, can also injected into the coal mill together with the coal, although they cannot be pulverised. To allow for a complete combustion of the comparably large sized biomass particles, a grate at the bottom of the boiler can be used (please refer below).
Wastes which are most suitable for mixing prior to combustion include sewage sludge, paper sludge and animal meal and manure. These wastes can be most readily used in coal fired combustion plant where there is excess drying capacity in the installed coal mill drying plant (where weight for weight of raw fuel, the drying requirements of sewage sludge is large compared to coal). Otherwise new or off site drying facilities will be required.</td></tr>
<tr><td>Criteria</td><td>Rating</td><td>Notes</td></tr>
<tr><td>Net Annual Average Energy Efficiency</td><td>🟩</td><td>A substantial amount of heat energy is required to dry sewage sludge / manure down to a suitable moisture content (<10%) prior to co-combustion. For small quantities of sewage sludge it can be assumed that the heat energy for drying is spare heat which would otherwise be wasted. Once dry, the overall net electrical efficiency obtained in a coal fired combustion plant with small amounts of waste (<5%) will be between 36 and 40%.</td></tr>
</table>

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[51] LCP BREF 2006 / 2007, eippcb.jrc.ec.europa.eu/reference/BREF/lcp_bref_0706.pdf

Technique Title:	**Mixing of waste with a primary fuel prior to combustion**	
Applicability	🟧	The technique is limited to coal or lignite fired LCPs which are being phased out. The amount of sewage sludge secondary fuel that can be added is currently limited to a maximum of 5% by weight. Many combustion plant operators will not want the extra burden of WID compliance.
Exclusion criteria	No	Some concern has been noted in the LCP BREF on mercury emissions but this can be controlled through suitable abatement measures. Spreading of sewage sludge / manure in the coal yard or bunker is excluded due to fire risk from methanation and odour issues.
TRL	9+	There are numerous examples of co-combustion of waste in combustion plants over the past 20 years, particularly in Germany.

2754

Technique Title:	**High efficiency Circulating Fluidised Bed gasification and co-firing of syngas in combustion plant**
Description	An alternative approach to building stand-alone plants to generate electricity is to install gasification plants at existing fossil fuel power plants[52]. The syngas generated can then be burnt in the existing boiler, displacing fossil fuels. There are several examples of this operating worldwide, for example the Kymijärvi plant built in Lahti, Finland, in 1998 where refuse derived fuel and biomass was gasified and the resulting syngas burnt in the existing coal fired plant to produce power and heat for the city of Lahti. This plant has operated since 1998, with a 60 MWth fluidised bed generating syngas, which with limited clean-up, successfully displaced fossil coal in the existing boiler. At the Vaskiluoto coal fired power station in Vaasa, Finland. Biomass is gasified with the resulting syngas blown into the existing coal fired boiler to directly displace up to 40% of coal. As the syngas secondary fuel has very different physical properties to pulverised coal, the syngas is burnt using specially developed gas burners. There are other examples in Holland and in N. America. The direct displacement of coal by syngas generated from waste in existing power stations can be an attractive environmental and economic option. Whilst there are a great number of fossil fuel power stations, age, environmental and regulatory issues or economics mean that the number of potential plants which could be converted to use syngas are much more limited. Pre-treatment is required to prepare the fuel for combustion. In the Finnish plant, the prepared SRF, plastics or wood waste fuel is fed into a Circulating Fluidised Bed (CFB) reactor where a syngas is produced. The hot syngas rises to the top of the gasifier and then into a cooling system where the gas temperature falls to 400°C. By cooling the gas

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[52] Fichtner Consulting Engineers – Valmet Gasification Of Waste Technology Review – November 2015

<table>
<tr><th>Technique Title:</th><th colspan="2">High efficiency Circulating Fluidised Bed gasification and co-firing of syngas in combustion plant</th></tr>
<tr><td></td><td colspan="2">to 400°C, impurities in the fuel, such as alkali chlorides, Pb and Zn, turn to solid form and are more easily removed. The gas impurities are removed inside 12 cooling chambers containing 300 high temperature ceramic candle filters, each collecting unwanted particles while allowing the gas to pass through. A nitrogen pulse every minute ejects collected dust, which falls to the chamber floor for removal.

The resulting gas is cleaned from corrosive components and therefore it is possible to achieve efficient electricity production by using high steam temperature and pressure. Typically for a coal fired combustion plant, this will be between 36 and 40%.</td></tr>
<tr><td>Criteria</td><td>Rating</td><td>Notes</td></tr>
<tr><td>Net Annual Average Energy Efficiency</td><td>🟩</td><td>The net annual electrical efficiency obtained in a co-fired coal combustion plant will be between 36 and 40%. As the gasifier is no more than a thermo-mechanical mill for fuel preparation, It is assumed that the energy required to gasify the waste is broadly similar to the energy input to prepare coal for combustion. Additional energy input will also be required to sort and pre-treat the waste feedstock.</td></tr>
<tr><td>Applicability</td><td>🟧</td><td>In many countries, coal fired power stations are not yet fitted with low emission technology. As firing of waste in a coal fired power station means the plant is regulated as a co-incinerator under the original Waste Incineration Directive, and now the Industrial Emissions Directive, this has limited the displacement of fossil fuels by these means.</td></tr>
<tr><td>Exclusion criteria</td><td>No</td><td>None noted</td></tr>
<tr><td>TRL</td><td>9+</td><td>There are two technique examples in Finland, one in Holland and several in N. America.</td></tr>
</table>

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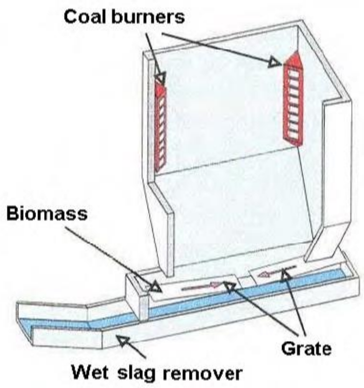
2757

Technique Title:	**Special grate for co-incineration of waste**
Description	For waste which cannot be pulverised or injected as a liquid / gas, a different approach is required to co-incinerate these larger particles of waste in a coal fired combustion plant. Typical wastes which fall into this category are waste wood or SRF derived from household and similar wastes. Special moving grates at the bottom end of the boiler hopper used for the introduction of secondary fuel lengthen the residence time of those materials in the furnace. Household and similar wastes will need preparation to form an SRF product. As shown below, the waste wood / SRF is fed into the boiler at the small front sides of the grate, which transport the fuel during combustion to the centre of the coal fired boiler[53]. Ash from the waste and bottom ash from the coal combustion, with less than 5 % unburned carbon, falls into the slag remover below the grates. Resulting flue-gases from the grate rise directly into the furnace without any heat losses. Energy will be recovered through the existing energy recovery plant, typically net annual electrical efficiency is between 36% and 40% for a coal fired combustion plant.  Image courtesy of LCP Bref document

Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟩	In a coal fired combustion plant, net annual electrical efficiency between 36% and 40% can be expected where low rates of substitution are adhered to. Energy input will also be required to create an SRF product.
Applicability	🟨	Substitution rates of waste as a secondary fuel will generally be limited to <5% to avoid significant impacts on LCP performance. Many LCP operators will not want the extra burden of WID compliance. The installation of such a grate requires a lot of free space below the boiler, which is rarely available.

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[53] LCP BREF 2006 / 2007

Technique Title:	**Special grate for co-incineration of waste**	
Exclusion criteria	Possible	SRF as a secondary fuel in coal fired combustion plants have experienced boiler issues such as too low a retention time (<2s), corrosion and fouling[54].
TRL	9+	There are numerous examples of co-combustion of waste in combustion plants over the past 20 years, particularly in Germany.

Technique Title:	**Feeding secondary fuels into a fluidised bed combustion plant**
Description	This technique generally refers to the partial substitution of SRF for biomass in biomass fired fluidised bed combustion plants. Other combination of primary and secondary fuel combustion in a fluidised bed combustion plant (such as coal and sewage sludge) are also possible. There are a number of operational biomass co-combustion plants which are in some cases are able to successfully increase the ratio of SRF co-combustion to over 50%[55] (whereas waste substitution ratios in coal fired plants are much more restricted). For co-combustion in a fluidised bed boiler, appropriate feeding of the main and secondary fuels is one of the most essential factors for good operation. One of the benefits of SRF co-incineration is that some biomass fuel sources are of relatively low quality with high moisture content of up to 60%. This can result in a low net calorific value (NCV) fuel typically between 5 and 15 MJ/kg. SRF is a fast burning material and has a high NCV typically of between 15 and 25 MJ/kg and oxygen content of close to zero. CO_2 emission factors are ~25% lower than that of coal. Thus, SRF can operate as a support fuel to biomass, assisting in ignition and support a more stable combustion and better burning of low grade biomass[56]. Initial pilot tests in Finland[57] in 2008 revealed that the co-firing of biomass and SRF is not without problems. Biomass contains high quantities of alkali metals (such as sodium and potassium) which react during combustion with chlorine (which is present in SRF plastics) to form alkali chlorides with low melting points. Existence of alkali components in fuel ash have an important role in deposit formation which can create technical problems such as boiler incrustation and fouling/slagging on the furnace/boiler.

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[54] MVW Lechtenberg & Partner, EfW London Conference, 2015

[55] FEAD comments to the WtE background document, April 2016.

[56] ERFO, February 2016

[57] Plastics Europe 2008 available at: http://www.localnet.abertay.ac.uk/media/Co-combustion%20of%20Solid%20Recovered%20Fuel%20and%20Solid%20Biofuels.pdf

Technique Title:		**Feeding secondary fuels into a fluidised bed combustion plant**
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟧	In a modern biomass fluidised bed combustion plant, net annual average electrical efficiency will be around 28 to 30%. In older plant designs, the net electrical efficiency will be nearer to 20%. Energy input will also be required to sort and pre-treat the waste feedstock to provide a suitable SRF fuel.
Applicability	🟧	Substitution rates of SRF as a secondary fuel are relatively high in this technique in comparison to others making it much more applicable. However, many operators will still not want the extra burden of WID compliance and will be wary of corrosion issues.
Exclusion criteria	No	None
TRL	9 +	There are over 10 biomass and SRF co-combustion plants located in Finland alone.

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6.5 Waste incineration

This section considers waste incineration plants dedicated to the thermal treatment of waste, with recovery of the combustion heat generated, through the direct incineration by oxidation of waste

6.5.1 Overview of waste incineration

Prior to considering techniques to improve energy efficiency in waste incineration, an overview of currently deployed waste incineration technology is provided below.

Moving Grate

Residual waste is taken from a storage bunker by a crane and dropped into a chute. Waste at the bottom of the chute is mechanically pushed onto the combustion grate, the pusher rate is carefully controlled to ensure an even feed of waste. The waste on the grate is combusted at a temperature of 1,000°C or more, with combustion air injected from below the grate.

The waste is moved forward on the grate and the resultant incinerator bottom ash (IBA) drops into a water bath at the end of the grate. Complete gas phase combustion is reached by injection of secondary air above the grate. The system ensures that a temperature of at least 850°C for a minimum of 2 seconds is reached (IED requirement) in the secondary combustion zone. Auxiliary fuel is only used for start-up and shutdown to achieve temperature conditions for waste feed.

The roller grate is a variation of the pushing-type grate; instead of moving the waste forward, the roller grate passes waste over a series of inclined rotating rollers. This form of combustion grate is much less common than the walking grate.

A rotary kiln may also be used to combust MSW. In the rotary kiln, the waste is mechanically pushed into the top of a tapering cylinder or kiln. In order to pass the waste through the kiln and control the rate of combustion, the kiln oscillates from side to side, passing the waste between paddles set into the internal walls of the kiln. In other respects, the rotating kiln is a conventional combustion process. There are more applications of the rotary kiln in the treatment of hazardous waste (due to the ability of the kiln to operate at elevated temperatures) than for MSW, but both are established.

Fluidised Bed combustion

Fluidised bed reactors are suitable for more homogeneous feedstocks such as chipped wood waste or residual waste resulting from a process of metal removal and shredding for size reduction. The prepared feedstock is transferred to the reactor chamber. The reactor chamber contains very hot sand, which is fluidised by an air stream from the wind box below. The IED requirement of minimum 2 seconds at 850°C is achieved in the secondary combustion zone. Energy is transferred to a boiler system similar to a pushing-type grate fired facility. However, both availability and energy efficiency of fluidised bed plants fired on MSW is lower than for pushing-type grate plants.

Energy Recovery Boiler

Typically hot gases from the combustion chamber pass to a boiler, which converts the energy from gases into superheated steam which powers steam turbine generators that make electrical energy. Such a process generates heat as a by-product which can also be recovered in a combined heat and power system. The most efficient designs incorporate an integrated furnace-boiler, rather than the transport of hot gases via ducting to a separate boiler.

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Typical steam data are 400°C and 45 bar. The boiler system typically has as an energy efficiency of around 85% for steam production.

Boiler feed water should be preheated in an economiser, which recovers the maximum heat from the flue gases leaving the boiler.

All boilers in WtE plants have radiation passes (empty, waterwalls for heat transfer) and convective passes (bundles in the gas stream). The final superheater in most cases is located in the convective section

Steam turbine and generator set

High pressure steam generated by the boiler is fed to the steam turbine. Steam enters the turbine and expands through the turbine blade system, converting energy (Enthalpy) in the steam to mechanical motion. A typical net electrical efficiency of 25% is achieved at the typical standard steam conditions of 400°C and 45 bar.

To maximise the energy recovered for electrical energy production, a condensing turbine is specified, where the expansion of the steam across the turbine is maximised and at the exhaust of the turbine, steam will generally be below atmospheric pressure.

Where significant heat load (process or heat network) is required, a back pressure turbine can be specified where the pressure drop will be less, thus retaining more energy in the condensed steam for heating purposes. CHP enabled condensing turbines have a controlled bleed point to extract steam mid-way along the turbine casing at a pressure suitable to provide high grade heat for district heating / cooling purposes.

The turbine is mechanically linked to a generator through a gearbox. The generator rotation is synchronised to the grid at 50 Hz, with electrical output stepped up to a voltage of 11KV through a transformer. Typically air-cooled condensers are installed onsite to condense the exhaust from the steam turbine, depending on the local features (ambient climate, river for cooling water supply etc.)

District heating and cooling

A district heating network will supply hot water to consumers through a pipeline loop. Steam from a WtE plant is bled from the turbine system (refer turbine description) and supplies heat energy to the district heating system through a heat exchanger located in or close to the EfW plant (the Energy Centre). There are a range of hot water flow and return temperatures in operation across Europe, but current best practice guidance for maximum system efficiency, is 70°C/40°C. The pipeline is lagged to limit heat loss and in urban areas, is generally laid in trenches in the road network.

Within the Energy Centre, a backup system (normally natural gas fired) is needed in the event that the EfW plant heat generator is shut down. This can be mitigated if there are several EfW plants or other heat sources supplying into the network. Back up stations may also operate as peak load stations in the event that heat demand outstrips supply.

High Grade Heat for industrial users

Some WtE plants are located in close proximity to commercial steam users providing an opportunity to supply steam which can be used in industrial processes. Ideally the consumer would be under 1km from the WtE plant, but longer pipelines are feasible. Steam is normally bled from the turbine at higher pressures than for a DHN, but is designed appropriate to the requirements of the consumer. Steam pipelines are higher maintenance than Medium Temperature Hot Water (MTHW) pipelines, so some supply systems are being de-steamed in favour of MTHW. Backup facilities are required to provide for WtE supply outages. These can be installed either at the WtE site or at the works.

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6.5.2 Energy efficiency

The highest efficiency waste incineration plants are characterised by the following features:

- A waste feedstock which is constant in terms of both composition and calorific value and low in moisture content. This can be achieved through effective pre-treatment, but it should be noted that this will increase plant parasitic load.
- Effective cleaning techniques to keep boilers free from fouling thereby allowing heat transfer surfaces to operate most effectively
- Optimised control of combustion conditions and stability of steam production
- Optimisation of the furnace including:
    - Reduction of excess air
    - Low flue-gas temperature at boiler outlet
- Optimisation of the steam cycle, including:
    - High steam parameters (p, T)
    - Steam reheating
    - Preheating of condensate and feedwater
    - Preheating combustion air with steam bleed from the turbine
    - Air preheating with a flue-gas heat exchanger
- Reduction of auxiliary power consumption
- Plant location - connection to a heat consumer, where heat is supplied at lower temperatures (close to 40°C)
- Plant location - connection to a consumer which has a constant annual demand such as heat to an industrial plant or cooling to a data centre
- demand such as heat to an industrial plant or cooling to a data centre

The range of energy efficiency in waste incinerators is shown below in Table 2.53.

Table 2.54: Net annual average energy efficiency of waste incinerators

Net annual average energy efficiency %	
Electricity only	CHP mode (80% heat load factor)
22 – 29	68 to 76

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6.5.3 Waste incineration – Proven energy efficiency improvement techniques

A list of proven waste incineration energy efficiency improvement techniques is provided below in Table 2.54.

Table 2.55: List of proven waste incineration energy efficiency improvement techniques

	Technique title
	Energy efficiency techniques related to waste firing
a	Waste pre-treatment
b	Advanced moving grates
c	Advanced combustion control
d	Environmentally optimised combustion processes
e	High steam parameters for boilers and super-heaters
f	Efficient cleaning
	Energy efficiency techniques related to flue gases
g	Flue Gas Condensation (FGC) and component cooling
h	Reduced parasitic energy consumption through flue gas recirculation
i	Heat pumps
	Energy efficiency techniques related to energy distribution [58]
j	4th Generation Heat Networks
k	District Cooling Networks
l	Co-generation using waste tyre feedstock

A full description of each waste incineration technique and the evaluation is shown below.

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[58] It should be noted that these heat distribution techniques could apply to any WtE process which produces large quantities of surplus heat. As they apply most frequently to waste incineration plants they are included within this grouping.

2897 **6.5.4 Waste incineration techniques evaluation**

Technique Title:	Waste pre-treatment
Description	There are two main categories of waste pre-treatment techniques of relevance to energy recovery, these are homogenisation and extraction / separation[59]. Homogenisation of waste feedstock mixes the wastes received at the plant using the physical techniques (e.g. bunker mixing and sometimes shredding) in order to supply a feed with consistent combustion qualities. The main benefits achieved are the improved process stability that results, which thus allows smooth downstream process operation. Steadier steam parameters result from the boiler, which can allow for increased electricity generation. The overall energy efficiency benefits are thought to be limited but cost savings and other operational benefits may arise. Extraction/separation involves the removal of certain fractions from the waste before it is sent to the combustion chamber. Techniques range from extensive physical processes for the production of solid recovered fuels (SRF) and the blending of liquid wastes to meet specific quality criteria, to the simple spotting and removal by crane operators of large items that are not suitable for combustion, such as concrete blocks or large metal objects. The main benefits achieved are: • increased homogeneity, particularly where more elaborate pre-treatment is used (see comments above for homogeneity benefits); • removal of bulky items – thus the risks of obstruction and thus of non-scheduled shut-downs; and • the waste composition can be modified into a form which enables the use of other techniques that may improve energy efficiency or enable alternative material products to be produced (such as cement or biofuels). • ability to remove certain wastes which give rise to corrosion allowing higher steam parameters to be used which gives higher energy efficiency. Extraction, separation and homogenisation of the waste can improve the energy efficiency of the incineration plant itself. This is because these processes can significantly change the nature of the waste that is finally delivered to the incineration process, which can then allow the incineration process to be designed around a narrower input specification, and lead to optimised (but less flexible) performance. However, it is important to note that the techniques that are used in the preparation of this different fuel, themselves require energy and will result in additional emissions. Other forms of pre-treatment specifically for organic feedstocks include extrusion and hydro thermal carbonisation. These techniques reduce the moisture content of organic feedstocks through either mechanical or thermochemical means to produce a solid fuel with low

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[59] WI BREF 2006/2007

Technique Title:	**Waste pre-treatment**	
	moisture content and a high calorific value. The energy input to these processes must be balanced by the gain in energy output when they are combusted.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟧	The energy consumption of a sorting process will depend on how elaborate it is. Numerous operational benefits are provided by pre-treatment but net energy efficiency gains are likely to be relatively modest or potentially negative. The main benefit is its applicability (as described below) and the ability of pre-treatment to support energy recovery processes other than a conventional moving grate.
Applicability	🟩	Pre-treatment supports the waste hierarchy as it enables recyclable elements of the waste to be removed so that only non-recyclable waste is left for incineration. Pre-treatment supports many emerging technologies.
Exclusion criteria	No	None noted
TRL	9+	Pre-treatment of waste is a well-established and proven technique.

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Technique Title:	**Advanced combustion control**
Description	Waste incineration is a complex process which needs to be closely controlled to minimise emissions and to maximise process energy efficiency and cost efficiency. Advanced fuzzy logic combustion control systems have been implemented on a number of WtE plants in Europe to provide optimised process performance. Fuzzy logic can provide a number of benefits by tightly controlling process variation rather than just checking the process operating values. To provide a similar level of control through plant operating personnel would require a large number of experienced workers. A number of WtE plants have reported to have achieved good results through the implementation of advanced control including[60]: • Increased waste throughput and steam generation; • Increased energy efficiency (by between 1% and 2.5% where a plant is not already optimised); • Reduced consumption of reagent; and • Implementation costs should enable a payback period of under one year as the existing optimised plant control system can be utilised.

Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟧	Advanced combustion control is not able to provide a step change in combustion energy efficiency but will help to maximise the performance of older plants within the current range of 22-29% net annual average electrical efficiency.
Applicability	🟩	This technique can be retro filled with a relatively short payback time. Will be most suited to older plants which are not already using an optimised control system.
Exclusion criteria	No	None noted
TRL	9+	There are around 25 reference installation examples in the EU-28 from a number of suppliers.

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[60] Viridor Waste Management, Lakeside WtE plant, UK, 22 November 2015

Technique Title:	**Advanced moving grates**	
Description	The moving grate has been continually improved over many decades to optimise its performance[61]. Two notable developments in recent years to improve combustion efficiency and environmental performance are: • Water cooling of the grate bars to reduce excess air. With water cooling, cooling is independent of combustion so the amount of combustion air can be more carefully controlled. This enables combustion air to be adjusted for optimal combustion conditions, flue gas volumes to be reduced (which reduces plant parasitic load), higher CV waste material can be treated and heat from the cooling water can be recovered in full through the boiler steam cycle. • Individually controlled grate zones - This technique is based on the proven reverse-acting principle where the grate is divided into three drive zones which can each be controlled individually as opposed to one speed across the whole grate surface. This enables the speed at which the fuel is fed and the combustion conditions to be optimally adjusted to fluctuating waste quality. This makes it possible to agitate the fuel/the combustion residues in several zones without adversely affecting the residence time. The replacement of the grate in a WtE plant is a major outlay and is unlikely to be economic for an existing plant.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟧	Small gains in energy efficiency can be achieved which be within current expectations of a modern plant installation.
Applicability	🟧	Is applicable to most waste types but retrofitting may not be cost effective.
Exclusion criteria	No	None noted
TRL	9+	These improvements feature on many of the latest WtE incineration plant installations.

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[61] Ricardo Energy & Environment

Technique Title:	**Environmentally optimised combustion process**	
Description	A process has been developed to provide an environmentally optimised combustion process[62]. The complex combustion control system, which makes use of infra-red thermography, and the adjusted secondary air injection system ensure that the combustion process is optimized. Tests were performed at the Coburg Waste-to-Energy plant in Germany. Following this, the first commercial plant was built in Arnoldstein, Austria. Since the second half of 2004, this plant has been operating on a continuous basis. In Sendai, Japan, a further plant started operating in 2005. The developer claims that the optimised process provides: • more intense, more uniform combustion • significantly reduced CO content in the flue gas • temperature in the fuel bed in the main combustion zone approx. 100°C higher with partial sintering of the bottom ash and consequently improved burnout and less leaching of heavy metals • flue gas flow reduced by approx. 35 % • higher boiler efficiency • reduced pollutant burden at stack • reduced fly ash flow Although the technology has been commercially available for a number of years, take up has been low.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟧	Small gains in energy efficiency can be achieved which will be within the current expectations of a modern incineration plant installation.
Applicability	🟧	Is applicable to most waste types but retrofitting may not be cost effective.
Exclusion criteria	No	None noted
TRL	9+	There are a small number of plants which have been operating the environmentally optimised process for a number of years

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[62] WI BREF 2006/2007

Technique Title:	**Effective boiler cleaning**
Description	Clean boiler tubes and other heat-exchange surfaces result in better heat exchange. Where extensive fouling has been allowed to build up in a boiler, steam temperatures can fall by as much as 50°C. As a technique, effective boiler cleaning encompasses both technical and operational elements. Boiler cleaning may be carried out on-line (during boiler operation) and off-line (during boiler shut downs and maintenance periods). The dimensions of the boiler and heat exchanger design (e.g. tube spacing) influence the cleaning regime. Techniques for on-line cleaning include: • Mechanical rapping; • Soot-blowing by steam injection; • High or low pressure water spraying (mainly on the wall in the empty passes of the boiler); • Ultra-/infra- sonic cleaning; • Shot cleaning or mechanical pellet scouring; • Explosive cleaning; and • High pressured air injection (from 10 to 12 bar) with movable lances. Off-line techniques include: • Periodic manual cleaning (in general once a year in a waste incinerator); and • Chemical cleaning. In addition to these techniques, it can also be beneficial to prevent higher temperature gases (above 650 °C when fly ash is more sticky and hence more likely to adhere to surfaces they come into contact with) coming into contact with convective heat-exchange bundles by suitable boiler design such as: • Including three vertical radiant boiler passes with water walls only; and • Specifying larger furnace dimensions and hence lower gas velocities before the bundles. Effective cleaning can improve plant energy efficiency by 1.5 to 3% where low performance is being experienced[63].

Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟧	More effective cleaning can help improve the energy efficiency of a low performing boiler.
Applicability	🟩	Applicable to all boilers and cleaning systems, can normally be retrofitted.
Exclusion criteria	No	
TRL	9+	These cleaning techniques are widely practiced.

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[63] WI Bref 2006/2007

Technique Title:	**Reduced energy consumption through flue gas recirculation**
Description	Flue gas recirculation (FGR) can reduce combustion plant energy consumption as the induced draft fan size / power consumption can be reduced which is a major power consumer in a combustion plant. Boiler efficiency also increases as flue gas mixing is more effective. FGR reduces nitrogen oxides (NO_x) emissions in boilers by recirculating a portion (~25%) of the boiler flue gas back into the main combustion chamber. This process reduces the peak combustion temperature and lowers the percentage of oxygen in the combustion air/flue gas mixture, thus retarding the formation of NOx caused by high flame temperatures (thermal NOx). FGR is normally combined with an SNCR system to achieve the required ELVs. The energy and environmental benefits are: • Can reduce overall plant energy consumption; • Increases boiler efficiency; • Relatively cheap and compact solution; and • Can reduce NO_x production by 10% - 30%. Disadvantages are: • Oxidising atmosphere, so corrosion can be an issue; • Leaks from recirculation ducting can be dangerous due to low O_2 content; and • Can't reach emissions likely from the IED directive on its own so it requires.

Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟧	Increases boiler efficiency by up to 3% and reduces ID fan power consumption by 20%[64]. Overall plant energy efficiency gain from these improvements is estimated at around 0.75 % - 2%[65].
Applicability	🟧	Is not able to reduce NO_x to the required ELVs so a secondary abatement system will also be needed – this increases overall capex and reduces the attractiveness of fitting FGR.
Exclusion criteria	No	None assuming FGR is fitted with a secondary abatement process.
TRL	9+	There are a large number of FGR installations across the EU-28.

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[64] SUEZ Environmental, February 2015

[65] WI Bref 06/07

Technique Title:	**High steam parameters for boilers and super heaters**
Description	Numerous techniques have been developed to help boost the energy efficiency of conventional incineration to above 30%. Compared to fossil fuel fired LCP boilers, waste-fuelled boilers have low electrical generation efficiency. This is primarily because of the severe corrosive environment created by waste incineration which limits steam temperatures and pressures to around 425°C and 50 bar. • External superheaters - An innovative solution is to provide an external super heater which is powered by the gasification of a cleaner and more homogenous fuel such as waste wood, which is proven. This additional, cleaner heat source can raise the steam generated by the waste fired 'base plant' to temperatures over 500°C without risking early failure of super heater tubes. This technique is offered commercially, the most suitable application would be in the co-location of MSW and waste biomass waste treatment plants. • Radiant pass superheaters - A number of technology providers have fitted superheaters in the radiant or first pass area of the boiler. This is where flue gases are hottest, the radiant section of the boiler is normally lined with refractory with the boiler tubes located behind the refractory wall. As the boiler tubes do not come into direct contact with the flue gases, the energy transfer is considered to be radiant. Unprotected steel components would not be able to withstand the intense heat of this section of the boiler and would rapidly corrode. Some plants with this boiler arrangement experience superheated life of under one year. To overcome this, a radiant superheater can be fitted where it is coated with Silicone Carbide (SiC) tiles. The radiant super heater operates in combination with the conventional downstream convection superheater bundles. A radiant superheater can raise steam temperatures by between 40 and 80°C which corresponds to an increase in electrical energy efficiency of around 3%. • Utility scale power plants using biomass and fossil fuels as a feedstock commonly employ reheat of turbine steam after its first passage through the turbine to increase electrical efficiency. For this application, steam temperature is limited to 400°C, but steam pressure increases considerably. After the first passage through the high-pressure section of the turbine, the resulting steam is superheated again and subsequently used in the turbine's middle and low-pressure sections. Usually after expanding in the high pressure turbine the steam has lower pressure (typically 20 % of pressure entering) and is reheated with flue-gas in the boiler to the same temperature. Achieved benefits are increased electrical efficiency by approximately 3 percentage points to reach 30% net electrical efficiency. In order to gain maximum effect from this setup, the steam pressure has to be increased to at least 120 bar. However, with the corrosive elements present in waste fuel derived flue gases, at this temperature level there is a high risk of corrosion, even if Inconel cladding is used for boiler tube

Technique Title:	**High steam parameters for boilers and super heaters**	
	protection[66]. The Amsterdam AEB plant in the Netherlands employs a steam reheat system through an intermediate superheater and operates at steam conditions of 480°C and 130 bar[67]. The superheaters are designed to be removed easily and due to rapid corrosion need replacement around every two years. On a very large plant such as Amsterdam, this may make economic sense as the revenues from increased electrical production outweigh the cost of superheater replacement. On most WtE plants this is not the case and superheater life needs to be at least five years to replacement.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟩	High steam parameters offer year round net electrical efficiencies up to 33%. Net electrical efficiencies of 35% are being targeted by developers but have not yet been achieved.
Applicability	🟧	Such high efficiency brings both high capex and opex and would only be cost effective on the very largest plants where large amounts of power are exported.
Exclusion criteria	No	None
TRL	9	Due primarily to cost / benefit, there are only a few commercial examples of the highest steam parameters which currently provide a net electrical efficiency over 33%.

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[66] http://www.volund.dk/~/media/Downloads/Conference_papers_-_WTE/NAWTEC_16_-_High_electrical_efficiency_by_dividing_the_combustion_products.pdf
[67] Martin GmbH, London EfW conference, 2016

Technique Title:	**Flue gas condensation and component cooling**	
Description	An extremely cost-effective method of recovering energy for a district or local heating grid is by condensing the water in flue gases. The amount of energy recovered depends on the district heating water temperature. Flue Gas Condensation (FGC) is a technique to recover further energy from the flue gases. The flue gases still contain water vapour following clean-up which can be condensed to a liquid form to enable additional low grade heat to be recovered. As a rough guide, a flue gas condensation installation can increase heat energy recovery by up to 15% of furnace energy output where the recovered energy can be transferred to a district heating system[68]. There is a small decrease in electrical energy efficiency associated with this. Smaller amounts of useful heat can also be recovered from water cooled plant components which generate large amounts of waste heat such as water cooled grates and HV transformers.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟩	There will be a small impact on electrical power production from FGC (around 0.5 to 1% reduction) but where heat is exported, overall energy efficiency will increase considerably. CHP net annual average efficiency is estimated to rise from 76% to 88% with the addition of FGC for the most advanced plants.
Applicability	🟧	Full benefits of FGC will only be realised where the plant exports heat. Otherwise the energy recovered by FGC can only be used for boiler feed water pre-heating which is limited.
Exclusion criteria	No	Plume visibility may increase due to low stack gas exit temperatures - this may have a visual impact but does not impact health.
TRL	9+	The latest installations of waste incineration plants employ FGC particularly in Scandinavia.

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[68] ISWA CE Report 5, 2015

Technique Title:	**Heat pumps**	
Description	It is possible to improve energy recovery by using a heat pump installation. A compressor driven heat pump is the most widely used heat pump. It is used in cooling equipment such as air conditioning and to extract heat from ground sources. An electrical motor normally drives the heat pump, but for big installations steam turbine driven compressors can be used. In a closed-circuit, a refrigerant substance is circulated through a condenser, expander, evaporator and compressor. The compressor compresses the substance, which condenses at a higher temperature and delivers the heat to the district heating water. There the substance is forced to expand to a low pressure, causing it to evaporate and absorb heat from the water from the flue-gas condenser at a lower temperature. Thus the energy at low temperature in the water from the flue-gas condenser has been transformed to the district heating system at a higher temperature level. At typical incineration conditions, the ratio between output heat and compressor power (heat to power ratio) can be as high as 5[69]. Heat pumps are frequently used in tandem with flue gas condensation equipment. A flue gas condensation installation can increase heat energy recovery by up to 15% of furnace energy output but in tandem with a heat pump installation, this figure increases to just over 20 percent[70]. A feasibility study[71] conducted within an operational WtE plant into increasing efficiency by the use of heat pumps (combined with flue gas condensing) concluded that energy recovery for district heating increased by 9.4MWth through the use of a 2.3 MW_{el} heat pump combined with flue gas condensing; an estimated investment cost of €6 million including €3 million for the heat pump was required. Flue gas temperatures at exit were reduced from 60°C to 37°C; reductions to as low as 30°C may be possible.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟩	CHP net annual average efficiency is estimated to rise from 76% to over 88% with the addition of heat pumps in tandem with FGC for the most advanced plants.
Applicability	🟧	Full benefits will only be realised where the plant exports heat in the form of district heating or steam.
Exclusion criteria	No	
TRL	9+	Many of the latest generation of WtE incineration plants incorporate FGC and heat pumps working in tandem.

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[69] WI Bref, 2006/07

[70] ISWA CE Report 5, 2015

[71] Statkraft, Norway

2983

Technique Title:	**District Cooling**

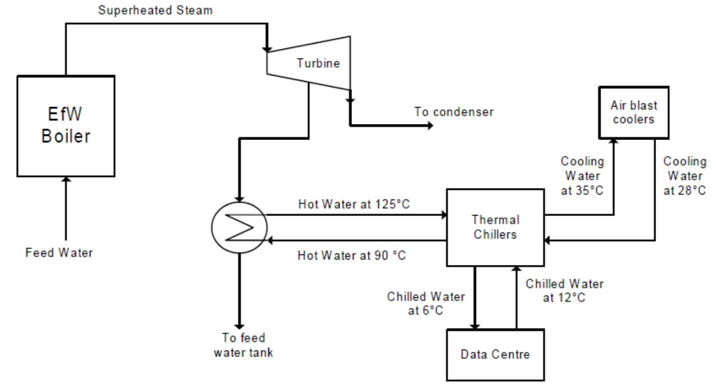
Description

This refers to the use of heat from an EfW plant to provide chilled water for air conditioning and other cooling applications. One option is to use steam from the EfW plant to drive the compressor for a vapour compression refrigeration system. However, a more commonplace option is to use lower-grade heat (e.g. low pressure steam or hot water) within an absorption refrigeration system. Absorption-based chiller systems are more widely used on account of their ability to use lower-grade heat, thereby reducing the penalty on the electrical output of the EfW plant.

