Annex 1: Process trees and system descriptions

1 GENERAL SYSTEM PARAMETERS

1.1 Optimised recycling chains

In this paragraph, optimised recycling chains are described for the different scenarios for which a CBA is performed. Final system flow diagrams are given in chapter 2 of this annex.

1.2 Industrial packaging approach

For the 2 industrial case studies, i.e. LDPE plastic films and cardboard, we calculated the minimum packaging waste production under which the selective collection is not beneficial.

The external benefits (EB) of collecting and recycling industrial packaging waste has been calculated as 11.7 EURO/t (corrugated board) and 208 EURO/t (PE film).

Collecting and transporting corrugated board and PE films as mixed waste is often cheaper than collecting and transporting source sorted packaging. There is thus an additional collection cost (ACC) to collect selectively.

The annual production of industrial packaging waste for which the ACC = EB is

- 5.5 t/year for cardboard
- 0.01 t/year for LDPE plastic films.

Above this waste production the environmental benefits outweigh the additional internal cost for the selective collection.

This means that, from a cost-benefit viewpoint, **the companies who produce more waste than 0.01 t of plastic film or 5.5 t of** corrugated board **per year should have a selective collection scheme** to recycle it. As the "break-even" amount is very low for PE films, it can be concluded that selective collection of industrial packaging should be systematic throughout the EU. As there are limits to the modelling, it has been assumed for this study that 95% of the industrial sites (percentage in packaging weight) should make the selective collection of packaging.

1.3 Kerbside collection

For PMC, it is assumed that the material is placed by the householder in a PMC selective collection bag.

The selective collection bag may contain "light packaging" : plastic bottles, metals and LBC. It is collected twice a month in high and low population density areas.

Collection vehicle is a truck with a volume of 16m³. The collected material is transported directly to the sorting facility. Distance to sorting plant is about :

Truck	Vehicle type	High population density	Low population density
Paper & board	17-25t truck	8 – 71,1 km/t	86,1 – 176,1 km/t
light packaging	17-25t truck	21,1 – 107,7 km/t	74,4 – 227,8 km/t

Employment and internal costs were determined based on Beture Environnement and FOST Plus data. Air emissions from trucks are based on Corinair. Transport distances were provided by Eco-emballages.

The paper and board selective collection happens once a month in high and low population density areas. Packaging and magazines are collected together without any condition on the conditioning (packaging).

Collection vehicle is a truck with a volume of 16m³.

Sources:[46], [48], [49], [66]

Note : The cost for selective collection is assumed to be independent from the amount of material to be collected separately because the collection frequency is adapted to the amount of waste. However, this is not true anymore for very low amounts (and frequencies) because there is a minimum frequency under which the system is not efficient anymore.

1.4 Bring scheme

Consumers bring their sorted[1] packaging waste and other waste to the bring scheme. Assumptions on the distance which has to be attributed to "packaging collection" has be given by Eco-Emballages..

In the bring scheme, packaging are collected in container of about 30m³. These containers are transported to the sorting plant or the recycling facility about once a week for light packaging and for paper & board packaging in high and low population density areas. The collected material is taken directly to the sorting facility. Distance to sorting plant is about :

Truck	High population density	Low population density
Paper & board	3,8 – 10,5 km/t	11,1 – 20,2 km/t
Light packaging	18 – 37,2 km/t	42,2 – 123,9 km/t

Sources:[46], [48], [66]

1.5 Sorting

Only limited data for the environmental impacts at a sorting plant was sourced. Data for energy consumption at the sorting plant (electricity to power conveyors and space heating) has been collected. For residual material arising at the sorting plant, the following assumption has been made:

- Waste arising at sorting plant from materials collected by separate kerbside collection – 20%
- Waste arising at sorting plant from materials collected by bring bank – 10%

The sorted material is baled. Energy consumption for baling has been included in the model.

[1] packaging waste are sorted in 2 fractions: light packaging on the first hand and paper & board + magazines on the other hand.

Bag opening

The selective collection bags are torn open by a mechanical ripping unit. The contents are then transported by conveyor belt to a drum sieve which separates out large-volume items and foils and films.

Foil and film and bags residues separation (not systematically)

The foils, films and bags pieces are then passed on to a so-called air separator, which automatically separates them from any impurities (items wrongly disposed of in the selective collection bag), before being pressed into bales.

Tinplate extraction

The recyclable materials, now minus the impurities, foils and films (if any), are then transported by conveyor belt to the magnet separator. A magnet extracts iron-containing metal packaging such as tinplate cans, crown caps and jar lids from the recycling stream.

Aluminium separation

Downstream of the magnet, an eddy current separator separates out the aluminium and composites containing aluminium.

Separation of beverage cartons (not taken into account in this study)

More and more sorting plants are using machines for the automatic identification and segregation of beverage cartons. These are passed in front of a near-infrared light, recognised by a computer and blown aside with compressed air. If this type of unit is positioned upstream of the eddy current separator, it can also separate out composites containing aluminium at the same time.

Plastics sorting

To sort the materials completely, plastic bottles have to be sorted by hand according to their characteristics:

- clear PET bottles,
- light blue PET bottles
- coloured PET bottles,
- HDPE bottles.

Note : There also exist different physical and opto-electronic based sorting machine for plastics such as the sink-float process or hydrocyclone process.

Sources :[47], [53], [63], [66]

Sorted / baled materials are transported to the reprocessor for recycling. The specific transport distances considered are summarised in the table below.

Transport from sorting plant to recycling facility

Stream	Transport distance (range in km/t)		Average load
	min	max	t
PET bottles	19,2	26,9	13
HDPE bottles	17,7	52,0	13
Glass bottles	2,0	9,6	20
Al	15,0	91,7	6
Steel	0,4	24,0	14-22
Paper and cardboard	2,0	6,3	24
Liquid beverage cartons	14,6	60,0	24

Sources :[47], [48], [66]

1.6 Case study : Commercial and Industrial LDPE palletisation film

In case of non selective collection, packaging waste are landfilled or incinerated. Both options are investigated.

This analysis is concerned with post-use commercial and industrial film, defined as "films for palletisation". This source of materials is fairly clean, at approximately 95-98% plastic. The results of this case study only apply where there is a high degree of source separation (homogeneity of material) and the material is clean. For example, where the source is clean shrink and stretch wrap used to transport bottles from production to filling – this film is homogenous, and has come from a food environment and should therefore be clean. Backdoor waste from supermarkets is also a major source of film for recycling, though cross-contamination of materials / plastics may occur at supermarkets due to the diversity of packs being handled.

Other materials that may be collected will be less clean, for example agricultural films which may be only 60% plastic, the remainder being contamination (stones, soil, etc). This contamination must be removed by washing otherwise damage to the blades during recycling can occur. The results of this case study do not apply to such materials.

For material recycling, it is assumed that the source separated material is collected and transported directly to the reprocessor.

Material losses through washing and sorting at the reprocessing are 27%. During reprocessing, the recyclate must be mixed with a degree of virgin material. In this analysis, it is assumed that the film produced is made up of 86% recycled LDPE and 14% virgin LLDPE material.

The recycled film is assumed to offset production of virgin LDPE film for white and other light coloured sacks, with a save ratio of 80%.

1.7 Case study : Commercial and industrial corrugated board

In case of non selective collection, packaging waste are landfilled or incinerated. Both options are investigated.

For material recycling, it is assumed that the collected corrugated board will be recycled into new corrugated board materials. In order to credit the system for increased recycling, the burdens for the production of testliner (a component of corrugated board which has a 100% recycled content) have been compared to the burdens for the production of kraftliner (a component of corrugated board with a recycled content of less than 20%). The difference between the high recycled content testliner and low recycled content kraftliner is the assumed environmental credit.

The displacement ratio is assumed to be 80%. The actual displacement ratio could be within the range 60 and 100% depending on the end use application and the quality of waste input (this is investigated in the sensitivity analysis). The quality of the collected material and its usability in the selected application is likely to reduce as the overall recycling rate increases.

It is important to note that the recycling loop for paper and board is extremely complex. Fibres degrade, and cannot be used for the same application indefinitely. Each application requires specific properties, and therefore specific mixes of fibres from different sources. Increasing the recycled content of corrugated board may reduce the properties of the board.

Therefore, the situation modelled in this analysis is a theoretical situation, which illustrates the range of costs and benefits that may be incurred where corrugated cases are recycled.

1.8 Case study : PET bottles

PET bottles can be

- collected with MSW and then landfilled or incinerated with energy recovery, according to the scenario
- selectively collected with aluminium, steel and LBC by kerbside collection
- selectively collected with aluminium, steel and LBC within a bring scheme

In case of **selective collection**, plastic bottles are transported to the sorting plant where they are manually sorted according to their characteristics (colour and polymer), crushed and baled.
Bales are transported to the recycling facility.

In the **mechanical recycling facility**, PET bottles are unbaled and PVC is separated. Then PET is ground, washed and dried. Mechanical recycling into granulate for use in bottle production has been considered in this study. The recycled material produced has been credited against the production of virgin PET. The displacement save ratio assumed is 100%. For PET bottles, other reprocessing routes are also available (for example fibre production or TBI process). These routes have not been considered in detail in this analysis.

Interpretation and application of the results should take into account the following limitations:

- The sorted/baled material sent to the reprocessor must meet required bale specifications in order to be recycled by this technology. Therefore, results only apply to clear PET bottles and baled materials that meet the required specifications.
- Internal and external costs for other reprocessing routes will be different from those considered in the analysis

The sensitivity analysis considers feedstock process as recycling alternative.

Sources :[55], [57], [63], [64], [65]

1.9 Case study : Mixed plastics from household sources

Four waste management options are considered for mixed plastics from household sources:

- Landfill
- Incineration with energy recovery
- Mechanical recycling (press forming) via separate kerbside collection
- Recovery in a blast furnace via separate kerbside collection.

In case of **selective collection**, mix plastic packaging waste are transported to the sorting plant where they are sorted, crushed and baled.
Bales are transported to the mechanical recycling facility or to the agglomeration plant (in case of use in cement kilns or in blast furnace), according to the scenario.
In the **mechanical recycling facility**, mix plastic packaging are unbaled. After a dry process, plastic is extruded in order to be used as palisade. The recovered material from mechanical recycling is used for plastic palisade, and is assumed to offset production of wood. A displacement save ratio of 100% is assumed, although in reality this is highly variable (it is therefore investigated in the sensitivity analysis). The recycling consists of a number of steps. Firstly, there is a dry treatment stage. The output of this process is ground plastics. Losses at this stage are 20%. The ground plastics are then press extruded into a product (in this case, palisade).
In the **agglomeration plant** the plastics mixture is processed in order to meet defined quality criteria as regards bulk density, grain size, chlorine and dust content and residual moisture.
In technical terms, agglomeration consists of a sequence of shredding and separating processes, followed by compacting of the plastic material. During the pelletisation process the shredded waste plastic is compacted by means of pressure. The material is forced through the drilled holes of a pelletiser and cut off with cutters : the process delivers agglomerate.

The so-called agglomerate is then transported or not to blast furnace or cement kiln where it is used as a partial substitute for heavy oil (reduction process in blast furnace) or as secondary fuel (cement kiln).

For recovery via the blast furnace, the system is credited against fuel oil (low sulphur). It is assumed that 1 tonne of agglomerate entering the blast furnace offset 964kg of fuel oil. The blast furnace recovery route consists of a number of steps. Firstly, agglomerate is produced. Losses at this stage are 24%. The agglomerate is then injected into the blast furnace, where it is assumed to offset fuel oil.

Interpretation of the results of the cost benefit analysis should consider the following:

- Other recovery routes are also available (for example, recovery in a cement kiln). These options have not been considered in this analysis. The internal and external costs for these options will be different.

Sources :[55], [57], [63]

Note : the bring system has not been analysed because there is no data available for such a system.

1.10 Case study : household steel applications

Five waste management options are considered for steel packaging arising from households

- Landfill
- Incineration with energy recovery
- Incineration with energy recovery and extraction of steel from slags
- Material recycling via separate kerbside collection, selectively collected with aluminium, plastic bottles and LBC
- Material recycling via bring scheme, selectively collected with aluminium, plastic bottles and LBC.

In case of **selective collection**, steel packaging are transported to the sorting plant where they are automatically sorted with magnetic separator and baled.

Bales are transported to the recycling facilities (blast furnace) where they are melt (after shredding or not).

Two production routes are assumed for production of packing steel. These are the oxygen furnace using principally iron ore as the raw material and the electric arc furnace using scrap steel. Increased recycling increases electric arc steel production whilst reducing blast furnace production, thereby yielding an environmental credit.

For incineration with extraction of slags it is assumed that 80% of the steel entering the incinerator is recovered and sent for recycling.

A save ratio of 100% is considered for the recycled steel.

1.11 Case study : Aluminium beverage packaging

Household aluminium packaging waste can be

- collected with MSW and then landfilled or incinerated with aluminium recovery, according to the scenario
- selectively collected with steel, plastic bottles and LBC by kerbside collection
- selectively collected with steel, plastic bottles and LBC within a bring scheme

Five waste management options are considered for aluminium beverage packaging arising from households

- Landfill
- Incineration with energy recovery
- Incineration with energy recovery and extraction of aluminium from slags
- Material recycling via separate kerbside collection, selectively collected with steel, plastic bottles and LBC
- Material recycling via bring scheme, selectively collected with steel, plastic bottles and LBC.

For **incineration with extraction of aluminium from slags**, it is assumed that 76% of the aluminium beverage packaging entering the incinerator is recovered and sent for recycling.

In case of **selective collection**, aluminium packaging are transported to the sorting plant where they are automatically sorted with Eddy current separator and baled.

Baled aluminium beverage cans from the sorting plant go through a scrap preparation stage. Losses at the scrap preparation stage are 19%. The material is then melted and alloyed. The recycled aluminium ingots are assumed to offset production of virgin aluminium ingots. A save ratio of 100% is assumed.

1.12 Case study : Other rigid and semi-rigid aluminium packaging

Five waste management options are considered for other rigid and semi-rigid aluminium packaging arising from households:

- Landfill
- Incineration with energy recovery
- Incineration with energy recovery and extraction of aluminium from slags
- Material recycling via separate kerbside collection, selectively collected with steel, plastic bottles and LBC
- Material recycling via bring scheme, selectively collected with steel, plastic bottles and LBC.

For incineration with extraction of aluminium from slags, it is assumed that 50% of the rigid and semi-rigid aluminium packaging except beverage cans entering the incinerator is recovered and sent for recycling.

Baled aluminium from the sorting plant go through a scrap preparation stage. Losses at the scrap preparation stage are 19%. The material is then melted and alloyed. The recycled aluminium ingots are assumed to offset production of virgin aluminium ingots. A save ratio of 100% is assumed.

1.13 Case study : household paper & board

Household Paper & Board packaging waste can be

- collected with MSW and then landfilled or incinerated with energy recovery, according to the scenario
- selectively collected with magazines by kerbside collection
- selectively collected with magazines within a bring scheme

Paper & board selectively collected are first purified and manually sorted into various qualities. They are then baled and transported to the pulp and paper plant.
At the pulp & paper plant, paper and board waste are pulped (after shredding or not). After screening or centrifugal cleaning the pulp is purified and is ridded of all undesirable elements. Fibbers are dried on a conveyer belt (Filtration - water is extracted and fibres remain).
Fibres are recovered and the rejects are incinerated or landfilled.

For material recycling, limited life cycle inventory data or internal cost data for recycling processes specific to household paper and cardboard packaging was available to the consultants.

Therefore the following limitations to the model should be recognised:

- It is assumed that the recovered fibre is reprocessed into testliner, and that the testliner offsets the production of kraftliner (a save ratio of 80% has been assumed). This is a considerable limitation of the model. The assumption has been made to facilitate a comparison of the burdens associated with the production of a high recycled content substrate with the production of a low recycled content substrate. In reality, recovered fibre from household paper and board packaging will be mixed with virgin fibre and recovered fibre from other sources. The final application of the substrate determines the properties required and therefore dictates the necessary pulp furnish. This therefore also dictates the achievable recycling rate in the paper and board sector as a whole. Increasing the recycling rate of paper and board packaging from household sources may not increase the recycling rate of fibre overall. Increased recycling of paper and board packaging from household sources may reduce recycling from other sectors such as newsprint. This has not been addressed in this study, and should be recognised as a further limitation of the model.

Therefore, the situation modelled in this analysis is a theoretical situation, which illustrates the range of costs and benefits that may be incurred where paper and cardboard packaging from household sources are recycled.

Sources: [66], [67]

1.14 Case study : liquid beverage cartons

Six waste management options are considered for liquid beverage cartons:

- Landfill
- Incineration with energy recovery
- Material recycling of the fibre via separate kerbside collection (rejected aluminium and PE to landfill)
- Material recycling of the fibre via separate kerbside collection (rejected aluminium and PE to incineration)
- Material recycling of fibre via bring scheme (rejected aluminium and PE to landfill)
- Material recycling of fibre via bring scheme (rejected aluminium and PE to incineration)

It is assumed that LBC is selectively collected with aluminium, plastic bottles and steel packaging.

In case of selective collection, LBC are transported to the sorting plant where they are automatically sorted with Eddy current separator, crushed and baled. Other sorting techniques are described in paragraph "Sorting ", but are not included in the CBA.