The overall energy efficiency of cooling systems is less than a system delivering heat energy, particularly refrigeration absorption. The performance of the chiller system is expressed in terms of its coefficient of performance (CoP, the ratio of cooling output to heat input), steam-based absorption systems can achieve CoPs in the order of 1.2 while hot water systems achieve CoPs of 0.6. In comparison to district heating which has a net energy efficiency of 65%, district cooling energy efficiency is around 42%[72].

Backup facilities are normally required to provide for EfW supply outages. This will typically be provided electrically-powered vapour compression chiller systems.

Applications are currently limited to a small number of schemes (e.g. Districlima in Barcelona, Spain), however one area of potential growth is the provision of cooling services to data centres, which have constant and very high cooling requirements. A schematic is shown below:



Criteria	Rating	Notes
Net Annual Average Energy Efficiency	100% load	Where district cooling is linked to a consumer such as a data centre, year round cooling is required. In these cases net annual average energy efficiency is estimated at 68%, even for the most efficient systems.

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[72] Ricardo Energy & Environment

Technique Title:	**District Cooling**	
	🟥 80% load	Otherwise where cooling is assumed to be required only 80% of the year due to seasonal demand, a net annual average energy efficiency of 60% can be expected, even for the most efficient systems.
Applicability	🟧	Cooling effort requires the input of primary (electrical) energy and is therefore more highly valued than heat energy and should attract more revenue. Better annual energy efficiency is dependent on being connected to large cooling energy consumers such as hospitals or data centres. Hot climates within the EU-28 will also offer seasonal demand.
Exclusion criteria	No	None
TRL	9+	All technology is proven but uptake and examples remain limited due to commercial reasons.

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Technique Title:	**4th generation heat networks**
Description	This refers to the technological and institutional concepts to broaden the suitability of district heating and cooling networks beyond their current areas of greatest suitability (densely populated areas located within cold climates). These concepts seek to reduce the minimum heat demand density required to make a network commercially viable. This allows networks to continue to be appropriate in areas where heat demand density are lower, either through lower dwelling density or the reduced heat demand as a result of energy efficiency improvements. The four main features of 4th generation heat networks are as follows[73]: • Ability to supply low-temperature district heating for space heating and hot water. This concerns the use of heat delivery temperatures below 50°C, compared to 100° for current generations; • Ability to distribute heat in networks with low grid losses; • Ability to utilise renewable heat and recycled heat from low-temperature sources. This includes waste heat from power generation (including WtE) as well as heat from other renewable sources (e.g. geothermal and solar thermal); and • Ability to form an integral part of smart energy systems (e.g. through intelligent control of demand and supply through demand-side response and thermal storage). The deployment of 4th Generation Heat Networks would make district heating viable in a greater number of situations, increasing the potential for heat networks to be developed in areas in the vicinity of WtE plants. This would enable these plants to operate in a cogeneration mode and, as a consequence, increase their energy efficiency. In addition, the use of lower operating temperatures would enable WtE plants to supply the necessary heat with less impact on their power output, leading to higher power to heat ratios. Examples of 4th Generation Heat Networks are available however these are currently limited to small-scale networks such as the 5MWth system installed at Stadsoevers in the Netherlands. It is reported that the delivery of heat has no reduction on electricity production[74]. Hot water is delivered at 40°C and may be raised to 65% locally using heat pumps so power consumption from the grid will be required.

Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟩	Low supply temperatures means turbine electrical generation losses in the WtE plant are minimal. Where this is true, net annual average energy efficiency is estimated to rise from 76% to 82% for the most advanced plants.

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[73] Lund et al, 2014

[74] SUEZ Environment, Showcase for WtE efficiency, February 2015

Technique Title:	**4th generation heat networks**	
	🟩	Heat pumps may be required to raise water supply temperatures locally for some applications, these will require additional energy input.
Applicability	🟧	4G networks still require a local energy user but the technology will help to expand the applicability of district heating and cooling.
Exclusion criteria	No	None
TRL	9	The only operating applications to date are relatively small scale.

Technique Title:	**Co-generation using waste feedstocks**	
Description	Industries are able to use waste feedstocks for the production of heat and power in industrial boilers. The most common feedstocks for industrial boilers are homogenous feedstock such as waste tyres or waste biomass such as sawdust which are often generated on the same premises as the energy recovery system. Examples of this include: • Generation of heat for district heating peak load and back up stations. In Scandinavia, waste tyres have been used to fire plants providing additional heat into district heating systems. These systems generally do not mix tyres with other forms of waste. The vast majority of waste tyres are utilised in cement kilns for energy recovery (92%) within the EU-28 Member States as they have a high calorific value and moreover, 25% of the tyre material content is recycled into the cement clinker[75]. This leaves approximately 8% of waste tyres which are used in other forms of energy recovery outside the cement industry. • In Italy, Marangoni operates a cogeneration plant which uses waste tyres to provide both heat and power to the tyre manufacturing plant.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟧	Heat only energy efficiency will be in the normal range of around 75% of waste thermal energy input.
Applicability	🟧	The location of the site can be chosen relatively easily to suit the heat user such as in an industrial complex. Is not as effective at recycling the tyre material content as a cement kiln application.
Exclusion criteria	No	None
TRL	9+	There are a number of examples of tyre co-generation across the EU, including the two described above.

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[75] ETRMA, interview February 2016

6.5.5 Waste incineration plant techniques – Technology to watch

In addition to the proven waste incineration plant techniques discussed above, there are emerging techniques which are not currently ready for widespread deployment but have the potential to increase the energy recovered from waste in the future. These are listed as follows in Table 2.55.

Table 2.56: List of emerging waste incineration plant energy efficiency improvement techniques

#	Technique title
a	High steam parameters (emerging techniques)
b	Use of the mass and energy balance method to measure waste biogenic content
c	Heat and power decoupling through heat pumps
d	Use of Ilmenite as a bed material in a circulating fluidised bed (CFB) reactor
E	Organic Rankine Cycle turbine for low grade heat utilisation

A full description of each emerging waste incineration plant energy efficiency improvement technique and the evaluation is shown below.

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2999 3000 6.5.6 Waste incineration plant improvement energy efficiency techniques evaluation

Technique Title:	High steam parameters (emerging techniques)
Description	Numerous techniques are also emerging to help boost the energy efficiency of conventional incineration to above 30%. Compared to fossil fuel fired LCP boilers, waste-fuelled boilers have low electrical generation efficiency. This is primarily because of the severe corrosive environment created by waste incineration which limits steam temperatures and pressures to around 425°C and 50 bar. • In combustion of MSW, the major parts of the corrosive species are released in the first part of the combustion grate and thereby in the front of the furnace. The rear parts of the grate are characterised by a burnout of a relatively clean char, thereby releasing relatively clean combustion products which are much less corrosive. This phenomenon can be exploited to split up the flue gases from the grate into two or more fractions, one of which exhibits high heat flux and a low chlorine concentration. That fraction could then be used in a high temperature superheater to increase the steam temperature and thereby the electrical efficiency of waste fired power plants. In order to ensure the separation of the two flue gas fractions in the furnace, a water cooled membrane wall is installed above the middle of the combustion grate. When the two streams of flue gases enter the post combustion chamber, they are then mixed by the secondary air system for final burnout. The basic idea of the concept is to use all the advantages of a modern waste fired power plant combined with an integrated final superheater. The final superheating increases the steam data to for example 500°C and 80 bar and results in an increase in electrical efficiency of 3 percentage points over the baseline steam conditions of 400°C and 45 bar. The overall objective is to achieve a net electrical efficiency of between 27% and 33%, depending on the design of the cooling system for the condenser. The concept has been trialled in a modified operational waste plant in Denmark, the results have shown the concept is feasible[76]. • Sulphur recirculation is an emerging technology that is able to reduce high temperature corrosion in superheaters. Alternatively, it can increase electricity generation at waste incineration installations, if superheater steam pressure and temperature are raised. In the process, sulphur from a wet flue gas cleaning system is returned to the furnace. The recirculated sulphur raises the SO_2 concentration in the furnace and reduces the chlorine / sulphur ratio in deposits and ashes, and the environment becomes less

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[76] Venice 2014, Fifth International Symposium on Energy from Biomass and Waste, http://www.volund.dk/~/media/Downloads/Brochures_-_WTE/BWV_NextBAT_technology.pdf

Technique Title:	**High steam parameters (emerging techniques)**	
	corrosive. Furthermore, the formation of dioxin is reduced, and the proportion of sulphates in the effluent water discharged from the wet flue gas cleaning is reduced. The process works in two stages. First sulphur dioxide is removed from the flue gases in the wet flue gas cleaning stage. The removed sulphur compounds are then sprayed into the boiler through nozzles with a surrounding carrier gas. In this way the level of sulphur in the water is raised. Thus each sulphur atom passes through the furnace several times. The process has been demonstrated in Gothenburg, Sweden. Dioxin samples, impactor measurements, deposit probe measurements, ash samples and 1,000-hour corrosion measurements were taken in full-scale trials with and without sulphur recirculation. With sulphur recirculation, corrosion rates in the superheaters for all materials evaluated (16Mo3, Sanicro 28 and Inconel 625) were reduced by more than 50 percent compared to the reference case[77].	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟩	High steam parameters offer year round net electrical efficiencies up to 33%.
Applicability	🟧	Traditionally, high steam parameters have been restricted to the largest plants due to the high costs of corrosion. It is too early to determine whether these techniques will lower the costs of operating WtE plants at higher temperatures and pressures.
Exclusion criteria	No	None
TRL	7	Small scale tests in commercial WtE facilities have been conducted with encouraging results.

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[77] Sulphur Recirculation for Low-corrosion Waste-to-Energy, available at: www.iswa.org/uploads/tx_iswaknowledgebase/Andersson.pdf

Technique Title:	**Use of the mass and energy balance method to measure waste biogenic content**
Description	Municipal Solid Waste is an extremely heterogeneous feedstock, and unless properly managed and mixed before firing can cause significant variation in combustion control and pollution abatement. Use of the mass and energy balance method to measure waste biogenic content is a measurement technique developed by the Technical University of Vienna[78]. It was originally designed to provide a method to determine biogenic content in order to facilitate carbon accounting and access to renewable benefit schemes. It is an approved method for reporting and obtaining applicable renewable energy support credits. The balance method is based on the mathematical solution of theoretical balance equations for materials, substances and energy together with plant data such as flue gas volume, steam production and bottom ash mass. It utilises operational plant data and can provide a continuous output of results. The method outputs biogenic content (ratio of green energy), fossil CO_2 emissions and calorific value. These results, properly analysed and interpreted, can assist operators with improving both the reception and mixing of waste prior to firing and the operation of combustion and pollution control systems, effectively providing an improved conversion efficiency and reduced operational costs. For example, reducing the variations in fuel quality leads to improved efficiency of combustion and therefore greater energy generation per tonne of waste.

Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟧	Some improvement in energy efficiency will be obtained through more stable process conditions, this improvement is expected to be within the boundaries of current expected performance.
Applicability	🟩	The technique can be applied to most waste incineration plants relatively easily.
Exclusion criteria	No	None
TRL	8	A number of trials have been conducted in operational WtE plants across the EU-28.

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[78] BIOMA - software for balance method, available at: http://iwr.tuwien.ac.at/ressourcen/downloads/bioma.html

Technique Title:	**Heat and power decoupling through heat pumps**
Description	Heat pumps can be used to decouple heat and power production in a waste fired plant district heating application[79]. An innovative design has been proposed whereby to maximise turbine power generation efficiency, no steam bleeds are provided to tap off steam for district heating energy and a condensing turbine set up for maximum power recovery is specified. The resulting turbine condensate is relatively cool so an array of heat pumps are used to increase the temperature of the turbine condensate from (approx. 40°C) to a temperature more suitable for district heating purposes (70°C). To enable this, electrical energy can be drawn from the grid when there is an excess of electrical energy available (e.g. peaks from wind power and otherwise the grid is not accepting power) to be transformed into heat energy within the district heating system. When there is no demand for heat, the heat pumps would not operate and only power export from the plant would occur. In this way heat and power can be produced independently according to demand and is a way of storing grid excess power generating capacity. Although the system is highly flexible, it is anticipated that overall energy efficiency will be low compared to a state of the art heat enabled combustion plant with a condensing turbine. A small scale operational example of a similar proposal is located in Drammen, Norway. The heat pump energy source is deep water (rather than WtE turbine condensate), but in a similar way, the scheme employs heat pumps to extract energy from a low temperature source to produce district heating water at a suitable temperature.

Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟧	The main benefit of this technique is flexibility, not energy efficiency. Although an overall analysis has not been performed it is thought unlikely that drawing excess grid power to operate heat pumps is more energy efficient than using surplus heat from a turbine bleed point.
Applicability	🟥	Applicability is restricted to a small number of district heating schemes.
Exclusion criteria	No	None
TRL	9	There are one or two small scale examples in Norway and Russia.

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[79] Ricardo Energy & Environment

<table>
<tr><th>Technique Title:</th><th colspan="2">Use of Ilmenite as a bed material in a circulating fluidised bed (CFB) reactor</th></tr>
<tr><td>Description</td><td colspan="2">A new combustion concept has been developed by Chalmers University of Technology in Göteburg, Sweden, developed from steel industry applications[80].
The principal of the new concept is to replace the inert silica sand bed material conventionally used in a CFB reactor with a metal oxide, Ilmenite. Ilmenite is the titanium-iron oxide mineral with the formula $FeTiO_3$.
Silica sand has one main purpose in a CFB reactor and that is to act as a heat carrier. Where metal oxide is used as a bed material, as well as carrying heat, the metal oxide carries oxygen for the combustion reaction and absorbs fly ash.
The benefits of this concept is that it is enable the input of up to 4% more heat energy to the boiler and with better oxygen distribution, there is considerably less CO in stack emissions.
The concept has gone from lab scale in 2013 to a commercial scale demonstrator at the Handeloverket waste treatment plant in Sweden. This plant has a thermal input of 75MW.
The cost of Ilmentite will be higher than silica sand, no data has been provided on the operational costs to replenish the Ilmenite bed material.</td></tr>
<tr><td>Criteria</td><td>Rating</td><td>Notes</td></tr>
<tr><td>Net Annual Average Energy Efficiency</td><td>🟧</td><td>With the input of up to 4% more heat energy to the boiler, a small gain in plant energy output may be realised.</td></tr>
<tr><td>Applicability</td><td>🟧</td><td>CFB technology is not widely applied to the larger waste streams such as household waste but may treat prepared waste derived fuels such as SRF and is well suited to waste wood. Therefore applicability is somewhat limited.</td></tr>
<tr><td>Exclusion criteria</td><td>No</td><td>None</td></tr>
<tr><td>TRL</td><td>9</td><td>Has been demonstrated at commercial scale in Sweden.</td></tr>
</table>

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[80] Chalmers University of Technology, London EfW conference, 2016

Technique Title:	**Organic Rankine Cycle (ORC) turbine for low grade heat utilisation**	
Description	Waste heat is often of low temperature quality and it can be difficult to efficiently utilise the heat contained. In these cases the ORC turbine can bring some additional benefit to raise the overall plant efficiency. The ORC turbine utilises this otherwise wasted energy and converts it into power. The Organic Rankine Cycle is named for its use of a working fluid with a boiling point occurring at a lower temperature than water / steam which is used in conventional Rankine Cycle turbine applications. The fluid allows Rankine Cycle heat recovery from lower temperature sources such as incinerator waste heat. The working fluid used is normally a refrigerant fluid which must conform to the requirements of the Montreal Protocol (non-ozone depleting). The working principle of the ORC turbine is the same as that of a conventional turbine; the working fluid is evaporated using (low grade) heat from the incineration process and passes through the turbine at pressure to produce mechanical energy. The fluid exits the turbine to a condenser heat exchanger where it is finally re-condensed. Because of the low working temperatures of the ORC, heat transfer inefficiencies are highly prejudicial and result in low overall energy efficiency.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟥	Net average annual electrical efficiency is estimated to be around 19%[81]. This is mitigated by the fact that the ORC turbine can utilise low grade heat which would otherwise be emitted to atmosphere.
Applicability	🟩	Most WtE plants produce waste low grade heat which could be used to provide an energy source for an Organic Rankine Cycle turbine.
Exclusion criteria	No	None
TRL	9	There are many commercial examples in operation but are uncommon in WtE plants.

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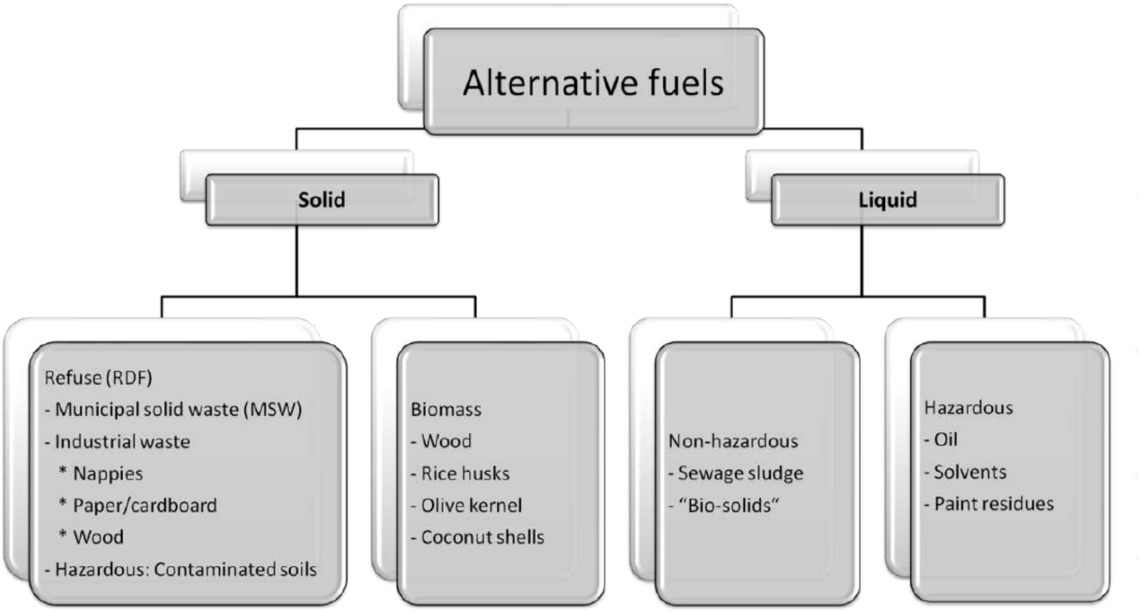
[81] http://www.energy.siemens.com/mx/pool/hq/power-generation/steam-turbines/downloads/brochure-orc-organic-rankine-cycle-technology_EN.pdf

6.6 CL plants: Cement and Lime production plants

This section considers techniques where waste is used as an alternative fuel (AF) in the production of cement and lime (CL). Of these three products, the production of cement using waste as an alternative fuel makes up the majority of plant capacity.

6.6.1 Overview of waste in CL applications

Co-firing of waste (such as tyres, oils and solvents, plastics, textiles and paper wastes) and biomass wastes (such as animal meal, sewage sludge, waste wood, sawdust) with fossil fuels is commonplace as an alternative fuel (AF) for firing CL plants. These AFs are shown in the illustration below:



Cement kilns (and other CL plants) require very large quantities of thermal energy so the use of waste derived alternative fuels can help reduce high energy costs and environmental impact. Cement kilns have highly exacting standards for waste derived fuels to ensure the cement product will:

(a) Conform to specification (as residual contamination from the waste fuel will be trapped in the cement clinker product) and

(b) To guarantee that all cement plant emissions to air stay within permitted IED levels. The unique process and energy requirements of the cement industry enable use of fuel mixes that would not be suitable for many other industries.

A second advantage of AF utilisation in cement kilns is that approximately 25% of the waste material content is recycled into production of the clinker, bringing together both energy recovery and material recycling (which is one step higher on the waste hierarchy). There is no residual bottom ash produced from the waste incineration process.

6.6.2 Energy efficiency

The highest energy efficiency CL plants are characterised by the following features:

- The type of cement kiln - a modern cyclone pre-heater plant with pre-calciner normally has higher energy efficiency than a long wet kiln or a kiln equipped with a grate pre-heater.
- Additional features to utilise waste heat for useful purposes such as drying of residues.

The range of energy efficiency in cement kilns varies between 65% and 85%[82] and is not subject to a heat load factor as cement manufacture is continuous.

6.6.3 CL plants – Proven improvement techniques and evaluation

Technique Title:	**Conversion of waste heat to power in cement kiln applications**
Description	Due to high electric energy consumption regarding the clinker burning process Rohrdorfer Zement implemented a waste heat recovery system to reduce the total amount of energy consumption and increase energy efficiency at their plant in Rohrdorf, Germany. In order to use the waste heat of the rotary kiln (the denitrification plant and the clinker cooler exhaust air) a waste heat power generation (WHPG) plant was installed in 2012. There steam is generated which is used for driving a turbine and produce electricity. The gained operational experience with the waste heat recovery plant has shown that the total power demand of Rohrdorf cement plant can be reduced by 4.5 to 5.5 MW_{el} with the new installation. As a consequence this increase in energy efficiency decreases the annual CO_2-emmisions by 16.000 tons per year – based on the German power mix. Although the technical feasibility of the technique was proven, the project was not commercially viable without government financial support. A similar project was implemented in Romania at the Fienei cement production plant where again a WHPG project was technically successful but again had significant government financial support and a long payback period. A WHPG can be retrofitted to an existing cement kiln facility where space permits. The **Organic Rankine Cycle** turbine may also be utilised in cement kiln applications to recover energy from low grade waste heat, this is discussed under waste incineration (outlet 2).

Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟩	As a CHP installation, energy efficiency achieved will be high at over 75%. The pre-treatment required to make SRF suitable for cement kiln applications will require energy input.
Applicability	🟩	The ability to retrofit waste heat energy recovery has been proven.

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[82] Cembureau, 11 April 2016

Technique Title:		**Conversion of waste heat to power in cement kiln applications**
Exclusion criteria	No	None
TRL	9+	At least two examples of this technique have been cited by Cembureau, which were commissioned within the past 5 years[83].

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[83] Cembureau, April 2016

6.6.4 CL plant energy efficiency improvement techniques – Technology to watch

In addition to the proven CL plant techniques discussed above, there are emerging techniques which are not currently ready for widespread deployment but have the potential to increase the energy recovered from waste in the future. These are listed as follows in Table 2.56:

Table 2.57: List of emerging CL plant energy efficiency improvement techniques

#	Technique title
a	Use of waste derived syngas as fuel for cement kiln burners
b	Hydrogen extracted from waste syngas as fuel for cement kiln burners

A full description of emerging CL plant energy efficiency technique and the evaluation is shown below.

6.6.5 Cement kiln emerging energy efficiency improvement techniques evaluation

Technique Title:	**Use of waste derived syngas as fuel for cement kiln burners**	
Description	Syngas from the gasification of more homogeneous waste streams may be used as an alternative fuel in cement kiln applications[84]. Syngas can be produced by pre-treating the waste prior to gasification. The syngas would need to be cooled and cleaned before being used as a fuel in a cement kiln, either in the main burner or in the calciner. The NCV of the syngas is much lower than natural gas (around 10MJ/Kg in comparison to natural gas at 47MJ/Kg). Cement manufactures are however considering this route, as it would allow them to: • Reduce chlorine content in the fuel by cleaning up the syngas prior to combustion. Manufacturers can then use high chlorine wastes, which were previously not acceptable but have a better (higher) gate fee. • Allow for use of AF on the main burner in very short kilns rather than in the pre calciner only with SRF fuel. • Have a mixed power generator / AF syngas fuel in kiln operation. Manufacturers could use part of the syngas to run reciprocating engines. Syngas from alternative fuels as a fuel has been used in clinker production since the mid-1990's at Rüddersdorf in Germany where a mix of RDF, wood and other fuels is gasified to produce a syngas[85]. The plant is still operating in 2016.	
Criteria	Rating	Notes
Net Annual Average Energy	🟧	The pre-treatment and gasification process will consume energy, no assessment has been made as to whether this will be more energy intensive than conventional SRF production processes. The syngas

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[84] Cembureau, April 2016

[85] http://www.gasification-syngas.org/resources/world-gasification-database/rdersdorf-fuel-gas-plant/

Technique Title:	**Use of waste derived syngas as fuel for cement kiln burners**	
Efficiency	🟧	produced will be of relatively low NCV in comparison to SRF.
Applicability	🟧	The gasification of mixed waste is unproven, only homogeneous waste streams could be used, although more difficult to treat high chlorine wastes may come into scope.
Exclusion criteria	No	
TRL	9	One commercial example has been noted.

Technique Title:	**Hydrogen extracted from waste syngas as fuel for cement kiln burners**	
Description	ECRA[86] considered the possibility of using hydrogen from syngas as a low carbon fuel to fire cement kiln burners where the syngas was derived from fossil fuels. The same syngas could equally be derived from the gasification or pyrolysis of waste. This technology is unlikely to be adopted as there are a large number of drawbacks: • As syngas could only be used for clinker burning, CO_2 emissions originating from the energy intensive calcination of limestone will remain unaffected. • Due to its explosive properties, hydrogen could not be used in existing cement kilns, but could be utilised after dilution with other gaseous fuels or inert gases like nitrogen or steam. • Furthermore, the combustion and radiation properties of hydrogen differ significantly from those of the fuels being used today in the cement industry meaning that - even if handling problems could be solved - the clinker burning process would have to be significantly modified and would necessitate new developments in burner and combustion technology. There are no accurate estimations of costs but due to the aforementioned technical barriers, costs are unlikely to be irrelevant.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟧	Energy efficiency is unknown due to low TRL but is unlikely to be better than existing processes due to the complex syngas generation process.
Applicability	🟧	This technique could not be retrofitted.
Exclusion criteria	Possible	The use of hydrogen may be incompatible with DSEAR / ATEX restrictions.
TRL	3	The technique only exists as a concept.

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[86] ECRA, Development of state of the art techniques in cement manufacturing, February 2009

6.7 Anaerobic Digestion

This section considers Anaerobic Digestion (AD) processes to produce biogas from a waste feedstock.

6.7.1 Overview of Anaerobic Digestion

AD can be used to treat both mixed household MSW, typically as part of a mechanical and biological treatment process (MBT) or source segregated household and commercial organic waste which may contain animal by-product (ABP) materials such as food waste. The process is operated under controlled conditions with the anaerobic digestion being undertaken within sealed tanks. This is undertaken on a scale ranging from small farm based AD plants to large industrial AD plants. The range of technology also varies from simple systems to very sophisticated and highly mechanised and automated systems.

The process has not always been deployed successfully for use in the treatment of 'black bag' mixed household MSW; emerging techniques for anaerobic digestion of the organic fraction of MSW are considered in Emerging AD Techniques.

Organic waste will be received at the site, will be inspected for compliance against waste codes and then treated to remove packaging and / or prepare it for the digestion process. Successful pre-treatment systems exist for household bio-waste and packaged food waste from stores. For wet AD processes, water will be added to create a slurry. The feedstock is anaerobically digested in a tank over a period of time which generated biogas. The biogas is captured and used to produce renewable electricity or heat. Following the completion of the digestion process, the digestate may be stored to allow stabilisation before being used either in liquid or dewatered form as a fertiliser or soil improver on agricultural land or land restoration. The digestate is mechanically screened to the required size grade for final use and to remove any residual physical contamination such as plastic which was not removed at the pre-treatment stage.

For a conventional AD plant, electrical output based on the energy content of the organic feedstock is 18%[87].

A common variation on wet AD processes are dry AD processes. The dry AD process is operated under controlled conditions with the anaerobic digestion being undertaken either in a 'tunnel' or 'box'. Due to the more capital equipment intensive nature of the dry AD process it is typically undertaken at scales in excess of 25,000 tpa. The process normally uses specialised machinery including shredders and screens make the process more efficient, introduce greater process control and reduce costs through greater mechanisation. Waste is commonly fed into the digestion vessels using walking floors. The biogas and digestate produced by dry AD processes is used in the same way as for wet AD systems.

6.7.2 Energy efficiency

The energy output from an Anaerobic Digestion plant depends to a great extent on the biomethane potential of the feedstock. High energy feedstocks such as glucose or kitchen waste will have much higher energy yields than feedstocks such as grass cuttings. Those organic feedstocks with the highest biomethane potential have ten times more energy potential than the lowest biomethane potential feedstocks such as sewage sludge.

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[87] ISWA CE Report 5, pg. 25

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In terms of converting the available feedstock input energy into heat and power, the following characteristics distinguish a high efficiency plant[88]:

- The overall net annual average energy efficiency of a mesophilic AD plant which operates at around 40°C will be better than a thermophilic AD plant which operates at higher temperatures of 70°C, even though more biogas will be produced at higher temperatures.
- The highest waste energy utilisation can usually be obtained where the heat generated by the combustion of the biogas can be supplied continuously to a heat consumer in combination with electricity generation. However the adoption of this output is very dependent on plant location and the availability of a long term user for the supplied energy.
- Where co-generation is not practical, high energy efficiency can be obtained by upgrading the biogas produced to biomethane and utilising this for transport fuels or by injecting the biomethane directly into the grid.
- From an operational point of view, the sooner that biowaste can be inputted into an AD plant, the better the energy yield will be fresh matter has a higher biomethane potential.
- Basic anaerobic digestion leaves much of the energy potential of the feedstock untapped. Advanced AD systems (which use a variety of techniques as described below) to extract more biomethane and residual energy from the waste will offer higher overall energy efficiency.
- Where AD digestate can be spread to land in lieu of manufactured fertilisers and the organic waste nutrient content is recycled, significant GHG savings can be made. Fertilisers derived from fossil fuel sources are energy intensive in their manufacture and when applied to land emit nitrous oxide which as a greenhouse gas is almost 300 times more potent than CO_2 in its warming potential.

The range of energy efficiency (based on the organic waste energy input) in AD plants is shown below in Table 2.57[89].

Table 2.58: Net annual average efficiency of AD processes

Net annual average efficiency %		
Electricity only	**CHP mode (80% heat load factor)**	**Gas network / liquefaction to biofuel**
16 – 24		> 40

Energy efficiency may be further increased by linked AD with other processes as described under emerging AD and biological techniques.

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[88] EBA Interview, May 2016

[89] ISWA CE Report 5, 2015

6.7.3 Anaerobic Digestion – Proven improvement techniques

A list of proven AD techniques is provided below in Table 2.58.

Table 2.59: List of proven Anaerobic Digestion improvement techniques

#	Technique title
a	AD with Gas to Grid
b	Sewage Sludge Advanced AD - THP
c	Sewage Sludge Advanced AD - ITHP
d	Vertical flow dry AD
e	Micro Anaerobic Digestion
f	AD with liquefaction of biogas to liquefied biomethane (LBM)
g	AD with compression of biogas to compressed biomethane (CBM)
h	AD with biomethane LBM slip streaming

A full description of each proven AD techniques and the evaluation is shown below.

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6.7.4 Anaerobic digestion techniques evaluation

Technique Title:	**Micro Anaerobic Digestion (AD)**	
Description	A containerised micro AD solution has been developed for treating organic waste which enables food waste to be processed next to producers and the outputs of power, heat and digestate to be made available. The technology is most applicable to larger commercial and municipal organisations producing kitchen food waste, used cooking oil, spent alcoholic drinks and garden waste. An 8kW combined heat and power unit (CHP) processes an average of 105 m3/day of biogas providing approximately 57MWh of electricity per annum. Through the generation of energy and the elimination of waste disposal costs, the unit is claimed to produce net energy revenues of around Eur 20,000 per annum.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟥	Net annual average energy efficiency for an AD CHP unit is estimated at 36%[90] where 80% of the heat output is utilised annually. This would increase to 41% if all the heat output was used which may be possible depending on the particular installation such as a large hotel or hospital with a large constant demand for hot water. As the unit can be used locally, there is a reduction in the energy used to transport the feedstock and distribute the energy outputs which may be significant and therefore makes the technique somewhat more attractive.
Applicability	🟧	A degree of energy efficiency is only possible where both heat and power can be utilised by the food waste producer. Can be used in any location and as a containerised solution is easy to retrofit. Restricted to organic wastes.
Exclusion criteria	No	None
TRL	9+	There are a number of operating examples around the EU 28.

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[90] ISWA CE report 5, pg. 25 - CHP heat output of 25% of feedstock energy input is adjusted to 20% for annual average consumption at 80% load factor plus 16% net electrical power output.

<table>
<tr><th>Technique Title:</th><th colspan="2">Sewage Sludge advanced AD - THP</th></tr>
<tr><td>Description</td><td colspan="2">The Thermal Hydrolysis Process (THP) first dewaters the incoming sludge stream to 16.5% Dry Solids (DS) before the dried biomass enters a pressure vessel. Steam is added to the pressure vessel at roughly 12bar, degrading the biomass before high rate AD occurs. Conventional sewage sludge digestion achieves volatile solids destruction (VSD) of 40-50% which yields 300-350m^3 of biogas per tonne of Dry Solids (DS) which translates to a 40% mass reduction.
Typical sites with THP achieve 60% VSD and produce 450m^3 biomass per tonne of dry solids, representing approximately a 30% increase in gross energy output. However, insufficient high grade heat is produced by the process through CHP to meet all the THP process steam requirements, resulting in additional fuel (natural gas) being needed.
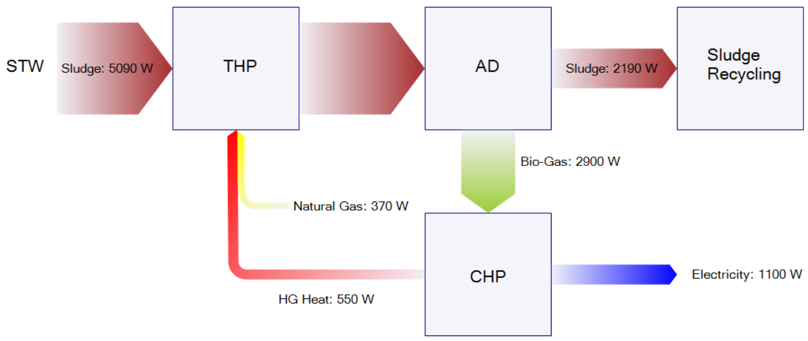
Image courtesy of DECC
There are a number of large THP plants successfully operating in Europe. The investment required in a new THP plant is quite significant. A number of basic AD plants have been upgraded to THP plants with commercially acceptable payback periods.</td></tr>
<tr><td>Criteria</td><td>Rating</td><td>Notes</td></tr>
<tr><td>Net Annual Average Energy Efficiency</td><td>🟧</td><td>Net annual electrical efficiency is estimated at 22%[91] which is 6% higher than for conventional sewage sludge AD (16%).</td></tr>
<tr><td>Applicability</td><td>🟧</td><td>An existing sewage sludge plant can be economically upgraded to a more advanced THP facility but payback times will be medium scale.</td></tr>
<tr><td>Exclusion criteria</td><td>No</td><td>None</td></tr>
<tr><td>TRL</td><td>9+</td><td>There are a large number of THP plants which are operating successfully across the EU.</td></tr>
</table>

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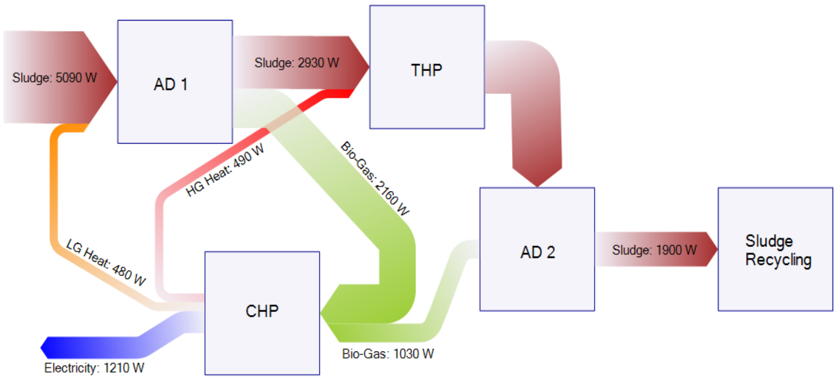
[91] UK Department for Energy and Climate Change

Technique Title:	**Sewage Sludge advanced AD - iTHP**
Description	The Intermediate Thermal Hydrolysis Process (ITHP) locates THP in the middle of two digestion stages. In the first stage of digestion, a conventional digester generates biogas and forms a residual sludge from the readily available organic matter. Digested and concentrated sludge is then hydrolysed in a plant which reduces its size. In the second stage digester, which operates at a higher loading rate, more biogas is produced. The total biogas production of both phases is approximately 500m³/tDS, representing an 11% improvement on conventional THP. Final VSD is around 65%. Increased energy production and reduced THP size results in the process being self-sufficient in heat when combined with a CHP unit.  Image courtesy of DECC There are a number of large iTHP plants successfully operating in Europe. The investment required in a new THP plant is quite significant. A number of basic AD plants have been upgraded to THP plants with commercially acceptable payback periods.

Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟧	Net annual energy efficiency is estimated at 23%[92] which is 7% higher than for conventional sewage sludge AD (16%)
Applicability	🟧	An existing sewage sludge plant can be economically upgraded to a more advanced THP facility but payback times will be medium scale.
Exclusion criteria	No	None
TRL	9+	There are a large number of THP plants which are operating successfully across the EU.

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[92] UK Department for Energy and Climate Change

<table>
<tr><th colspan="2">Technique Title:</th><th>Vertical flow dry AD</th></tr>
<tr><td>Description</td><td colspan="2">A technique has been developed to enable a relatively wide range of organic wastes to be digested as it uses gravity to enable the flow of material through the process (as opposed to more common horizontal systems where the organic material needs to be wetter to enable it to flow through the process).

Organic waste is pre-treated to reduce its size to below 40mm, this enhances the quality of the end product and may reduce energy consumption and abrasion. The pre-treated fraction is mixed with digested residue from the digester at a mixing ratio of typically 1 ton of feedstock to 6-8 ton of digested residue. Small amounts of steam are added to raise the temperature to 35-50^{o}C for mesophilic operation and 50-55^{o}C for thermophilic operation. The resulting material is then pumped to the top of the digester through feeding tubes and is pushed out onto the top of the digesting mass in the digester. Once the material enters the main body of the digester it takes a couple of days to reach the bottom, descending by gravity only. No mixing equipment or gas injection is needed in the inner part of the digester, with biogas rising and exiting through the roof, glowing towards the gas storage and treatment.

The process can operate at a total solids concentration of up to 45-50% going into the digester, with total solids concentrations up to 45% for the digested residues. These high concentrating operating conditions are due to the mass moving in a vertical direction. Dry AD systems with a horizontal mass through the digester require a higher level of flow-ability, with solids concentrations that are roughly 10-20% lower. The higher concentration of solids allows for higher biogas production rates of up to 10m^3 of biogas per m^3 of active digester volume per day. The process also requires no additional water input.</td></tr>
<tr><td>Criteria</td><td>Rating</td><td>Notes</td></tr>
<tr><td>Net Annual Average Energy Efficiency</td><td>🟥</td><td>The vertical flow dry AD system does not have a net electrical energy efficiency which is superior to wet AD (~16%).</td></tr>
<tr><td>Applicability</td><td>🟧</td><td>The main advantage of dry AD is its ability to take a wider range of feedstocks than wet AD, such as green waste which would otherwise by composted with no energy recovery.</td></tr>
<tr><td>Exclusion criteria</td><td>No</td><td></td></tr>
<tr><td>TRL</td><td>9+</td><td>There are a very large number of dry AD plants across the EU-28.</td></tr>
</table>

Technique Title:	**AD with biogas injection to grid (GtG)**
Description	Biomethane produced from the anaerobic digestion (AD) of food waste and sewage sludge has the same composition as fossil-fuel derived methane and therefore is suitable for use as a substitute for natural gas via a gas to grid network. In an AD process, micro-organisms in the feedstock break down organic waste in the absence of oxygen to produce methane rich biogas. The biogas is upgraded to biomethane and impurities such as CO_2 and H_2S are removed by scrubbers and activated carbon filters. A small volume of propane is added to the methane to ensure the gas has the same natural gas quality, and then fed in to the local gas distribution network. The 'upgrading' of biogas to meet quality standards necessary to permit the injection of gas into the natural gas network involves the following principal stages. • removal of hydrogen sulphide and carbon dioxide from the biogas • enrichment using propane to meet calorific value and Wobbe Index requirements • compression to meet network pressure requirements A number of separation technologies exist for the removal of carbon dioxide but the most commonly used a membrane separation and 'water wash'. In 2014 the number of operating biomethane production plants stood at almost 400, with concentrations of plants in Germany, the Netherlands and Sweden. The overall energy efficiency of the AD - GtG process is 41% based on the energy content of the organic waste input versus biomethane injected to grid[93]. The true carbon savings will depend on the final use of the gas by the consumer. The European Biogas Association predicts that GtG will be a more popular route of delivering biomethane to consumers than other more energy intensive routes such as liquefaction and compression / trailer transport[94].

Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟩	With the biomethane supplied to the grid, seasonal fluctuations are mostly eliminated. 41% net average annual energy efficiency is possible.
Applicability	🟩	It is considered that biogas plants and suitable biogas injection points can be reasonably co-located. The biomethane can also be used in LCP applications.
Exclusion criteria	No	None
TRL	9+	There are now a large number of GtG installations across the EU.

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[93] ISWA CE Report 5, pg. 25

[94] EBA interview, February 2016

Technique Title:	**AD with liquefaction of biogas to liquefied biomethane (LBM)**
Description	Prior to liquefaction, biogas generated from organic waste sources is upgraded to biomethane which involves removing the carbon dioxide and trace contaminant gases. A number of technologies can be used to remove carbon dioxide such as membrane separation, chemical scrubbing, water scrubbing and pressure swing adsorption. In liquefaction, the amount of moisture has to be carefully controlled otherwise ice will form during cooling which will block the flow of the gas produced. The resulting biomethane product (which is equivalent to natural gas) is converted to a liquid via a cooling process (normally using liquid nitrogen) and stored in large cryogenic insulated tanks prior to transportation. Due to the high capital costs, liquefaction of biomethane is only commercially viable at a relatively large scale; production of 20 tonnes/day of LBM requires roughly 1900m^3/hr from an AD plant. Liquefaction is therefore more suited to larger AD sites. An advantage of liquefaction is that the product can be effectively carried by road tanker, so there are few restrictions on the location of the biogas plant. A disadvantage is that the cooling process is energy intensive so the energy efficiency of biogas conversion to LBM is lower than for gas to grid (GtG) injection (but GtG is slightly more constrained by location).

Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟨	Although all the biogas energy output is recovered without seasonal variation, plant parasitic electrical consumption is high. It is estimated that liquefaction takes 10% of the waste input energy in comparison to 5% for GtG upgrading and pressurising[95]. Net annual average energy efficiency is therefore approximately 36%.
Applicability	🟩	LBM has the advantage that the plant location is wholly flexible and the liquefied biomethane can be transported by tanker to the required location for use.
Exclusion criteria	No	None
TRL	9+	There are many LBM applications operating, particularly in Scandinavia.

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[95] ISWA CE Report 5, Table 5

3195

Technique Title:	**AD with compression of biogas to compressed biomethane (CBM)**
Description	As per GtG, prior to compression, biogas generated from organic waste sources is upgraded to biomethane which involves removing the carbon dioxide and trace contaminant gases. A number of technologies can be used to remove carbon dioxide such as membrane separation, chemical scrubbing, water scrubbing and pressure swing adsorption. The resulting biomethane product (which is equivalent to natural gas) is compressed to 250bar for easier storage and distribution and can then be dispensed as CBM by: • Directly supply through a dispensing station on the biogas producing site; or • Transfer to a trailer which transport the gas off site. To be commercially viable, a typically sized plant would need to be circa 10 tonnes of CBM per day. The option of an onsite filling station is likely to be dictated by the plant location. With commercial vehicles in particular, operators will not wish to make detours to refuel and dispensing stations would need to be close to main transport routes or depots. This could be an issue for remote landfill sites in particular. For transportation by trailer, a round trip of 100km is considered economically viable from the biogas production site to the CBM dispensing station. The amount of CBM product that can be transported on one 44 tonne truck load is quite low as the high pressures require very robust trailer construction; for a steel trailer around 5 tonnes can be transported. For more costly carbon fibre trailers (which have lower net weight than steel trailers) around 10 tonnes of CBM can be transported in one load. The compression process to 250 bar for transport applications is energy intensive so the energy efficiency of biogas conversion to CBM is lower than for (lower pressure) gas to grid (GtG) injection (but GtG is more constrained by location).

Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟩	All of the biogas energy output is recovered without seasonal variation. Upgrading and pressurising will require slightly more energy input than GtG as 250bar pressure has to be met rather than 10bar for grid injection. The marginal effort for the extra compression from 10bar to 250bar is not however very significant[96].
Applicability	🟩	CBM has the advantage that the plant location is wholly flexible and the liquefied biomethane can be transported by tanker to the required location for use.
Exclusion criteria	No	None
TRL	9+	There are many CBM applications operating within the EU-28.

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[96] Ricardo Energy & Environment

6.7.5 Anaerobic digestion and biological techniques – Technology to watch

In addition to the proven AD techniques discussed above, there are emerging AD and biological techniques which are not currently ready for widespread deployment but have the potential to increase the energy recovered from waste in the future. These are listed as follows in Table 2.59:

Table 2.60: List of emerging AD and biological improvement techniques

#	Technique title
a	Sewage Sludge Advanced AD with Advanced Energy Recovery (Gasification)
b	Sewage Sludge Advanced AD with Advanced Energy Recovery (Pyrolysis)
c	Enzymatic conversion of waste to biogas
d	Fermentation of packaged food waste
e	Bio-thermic digestion

A full description of each emerging AD technique and the evaluation is shown below.

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6.7.6 AD and biological emerging techniques evaluation

<table>
<tr><th>Technique Title:</th><th colspan="2">Sewage Sludge Advanced AD with Advanced Energy Recovery (Pyrolysis)</th></tr>
<tr><td>Description</td><td colspan="2">A similar process to sewage sludge advanced AD with advanced energy recovery (gasification) with pyrolysis replacing gasification as the final stage of energy recovery from the sewage sludge stream. Before the pyrolysis process, a dryer produces a solid fuel feed using biomass from either a THP sludge treatment process (as shown below) or an ITHP process. The pyrolysis process has been shown to reduce the mass of the biomass solids by 90%, liberating a pyrolysis gas with a high CV of 11 - 20MJ/m^3 and leaving very little residual product for disposal.

The fuel gas from the pyrolysis process is then utilised in a second gas engine (CHP2). CHP1 is a gas engine running on biogas from the AD process. Both CHP units produce heat which is split into a high and low grade. The high grade heat (200°C) is used to raise steam for THP and low grade heat used for sludge drying. Unlike other THP processes there is no requirement for support fuel due to the combination of CHP units raising all of the steam for THP. Pyrolysis shows the most potential as a form of advanced energy recovery.
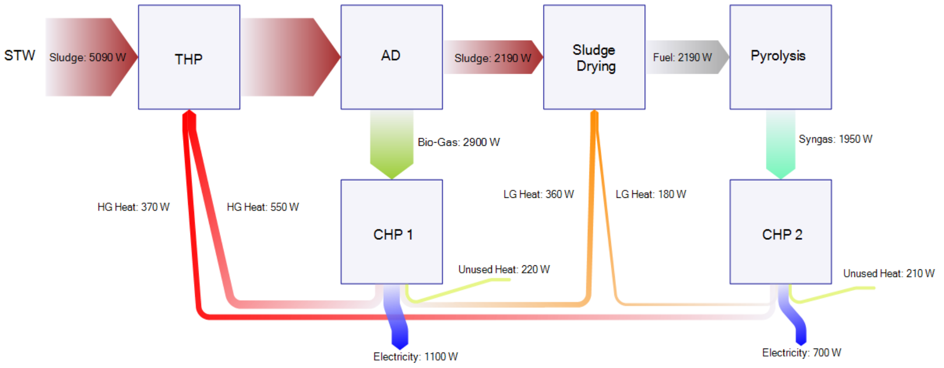
Image courtesy of DECC</td></tr>
<tr><td>Criteria</td><td>Rating</td><td>Notes</td></tr>
<tr><td>Net Annual Average Energy Efficiency</td><td>🟩</td><td>Net annual energy efficiency is estimated at 35%[97] which is 19% higher than for conventional sewage sludge AD (16%).</td></tr>
<tr><td>Applicability</td><td>🟩</td><td>An existing sewage sludge plant can be upgraded to a more advanced facility</td></tr>
<tr><td>Exclusion criteria</td><td>No</td><td>None</td></tr>
<tr><td>TRL</td><td>6</td><td>The concept has been demonstrated</td></tr>
</table>

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[97] UK Department for Energy and Climate Change (DECC)

Technique Title:	**Sewage Sludge Advanced AD with Advanced Energy Recovery (Gasification)**
Description	A similar process to sewage sludge advanced AD with advanced energy recovery (pyrolysis), with gasification replacing pyrolysis as the final stage of energy recovery from the sewage sludge stream. To sustain the conversion process, partial combustion of the syngas occurs during gasification of the dried biomass feedstock. The resulting syngas CV is lower than for pyrolysis, typically in the range of 4-8MJ/m^3 as nitrogen is introduced with air, diluting the syngas and some fuel. The gasification process is therefore not as efficient as the pyrolysis processes, with a 20% reduction in conversion efficiencies being expected between the two approaches.

Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟧	Net annual energy efficiency is estimated at 28%[98] which is 12% higher than for conventional sewage sludge AD (16%)
Applicability	🟩	An existing sewage sludge plant can be upgraded to a more advanced facility
Exclusion criteria	No	None
TRL	6	The concept has been demonstrated

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[98] UK Department for Energy and Climate Change

Technique Title:	**Fermentation of packaged food waste**
Description	Anaerobic digestion (AD) of food waste is often made more difficult by the presence of contaminants including food packaging. Large quantities of food waste are disposed of by large retailers which are frequently sold in packaging containing plastics or aluminium both of which are non-digestible and will either clog digesters or appear as contamination in the digestate product. Contamination in the digestate product is strictly controlled and where limits are exceeded, applying the digestate to land will not be permitted. An alternative to AD of suitable types of food waste (particularly food waste which is not segregated from packaging) is to use fermentation[99]. The Fraunhofer Institute for Interfacial Engineering and Biotechnology in Germany has been operating a pilot plant since 2012 to develop the technique. Food waste contains a lot of water and has a very low lignocellulose content making it highly suitable for rapid fermentation. The food waste and packaging feedstock are milled down to a maximum of 2 or 3 cm or until it forms a pumpable slurry. The slurry is fermented to release biogas from the organic fraction, non-organics such as plastic are separated out from the residual sludge. The fermentation process takes two or three days which is a much shorter processing timeframe than AD which is typically 2 to 3 weeks. A key challenge for researchers is maintaining constant environmental conditions for the micro-organisms to perform effectively. To achieve this a feedstock management system has been devised where food waste is held in several storage tanks, where a number of parameters are automatically calculated - including the pH value. The management system determines exactly how many litres of waste from which containers should be mixed together. In addition to using the biogas for conversion to biofuel, the contaminant fractions could be used for energy recovery and the fermentation sludge may be treated to recovery further biomethane.

Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟧	Not known due to low TRL.
Applicability	🟩	Fermentation offers a potential solution to some of the practical difficulties experienced with AD such as contamination. Packaging contamination is a very common issue.
Exclusion criteria	No	None
TRL	6	The technique is at the early stages of development (pilot plant).

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[99] https://waste-management-world.com/a/rapid-food-waste-fermentation-developed-at-german-university

Technique Title:	**Enzymatic conversion of waste to biogas**
Description	A process has been developed which involves solubilising the biodegradable organic fraction of unsorted MSW with enzymes. The resulting treated waste may then be refined to produce high purity recyclates, RDF products as well as a bio-liquid suitable for anaerobic digestion. Anaerobic digestion of the bio-liquid produces a biogas which could then be used for energy recovery through conventional gas engines or injected to the gas network. The developer has been testing the technology at a demonstration plant since 2009 and is currently in the process of building a commercial scale plant[100]. The net energy gain of the process may be limited as the processing system (including the various mechanical treatment steps, water treatment plant and enzyme reactor) may have significant energy requirements.

Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟧	Not known, but may be less than for conventional AD as the biogas produced needs to also power a highly complex plant.
Applicability	🟩	The process can take in a wide range of feedstocks including MSW.
Exclusion criteria	No	None
TRL	8	The first commercial plant will begin operation in 2017, which will fully establish the performance of the process on actual MSW with all its inherent variation.

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[100] http://www.mrw.co.uk/news/worlds-first-bio-plant-set-for-uk/10003182.article

Technique Title:	**Bio-Thermic digestion (BTD)**	
Description	A process has been developed that will use extremophile bacteria harvested from deep ocean volcanos to reduce organic content in trade and black bag waste[101]. The lowest temperature theses bacteria will operate is 90 degrees centigrade. Because extremophile bacteria live in extreme conditions they are very voracious and consume the organic load very quickly. As the bacteria consume the organic load they produce two by products, which is heat and water. The process heat by product helps limit the operating costs of the BTD process but some additional heat energy will need to be added. The main advantage of the technique (which is aerobic) is much reduced digestion time (2 to 3 days). The process is designed to treat organic rich sorting residues from the recycling processes which may otherwise go straight to landfill. The process digests the organic content from trommel fines, and removes odour and with a resulting discharge of water and an inert powdery residue. Trials in 2016 demonstrated that the organic content in the treated trommel fines was reduced by 87%. The resulting 13% residue is biologically inert and with a dry NCV of around 12MJ/Kg, it could be utilised as a waste derived fuel or added to Biomass fuel.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟥	No information is available on the net energy efficiency of the process or whether indeed biogas can be recovered as the process is aerobic. However the higher operating temperatures would suggest energy efficiency is lower than for conventional AD.
Applicability	🟥	BTD is a niche process for treating organic trommel fines and other organic wastes. Therefore applicability is somewhat limited in scale.
Exclusion criteria	No	
TRL	8	Some demonstration scale trials have been completed during the past 8 years of research and a commercial scale plant is in development.

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[101] https://waste-management-world.com/a/advetec-bio-thermic-digester-to-cut-recycling-firms-costs-by-400k-pa

6.8 Other waste to energy plants

This section considers other proven waste to energy techniques which make up the remainder of WtE capacity in the EU-28 outside the four main outlets.

6.8.1 Overview of other waste to energy plants

The majority of waste is treated in one of the four outlets already examined, but there are a range of 'other' WtE plants which treat other waste streams. The overview below provides a summary of the main 'Other' proven techniques.

Hazardous waste thermal treatment

Chemicals, solvents, clinical waste and other hazardous materials are commonly incinerated in high temperature processes in accordance with IED requirements (1100°C with a minimum residence time of 2 seconds). In the case of low NCV hazardous wastes, significant quantities of support fuel may be required to achieve this temperature. Where the waste disposal site also has a heat demand, a simple waste heat boiler is sometimes used to recover a proportion of the thermal energy from the combustion process.

The most popular medium for hazardous waste incineration is within a rotating kiln. More advanced processes for the plasma gasification of small quantities of hazardous waste are also established with around 80 reference plants worldwide. Following gasification, hazardous compounds are broken down by the intense heat of the plasma arc, with the residues trapped in a stable vitrified clinker which can be recycled.

Hazardous Waste Europe (HWE) have stated that energy recovery is of secondary importance to hazardous waste 'destruction' and as a result, there is not currently much research or development being conducted into new forms of energy conversion form hazardous waste[102].

Waste vegetable oils and fats conversion to biodiesel

There are a number of well-established processes for the conversion of waste vegetable oils and fats to biodiesel:

Used cooking oil (UCO) is composed of purified oils and fats used by restaurants, catering facilities and kitchens to cook food for human consumption. UCO is a waste that is no longer fit for purpose and can subsequently be used as a feedstock for the production of biofuels. Pre-treatment of UCO is required to remove any solid matter followed by free fatty acid treatment. Transesterification then takes place, converting the UCO to short chain alcohols suitable for the production of biodiesel. A restriction to this technique is that this form of Fatty Acid Methyl Ester (FAME) biodiesel can only be blended in small quantities with conventional biodiesel, European diesel standard (EN590) restricts biodiesel content to a maximum of 7% by weight. The same technique can be used to produce biofuel from tallow (animal fats).

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[102] HWE interview, April 2016

6.8.2 Other WtE plants – Proven improvement techniques and evaluation

Technique Title:	**Hydro treatment of oils and fats to produce biodiesel (Hydro-treated vegetable oil)**
Description	An alternative to the traditional Fatty Acid Methyl Ester process for converting UCO and animal fat waste streams to biodiesel is to refine these feedstocks into biodiesel using hydrogen. One of the benefits of biodiesel produced in this way is that it can be used directly in engines and fuel distribution systems (rather than as a drop in fuel, blended with fossil diesel) as its composition is similar to fossil alternatives[103]. The hydro treatment process consists of three main process steps / reactors: 1) Catalytic hydro treatment 2) Stripping 3) Isomerisation This process is a continuous process during which the feedstock flows from one reactor to the next without intermediate storage. The reactors are fixed bed reactors specially designed to withstand high pressure and temperatures needed for the process. Process conditions are: Pressure : min. 30 bar Temperature : min. 265°C Finland has also stated that over 1.6m tonnes of biodiesel was produced in 2015 using this technique. Biodiesel has the advantage that it provides lower NO_x emissions than conventional fossil diesel and can therefore assist with improving air quality in urban areas.

Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟩	The precise net annual energy efficiency has not been made publically available but is known to be well in excess of 40%.
Applicability	🟥	The process is not location dependent, but waste oils and fats are a relatively small waste stream.
Exclusion criteria	No	
TRL	9+	There are at least five commercial scale operational plants in Europe.

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[103] Finish Ministry of the Environment, April 2016

6.8.3 Other WtE plants – Technology to watch

In addition to the 'Other' proven WtE processes discussed above, there are emerging techniques which are not currently ready for widespread deployment but have the potential to increase the energy recovered from waste in the future. These are listed as follows in Table 2.60.

Table 2.61: List of other emerging WtE improvement techniques

#	Technique title
Advanced thermal treatment	
a	Bubbling Fluidised Bed Gasifier
b	Two Stage Combustion
c	Two Stage Combustion with Plasma
d	High Efficiency CFB Gasification
e	Plasma Gasification
f	Direct Melting Systems
g	High Temperature Gasification
h	Combined Pyrolysis and Gasification
i	Slow Pyrolysis
j	Flash Pyrolysis
k	Pyrolysis of Waste Tyres
l	Pyrolysis of Paper Sludge
m	Gas turbines
Biofuels from waste	
a	Waste Plastics to Diesel
b	Bioethanol from MSW
c	Bioethanol from organic wastes and residues
d	Gasification with syngas methanation and conversion to biomethane
e	Direct liquefaction

6.8.4 Overview of other emerging WtE techniques

Pyrolysis

Pyrolysis is the thermal degradation or decomposition (thermolysis) of organic materials by heat (and some inorganic materials such as tyres), without combustion, in either the complete absence of oxygen or where it is so limited that gasification does not occur to any appreciable extent. Conventional pyrolysis takes place at temperatures between 400-900°C and products include syngas, liquid and solid char. Liquid product is also known as pyrolysis oil, olefin, or bio-oil when processing biomass. Utilising pyrolysis for waste treatment is currently less well developed than gasification although there are some examples of these systems being installed.

Pyrolysis is a mature technology in terms of its application to coal, peat and liquid fossil fuels, however there are limited examples in its application to waste derived fuels. There is some experience of slow pyrolysis of MSW, but these still tend to be in development stages, and there are several examples of project failures. Successful examples of pyrolysis tend to be those plants using homogenous waste streams such as tyres and wood chip. There are different configurations of pyrolysis equipment, including fluidised bed, moving bed and rotating cone.

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The design of the pyrolysis process will impact on the characteristics of the process outputs. For example, slow pyrolysis will produce charcoal, oil and gas, whereas fast pyrolysis is designed to maximise the production of pyrolysis oils. The pyrolysis process requires the input of energy to sustain pyrolysis process (equivalent to 20-25% of input energy). Whilst gasification systems can be designed to release some of the energy in the feedstock to sustain the gasification process, Pyrolysis generally needs energy from an external source to sustain the process.

Gasification

Gasification is the thermal breakdown/partial oxidation of waste under a controlled oxygen atmosphere (the oxygen content is lower than necessary for combustion). The waste reacts chemically with steam or air at a high temperature (>750°C). The process is sustained by the heat generated by the partial combustion of the feedstock. The syngas (primarily consisting of CO and H2) produced by gasification has a lower calorific value than pyrolysis gas and is dependent upon the gasification process. The tar levels in the syngas are lower than for pyrolysis gas but depend on the actual gasification technology. Potential syngas uses are the same as for pyrolysis.

Successful examples of gasification also tend to be those plants using homogenous waste streams such as tyres and wood chip; a large MSW gasification plant in the UK was abandoned in 2016 following over 2 years of effort to complete the commissioning process.

Plasma gasification

Plasma gasification is the term that applies to a range of technologies that involve the use of a plasma torch or arc. Plasma is an electrically conductive gas, such as nitrogen or argon, which is heated by an electrical current to very high temperatures. The reaction takes place within a chamber connected to a plasma torch, which is refractory lined to withstand the high temperatures produced by the plasma torch.

The plasma torch can be applied directly to the feedstock, or to the syngas produced by a proceeding gasification process. Plasma gasification operates at temperatures as high as 7,000°C, resulting in rapid chemical reactions to break down the feedstock into gases. Inorganic materials are melted into a liquid slag, which is cooled into a solid.

The higher temperatures ensure that the syngas produced by a plasma process is cleaner than conventional combustion, as the higher temperatures allow for the breakdown of tars. Whilst the syngas can be used for energy utilisation, the plasma process itself has a high electric consumption. Syngas can be utilised to generate electricity via boilers, gas turbines or engines. Plasma gasification is a complex and expensive process and the technology is not considered proven yet. Significant energy input is required. Syngas cleaning is complex.

Plasma pyrolysis

Plasma pyrolysis is a process for converting high calorific wastes, typically plastics, in to a syngas be means of thermal plasma. The process uses temperatures up to 6000° in an oxygen-starved environment to decompose input plastic waste into a syngas, consisting of CO, H2 and small amount of higher hydrocarbons.

Catalytic direct liquefaction

The catalytic direct liquefaction process is one in which solid waste is converted into liquid carbohydrates in a single-stage process using catalysts. The resulting liquids have fuel-like properties that can be used as a diesel substitute.

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Thermal depolymerization

Thermal depolymerization (TDP) is a depolymerization process using hydrous pyrolysis for the reduction of complex organic materials (usually waste products of various sorts, often biomass and plastic) into light crude oil. Materials are subjected to high temperatures and pressure in the presence of water, resulting in a hydrous pyrolysis process. The high pressure and heat work to produce crude hydrocarbons and solid minerals which are then separated by distillation and oil refining techniques.

Hydrothermal carbonisation

The hydrothermal carbonisation process uses a combination of heat and pressure to chemically convert biowaste in to a carbon dense material which typically has a high energy value. The process is suitable for the pre-treatment of both wet and dry biomass waste prior to energy recovery, including agricultural biowaste, municipal bio-wastes, waste wood, and sewage sludge.

A full description of emerging other WtE technique and the evaluation is shown below.

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6.8.5 Other WtE emerging techniques evaluation

Technique Title:	**Bubbling Fluidised Bed Gasification**	
Description	This is a gasification technology based on a bubbling fluidized bed reactor. The bubbling fluidised bed reactor enables flexibility in the types of waste that can be processed, because it achieves a better mixture between inert and combustible material due to its high heat transfer index, and because it reaches high heating speeds. Temperatures within the reactor reach in excess of 800ºC. The fluidisation air is supplied at the bottom of the reactor. The technique also uses mineral catalysts to accelerate the decomposition reactions in combustible materials, improving performance. Syngas leaves the reactor via a series of cyclones which remove particles in the gas stream. A further thermochemical treatment stage reduces tars in the gas. The syngas gas leaves the reactor chamber at a temperature of around 600ºC and in a second stage, part of its thermal energy is transferred to a heat recovery circuit that supplies other sections of the plant.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟩	The technology is claimed to be able to deliver higher electric performance than other alternative technologies (from 26% to 34%)[104]. However, as the technology is at demonstration scale, no independently verified data is yet available from commercial operations. The pre-treatment required to make the waste suitable for gasification will require energy input.
Applicability	🟨	Reasonable flexibility on waste types.
Exclusion criteria	No	None
TRL	8	There are a number of small scale (up to 5MW) demonstration plants operating throughout Europe on biomass or waste.

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[104] EfW London Conference 2015, EQTEC

Technique Title:	**Two Stage Combustion**	
Description	Gasification sometimes consists of a two-stage combustion process, whereby thermal conversion is carried out in two stages: • Stage one: gasification of waste in to a syngas takes place in a primary chamber. • Stage two: The syngas is oxidised at high temperature in a secondary chamber. Some of the facilities have been in operation for 10 years, but it is notable that most of the facilities are designed with relatively low steam parameters with no power output (only heat export), require waste pre-treatment, and experience lower availability compared to moving grate fired plant. Where power is generated, net electrical efficiency is around 20% which is lower than conventional combustion due to the relatively low steam conditions (20 bar, 350°C)[105]. The waste is first shredded and then fed into a primary gasification chamber, where it is used to produce a syngas. This syngas is transferred to a secondary high temperature oxidation chamber where it is fully combusted under tightly controlled conditions which results in very low emissions – this is the primary advantage of the technique. The resulting heat energy is used to produce steam, which can be used to supply renewable heat and/or generate renewable electricity.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟥 🟩	For power only, electrical efficiency is lower than conventional combustion. For heat only applications, net annual energy efficiency of 80% is achievable and has been commercially demonstrated in Norway. The pre-treatment required to make the waste suitable for gasification will require energy input.
Applicability	🟩	Independent of location, able to treat most wastes subject to pre-treatment requirements. There are higher subsidies for advanced thermal treatment in some Member States.
Exclusion criteria	No	None
TRL	9	Several examples of plants across Europe. Plant performance with power export is considered much less well proven than for heat only which is considered proven.

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[105] ISWA, Alternative Waste Conversion Technologies, January 2013

Technique Title:	**Two stage combustion with Plasma**	
Description	This technique involves a two stage combustion process which combines a gasification stage with a second plasma stage, i.e. the gasification of waste and biomass followed by the post-treatment of gasification products with plasma. Waste requires pre-treatment such as shredding and the removal of metals and inert waste and mixed to ensure a homogenous fuel to optimise the process. The prepared fuel is fed in to the gasification stage where it is converted to a syngas. The syngas obtained can be used for chemical applications or for electricity production.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟩	The net electrical efficiency of such a system is stated as being able to reach 35-40%[106]. However, no independently verified data is available from commercial operations. Efficiency is also improved if heat is recovered. The pre-treatment required to make the waste suitable for gasification will require energy input.
Applicability	🟧	Independent of location, can be used on wide range of waste streams.
Exclusion criteria	None	None
TRL	8	There is a commercial scale demonstration plant in France with others in development.

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[106] Performance analysis of RDF gasification in a two stage fluidized bed–plasma process, 2015, M. Materazzi et al.

Technique Title:	**High Efficiency Circulating Fluidised Bed Gasification**
Description	This technique is used for treating Solid Recovered Fuel (SRF). The SRF is conveyed in to Circulating Fluidised Bed (CFC) reactors. The gasifiers contain a medium such as hot sand and limestone that is fluidised with air blown from the bottom of the gasifier. The SRF is mixed with the fluidised bed at a temperature of 900°C. The fuel will not burn as there is insufficient oxygen, but instead is broken down into a gas. The hot gases rise to the top of the gasifier and then into a cooling system where the gas temperature falls to 400°C. The resulting gas is treated so that it can be considered equal to natural gas in terms of its purity and can be used in a boiler or other recovery applications. Efficient gas cleaning results in reduced levels of corrosion in the boiler. Therefore, the steam temperature and pressure are high, and can provide highly efficient electricity generation. As well as stand-alone waste plants, the system also offers the potential to convert or co-fire fossil fuel powered boilers, where the syngas produced has end of waste status. Co-firing of biomass waste could replace up to 40% of coal energy input, please refer also to this techniques as applied to Combustion Plant outlets[107].

Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟩	If heat and power are recovered, 90% overall energy efficiency can be achieved. In power only mode electrical efficiency will be high also. The pre-treatment and sorting required to make the waste suitable for gasification will require energy input.
Applicability	🟩	High – the technique can be used as a stand-alone waste plant and to convert / co-fire fossil fuel fired boilers.
Exclusion criteria	No	None
TRL	9	Commercial scale facilities are in operation.

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[107] Fichtner Consulting Engineers – Valmet Gasification Of Waste Technology Review – November 2015

Technique Title:	**Plasma Gasification**	
Description	Plasma gasification technology can be used to convert a wide range of waste streams in to syngas, including municipal solid waste, hazardous wastes and sewage sludge. Plasma gas is created by combining electricity and air to form a plasma torch. The process typically combines gasification and plasma technologies. The plasma gas reaches very high temperatures, 5000 - 8000 °C, and is then directed into a gasifier chamber. The gasifier is starved of oxygen, and so instead of combusting, heat from the plasma breaks the feedstock down into elements like hydrogen and simple compounds like carbon monoxide and water. The organic components from the waste are converted into syngas while the inorganic components such as glass/ metals are melted and converted into an inert slag which may be sold as an aggregate. Quantities of slag and syngas cleaning residues produced are dependent upon the input waste composition. The syngas produced in the plasma gasification process can be converted into electricity through gas turbines or reciprocating engines, heat and steam, and liquid fuels. In most cases, and when MSW is the feedstock, syngas clean-up will include the removal of particulates, acid gases and heavy metals.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟥	The technique is claimed to be able to achieve between 25% and 33% net electrical efficiency. The pre-treatment required to make the waste suitable for gasification will require energy input. However, no independently verified data is available from commercial operations. ISWA[108] estimated that overall net electrical efficiency is below 20%.
Applicability	🟧	Some flexibility on waste types, subject to pre-treatment. Application to MSW has not been proven.
Exclusion criteria	No	None
TRL	8	Technology has historically been used for the destruction of hazardous wastes, however there are a number of small scale commercial plants in Europe which are used for energy recovery. A developer has recently reported to have abandoned the commissioning of a large plasma gasification facility with significant financial losses.