Bales are transported to the recycling facilities (pulp & paper plant) where they are pulped (after shredding or not). After screening or centrifugal cleaning pulp is purified and is ridded of all undesirable elements. Fibbers are dried on a conveyer belt (Filtration - water is extracted and fibres remain).

As with the household paper and cardboard packaging model, it is assumed that the recovered fibre is reprocessed into testliner, and that the testliner offsets the production of kraftliner (with a save ratio of 80% assumed). The same limitations therefore apply as in the household paper and card model.

The Al/PE fraction can be energetically valorised in cement kilns/incinerators or used in pyrolysis. Both landfill and incineration routes are analysed in this study.

Source :[66], [68]

1.15 Case study Glass bottles

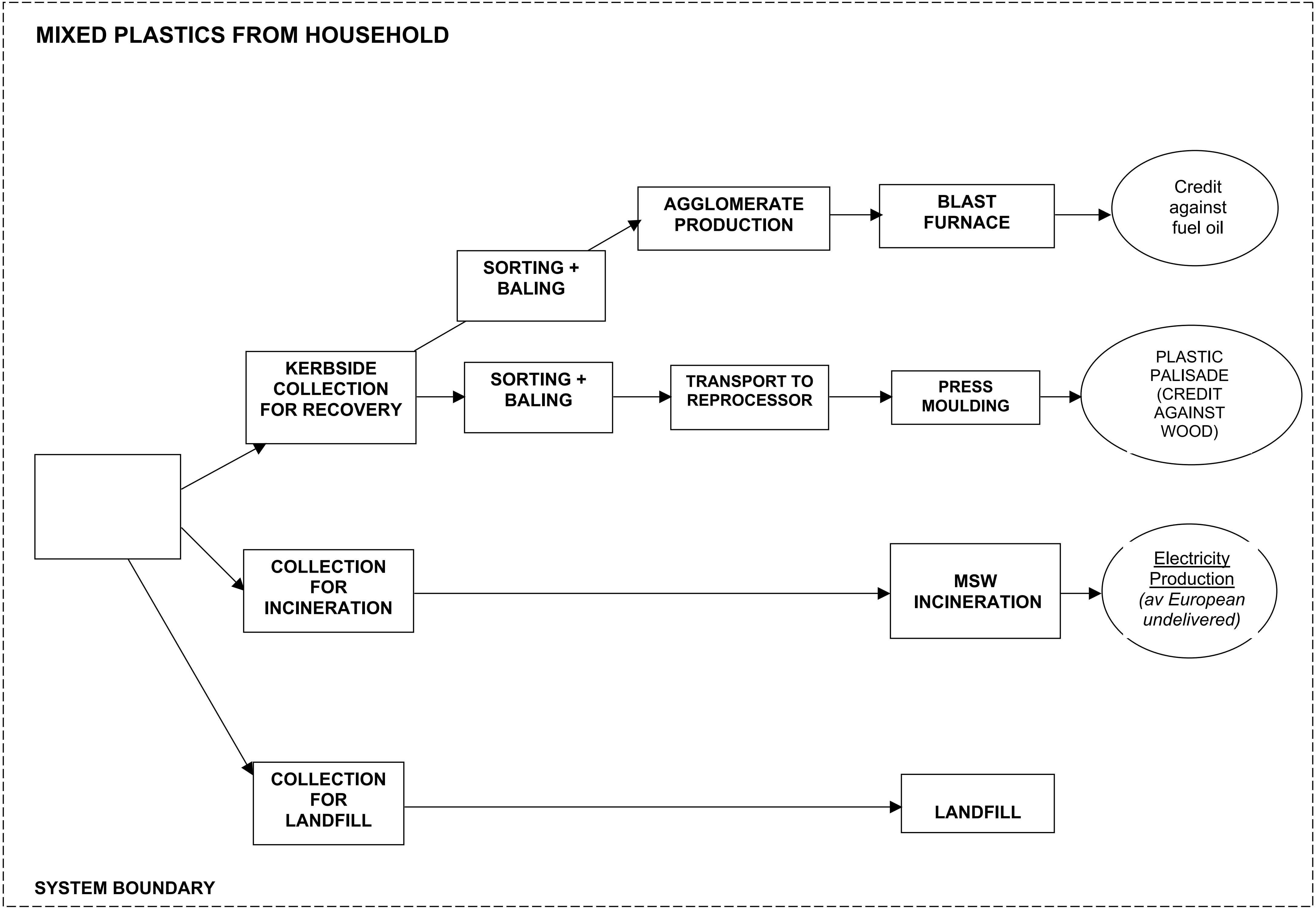
Three waste management options are considered for household glass beverage packaging:

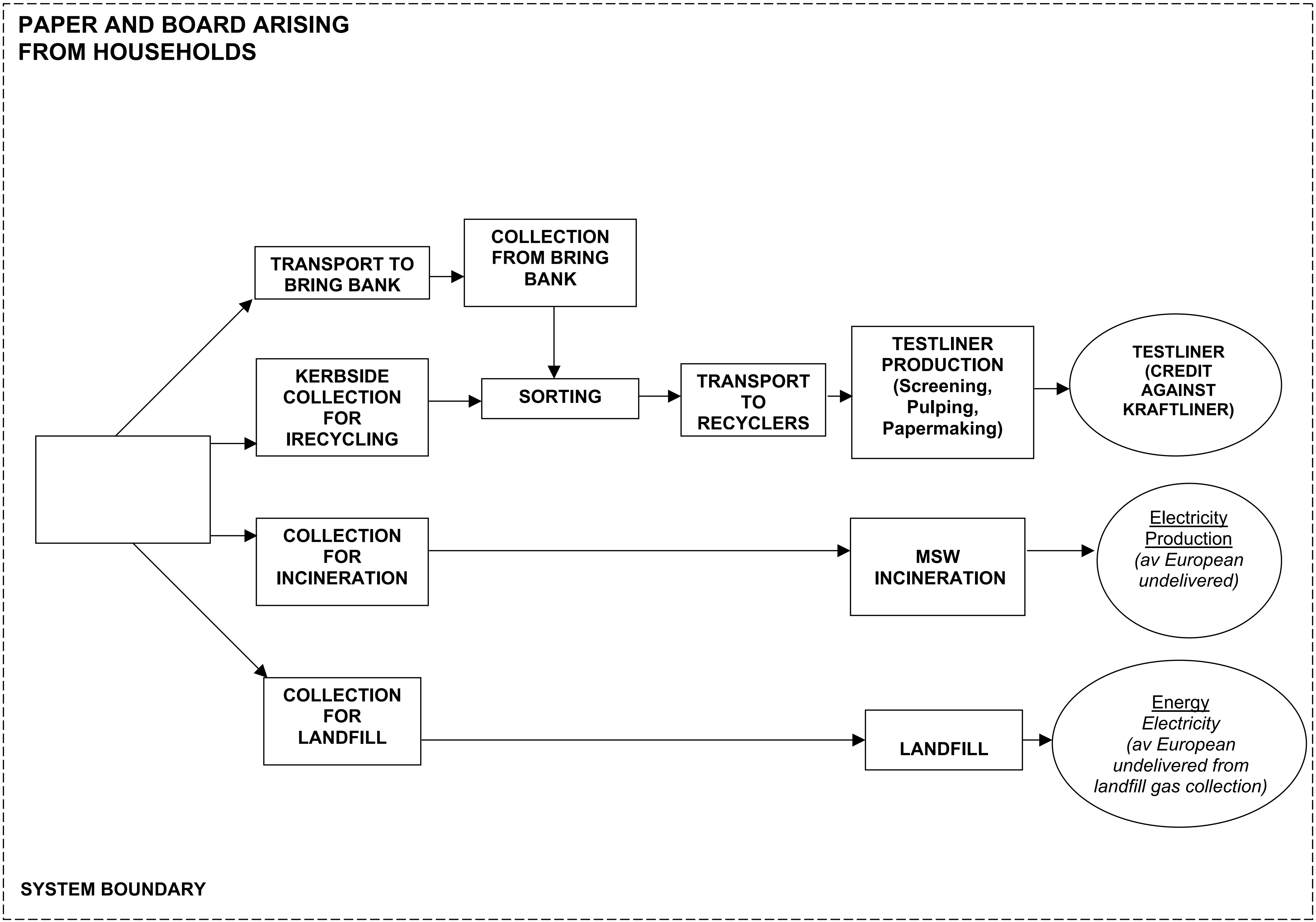
- Landfill
- Incineration with energy recovery
- Material recycling via a bring scheme

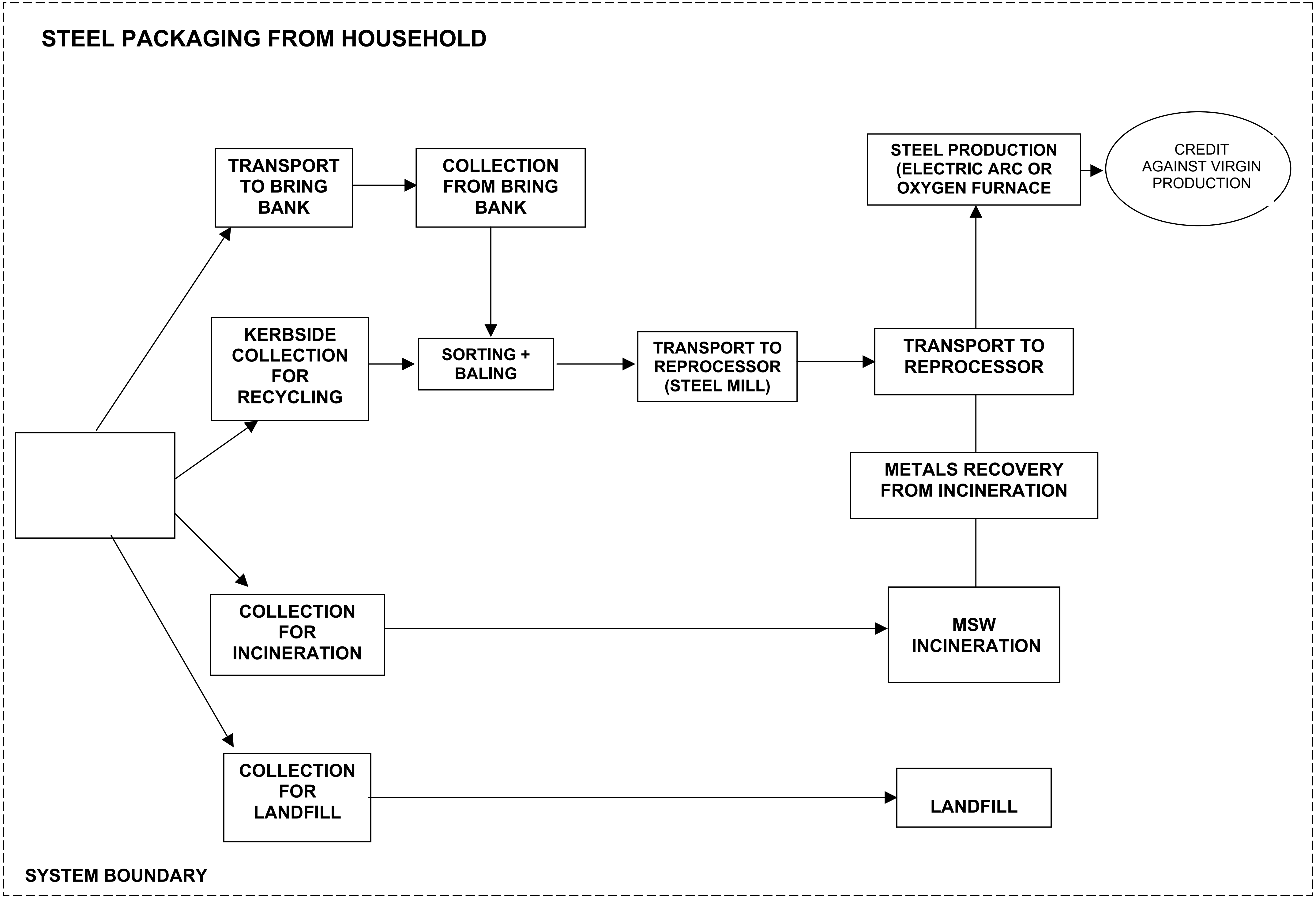
The LCI data available to the consultants is lacking in transparency. The data aggregates the reprocessing steps and environmental credit, but no description of the assumptions made and conditions under which the data is applicable are provided. No indication of the type of cullet being recycled is given.

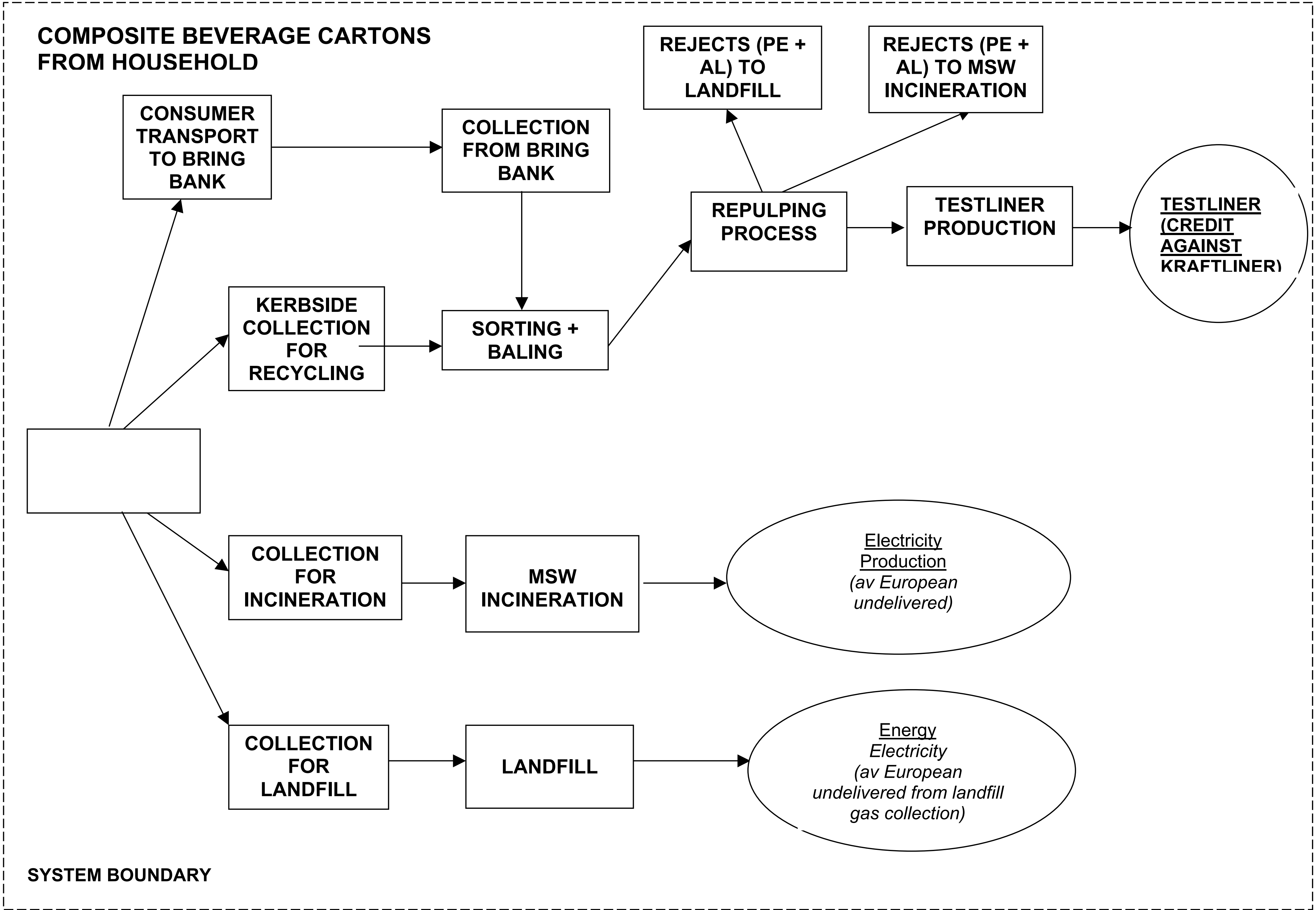
Therefore, the results of this case study should be considered only as indicative to the possible costs and benefits that may be incurred when glass bottles from household sources are recycled.