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[108] ISWA, Alternative Waste Conversion Technologies, January 2013

Technique Title:	**Direct Melting Systems**	
Description	The direct melting system (DMS) will typically consist of a waste charging system, a gasifier, a combustion chamber, a boiler and a flue gas cleaning system. One of the reported advantages of the DMS process is that no pre-treatment of waste is required, unlike in other gasification technologies, such as a fluidised bed gasifier. The high temperature gasification means that the technology is suited to a variety of wastes. The principle of the process is the treatment of waste is a fixed bed gasifier. Coke or limestone is added at 5-10%. Waste is loaded from above together with the coke. The combustion in the lower part of the furnace (300-400°C) provides the energy for the subsequent gasification. Thermal decomposition takes place at 300-1000°C. Combustion occurs at 1000-1700°C, with melting finally taking place in the melting zone at 1700-1800°C. The syngas is drawn off at the top of the reactor, and is typically combusted in a separate combustion chamber and power generated in a steam turbine.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟥	The addition of support fuel is also required in some cases, otherwise pre-treatment of the waste is required to make it suitable for gasification; this will require energy input. Gross efficiency of the plant is 23%, at 400°C and 40 bar, net efficiency is estimated to be well below 20%[109].
Applicability	🟩	No pre-treatment of waste is required with some forms of direct melting systems, not considered to be location dependent.
Exclusion criteria	No	None
TRL	9+	There are a large number of direct melting plants in Japan / Korea so the technique is well proven. Much progress has been made on improving energy efficiency but is still lower than conventional combustion.

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[109] ISWA, Alternative Waste Conversion Technologies, January 2013

Technique Title:	**High Temperature Gasification**	
Description	High temperature gasification occurs at a temperature up to 2,000 °C. The high gasification temperature is achieved by partial combustion with the addition of pure oxygen and natural gas. Metals and most minerals melt at this temperature, and are quenched in water. The solidified iron is recycled, while the mineral fraction is used as synthetic gravel. The heat energy in the hot syngas is quenched away, and hereby lost, in a water bath and then passed through a scrubber based gas cleaning system. The syngas produced is primarily used the syngas in a steam boiler and to a minor extent as input for gas engines. The main reason of the limited usage in a gas engine is due to significant costs of cleaning the syngas to a quality suitable for gas engines.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟥	Limited operational data but ISWA estimated net energy efficiency at below 20%[110].
Applicability	🟥	Advantages for use a vitrification as opposed to recovery of energy from waste. Not commercially or technically proven in Europe.
Exclusion criteria	Yes	Reported high costs and technical challenges.
TRL	8	Widely demonstrated in Japan, but waste destruction and not energy recovery is the main priority, for example some plants are used to vitrify slag from WtE facilities. A developer abandoned the operation of a large facility in Germany in 2010 after 5 years of difficult operation with significant financial losses.

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[110] ISWA, Alternative Waste Conversion Technologies, January 2013

Technique Title:	**Combined pyrolysis and gasification**
Description	This technique uses a combination of pyrolysis and gasification to process a Refuse Derived Fuel (RDF)[111]. The RDF is first conveyed in to a pyrolysis reactor, where in the absence of oxygen the RDF is heated and converted to a syngas and a carbon-rich char. The char is fed in to a gasification reactor where it is heated using high-temperature steam with the controlled addition of oxygen. This converts the char into further gases. The gases from both the pyrolysis and gasification processes are combined. The high temperature gas can be used to provide heat to pyrolysis stage and to a conventional steam boiler. Some process have been designed to accept a wide range of wastes from various processes, including MSW, auto shredder residue, industrial waste, medical waste, electronic waste, and oil and sewage sludge.

Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟥	No operational data available to determine this. The pre-treatment required to make the waste suitable for the process will require energy input.
Applicability	🟧	Reasonable flexibility on waste types subject to pre-treatment. Modular and scalable.
Exclusion criteria	No	None
TRL	9	This technology is being used in several fully operational plants at a commercial scale. However, it has been reported that the facilities using variations of this technique have all experienced operating difficulties.

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[111] IEA Task 36 UK Workshop EfW Next Generation, 2014

Technique Title:	**Slow Pyrolysis**	
Description	A criteria used to distinguish between different types of pyrolysis is the residence time of gas within the reactor. Slow pyrolysis takes place at medium to high temperatures and the longer residence times allow for the composition of liquid or solid reaction products. Char production through slow pyrolysis of waste wood and other biomass has been demonstrated. Finely diced waste is pyrolysed in either in a screw conveyor or reactor vessel that is indirectly heated. The slower heating rate favours char and liquid production over gas. The properties of the reaction products will depend on the waste composition. Processes taking a waste feedstock are considered unlikely to produce a solid char product, rather to use char to produce additional energy for parasitic supply (e.g. for heat to dry waste) or dispose of char residue to landfill.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟥	Limited operational data available to determine this.
Applicability	🟥	Mainly applicable to wood waste and other forms of biomass.
Exclusion criteria	Yes	Limited examples available.
TRL	6	The slow pyrolysis process is innovative in its conversion of the char for use in agriculture but is currently at the early stages of development.

Technique Title:	**Flash pyrolysis**
Description	A criteria used to distinguish between different types of pyrolysis is the residence time of gas within the reactor. When input materials are rapidly heated, the process is called flash (or fast) pyrolysis. A higher yield of liquid products can be achieved, particularly where lower temperatures are used. Waste is injected into a fluidised bed of inert material operating at 500°C. The size of the fuel and the heat transfer characteristics of the fluid bed ensure a very fast heating rate which maximises the production of vapour. The vapour is subsequently condensed as a liquid that contains approximately 70% of the energy value of the waste feedstock. The by-product char and gas is used in part to provide heat to drive the process. The liquid fuel has been successfully used to fire boilers and kilns. Trials have been undertaken in reciprocating engines and gas turbines. Excess char can be sold as a product for activated carbon manufacture or reducing agent in metal production. The char can also be used as fuel either on its own or as a slurry with the pyrolysis liquids. The main use for fast pyrolysis processes at present is the manufacture of speciality chemicals and food additives although this is expected to change to energy use when further plants are developed. Other fuels include whole tree chips from short rotation coppice, wood waste, and agricultural residues such as straw.

Technique Title:	**Flash pyrolysis**	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟥	Limited operational data to confirm energy efficiency.
Applicability	🟥	Mainly applicable to wood waste and other forms of biomass.
Exclusion criteria	Yes	Limited examples available.
TRL	5	Flash pyrolysis of waste has been in development for several decades at laboratory scale but has not progressed.

Technique Title:	**Pyrolysis of waste tyres**	
Description	A number of facilities have been developed for the pyrolysis of waste tyres[112]. Pyrolysis of tyres generates pyrolysis oil, char and syngas. The pyrolysis oil can be further processed in to a fuel oil, and the syngas can be combusted to generate heat and/or power. The char can be recycled in to carbon black which is a raw material in tyre production. However, there are challenges in the achieving the quality requirements. The economics of some of these plants have not proved attractive and many have closed after 5 to 7 years of operation. There are currently only a few waste tyre pyrolysis plants in operation at an industrial scale in Europe. There are also plants in Japan. The technology pyrolyses rubber granules from tyres in the absence of oxygen at temperatures between 350-700°C. The technique developer claims that the residual carbon black char meets the highest quality standards and does not contain toxic or carcinogenic components in any significant concentration.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟥	Limited operational data to confirm energy efficiency.
Applicability	🟥	Specific to waste tyres only but is a significant mono waste stream.
Exclusion criteria	No	None
TRL	9	Although the process is well understood, the results have not been as expected, particularly with regard to recycling of the char as a raw material in tyre manufacture.

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[112] ERTMA, 2016

<table>
<tr><th>Technique Title:</th><th colspan="2">Pyrolysis of paper sludge</th></tr>
<tr><td>Description</td><td colspan="2">High temperature pyrolysis is being developed to pyrolyse paper sludge to produce 2nd generation biofuels and minerals including calcium carbonate and kaolinite. The technology is currently at pilot scale.
With a homogeneous feedstock, the pyrolysis process may be more successful than for other feedstocks trialled[113].</td></tr>
<tr><td>Criteria</td><td>Rating</td><td>Notes</td></tr>
<tr><td>Net Annual Average Energy Efficiency</td><td>🟥</td><td>Unknown due to early stages of development.</td></tr>
<tr><td>Applicability</td><td>🟧</td><td>Applicable to paper sludge only but this is a significant mono waste stream.</td></tr>
<tr><td>Exclusion criteria</td><td>No</td><td>None</td></tr>
<tr><td>TRL</td><td>6</td><td>The process has been demonstrated at a very small scale.</td></tr>
</table>

<table>
<tr><th>Technique Title:</th><th colspan="2">Gas turbines</th></tr>
<tr><td>Description</td><td colspan="2">In an Integrated Gasification Combined Cycle (IGCC) process, syngas can be combusted in gas turbines to generate electricity. Gas turbines used for this process are similar to those that have been specially adapted for use with syngas which in these plants are similar to natural gas combined-cycle gas turbines but will have been specially adapted for use with syngas. This is primarily due to the higher levels of hydrogen found in syngas.
In an IGSS power plant, the gasification process will typically consist of one or more gas turbines and a steam turbine. The cleaned and conditioned syngas will be combusted in the gas turbine to generate electricity, with excess heat from the gas turbine being used as steam in a steam turbine to generate further power. There are examples of gas turbines being used with syngas, but work is ongoing to further develop this technology.</td></tr>
<tr><td>Criteria</td><td>Rating</td><td>Notes</td></tr>
<tr><td>Net Annual Average Energy Efficiency</td><td>🟧</td><td>The gas turbine could in theory provide higher energy efficiency than a steam turbine, but so far has not been proven to work on syngas.</td></tr>
<tr><td>Applicability</td><td>🟧</td><td>Potential to be retrofitted in some instances, but the quality and cleanliness of the syngas used will be critical to its successful operation.</td></tr>
<tr><td>Exclusion criteria</td><td>No</td><td>None</td></tr>
</table>

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[113] CEPI, interview February 2016

Technique Title:	**Gas turbines**	
TRL	8	The use of gas turbines for syngas has been demonstrated on a commercial basis but development is ongoing.

Technique Title:	**Waste plastics to diesel**	
Description	Pyrolysis technologies are being applied the conversion of non-recyclable waste plastics into liquid hydrocarbon fuels. The technology effectively reverses the plastics production process, where hydrocarbons are used to create plastics. Instead, the process cracks the hydrocarbon chains within the plastics, to produce distilled fuels. The feedstock first needs to be chipped to produce a plastic flake. The material also needs to be is washed to remove impurities, and then dried to remove moisture. The flakes are fed in to a pyrolysis reaction chamber, in the absence of oxygen. The pyrolysis gases are then condensed in to a distillate which is further refined in to diesel based products.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟩	Limited operational data, however the pyrolysis process will require heat input and the process plant will have a parasitic load. One developer of this type of process estimates that approximately 85% of the plastic energy content can be converted into useful fuel products, however due to the early stage of development, this cannot be independently verified through commercial operation.
Applicability	🟧	Applicable to non-recyclable plastics only, requires separation of non-recyclable plastics from mixed waste streams. Commercial considerations mean that this can be a significant mono waste stream.
Exclusion criteria	Yes	Could be seen as preventing increased recycling of plastics. As the plastic feedstock is fossil fuel derived (with no biogenic content) the fuel will not be eligible for support under the Renewable Energy Directive and support as implemented nationally by Member States. This policy may hold back the development of this technology. The UK is of the view that 'End of waste' issues and compliance with the REACH Directive are substantial barriers to implementation[114].
TRL	7	The companies developing these process are currently at demonstration plant stage. Commercial sale plants are being developed from demonstration plant experience where the developers are resolving practical difficulties in scaling up production.

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[114] Feedback from the UK to the WtE background document, April 2016

Technique Title:	**Bioethanol from MSW**	
Description	There are a number of processes being developed which convert MSW to biomethanol / bioethanol and potentially other commodity chemicals[115]. An example of this is the conversion of pre-treated waste to a syngas, which is subsequently then converted into biofuels and commodity chemicals, using commercially available catalysts. The process will typically consist of feedstock preparation, gasification, cleaning and conditioning of the syngas, and finally synthesis of the syngas in the products, which can include methanol and ethanol. The Fisher-Tropsch process used for synthesis is a combination of chemical reactions which is used to convert syngas into liquids hydrocarbons. The syngas produced can also be used in boilers and engines or turbines. In addition to using syngas, products from gasification can be used in other applications. Syngas can be used to synthesise a range of liquid hydrocarbons including distillate fuels (including diesel fuel and kerosene), alcohols (methanol and ethanol) and fertilisers (ammonia).	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟩	There is no commercially available data available to verify claims performance from the developers, but some processes have been able to provide data which indicate that between 40% and 50% of the waste input energy can be converted into biofuels. The pre-treatment required to make the waste suitable for gasification will require energy input.
Applicability	🟧	Reasonable flexibility on waste types (including MSW) dependent on effective pre-treatment.
Exclusion criteria	No	None
TRL	8	Some commercial scale process demonstration examples, with more in development.

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[115] London EfW Conference 2015, Enerkem

Technique Title:	**Bioethanol from organic wastes and residues**	
Description	A process has been developed in Finland to produce bioethanol from second generation feedstcoks such as food industry process residues, household biowaste, cellulosic residues and waste[116]. The technique has been developed to enable cost-effective ethanol production by fermentation in distributed small plants so that the production plants can be built near the "source of waste" (e.g. brewery, enzyme production), which minimizes the transport costs and emissions. The main product is bioethanol, which is used in high blend ethanol fuels and as a bio-component in low blend petrol. Other useful by-products obtained are: animal feed, fertilizers, chemicals, lignin, electricity and/or heat, and biogas. The precise nature of the by-products depends on raw material used.	
Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟩	The energy efficiency of the process is unknown but to produce biofuels which are Renewable Energy Directive compliant, process energy efficiency is likely to be high.
Applicability	🟥	The process is highly rated in terms of its ability to be co-located with waste production sites, but the waste stream quantities will still be relatively small.
Exclusion criteria	None	
TRL	9	Currently there are five operational plants in Finland. The sum of the production capacities of these five plants is 15 million litres of bioethanol per year. A new plant producing bioethanol from saw dust is under construction and will be started in 2016. This will add the production capacity by 10 million litres.

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[116] Finnish Ministry of the Environment

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Technique Title:	**Gasification with syngas methanation and conversion to biomethane**
Description	This technique is currently being developed to produce a syngas which is free from intractable levels of tar which can subsequently be treated by conventional technologies to allow methanation of the syngas produced. The biomethane produced by the process can be injected to the grid or used as a transport fuel[117]. The waste feedstock needs to be prepared to provide a homogenous material such as SRF. Methanation requires the syngas to be free of contaminants, notably of condensed hydrocarbons, heavy metals, sulphur and halogens. The technology utilises a gasifier and plasma converter close-coupled to produce a suitably clean syngas reformed from the contaminants, allowing constituent sulphur and halogens to be removed by conventional techniques as well as heavy metals. The technology has been tested on a range of mixed and organic waste feedstocks. Key performance indicators were a carbon conversion efficiency of near to 100%, with cold gas conversion efficiencies of 75-90% depending on feedstock. Depending on feedstock, the gas calorific value was 7-14MJ/Nm^3 with the system producing a consistent syngas. Measured tar levels by mass were below 0.05%, sulphur compounds below 0.02% and nitrogen compounds below 0.2%. Heavy metals contamination is below 6 parts per billion by mass. The syngas methanation process is well established with the technology using a combined high temperature water gas shift using an iron catalyst with methanation using a nickel catalyst. A by-product of the methanation process is CO2 which is produced in large quantities. This CO2 by-product would need to be utilised in order to achieve the desired levels of GHG emission reductions.

Criteria	Rating	Notes
Net Annual Average Energy Efficiency	🟩	There is no commercially available data available to verify claimed performance, but data has been provided by the developer which indicates that the process net energy efficiency will be between 40% and 50%. The pre-treatment required to make the waste suitable for gasification will require energy input.
Applicability	🟧	The process has the potential to use a wide range of feedstocks but extensive pre-treatment is required to achieve sufficient homogeneity.
Exclusion criteria	No	None
TRL	6	Not yet operating commercially, demonstration scale plant is currently being developed.

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[117] UK Department for Transport

<table>
<tr><th>Technique Title:</th><th colspan="2">Direct liquefaction</th></tr>
<tr><td>Description</td><td colspan="2">This technique involves liquefying high-molecular substances of an organic origin. It is a single-stage process (direct liquefaction) that differs from other processes in that the liquid energy carriers are derived not as distillate but by means of Fischer-Tropsch synthesis subsequent to gasification/carbonization.

Unlike other methods of direct liquefaction, the process does not require high pressure, high temperature or the addition of hydrogen. The process results in distillates, which can be used as a fuel or as a material for further processing.</td></tr>
<tr><td>Criteria</td><td>Rating</td><td>Notes</td></tr>
<tr><td>Net Annual Average Energy Efficiency</td><td>🟧</td><td>Not known</td></tr>
<tr><td>Applicability</td><td>🟧</td><td>Applicable only to pre-treated waste, i.e. Refuse Derived Fuels.</td></tr>
<tr><td>Exclusion criteria</td><td>None</td><td>No</td></tr>
<tr><td>TRL</td><td>6</td><td>Demonstration plants only</td></tr>
</table>

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6.9 Discussion

6.9.1 Threats and opportunities of full deployment of proven techniques

As technology progresses, the landscape in which WtE operates is subject to constant change. The chart below presents some of the threats and opportunities for proven WtE technologies such as incineration, CL plants and anaerobic digestion.

Opportunities	**Threats**
Greater support from governments for the deployment of district heat and cooling	Continued poor public perception of incineration
Residue treatment to reduce operational cost	Lack of grid access priority for WtE
Bottom ash is highly recyclable	Unforeseeable changes in WtE treatment capacity required
Firmer application of landfill diversion targets (50% in 2020 and 65% by 2030)	Lack of good waste data (especially C&I data) makes capacity planning more difficult
Potential for landfill bans for certain materials such as organics	Planning and permitting remains a significant burden on developers
Firmer application of existing legislation associated with the Landfill Directive to avoid premixing (dilution) of hazardous waste. This would encourage more incineration of hazardous waste with energy recovery.	AD digestate can be difficult to dispose of to land
Regulatory standards for both Refuse Derived Fuels (RDF) & Solid Recovered Fuels (SRF) to improve the quality of feedstock	As utility scale power generation moves away from carbon, WtE will lose its renewable advantage
Mandatory requirements for separate collection of organic waste from households	Extension of End of Waste criteria to more products will favour emerging techniques
Minimum standards for energy conversion efficiency (R1) are made mandatory	

6.9.2 Threats and opportunities of full deployment of emerging techniques

For emerging techniques which produce syngas and biofuels, there are further opportunities and threats which are specific to these technologies:

Opportunities	Threats
Renewable Energy Directive (RED) requiring more renewable transport fuels such as those produced from biogenic waste	Lack of support for non-biogenic wastes such as plastic
Government financial incentives for emerging technology	Changes in government financial incentives for emerging technology which causes uncertainty for investors
Extension of End of Waste criteria to more products	Lack of a market for waste derived CO_2
Versatility of syngas	Advanced processes can be highly sensitive to feedstock
	Oil price volatility
	High profile failures damage confidence in emerging technologies for both developers and investors

6.9.3 Ancillary WtE techniques to help address threats and opportunities to WtE

There are a number of mature and emerging techniques which are ancillary to the main energy recovery techniques already discussed within this study which none the less are key in helping address the threats and opportunities associated with the wider deployment of WtE.

6.9.3.1 WtE residues

A key issue for WtE is the disposal of residues. The disposal of residues can be very costly for an operator and incorrect disposal can cause environmental harm. For waste incineration, there are two main residues which require disposal, these are Incinerator Bottom Ash (IBA) and Air Pollution Control Residues (APCr).

Incinerator Bottom Ash

IBA is an inert material and there are opportunities to recycle both the post burn metals and the ash itself. The ability to recycle IBA is important in establishing the environmental credentials of waste incineration.

Although very common in some EU Member States (e.g. Denmark, the Netherlands and Germany), recycling of IBA is not fully established in Europe and is therefore a mature but developing technique. Recovery of IBA as a secondary aggregate has three main steps of crushing, maturation/weathering and screening/separation.

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- Crushing is a general pre-treatment technique to refine particle size for the use of IBA in construction materials. During crushing IBA can sometimes be washed with a leachate to remove heavy metal components.
- Maturation or weathering exposes IBA to the atmosphere for an extended period, after which it is ready for processing. Exposure to the atmosphere aids in stabilising the material through hydration and carbonation which reduces the pH and removes soluble salts.
- The weathered IBA is then processed by a series of screens and conveyors, coupled with magnets and eddy current separators. Recovered metals are collected for recycling and grade of material sorted by particle size. Through the process small reject materials or fines will commonly be disposed of to landfill however more advanced processes are able to extract metals from the fines and retain the fine aggregate fraction for recovery. The separated grades of aggregate are then stockpiled for collection and use.

IBA exhibits similar properties to natural aggregates and its use can give significant environmental and social benefits. Such examples of these benefits are reducing the quarrying of primary aggregates and associated processing; additional recovery of recyclable material through ferrous and non-ferrous metals extraction; IBA landfill reduction; and a lower carbon footprint compared to primary aggregates.

Air Pollution Control Residues

APCr is classed as hazardous waste. The most common disposal route is currently pH neutralisation prior to disposal in hazardous landfill. However, APCr requires a derogation to enable this disposal route as the concentration of contaminants is up to three times above the upper permissible limit. It is widely acknowledged that this derogation is likely to be withdrawn in the coming years and therefore alternative treatment methods will be required.

Some examples of emerging APCr treatment routes to avoid disposal to hazardous landfill are as follows:

- Vitrification which involves the melting of APCr and a glass precursor (silica) at high temperatures to form an amorphous glassy clinker and bind/encapsulate the residue. The high temperatures effectively destroy dioxins, furans and other toxic organic compounds. This treatment allows for the reuse of a melted slag as a resource. APCr vitrification is integral to high temperature gasification and melting technologies.

- Accelerated Carbonation Technology involves a controlled, accelerated version of the naturally occurring carbonation reaction. When CO_2 reacts with lime and calcium compounds in APCr, limestone is formed. As a result, the chemical and physical properties of treated materials are improved, including neutralised pH and reduced leachability of heavy metals. The finished aggregate is used as a replacement raw material for virgin aggregate in lightweight concrete blocks. Chlorides in APCr act as an accelerant and are beneficial to the block making process

- Cement production: APCr contains calcium oxide (CaO), silica (SiO_2), iron oxide (Fe_2O_3) and alumina (Al_2O_3), similar to the composition of raw materials for cement production, and can be used to replace limestone dependent on the quality of the final product and market acceptability. A potential application for APCr is low energy cements, also called calcium sulfoaluminate cements, which can be synthesised at low temperatures and present high strength and rapid

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hardening. APCr provides a source of both alumina, for the formation of calcium sulfoaluminates, and silica, for the formation of calcium silicates.

- Concrete is a construction material that consists of cement, aggregate, water and admixtures. It solidifies and hardens after mixing and placement due to a chemical process known as hydration and the reactions that occur are the basis of the stabilisation and solidification (S/S) process. The S/S process is applied world-wide for the treatment of hazardous waste. Since the size of APCr particles is small (<150µm) they become encapsulated inside the concrete matrix. The main disadvantages are that the physical integrity of the product may deteriorate over time and that APCr mass and volume increases with treatment.

6.10 Task 2 - Conclusions on technical improvement potential of WtE

The main conclusion to be drawn from Task 2 of this study is 'what are the key energy efficiency improvement techniques which will be able to change the landscape of WtE throughout the EU-28, particularly in the short term?' This has been examined for each of the five WtE outlets.

6.10.1 Combustion plants co-incinerating waste

A number of proven improvement techniques are available that would allow waste to be co-incinerated with primary combustion fuels at relatively high net electrical efficiency. The main drawbacks to some of these techniques are that some are strictly limited in terms of the quantities of waste that can be co-fired (without causing deleterious effects to the combustion plant) and as there are no thresholds for WID compliance, all combustion plants co-firing waste need to be permitted by the relevant national Environment Agency and meet EU wide IED emissions standards.

The most promising of the improvement techniques examined in this group are:

- The production of gas products from waste which can be fired in high efficiency combustion plants and at a relatively high substation rate. Syngas produced from waste can be fired in coal fired plants with a net electrical efficiency of between 36 and 40% and at a substation rate of up to 40%. Biomethane produced from waste which is of a similar standard to natural gas can be fired in CCGT power stations with an electrical efficiency of over 50%.
- Biomass and prepared fuels such as SRF can be co-fired in fluidised bed units at an electrical efficiency of around 30%.

6.10.2 Waste incineration

Waste incineration has traditionally struggled to achieve high energy efficiency as the waste feedstock is not homogeneous and contains pollutants which cause rapid corrosion to boiler systems at the high steam temperatures and pressures required to achieve high electrical efficiency. This is despite major advances in steel corrosion protection such as nickel based coatings.

The most promising of the improvement techniques examined in this group are in two main groupings:

- Innovative ways of superheating steam without serious corrosion effects
- Extracting low grade energy from flue gases

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It is possible that the net electrical efficiency of waste incineration can rise from a current average of around 25% to around 33% through the application of these techniques.

6.10.3 Cement and Lime production

Cement kilns are able to use both the energy and recycle a proportional of the material content of waste. In this respect they are a valuable outlet for Waste to Energy. Most of the gains in energy efficiency have been from incremental changes in detailed design which have increased energy efficiency from 66% several decades ago to the latest designs which offer 85% energy efficiency.

It is also noted that the levels of waste substitution (alternative fuels in lieu of fossil fuels) could rise from current average levels of around 40% to a realistic target of 70%. This would increase the total energy derived from waste in the EU-28, but does not change the energy efficiency of the technique.

6.10.4 Anaerobic digestion

Anaerobic Digestion (AD) has been a steadily growing outlet for energy recovery from organic wastes with a high moisture content (up to 95%) which in their natural form do not have sufficient calorific value for combustion. Anaerobic Digestion in its basic form will only ever convert around 50% of the energy content of the feedstock into a useable form as biogas, which then must be converted into energy. Traditionally, gas engines have been utilised to produce power, which extract approximately 40% of the biogas energy as electrical power reducing overall process electrical efficiency to below 20% once parasitic loads have been accounted for.

The most promising of the improvement techniques examined in this group are:

- Improvement techniques such as gas to grid and more advanced forms of AD which offer the potential to improve the energy efficiency performance, with the potential to extract up to 40% of the feedstock energy input as useful energy. Some techniques such as gas to grid are quite location dependent (which impacts technique applicability) but biomethane compression or liquefaction can help overcome this issue, albeit with slightly less overall energy efficiency.
- There are more advanced emerging techniques which can further process sewage sludge and other organic feedstocks to more completely extract the available energy and also reduce the amount of by product for disposal. Although the digestate by-product from AD can have value as a soil improver, replacing energy and greenhouse gas intensive manufactured fertilisers (with particular regard to nitrous oxide emissions), distribution to land can be problematic depending on demand from agricultural outlets.

6.10.5 Other WtE processes

This category has focussed on emerging WtE improvement techniques which have attracted a great deal of attention in recent years.

Pyrolysis and gasification of mono waste streams such as waste wood, tyres and plastic appear to have had some success in terms of commercial applications. Gasification and pyrolysis of MSW and other mixed wastes has not been commercially proven to date, even with extensive pre-treatment of the waste to achieve better homogeneity. There have been many costly failures of MSW gasification and pyrolysis plants throughout the EU-28 Member States in the past decades.

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Considering the requirement for extensive waste pre-treatment and the production of combustion support materials such as oxygen or steam, gasification and pyrolysis technologies (where the syngas produced is combusted in a boiler or gas engine) are unlikely to achieve higher overall net electrical efficiencies than conventional combustion plants. Conventional combustion plants have been proven to reach net electrical efficiencies of well over 30% through the application of improvement techniques.

The most promising of the improvement techniques examined in this group are:

- The production of syngas, where the gas is cooled and extensively cleaned before being combusted in a high efficiency boiler. These plants have been operating for over five years and the data provided by Finland has shown steady progress towards commercially viable performance[118].
- As the combustion of syngas in a gas engine or boiler has proved to be limited in terms of both energy efficiency and reliability, the highest potential for emerging WtE processes may be those techniques which are able to convert cool, clean syngas to biomethane or biofuels. If these technologies can be commercially proven, over 40% of the waste input energy content may be recoverable.

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[118] https://waste-management-world.com/a/all-good-as-140-mw-finnish-waste-gasification-plant-passes-25-000-hours

6.11 Detailed analysis of selected techniques

The following techniques have been selected for a more detailed analysis. These are mostly proven techniques, the emerging techniques analysed are marked as (E).

Combustion plants

1 High efficiency Circulating Fluidised Bed gasification and co-firing of syngas in combustion plant
2 Feeding secondary fuels into a fluidised bed combustion plant

Waste incineration plants

3 High steam parameters for boilers and super heaters
4 Flue gas condensation and component cooling
5 Heat pumps
6 District cooling (100% load)
7 4th generation heat networks

Cement and Lime plants

8 Conversion of waste heat to power in cement kiln applications

Anaerobic Digestion

9 Sewage Sludge advanced AD - THP
10 AD with biogas injection to grid (GtG)
11 Sewage Sludge Advanced AD with Advanced Energy Recovery (Pyrolysis) (E)

Other WtE plants

12 Biodiesel from hydro treatment of waste edible oils and fats
13 Two Stage Combustion with Plasma (E)
14 Bioethanol from organic sources (E)

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Combustion plants

	Title: **High efficiency Circulating Fluidised Bed gasification and co-firing of syngas in combustion plant - Item 1**
1	***Technical description*** This technique is used for treating Solid Recovered Fuel (SRF). The SRF is conveyed in to Circulating Fluidised Bed (CFC) reactor. The gasifiers contain a medium such as hot sand and limestone that is fluidised with air blown from the bottom of the gasifier. The SRF is mixed with the fluidised bed at a temperature of 900°C. The fuel will not burn as there is insufficient oxygen, but instead is broken down into a syngas. The hot gases rise to the top of the gasifier and then into a cooling system where the gas temperature falls to 400°C. At this lower temperature, impurities in the fuel, such as alkali chlorides, Pb and Zn, turn to a solid form and are more easily removed inside a series of cooling chambers. A series of filters within the cooling chambers will collect unwanted particles, whilst allowing the gas to flow through. A nitrogen pulse will regularly eject collected dust, which falls to the chamber floor for removal. The resulting gas is cleaned from corrosive components and therefore it is possible to achieve efficient electricity production by using high steam temperature and pressure. If both heat and power are recovered, 90% overall energy efficiency can be achieved. In power only mode electrical efficiency will be high also. By using reheat in the boiler/steam cycle it is possible to further improve electrical efficiency close to 35%.The pre-treatment and sorting required to make the waste suitable for gasification will require energy input. As well as stand-alone waste plants, the technique also offers the potential to convert or co-fire fossil fuel powered boilers. This technique will be most effective where the syngas produced has end of waste status otherwise a waste incineration permit is needed. Co-firing of biomass waste could replace up to 40% of coal energy input, please refer also to this technique as applied to Combustion Plant outlets. Pre-treatment is still required to prepare the fuel for gasification. The resulting gas is injected into the existing combustion plant boiler where it is co-fired with coal to generate steam and power through a turbo generator set. Due to the efficient gas cleaning process, there are few impurities to cause corrosion in the combustion plant boiler. Therefore, the steam operating temperature and pressure are high, and can provide efficient electricity generation. Typically this will be between 36 and 40% for a coal combustion plant.
2	***Costs*** The capex for a 250,000 tpa plant utilising this technique is estimated at Eur245M [2]. In comparison, a conventional incineration plant of similar capacity is estimated to have a capex of Eur235M. Although there is only a small additional capex associated with this technique, the gap is likely to reduce further as follow on plants benefit from the learning and experience gained with the first commercial plants. There is no publically available data on technique opex costs.
3	***Achieved economic benefits*** The direct displacement of coal in existing power stations by a syngas generated from waste can be an attractive environmental and economic option.

Title: **High efficiency Circulating Fluidised Bed gasification and co-firing of syngas in combustion plant - Item 1**

4 ***Operational data***

A gasification plant is operated in Lahti, Finland, where refuse derived fuel and biomass are gasified and the resulting syngas co-fired in an existing coal fired plant to produce power and heat for the city. [1] The plant entered operation in 1998, and includes of a 60 MWth fluidised bed gasifier.

The technique developer has also recently published updated operational data for its demonstration plant at Kymijärvi. This plant is operated on waste only, and was developed to commercially demonstrate the high efficiencies that can be achieved. This facility has been operating successfully for over three years, with a reported net electrical efficiency of 30%; the developer plans to increase this efficiency further in the next generation of plants. It is also reported that the operation of a high temperature steam boiler on waste derived syngas is achievable without significant corrosion. The plant has operated for more than 25,000 hours since its commissioning in 2012 [3].

In 2014, the plant reported [4]:

Operational hours	6967
Availability	88.8%
Electricity	241 GWh
District heating	514 GWh

6 ***Environmental and/or human health benefits and drawbacks***

The reported high energy efficiency and displacement of fossil fuels have clear environmental and carbon reduction benefits.

The utilisation of low grade or low value wastes can provide an alternative to landfill for these waste streams.

7 ***Technical considerations relevant to applicability***

The technique can be used as a stand-alone waste plant or can be applied to convert / co-fire fossil fuel fired boilers. It therefore has wide applicability.

The gas quality enables the gas to be co-fired in existing boilers, therefore there is potential for retrofitting this technique with minimum boiler alterations, across EU member states.

Existing fossil fuel power plant infrastructure can be utilised.

Effective gas cleaning can ensure that corrosive and harmful compounds are removed from the gases, enabling the syngas to potentially have a wider number of uses beyond combustion.

8 ***Driving forces or barriers for implementation including feedstock availability***

Drivers:

- Higher efficiencies can be achieved by avoiding or minimising corrosion-related issues in conventional waste fired boilers. Corrosion in the boiler will limit the temperature of the steam, therefore reducing efficiency of electricity production. Converting the waste in to a gas, which is subsequently cleaned and upgraded prior to use in a boiler can limit corrosion, and thereby increase efficiency,

Title: High efficiency Circulating Fluidised Bed gasification and co-firing of syngas in combustion plant - Item 1

Barriers:

- For co-firing of syngas in a combustion plant, the facility will need to be compliant with the Industrial Emissions Directive (formerly the Waste Incineration Directive) or be able to demonstrate that end of waste status has been achieved. Operators of combustion plants may not wish to pursue either option.
- The age, condition and regulatory issues could present a barrier for the conversion of some combustion plant to co-fire syngas.

9 ***Residual risks***

As indicated above, it may not be possible for a wide number of existing combustion plant facilities to be converted. There are other competing uses of SRF which can be used directly and without gasification, i.e. in cement kilns.

10 ***Example plants or TRL readiness***

In addition to the facilities named above, a further example includes a 30MW waste wood gasifier in Amercentrale, Holland which was supplied and commissioned in 2000. The syngas is used as a coal replacement in the original coal fired boiler.

TRL Readiness Level		9	Commercial scale facilities are in operation.

11 ***References***

	Reference	**Strength of Evidence**
[1]	Valmet Gasification of Waste Technology Review, Fichtner Consulting Engineers, 2015	80%
[2]	Valmet / Ricardo meeting, RWM, 2014	50%
[3]	https://waste-management-world.com/a/all-good-as-140-mw-finnish-waste-gasification-plant-passes-25-000-hours	70%
[4]	Kymijärvi II Waste Gasification Power Plant, published by Valmet.	90%

Dra

Title: Feeding secondary fuels into a fluidised bed combustion plant - Item 2

1 ***Technical description***

This technique description is focused on the partial substitution of SRF for biomass in biomass fired fluidised bed combustion plants. However, other combination of primary and secondary fuel combustion in a fluidised bed combustion plant (such as coal and sewage sludge) are also possible.