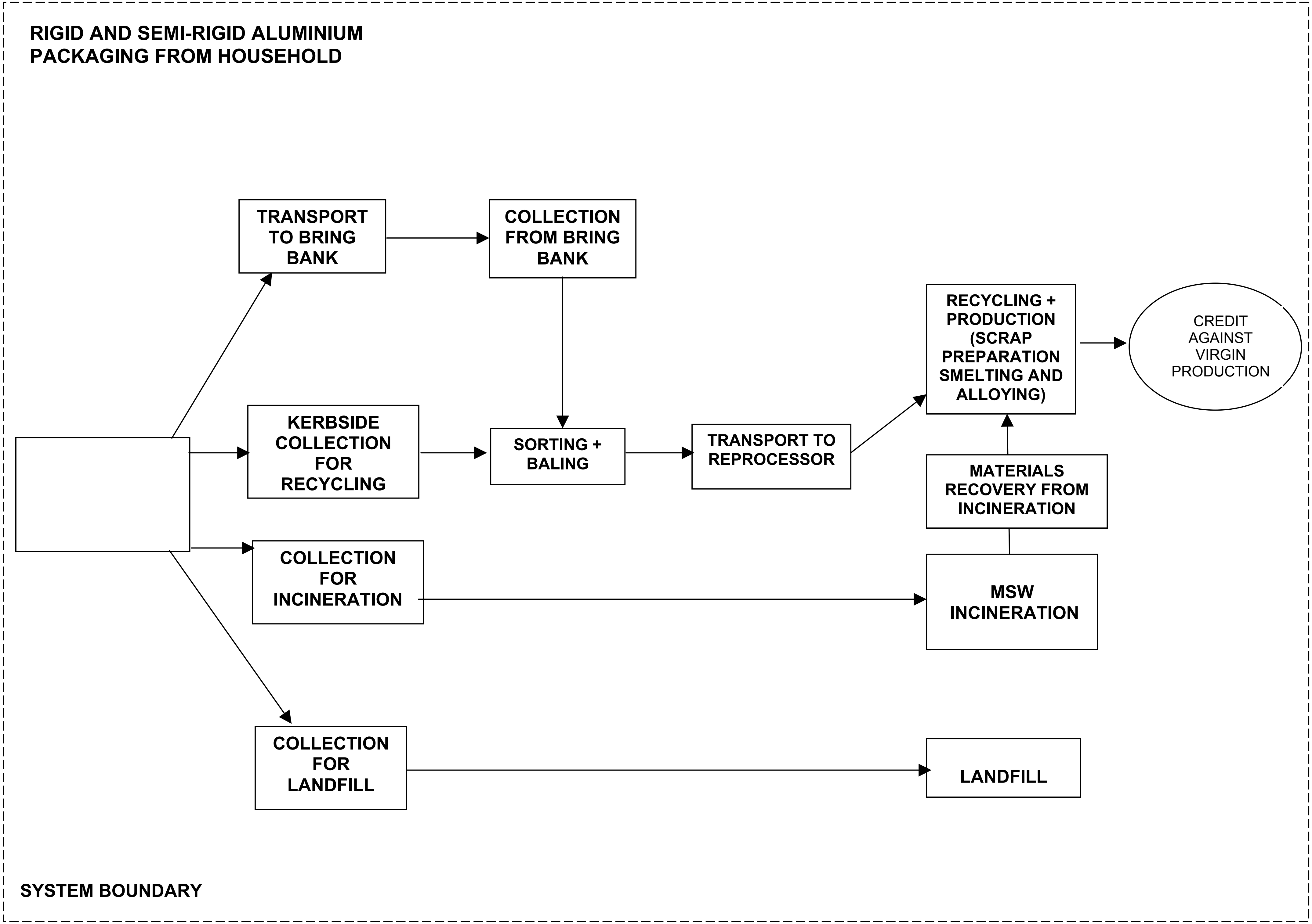
2 CASE STUDY PROCESS TREES

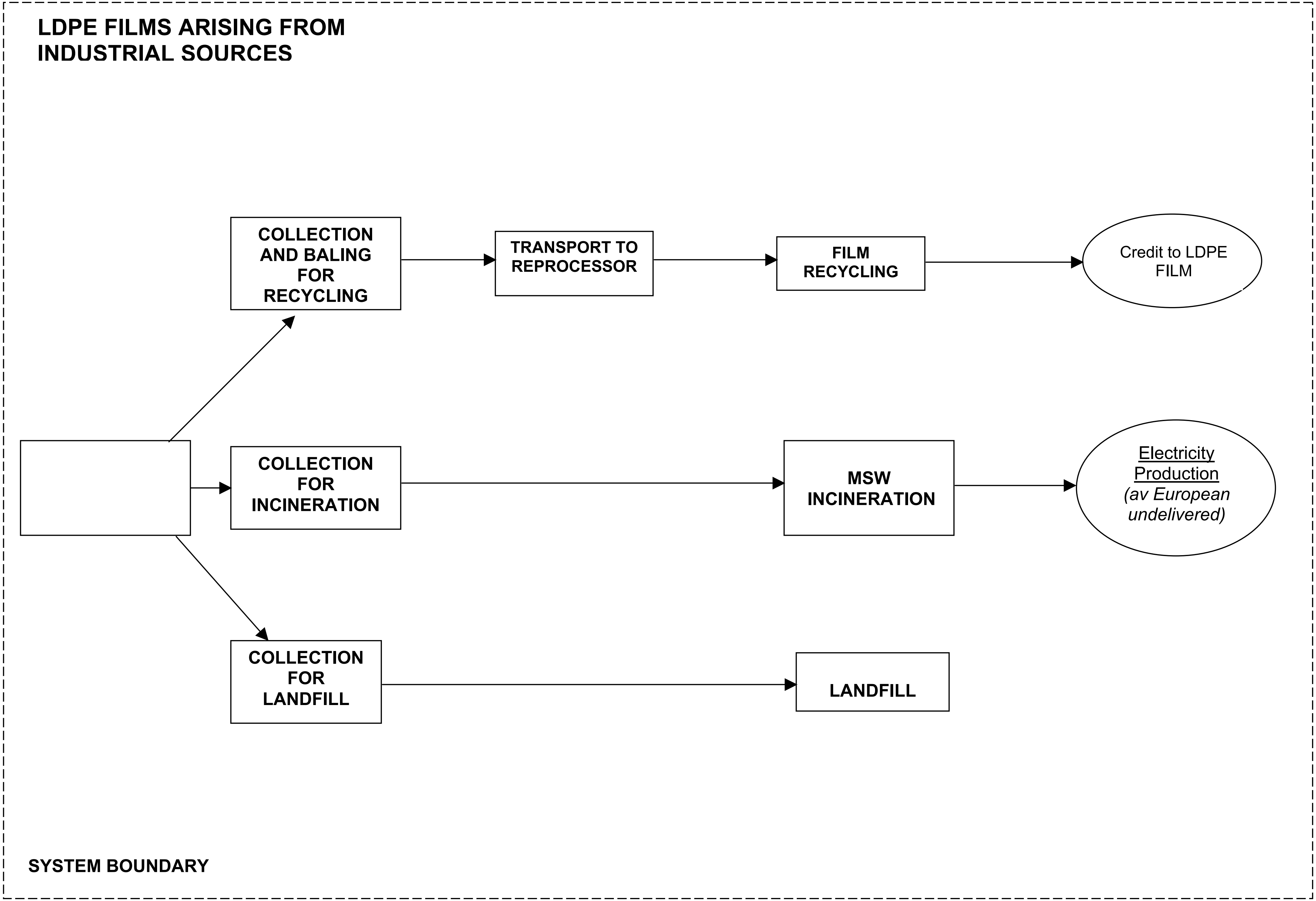

MIXED PLASTICS FROM HOUSEHOLD
AGGLOMERATE PRODUCTION
BLAST FURNACE
Credit against fuel oil
SORTING + BALING
KERBSIDE COLLECTION FOR RECOVERY
SORTING + BALING
TRANSPORT TO REPROCESSOR
PRESS MOULDING
PLASTIC PALISADE (CREDIT AGAINST WOOD)
COLLECTION FOR INCINERATION
MSW INCINERATION
Electricity Production
(av European undelivered)
COLLECTION FOR LANDFILL
LANDFILL
SYSTEM BOUNDARY

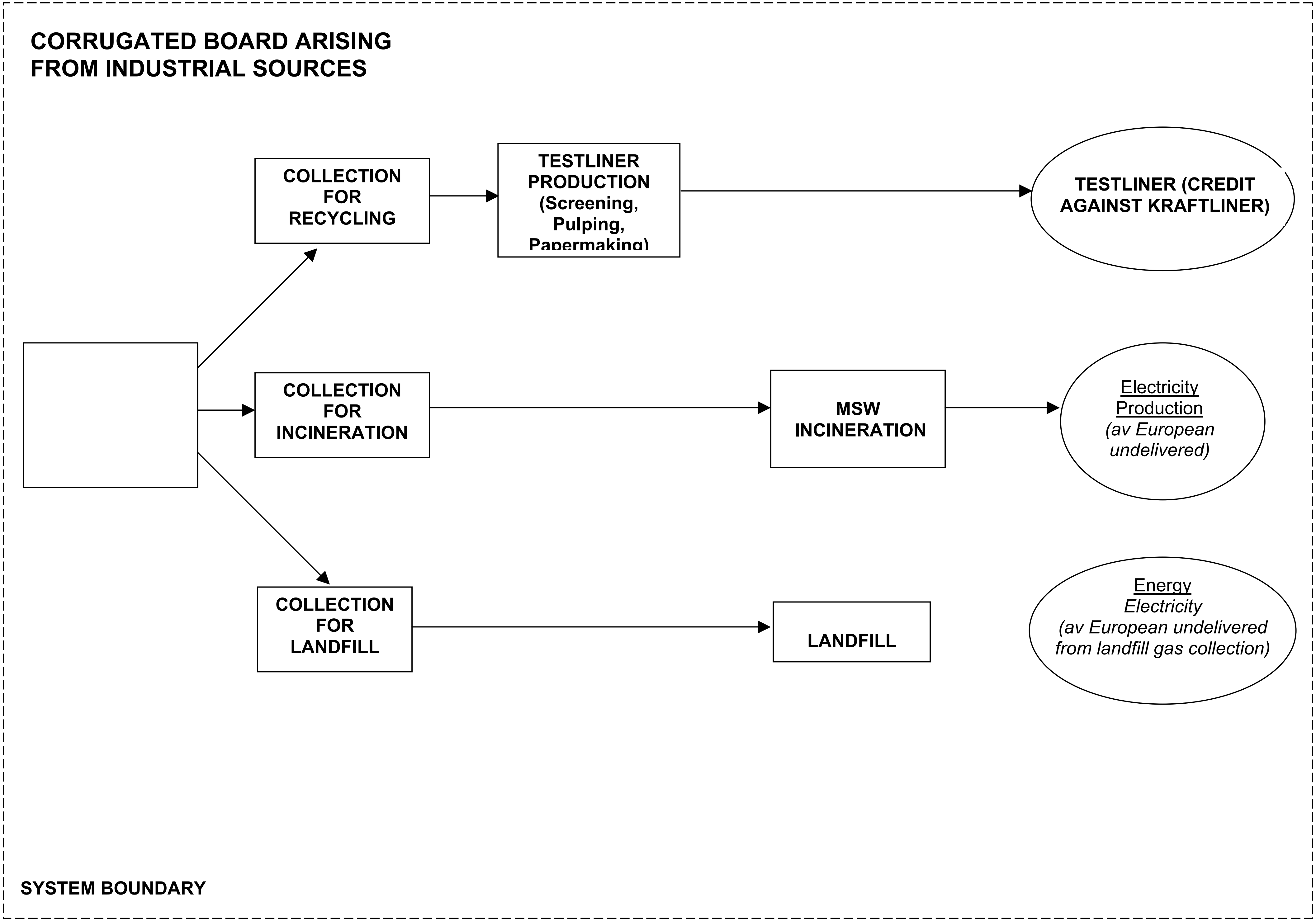

PAPER AND BOARD ARISING FROM HOUSEHOLDS
TRANSPORT TO BRING BANK
COLLECTION FROM BRING BANK
KERBSIDE COLLECTION FOR IRECYCLING
SORTING
TRANSPORT TO RECYCLERS
TESTLINER PRODUCTION (Screening, Pulping, Papermaking)
TESTLINER (CREDIT AGAINST KRAFTLINER)
COLLECTION FOR INCINERATION
MSW INCINERATION
Electricity Production (av European undelivered)
COLLECTION FOR LANDFILL
LANDFILL
Energy Electricity (av European undelivered from landfill gas collection)
SYSTEM BOUNDARY

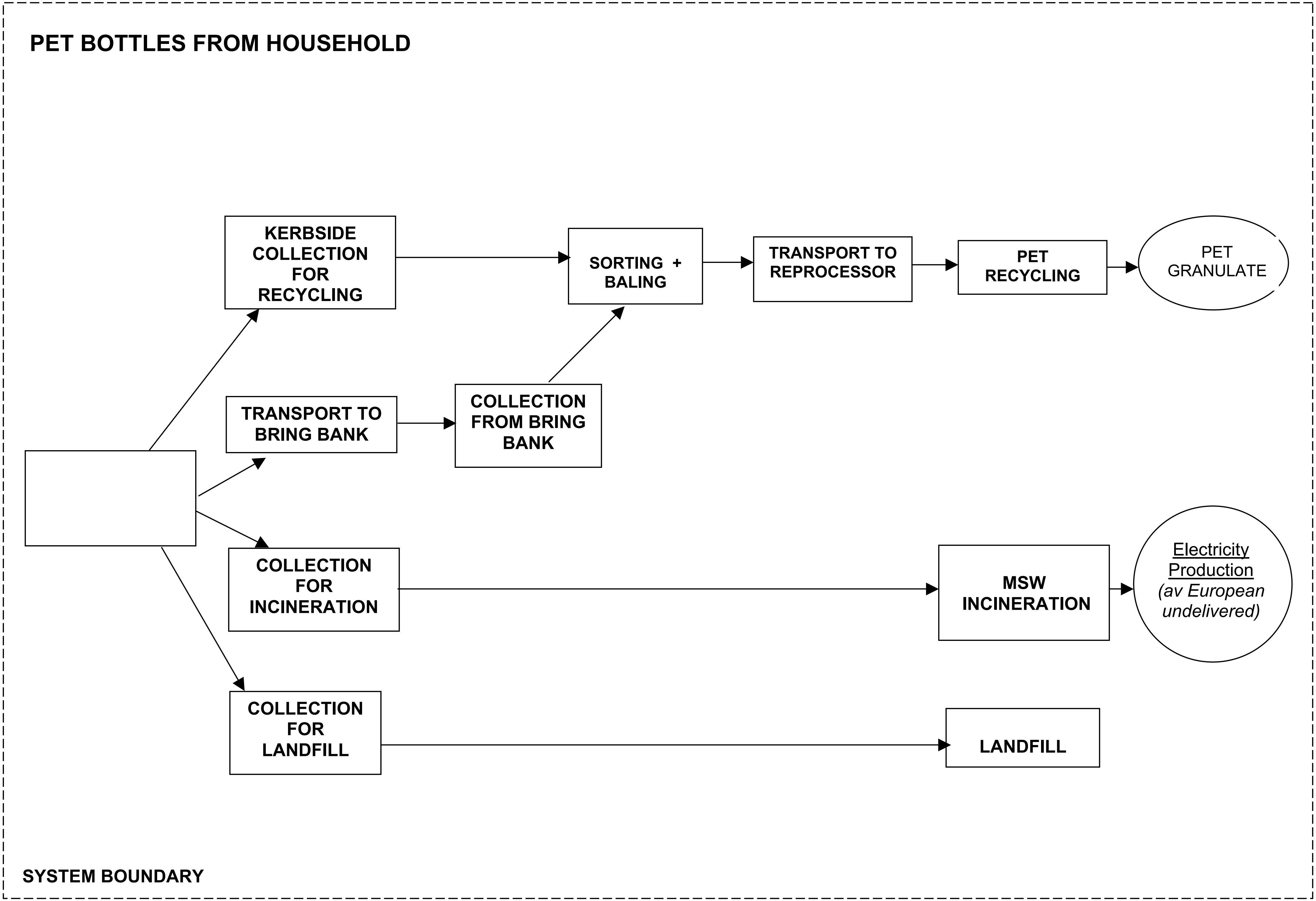

STEEL PACKAGING FROM HOUSEHOLD
TRANSPORT TO BRING BANK
COLLECTION FROM BRING BANK
STEEL PRODUCTION (ELECTRIC ARC OR OXYGEN FURNACE
CREDIT AGAINST VIRGIN PRODUCTION
KERBSIDE COLLECTION FOR RECYCLING
SORTING + BALING
TRANSPORT TO REPROCESSOR (STEEL MILL)
TRANSPORT TO REPROCESSOR
METALS RECOVERY FROM INCINERATION
COLLECTION FOR INCINERATION
MSW INCINERATION
COLLECTION FOR LANDFILL
LANDFILL
SYSTEM BOUNDARY