There are a number of operational biomass co-combustion plants which are in some cases are able to successfully increase the ratio of SRF co-firing to over 50% (whereas waste substitution ratios in coal fired plants are much more restricted). For co-firing in a fluidised bed boiler, it has been demonstrated that careful feeding of the primary and secondary fuels is one of the most important factors for good operation.

One of the benefits of SRF co-incineration is that some biomass fuel sources are of relatively low quality with a high moisture content of up to 60%. This can result in a low net calorific value (NCV) fuel typically between 5 and 15 MJ/kg. SRF is a fast burning material and has a high NCV typically of between 15 and 25 MJ/kg and oxygen content of close to zero. CO_2 emission factors are ~25% lower than that of coal. Thus, SRF can operate as a support fuel to biomass, assisting in ignition and support a more stable combustion and better burning of low grade biomass.

In a modern biomass fluidised bed combustion plant, net annual average electrical efficiency will be around 28 to 30%. In older plant designs, the net electrical efficiency will be nearer to 20%. Energy input will also be required to sort and pre-treat the waste feedstock to provide a suitable SRF fuel.

2 ***Costs***

To co-fire SRF, a number of modifications would be required to the combustion plant. These include:

- storage of the waste feedstock;
- a suitable system to screen out or crush unsuitable particles of waste in the SRF;
- a system to either mix the waste with primary fuel prior to combustion or a separate feed system for the waste; and
- there may be a requirement for enhanced abatement measures to control emissions from the SRF fraction of the fuel.

Costs would be dependent on the scale of the combustion plant being considered for co-firing.

There would also be administrative costs associated with the process of obtaining an environmental permit to co-fire waste and maintaining IED compliance through annual testing and certification.

3 ***Achieved economic benefits***

The key economic benefit of this technique is to replace biomass which would be supplied at cost to the combustion plant at approximately Eur154 per tonne [1] with SRF which could provide a revenue to the combustion plant. A gate fee of around 60Eur per tonne may be charged for SRF depending on the composition of the fuel.

	Title: Feeding secondary fuels into a fluidised bed combustion plant - Item 2
4	***Operational data*** Operations have shown that correct mixing of the primary and secondary fuels is key to operational success in a fluidised bed boiler. Fuels should either be thoroughly mixed before being fed into the boiler or a separate feeding system should be used which can be carefully controlled; although SRF is reasonably homogenous (as a prepared fuel), it is still a waste and subject to more variation than a primary fuel. Therefore the in-feed of the SRF needs careful monitoring, where contrary material can be removed quickly. Early trials in Finland raised some issues with chemical interactions between compounds in biomass and SRF which gave rise to boiler fouling, but these are now reported to be resolved [2].
5	***Environmental and/or human health benefits and drawbacks*** The substitution of biomass with SRF may help avoid sustainability issues associated with the consumption of virgin biomass. SRF incineration needs to be performed in compliance with the IED to avoid damage to the environment; any co-incineration activity needs to be monitored by the relevant national authority. Extensive pre-treatment of waste is required to manufacture high quality SRF. If the SRF used has a high fossil fuel content (for example a high plastics content), it will provide reduced benefits in terms of GHG emissions savings than biomass. SRF will need to be stored such that no deleterious effects from odour or leachate are observed.
6	***Technical considerations relevant to applicability*** SRF and biomass co-firing has been proven at ratios up to 50:50. [3]
7	***Driving forces or barriers for implementation including feedstock availability*** Drivers: • The key driver for this technique is cost reduction for combustion plants, where a gate fee can be charged for SRF. Drawbacks • Any combustion plants co-firing waste need to be permitted and be IED compliant. Feedstock availability • Task 1 has shown that feedstock availability is high where HSW, sorting residues and mixed wastes can all be processed to manufacture SRF
8	***Residual risks*** The technique has been commercially proven in many plants but there is a small residual risk that combustion plant performance may be reduced through the introduction of a waste feedstock (from boiler fouling etc.) and operators will need to remain vigilant that emissions from a combustion plant are in full compliance with the IED.

	Title: Feeding secondary fuels into a fluidised bed combustion plant - Item 2
9	***Example plants or TRL readiness***

TRL Readiness Level	9+	Over 15 operational examples of biomass and waste co-firing plants have been provided for the current BREF update work [4].

10	***References***

	Reference	**Strength of Evidence**
[1]	http://www.biomassenergycentre.org.uk /portal/page?_pageid=75,59188&_dad=portal	90
[2]	Finnish Ministry of the Environment	70
[3]	Finnish Ministry of the Environment	90
[4]	Finnish Ministry of the Environment	90

Draft - Work in prog

Waste incineration plants

Title: High steam parameters for boilers and superheaters – Item 3

1 ***Technical description***

Compared to fossil fuel fired LCP boilers, waste-fuelled boilers have lower electrical generation efficiency. This is primarily because of the severe corrosive environment created by waste incineration which limits steam temperatures and pressures to around 425°C and 50 bar. However, numerous techniques have been developed to help boost the energy efficiency of conventional incineration to above 30%.

These include external superheaters, radiant pass superheaters and the re-heating of turbine steam.

- External superheaters - An innovative solution is to provide an external super heater which is powered by the gasification of a cleaner and more homogenous fuel such as waste wood, which is proven. This additional, cleaner heat source can raise the steam generated by the waste fired 'base plant' to temperatures over 500°C without risking early failure of super heater tubes. This technique is offered commercially, the most suitable application would be in the co-location of MSW and waste biomass waste treatment plants. [1]

- Radiant pass superheaters - A number of technology providers have fitted superheaters in the radiant or first pass area of the boiler. This is where flue gases are hottest, the radiant section of the boiler is normally lined with refractory with the boiler tubes located behind the refractory wall. As the boiler tubes do not come into direct contact with the flue gases, the energy transfer is considered to be radiant. Unprotected steel components would not be able to withstand the intense heat of this section of the boiler and would rapidly corrode. Some plants with this boiler arrangement experience superheated life of under one year. To overcome this, a radiant superheater can be fitted where it is coated with Silicone Carbide (SiC) tiles. The radiant super heater operates in combination with the conventional downstream convection superheater bundles. A radiant superheater can raise steam temperatures by between 40 and 80°C which corresponds to an increase in electrical energy efficiency of around 3%. [2]

- Turbine steam reheating - Utility scale power plants using biomass and fossil fuels as a feedstock commonly employ reheat of turbine steam after its first passage through the turbine to increase electrical efficiency. For this application, steam temperature is limited to 400°C, but steam pressure increases considerably. After the first passage through the high-pressure section of the turbine, the resulting steam is superheated again and subsequently used in the turbine's middle and low-pressure sections. Usually after expanding in the high pressure turbine the steam has lower pressure (typically 20 % of pressure entering) and is reheated with flue-gas in the boiler to the same temperature. Achieved benefits are increased electrical efficiency by approximately 3 percentage points to reach 30% net electrical efficiency. In order to gain maximum effect from this setup, the steam pressure has to be increased to at least 120 bar. However, with the corrosive elements present in waste fuel derived flue gases, at this temperature level there is a high risk of corrosion, even if Inconel cladding is used for boiler tube protection. Amsterdam AEB plant in the Netherlands

	***Title:* High steam parameters for boilers and superheaters – Item 3**
	employs a steam reheat system through an intermediate superheater and operates at steam conditions of 480°C and 130 bar [3]. The superheaters are designed to be removed easily and due to rapid corrosion need replacement around every two years. On a very large plant such as Amsterdam, this may make economic sense as the revenues from increased electrical production outweigh the cost of superheater replacement. On most WtE plants this is not the case and superheater life needs to be at least five years to replacement.
2	***Costs*** Such high efficiency brings both high capex and opex and would only be cost effective on the very largest plants where large amounts of power are exported.
3	***Achieved economic benefits*** High steam parameters can bring increased power revenues.
4	***Operational data*** Operational data from AEB Amsterdam indicates net electrical efficiency of 33%.
5	***Environmental and/or human health benefits and drawbacks*** Increased electrical efficiency from waste feedstocks enables a greater reduction in fossil fuel use.
6	***Technical considerations relevant to applicability*** High steam parameters offer year round net electrical efficiencies up to 33%. Net electrical efficiencies of 35% are being targeted by developers but have not yet been achieved.
7	***Driving forces or barriers for implementation including feedstock availability*** The price of electrical power is currently very low in Europe (around Eur50 per MWh), so the additional costs of this technique may not currently be economically viable.
8	***Residual risks*** Higher steam pressures with or without higher superheating temperatures will result in increased corrosion risks, especially in the superheaters, and thus a risk of reduced plant availability and increased maintenance costs. Higher steam parameters will also result in a higher capital investment cost, partially due to additional corrosion protection measures.
9	***Example plants or TRL readiness*** Due primarily to cost / benefit, there are only a few commercial examples of the highest steam parameters which currently provide a net electrical efficiency over 33%.

	***Title:* High steam parameters for boilers and superheaters – Item 3**		
	TRL Readiness Level	9+	There are a limited number of examples operating on a commercial basis

10 ***References***

	Reference	**Strength of Evidence**
[1]	Volund technical papers	70%
[2]	Volund technical papers	70%
[3]	AEB Amsterdam	90%

Draft - Work in progress

3729

Title: **Flue gas condensation and component cooling - Item 4**

1 *Technical description*

Flue Gas Condensation (FGC) is a technique to recover further energy from the flue gases produced during combustion. The flue gases still contain water vapour following clean-up which can be condensed to a liquid form to enable additional low grade heat to be recovered. FGC can be a cost-effective method of recovering energy for a district or local heating grid. As a rough guide, a flue gas condensation installation can increase heat energy recovery by up to 15% of furnace energy output where the recovered energy can be transferred to a district heating system [1]. There is a small decrease in electrical energy efficiency associated with this.

The technique works by cooling the water in the flue gas below its water dew point. The heat that is released by the resulting condensation of the water is recovered as low temperature heat. The flue gas can be cooled either directly via a heat exchanger, or indirectly via a condensing scrubber. The heat that is recovered can then be distributed via a district heating network.

Flue gas condensing in a scrubber will comprise [2]:

- Cooling of the flue gas to dew point, by injecting water if not already saturated
- The gas is then passed through a scrubber which is cooled by a heat exchanger on the recirculating scrubber liquid
- The heated water from the scrubber is then pumped through a heat exchanger and recirculated
- The condensate is removed from the scrubber circuit and can be further used as process water, or discharged as wastewater
- The cooled flue gas is then passed to the stack

Smaller amounts of useful heat can also be recovered from water cooled plant components which generate large amounts of waste heat such as water cooled grates and HV transformers.

2 *Costs*

A feasibility study [3] conducted within an operational WtE plant into increasing efficiency by the use of heat pumps (combined with flue gas condensing) concluded that energy recovery for district heating increased by 9.4MWth through the use of a 2.3 MW_{el} heat pump combined with flue gas condensing; an estimated investment cost of €6 million including €3 million for the heat pump was required. Flue gas temperatures at exit were reduced from 60°C to 37°C; reductions to as low as 30°C may be possible.

3 *Achieved economic benefits*

Greater quantities of heat can be extracted from the flue gases resulting in higher heat sale revenues.

Reducing the flue gas temperature has the effect of reducing overall gas flow. This reduces the power demand of the induced draft (ID) fan, therefore resulting in a parasitic load saving.

***Title:* Flue gas condensation and component cooling - Item 4**

4 ***Operational data***

There will be a small impact on electrical power production from FGC (around 0.5 to 1% reduction) but where heat is exported, overall energy efficiency will increase considerably. CHP net annual average efficiency is estimated to rise from 76% to 88% with the addition of FGC for the most advanced plants [4].

5 ***Environmental and/or human health benefits and drawbacks***

Plume visibility may increase due to an increased droplet precipitation due to the lower stack gas exit temperatures. This may have a potential visual impact but will not impact on health. This issue can be overcome by reheating the flue gas, however this would then impact on the net efficiency gains of the flue gas condensation.

6 ***Technical considerations relevant to applicability***

Full benefits of FGC will only be realised where the plant exports heat, ideally to a district heating network which has suitable low return temperatures. Otherwise the energy recovered by FGC can only be used for boiler feed water pre-heating which is limited.

7 ***Driving forces or barriers for implementation including feedstock availability***

The potential to recovery heat by flue gas condensation is highest for high moisture content fuels, including biomass and municipal waste. The potential is also increased where heat is useful at the lowest possible temperatures, for example, in district heating or an industrial user of low grade heat.

8 ***Residual risks***

The high level of condensate can be corrosive.

9 ***Example plants or TRL readiness***

TRL Readiness Level	9+	The latest installations of waste incineration plants employ FGC particularly in Scandinavia

10 ***References***

	Reference	**Strength of Evidence**
[1]	ISWA CE Report 5, 2015	90%
[2]	NLWA Flue Gas Treatment Technology Options Consultation	90%
[3]	Statkraft, Norway – A case study of Trondheim WtE plant	70%
[4]	Calculation by Ricardo Energy & Environment based on efficiencies presented in ISWA CE Report 5, 2015, Appendix 1.	90%

Title: Heat Pumps - Item 5

1 *Technical description*

The principle of a heat pump is to upgrade a low temperature waste heat flow to a useful high temperature heat. There are many different types of heat pumps, including compressor heat pumps (using electricity) or absorption heat pumps (using heat from steam, hot water or flue gas).

In compressor heat pumps, the main components are the compressor, expansion valve, and two heat exchangers in the form of an evaporator and condenser. A working fluid known as a refrigerant is through all components of the system. In the evaporator, the working fluid is heated by the transfer of heat from the heat source, i.e. flue gases, which causes the evaporation of the working fluid. This vapour is then compressed to a higher pressure and temperature. The hot vapour then enters the condenser, as the vapour condenses heat is released which can then be used. The condensed working fluid is then expanded in the expansion valve and is returned to the evaporator where the cycle starts again.

Absorption heat pumps are thermally driven as opposed to mechanically. They work on the principle of the ability of liquids or salt to absorb vapour. For example, commonly paired working fluids and absorbents include water and lithium bromide, and ammonia and water. An absorption heat pump consists of an absorber, a solvent pump, a thermal compressor and an expansion valve. Vapour is produced in the evaporator, at low pressure, which is them absorbed in the absorber and produced heat. The solution is then pressurised in the compressor, where the working fluid then evaporates. The vapour is then condensed, and the absorbent returned to the absorber via the expansion valve. Heat is recovered from the heat source in the evaporator.

Large absorption heat pumps are increasingly being used to recover heat from flue gas condensation.

2 *Costs*

A feasibility study [1] conducted within an operational WtE plant into increasing efficiency by the use of heat pumps (combined with flue gas condensing) concluded that energy recovery for district heating increased by 9.4MWth through the use of a 2.3 MW_{el} heat pump combined with flue gas condensing; an estimated investment cost of €6 million including €3 million for the heat pump was required. Flue gas temperatures at exit were reduced from 60°C to 37°C; reductions to as low as 30°C may be possible.

3 *Achieved economic benefits*

Greater quantities of heat can be extracted from the flue gases resulting in higher heat sale revenues.

4 *Operational data*

In the EC-JRC study on Best Available Technologies for the heat and cooling market, [2], large absorption heat pumps using flue gas condensation in connection with MSW are reported to raise district heating temperatures from 40 °C – 60 °C to about 80 °C.

A flue gas condensation installation can increase heat energy recovery by up to 15% of furnace energy output but in tandem with a heat pump installation, this figure increases to just over 20 percent [3].

CHP net annual average efficiency is estimated to rise from 76% to over 88% with the addition of heat pumps in tandem with FGC for the most advanced plants. [4]

5 *Environmental and/or human health benefits and drawbacks*

Heat pump technologies have low CO_2 emissions.

	Title: **Heat Pumps - Item 5**
6	***Technical considerations relevant to applicability*** Full benefits will only be realised where the plant exports heat in the form of district heating or steam. Can be used to recover heat from flues gases from consumption of MSW, biomass and other wastes.
7	***Driving forces or barriers for implementation including feedstock availability*** An advantage of heat pumps is that they can utilise waste heat that would have otherwise been lost, by transforming it to a higher temperature. However, the pump itself will need energy to facilitate the transformation from low to high temperature, either in the form of electricity or a further high-temperature heat source. The driver for installation of this technology will be dependent on the availability of a heat user or the presence of a district heating network.
8	***Residual risks*** Investment is dependent on security of heat user.
9	***Example plants or TRL readiness*** Examples of plants with heat pumps installed in • Öresundskraft Filborna WTE, plant, Helsingborg, Sweden – This 70MW facility was opened in 2012. The plant's energy recovery process is designed in to maximise energy output via a heat pump system. The plant was installed with a two stage condensing system, where in the first stage the flue gas is cooled by the return district heating water and in the second stage by an absorption heat pump [5]. • Vestforbrænding Waste-to-Energy plant, Copenhagen, Denmark – This plant was upgraded in 2006 by the installation of a flue gas condensation and integrated absorption heat pump. The flue gases are cooled by a circulating cooling water system. The temperature of the heat recovered from the flue gases is lower than the district heating return temperature and is therefore is raised to the required temperature by two steam driven heat pumps in series, increasing the district heating temperature from 60ºC to 80ºC [6].
	TRL Readiness Level — 9+ — Many of the latest generation of WtE incineration plants incorporate FGC and heat pumps working in tandem.
10	***References***

	Reference	**Strength of Evidence**
[1]	Statkraft, Norway – A case study of Trondheim WtE plant	70%
[2]	European Commission, Joint Research Centre, Institute for Energy and Transport, Best available technologies for the heat and cooling market in the European Union, 2012.	90%
[3]	ISWA CE Report 5, 2015	90%
[4]	Calculation by Ricardo based on efficiencies presented in ISWA CE Report 5, 2015, Appendix 1.	90%
[5]	Götavergen Miljö Reference Case Study, Filborna WTE, plant, Helsingborg, Sweden	90%
[6]	Götavergen Miljö Reference Case Study, Vestforbrænding Waste-to-Energy plant, Copenhagen, Denmark	90%

3736

Title: District Cooling - Item 6

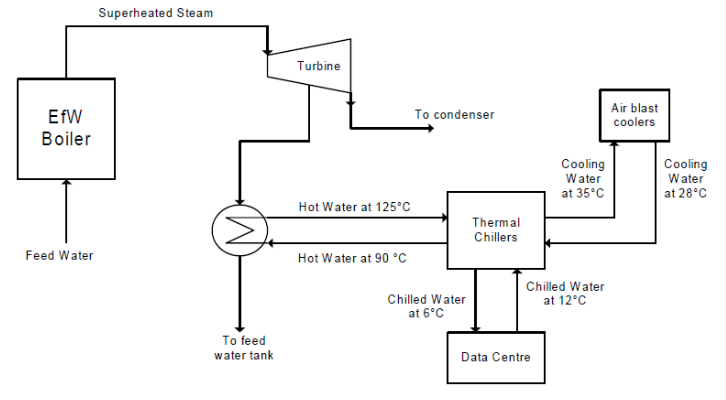
1 ***Technical description***

This refers to the use of heat from an EfW plant to provide chilled water for air conditioning and other cooling applications. One option is to use steam from the EfW plant to drive the compressor for a vapour compression refrigeration system. However, a more commonplace option is to use lower-grade heat (e.g. low pressure steam or hot water) within an absorption refrigeration system. Absorption-based chiller systems are more widely used on account of their ability to use lower-grade heat, thereby reducing the penalty on the electrical output of the EfW plant.

The overall energy efficiency of cooling systems is less than a system delivering heat energy, particularly refrigeration absorption. The performance of the chiller system is expressed in terms of its coefficient of performance (CoP, the ratio of cooling output to heat input), steam-based absorption systems can achieve CoPs in the order of 1.2 while hot water systems achieve CoPs of 0.6. In comparison to district heating which has a net energy efficiency of 65%, district cooling energy efficiency is around 42%.

Backup facilities are normally required to provide for EfW supply outages. This will typically be provided electrically-powered vapour compression chiller systems. Such systems will also often be allied with sources of free cooling such as bodies of water, which are more capable of providing cooling services in winter.

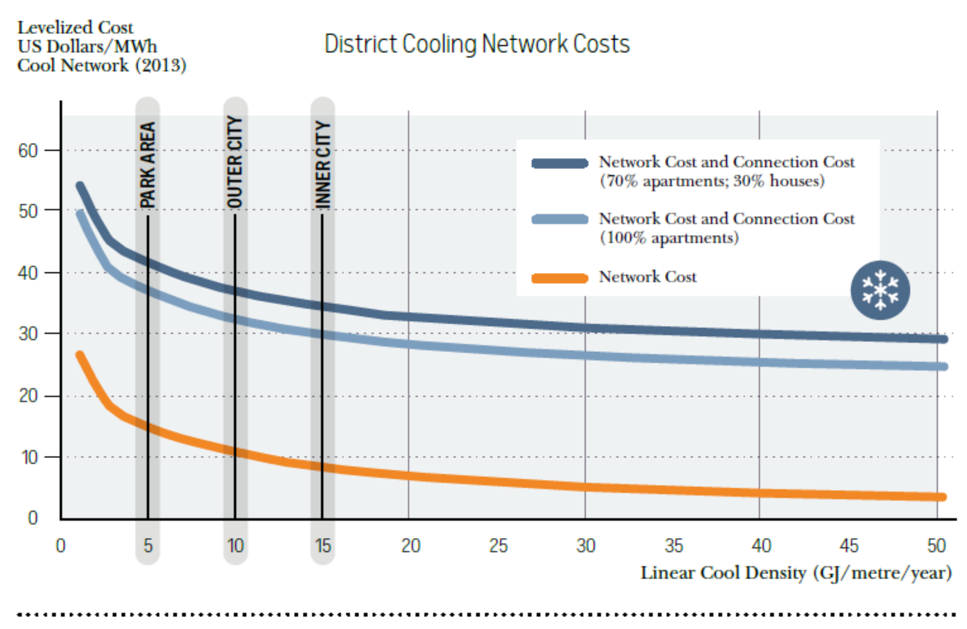
Applications are currently limited to a small number of schemes (e.g. Districlima in Barcelona, Spain), however one area of potential growth is the provision of cooling services to data centres, which have constant and very high cooling requirements. A schematic is shown below:



2 ***Costs***

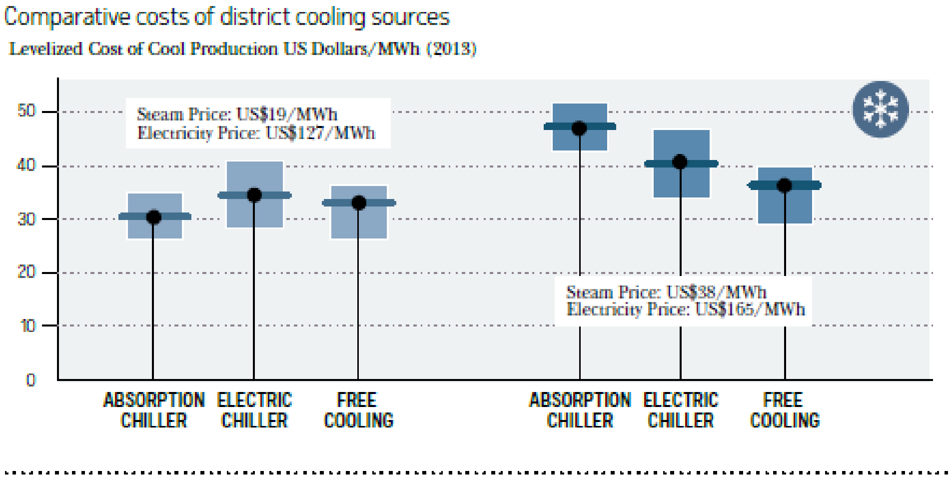
Levelised costs for district cooling network costs are given in the following figure

Title: District Cooling - Item 6



(Source: UNEP [1])

Levelised costs for district cooling sources are given in the following figure



(Source: UNEP [1])

3 *Achieved economic benefits*

Cooling effort requires the input of primary (electrical) energy and is therefore more highly valued than heat energy and should attract more revenue.

Because heat demand is seasonal and will be lower during summer, utilising waste heat for district cooling provides and additional revenue source.

If supplying 100% load to a cooling user such as data centre, both efficiencies and revenues will be greater.

4 *Operational data*

Only very limited examples of operating data for district cooling systems were available. One example where data was available was the 2015 annual report for HOFOR P/S[2], who own and operate one of the main district heating and cooling

	***Title:* District Cooling - Item 6**
	networks serving Copenhagen, Denmark reported the following details regarding its District Cooling Business area during 2015: • The company has 54 cooling customers • The total cooling capacity for the system is $50MW_{th}$ • The overall district cooling network length is 17km • Annual cooling supplied was 15 GWh • Net sales (including other operating income) was 38.3 million krone (5.15 million euro) • Operating expenses (excluding raw materials and consumables) were 6.4 million krone (0.86 million euro) • Raw materials and consumables costs were 3 million krone (0.4 million euro).
5	***Environmental and/or human health benefits and drawbacks*** District cooling using waste heat from the combustion of waste will potentially have lower CO_2 emissions and use less energy than alternative systems. Absorption chillers such as those used to convert waste heat in to cold water for district heating do not use refrigerants which can be considered environmentally damaging. However absorption chillers can use compounds that are hazardous to health if ingested.
6	***Technical considerations relevant to applicability*** Where district cooling is linked to a consumer such as a data centre, year round cooling is required. In these cases net annual average energy efficiency is estimated at 68%, even for the most efficient systems. Otherwise where cooling is assumed to be required only 80% of the year due to seasonal demand, a net annual average energy efficiency of 60% can be expected, even for the most efficient systems. Better annual energy efficiency is dependent on being connected to large cooling energy consumers such as hospitals or data centres. Hot climates within the EU-28 will also offer seasonal demand.
7	***Driving forces or barriers for implementation including feedstock availability*** The driving force for district cooling is more aligned with cooling demand, as opposed to feedstock availability. The technique is particularly relevant for hot countries. Alternatively, users with constant cooling demands such as data centres are a potential market.
8	***Residual risks*** Many of the risks match those associated with district heat networks, namely the need to secure a stable, long-term demand (in this case for cooling) to justify the significant capital investment. There therefore exists a risk of the distribution network becoming stranded in the event of there being a collapse in network demand. The decentralised technology alternatives for district cooling (namely electrically driven air conditioning) can be installed relatively readily and, unlike heating,

Title: District Cooling - Item 6

could not be readily prohibited from being developed within a network area. As such there would be a greater risk compared to heat networks of individual users switching away from cooling networks in the event that cooling prices to customers do not remain competitive (e.g. due to a fall in electricity prices).

9 ***Example plants or TRL readiness***

The technology is slowly building traction in some countries because of its ability to alleviate demand on power systems.

Some examples include:

- San Adrià de Besòs Waste to Energy plant, Barcelona/Spain [3]. This plant provides cooling power via 2 x 4.5MW absorption chillers. Cooling is distributed (along with heating) by Districtlima. Cooling temperatures are 5.5°C, with a return temperature of 14°C. The plant also has 20MW electrically driven chiller and 10.4MW of chilling capacity in the form of a 5,000m^3 chilled water tank.
- Adelgade District Cooling, Copenhagen/Denmark [4]. The system provides chilled water to nearby users including banks, hotels, museums, offices and a mint. The capacity of cooling centre is 15 MW$_{th}$ and comprises a combination of free cooling using water from the nearby Nyhavn canal as well as a steam-driven absorption chiller. The capacity of the absorption chiller is 3.5 MW$_{th}$ and is driven using heat from the local district heating network. Water from the canal is also used for heat rejection, eliminating the need for cooling towers.

TRL Readiness Level	9+	All technology is proven but uptake and examples remain limited due to commercial reasons.

10 ***References***

	Reference	Strength of Evidence
[1]	*District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy*, UNEP, 2015	90%
[2]	Hofor Forsyning P/S Annual Report 2015 [In Danish]	80%
[3]	Hitachi Zosen Innova presentation, European Union Sustainable Energy Week, 2011	90%
[4]	Thermax Europe Website, *http://www.thermax-europe.com/district-cooling.aspx,*	70%

Title: 4th Generation Heat Networks - Item 7

1 *Technical description*

The evolution of district heating can be said to have evolved through three generations since its first introduction [1], the 1st generation being steam-based systems, the 2nd generation being high network supply temperatures (above 100°C) and the 3rd generation referring to district heating networks (DHN) using medium supply temperatures (between 80-100°C). The 4th generation of heat networks therefore refers to emerging new systems which use low-temperature district heating (LTDH).

In general, 4th generation heat networks refer to the technological and institutional concepts to broaden the suitability of district heating and cooling networks beyond their current areas of greatest suitability (densely populated areas located within cold climates). These concepts seek to reduce the minimum heat demand density required to make a network commercially viable. This allows networks to continue to be appropriate in areas where heat demand density are lower, either through lower dwelling density or the reduced heat demand as a result of energy efficiency improvements.

The four main features of 4th generation heat networks are as follows :

1. Ability to supply low-temperature district heating for space heating and hot water. This concerns the use of heat delivery temperatures below 50°C, compared to 100° for current generations;
2. Ability to distribute heat in networks with low grid losses;
3. Ability to utilise renewable heat and recycled heat from low-temperature sources. This includes waste heat from power generation (including WtE) as well as heat from other renewable sources (e.g. geothermal and solar thermal); and
4. Ability to form an integral part of smart energy systems (e.g. through intelligent control of demand and supply through demand-side response and thermal storage).

The deployment of 4th Generation Heat Networks would make district heating viable in a greater number of situations, increasing the potential for heat networks to be developed in areas in the vicinity of WtE plants. This would enable these plants to operate in a cogeneration mode and, as a consequence, increase their energy efficiency. In addition, the use of lower operating temperatures would enable WtE plants to supply the necessary heat with less impact on their power output, leading to higher power to heat ratios.

Examples of 4th Generation Heat Networks are available however these are currently limited to small-scale networks such as the $5MW_{th}$ system installed at Stadsoevers in the Netherlands. It is reported that the delivery of heat has no reduction on electricity production. Hot water is delivered at 40°C and may be raised to 65°C locally using heat pumps, so power consumption from the grid will be required. [1]

2 *Costs*

Cost data is limited however, work by the IEA [2] analyses a series of seven LTDH case studies and identifies investment costs of in the range €115 - 206 per metre network length and distribution costs of €3.2 – 13.7 per GJ of heating

	***Title:* 4th Generation Heat Networks - Item 7**
	delivered. The study explains that the wide variation in costs is due to the case studies covering a wide range of different LTDH design approaches.
3	***Achieved economic benefits*** In the case of utilising heat from Waste to Energy, the use of LTDH enables higher heat utilisation from flue gas condensation. The low return temperature from the system also makes direct flue gas condensation from combustion flue gases possible. This is due to the high moisture content in the feedstock. In addition, LTDH makes the use of heat pumps as a form of heat recovery more financially competitive, as both pressure and temperature can be lower in the heat pump condenser, therefore using less energy and giving a higher coefficient of performance. It is also possible to achieve a higher utilisation of low temperature sources, such as component cooling.
4	***Operational data*** Low supply temperatures means turbine electrical generation losses in the WtE plant are minimal. Where this is true, net annual average energy efficiency is estimated to rise from 76% to 82% for the most advanced plants.
5	***Environmental and/or human health benefits and drawbacks*** The principal benefit are the additional carbon emissions savings brought about by increased thermal efficiency and reduced network losses. In addition, as with previous generations of district heating, there will be local air quality benefits brought about by removing the need for local heat generating plant. This will be particularly marked where the incumbent heat generation is based on solid or liquid fuel.
6	***Technical considerations relevant to applicability*** Heat pumps may be required to raise water supply temperatures locally for some applications, these will require additional energy input. The network design must be compatible with lower temperatures.
7	***Driving forces or barriers for implementation including feedstock availability*** An advantage of LTDH are reduced heat losses and an improved synchronisation between heat supply and heat demand temperatures. This has the added benefit of reducing thermal stresses in pipework, offers the potential to use alternative pipe materials, and reduces the risk of the water boiling and risk of scalding. 4G networks still require a local energy user but the technology will help to expand the applicability of district heating and cooling. A further barrier is that LTDH will not be able to supply high-temperature heat demands.
8	***Residual risks*** There is a risk of legionella growth at low hot-water temperatures The transition from current DH systems to the next generation DH system requires coordinated efforts for building energy reduction [2]. As such, the failure to adopt higher standards of energy efficiency in terms of building fabric could restrict the applicability of LTDH.

***Title:* 4th Generation Heat Networks - Item 7**

9 ***Example plants or TRL readiness***

IEA[2] identify the following case studies for LTDH:

i. Kirsehir, Turkey
ii. Ringgården 34, Lystrup, Denmark
iii. Drake Landing, Okotoks, Canada
iv. Söndrum, Halmstad
v. Herting, Falkenberg
vi. Ackermannbogen, Munich, Germany
vii. Greenwatt Way, Slough, UK

None of the case studies identified were configured to directly utilise WtE as a heat source.

TRL Readiness Level	9	The only operating applications to date are relatively small scale.

10 ***References***

	Reference	**Strength of Evidence**
[1]	SUEZ Environment, Showcase for WtE efficiency, London, February 2015	70%
[2]	IEA DHC CHP, Toward 4th Generation District Heating: Experience and Potential of Low-Temperature District Heating, 2014	90%

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CL Plants

***Title:* Conversion of waste heat to power in cement kilns - Item 8**

1 ***Technical description***

The use of waste derived fuels in cement kilns is well established and well documented. The fuel is co-combusted with fossil fuels in the kiln, in order that the required temperatures are achieved for the production of clinker from raw mineral materials. The waste is fully combusted within the kiln.

Previously, waste heat from the process is used to pre-heat incoming materials, or is otherwise emitted to atmosphere. To increase the efficiency of this process, developments are being made to convert waste heat into power.

Heat is recovered from exhaust gases, and can either be used to provide low temperature heating within the process, or can be used to generate electricity.

Direct heat recovery to the process [1]

This method utilises heat that is directly in contact with incoming cooler materials, or air. Heat is transferred from the higher to lower temperature medium, effectively preheating the temperature of inputs to the kiln. This results in an increase in the efficiency of the kiln or preheater.

Waste heat boilers [1]

A further waste heat recovery (WHR) method is to use waste heat in a boiler. A waste heat boiler will consist of a series of tubes, similar to a conventional boiler. In this case, the boiler will raise steam by the water in the boiler being heated by waste heat from exhaust gases. This system can be used to provide further steam or hot water to the process.

Waste heat power generation [1]

Power can be generated using a Waste Heat Recovery Power Generation (WHRPG) system, which typically consists of a low-parameter steam turbine. The turbine is powered by steam generated from the waste heat, in turn producing electricity. There are several different ways in which power can be generated. A traditional steam Rankine cycle is the most efficient option for recovery of heat from exhaust gases when gas temperatures are in the range of 340°C–370°C *[1]*. When gas temperatures are lower, an organic Rankine cycle (ORC) or Kalina cycle is a more efficient option as they use working fluids with lower boiling temperatures.