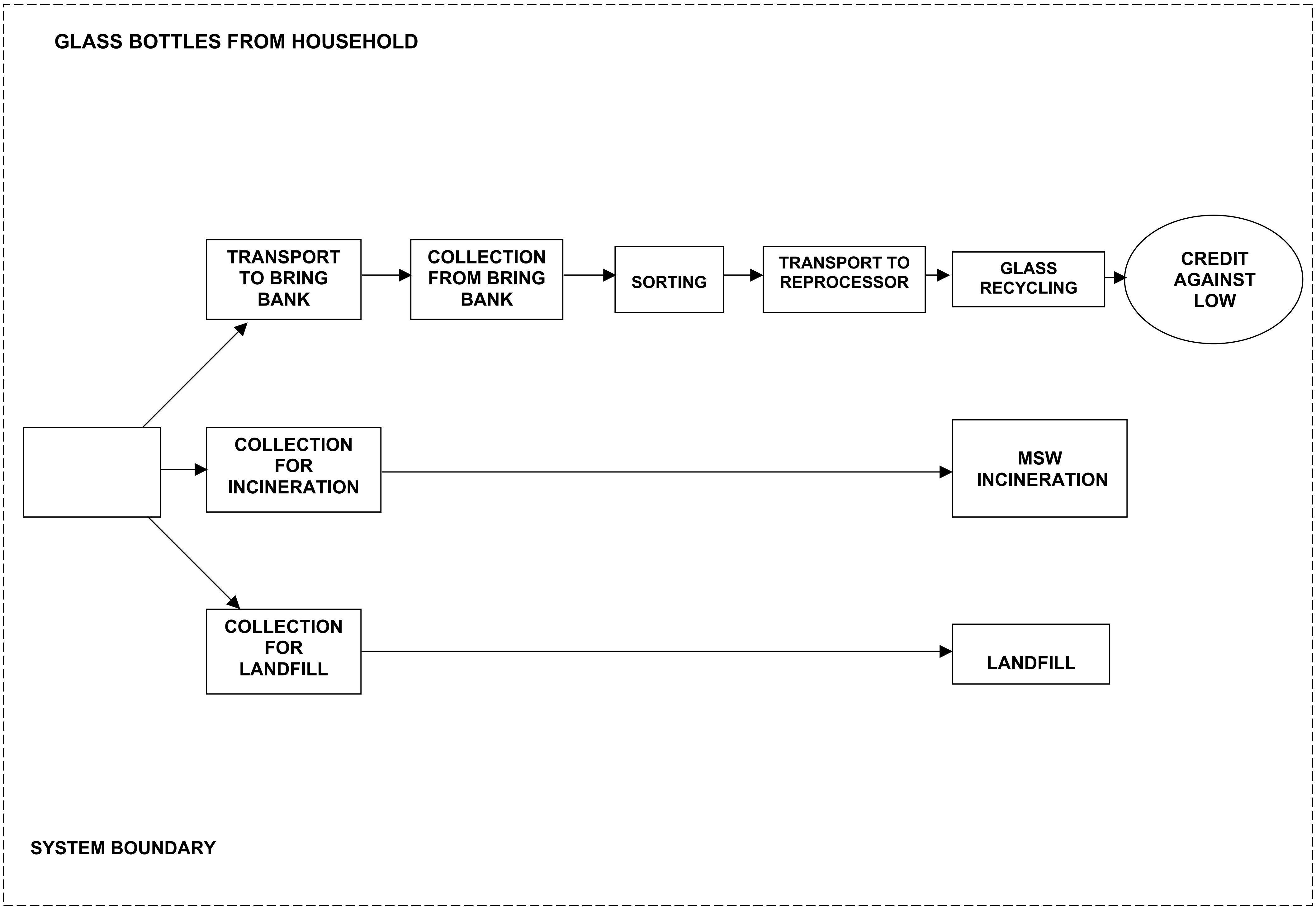

COMPOSITE BEVERAGE CARTONS FROM HOUSEHOLD
CONSUMER TRANSPORT TO BRING BANK
COLLECTION FROM BRING BANK
REJECTS (PE + AL) TO LANDFILL
REJECTS (PE + AL) TO MSW INCINERATION
REPULPING PROCESS
TESTLINER PRODUCTION
TESTLINER (CREDIT AGAINST KRAFTLINER)
KERBSIDE COLLECTION FOR RECYCLING
SORTING + BALING
COLLECTION FOR INCINERATION
MSW INCINERATION
Electricity Production (av European undelivered)
COLLECTION FOR LANDFILL
LANDFILL
Energy Electricity (av European undelivered from landfill gas collection)
SYSTEM BOUNDARY


RIGID AND SEMI-RIGID ALUMINIUM PACKAGING FROM HOUSEHOLD
TRANSPORT TO BRING BANK
COLLECTION FROM BRING BANK
KERBSIDE COLLECTION FOR RECYCLING
SORTING + BALING
TRANSPORT TO REPROCESSOR
RECYCLING + PRODUCTION (SCRAP PREPARATION SMELTING AND ALLOYING)
CREDIT AGAINST VIRGIN PRODUCTION
MATERIALS RECOVERY FROM INCINERATION
COLLECTION FOR INCINERATION
MSW INCINERATION
COLLECTION FOR LANDFILL
LANDFILL
SYSTEM BOUNDARY

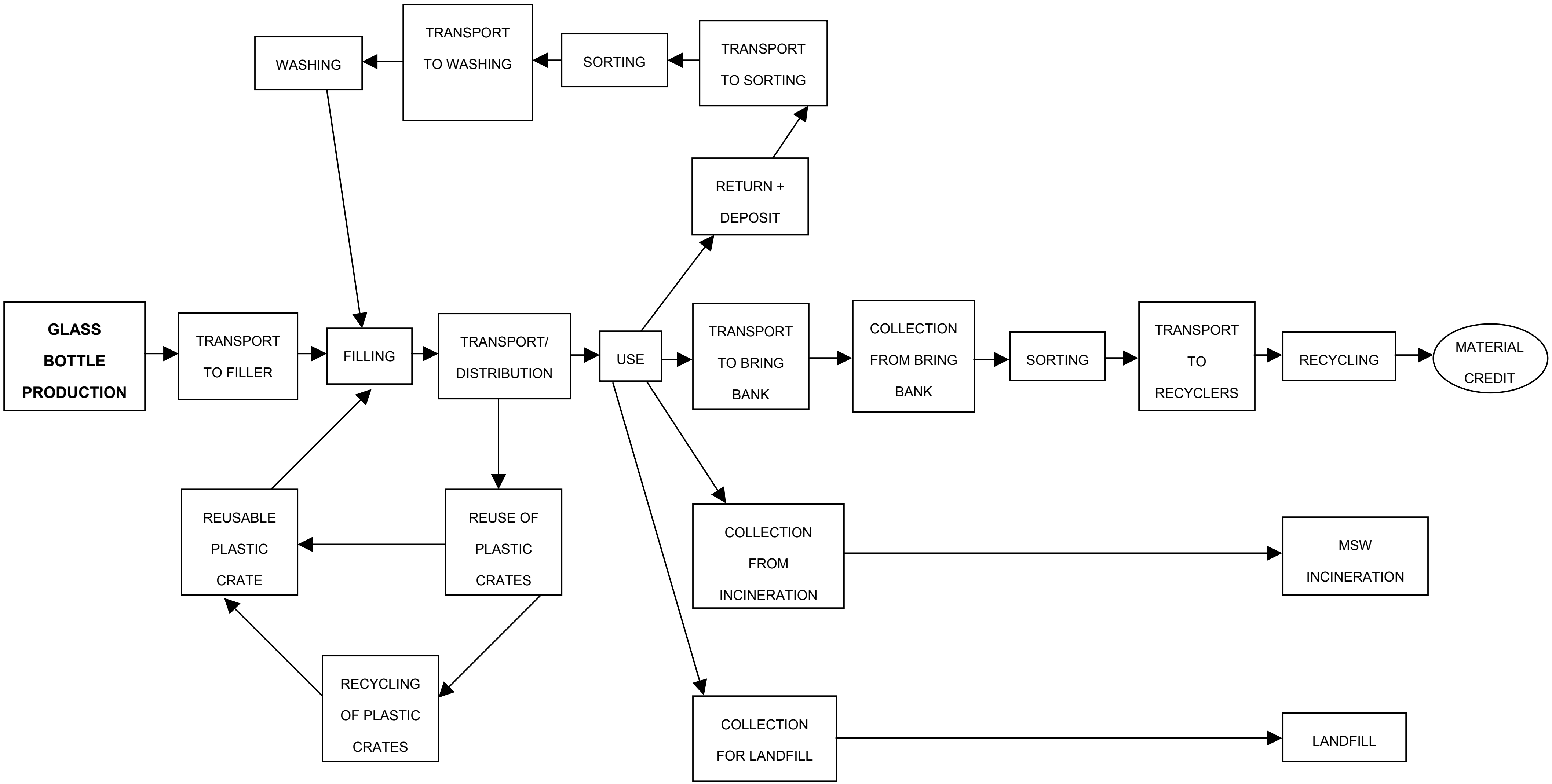

LDPE FILMS ARISING FROM INDUSTRIAL SOURCES
COLLECTION AND BALING FOR RECYCLING
TRANSPORT TO REPROCESSOR
FILM RECYCLING
Credit to LDPE FILM
COLLECTION FOR INCINERATION
MSW INCINERATION
Electricity Production (av European undelivered)
COLLECTION FOR LANDFILL
LANDFILL
SYSTEM BOUNDARY


CORRUGATED BOARD ARISING
FROM INDUSTRIAL SOURCES
COLLECTION FOR RECYCLING
TESTLINER PRODUCTION (Screening, Pulping, Papermaking)
TESTLINER (CREDIT AGAINST KRAFTLINER)
COLLECTION FOR INCINERATION
MSW INCINERATION
Electricity Production (av European undelivered)
COLLECTION FOR LANDFILL
LANDFILL
Energy Electricity (av European undelivered from landfill gas collection)
SYSTEM BOUNDARY

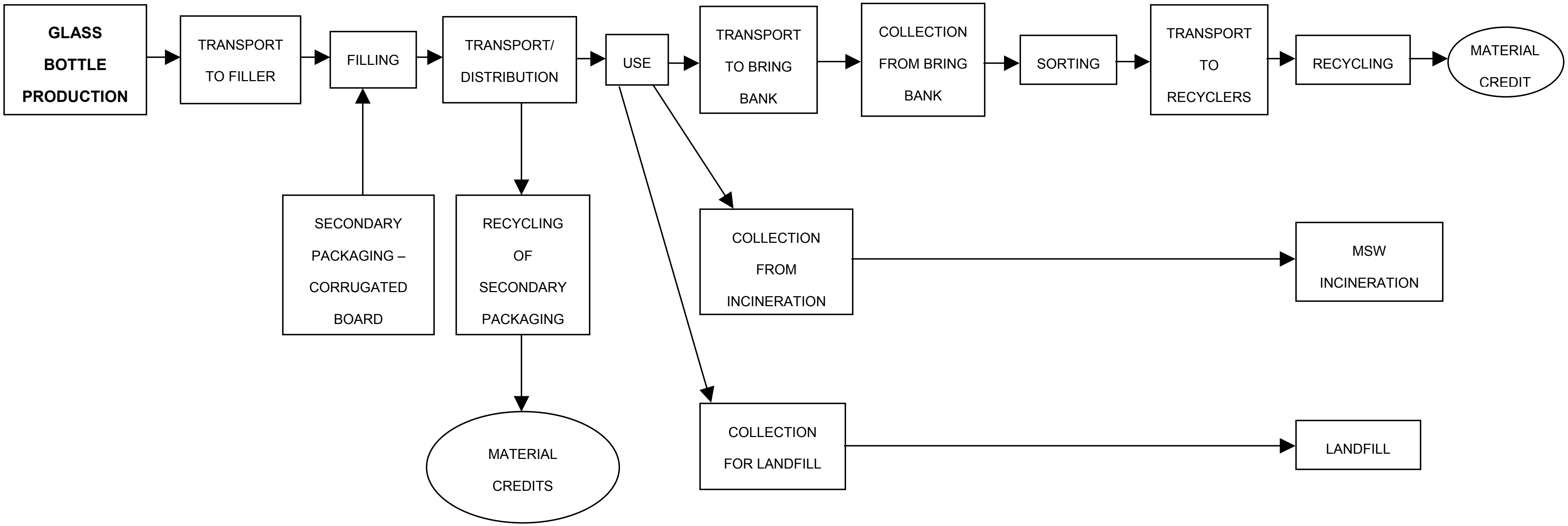

PET BOTTLES FROM HOUSEHOLD
KERBSIDE COLLECTION FOR RECYCLING
SORTING + BALING
TRANSPORT TO REPROCESSOR
PET RECYCLING
PET GRANULATE
TRANSPORT TO BRING BANK
COLLECTION FROM BRING BANK
COLLECTION FOR INCINERATION
MSW INCINERATION
Electricity Production (av European undelivered)
COLLECTION FOR LANDFILL
LANDFILL
SYSTEM BOUNDARY


GLASS BOTTLES FROM HOUSEHOLD
TRANSPORT TO BRING BANK
COLLECTION FROM BRING BANK
SORTING
TRANSPORT TO REPROCESSOR
GLASS RECYCLING
CREDIT AGAINST LOW
COLLECTION FOR INCINERATION
MSW INCINERATION
COLLECTION FOR LANDFILL
LANDFILL
SYSTEM BOUNDARY

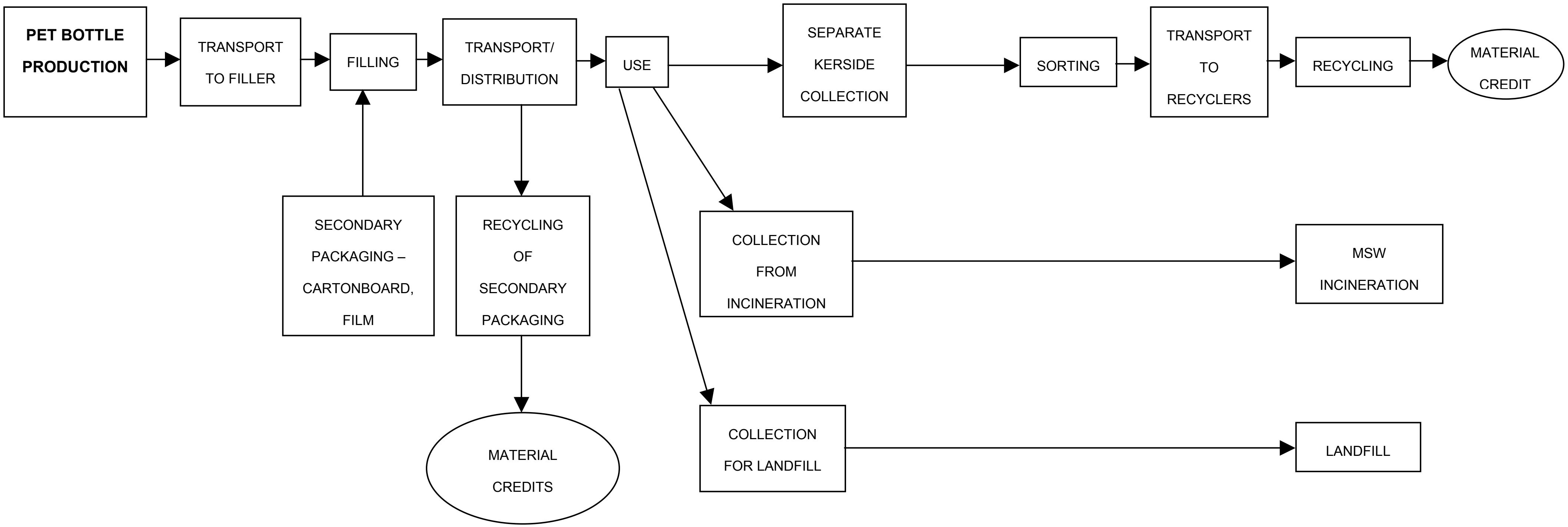
PROCESS TREE: GLASS BOTTLES RETURNABLE



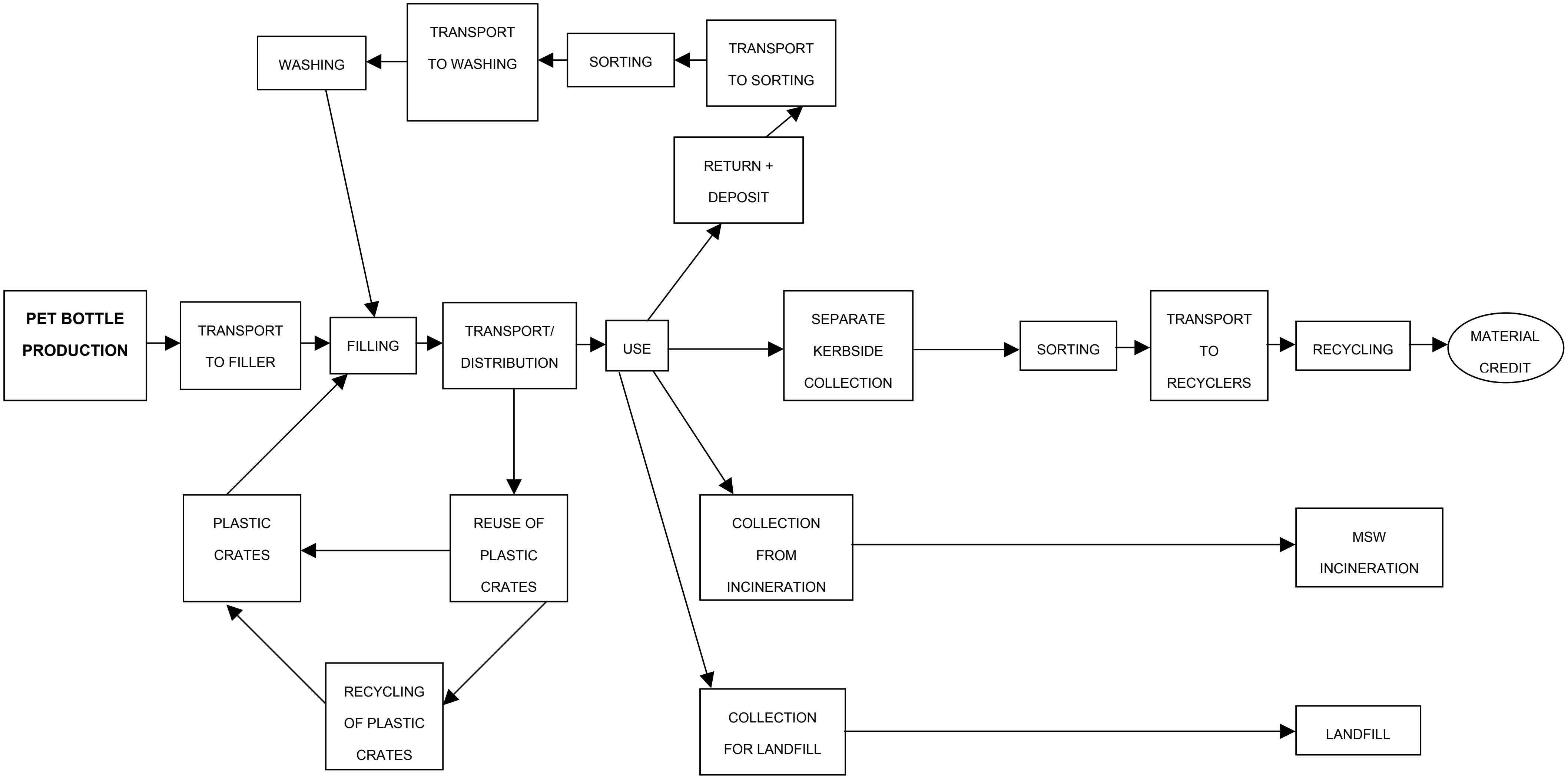
PROCESS TREE: GLASS BOTTLES SINGLE TRIP



PROCESS TREE: PET BOTTLES SINGLE TRIP



PROCESS TREE: PET BOTTLES RETURNABLE



Annex 2: Incineration and landfill models

1 NON SELECTIVELY COLLECTED MSW COLLECTION SYSTEM

The grey bag is collected

- twice a week in high population density areas and
- once a week in low population density areas.