Waste heat for district heating [2]

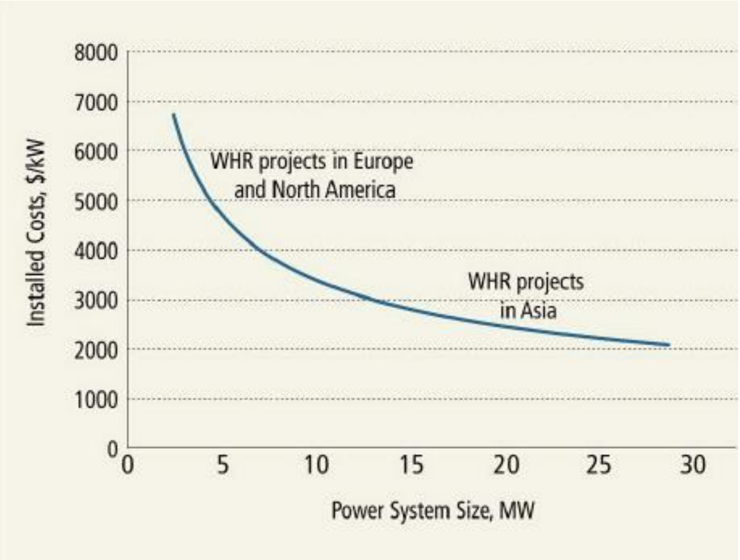
A further example of waste heat recovery from cement kilns is the use of heat for district heating networks. Heat is extracted via heat exchangers from the flue gas of the cement kilns.

2 ***Costs***

The capital costs of each waste heat recovery project will be dependent on site specific and project specific factors. For example, the amount of heat available, and the temperature of the exhaust gases will determine the size of the equipment required and the overall generation efficiency that can be achieved. WHRPG systems can be complex installations, consisting of boilers or heat exchangers, steam turbine, gearbox, generator, condenser, and associated piping, lubrication, water-treatment system and electrical equipment and controls. [3] Capex is closely correlated with size, with smaller systems incurring a higher cost

***Title:* Conversion of waste heat to power in cement kilns - Item 8**

per kW of output, see figure below [3].



3 *Achieved economic benefits*

- Reduced use of fossil fuels through the generation of power on site, and for a reduction in heat demand when heat is reused in the process
- Potential sale of district heating
- Project payback is directly linked to the price of electricity that the WHRPG is replacing

4 *Operational data*

A selection of operational data is summarised in the table below [5].

Company	**Country**	**Facility**	**Production capacity**	**WHR tech used**	**Output (kW)**	**Date of install**
Yingde CONCH Cement	China	Yingde	15,000 tonnes/day	AWC/PH*	27,000	2007
Siam Cement	Thailand	Kaeng Khoi	5,500 tonnes/day	AWC/PH*	9,100	2008
Aalborg Portland	Denmark	Aalborg	1.8 million tonnes/year	District Heating	1,200,000 (GJ)	1998

*Air Quenching Chamber boiler (recovers heat from exhaust gases)

** Pre Heater boiler (recovers heat from pre-heat system

5 *Environmental and/or human health benefits and drawbacks*

- Increases efficiency of the cement plant
- Reduces fossil fuel usage and associated carbon emissions
- CO2 emissions to the environment are also reduced by lowering the temperature of the exhaust gases.

6 *Technical considerations relevant to applicability*

The suitability of heat recovery from exhaust gases is impacted on by the moisture content of raw materials. Materials with a high moisture content can limit the

Title: **Conversion of waste heat to power in cement kilns - Item 8**

potential for waste heat recovery as the temperature and amount of exhaust gases will be reduced.

Retro-fitting to existing cement kilns to improve their efficiency is possible and therefore this technique is applicable to all member states which have cement kilns. In terms of applicability to waste streams, cement kilns are able to accept a wide range of waste derived fuels, including Solid Recovered Fuel, tyres, dried sewage sludge, animal wastes, spent solvents, and plastic wastes.

7 ***Driving forces or barriers for implementation including feedstock availability***

Drivers:

- Can contribute up to 30% of a plant's power demand
- Technology can contribute to sustainability and carbon reduction targets for the sector

Barriers:

- Moisture content of the input material can impact on the potential for heat recovery from exhaust gases
- High capital costs can make payback periods too long for developers

8 ***Residual risks***

- Supplying heat when plant is in shut down
- Financial benefits dependent on energy markets
- Cement industry output can be impacted on by national economic downturns
- Technology is widely deployed in China, India and US, but there are currently fewer examples in the EU.

9 ***Example plants or TRL readiness***

There are >700 plans in China, with other plants located in Asia, and a smaller number in the middle-waste, US and Europe.

TRL Readiness Level	9+	Technology widely demonstrated outside of Europe, particularly in China

10 ***References***

	Reference	**Strength of Evidence**
[1]	Amiri, A, Vaseghi M R, Waste Heat Recovery Power Generation Systems for Cement Production Process, 2014	80%
[2]	Aalborg Portland Case Study	80%*
[3]	International Finance Corporation, World Bank, Waste Heat Recovery for the Cement Sector: market and supplier analysis, 2014	80%
[4]	Information provided by Cembureau	80%
[5]	Waste Heat Recovery Power Plant in Cement Plants, Kawasaki Plant Systems Ltd	60%

Anaerobic Digestion

Title: **Sewage Sludge advanced AD – Thermal Hydrolysis Process (THP) – Item 9**

1 ***Technical description***

Thermal hydrolysis technology pre-treats sewage sludge in a two-stage process, which combines the medium-pressure boiling of sludge with a rapid decompression. This effectively sterilises the sludge and means that it is more suitable for anaerobic digestion and increases the production of biomethane. The sterilisation process destroys pathogens in the sludge, ensuring it is suitable for subsequent use in agriculture.

The Thermal Hydrolysis Process (THP) first dewaters the incoming sludge stream to 16.5% Dry Solids (DS) before the dried biomass enters a pressure vessel. Steam is added to the pressure vessel at roughly 12bar, degrading the biomass before high rate AD occurs. Conventional sewage sludge digestion achieves volatile solids destruction (VSD) of 40-50% which yields 300-350m^3 of biogas per tonne of Dry Solids (DS) which translates to a 40% mass reduction.

Typical sites with THP achieve 60% VSD and produce 450m^3 biomass per tonne of dry solids, representing approximately a 30% increase in gross energy output. However, insufficient high grade heat is produced by the process through CHP to meet all the THP process steam requirements, resulting in additional fuel (natural gas) being needed.

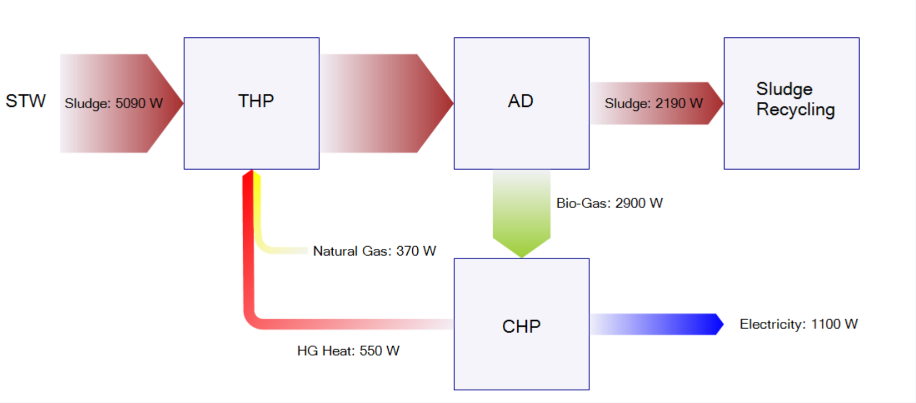


Image courtesy of DECC

2 ***Costs***

The investment required in a new THP plant is significant. A number of basic AD plants have been upgraded to THP plants with commercially acceptable payback periods.

The estimated costs of a large sewage treatment plant (100tpd DM) for conventional AD and in comparison to THP [1]:

Title: Sewage Sludge advanced AD – Thermal Hydrolysis Process (THP) – Item 9

	Conventional AD plant	Advanced AD and advanced energy recovery plant
Capex new build (M EUR)	70	73
Power output	3.5MW	4.9MW
Capex to retrofit advanced AD and energy recovery to a conventional AD plant (M EUR)	46	-

It can be seen that the predicted investment costs of a THP plant is broadly similar to a conventional AD plant, but the revenues from power output will be higher due to higher net energy efficiency.

3 ***Achieved economic benefits***

Higher biogas yields will increase power generation income.

4 ***Operational data***

Net annual electrical efficiency is estimated at 22% which is 6% higher than for conventional sewage sludge AD (16%). [1]

5 ***Environmental and/or human health benefits and drawbacks***

The technique is reported to have a low environmental impact, especially in relation to odour, visual impact and H&S [2]

6 ***Technical considerations relevant to applicability***

The high investment costs and planning & permitting restrictions limit the application of this process to large organic waste treatment facility (capacity of >50tDS/day).

The technique is applicable to a wide range of organic waste streams as many of the issues encountered when digesting a range of variable waste streams have been addressed by the thermal hydrolysis process. Therefore the technology meets the demand for a biological technology that is efficient in treating organic waste from multiple sources.

7 ***Driving forces or barriers for implementation including feedstock availability***

Drivers:

- The technology can result in increased biogas yields and increased volatile solids destruction. Land spreading of residual sewage sludge is becoming less accepted so a process which minimises the quantity of residual by-product is positive;
- The reduction in mass is greater when compared with conventional digestion;
- Transport costs can be reduced through enhance dewatering; and
- The effective destruction of pathogens ensures a high quality, marketable

***Title:* Sewage Sludge advanced AD – Thermal Hydrolysis Process (THP) – Item 9**

digestate.

Barriers

- Whilst biogas increases, the requirement for an input of high grade heat does not necessarily result in an overall net increase in energy yield, with many early plants requiring a support fuel, typically natural gas, to support the process. [3] However second generation THP plants do not require support fuel and are able to recover sufficient heat from the process to be self-sufficient. [4]

8 ***Residual risks***

Residual risks are considered to be low as this is a well-established technique.

9 ***Example plants or TRL readiness***

Since the first installation in Hamar, Norway in 1996, there are now estimated to be over 30 AD plants incorporating thermal hydrolysis globally [5]

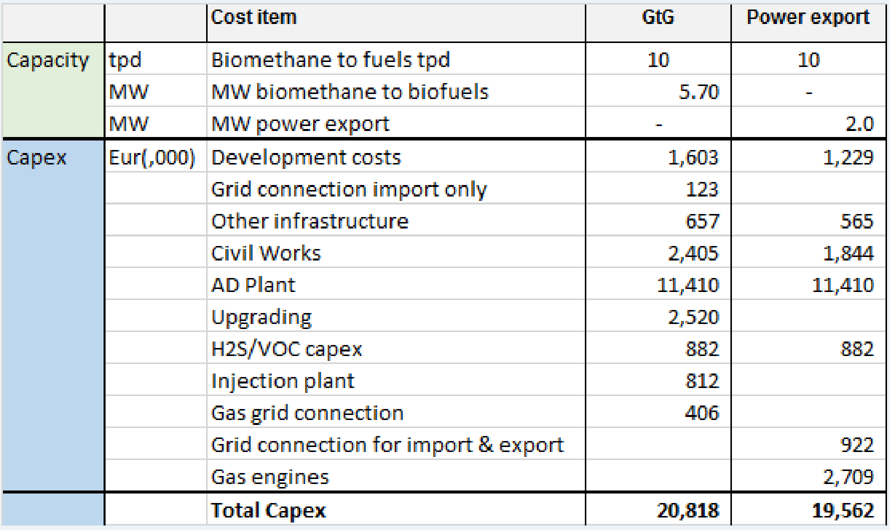
TRL Readiness Level	9+	There are a number of large THP plants successfully operating in Europe.

10 ***References***

	Reference	**Strength of Evidence**
[1]	UK Department of Energy and Climate change and UK Water Industry. Cost in GBP converted to EUR at 1:1.4.	50%
[2]	Treating organic waste with Cambi THP, Wojtech.Sargalski, Odd Egil Solheim, Carsten Fjordside Cambi AS.	80%
[3]	Mills, N, et al, Life Cycle Assessment Of Advanced Anaerobic Digestion Process Configurations For Sewage Sludge - A UK Perspective	80%
[4]	UK Department of Energy and Climate change and UK Water Industry.	50%
[5]	Beckton & Crossness Thermal Hydrolysis Plants advanced sludge digestion facility (ESDF) Case Study, Andre Le Roux & Andrew Bowen	90%

	Title: **AD with biogas injection to grid - Item 10**
1	***Technical description*** Anaerobic digestion (AD) is a biological process through which micro-organisms break down organic material in an enclosed system without the presence of oxygen. As the material is digested, it is converted to biogas, a mixture of methane and carbon dioxide. The biogas can be combusted in an engine to produce electricity and heat. However, the biogas produced has the same composition as fossil-fuel derived methane and therefore is also suitable for use as a substitute for natural gas via a gas to grid network. The methane rich biogas is upgraded to biomethane by the removal of impurities such as CO_2 and H_2S, which are removed by scrubbers and activated carbon filters. A small volume of propane is added to the methane to ensure the gas has the same natural gas quality. The biomethane is continuously analysed under strict quality control procedures prior to being fed into the local gas distribution network In summary, the 'upgrading' of biogas to meet quality standards necessary to permit the injection of gas into the natural gas network involves the following principal stages. • removal of hydrogen sulphide and carbon dioxide from the biogas • enrichment using propane to meet calorific value and Wobbe Index requirements • compression to meet network pressure requirements A number of separation technologies exist for the removal of carbon dioxide but the most commonly used a membrane separation and 'water wash'. The overall energy efficiency of the AD - GtG process is 41% based on the energy content of the organic waste input versus biomethane injected to grid [1]. The European Biogas Association predicts that GtG will be a more popular route of delivering biomethane to consumers than other more energy intensive routes such as liquefaction and compression / trailer transport [2].
2	***Costs*** Costs for development of a biomethane gas to grid project will be site specific, and will depend on the complexities of each site, and also the degree of civil engineering work required. The capex required for biogas upgrading equipment is over and above that required for standard AD, but this is offset as no gas engine purchase is required. An estimation of the capex for an AD plant injecting 10 tpd of biomethane to grid is shown below in comparison to an equivalent power only plant (with 2MW power export) [4].

Title: AD with biogas injection to grid - Item 10



		Cost item	GtG	Power export
Capacity	tpd	Biomethane to fuels tpd	10	10
	MW	MW biomethane to biofuels	5.70	-
	MW	MW power export	-	2.0
Capex	Eur(,000)	Development costs	1,603	1,229
		Grid connection import only	123	
		Other infrastructure	657	565
		Civil Works	2,405	1,844
		AD Plant	11,410	11,410
		Upgrading	2,520	
		H2S/VOC capex	882	882
		Injection plant	812	
		Gas grid connection	406	
		Grid connection for import & export		922
		Gas engines		2,709
		Total Capex	**20,818**	**19,562**

There is some evidence that the cost of gas grid connections is reducing, as the technology becomes more widely deployed.

3 ***Achieved economic benefits***

In terms of Opex, injecting the gas (as biomethane) into a gas grid can access to a higher price when compared to other biogas applications [3] as domestic gas use tariffs can be charged.

Biomethane is often exempt of tax, and can be eligible for other financial incentives, for example biomethane injection to grid in the UK is eligible for tariffs under the Renewable Heat Incentive.

4 ***Operational data***

There are approximately 200 plants across Europe that upgrade biogas to biomethane for injection to grid, and this number is growing. Example operational data of the Rainbarrow Farm Biomethane grid injection facility opened in Poundbury, UK in 2012 is included below [5].

Feedstock	4,000 tonnes potato waste, 26,000 tonnes maize silage, 4,000 tonnes grass silage, and 7000 tonnes food waste
Annual raw gas production	7,450,000 m3
Grid injection	400m3/hr, Annual biomethane injected to grid – 3,500,000 m3
Gas composition	Methane content in raw biogas – 53% Methane content in product gas – 96%
Target CV of gas grid	39.5 MJ/m^3

5 ***Environmental and/or human health benefits and drawbacks***

There are clear environmental benefits of utilising organic waste to produce biomethane for gas grid injection. Waste derived biomethane can be used in energy efficient installations such as domestic heating and cooking facilities or to feed CCGT combustion plants.

Title: AD with biogas injection to grid - Item 10

6 *Technical considerations relevant to applicability*

The level of biogas clean-up is more significant for injection of gas to grid, that the gas purity levels needed for use in CHP engines.

Connections to the local gas network can be complex, and may require a long lead time.

7 *Driving forces or barriers for implementation including feedstock availability*

Drivers:

- This technology is applicable to a wide range of waste feedstocks, including food waste from households, agricultural waste, commerce and industry, industrial effluents and sewage sludge.
- Biomethane has a higher energy density than biogas and can increase overall net efficiency
- Contribution to renewable energy targets

Barriers

- Degree of upgrading can add substantially to the cost and energy requirement
- Limited financial incentives or subsidies
- Distance of AD plants to gas distribution network

8 *Residual risks*

- Ability to meet gas quality standards which differ across member states
- Acceptance by, and capacity of local grid

9 *Example plants or TRL readiness*

The European Biogas Assocation report that there are in the region of 200 biogas plants which are injecting biomethane to the gas grid.

TRL Readiness Level	9+	Biomethane injection to grid in 200 biogas plants across 16 member states

10 *References*

	Reference	**Strength of Evidence**
[1]	ISWA CE Report 5, pg. 25	
[2]	EBA interview, February 2016	90%
[3]	Department of Energy & Climate Change, UK, Biomethane in to the Gas Network – A Guide for producers, 2009	90%
[4]	UK Department for Transport / Ricardo, 2015	90%
[5]	EU GreenGasGrids Best Practice Example – Rainbarrow Farm, Poundbury	100%

Title: Sewage Sludge Advanced AD with Advanced Energy Recovery (Pyrolysis) – Item 11

1 ***Technical description (Emerging technique)***

This technique incorporates sewage sludge advanced AD with advanced energy recovery (pyrolysis) as the final stage of energy recovery from the sewage sludge stream. Before the pyrolysis process, a dryer produces a solid fuel feed using biomass from either a THP sludge treatment process (as shown below) or an ITHP process. The pyrolysis process has been shown to reduce the mass of the biomass solids by 90%, liberating a pyrolysis gas with a high CV of 11 - 20MJ/m^3 and leaving very little residual product for disposal.

The fuel gas from the pyrolysis process is then utilised in a second gas engine (CHP2). CHP1 is a gas engine running on biogas from the AD process. Both CHP units produce heat which is split into a high and low grade. The high grade heat (200°C) is used to raise steam for THP and low grade heat used for sludge drying. Unlike other THP processes there is no requirement for support fuel due to the combination of CHP units raising all of the steam for THP. Pyrolysis shows the most potential as a form of advanced energy recovery.

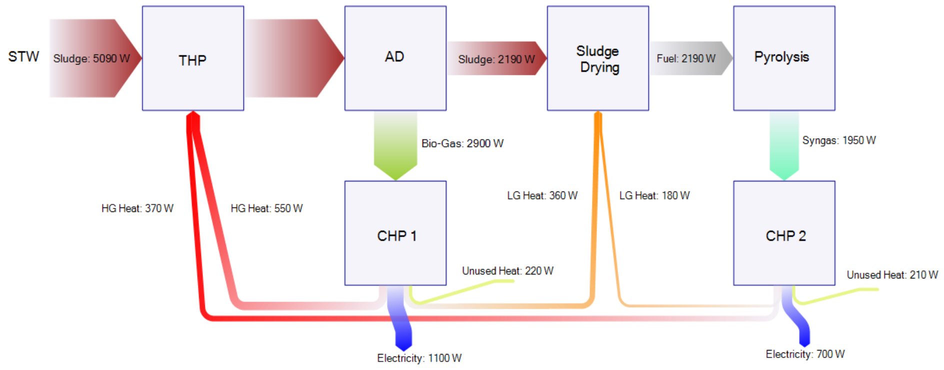


Image courtesy of DECC

2 ***Costs***

The estimated costs of a large sewage treatment plant (100tpd DM) for conventional AD and in comparison to an advanced energy recovery plant are shown below [1]:

	Conventional AD plant	Advanced AD and advanced energy recovery plant
Capex new build (M EUR)	70	73
Power output	3.5MW	8.5MW
Capex to retrofit advanced AD and energy recovery to a conventional AD plant (M EUR)	84	-

It can be seen that the predicted investment costs of an advanced plant are significantly more than for a conventional AD plant, but the revenues from power output will be higher and by-product disposal costs will be reduced due to lower quantities.

As an advanced process some Member States may also offer financial incentives.

	Title: **Sewage Sludge Advanced AD with Advanced Energy Recovery (Pyrolysis) – Item 11**
3	***Achieved economic benefits*** This technique greatly reduces the amount of residual by-product following treatment of sewage sludge. Volume reduction is 96% compared to 40% for conventional AD. Spreading of sludge to land is not always possible (about 60% of sludge produced is spread to land on average) and may come at a cost so minimising the quantity of residual by-product is financially advantageous. The high net electrical efficiency of the process can generate increased power sales revenue. Net annual average efficiency is estimated at 35% which is 19% higher than for conventional AD (16%) [2].
4	***Operational data*** As a low TRL emerging process, there is no operational data available.
5	***Environmental and/or human health benefits and drawbacks*** Alternative methods of treating sewage sludge have been developed as restrictions on the disposal of sewage sludge have gradually tightened across the EU-28.
6	***Technical considerations relevant to applicability*** The high investment costs and planning & permitting restrictions limit the application of this process to large sewage works (capacity of >50tDS/day). Although this technique has been developed for sewage sludge, potentially other organic feedstocks could be used which would broaden the applicability of the technique.
7	***Driving forces or barriers for implementation including feedstock availability*** Drivers: • The Renewable Energy Directive requires a 15% reduction in carbon emissions by 2020 in all EU-28 Member States. This is driving the development of low carbon energy generation. • The technology can result in increased biogas yields and increased volatile solids destruction. Land spreading of residual sewage sludge is becoming less accepted so a process which minimises the quantity of residual by-product is positive. Feedstock availability • Task 1 has shown that feedstock availability is reasonable with approximately 10M tpa of municipal sewage sludge (dry matter) being available.
8	***Residual risks*** • Pyrolysis has been shown in trials to more effective on homogenous waste streams such as biomass or paper sludge [3] but the process has not been proven on these feedstocks or dried sewage /sludge cake as is proposed in this technique. The most difficult aspect remains the combustion of the pyrolysis syngas in a reciprocating gas engine.

	Title: **Sewage Sludge Advanced AD with Advanced Energy Recovery (Pyrolysis) – Item 11**
9	***Example plants or TRL readiness*** The pyrolysis aspect of the technique as a whole is at a low stage of development, the advanced AD element is however commercially proven.

TRL Readiness Level	5	Only pilot studies have been completed for the whole end to end process.

10	***References***

	Reference	**Strength of Evidence**
[1]	UK Department of Energy and Climate change and UK Water Industry. Cost in GBP converted to EUR at 1:1.4.	50%
[2]	UK Department of Energy and Climate change and UK Water Industry	50%
[3]	CEPI, study expert workshop, March 2016	50%

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Other WtE plants

Title: Hydro treatment of waste edible oils and fats to produce biodiesel – Item 12

1 ***Technical description***

An alternative to the traditional Fatty Acid Methyl Ester process for converting UCO and animal fat waste streams to biodiesel is to refine these feedstocks into biodiesel using hydrogen. One of the benefits of biodiesel produced in this way is that it can be used directly in engines and fuel distribution systems (rather than as a drop in fuel, blended with fossil diesel) as its composition is similar to fossil diesel alternatives i.e. C_nH_{2n+2} [1]. The processes is reported to be compatible with existing fuel distribution systems and engines and meets manufacturer quality requirements.

Following bleaching pre-treatment (using acids precipitating out as a salt) to remove impurities from the feedstock, the hydro treatment process consists of three main process steps / reactors:

1) Catalytic hydro treatment
2) Stripping
3) Isomerisation

This process is a continuous process during which the feedstock flows from one reactor to the next without intermediate storage. The reactors are fixed bed reactors specially designed to withstand high pressure and temperatures needed for the process. Process conditions are:

Pressure : min. 30 bar

Temperature : min. 265°C

The process requires the production and use of both hydrogen and steam.

2 ***Costs***

The most recent plant constructed utilising this technique in Rotterdam in 2011 has an output capacity of 1m tpa of biodiesel (using both waste and non-wastes feedstock). This large plant had an investment cost of Eur. 670m [2].

3 ***Achieved economic benefits***

Much of the global market for biofuels is driven by demand in the United States (and particular California) where EISA legislation requires minimum volumes of biofuels to be supplied to the US market otherwise a waiver fee is applicable. This is a significant export opportunity for European companies.

In Europe, incentives are being offered in Member States for the production and sale of renewable transport fuels.

4 ***Operational data***

Operational data has been provided for a plant in Singapore producing biodiesel [3]:

Title: Hydro treatment of waste edible oils and fats to produce biodiesel – Item 12

Feedstock and consumables	1.21 m tpa waste animal fats, edible oil, palm oil (30,000 tpa rejects) 3,800 tpa hydrogen
Annual production	1m tpa biodiesel Smaller quantities of bio naphtha and propane rich off gas

There are also production plants in Finland, Netherlands, Italy and Sweden.

5 ***Environmental and/or human health benefits and drawbacks***

Biodiesel has the advantage that it provides lower NO_x and particulate emissions than conventional fossil diesel and can therefore assist with improving air quality in urban areas.

Biodiesel produced using this process is claimed to provide an 85% reduction in GHG emissions as calculated in accordance with the RED directive.

This form of technique can also utilise crop based feedstocks. This needs to be monitored to ensure waste feedstock is used where possible and any crop feedstocks added are from environmentally certified sources.

Animal by-products feedstock (Category 2 and 3) has been approved as a safe feedstock. Category 1 by-products are not yet approved for use.

6 ***Technical considerations relevant to applicability***

Traditional biodiesel is limited in applicability as it is strictly limited in the quantity that manufacturers will permit for use within internal combustion engines. Where biodiesel from hydro treatment can be used as a direct replacement for fossil diesel, this will enhance the applicability of the product.

7 ***Driving forces or barriers for implementation including feedstock availability***

Drivers:

- The Renewable Energy Directive requires a 15% reduction in carbon emissions by 2020 in all EU-28 Member States. This is driving the development of low carbon biofuels processes.
- As this technique can produce a jet fuel, this is a key advantage as there are currently no alternative means of jet propulsion other than the combustion of fuel in a jet engine (i.e. road vehicles can be run on electric power or hydrogen fuel cells)

Barriers

- Feedstock availability - from task 1, it was estimated that 500,000 tonnes of edible oil and fats waste was collected in the EU-28 and an equivalent amount of biodiesel was produced. This is only 1% of the total available waste in the EU_28 so is therefore quite a limited feedstock. The process can also utilise non-wastes such as palm oil as feedstock but this is not the preferred option.

	Title: **Hydro treatment of waste edible oils and fats to produce biodiesel – Item 12**
8	***Residual risks*** - With many large plants providing significant quantities of biofuel, residual technology risks are considered low
9	***Example plants or TRL readiness*** There are many large plants globally with a total capacity of 3.5m tonnes provided by a number of suppliers.
10	***References***

TRL Readiness Level	9+	

	Reference	**Strength of Evidence**
[1]	Finish Ministry of the Environment, April 2016	90%
[2]	Neste, March 2016	90%
[3]	Finish Ministry of the Environment, April 2016	90%

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Title: Two stage combustion with Plasma – Item 13

1 *Technical description (Emerging technique)*

Plasma is the term that applies to a range of technologies that involve the use of a plasma torch or arc. Waste is exposed to extremely high temperatures (over 5,000°C / 10,000°F) in the presence of controlled amounts of steam, air and oxygen. Waste is converted to syngas, composed primarily of carbon monoxide (CO), hydrogen (H_2) and other gaseous constituents. The syngas can then be cleaned and used within gas engines for electrical and heat energy recovery. Materials which are not gasified are vitrified leaving the bottom of the gasifier as an inert glass-like slag

Plasma arc processing has been used for years for many years for the treatment of waste, in particular hazardous waste, such as incinerator fly ash and chemical weapons, and convert them into non-hazardous slag. Plasma gasification is still an emerging technology in terms of its application to mixed waste streams, but there are a number of examples of the technology being utilised to convert municipal solid waste to energy, with the potential to achieve higher efficiencies that other energy from waste systems. High efficiencies are attributed to the high temperatures involved, in addition to the high heat density and almost complete conversion of the carbon-based materials to syngas, and the conversion of non-organic materials to slag.

The two stage combustion with plasma process is multi-stage. The first step will typically be to pre-treat the feedstock to ensure it is homogenous and dry, and also to remove recyclable materials. The second step is to gasify the waste, where the carbon in the waste streams will be broken down in to gases, and the inorganic materials will melt in to a liquid slag. The slag will be tapped off and cooled. The third stage is to treat the syngas further with a plasma torch, which results in a polished, high quality syngas.

2 *Costs*

The capital costs for this technology are likely to be higher than conventional combustion as the immaturity of the technology, when applied to municipal waste, is not sufficient to secure as much investor confidence or for competition amongst suppliers to drive down equipment costs [1].

3 *Achieved economic benefits*

The economic benefits of this technology include:

- Income from gate fees for incoming waste
- Income from sale of recyclables
- Income from sale of power – electricity, or liquid fuels and other chemical commodities that can be derived from the syngas.

4 *Operational data*

Due to the low TRL, there is no publically available operational data.

5 *Environmental and/or human health benefits and drawbacks*

Some operators claim high efficiencies when compared to conventional combustion [2]. A further environmental benefit is that the syngas can be cleaned, via the plasma torch polishing, and therefore flue gases should be have require less clean up, and this should be at a lower cost than the post-combustion cleaning of conventional combustion flue gases.

	Title: **Two stage combustion with Plasma – Item 13**
6	***Technical considerations relevant to applicability*** Refuse Derived Fuel such as that used in combustion or gasification can contain a high quantity of ash and volatile materials [3]. These can decrease the thermal output in the combustion or gasification process, resulting in high ash clinkering, and increasing the emission of tars and CO_2. This in turn can affect the potential for achieving clean syngas for further industrial use. This technical issue can be addressed by using the two-stage process which separates the primary gasification from the plasma torch polishing which can remove the organic contaminants from the gas.
7	***Driving forces or barriers for implementation including feedstock availability*** Drivers: • Potential to utilise higher efficiency energy recovery systems • Processing of organic waste into combustible syngas for electric power and thermal energy • The plasma torch process results in a polish, high quality syngas which can be used in gas engines or further upgraded or synthesised to other products • Can be used for the reliable destruction of hazardous wastes Barriers: • Requires pre-treatment or specific feedstocks • Large initial investment costs
8	***Residual risks*** • Limited commercial scale examples • A number of plasma processes have experienced difficulty in achieving commercial viability, where technical issues have caused low availability • High capital costs
9	***Example plants or TRL readiness*** A two stage combustion process has been developed which combines a gasification stage with a second plasma stage, i.e. the gasification of waste and biomass followed by the post-treatment of gasification products with plasma. The plant in Morcenx, 100km south of Bordeaux, utilises 50,000t/y of commercial and industrial waste plus 7000t/y waste wood fuel and 30,000t/y of solid recovered fuel (8t/hour). The Solid Recovered Fuel is produced on-site from commercial and industrial waste. Waste is shredded and inerts and metals removed. If necessary, waste is dried using heat from the process. All fuels are mixed to ensure a homogenous fuel to optimise the process. The prepared fuel is fed in to the gasification where it is converted to a syngas. The gas is then refined using a patented Turboplasma process. The plasma torch uses 10MW, which is maintained for approximately 1 second. This heats the syngas to 1200°C which thermally cracks the syngas. The Turboplasma technology acts to polish the syngas, in that it reduces the amount of tar formed during the gasification reaction. The syngas obtained can then be used for chemical applications or for electricity production. In the Morcenx facility, the syngas is then cooled, its heat recovered, then filtered. At this stage, the syngas is of commercial quality. The syngas is injected in to gas engines to produce electricity. Heat from both the gasification process and the gas engines is used to raise steam in a turbine, generating 11MWe of

***Title:* Two stage combustion with Plasma – Item 13**

power. 18MWth of heat is used deliver heat to a wood dryer which is used to dry wood chip to <20% moisture content and there are plans to also supply heat to a greenhouse. The electrical efficiency of the CHO Power system is stated as being able to reach 35-40%.

Other companies have also developed two stage processes which combines fluidised bed gasification with plasma technology [3]. This process uses a bubbling fluidized bed gasifier. The syngas produced is then treated in a direct current (DC) plasma converter that polishes the gas by removing the organic contaminants and collects the inorganic material in an inert, molten slag. This technology is currently at demonstration stage.

TRL Readiness Level	8	There is a commercial scale demonstration plant in France with other plants in development using similar plasma technology.

10 ***References***

	Reference	**Strength of Evidence**
[1]	Ducharme, C, Technical and economic analysis of Plasma-assisted Waste-to-Energy processes, Thesis, 2010	
[2]	CHO Power brochure	
[3]	Materazzi, M., et al. Performance analysis of RDF gasification in a two stage fluidized bed–plasma process. Waste Management, 2015	

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Title: Bioethanol from waste – Item 14

1 ***Technical description (Emerging technique)***

In addition to being used directly to generate heat and power, municipal waste and other biowastes can be converted into intermediate liquid and gaseous biofuels, including ethanol.

Ethanol is traditionally produced either through the fermentation of sugar and starch or through the hydrolysis and fermentation of cellulosic material. Bioethanol is produced mainly from sugar or starch rich food crops. However, bioethanol can also be produced by treating a certain range of organic fractions of waste. Different technologies exist; each of which involving separate stages for hydrolysis (by enzymatic treatment), fermentation (by use of microorganisms) and distillation.

An example of this is the conversion of pre-treated waste to a syngas, which is subsequently then converted into biofuels and commodity chemicals, using commercially available catalysts. The process will typically consist of feedstock preparation, gasification, cleaning and conditioning of the syngas, and finally synthesis of the syngas in the products, which can include methanol and ethanol. The Fisher-Tropsch process used for synthesis is a combination of chemical reactions which is used to convert syngas into liquids hydrocarbons.

The syngas produced can be used in boilers and engines or turbines, or can be used to synthesise a range of liquid hydrocarbons including distillate fuels (including diesel fuel and kerosene), alcohols (methanol and ethanol) and fertilisers (ammonia).

Waste-based ethanol can be refined from a number of industrial and municipal sources of waste. There are 3 main techniques for the conversion of waste to bioethanol: [1]

- *Biochemical ethanol processing:* This process uses enzymes to break cellulose in the waste in to into simple sugars, such as glucose. These are then pre-treated with an acid, alkali or steam, before the enzymic conversion in to ethanol.
- *Gasification and Fischer Tropsch*: This process first gasifies the feedstock in a gasification chamber, at temperatures in excess of 700°C and in the presence of limited oxygen and/or steam. The syngas is then converted into diesel by the addition of catalysts, and at temperatures of 150-300°C.
- *Pyrolysis:* unlike gasification, pyrolysis of waste takes place at high temperatures but in the absence of oxygen. Waste is converted in to bio-oil, biochar and syngas. The bio-oil can up upgraded by to break it down in to hydrocarbons for diesel.

Ethanol can be used as a transport fuel as an alternative to replace petrol or diesel, in power generation by thermal combustion, as a fuel in cogeneration systems and as a feedstock in the chemicals industry.

2 ***Costs***

The conversion of wastes to bioethanol is understood to be possible at a lower cost than traditional crop based feedstocks as the feedstock is available at low cost, or can be subject in a gate-fee income, as opposed to the cost of cultivating crop based feedstocks. However, the capex and opex costs are likely to be higher than for crop-based ethanol due to the feedstock preparation required, and other technical factors associated with using a less homogenous feedstock.