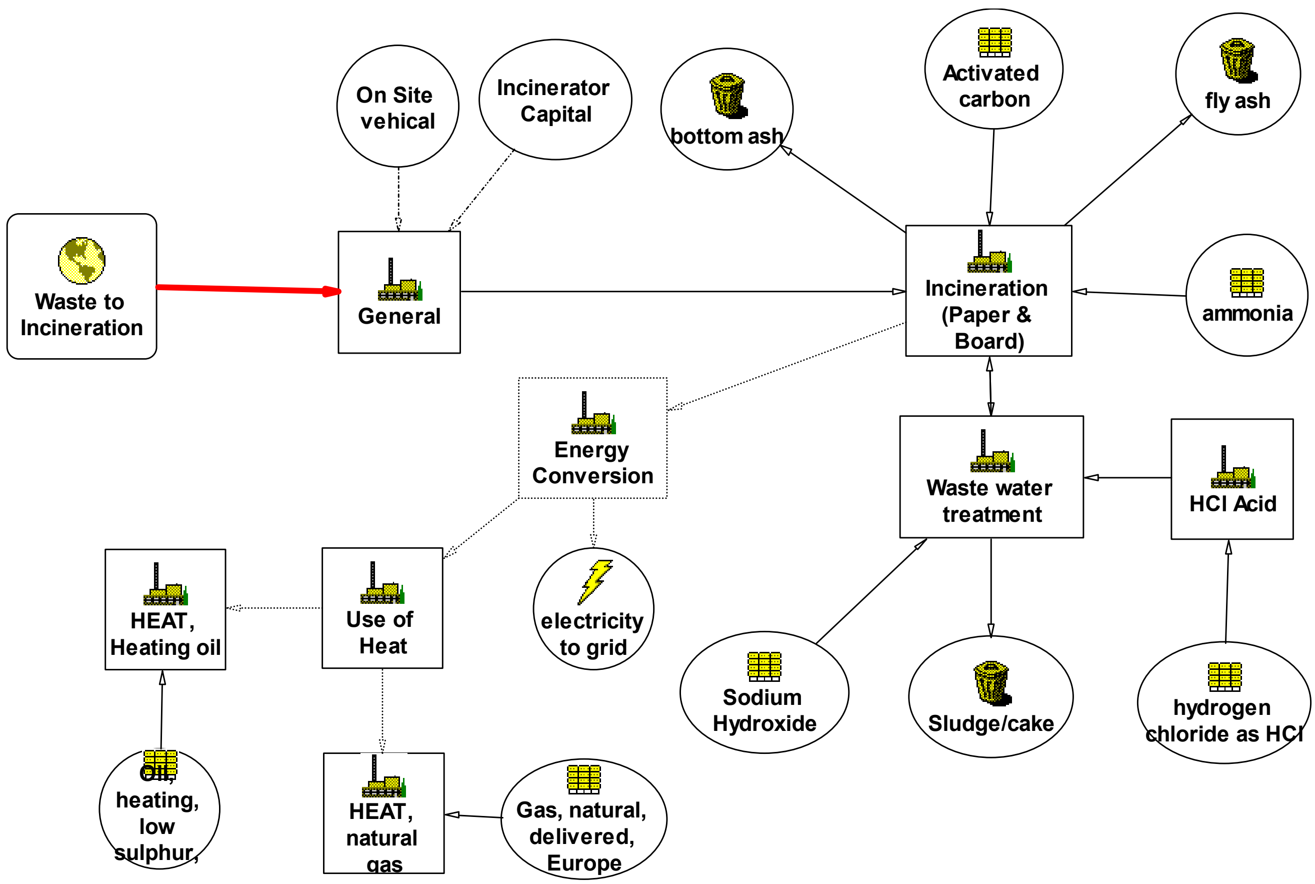
Collection vehicle is a truck with a volume of $16m^3$.

Employment and internal costs were determined by Beture Environnement [46].

2 INCINERATION MODEL

Pira Int. developed the incineration model shown in Figure 1.

Figure 1 : Incineration model



2.1 Internal costs data

Allocation rules for the incineration cost

The allocation principle is to find a causal link between the waste composition and the incineration cost.

The possible bases for the allocation are :

* The waste volume (or mass when only mass data are available and it is difficult to determine the density) : to be used for the processes concerned when the waste is transported and stored
* The stoechiometric oxygen demand for full combustion (or fume volume or waste calorific value) : to be used for the processes concerned when the waste produces heat and flue gas
* The waste inert content : to be used for the processes concerning the waste combustion residues
* The pollutant concentration : to be used for the flue gas cleaning

Next tables give the allocation rules and the data and assumptions.

Cost Item		Allocation base
A. Fixed cost		
Construction		
Reception, offices, waste pit		mass
Furnace		
	grid	mass
	chamber	stoichiometric oxygen demand for full combustion
Boiler, gas cleaning, chimney		stoichiometric oxygen demand for full combustion
energy recovery (turbine, alternator)		caloric value
Bottom ash extractor and treatment		inert content
Magnetic separation		Ferrous metal content
Eddy current separation		Non ferrous metal content
Maintenance and replacement of pieces		proportional to construction cost
Personnel		proportional to construction cost
B. Variable cost		
Electricity consumption		stoichiometric oxygen demand for full combustion
Disposal of		
Fly ash		ash content
Boiler ash		ash content
Bottom ash		inert content
Gas cleaning residues		
	for acidic stage	chlorine content
	for basic stage	sulphur content
	activated carbon	stoichiometric oxygen demand for full combustion
Consumption of additives		
Activated carbon		stoichiometric oxygen demand for full combustion
CaO	for acidic stage	chlorine content
CaO	for basic stage	sulphur content
Ammonia	De-Nox	stoichiometric oxygen demand for full combustion
C. Variable revenues		
Electricity production		calorific value
Ferrous metals		Ferrous metal content
Non Ferrous metals (Al)		Non ferrous metal content

should be volume but very complicated to apply

Incineration model - main data and assumptions

capacity			200 000	t/y
staff	65 pers * 1.650.000 F		2 658 658	€/y
		Depreciation period	20	years
		interest rate	6.0%	
Fixed cost			0	
	Reception, offices, waste pit		8 924 167	€
	Furnace - grid		5 949 445	€
	Furnace - chamber		8 924 167	€
	Boiler, gas cleaning, chimney		36 688 242	€
	energy recovery (turbine, alternator)		33 713 519	€
	Bottom ash extractor and treatment		2 974 722	€
	Magnetic separation		991 574	€
	Eddy current separation		148 736	€
		Total	98 314 572	€
Variable cost				
	cost of treatment of dangerous waste (fly ash, gas cleaning residues) + landfilling class 1		149	€/t
	amount of CaCl2.H2O + Ca(OH)2 generated		2.49	t residue / t Cl (CaCl2 + Ca(OH)2))
	stoechiometric coefficient (dictated by HCl)		1.65	
	amount of CaSO4.1/2H2O generated for stoechiometry = 1		4.53	t CaSO4 / t S
	amount of Ca(OH)2 residue generated		1.50	t CaSO4 / t S
	amount of CaSO4 + Ca(OH)2 in landfill		6.03	t CaSO4 / t S
	sale value of Fe recovered from bottom ash		-50	€/t Fe
	sale value of Al recovered from bottom ash		-193	€/t Al
	Ca(OH)2 cost		112	€/t Ca(OH)2
	Ca(OH)2 use for acidic stage		1.72	t Ca(OH)2 / t Cl
	Ca(OH)2 use for basic stage		3.82	t Ca(OH)2 / t S
	cost of activated carbon		1 116	€/ t act. carbon
	use of activated carbon		113	t act. Carbon /y
	cost of landfilling class 2		50	€/t
	ammonia cost		91	€/t
	ammonia use		114	t/y
	fly ash and boiler ash production		2.5%	t/t MSW
	efficiency of electricity production (overall)		24.0%	
	Internal electricity consumption		-2.5%	of low calorific value
	efficiency of electricity production (net)		21.5%	
	waste - low caloric value (positive)		10.2	GJ/t
	conversion factor		3.6	GJ/MWh
	electricity sale price		-37	€/MWh
	production total		136 588	MWh/y
	Internal electricity consumption		-14 228	MWh/y
	net production		122 360	MWh/y
Specific flue gas volume (11% O2 dry)			6 000	Nm3/t (11% O2 dry)
Inert conten in MSW (including Fe and Al)			21%	t inert/t MSW
	bottom ash humidity		20%	t water / t dry bottom ash
Ferrous metal content in MSW			2%	t Fe / t MSW
Al content in MSW			0.5%	t Al / t MSW
chlorine content			0.48%	t Cl / t MSW
sulphur content			0.075%	t S / t MSW
Fe extraction rate from bottom ash			80%	t Fe extracted / t Fe in MSW
Al extraction rate from bottom ash (only cans)			76%	t Al extracted / t Al in MSW (only rigid)
Electricity consumption for Fe extraction			0.007	MWh/t Fe extracted
Electricity consumption for Al extraction			0.114	MWh/t Al extracted

Therefore the costs are apportioned as follows :

	Fixed cost	Variable cost	Total cost
	EURO / t	EURO / t	EURO / t
PVC	117	263	**380**
water	15	6	**20**
paper & board	105	18	**123**
glass	24	50	**73**
composites (LBC)	140	-1	**139**
flexible Al	115	96	**211**
PE	271	-75	**196**
PET	161	-63	**98**
Fe	27	-2	**25**
Rigid Al	48	-340	**-291**
PP	271	-86	**185**
MSW	80	-3	**77**

Sources :[69], [70], [71]

2.2 Environmental data

The incinerator modelled in this study assumes full compliance with current European requirements for MSW incineration. In its original form the data assumed a set MSW mix. The information summarised below has been use to allocate emissions between different components of the waste stream:

- The allocation of CO_2 emissions have been made on the basis of the carbon content of the waste component
- The allocation of energy credits on the basis of the net energy yield of the waste component
- The allocation of the bottom ash on the basis of the ash content of the waste component
- The allocation of the process related burdens, (e.g. NOx, SO_2 & particulates) on the basis of exhaust gas quantity

- The allocation of waste independent burdens here assumed to include pre-treatment, on site transport and burdens associated with the capital are allocated on a weight basis.

Main Assumptions

	% Water[2]	% Carbon[1&2]	% ash Content[3]	Energy dry weight)[2]	Exhaust Gas (dry weight)[4]	Energy used by water[1]
	%	%	%	MJ/kg	kg/kg	MJ/kg
Paper & board	24%	44%	8%	11	8	-480
Mixed Film	28%	85%	12%	22	24	-560
PE/PP Film	28%	86%	12%	31	24	-560
Rigid Plastic Mixed	10.50%	80%	7%	22	24	-210
PET	10.50%	58%	7%	22	14	-210
PE/PP	10.50%	86%	7%	31	24	-210
Ferrous metals	4.50%	0%	100%		0	-90
Aluminum (rigid)	12%	0%	100%	-1		-240
Aluminum (foil)	12%	0%	189%	25	6	-240
Glass	2.50%	0%	100%	-1		-50
Composite beverage	24%	49%	17%	15	11	-482

1 Calculated
2 sourced from Life Cycle Inventory Development for Waste Management Operations: Incineration, R&D Project Record P1/392/6, for the UK Environment Agency
3 sourced from Integrated Waste Management, A Life Cycle Inventory, PR White, M Franke and P Hindle, 1995
4 from information supplied by RDC

3 LANDFILL MODEL

3.1 Internal costs

The landfill is operated in line with the landfill directive of April 26, 1999 (EC/1999/31).
The main environmental impact is the disamenity. The disamenity caused by waste is assumed to be proportional to the waste volume.

The landfill costs (50 EURO/t of MSW) are also allocated proportionally to the waste volume. The waste density is assumed to be the same as the bales density after sorting as both are crushed. The costs are :

	Density	Cost	Cost
	kg/m3	EURO/t	EURO/m3
MSW	700	50	35
steel	800	43.75	35
aluminium	200	175	35
PET bottles	250	140	35
LBC	500	70	35
paper & board	500	70	35

3.2 Environmental data

The data used in this study is based on data generated in a study for the UK environment agency. The landfill considered is fully lined with active gas management, energy generation and an on site biological effluent treatment plant.

The model assumes that roughly one third of the landfill gas generated over the life time of the site is flared, with one third being burnt for energy generation and one third lost to atmosphere. The losses to atmosphere mainly occur during loading and after the active gas management of the site has ceased. Leachate in this study has been assumed to be related to moisture content, Alternative allocations have not been considered due to the low significance of the leachate emissions for packaging related systems.

	Dry quantity	**% Water**	**Land Fill Gas**	**Leachate**	**Residual waste**
	%	**kg**	**kg**	**kg**	
Paper & Board	1000	24%	913	316	87
Plastic Film	1000	28%	0	389	1000
Rigid Plastic	1000	10.50%	0	117	1000
Ferrous metals	1000	4.50%	0	47	1000
Non Ferrous Metals	1000	12%	0	136	1000
Glass	1000	2.50%	0	26	1000

Annex 3: Internal cost data

Costs for Landfilling 1 tonne PET bottles

Euro per tonne of packaging	Collection costs	Landfill costs	Total internal costs
High population density	294	140	**434**
Low population density	234	140	**374**

Costs for Landfilling 1 tonne glass bottles

Euro per tonne of packaging	Collection costs	Landfill costs	Total internal costs
High population density	99.3	73.1	**172.5**
Low population density	79.1	73.1	**152.2**

Costs for Landfilling 1 tonne steel packaging

Euro per tonne of packaging	Collection costs	Landfill costs	Total internal costs
High population density	88.2	43.8	**132**
Low population density	68.4	43.8	**112.2**

Costs for Landfilling 1 tonne rigid and semi - rigid aluminium packaging

Euro per tonne of packaging	Collection costs	Landfill costs	Total internal costs
High population density	490	175	**665**
Low population density	380	175	**555**

Costs for Landfilling 1 tonne paper & board packaging

Euro per tonne of packaging	Collection costs	Landfill costs	Total internal costs
High population density	78.8	70	**148.8**
Low population density	61.1	70	**131.1**

Costs for Landfilling 1 tonne Liquid Beverage Cartons

Euro per tonne of packaging	Collection costs	Landfill costs	Total internal costs
High population density	126	70	**196**
Low population density	98	70	**168**

Costs for Landfilling 1 tonne mix plastics packaging

Euro per tonne of packaging	Collection costs	Landfill costs	Total internal costs
High population density	294	140	**434**
Low population density	228	140	**368**

Costs for Incineration of 1 tonne PET bottles

Euro per tonne of packaging	Collection costs	Incineration – fixed costs	Incineration – variable costs	Total internal costs
High pop. density	294	161	-63	**392**
Low pop. density	228	161	-63	**326**

Costs for Incineration of 1 tonne glass bottles

Euro per tonne of packaging	Collection costs	Incineration – fixed costs	Incineration – variable costs	Total internal costs
High pop. density	99.3	24	50	**173.3**
Low pop. density	79.1	24	50	**152.1**

Costs for Incineration of 1 tonne steel packaging

Euro per tonne of packaging	Collection costs	Incineration – fixed costs	Incineration – variable costs	Total internal costs
High pop. density - no slag recovery	88.2	73*		**161.2**
High pop. density - slag recovery	88.2	27	-2	**113.2**
Low pop. density - slag recovery	68.4	73*		**141.4**
Low pop. density - slag recovery	68.4	27	-2	**93.4**

Costs for Incineration of 1 tonne rigid and semi-rigid aluminium packaging

Euro per tonne of packaging	Collection costs	Incineration – fixed costs	Incineration – variable costs	Total internal costs
High pop. density with no slag recovery	490	73*		**563**
High pop. density with slag recovery (cans)	490	48	-340	**198**
High pop. density with slag recovery (rigid/semi rigid)	490	48	-206	**332**
Low pop. density with no slag recovery	380	73*		**453**
Low pop. density with slag recovery (cans)	380	48	-340	**88**
Low pop. density with slag recovery (rigid/semi rigid)	380	48	-206	**222**

Costs for Incineration of 1 tonne Paper & Board packaging

Euro per tonne of packaging	Collection costs	Incineration – fixed costs	Incineration – variable costs	Total internal costs
High pop. density	78.8	105	18	**201.8**
Low pop. density	61.1	105	18	**184.1**

Costs for Incineration of 1 tonne Liquid Beverage Cartons

Euro per tonne of packaging	Collection costs	Incineration – fixed costs	Incineration – variable costs	Total internal costs
High pop. density	126	140	-1	**265**
Low pop. density	98	140	-1	**237**

Costs for Incineration of 1 tonne mix plastics packaging

Euro per tonne of packaging	Collection costs	Incineration – fixed costs	Incineration – variable costs	Total internal costs
High pop. density	294	271	-75	**490**
Low pop. density	228	271	-75	**424**

Costs for Recycling 1 tonne of PET bottles via separate kerbside collection

	Collection costs (Euro per tonne of PET bottles recycled)	Sorting costs (Euro per tonne of PET bottles recycled)	Transport from sorting plant to reprocessor (Euro per tonne of PET bottles recycled)	Reprocessing cost (Euro per tonne of output)	Revenue received for reprocessed material	Total internal cost per tonne PET bottles recycled
High pop. density	255	474	46	332	-540*	**566**
Low pop. density	306	474	46	332	-540	**618**

*corresponding to a 540-332-46 = 162 EURO/t at the outlet of the sorting plant. This value is representative for the 2001 market situation. It is supposed to be more representative of the situation in 2006 than the average value over the last years (1998-2000) because the market has not been stable and prices did not reflect the real cost in an efficient market.