	***Title:* Bioethanol from waste – Item 14**
3	***Achieved economic benefits*** Economic benefits are linked to oil prices as this also determines the production cost of competitors to biofuel, i.e. fossil transport fuels. The production costs of agricultural commodities are also dependent on the movement of oil prices. Therefore the economics of the production of bioethanol from wastes, and in particular municipal solid wastes, can be an important driver.
4	***Operational data*** The majority of advanced biofuels plants currently producing ethanol from second generation feedstocks (which excludes feedstocks such waste edible oils) are relatively small scale. For example, there are currently there are five operational plants in Finland using one variant of biochemical ethanol processing. The sum of the production capacities of these five plants is 15 million litres of bioethanol per year which represents an average output of 3 million litres (approx 2,400 tonnes). A new plant producing bioethanol from saw dust is under construction and will be started in 2016. This will add to the production capacity by 10 million litres.
5	***Environmental and/or human health benefits and drawbacks*** Lifecycle CO2 costs are lower than for fossil fuels or crop-based biofuels [2]. In many parts of Europe where municipal solid waste is still predominantly landfilled, its conversion to biofuels would provide significant GHG savings. The displacement GHG emissions for ethanol from municipal solid waste is estimated at -225g CO2e/MJ [1].
6	***Technical considerations relevant to applicability*** Whilst waste based feedstock offer a stable and cost effective feedstock for ethanol production, the technology for conversion of wastes to biofuels is less proven than crop-based and other first generation conversion technologies. A further technical consideration is that municipal solid waste may require extensive pre-treatment, i.e. a Solid Recovered Fuel may need to be produced, as opposed to raw residual waste. However, the technique is applicable to a wide range of organic-wastes.
7	***Driving forces or barriers for implementation including feedstock availability*** Drivers: • The use of waste-derived bioethanol can contribute to mitigating climate change, and deliver additional benefits such as reducing land competition between energy and food crops • There are potential economic benefits achievable from using low value feedstocks • The technology could be applicable to the onsite conversion of some specific organic waste streams that are difficult to economically transport for disposal or treatment, i.e. liquid waste streams from food and beverage processing • Potential to increase the value of high value utilisation of low value waste streams, improving revenue for the industries that produce and process these residue streams

***Title:* Bioethanol from waste – Item 14**

- Some conversion processes can convert over 40% of the waste input energy into biofuel. Where heat use is not possible, this is a potential route to increase the energy efficiency of WtE

Barriers:

- Competing uses of waste feedstocks could be a barrier in some locations
- The collection of organic waste feedstocks may not be widely deployed in some member states
- Technologies could still be considered immature, with investors lacking confidence
- There is a call for more policy support and incentives, including increasing targets for the use of biofuels in transport

8 ***Residual risks***

- Limited commercially
- Competition with other proven energy from waste technologies, impacting on feedstock cost and security of supply
- Price volatility of competing products
-

9 ***Example plants or TRL readiness***

Example plants include:

Edmonton [3] – The Edmonton plant uses patented technology chemically recycles the carbon molecules contained in non-recyclable waste by converting these first in to a syngas, which is then converted into biofuels and commodity chemicals, using commercially available catalysts. The thermochemical process consists of 4 steps: feedstock preparation, gasification, cleaning and conditioning of syngas, and catalytic synthesis. In this technique, waste feedstocks are converted into methanol, ethanol or other renewable chemicals

Finland and Sweden [4] - There are five plants in which convert sugar and starch-rich waste streams from bakeries, breweries and potato processing factories in to ethanol. They also have a Bionolic plant which converts the biological fractions of municipal solid waste.

TRL Readiness Level	9	Some commercial scale process demonstration examples, with more in development.

10 ***References***

	Reference	**Strength of Evidence**
[1]	Wasted: Europe's Untapped Resource – An Assessment of Advanced Biofuels from Waste & Residues	90%
[2]	Recreate: Policy Brief No. 2, November 2015, Producing Bio-ethanol from residues and wastes	90%
[3]	Information provided by Enerkem	60%
[4]	St1 Biofuels White Paper: Creating New Business from Waste-Based Advanced Ethanol – www.st1biofuels.com	70%

7 Task 3 - Outlook on developments in the Waste-to-energy landscape

Future development in the waste-to-energy landscape will depend on two main aspects:

- Evolution of waste management practices in accordance with the waste hierarchy;
- Technical improvement, especially on the energy efficiency of techniques used in Europe.

Based on information from tasks 1 and 2, this task aims at providing an in-depth analysis of these two aspects.

7.1 Adapt the amount of waste sent to energy recovery

According to task 1, most waste streams that are currently being sent for energy recovery are also partially recycled and landfilled. The waste hierarchy states that whenever possible, material recovery (recycling) and energy recovery should be preferred to landfill disposal. For technical, economic and environmental reasons, in Europe all these treatment pathways will continue to be used, but it is possible to adapt the amount of waste sent to incineration to better comply with the waste treatment hierarchy. In this context, a methodology has been developed to estimate the amount of waste that could be sent to energy recovery by moving up in the waste treatment hierarchy. This methodology is based on scenarios defined by Member States' waste management practices in 2012, and assuming that countries move forward to frontrunners.

Annex 5 provides for all waste streams, the data used to build the scenarios. In the following paragraphs we provide a methodology, but the reader could feel free to use the data provided in Annex 5 to develop his own methodology and to build additional scenarios.

7.1.1 Description of the methodology

A two steps methodology was used to provide an outlook on possible developments in the EU-28 waste management practices (an example is provided in the next paragraph to provide a better understanding of the methodology):

- **Step 1**: selection of EU-28 frontrunners for each waste streams. These frontrunners are Member States whose management practices are considered as more compliant with the waste hierarchy. Using the database built in task 1, frontrunners are Member States with lowest landfill rates and representing 20% (in weight) of wastes treated.
- **Step 2**: definition of the 3 scenarios. We assume that diversion from landfill by "follower countries" will either be realised by more incineration or by more recycling/non-energy recovery. In order to have an indication in what interval of incineration/non-energy recovery countries will operate, we examine what the group of frontrunners are doing.

  To this extent, we look at those countries relying less and those countries relying more on incineration. In mathematical terms, this means that we respectively pick the 20-percentile and 80-percentile values for incineration. The complementing recovery (other than energy recovery) rates are then obtained as 100%-average landfill rate from the frontrunners-percentile values of incineration from the frontrunners. Based on this approach, the 3 scenarios are defined as follow:

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  - **Baseline scenario**: management practices of EU-28 Member States in 2012, using data from task 1. Baseline scenario is the current (2012) solution.
  - **Scenario 1 (high incineration, some recovery other than energy recovery)**: landfill in all countries is capped at the average from the frontrunners, a minimum recovery (other than energy recovery) rate is imposed based on the 80-percentile value for incineration from the frontrunner group, and the rest is sent for incineration;
  - **Scenario 2 (moderate incineration, more recovery other than energy recovery)**: landfill in all countries is capped at the average from the frontrunners, a minimum recovery (other than energy recovery) rate is imposed based on the 20-percentile value for incineration from the frontrunner group, and the rest is sent for incineration.
- **Step 3**: determination of waste management practices for all Member States for scenarios 1 and 2. In those 2 scenarios, countries cannot perform worse in terms of landfilling or non-energy recovery than what they are currently doing. So, if their landfill rate is lower than the average from the top-group, they keep the value from the baseline scenario. The same applies for non-energy recovery: if their non-energy recovery is higher than the value demanded by the percentiles from the top-group, they keep the value from the baseline scenario. Incineration rates are always calculated as the complement of landfill and non-energy recovery.
- **Step 4**: calculation of the amount of wastes sent to each treatment method at European level for the two scenarios. Applying steps 1 to 3 to all Member States and for each of the waste stream, it is possible to estimate the amount of wastes sent in landfill, incineration and recovery (other than energy recovery) in the EU-28.

The described methodology is mainly based on Eurostat Waste Statistics for 2012. Thus, it doesn't take into account evolutions in country waste management system after 2012, such as the Spanish National Waste Management Plan approved at the end of 2015 to comply with the hierarchy of waste management.

The aforementioned methodology cannot be used for all combustible wastes studied in task 1:

- by definition, waste-derived-biofuels (biogas, bioethanol, and biodiesel) are used for energy production, and are therefore excluded from the scenarios;
- datasets for the treatment of "used oils" and "Edible oil and fat" don't provide sufficient detail to use the aforementioned methodology. These two waste streams are therefore also excluded from the scenarios. It does not impact the robustness of the methodology, because these two waste streams account for less than 1% in mass and less than 1% in energy potential of all combustible waste studied;

More details on the data used to build the scenarios is available for each waste stream in Annex 5.

7.1.2 Example of the methodology for Mixed and Undifferentiated Materials (M&UM)

This paragraph presents the approach step by step for M&UM.

Step 1: selection of frontrunners based on lowest landfill rates

Using data from task 1, Table 3.61 shows the management practices for the 14 Member States with lowest landfill rates for Mixed and Undifferentiated Materials in 2012.

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Table 3.61: Management practices for the 14 Member States with lowest landfill rates for Mixed and Undifferentiated Materials in 2012 – frontrunners in yellow

Share of the country in total	Cumulative share	Country	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration (D10 & R1) (%)	Recovery other than energy recovery (%)
0.0%	0%	Luxembourg	1	0%	31%	69%
0.3%	0%	Austria	110	0%	94%	1%
11%	12%	Belgium	3 779	3%	93%	4%
1%	12%	Greece	244	5%	1%	94%
3%	15%	Denmark	981	7%	36%	56%
8%	23%	Poland	2 629	8%	4%	88%
16%	39%	Germany	5 160	8%	43%	48%
9%	48%	Sweden	2 928	10%	80%	9%
0.2%	48%	Slovenia	50	11%	14%	75%
13%	61%	Italy	4 408	13%	20%	67%
1%	62%	Hungary	329	15%	64%	22%
3%	65%	Netherlands	865	17%	17%	66%
1%	66%	Romania	447	17%	16%	67%
1%	67%	Latvia	266	17%	1%	82%

Step 2: definition of the 2 scenarios (other than the baseline scenario)

Based on frontrunners data from Table 3.61, mathematic formulae have been used to calculate the following waste management parameters:

- Landfill weighted average: 5.3%
- Incineration 80%-percentile: 92.6% / resulting recovery (other than energy recovery) lower percentage: 2.1%
- Incineration 20%-percentile: 3.8% / resulting recovery (other than energy recovery) lower percentage: 90.9%

Using these figures, the two scenarios are defined as follow.
Definition of scenario 1 (high incineration, some recovery other than energy recovery):

- Maximum landfill rate: 5.3%
- Minimum recovery (other than energy recovery) rates: 2.1%

Definition of scenario 2 (moderate incineration, more recovery other than energy recovery):

- Maximum landfill rate: 5.3%
- Minimum recovery (other than energy recovery) rates: 90.9%

Step 3: determination of waste management practices for all Member States

These waste management rates are applied to all Member States, as described in Table 3.62.

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Table 3.62: Repartition of waste management practices according the scenario 1 and 2, applied to the 14 Member States with lowest landfill rates for Mixed and Undifferentiated Materials in 2012 – frontrunners in yellow

Country	Scenario 1: high incineration			Scenario 2: moderate incineration		
	Landfill / disposal (D1-D7, D12) (%)	Incineration (D10 & R1) (%)	Recovery other than energy recovery (%)	Landfill / disposal (D1-D7, D12) (%)	Incineration (D10 & R1) (%)	Recovery other than energy recovery (%)
Luxembourg	0.0%	30.8%	69.2%	0.0%	9.1%	90.9%
Austria	0.0%	97.9%	2.1%	0.0%	9.1%	90.9%
Belgium	3.2%	92.6%	4.2%	3.2%	6.0%	90.9%
Greece	5.1%	0.5%	94.4%	5.1%	0.5%	94.4%
Denmark	5.3%	38.4%	56.3%	5.3%	3.8%	90.9%
Poland	5.3%	6.4%	88.3%	5.3%	3.8%	90.9%
Germany	5.3%	46.7%	48.0%	5.3%	3.8%	90.9%
Sweden	5.3%	85.4%	9.3%	5.3%	3.8%	90.9%
Slovenia	5.3%	20.0%	74.7%	5.3%	3.8%	90.9%
Italy	5.3%	28.0%	66.7%	5.3%	3.8%	90.9%
Hungary	5.3%	73.1%	21.5%	5.3%	3.8%	90.9%
Netherlands	5.3%	28.6%	66.0%	5.3%	3.8%	90.9%
Romania	5.3%	27.4%	67.3%	5.3%	3.8%	90.9%
Latvia	5.3%	12.7%	82.0%	5.3%	3.8%	90.9%

In Table 3.62, in orange cells the maximum landfill rate has been used, and in grey cells the minimum recovery (other than energy recovery) rate has been used.

Step 4: calculation of the amount of wastes sent to each treatment method at European level for the two scenarios

The last step provides, for the 2 scenarios studied and the baseline scenario, the amount of waste sent to landfill, incineration and recovery (other than energy) at European level (see Table 3.63).

Table 3.63: Repartition of Mixed and Undifferentiated Materials management practices in the EU-28 for the 3 scenarios studied

	Repartition in %			Repartition in 1000 tonnes		
	Landfill / disposal (D1-D7, D12) (%)	Incineration (D10 & R1) (%)	Recovery other than energy recovery (%)	Landfill / disposal (D1-D7, D12) (kt)	Incineration (D10 & R1) (kt)	Recovery other than energy recovery (kt)
Baseline	28%	35%	38%	9 199	11 476	12 447
Scenario 1	5%	57%	38%	1 676	19 004	12 448
Scenario 2	5%	4%	91%	1 676	1 336	30 117

7.1.3 Results for all waste streams

Data presented in tables below comes from the analysis of scenarios based on the Member States waste management practices in 2012. Therefore, they should not be considered as prospective scenarios, but rather as scenarios for exploring the potential of applying the waste hierarchy more stringently than in the existing management systems.

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Based on the aforementioned methodology, Table 3.64 shows the evolution of the repartition of waste treatment methods for the 3 scenarios in the EU-28.

Table 3.64: Evolution of the repartition of waste treatment methods for the 3 scenarios in the EU-28

	Baseline scenario			Scenario 1: high incineration			Scenario 2: moderate incineration		
	Landfill / disposal (D1-D7, D12) (%)	Incineration (D10 & R1) (%)	Recovery other than energy recovery (%)	Landfill / disposal (D1-D7, D12) (%)	Incineration (D10 & R1) (%)	Recovery other than energy recovery (%)	Landfill / disposal (D1-D7, D12) (%)	Incineration (D10 & R1) (%)	Recovery other than energy recovery (%)
HSW	50%	38%	12%	1%	87%	12%	1%	85%	15%
M&UM	28%	35%	38%	5%	57%	38%	5%	4%	91%
Sorting residues	52%	35%	13%	6%	81%	13%	6%	69%	25%
Wood wastes	1%	53%	46%	0%	41%	59%	0%	5%	95%
Plastic wastes	11%	13%	75%	0%	17%	83%	0%	11%	89%
A&VW	9%	6%	86%	0%	5%	95%	0%	0%	100%
Chemical wastes	13%	37%	51%	1%	31%	67%	1%	9%	90%
Paper wastes	0%	1%	99%	0%	0%	100%	0%	0%	100%
Textile wastes	6%	6%	88%	0%	5%	94%	0%	0%	100%
Waste solvents	1%	60%	39%	0%	53%	47%	0%	0%	100%
Sludge	8%	27%	65%	0%	24%	76%	0%	0%	100%
Waste tyres	3%	48%	49%	0%	39%	61%	0%	13%	87%
Average	**27%**	**29%**	**44%**	**1%**	**50%**	**48%**	**1%**	**37%**	**61%**
Average without HSW	**17%**	**25%**	**58%**	**2%**	**34%**	**64%**	**2%**	**16%**	**82%**

Considering the methodology used, it is not surprising that looking at Table 3.64, the share of waste sent to landfill in the two scenarios is very small. However, the repartition of remaining wastes between incineration and recovery (other than energy recovery) varies across waste streams and between the two scenarios. Especially, the amount of HSW sent to incineration increased from 38% in 2012 to above 85% in the two scenarios. On the contrary, looking at this table, waste streams which can mostly be recovered (other than energy recovery), such as plastics, papers, textiles, and A&VW would hardly be incinerated anymore.

At European level, the evolution of the waste management practices is in line with the definition of the two scenarios:

- Scenario 1(high incineration, some recovery other than energy recovery): incineration is the main treatment method, representing 50% of all wastes treated.
- Scenario 2 (moderate incineration, more recovery other than energy recovery): recovery is the main treatment methods with 61% of total waste treated, but the amount of waste incinerated also increased from 29% in the baseline scenario to 37%.

Based on results from Table 3.64, Table 3.65 shows the evolution (in 1000 tonnes) of waste management practices for the 3 scenarios in the EU-28.

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Table 3.65: Evolution (in 1000 tonnes) of waste management practices for the 3 scenarios in the EU-28

	Baseline scenario			Scenario 1: high incineration			Scenario 2: moderate incineration		
	Landfill / disposal (D1-D7, D12)	Incineration (D10 & R1)	Recovery other than energy recovery	Landfill / disposal (D1-D7, D12)	Incineration (D10 & R1)	Recovery other than energy recovery	Landfill / disposal (D1-D7, D12)	Incineration (D10 & R1)	Recovery other than energy recovery
HSW	68 421	52 180	16 743	1 085	119 155	17 104	1 085	116 191	20 067
M&UM	9 199	11 476	12 447	1 676	19 004	12 448	1 676	1 336	30 117
Sorting residues	32 604	22 281	8 109	3 657	51 176	8 160	3 657	43 438	15 899
Wood wastes	493	27 965	24 452	2	21 748	31 161	2	2 499	50 410
Plastic wastes	1 439	1 705	9 590	9	2 124	10 600	9	1 442	11 282
A&VW	7 284	4 850	72 681	11	3 926	80 879	11	385	84 420
Chemical wastes	1 264	3 714	5 104	150	3 179	6 780	150	904	9 054
Paper wastes	183	341	38 277	0	114	38 688	0	4	38 797
Textile wastes	153	134	2 082	7	127	2 236	7	1	2 362
Waste solvents	14	1 075	698	0	946	840	0	0	1 786
Sludge	674	2 306	5 495	16	2 043	6 416	16	2	8 457
Waste tyres	67	1 195	1 202	0	968	1 496	0	318	2 146
Total (million tonnes)	**122**	**129**	**197**	**7**	**225**	**217**	**7**	**167**	**275**
Total without HSW (million tonnes	**53**	**77**	**180**	**6**	**105**	**200**	**6**	**50**	**255**

Evolution of the amount of other waste streams incinerated in the EU-28 based on the three scenarios

Looking at Table 3.65, it appears that, if all Member States reduced landfilling in compliance with the waste hierarchy, the total amount of waste streams sent to incineration (by weight) would increase by 29% according to scenario 2 and by 74% according to scenario 1. However, HSW is responsible for most of this increase and looking at all waste streams except for HSW, the amount of wastes sent to incineration decrease by 35% in scenario 2.

Incineration of HSW is only one part of the global waste management system of a country; and the implementation of more efficient separate collection systems (in line with the waste hierarchy) should result in a decrease in the production and treatment of HSW. Therefore, the result of the extrapolation of current data of mixed waste streams management practices provides useful information on what can be achieved under certain conditions, but should be used with the necessary caution. As a result from a better separate collection system, treatment of HSW could be reduced to a point where the total amount of waste sent to incineration is more in line with scenario 2 and decreases compared to the baseline scenario for 2012.

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Table 3.66: Wastes streams incineration in the EU-28 based on the analysis of three scenarios

	Total treated in EU-28 (kt)	LHV (MJ/kg)	Incineration R1 & D10 (in kt)			Incineration R1 & D10 (in PJ)		
			Baseline scenario	Scenario 1	Scenario 2	Baseline scenario	Scenario 1	Scenario 2
HSW	137 343	9	52 180	119 155	116 191	470	1 072	1 046
M&UM	33 123	13	11 476	19 004	1 336	149	247	17
Sorting residues	62 994	15	22 281	51 176	43 438	334	768	652
Wood wastes	52 910	13	27 965	21 748	2 499	375	291	33
Plastic wastes	12 734	36	1 705	2 124	1 442	61	76	51
A&VW	84 815	16	4 850	3 926	385	77	62	6
Chemical wastes	10 082	25	3 714	3 179	904	92	79	22
Paper wastes	38 801	17	341	114	4	6	2	0
Textile wastes	2 370	17	134	127	1	2	2	0
Waste solvents	1 786	28	1 075	946	0	30	26	0
Sludge	8 475	10	2 306	2 043	2	22	20	0
Waste tyres	2 464	29	1 195	968	318	35	28	9
Total	447 897		129 223	224 511	166 520	1 653	2 674	1 838
Total without HSW	310 554		77 043	105 356	50 329	1 183	1 602	792

Note on hazardous wastes

The applied methodology doesn't provide specific figures hazardous wastes (HW), which are included in the various waste streams discusses above. However, the incineration installations and management practices can be different for hazardous and non-hazardous wastes, and it is interesting to make a specific focus on hazardous wastes, using a similar approach.

According to Hazardous Waste Europe (HWE), with 30% of HW sent to landfill, 19% recycled and 38% sent to incineration and co-incineration (including 9% in cement kilns), France can be considered as a frontrunner for the treatment of HW in the EU-28. Since the same level of information was not available for other Member States, it was decided to apply this ratio of 38% to the 50 million tonnes of HW produced in Europe. It is thus estimated that 14 million tonnes of HW (with an average LHV of 12MJ/kg) could be sent to incineration and co-incineration, in addition to the current 5 million tonnes.

Comments on the methodology used

The proposed methodology is based on the assumption that waste streams are rather homogenous across Member States, and that efficient waste management systems using separate collection of recyclable waste streams can be implemented.

Of course, at the time being not all countries can achieve the same level of efficiency for technical, economic and cultural reasons. But, all Member States are continuously improving their waste management systems and it is important to provide outlooks on developments that are both ambitious and achievable in coming years.

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7.2 Calculation of the technical potential of Waste to Energy based on both the waste hierarchy and improvement techniques

Three steps have been identified towards the better deployment of WtE across the EU-28, these are as follows:

Step 1 - From section 7.1, it has been determined that a higher incineration scenario can be established. The calculations from section 7.1 are pulled forward and shown below in Table 3.67.

Table 3.67: Energy content of waste streams in the EU-28 for the three scenarios

	LHV (MJ/kg)	Incineration R1 & D10 (in kt)			Incineration R1 & D10 (in PJ)		
		Baseline scenario	Moderate Incineration	Higher incineration	Baseline scenario	Moderate incineration	Higher incineration
HSW	9	52,180	116,191	119,155	470	1,072	1,072
M&UM	13	11,476	1,336	19,004	149	247	247
Sort Res	15	22,281	43,438	51,176	334	768	768
Wood	13	27,965	2,499	21,748	375	291	291
Plastics	36	1,705	1,442	2,124	61	76	76
A&VW	16	4,850	385	3,926	77	62	62
Chemical	25	3,714	904	3,179	92	79	79
Paper	17	341	4	114	6	2	2
Textile	17	134	1	127	2	2	2
Solvents	28	1,075	-	946	30	26	26
Sludge	10	2,306	2	2,043	22	20	20
Tyres	29	1,195	318	968	35	28	28
Total		**129,223**	**166,520**	**224,511**	**1 653**	**2 674**	**2 674**

It can be seen that the energy potential of waste increases from 1,644 PJ under the baseline (current) scenario to 2,668 PJ under the higher incineration scenario, an increase of 62%.

Using the quantities of waste and the corresponding waste energy content under this higher incineration scenario, it is also possible to make an estimation of the potential of WtE in the EU-28 through the better application of technology in two future scenarios. These are:

Step 2 - The application of proven improvement techniques in the short term. An assessment of the total technical potential in PJ has been made in the following sections.

Step 3 - The application of emerging improvement techniques in the longer term. These techniques may be able to provide benefits in terms of greater energy recovery in the future, but these benefits are difficult to reliably quantify at this time.

The impact of the higher incineration scenario, application of proven techniques and application of emerging techniques is applied for the following WtE outlets:

Waste incineration plants (electrical power): From task 1, Table 1.47 (re-provided below), it can be seen that WI plants produced 110PJ of electrical power in 2013. From task 2, it is assumed that net electrical efficiency is 20% (where approximately 80% of WI plants in the EU-28 operate in CHP mode).

Applying this current level of electrical efficiency to the higher incineration scenario, (where more 62% more waste is treated in WI plants) power output could increase to 178PJ.

Where proven improvement techniques are applied to the higher incineration scenario (where WI plants could operate at a net electrical efficiency of 29% in CHP mode using improvement techniques such as radiant superheaters) power output could increase to 252PJ. This is summarised below.

WI plants - Power	**PJ**	**Electrical Efficiency %**
Baseline scenario	110	20%
Higher incineration scenario	178	20%
Proven improvement techniques	252	29%

Copy of Table 1.47: Estimation of the waste-derived energy production in the EU-28 for the 5 outlets studied

	Com-bustion plants	WI plants		CL plants	AD plants			Other WtE plants
		Heat production (PJ)	Electricity production (PJ)	Thermal energy conversion (PJ)	Utilised heat production (PJ)	Electricity production (PJ)	Biomethane production (PJ)	
2006	n.a.	180	81	127	n.a. (not available)			
2007		165	89	141				
2008		183	92	149				
2009		177	97	154				
2010		199	105	165				
2011		228	106	184				
2012		265	106	177				
2013		275	110	176				
2014		n.a.	n.a.	n.a.	33	70	12	n.a.

Waste incineration plants (heat export): From task 1, Table 1.47 it can be seen that WI plants exported 275PJ of heat in 2013. From task 2, it is assumed that net annual average heat export efficiency is currently 51%. Applying this current level of heat efficiency to the higher incineration scenario, (where 62% more waste is treated in WI plants) heat output could increase to 446PJ.

Where proven improvement techniques are applied to the higher incineration scenario (where WI plants could operate at a net annual average heat efficiency of 66% using improvement techniques such as flue gas condensation) heat output could increase to 557PJ. This is summarised below.

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WI Plants - Heat	PJ	Net annual average heat efficiency %
Baseline scenario	275	51%
Higher incineration scenario	446	51%
Proven improvement techniques	577	66%

Cement and lime production, thermal energy conversion: From task 1, Table 1.47 it can be seen that CL converted 176PJ of thermal energy from waste in 2013. From task 2, it is assumed that net annual average energy conversion efficiency is currently 75%.

Applying this current level of energy conversion efficiency to the higher incineration scenario, (where 62% more waste is utilised in CL plants) energy conversion could increase to 286PJ.

Where proven improvement techniques are applied to the higher incineration scenario (where CL plants could operate at a net annual average heat efficiency of 80% by incremental improvements in design) energy conversion could increase to 305PJ. This is summarised below.

CL plants	PJ	Thermal energy conversion efficiency %
Baseline	176	75%
Higher incineration scenario	286	75%
Proven improvement techniques	305	80%

Anaerobic Digestion plants: From task 1, Table 1.47 it can be seen that AD plants produced a total of 115PJ of energy in 2014, split between power, heat and biomethane.

Where proven improvement techniques from task 2 are applied to AD (such as gas to grid which has a net annual average energy efficiency of 41%) it is estimated that energy production could increase to 171PJ. This calculation assumes that current levels of organic waste treatment continue, there may be the potential to capture higher levels of organic waste for AD. This is summarised below.

AD plants	PJ	Energy conversion efficiency %
Baseline	115	18% to 41%
Proven improvement techniques	171	41%

Combustion and other WtE Plants: From task 1, Table 1.47 it can be seen that no reliable estimates of current energy production from waste in combustion and other WtE plants across the EU-28 have been able to be established in this study. Therefore no reliable estimation of increased energy production can be made at this time.

7.2.1 Summary

Taking the contributions from each of the three WtE outlets studied, the overall technical potential for the improvement of energy recovery from WtE is summarised

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below in Table 3.68 for the higher incineration scenario and the application of proven techniques.

It can be seen below that the higher incineration scenario can deliver an extra 349PJ of energy in total and the application of proven improvement techniques can increase this by a further 279PJ.

Table 3.68: Summary of WtE technical potential

Scenario	**Energy Produced PJ**	**Improvement potential PJ**	**Notes**
Baseline	676	-	Current levels of energy recovery in 2013/ 2014
Higher incineration scenario	1025	349	
Proven improvement techniques	1304	279	

It is recognised that emerging improvement techniques may be able to make a significant contribution to the technical potential of WtE in the longer term, but this contribution is not able to be reliably quantified at this time.

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8 Annexes

8.1 Annex 1- list of conversion factors

8.1.1 Conversion factors for energy

	Unit	Low Heating Value			Sources
		Average	Min	Max	
Biogas	MJ/Nm^3	25,6	25,6	25,6	1
Biodiesel	MJ/kg	36,6	36,6	36,6	1
Bioethanol	MJ/kg	36,6	26,7	26,7	1
Sorting residues	MJ/kg	15,5	13,0	18,0	1
Household and similar wastes	MJ/kg	14,5	13,0	16,0	2
Mixed and undifferentiated materials	MJ/kg	14,5	13,0	16,0	2
Waste Oil (mineral and synthetic)	MJ/kg	30,6	27,0	34,2	1
Waste tyres, waste rubber	MJ/kg	29,4	27,2	31,5	1
Edible waste oil and fat	MJ/kg	21,9	12	31,8	1
Waste solvents	MJ/kg	27,5	23,0	32,0	1
Wood waste	MJ/kg	13,4	7,3	19,5	1
Plastic waste	MJ/kg	27,3	13,6	41,0	1
Paper waste	MJ/kg	16,7	9,4	23,9	1
Textile waste	MJ/kg	17,4	13,0	21,8	1
Discarded equipment	MJ/kg	15,0(1)	15,0	15,0	3
Waste containing PCB	MJ/kg	15,0	15,0	15,0	4
Combustion wastes	MJ/kg	15,0	15,0	15,0	4
Mineral waste from construction and demolition	MJ/kg	5,2(2)	5,2	5,2	5
Soils	MJ/kg	11,0(3)	9,0	13,0	6
Chemical wastes	MJ/kg	24,9	8,5	41,2	7
Animal and mixed food waste	MJ/kg	28,0	17,0	39,0	1
Animal faeces, urine and manure	MJ/kg	12,0	12,0	12,0	8
Vegetal wastes	MJ/kg	17,0	16,0	18,0	9
Dried/dewatered municipal sewage sludge	MJ/kg	9,7	3,7	15,7	1

(1) Assuming discarded vehicles refers to car shredded waste
(2) Assuming mineral waste construction is mainly cement
(3) Assuming soils refers to milled and sod peat

Sources:
1 – UBA, 2013 ""Waste-derived fuels: Characterisation and suitability for end-of-waste"
2 – Carl Wilen, "Review of waste processing technology for SRF" for IEA Bioenergy Agreement - Task 36, March 2004
3 – Anne Dekeukelaere, "Co-processing waste in the cement industry: A solution to natural resource preservation and total emission reduction", Cementis Consulting, 2011
4 – Default value based on average of LHV of wastes sent for incineration considered in this study

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5 – Anna Gaki, LEEMA project: Novel Inorganic Insulating Materials for Energy efficient Buildings, based on Mineral Wastes, 2014
6 – Statistics Finland
(http://stat.fi/tup/khkinv/khkaasut_polttoaineluokitus_maaritelmat_2015_en.pdf)
7 – Janusz Bujak, "Experimental Study of the Lower Heating Value of Medical Waste", Polish Journal of Environmental Studies, Vol. 19, No. 6 (2010), 1151-1158
8 - Biofuel.org.uk (http://biofuel.org.uk/solid-biofuels.html)
9 - GREET, "The Greenhouse Gases, regulated emissions, and energy use in transportation model", released August 26, 2010

8.1.2 Conversion factors for units

Prefix	Symbol	Conversion factor
Kilo	K	10^3
Mega	M	10^6
Giga	G	10^9
Tera	T	10^{12}
Peta	P	10^{15}

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8.2 Annex 2 – Detailed list of waste treatment methods according to the Waste Statistics Regulation

Recovery operations pursuant to Annex II of the Waste Statistics Regulation

Code	Types of recovery operations
R1	Use principally as a fuel or other means to generate energy
R2	Solvent reclamation/regeneration
R3	Recycling/reclamation of organic substances which are not used as solvents (including composting and other biological transformation processes)
R4	Recycling/reclamation of metals and metal compounds
R5	Recycling/reclamation of other inorganic materials
R6	Regeneration of acids or bases
R7	Recovery of components used for pollution abatement
R8	Recovery of components from catalysts
R9	Oil re-refining or other reuses of oil
R10	Land treatment resulting in benefit to agriculture or ecological improvement
R11	Use of wastes obtained from any of the operations numbered R1 to R10

Disposal operations pursuant to Annex I of the Waste Statistics Regulation

Code	Types of disposal operations
D1	Deposit into or onto land (e.g. landfill, etc.)
D2	Land treatment (e.g. biodegradation of liquid or sludgy discards in soils, etc.)
D3	Deep injection (e.g. injection of pumpable discards into wells, salt domes or naturally occurring repositories, etc.)
D4	Surface impoundment (e.g. placement of liquid or sludgy discards into pits, ponds or lagoons, etc.)
D5	Specially engineered landfill (e.g. placement into lined discrete cells which are capped and isolated from one another and the environment, etc.)
D6	Release into a water body except seas/oceans
D7	Release into seas/oceans including sea-bed insertion
D10	Incineration on land
D12	Permanent storage (e.g. emplacement of containers in a mine, etc.)