Costs for Recycling 1 tonne PET bottles via bring bank collection

	Transport costs from bring bank to sorting plant (Euro per tonne of PET bottles recycled)	Sorting costs (Euro per tonne of PET bottles recycled)	Transport from sorting plant to reprocessor (Euro per tonne of PET bottles recycled)	Reprocessing cost (Euro per tonne of output)	Revenue received for reprocessed material	Total internal cost per tonne PET bottles recycled
High pop. density	196	474	46	332	-540	**508**
Low pop. density	242	474	46	332	-540	**553**

Costs for Recycling 1 tonne glass bottles via bring bank collection

	transport from bring bank to sorting plant	recycling (cullets preparation)	transport from recycling to glass factory	Total internal cost per tonne Glass bottles recycled
High pop. density	31	20.6	4.9	**56.5**
Low pop. density	37	20.6	4.9	**62.5**

Costs for Recycling 1 tonne of steel packaging via separate kerbside collection

Euro per tonne of steel recycled	Collection costs	Sorting costs	Transport from sorting plant to reprocessor	Revenue received for material ready for use in steel production	Total internal cost
High population density	83.5	75.4	22.9	-34	**147.8**
Low population density	100.5	75.4	22.9	-34	**164.8**

Costs for Recycling 1 tonne steel packaging via bring bank collection

Euro per tonne of steel recycled	Transport costs from bring bank to sorting plant	Sorting costs	Transport from sorting plant to reprocessor	Revenue received for material ready for use in steel production	Total internal cost
High population density	64.4	75.4	22.9	-34	**128.7**
Low population density	79.2	75.4	22.9	-34	**143.5**

Costs for Recycling 1 tonne of rigid and semi-rigid aluminium packaging via separate kerbside collection

Euro per tonne of aluminium sorted	Collection costs	Sorting costs	Transport from sorting plant to reprocessor	Revenue received for material ready for use in Al production	Total internal cost
High population density	178.3	571.9	53.4	-316	**487.6**
Low population density	214.6	571.9	53.4	-316	**523.9**

Costs for Recycling 1 tonne rigid and semi-rigid aluminium packaging via bring bank collection

Euro per tonne of aluminium sorted	Transport costs from bring bank to sorting plant	Sorting costs	Transport from sorting plant to reprocessor	Revenue received for material ready for use in Al production	Total internal cost
High population density	137.4	571.9	53.4	-316	**446.7**
Low population density	169.1	571.9	53.4	-316	**478.4**

Costs for Recycling 1 tonne of Paper & Board packaging via separate kerbside collection

Euro per tonne of paper & board	Collection costs	Sorting costs	Transport from sorting plant to reprocessor	Revenue received for baled paper	Total internal cost
High population density	41.2	35	22.9	-21.6	**77.5**
Low population density	49.6	35	22.9	-21.6	**85.9**

Costs for Recycling 1 tonne Paper & Board packaging via bring bank collection

Euro per tonne of paper & board	Transport costs from bring bank to sorting plant	Sorting costs	Transport from sorting plant to reprocessor	Revenue received for baled paper	Total internal cost
High population density	34	35	22.9	-21.6	**70.3**
Low population density	41	35	22.9	-21.6	**77.3**

Costs for Recycling 1 tonne of Liquid Beverage Cartons via separate kerbside collection (incineration of rejects)

Euro per tonne of LBC sorted	Collection costs	Sorting costs	Transport from sorting plant to reprocessor	Revenues from bales	Reprocessing costs	Revenues from paper product	Costs - revenues of incineration of rejects (euro/t rejects)	Total internal cost
High pop. density	146.2	302.3	22.9	-20	433	-455	57	**486.4**
Low population density	175.9	302.3	22.9	-20	433	-455	57	**516.1**

Costs for Recycling 1 tonne Liquid Beverage Cartons via bring bank collection (incineration of rejects)

Euro per tonne of LBC sorted	Transport costs from bring bank to sorting plant	Sorting costs	Transport from sorting plant to reprocessor	Revenues from bales	Reprocessing costs	Revenues from paper product	Costs - revenues of incineration of rejects (euro/t rejects)	Total internal cost
High pop. density	112.6	302.3	22.9	-20	433	-455	57	**452.8**
Low pop. density	138.6	302.3	22.9	-20	433	-455	57	**478.8**

Costs for Recycling 1 tonne of Liquid Beverage Cartons via separate kerbside collection (landfilling of rejects)

Euro per tonne of LBC sorted	Collection costs	Sorting costs	Transport from sorting plant to reprocessor	Revenues from recycling	Reprocessing costs	Revenues from paper product	Costs - revenues of landfilling of rejects (euro/t rejects)	Total internal cost
High population density	146.2	302.3	22.9	-20	433	-455	38.2	**467.6**
Low population density	175.9	302.3	22.9	-20	433	-455	38.2	**497.3**

Costs for Recycling 1 tonne Liquid Beverage Cartons via bring bank collection (landfilling of rejects)

Euro per tonne of LBC sorted	Transport costs from bring bank to sorting plant	Sorting costs	Transport from sorting plant to reprocessor	Revenues from recycling	Reprocessing costs	Revenues from paper product	Costs - revenues of landfilling of rejects (euro/t rejects)	Total internal cost
High pop. density	112.6	302.3	22.9	-20	433	-455	38.2	**434**
Low pop. density	138.6	302.3	22.9	-20	433	-455	38.2	**460**

Costs for Recycling 1 tonne of mix plastics packaging via separate kerbside collection (mechanical recycling)

Euro per tonne of mix plastics sorted	Collection, sorting, transport 1	Processing & transport 2	Overhead	Revenue	Total internal cost
High population density	1227	354	73	0	**1654**
Low population density	1227	354	73	0	**1654**

Costs for Recycling 1 tonne mix plastics packaging via separate kerbside collection (feedstock recycling)

Euro per tonne of mix plastics sorted	Collection, sorting, transport 1	Processing & transport 2	Overhead	Revenue	Total internal cost
High population density	1227	354	73	0	**1654**
Low population density	1227	354	73	0	**1654**

Annex 4: Economic valuations applied – sources and derivation

1 INTRODUCTION

The cost benefit analysis methodology used in the study is based on a life cycle assessment to determine the environmental impacts of the selected systems, and economic valuation to convert these environmental impacts into monetary values. The underlying characterisation tables used are included in Table 1 (annex 4bis). Table 2 (annex 4bis) contains data on a range of valuation and moneterisation methods, including the values applied in this study.

The environmental costs and benefits are summed to determine the total externality.

In parallel to this, the internal costs of the system are determined. The internal costs of the system are the total costs minus the total revenues.

The externalities and internal costs of the system are summed to determine the total social cost of the system.

The detail of determining environmental costs is discussed in the sections below.

The economic valuations applied in this study have been sourced by Pieter van Beukering of IVM (Institute for Environmental Studies, University of Amsterdam) unless otherwise indicated. The economic valuations have been sourced from a variety of reports and documents. As far as possible, damage cost values are applied. However, where necessary prevention costs have been used.

2 ENVIRONMENTAL IMPACTS

LCA is used to determine the environmental impacts of the system. The quantitative life cycle inventory is generated. Characterisation and classification is then applied to the inventory data. Characterisation assigns each environmental input and output (the inventory data) to the environmental impacts to which it may potentially contribute. Classification then applies a weighting factor according to the potential level of impact relative to a specific reference emission. For example, the reference emission for global warming is CO_2. The weighting applied to CO_2 is therefore 1. All other emissions which contribute to CO_2 are weighted relative to their CO_2 equivalence. For example, the effect of global warming caused by a 1kg emission of methane is 21 times greater than the effect caused by 1kg of CO_2. Therefore methane is given a classification of 21.

The impact assessment data is then converted to monetary values through the application of economic valuations to each individual impact category. The impact categories considered and the impact assessment methodology applied have been developed with a consideration of the needs of the economic valuations then applied. In some cases, this influences the type of inventory data that is required in order to make a complete external economic analysis.

The sections below and accompanying tables detail the classification values and economic valuations applied.

2.1 Global warming

Global warming is characterised in CO_2 equivalents. The classification values applied -Time Horizon 100 years - are taken from figures given in Climate Change 1995 (Contribution of WG1 to IPPC second assessment report). The two principal contributors to this category are carbon dioxide and methane with a GWP of 1 and 21 respectively.
The valuation stage is based on the most recent estimates from the FUND II model (Tol and Downing 2000, FUND2 model, forthcoming).
Tol and Downing report the following marginal damages expressed per tonne of carbon (tC not tCO_2):

Pure time preference rate = 0%	$75
Pure time preference rate = 1%	$46
Pure time preference rate = 3%	$16

Applying a 5% pure time preference rate, a value for GWP of US$46 tC, or US$12.5tCO_2 (converted to 13.44 Euro per tonne CO_2) is considered for this study.

As global warming is not site specific, the emissions from different processes can be directly summed. Overlap with other environmental effects can be ignored. One issue of potential importance is that of the time horizon over which the emissions occur (i.e. in incineration immediately and in landfill over many years). This issue has not been addressed directly in the method applied, however previous studies suggest that application of a time dependant analysis is of low significance. Where global warming is critical in the results and time issues might be significant then the issue will be addressed in sensitivity analysis.

New classification figures are due to be released shortly from the IPPC's Third assessment report but these were not available in time to be included in this study.

2.2 Ozone depletion

This category is typically unimportant for packaging waste systems, it is quantified in CFC 11 equivalents : The classification values applied are based on those in Climate Change 1995 and are listed in Annex 4 bis. The economic valuation applied to the impact assessment data is 680 Euro per tonne of CFC 11 equivalents. This is based on an estimated cost, associated with increased radiation, of 177 billion dollars and cumulative emissions of an estimated 200 billion kg and should be considered as very approximate. This value has been derived by Pira International specifically for inclusion in this study.

2.3 Human toxicity (Carcinogens)

Toxicity (carcinogens) refers to carcinogenic airborne emissions. Toxicity (carcinogens) is quantified in Cd equivalents. The classification values applied to carcinogenic emissions are listed in Annex 4 bis. The economic valuation applied to the impact assessment data is 22 140 Euro per tonne of Cd equivalents. This value is the average of the range of damage costs reported by Dorland et al, 2000. The range reported is 5774 – 38498 Euro per tonne.

The range applies to damages to human health by emissions of cadmium arising from production processes and electricity production.

2.4 Human toxicity (Smog)

Toxicity (smog) relates to the production of ozone in the troposphere and is characterised in Ethylene equivalents based on the values developed by Harwell Laboratories (Derwent & Jenkin, 1990). NOx which also contributes to the formation of low level ozone is given a value equivalent to 1.19kg ethylene/kg. The classification values applied to emissions that contribute to Toxicity (smog) are listed in Annex 4 bis.

The economic valuation applied to the impact assessment data is 734 Euro per tonne of Ethylene equivalents. The valuation is for VOC indirect impacts through ozone formation, as reported in Dorland et al, (2000). The value refers to damages to human health by emissions of production processes and electricity generation.

2.5 Human Toxicity (particulates)

Toxicity (particulates) refers to airborne emissions typically generated and measured directly, such as PM10 or indirectly through the production of aerosols (Sulphate & Nitrate). Toxicity (particulates) is measured in PM10 equivalents. The classification values applied to emissions that contribute to Toxicity (particulates) are listed in Annex 4 bis. The economic valuation applied to the impact assessment data is 23686 Euro per tonne of PM10 equivalents, as reported in Dorland et al, (2000). This value is for emissions of PM10 (directly emitted). The value refers to damages to human health by emissions arising from production processes and electricity generation.

2.6 Human toxicity (Other air)

Toxicity (Other air) refers to airborne emissions which have toxic effects, other than carcinogenic effects or effects caused by smog or particulates. Toxicity (other air) is quantified in SO_2 equivalents. The classification values applied to emissions that contribute to this category are based on their relative human toxicity value and are listed in Annex 4 bis.

The economic valuation applied to the impact assessment data is 1002 Euro per tonne of SO_2 equivalents. This value is non-specific and based on general non-transport related emissions. Should this category prove important then a sensitivity analysis will be conducted to consider the significantly higher burden associated with SO_2 emitted from vehicles (over 2000 Euro/tonne).

2.7 Acidification

Acidification is quantified in Acid equivalents (H^+). The classification values applied to emissions that contribute to acidification are listed in Annex 4 bis. The economic valuation applied to the impact assessment data is 8.7 Euro per kg of Acid equivalents equivalent to 0.27 Euro/kg of SO_2. This value excludes the costs due to damage to buildings but includes damage to crops, forestry and lakes (see Table 1).

Table 1

Crop Damage Dorland et al. (2000)	*Forests (EC 1995)*	*Lakes (EC 1995)*	*Total*
0.215	***0.036***	***0.015***	***0.27/kg SO2***
			= 8.7/kg H+ equiv.

2.8 Damage to structures

Damage to structures refers to soiling of buildings caused by black smoke. The definition of black smoke is based on chemical properties of particles rather than on particle size, so the size composition of black smoke can vary considerably. However, roughly speaking black smoke consists of particles with a diameter of less than 15µm.

Damage to structures is measured in dust equivalents: The classification values applied to emissions that contribute to Damage to structures are listed in Annex 4 bis. The economic valuation applied to the impact assessment data is 662 Euro per tonne of dust equivalents.

This value is sourced from Dorland et al 2000 who determine a damage cost of 662 Euro per tonne of particulate emitted in the form of black smoke. This value is calculated by Pieter van Beukering, estimated based on the total UK emissions of black smoke and an assessment of the size of the UK market for cleaning buildings that is completely attributable to soiling from particle pollution (as reported in Newby et al 1991).

In the methodology applied in this analysis, no distinction is made between emissions arising from processes and emissions arising from transport.

2.9 Fertilisation

Deposited nitrogen has a beneficial effect on crop yields because it acts as a fertiliser. The level of this externality is determined by the value of the yield increase due to the deposited nitrogen. Pieter van Beukering provides a value of –697 Euro per tonne of NOx (expressed as NO_2 mass equivalents). It is uncertain whether these fertilisation effects are sustainable in the long term.

The classification values applied to emissions that contribute to Fertilisation are listed in Annex 4 bis.

2.10 Traffic accidents

The economic valuation applied to traffic accidents in this study has been calculated by Pira International specifically for this project.

Traffic accidents is quantified in Car km equivalents. The classification values applied to different road types are listed in Annex 4 bis and based on UK transport statistics. Little evidence was found in these statistics of a difference between HGV/Commercial vehicles and passenger cars in terms of the accidents or deaths/km driven (see Table 2).

Table 2

Rate of Serious & Fatal Accidents/ 100 million vehicle km	
Car	12
Light Van	10
Goods Vehicle	12

Road type however is significant - motorways being considerably safer. The higher value for rural roads seems counter intuitive - however Rural roads are defined here as roads with a speed restriction above 40 mph (~64 km/h). The overall accident rate goes counter to this with urban roads having a rate more than twice as high. (See Table 3)

Table 3

	Fatalities 1999	**Serious Accidents**	**Total road traffic billion vehicle km**	**Deaths /billion vehicle km**	**Serious Accidents /billion vehicle km**	**Characterisation (fatality equivalent)**	*Characterisation - Serious accident equivalent.*
Motorway	176	1218	83.6	2.1	14.6	**0.31**	*0.19*
Urban	1338	23011	200.2	6.7	114.9	**1.00**	*1.47*
Rural	1621	12176	183.3	8.8	66.4	**1.32**	*0.85*
All	3135	36405	467.1	**6.7**	77.9	**1.00**	*1.00*

The methodology assumes that the average European situation follows the UK situation and uses the characterisation values above to combine the different road types.

The serious accident figures are being excluded; firstly because the low valuation of injury versus fatality means that it becomes insignificant and secondly because there is a risk of double counting as the statistics for serious accidents include accidents, which led to fatalities.

The economic valuation applied to the impact assessment data is **16.9 Euro** per 1000 km travelled on an average road.

2.11 Traffic congestion

The external costs of congestion result from various effects. The most important costs are the time costs of delay. Indirect effects include increased emissions levels and danger in traffic. Traffic congestion is quantified in Car km equivalents with a HGV or van equivalent to 2 cars. The differentiation between road types is based on UK data. The classification values applied are listed in Annex 4 bis. The economic valuation applied to the impact assessment data is **85.5 Euro** per 1000 car km equivalents.

Brossier (1996) estimates the marginal congestion costs of trucks averaged over a year on "National roads" at 17.1 Euro per 100 HGV km. No description of the term "national roads" is provided, but assuming that this refers to a typical UK A road (rather than an urban road) this gives an economic value of 8.55 Euro per 100 car km equivalents.

2.12 Traffic Noise

Noise is any unwanted sound. The main source of noise in recycling systems is transport and disposal sites. The noise externality of landfill sites is included in the disamenity value of landfilling (Section 2.14), so the focus of this impact category is transport related noise. In many EU countries, transport is the most pervasive source of noise in the environment (Houghton 1994).

It is difficult to relate noise or noise nuisance to a parameter that is quantifiable in a life cycle study. The impact pathway is complex with many influencing factors. However, as waste disposal and recycling activities involve a considerable amount of transport. The disamenity of noise from transport cannot be neglected. Therefore, an attempt to quantify this important impact has been made for the purposes of this study.

Two types of noise exist:

- Acute noise – arising from the operation of heavy machinery, and therefore mainly related to occupational health
- Nuisance noise – less sudden noise, such as that experienced by people living near a main road or rail track. The effects can include impairment of communication, loss of concentration and loss of sleep.

The actual damage of noise has three forms:

- Property value reductions
- Productivity loss resulting due to medical complaints of workers
- Damage to ecosystems (frightened wildlife)

An overview of available hedonic and contingent valuations is presented in Table 4.

Table 4 : Summary of studies on the WTP to halve the noise exposure level

Study	Hedonic valuation (in Euro)	Contingent valuation (in Euro)
Pommerehne (1988)	51	46
Iten and Maggi (1988)	43	-
Willeke et al (1990)	-	81
Soguel (1994)	37	35-42

Source: Soguel 1994

Even though two different techniques are applied, the estimates are within the same range. Assuming a linear relationship between WTP and noise exposure, the average WTP for a reduction of noise exposure is 3.8 Euro per dB(A).

Kageson (1993) determines the noise costs for road transport at 2-3 Euro per 1000 km and passenger km, and rail transport at 0.5 – 0.7 Euro per 1000 km.

For this study, "Traffic noise" is quantified in Car km equivalents, using the economic value of **3 Euro** per 1000 car km equivalents. The classification values applied to different transportation modes are listed in Annex 4 bis.

2.13 Water Quality – Eutrophication

Several difficulties exist in transferring the external effects of surface water pollution for externalities occurring in recycling processes. Firstly, most values are presented in an aggregated manner, whereas waste related and recycling processes are valued on a marginal basis. Secondly, transferability is hampered by demographic differences. Most water pollution studies have been conducted in Scandinavian countries. Thirdly, the type of water pollution may differ from the type of water contamination. Forth, there remains a lack of reliable dose-response function information.

In this study, Water Quality – Eutrophication is quantified in P equivalents. The classification values applied to water borne emissions that contribute to Eutrophication are listed in Annex 4 bis. The economic valuation applied to the impact assessment data is 4700 Euro per tonne P equivalents. This is derived from Gren et al (1996), and is based on the costs of increased abatement capacity at sewage or industrial plants necessary to reduce these emissions.

2.14 Disamenity

Disamenity effects of waste management processes are likely to make up a significant share of the externalities caused. In particular, landfill sites and incineration facilities generate substantial social costs to their neighbouring population. The disamenity may take a number of forms:

- Increased traffic noise (see Section 2.12 for details of valuation applied)
- Increased traffic congestion (see Section 2.11 for details of valuation applied)
- Odour and visual pollution
- (Perceived) increased health risk

A common approach to determine disamenity effects is to use variations in house prices (hedonic price method). In this study, the externality of increased traffic noise and congestion are valued separately. Changes in house price are assumed to relate to odour and visual disamenity only, as these aspects are not valued elsewhere in the methodology. It should be highlighted that this approach may lead to potential double counting of some of the externalities.

Several hedonic price method studies on the value of disamenity effects of landfill have been performed. Landfilling and incineration produce different effects, and therefore should be assigned different externalities. Households are reluctant to live near an incinerator due to the perceived health effects of emissions. Disamenity of landfill is caused by the perception of groundwater pollution, and the visual pollution and odour nuisance. However, as no valuation data have been found to distinguish between their waste management practices the overall disamenity value for landfilling and incineration has been assumed to be equal.

All studies identify a significant house price reduction due to the existence of waste sites nearby. House prices increase approximately 3-4% per kilometre distance from a landfill site, within a radius of approximately 5.5 km.

Similarly, Contingent valuation studies demonstrate that WTP[1] declines with distance to the facility. An important determinant of WTP is income and perception of the risk of leachate pollution of water supplies. Households with a high income whose water supplies were at risk are willing to pay substantially more than low-income households dependent on piped city-water. However, the CVM[2] findings are generally consistent with the findings of the HPM[3].

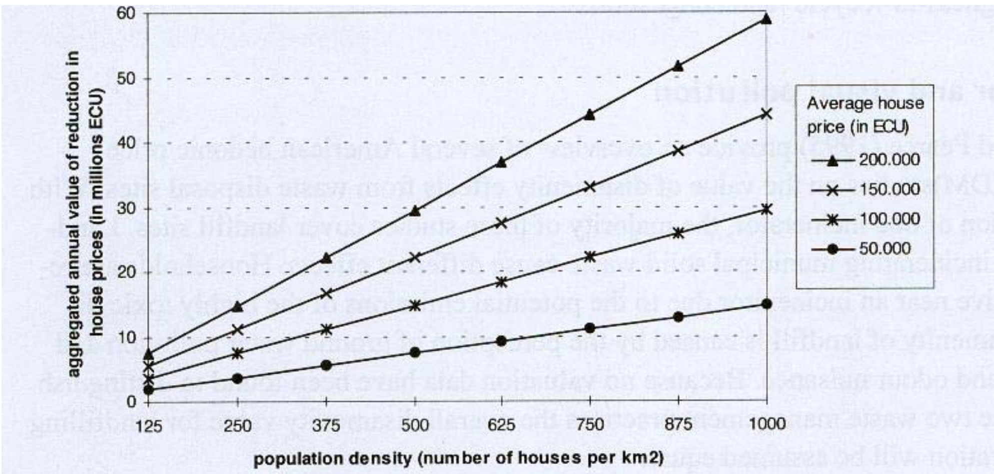
Based on the literature, the following linear regression equation is determined (Brisson and Pearce 1995): $\Delta HP = 12.8 - 2.34 * D$

(ΔHP = the percentage change in house price, D = distance in km from facility)

This suggests a maximum house price depreciation of 12.8% at the site of the facility, with no price differential beyond 5.5 km.

Based on the disamenity function, the annual value of reduction in the real estate prices can be calculated. Graph 1 shows how this varies substantially considering five categories of household density and five levels of average house price. The overall values are converted to annual values by taking 8% of the total reduction.

Graph 1



To link variations in the life cycle and economic valuation, external costs are then calculated on a per unit basis. This step in the analysis is uncommon – in reality the disamenity is not

[1] Willingness To Pay
[2] Contingent Valuation Method
[3] Hedonic Price Method

determined by the quantity of waste processed by the facility, but by the simple existence of the facility. However, to facilitate a link disamenity value is assumed to be proportional to the total amount of waste processed. Values reported in the literature vary from 1.2 Euro per tonne for a study relating to landfilling in Minnesota (IIED 1996) to 10.6 Euro per tonne for a study in Milan, Italy (Ascari and Cernischi 1996). These differences may arise due to the processing capacities of the facilities.

Table 5 determines the annual disamenity value of 1 tonne of landfilled and incinerated solid waste. However, due to the potential influence of the simplifying assumptions, such as the uniform disamentiy value for landfill and incinerator, and the neglect of income elasticity, these values should be treated with caution. Ideally, the values should be determined on a marginal basis and considering local circumstances such as average house price, population density and processing capacity.

Table 5 : Calculation of disamenity valuation per tonne of solid waste

	Annual processing capacity (ton / annum)	Total disamenity (million Euro)***	**Disamenity per unit of waste (Euro per tonne)**
Landfill*	200000	7.4	**37**
Incinerator**	730000	7.4	**10**

* Total capacity estimated at 4 million tonnes over 20 year life time
** Total capacity estimated at 10 million tonnes over a 14 year life time
*** Based on an average house price of Euro 100000 and a density of 250 houses per km^2

2.15 Heavy metals (airborne)

An accurate valuation is not available for this category. However a crude approximation has been generated by Pira International specifically for this study, by dividing the estimated total damage cost by the total emissions. Dubourg (1996) estimates that airborne Pb was responsible for 62 deaths in England & Wales in 1987. Taking this figure and multiplying by 3.1 million Euro (the value for a statistical life assumed for this calculation) gives us a total cost of 192.2 million Euro. Another publication (The Environment in Europe and North America, Annotated Statistics 1992, Economic Commission for Europe, United Nations Publication) gives the total emissions of lead in the UK as 3100 tonnes in 1988. This gives us an economic value of 62 Euro/kg of Pb emitted.

2.16 Employment

Standard economic theory says that it is not possible to create a job without displacing other employment. The argument is that for every job that is created, some other job is lost – the reason being that economics assumes full employment in the economy. Any one not in employment is in a transitional stage between one job and another, rather than being "involuntarily unemployed", and has therefore internalised the costs of unemployment in their decision-making. If you now create a job for this person in recycling, it means that this person is now not available for the job he/she would have taken if this job hadn't been created. There is therefore no social value in creating employment.

However, the fact is that a proportion of the unemployed in Europe are not unemployed voluntarily (i.e. they are not in a transitional stage, and have not internalised the costs of unemployment in a decision). In such a case, the unemployment represents a social cost. If such involuntary unemployment represents a significant and long-term proportion of the total unemployment, then it may be argued that employment creation policies will have a positive social impact and employment should have an economic valuation.

Table 6 presents unemployment rates in the EU for May 2000. For some Member States high unemployment rates are experienced. This may include long-term involuntary unemployment, and therefore an economic valuation of employment could be appropriate. Thus, for this study, an economic valuation for employment is included in the sensitivity analysis. The economic valuation applied is **2945 Euro per job per annum**. This value has been derived by RDC-Environment specifically for this study, and is based on the economic support to job creation in Belgium. It is the value of the reduction of social security taxes for newly employed workers in Belgium (law of 1999-03-26).

Table 6 :Unemployment rates in Europe (as at May 2000)

Country	%
Austria	3.2
Belgium	8.4
Denmark	4.7
Finland	9.5
France	9.8
Germany	8.4
Greece	No data
Ireland	4.7
Italy	10.7*
Luxembourg	2.2
Netherlands	3.0*
Portugal	4.5
Spain	14.3
Sweden	6.1
UK	5.7**

* *as at April 2000*
** *as at March 2000*

3 ALTERNATIVE ECONOMIC VALUATIONS

Economic valuation and cost benefit analysis are developing disciplines. Different practitioners apply different economic valuations. Some alternative economic valuations are list in annex 4 bis.

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Appendix 1 - Characterisation Tables

Burden Name:	Multiplier:	Notes:
GWP (kg CO2 eq.)		
carbon tetrachloride	-225	
CFC (unspecified)	1320	assumed as CFC-11
CFC-11	1320	
CO2 (non renewable)	1	
CO2 (renewable)	1	
CO2 (unspecified)	1	
dichloromethane	9	
haloginated HC (unspecified)	4	
halon -1301	-49750	
halons (unspecified)	-49750	assumed as halon-1301
HCFC (unspecified)	1350	assumed as HFC-22
HCFC-22	1350	
hexafluoroethane	9200	
HFC (unspecified)	1000	
methane	21	
N2O	310	
tetrafluoromethane	6500	
tetrafluroethylene	1300	
trichloroethane	-1525	
trichloromethane	4	
Ozone depletion (kg CFC 11 eq.)		
carbon tetrachloride	1.08	
CFC (unspecified)	1	assumed as for CFC 11
CFC-11	1	
halon -1301	16	
halons (unspecified)	0.14	assumed as for Halon-2311
HCFC (unspecified)	0.055	assumed as for HCFC 22
HCFC-22	0.055	
trichloroethane	0.12	
Acidification (Acid equiv.)		
acid as H+ (waterborne)	1	
HCl	0.0274348	
HF	0.050005	
NH3	0.0294118	
NOx	0.0108696	
SO2	0.03125	
Toxicity Carcinogens (Cd equiv)		
acetaldehyde	0.0000016	acetaldehyde
aromatics (unspecified)	0.000019	assumed as benzene
As	0.18	Arsenic
As (soil)	0.098	Arsenic (ind.)
As (waterborne)	0.49	Arsenic
benzene	0.000019	benzene
benzene (waterborne)	0.000031	benzene
benzo(a)pyrene	0.029	benzo(a)pyrene
benzo(a)pyrene (waterborne)	22	
butadiene	0.00012	1,3-butadiene
carbon tetrachloride	0.0062	carbontetrachloride
Cd	1	Cadmium
Cd (soil)	0.029	Cadmium (ind.)
Cd (waterborne)	0.53	Cadmium

Appendix 1 - Characterisation Tables

Burden Name:	Multiplier:	Notes:
Cr (IV)	13	assumed as Cr (6+)
Cr (unspecified)	13	
Cr (unspecified) (soil)	2	Chromium (ind.)
Cr (unspecified) (waterborne)	2.5	as Cr IV
Cr-VI (waterborne)	0.029	Chromium (VI)
dichloroethane	0.00022	1-2 dichloroethane
dichloromethane	0.0000032	dichloromethane
dioxins and furanes (unspecified)	1300	assumed as 2,3,7,8-TCDD Dioxin
ethylene oxide	0.0014	ethylene oxide
formaldehyde	0.0000073	formaldehyde
formaldehyde (waterborne)	0.000037	formaldehyde
haloginated HC (unspecified)	0.0000032	assumed as dichloromethane
heavy metals (air)	0.039	assumed as metals
insecticide (unspecified)	0.0026	as lindane
lindane	0.0026	gamma-HCH (Lindane)
metals (unspecified)	0.039	metals
Ni	0.17	Nickel
Ni (soil)	0.029	Nickel (ind.)
Ni (waterborne)	0.23	Nickel
PAH (unspecified)	0.43	as Benzo(a) anthracene
PAH (waterborne)	4.9	as Benzo(a) anthracene
particulate (diesel)	0.000072	particles diesel soot
pesticides (unspecified) (waterborr	0.031	gamma-HCH (Lindane)
styrene	1.8E-07	styrene
tetrachloride-dibenzo-dioxin	1300	2,3,7,8-TCDD Dioxin
tetrachloroethene	0.0000036	perchloroethylene
trichloromethane	0.00019	chloroform
vinyl chloride	0.0000015	vinyl chloride
Toxicity Metals non carcinogens (Pb equiv.)		Relative toxicities taken from Ecoindicator 95
B (waterborne)	0.03	
Ba (waterborne)	0.14	
Cu (waterborne)	0.005	
heavy metals (air)	1	
heavy metals (waterborne)	1	assumed as Pb
Hg	1	
Hg (waterborne)	10	
metals (unspecified)	1	assumed as Pb
metals (unspecified) (waterborne)	1	assumed as Pb
Mn	1	
Mn (waterborne)	0.02	
Mo (waterborne)	0.14	
Pb	1	
Pb (waterborne)	1	
Toxicity Gaseous non carcinogens (SO2 equiv.)		
CO	0.67	Value based on EI99 (Respirotary effects - Egalitarian)
H2S	43.59	
NH3	1.12	
SO2	1.00	
Toxicity Particulates & aerosols (PM10 equiv)		
NOx	0.2	
particulate (diesel)	15.7	
PM10	1	
SO2	0.24	
TSP	0.7	Assumed as PM10 *.7