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8.3 Annex 3 – Mass balance between waste generation and use

8.3.1 Mass balance for household and similar wastes

Difference (%) = (Use-Generation)/Generation

	2010			2012		
	Generation	Use	Difference	Generation	Use	Difference
Total EU-28	**178 896**	**153 150**	-14%	**169 655**	**137 343**	-19%
United Kingdom	28 956	20 791	-28%	28 261	17 019	-40%
France	22 179	21 281	-4%	22 371	21 949	-2%
Germany	21 376	20 895	-2%	20 955	16 764	-20%
Spain	21 120	13 359	-37%	19 584	10 299	-47%
Italy	21 378	22 092	3%	18 043	16 939	-6%
Poland	8 638	8 080	-6%	8 774	9 578	9%
Netherlands	7 432	5 616	-24%	7 185	5 865	-18%
Romania	4 464	4 309	-3%	5 343	4 690	-12%
Portugal	6 024	5 817	-3%	4 661	4 564	-2%
Greece	4 771	4 771	0%	4 305	4 342	1%
Bulgaria	3 107	3 043	-2%	3 110	3 073	-1%
Czech Republic	3 309	3 519	6%	3 100	3 176	2%
Hungary	3 195	3 104	-3%	2 897	2 954	2%
Belgium	2 570	1 856	-28%	2 837	2 141	-25%
Ireland	3 265	1 103	-66%	2 737	1 021	-63%
Denmark	2 806	2 566	-9%	2 733	2 528	-7%
Austria	3 664	1 225	-67%	2 624	1 138	-57%
Sweden	2 511	2 367	-6%	2 587	2 326	-10%
Finland	2 031	1 668	-18%	1 594	2 007	26%
Croatia	1 337	1 218	-9%	1 396	1 352	-3%
Slovakia	1 458	1 446	-1%	1 382	1 362	-1%
Lithuania	1 065	1 064	0%	1 016	792	-22%
Latvia	563	586	4%	727	526	-28%
Slovenia	777	560	-28%	560	314	-44%
Estonia	305	277	-9%	294	137	-53%
Luxembourg	210	154	-27%	208	166	-20%
Malta	218	210	-4%	206	153	-25%
Cyprus	173	173	0%	166	166	0%

8.3.2 Mass balance for mixed and undifferentiated materials

Difference (%) = (Use-Generation)/Generation

	2010			2012		
	Generation	Use	Difference	Generation	Use	Difference
Total EU-28	**52 372**	**34 948**	**-33%**	**46 941**	**33 123**	**-29%**
France	12 258	8 532	-30%	9 869	4 990	-49%
United Kingdom	7 117	1 251	-82%	7 408	1 761	-76%

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	2010			2012		
	Generation	Use	Difference	Generation	Use	Difference
Germany	6 861	5 398	-21%	6 996	5 160	-26%
Italy	6 429	5 059	-21%	5 859	4 408	-25%
Poland	2 056	1 622	-21%	3 631	2 629	-28%
Belgium	4 641	2 024	-56%	3 061	3 779	23%
Spain	2 068	2 530	22%	2 021	2 236	11%
Denmark	961	890	-7%	1 039	981	-6%
Finland	1 884	1 951	4%	993	980	-1%
Greece	998	258	-74%	989	244	-75%
Netherlands	894	791	-11%	905	865	-4%
Sweden	1 093	1 913	75%	835	2 928	251%
Ireland	466	120	-74%	741	155	-79%
Portugal	369	253	-31%	387	255	-34%
Hungary	392	158	-60%	380	329	-13%
Czech Republic	288	325	13%	348	232	-33%
Latvia	13	54	315%	307	266	-13%
Romania	2 610	1 153	-56%	288	447	55%
Bulgaria	87	20	-77%	167	33	-80%
Austria	86	49	-44%	140	110	-21%
Slovenia	86	54	-38%	134	50	-63%
Slovakia	130	109	-17%	130	105	-20%
Estonia	53	19	-63%	81	10	-87%
Cyprus	89	89	0%	78	78	0%
Croatia	258	246	-5%	59	58	-1%
Lithuania	82	78	-5%	51	37	-29%
Luxembourg	92	1	-99%	33	1	-96%
Malta	11	1	-91%	11	1	-94%

8.3.3 Mass balance for sorting residues

Difference (%) = (Use-Generation)/Generation

	2010			2012		
	Generation	Use	Difference	Generation	Use	Difference
Total EU-28	**54 877**	**53 860**	**-2%**	**65 417**	**62 994**	**-4%**
Germany	13 972	12 584	-10%	16 396	15 171	-7%
Italy	9 971	5 976	-40%	13 536	11 421	-16%
Spain	6 080	6 219	2%	7 505	7 628	2%
United Kingdom	4 181	11 966	186%	5 944	10 599	78%
France	6 193	4 478	-28%	5 857	4 278	-27%
Poland	4 664	3 903	-16%	5 651	4 813	-15%
Belgium	1 538	1 844	20%	1 700	809	-52%
Sweden	1 278	855	-33%	1 656	1 000	-40%
Austria	1 395	999	-28%	1 611	1 535	-5%
Netherlands	2 336	1 821	-22%	1 412	2 073	47%
Romania	602	666	11%	695	741	7%
Denmark	490	283	-42%	510	280	-45%
Ireland	501	548	9%	491	440	-10%
Portugal	166	133	-20%	357	272	-24%
Czech	295	269	-9%	352	329	-6%

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	2010			2012		
	Generation	Use	Difference	Generation	Use	Difference
Republic						
Bulgaria	56	32	-43%	323	99	-69%
Finland	683	706	3%	293	351	20%
Greece	155	155	0%	253	250	-2%
Hungary	148	248	68%	228	315	38%
Lithuania	36	23	-36%	219	148	-33%
Estonia	35	29	-18%	144	74	-48%
Slovenia	17	56	236%	81	61	-25%
Slovakia	24	19	-19%	78	71	-8%
Malta	8	9	9%	50	60	22%
Luxembourg	41	34	-16%	34	41	23%
Croatia	8	1	-83%	29	5	-82%
Latvia	4	0	-97%	11	127	1062%
Cyprus	2	2	0%	3	3	0%

	Unit	Low Heating Value	
		Min	Max
Biogas	MJ/Nm^3	25.6	25.6
Biodiesel	MJ/kg	36.6	36.6
Bioethanol	MJ/kg	26.7	26.7
Sorting residues	MJ/kg	13.0	18.0
Waste Oil (mineral and synthetic)	MJ/kg	27.0	34.2
Waste tyres, waste rubber	MJ/kg	27.2	31.5
Edible waste oil and fat	MJ/kg	12.0	31.8
Waste solvents	MJ/kg	23.0	32.0
Wood waste	MJ/kg	7.3	19.5
Plastic waste	MJ/kg	13.6	41.0
Paper waste	MJ/kg	9.4	23.9
Textile waste	MJ/kg	13.0	21.8
Biowaste	MJ/kg	6.7	7.3
Animal by-products and derived products	MJ/kg	17.0	39.0
Dried/dewatered municipal sewage sludge	MJ/kg	3.7	15.7

Source: UBA 2013

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8.4 Annex 4 - Calculation of improvement technique ratings

The calculation of average annual net efficiency for CHP installations is shown below:

Reduced efficiency	Net CHP energy efficiency	Net **annual average** energy efficiency
Electrical < 22% net eff. in power only (20% of time) Electrical < 16% net eff. in CHP mode (80% of time)		< 17%
Heat < 64% net eff. in CHP mode (80% of time)		< 51%
Overall	<80%	< 68%

No change in efficiency	Net CHP energy efficiency	Net **annual average** energy efficiency
Electrical – approx 25% eff. in power only (20% of time) Electrical – approx 18% eff. in CHP mode (80% of time)		Approx 19%
Heat – approx 65% eff. at 80% load factor		Approx 51%
Overall	Approx 83%	Approx 71%

increased efficiency	Net CHP energy efficiency	Net **annual average** energy efficiency
Electrical > 29% eff. in power only (20% of time) Electrical > 22% eff. in CHP mode (80% of time)		> 23%
Heat > 66% eff. at 80% load factor		> 53%
Overall	> 88%	> 76%

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8.5 Annex 5 - Calculation data for the construction of the two energy recovery scenarios

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Wood waste treatment methods for 2012

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
0%	0%	Luxembourg	15	0	0	0	15	0%	0%	0%	100%
0%	0%	Ireland	160	0	0	18	142	0%	0%	11%	88%
20%	21%	Germany	10 836	0	5	8 260	2 571	0%	0%	76%	24%
11%	32%	Poland	5 678	0	2	2 286	3 390	0%	0%	40%	60%
21%	53%	Finland	11 252	2	44	8 426	2 780	0%	0%	75%	25%
1%	54%	Estonia	707	0	0	289	419	0%	0%	41%	59%
3%	57%	Belgium	1 613	1	786	136	691	0%	49%	8%	43%
7%	64%	Italy	3 854	2	13	776	3 064	0%	0%	20%	80%
6%	70%	Romania	3 033	1	0	1 039	1 993	0%	0%	34%	66%
0%	71%	Slovenia	242	0	0	202	40	0%	0%	83%	16%
4%	75%	Netherlands	2 032	3	11	1 043	975	0%	1%	51%	48%
2%	76%	Austria	957	3	0	446	508	0%	0%	47%	53%
0%	77%	Lithuania	143	0	0	85	58	0%	0%	59%	41%
2%	79%	Sweden	1 258	6	3	1 191	58	1%	0%	95%	5%
1%	80%	Portugal	743	5	1	585	152	1%	0%	79%	20%
0%	81%	Hungary	135	1	0	29	104	1%	0%	22%	77%
4%	85%	United Kingdom	2 109	25	0	347	1 736	1%	0%	16%	82%
1%	85%	Slovakia	332	4	5	56	266	1%	2%	17%	80%
0%	85%	Croatia	74	1	0	21	51	2%	0%	29%	70%
2%	88%	Spain	1 247	26	0	3	1 218	2%	0%	0%	98%
0%	88%	Denmark	177	5	0	30	142	3%	0%	17%	80%
11%	99%	France	5 964	274	93	1 614	3 983	5%	2%	27%	67%
0%	100%	Bulgaria	155	26	0	79	50	17%	0%	51%	32%
0%	100%	Czech Republic	49	10	1	26	12	20%	3%	52%	25%
0%	100%	Latvia	18	4	0	6	8	23%	3%	30%	44%
0%	100%	Greece	116	80	0	11	26	69%	0%	9%	22%

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
0%	100%	Cyprus	12	11	0	0	1	90%	0%	0%	10%
0%	100%	Malta	1	1	0	0	0	96%	4%	0%	0%

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Plastic waste treatment methods for 2012

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
3%	3%	Austria	352	0	0	40	312	0%	0%	11%	89%
0%	3%	Luxembourg	18	0	0	6	12	0%	0%	34%	66%
2%	4%	Sweden	202	0	0	105	97	0%	0%	52%	48%
17%	21%	Germany	2 113	2	31	436	1 644	0%	1%	21%	78%
3%	24%	Romania	428	2	1	19	407	1%	0%	4%	95%
1%	25%	Ireland	74	1	0	0	73	1%	0%	0%	99%
0%	25%	Latvia	35	0	0	0	35	1%	0%	0%	99%
4%	29%	Netherlands	511	7	3	87	414	1%	1%	17%	81%
5%	34%	Poland	583	10	0	9	564	2%	0%	2%	97%
12%	46%	Italy	1 523	44	32	44	1 403	3%	2%	3%	92%
0%	46%	Finland	52	2	10	32	8	4%	19%	61%	16%
21%	67%	United Kingdom	2 619	122	0	0	2 497	5%	0%	0%	95%
2%	69%	Belgium	230	13	3	17	196	6%	2%	7%	85%
1%	69%	Denmark	100	6	0	4	89	6%	0%	4%	89%
0%	70%	Croatia	22	2	0	0	20	7%	0%	0%	93%
9%	79%	Spain	1 143	81	0	0	1 062	7%	0%	0%	93%
0%	79%	Estonia	3	0	0	0	3	10%	0%	0%	90%
1%	79%	Hungary	114	13	3	8	91	11%	2%	7%	80%
1%	80%	Bulgaria	73	8	0	3	61	11%	0%	5%	84%
1%	81%	Portugal	84	10	0	3	71	11%	0%	4%	84%
0%	81%	Slovenia	39	5	2	0	32	13%	4%	0%	83%
0%	81%	Lithuania	31	5	0	0	26	15%	0%	0%	84%
1%	82%	Slovakia	69	11	0	1	57	16%	0%	1%	83%
2%	84%	Czech Republic	225	46	0	28	151	20%	0%	13%	67%
15%	99%	France	1 934	931	0	776	227	48%	0%	40%	12%

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
1%	99%	Greece	83	53	0	1	29	64%	0%	1%	36%
1%	100%	Cyprus	74	66	0	0	8	89%	0%	0%	11%
0%	100%	Malta	0	0	0	0	0	100%	0%	0%	0%

Draft - Work in pro

Paper waste treatment methods for 2012

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
0%	0%	Ireland	2	0	0	0	2	0%	0%	0%	100%
1%	1%	Slovenia	382	0	0	0	382	0%	0%	0%	100%
0%	1%	Latvia	26	0	0	0	26	0%	0%	0%	100%
4%	5%	Sweden	1 503	0	0	6	1 497	0%	0%	0%	100%
5%	10%	Austria	2 006	0	0	11	1 995	0%	0%	1%	99%
11%	21%	Germany	4 423	0	4	38	4 381	0%	0%	1%	99%
13%	34%	France	4 913	0	0	204	4 709	0%	0%	4%	96%
0%	34%	Luxembourg	0	0	0	0	0	0%	0%	0%	0%
0%	34%	Malta	0	0	0	0	0	0%	100%	0%	0%
4%	38%	Poland	1 507	0	0	3	1 505	0%	0%	0%	100%
1%	40%	Finland	569	0	13	34	522	0%	2%	6%	92%
6%	45%	Netherlands	2 242	0	0	0	2 242	0%	0%	0%	100%
2%	47%	Denmark	711	0	0	4	707	0%	0%	1%	99%
11%	58%	Italy	4 308	1	2	0	4 305	0%	0%	0%	100%
3%	62%	Belgium	1 312	0	0	0	1 311	0%	0%	0%	100%
0%	62%	Croatia	183	0	0	0	183	0%	0%	0%	100%
17%	79%	United Kingdom	6 578	5	0	0	6 573	0%	0%	0%	100%
2%	81%	Romania	955	1	0	10	944	0%	0%	1%	99%
0%	82%	Estonia	7	0	0	0	7	0%	0%	0%	100%
1%	83%	Portugal	444	1	0	0	443	0%	0%	0%	100%
0%	83%	Lithuania	65	0	0	0	65	0%	0%	0%	100%
13%	96%	Spain	4 934	14	0	0	4 920	0%	0%	0%	100%
2%	97%	Hungary	725	5	0	1	719	1%	0%	0%	99%
1%	98%	Greece	225	2	0	0	223	1%	0%	0%	99%
1%	99%	Czech Republic	349	5	0	9	334	1%	0%	3%	96%

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
0%	99%	Slovakia	93	2	0	0	91	2%	0%	0%	97%
1%	100%	Bulgaria	202	64	0	0	138	32%	0%	0%	68%
0%	100%	Cyprus	136	83	0	0	53	61%	0%	0%	39%

Draft - Work in progress

Textile waste treatment methods for 2012

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
5%	5%	France	126	0	0	0	126	0%	0%	0%	100%
0%	5%	Ireland	0	0	0	0	0	0%	0%	13%	87%
2%	7%	Austria	47	0	0	23	24	0%	0%	48%	52%
0%	7%	Luxembourg	0	0	0	0	0	0%	0%	0%	0%
0%	7%	Malta	0	0	0	0	0	0%	0%	0%	0%
0%	7%	Sweden	0	0	0	0	0	0%	0%	0%	0%
11%	18%	Germany	264	0	5	41	217	0%	2%	16%	82%
56%	75%	United Kingdom	1 331	6	10	0	1 315	0%	1%	0%	99%
3%	77%	Belgium	68	1	0	0	66	2%	0%	0%	98%
0%	78%	Finland	8	0	0	0	8	4%	0%	0%	96%
8%	86%	Italy	198	11	2	0	185	6%	1%	0%	94%
2%	89%	Netherlands	57	3	0	20	34	6%	0%	35%	59%
0%	89%	Latvia	1	0	0	1	0	7%	0%	93%	0%
0%	89%	Denmark	3	1	0	0	2	19%	0%	6%	75%
0%	89%	Greece	2	0	0	0	1	22%	0%	0%	78%
1%	90%	Poland	35	8	0	2	25	22%	0%	6%	72%
0%	90%	Slovenia	1	0	0	0	1	28%	0%	0%	72%
0%	91%	Romania	7	2	1	2	2	34%	8%	32%	27%
3%	94%	Czech Republic	73	28	0	21	25	38%	0%	28%	34%
0%	94%	Bulgaria	2	1	0	0	1	42%	0%	7%	51%
0%	94%	Hungary	8	4	0	2	2	46%	1%	28%	24%
3%	97%	Spain	77	35	0	2	39	46%	0%	3%	51%
0%	98%	Slovakia	6	4	0	1	1	67%	1%	15%	17%
0%	98%	Lithuania	7	5	0	0	2	68%	0%	1%	31%

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
0%	98%	Croatia	2	1	0	0	0	73%	0%	0%	27%
1%	99%	Portugal	20	15	0	1	5	73%	0%	3%	24%
0%	99%	Estonia	1	1	0	0	0	98%	0%	0%	2%
1%	100%	Cyprus	28	27	0	0	0	99%	0%	0%	1%

Draft - Work in progress

Waste tyres and waste rubber treatment methods for 2012

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
1%	1%	Denmark	36	0		0	36	0%	0%	0%	100%
2%	3%	Finland	46	0		3	43	0%	0%	7%	93%
3%	6%	Netherlands	62	0		11	51	0%	0%	18%	82%
3%	9%	Belgium	66	0		12	54	0%	0%	18%	82%
1%	9%	Slovakia	23	0		6	17	0%	0%	26%	74%
1%	11%	Hungary	36	0		10	26	0%	0%	28%	72%
3%	14%	Portugal	64	0		24	40	0%	0%	38%	63%
0%	14%	Slovenia	10	0		5	5	0%	0%	50%	50%
9%	23%	Spain	219	0		116	103	0%	0%	53%	47%
8%	30%	Poland	185	0		100	85	0%	0%	54%	46%
13%	43%	France	323	0		175	148	0%	0%	54%	46%
17%	61%	Germany	424	0		234	190	0%	0%	55%	45%
2%	63%	Romania	46	0		26	20	0%	0%	57%	43%
2%	65%	Austria	60	0		36	24	0%	0%	60%	40%
3%	68%	Sweden	76	0		48	28	0%	0%	63%	37%
0%	68%	Croatia						0%	0%	0%	0%
0%	68%	Luxembourg						0%	0%	0%	0%
0%	68%	Malta	0	0		0	0	0%	0%	0%	0%
11%	79%	United Kingdom	282	12		127	143	4%	0%	45%	51%
1%	81%	Greece	36	2		21	13	6%	0%	58%	36%
13%	94%	Italy	330	20		191	119	6%	0%	58%	36%
0%	95%	Estonia	11	1		0	10	9%	0%	0%	91%
0%	95%	Latvia	11	1		5	5	9%	0%	45%	45%
1%	96%	Ireland	24	3		10	11	13%	0%	42%	46%
2%	98%	Czech Republic	54	12		27	15	22%	0%	50%	28%
1%	99%	Lithuania	13	3		4	6	23%	0%	31%	46%

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
1%	100%	Bulgaria	22	8		4	10	36%	0%	18%	45%
0%	100%	Cyprus	5	5		0	0	100%	0%	0%	0%

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Waste solvents treatment methods for 2012

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
0%	0%	Croatia	0,033	0,000	0,000	0,000	0,033	0%	0%	0%	100%
0%	0%	Greece	0,189	0,000	0,000	0,000	0,189	0%	0%	0%	100%
0%	0%	Latvia	0,255	0,000	0,000	0,000	0,255	0%	0%	0%	100%
0%	0%	Portugal	3,784	0,000	0,000	0,013	3,771	0%	0%	0%	100%
10%	11%	Italy	183,334	0,000	42,976	0,000	140,358	0%	23%	0%	77%
0%	11%	Estonia	0,188	0,000	0,001	0,098	0,089	0%	1%	52%	47%
3%	14%	Belgium	55,009	0,000	37,994	0,003	17,012	0%	69%	0%	31%
40%	53%	Germany	709,239	0,000	215,206	305,734	188,299	0%	30%	43%	27%
0%	54%	Sweden	6,912	0,000	5,000	1,393	0,519	0%	72%	20%	8%
0%	54%	Czech Republic	7,548	0,000	5,477	1,547	0,524	0%	73%	20%	7%
0%	55%	Slovenia	8,122	0,000	6,645	0,917	0,560	0%	82%	11%	7%
1%	56%	Finland	21,940	0,000	20,856	0,000	1,084	0%	95%	0%	5%
1%	57%	Ireland	21,382	0,000	12,889	8,005	0,488	0%	60%	37%	2%
2%	59%	Austria	31,599	0,000	0,000	31,599	0,000	0%	0%	100%	0%
0%	59%	Lithuania	0,049	0,000	0,049	0,000	0,000	0%	100%	0%	0%
0%	59%	Luxembourg	0,347	0,000	0,006	0,341	0,000	0%	2%	98%	0%
0%	59%	Malta	0,000	0,000	0,000	0,000	0,000	0%	0%	0%	0%
5%	64%	Netherlands	91,236	0,014	13,192	34,181	43,849	0%	14%	37%	48%
2%	66%	Hungary	31,546	0,005	18,042	0,000	13,499	0%	57%	0%	43%
0%	66%	Poland	4,685	0,001	1,484	0,082	3,118	0%	32%	2%	67%
22%	88%	France	394,546	0,933	101,990	164,328	127,295	0%	26%	42%	32%
0%	88%	Cyprus	0,051	0,001	0,002	0,000	0,048	2%	4%	0%	94%
0%	88%	Romania	1,248	0,037	0,106	0,015	1,090	3%	8%	1%	87%
11%	99%	Spain	190,131	6,355	0,000	30,103	153,673	3%	0%	16%	81%
0%	99%	Slovakia	1,106	0,189	0,150	0,011	0,756	17%	14%	1%	68%
0%	99%	United Kingdom	0,060	0,012	0,000	0,000	0,048	20%	0%	0%	80%

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
1%	100%	Denmark	21,735	6,078	0,000	14,277	1,380	28%	0%	66%	6%
0%	100%	Bulgaria	0,039	0,019	0,000	0,000	0,020	49%	0%	0%	51%

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Chemical waste treatment methods for 2012

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
0%	0%	Luxembourg	2	0	0	0	2	0%	0%	0%	100%
24%	24%	Germany	2 409	36	448	601	1 324	1%	19%	25%	55%
9%	33%	Netherlands	937	16	510	82	330	2%	54%	9%	35%
0%	33%	Slovenia	27	0	3	11	13	2%	11%	40%	47%
6%	39%	Italy	575	20	159	73	323	3%	28%	13%	56%
0%	39%	Greece	25	1	0	2	23	4%	0%	7%	89%
0%	39%	Latvia	2	0	0	0	2	4%	0%	0%	96%
14%	53%	France	1 366	74	626	409	257	5%	46%	30%	19%
0%	53%	Ireland	8	0	0	5	1	6%	6%	69%	19%
5%	58%	Poland	532	37	46	2	447	7%	9%	0%	84%
3%	61%	United Kingdom	334	32	131	0	171	9%	39%	0%	51%
1%	63%	Austria	119	12	0	79	2	10%	0%	66%	1%
1%	64%	Hungary	106	12	41	26	26	12%	39%	25%	25%
1%	64%	Romania	73	9	8	10	46	12%	11%	14%	63%
2%	67%	Belgium	235	31	111	1	93	13%	47%	0%	40%
1%	68%	Denmark	100	21	0	66	13	21%	0%	66%	13%
9%	76%	Spain	861	185	0	65	611	21%	0%	8%	71%
15%	91%	Estonia	1 515	383	0	3	1 129	25%	0%	0%	75%
1%	92%	Czech Republic	76	20	31	11	14	26%	41%	15%	18%
0%	92%	Lithuania	33	9	0	0	24	26%	1%	0%	72%
0%	92%	Croatia	4	1	0	2	1	30%	0%	38%	31%
2%	94%	Finland	192	73	55	2	61	38%	29%	1%	32%
3%	98%	Sweden	354	137	24	49	144	39%	7%	14%	41%
1%	99%	Portugal	122	79	14	1	27	65%	12%	1%	23%
1%	100%	Slovakia	63	43	4	1	15	68%	6%	1%	24%
0%	100%	Cyprus	0	0	0	0	0	72%	1%	4%	23%

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
0%	100%	Malta	1	1	0	0	0	75%	25%	0%	0%
0%	100%	Bulgaria	38	33	0	0	4	88%	1%	0%	11%

Draft - Work in progress

Mixed and undifferentiated materials treatment methods for 2012

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
0%	0%	Luxembourg	1	0	0	0	1	0%	31%	0%	69%
0%	0%	Austria	110	0	0	103	1	0%	0%	94%	1%
11%	12%	Belgium	3 779	119	617	2 882	160	3%	16%	76%	4%
1%	12%	Greece	244	12	0	1	231	5%	0%	1%	94%
3%	15%	Denmark	981	73	0	356	552	7%	0%	36%	56%
8%	23%	Poland	2 629	208	8	91	2 321	8%	0%	3%	88%
16%	39%	Germany	5 160	439	319	1 925	2 477	8%	6%	37%	48%
9%	48%	Sweden	2 928	300	3	2 354	272	10%	0%	80%	9%
0%	48%	Slovenia	50	6	0	7	37	11%	0%	14%	75%
13%	61%	Italy	4 408	587	202	679	2 940	13%	5%	15%	67%
1%	62%	Hungary	329	48	2	208	71	15%	1%	63%	22%
3%	65%	Netherlands	865	144	33	117	571	17%	4%	14%	66%
1%	66%	Romania	447	76	1	69	300	17%	0%	15%	67%
1%	67%	Latvia	266	46	0	2	218	17%	0%	1%	82%
5%	72%	United Kingdom	1 761	387	131	65	1 178	22%	7%	4%	67%
1%	73%	Portugal	255	56	1	13	186	22%	0%	5%	73%
3%	76%	Finland	980	267	61	436	217	27%	6%	44%	22%
0%	76%	Lithuania	37	15	0	3	19	41%	0%	8%	51%
1%	77%	Czech Republic	232	118	2	14	98	51%	1%	6%	42%
0%	77%	Bulgaria	33	18	0	9	6	54%	0%	26%	20%
0%	77%	Estonia	10	6	0	0	4	62%	0%	1%	37%
0%	77%	Croatia	58	37	0	0	21	64%	0%	0%	36%
0%	77%	Slovakia	105	68	2	2	33	65%	2%	2%	32%
0%	78%	Ireland	155	103	0	29	23	67%	0%	19%	15%
15%	93%	France	4 990	4 080	231	304	376	82%	5%	6%	8%
7%	100%	Spain	2 236	1 911	0	194	131	85%	0%	9%	6%

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
0%	100%	Cyprus	78	74	0	0	4	95%	0%	0%	5%
0%	100%	Malta	1	1	0	0	0	99%	1%	0%	0%

Draft - Work in prog

Sorting residues treatment methods for 2012

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
0%	0%	Latvia	127	0	0	127	0	0%	0%	100%	0%
3%	3%	Netherlands	2 073	75	13	1 337	649	4%	1%	64%	31%
24%	28%	Germany	15 171	949	1 952	9 606	2 663	6%	13%	63%	18%
0%	28%	Denmark	280	25	0	133	122	9%	0%	47%	44%
2%	30%	Austria	1 535	163	0	1 151	222	11%	0%	75%	14%
1%	31%	Czech Republic	329	40	2	114	174	12%	1%	35%	53%
0%	31%	Portugal	272	65	0	148	59	24%	0%	54%	22%
0%	32%	Estonia	74	18	0	52	4	24%	0%	70%	5%
0%	32%	Hungary	315	78	1	117	119	25%	0%	37%	38%
2%	34%	Sweden	1 000	256	0	442	302	26%	0%	44%	30%
1%	35%	Belgium	809	229	509	50	21	28%	63%	6%	3%
0%	35%	Slovenia	61	19	20	17	4	31%	33%	29%	7%
1%	36%	Ireland	440	169	0	178	94	38%	0%	40%	21%
0%	36%	Luxembourg	41	18	11	12	0	45%	27%	29%	0%
0%	36%	Croatia	5	2	0	2	1	46%	0%	32%	22%
0%	36%	Bulgaria	99	46	0	52	0	47%	0%	53%	0%
1%	36%	Finland	351	171	15	41	125	49%	4%	12%	36%
0%	37%	Slovakia	71	41	0	30	0	57%	0%	42%	0%
8%	44%	Poland	4 813	2 776	85	958	995	58%	2%	20%	21%
1%	45%	Romania	741	490	0	248	2	66%	0%	34%	0%
18%	64%	Italy	11 421	7 638	2 479	573	731	67%	22%	5%	6%
12%	76%	Spain	7 628	5 739	0	956	933	75%	0%	13%	12%
7%	82%	France	4 278	3 505	148	394	231	82%	3%	9%	5%
0%	83%	Malta	60	50	0	0	10	83%	0%	0%	17%
0%	83%	Greece	250	222	0	0	28	89%	0%	0%	11%
17%	100%	United Kingdom	10 599	9 670	6	302	621	91%	0%	3%	6%

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
0%	100%	Lithuania	148	148	0	0	0	100%	0%	0%	0%
0%	100%	Cyprus	3	3	0	0	0	100%	0%	0%	0%

Draft - Work in prog

Animal and vegetal waste treatment methods for 2012

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
0%	0%	Luxembourg	86	0	0	0	86	0%	0%	0%	100%
2%	2%	Austria	1 914	0	0	14	1 899	0%	0%	1%	99%
4%	7%	Belgium	3 637	0	43	16	3 579	0%	1%	0%	98%
16%	23%	Germany	13 729	3	32	1 403	12 292	0%	0%	10%	90%
2%	25%	Sweden	1 599	1	0	26	1 572	0%	0%	2%	98%
0%	25%	Slovenia	234	0	0	6	228	0%	0%	3%	97%
4%	29%	Poland	3 268	6	46	42	3 174	0%	1%	1%	97%
7%	36%	Italy	5 743	11	15	187	5 530	0%	0%	3%	96%
17%	53%	Netherlands	14 458	42	484	352	13 580	0%	3%	2%	94%
0%	53%	Ireland	288	3	0	29	256	1%	0%	10%	89%
1%	54%	Denmark	759	11	0	63	686	1%	0%	8%	90%
0%	54%	Latvia	78	1	0	3	73	2%	0%	4%	94%
0%	54%	Estonia	65	1	0	0	63	2%	0%	1%	97%
0%	54%	Lithuania	261	8	0	9	243	3%	0%	3%	93%
2%	57%	Finland	1 841	60	152	61	1 568	3%	8%	3%	85%
8%	65%	United Kingdom	7 008	233	312	589	5 874	3%	4%	8%	84%
3%	68%	Spain	2 363	80	0	100	2 183	3%	0%	4%	92%
1%	68%	Hungary	620	23	1	167	428	4%	0%	27%	69%
0%	69%	Czech Republic	282	15	2	53	212	5%	1%	19%	75%
9%	77%	France	7 296	586	15	325	6 371	8%	0%	4%	87%
1%	78%	Slovakia	757	105	28	5	618	14%	4%	1%	82%
0%	78%	Portugal	133	19	11	15	88	14%	8%	11%	66%
0%	78%	Croatia	114	17	0	2	95	15%	0%	2%	83%
1%	79%	Greece	452	73	18	57	304	16%	4%	13%	67%
0%	79%	Cyprus	222	52	7	2	162	23%	3%	1%	73%
20%	99%	Romania	16 855	5 214	40	100	11 501	31%	0%	1%	68%

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
0%	99%	Malta	14	9	5	0	0	61%	37%	0%	2%
1%	100%	Bulgaria	738	712	0	11	15	97%	0%	1%	2%

Draft - Work in prog

Dried/dewatered municipal sewage sludge treatment methods for 2012

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
0%	0%	Cyprus	3	0	0	0	3	0%	0%	0%	100%
1%	1%	Italy	72	0	0	0	72	0%	0%	0%	100%
0%	1%	Lithuania	18	0	0	0	18	0%	0%	0%	100%
10%	11%	Denmark	869	0	34	0	836	0%	4%	0%	96%
0%	11%	Luxembourg	4	0	1	0	4	0%	16%	0%	84%
1%	13%	Belgium	107	0	89	0	19	0%	83%	0%	17%
0%	13%	Croatia	0	0	0	0	0	0%	0%	0%	0%
0%	13%	Latvia	0	0	0	0	0	0%	0%	0%	0%
1%	13%	Poland	57	0	57	0	0	0%	100%	0%	0%
13%	26%	United Kingdom	1 078	5	229	0	844	0%	21%	0%	78%
1%	27%	Spain	103	1	100	0	2	1%	97%	0%	2%
0%	27%	Malta	10	0	0	0	10	2%	0%	0%	98%
1%	28%	Estonia	75	1	0	0	74	2%	0%	0%	98%
4%	32%	Netherlands	331	10	321	0	0	3%	97%	0%	0%
3%	35%	Austria	266	14	139	0	114	5%	52%	0%	43%
2%	37%	Slovenia	135	7	13	0	115	5%	10%	0%	85%
9%	46%	Hungary	748	40	24	0	684	5%	3%	0%	91%
3%	49%	Czech Republic	247	13	8	0	226	5%	3%	0%	91%
2%	50%	Greece	149	10	39	0	100	6%	26%	0%	67%
1%	52%	Romania	113	11	0	0	102	10%	0%	0%	90%
39%	91%	Germany	3 314	384	1 009	0	1 922	12%	30%	0%	58%
1%	92%	Finland	53	6	32	0	15	12%	59%	0%	29%
3%	95%	France	262	40	207	0	14	15%	79%	0%	5%
1%	95%	Sweden	47	8	1	0	38	16%	3%	0%	80%
0%	96%	Bulgaria	33	7	0	0	27	20%	0%	0%	80%
2%	97%	Ireland	132	26	0	0	105	20%	0%	0%	80%

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
2%	99%	Portugal	195	47	0	0	148	24%	0%	0%	76%
1%	100%	Slovakia	50	43	3	0	4	86%	6%	0%	7%

Draft - Work in prog

Household and similar waste treatment methods for 2012

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
12%	12%	Germany	16 764	30	6 905	7 474	2 356	0%	41%	45%	14%
2%	14%	Sweden	2 326	27	0	2 296	4	1,2%	0%	99%	0%
1%	15%	Austria	1 138	18	0	1 069	51	2%	0%	94%	5%
4%	19%	Netherlands	5 865	125	25	5 705	10	2%	0%	97%	0%
2%	21%	Belgium	2 141	47	569	1 479	45	2%	27%	69%	2%
2%	22%	Denmark	2 528	91	0	2 232	205	4%	0%	88%	8%
0%	23%	Luxembourg	166	22	122	0	22	14%	73%	0%	13%
12%	35%	Italy	16 939	6 200	2 595	33	8 111	37%	15%	0%	48%
16%	51%	France	21 949	9 223	5 058	6 728	940	42%	23%	31%	4%
1%	52%	Finland	2 007	887	2	902	216	44%	0%	45%	11%
3%	56%	Portugal	4 564	2 713	42	923	887	59%	1%	20%	19%
12%	68%	United Kingdom	17 019	10 562	5 190	0	1 267	62%	30%	0%	7%
7%	75%	Poland	9 578	7 158	51	17	2 352	75%	1%	0%	25%
0%	75%	Cyprus	166	130	0	0	36	78%	0%	0%	22%
2%	77%	Czech Republic	3 176	2 558	0	586	32	81%	0%	18%	1%
7%	85%	Spain	10 299	8 796	7	1 496	0	85%	0%	15%	0%
2%	87%	Hungary	2 954	2 533	0	366	55	86%	0%	12%	2%
1%	88%	Ireland	1 021	883	0	134	4	86%	0%	13%	0%
1%	89%	Slovakia	1 362	1 188	4	163	7	87%	0%	12%	1%
0%	89%	Estonia	137	127	0	0	10	93%	0%	0%	7%
3%	92%	Romania	4 690	4 557	0	6	126	97%	0%	0%	3%
0%	93%	Slovenia	314	311	0	0	3	99%	0%	0%	1%
1%	94%	Croatia	1 352	1 347	0	0	6	100%	0%	0%	0%
0%	94%	Latvia	526	526	0	0	0	100%	0%	0%	0%
2%	96%	Bulgaria	3 073	3 073	0	0	0	100%	0%	0%	0%
3%	99%	Greece	4 342	4 342	0	0	0	100%	0%	0%	0%

Share of the country in total	Cumulated share	GEO/WST_OPER	Total waste treatment (kt)	Landfill / disposal (D1-D7, D12) (kt)	Incineration / disposal (D10) (kt)	Incineration / energy recovery (R1) (kt)	Recovery other than energy recovery (kt)	Landfill / disposal (D1-D7, D12) (%)	Incineration / disposal (D10)(%)	Incineration / energy recovery (R1) (%)	Recovery other than energy recovery (%)
1%	100%	Lithuania	792	792	0	0	0	100%	0%	0%	0%
0%	100%	Malta	153	153	0	0	0	100%	0%	0%	0%

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