Appendix 1 - Characterisation Tables

Burden Name:	Multiplier:	Notes:
Toxicity Smog (ethylene equiv.)		
acetaldehyde	1.4	
acetic acid	1.1	assumed as for Non Methane hydrocarbons (average)
acetone	0.47	
acrolein	1.1	assumed as for Non Methane hydrocarbons (average)
alcohols (unspecified)	0.52	
aldehydes (unspecified)	1.2	
alkanes (unspecified)	1.1	
alkenes (unspecified)	2.4	
aromatics (unspecified)	2	
benzene	0.5	
benzo(a)pyrene	1.1	assumed as for Non Methane hydrocarbons (average)
butadiene	1.1	assumed as for Non Methane hydrocarbons (average)
butane (i)	0.84	
butane (n)	1.1	
butane (unspecified)	0.84	assumed as for i-butane
butene	2.6	
carbon tetrachloride	0.056	assumed as for halogenated hydrocarbons (average)
CFC (unspecified)	0.056	assumed as for halogenated hydrocarbons (average)
CFC-11	0.056	assumed as for halogenated hydrocarbons (average)
cyclic alkanes (unspecified)	1.1	assumed as for Non Methane hydrocarbons (average)
dichloromethane	0.027	
dioxins and furanes (unspecified)	0.056	assumed as for halogenated hydrocarbons (average)
esters (unspecified)	0.59	
ethane	0.22	
ethanol	0.71	
ethene	2.7	
ethers (unspecified)	1.1	assumed as for Non Methane hydrocarbons (average)
ethylbenzene	1.6	
ethylene dichloride	1.1	assumed as for Non Methane hydrocarbons (average)
ethylene oxide	1.1	assumed as for Non Methane hydrocarbons (average)
ethyne	0.45	
formaldehyde	1.1	
haloginated HC (unspecified)	0.056	
halon -1301	0.056	assumed as for halogenated hydrocarbons (average)
halons (unspecified)	0.056	assumed as for halogenated hydrocarbons (average)
HC (unspecified)	1	
HC excl CH4 (unspecified)	1.1	
HCFC (unspecified)	0.056	assumed as for halogenated hydrocarbons (average)
HCFC-22	0.056	assumed as for halogenated hydrocarbons (average)
heptane	1.4	
hexafluoroethane	0.056	assumed as for halogenated hydrocarbons (average)
hexane	1.1	assumed as for n-hexane
HFC (unspecified)	0.056	assumed as for halogenated hydrocarbons (average)
ketone	0.86	
mercaptans/smell gas (unspecifiec	1.1	assumed as for Non Methane hydrocarbons (average)
methane	0.019	
methanol	0.33	
methyl tert-butyl ether	1.1	assumed as for Non Methane hydrocarbons (average)
naphthalene	1.1	assumed as for Non Methane hydrocarbons (average)
non methane VOC (unspecified)	1.1	assumed as for Non Methane hydrocarbons (average)
NOx	1.2	
organic acids (unspecified)	1.1	assumed as for Non Methane hydrocarbons (average)
PAH (unspecified)	1.1	assumed as for Non Methane hydrocarbons (average)
pentane	0.93	
phenol	1.1	assumed as for Non Methane hydrocarbons (average)
phenols (unspecified)	1.1	assumed as for Non Methane hydrocarbons (average)
phthalates (unspecified)	1.1	assumed as for Non Methane hydrocarbons (average)
propane	1.1	
propene	2.7	
propionaldehyde	1.6	
propionic acid	1.1	assumed as for Non Methane hydrocarbons (average)
styrene	1.1	assumed as for Non Methane hydrocarbons (average)
tetrachloride-dibenzo-dioxin	0.056	assumed as for halogenated hydrocarbons (average)

Appendix 1 - Characterisation Tables

Burden Name:	Multiplier:	Notes:
tetrafluoromethane	0.056	assumed as for halogenated hydrocarbons (average)
tetrafluroethylene	0.056	assumed as for halogenated hydrocarbons (average)
toluene	1.5	
trichloroethane	0.056	assumed as for halogenated hydrocarbons (average)
trichloromethane	0.056	assumed as for halogenated hydrocarbons (average)
VOC	1	
xylene (unspecified)	2.3	assumed as average xylene
xylene(m-)	2.6	
xylene(o-)	1.8	
xylene(p-)	2.4	
Damage to Structures (kg dust eq.)		
NOx	0.37	
particulate (diesel)	1	
PM10	1	
SO2	1.06	702 ecu/662 ecu
TSP	1	assumed as particulates
Fertilisation		
NOx	1	
Traffic accidents		
Car (motorway)	0.31	impact supposé en km
Car (rural)	1.32	
Car (unspecified)	1	
Car (urban)	1	
HGV (motorway)	0.31	
HGV (rural)	1.32	
HGV (unspecified)	1	
HGV (urban)	1	
Road transport (rural)	0.31	
Road transport (unspecified)	1	
Road transport (urban)	1	
Traffic Congestion (car km equiv.)		
Car (motorway)	0.08	
Car (rural)	0.03	
Car (unspecified)	1	
Car (urban)	4.9	
HGV (motorway)	0.15	
HGV (rural)	0.06	
HGV (unspecified)	2	
HGV (urban)	9.8	
Road transport (rural)	0.06	Car km congestion equiv.
Road transport (unspecified)	2	Car km congestion equiv.
Road transport (urban)	9.8	Car km congestion equiv.
Traffic Noise (car km equiv.)		
Car (motorway)	1	
Car (rural)	1	
Car (unspecified)	1	
Car (urban)	1	
HGV (motorway)	6	
HGV (rural)	6	
HGV (unspecified)	6	
HGV (urban)	6	
Road transport (rural)	6	Car km noise equiv.
Road transport (unspecified)	6	Car km noise equiv.
Road transport (urban)	6	Car km noise equiv.

Appendix 1 - Characterisation Tables

Burden Name:	Multiplier:	Notes:
Water Quality Eutrophication (P equiv.)		
COD	0.0072	
N (waterborne)	0.14	
NH3	0.029	Assuming 25% ends up in surface water
nitrates (waterborne)	0.033	Average value for NO3- to water
nitrites (waterborne)	0.033	Average value for NO3- to water
nitrogenous compounds (unspecifi	0.033	Average value for NO3- to water
NOx	0.011	Assuming 25% ends up in surface water
P (waterborne)	1	
phosphates (waterborne)	0.33	
Disaminity (kg LF waste equiv.)		
Waste into Incinerator	0.274	200000/730000 ton/year
Waste into Landfill	1	
Ecotoxicity (cu equiv.)		
As	0.41	Arsenic
As (soil)	0.42	Arsenic (ind.)
As (waterborne)	0.0078	Arsenic
benzene	0.0000019	benzene
benzene (waterborne)	0.000033	benzene
Cd	6.6	Cadmium
Cd (soil)	6.8	Cadmium (ind.)
Cd (waterborne)	0.33	Cadmium
Cr (IV)	2.8	as Cr
Cr (unspecified)	2.8	Chromium
Cr (unspecified) (soil)	2.9	Chromium (ind.)
Cr (unspecified) (waterborne)	0.047	Chromium
Cu	1	Copper
Cu (soil)	1	Copper (ind.)
Cu (waterborne)	0.1	Copper
Hg	0.57	Mercury
Hg (soil)	1.2	Mercury (ind.)
Hg (waterborne)	0.13	Mercury
insecticide (unspecified)	0.08	Malathion
lindane	0.0015	gamma-HCH (Lindane)
metals (unspecified)	0.18	metals
Ni	4.9	Nickel
Ni (soil)	5	Nickel (ind.)
Ni (waterborne)	0.098	Nickel
PAH (unspecified)	5.3E-07	PAH's
PAH (waterborne)	0.0000014	PAH's
Pb	1.7	Lead
Pb (soil)	0.0088	Lead (ind.)
Pb (waterborne)	0.0051	Lead
pesticides (unspecified) (waterborr	0.0071	gamma-HCH (Lindane)
tetrachloride-dibenzo-dioxin	90	2,3,7,8-TCDD Dioxin
toluene	1.6E-07	toluene
toluene (waterborne)	0.00012	toluene
Zn	2	Zinc
Zn (soil)	2	Zinc (ind.)
Zn (waterborne)	0.011	Zinc

Appendix 2 - Moneterisation/Valuation

Impact / Flux	Avoidance cost from Delft university (Vogtlander et al 1999) marginal cost (1)	Avoidance cost from Delft university (Vogtlander et al 1999) average cost (1)	Avoidance cost GUA méthodology (CBA) (1)	Eco-INDICATOR 95 (min)	Eco-INDICATOR 95 (max)	Ec--Indicator 95	Environmental damage cost (Krewitt et al. 1997 and Eyres et al 1997) (min)	Environmental damage cost (Krewitt et al. 1997 and Eyres et al 1997) (max)	Pira International economic valuation
Global Warming Potential /kg CO2 e	0.114	0.08							0.01344
CO2			0.0632	0.0014	0.0018	0.01375	0.003	0.193	
CH4			1.548						
Acidification	204.8	22.857					1.86	3.27	8.73
SOx	6.4		2.5435	1.03	1.4	0.47	0.06	0.10	
NOx			2.0348	0.911	1.16		2.3	16	
Photochemical pollution due to VOC	50	3.5	2.0348			3.55			0.734
O3				0.44	0.58		2.5	2.5	
Ozone depletion (CFC11)						4.459			0.68
Toxicity : other emissions to air (SO2 equ.)									1.002
CO	NA	NA	0.0763	NA			NA		0.01002
Eutrophication kg Phosphate equi.	3.05	0.0009		NA		2.357	NA		1.5369
COD in water			0.7122	NA			NA		
Eutrophication kg P equi.	9.327217125	0.002752294		NA			NA		4.7
Winter Smog									
Particulates (<10 µm)	12.3	5	0.5087	0.39	0.51	1.43	17	29	23.686
SO2									
TSP									
NOx									
Heavy metals (Pb)			NA			1571			62
Zn	680	0.3							
Toxicity : carcinogenic substances		NA	NA						
PAH	12.3					3837			6022.08
Dioxines				NA			2000000		19720319
Arsenic				33		1571.4	44		6.642
Cadnium				9100	12000	78571	81		22.14
Chromium				330	440	314.2	820		128
Nickel				330		1688	17		7.08
Damages to structures (S02)									0.662
Disamenity Landfill									0.037
Disamenity Incinerator									0.01
Traffic accident /1000 km									16.9
Traffic congestion/1000km									86
Traffic noise/1000km									3
Fertilisation (N02 equ.)								0	-0.697
Ecotoxicity									
Resource depletion (MJ)									0
Resources - fossil (MJ)									0
Land Use (m2.a)									0

Appendix 2 - Moneterisation/Valuation

Impact / Flux	Eco-INDICATOR 99 (min) Not moneterisation!	Eco-INDICATOR 99 (max) Not moneterisation!	MIN excluding EI 99	MAX excluding EI 99
Global Warming Potential /kg CO2 e			0.0014	0.193
CO2	0.0041	0.0133		
CH4	0.0852	0.2933		
Acidification	0.06	0.10	1.860	205
SOx				
NOx				
Photochemical pollution due to VOC	0.01	0.04	0.734	50
O3				
Ozone depletion (CFC11)	20.32	56.67	1	4.459
Toxicity : other emissions to air (SO			1.002	1.002
CO			0.010	0.0763
Eutrophication kg Phosphate equi.			0.0009	3.05
COD in water			0.712	0.7122
Eutrophication kg P equi.			0.00275	9.327217125
Winter Smog				
Particulates (<10 µm)	7.26	18.27	0.390	29
SO2	1.06	2.60		
TSP	2.13	5.35		
NOx	0.08	2.31		
Heavy metals (Pb)	2.18	247.65	62.00	1571
Zn	46.48	281.78	0.3	680
Toxicity : carcinogenic substances				
PAH	0.00	4.42	12.3	6022
Dioxines	0.00	4654000.00	2000000	19720319
Arsenic	66.67	639.60	6.64	1571
Cadnium	686.67	3510.00	22.14	78571
Chromium	11933.39	45500.00	128	820
Nickel	452.67	611.00	7.08	1688
Damages to structures (S02)			0	0.662
Disamenity Landfill			0	0.037
Disamenity Incinerator			0	0.01
Traffic accident /1000 km			0	16.9
Traffic congestion/1000km			0	86
Traffic noise/1000km			0	3
Fertilisation (N02 equ.)			-0.697	0
Ecotoxicity	2.18	247.65	0.00	0
Resource depletion (MJ)	0.87	48.92	0	0
Resources - fossil (MJ)	0.00	0.14	0	0.000
Land Use (m2.a)	0.06	0.11	0	0.000

Appendix 3 - Valuation table

	Unit	Valuation	Min	Max
GWP (kg CO2 eq.)	€ /kg CO2	0.01344	0.0014	0.19
Ozone depletion (kg CFC 11 eq.)	€ /kg CFC11	0.68	0.68	0.68
Acidification	€ /kg H+	8.70	1.9	200
Toxicity Carcinogens (Cd equiv)	€ /kg Cadmium (carcinogenic effects only) from e	22	22	12000
Toxicity Gaseous non carcinogens (SO2 equiv.)	€ /kg SO2 from electricity production	1	0	1
Toxicity Metals non carcinogens (Pb equiv.)	€ /kg Pb	62	0	62
Toxicity Particulates & aerosols (PM10 equiv)	€ /kg PM10 from electricity production	24	0.39	29
Smog (ethylene equiv.)	€ /kg VOC indirect impacts through ozone formati	0.73	0.73	50
Black smoke (kg dust eq.) [damage to structure]	€/kg smoke	0.66	0	0.66
Fertilisation	€/kg expressed as NO2 mass equivalents	-0.7	-0.7	0
Traffic accidents (risk equiv.)	euro/1000 km travelled on an average road	17	0	17
Traffic Congestion (car km equiv.)	Euro per 1000 car km equivalents	86	0	86
Traffic Noise (car km equiv.)	Euro per 1000 car km equivalents	3	0	3
Water Quality Eutrophication (P equiv.)	€ /kg P	4.7	0.0028	9.3
Disaminity (kg LF waste equiv.)	€ /kg landfill	0.037	0	0.037

Annex 5: Employment data –jobs for waste management activities

1 PACKAGING FROM HOUSEHOLD SOURCES

Gross Employment, Landfilling 1 tonne PET bottles

Jobs per 1000 tonne per annum	Collection	Landfill management / operation	Total
High population density	1.2	0.1	1.3
Low population density	1.15	0.1	1.25

Gross Employment for Landfilling 1 tonne steel packaging

Jobs per 1000 tonne per annum	Collection	Landfill management / operation	Total
High population density	1.2	0.1	1.3
Low population density	1.15	0.1	1.25

Gross Employment for Landfilling 1 tonne rigid and semi - rigid aluminium packaging

Jobs per 1000 tonne per annum	Collection	Landfill management / operation	Total
High population density	1.2	0.1	1.3
Low population density	1.15	0.1	1.25

Gross Employment for Landfilling 1 tonne paper & board packaging

Jobs per 1000 tonne per annum	Collection	Landfill management / operation	Total
High population density	1.2	0.1	1.3
Low population density	1.15	0.1	1.25

Gross Employment for Landfilling 1 tonne Liquid Beverage Cartons

Jobs per 1000 tonne per annum	Collection	Landfill management / operation	Total
High population density	1.2	0.1	1.3
Low population density	1.15	0.1	1.25

Gross Employment for Landfilling 1 tonne mix plastics packaging

Jobs per 1000 tonne per annum	Collection	Landfill management / operation	Total
High population density	1.2	0.1	1.3
Low population density	1.15	0.1	1.25

Gross Employment for Landfilling 1 tonne glass

Jobs per 1000 tonne per annum	Collection	Landfill management / operation	Total
High population density	1.2	0.1	1.3
Low population density	1.15	0.1	1.25

Gross Employment for Incineration of 1 tonne PET bottles

Jobs per 1000 tonne per annum	Collection	Incinerator management / operation	Total
High pop. density	1.2	0.27	1.47
Low pop. density	1.15	0.27	1.42

Gross Employment for Incineration of 1 tonne steel packaging

Jobs per 1000 tonne per annum	Collection	Incinerator management / operation	Total
High pop. density	1.2	0.27	1.47
Low pop. density	1.15	0.27	1.42

Gross Employment for Incineration of 1 tonne rigid and semi-rigid aluminium packaging

Jobs per 1000 tonne per annum	Collection	Incinerator management / operation	Total
High pop. density	1.2	0.27	1.47
Low pop. density	1.15	0.27	1.42

Gross Employment for Incineration of 1 tonne Paper & Board packaging

Jobs per 1000 tonne per annum	Collection	Incinerator management / operation	Total
High pop. density	1.2	0.27	1.47
Low pop. density	1.15	0.27	1.42

Gross Employment for Incineration of 1 tonne Liquid Beverage Cartons

Jobs per 1000 tonne per annum	Collection	Incinerator management / operation	Total
High pop. density	1.2	0.27	1.47
Low pop. density	1.15	0.27	1.42

Gross Employment for Incineration of 1 tonne mix plastics packaging

Jobs per 1000 tonne per annum	Collection	Incinerator management / operation	Total
High pop. density	1.2	0.27	1.47
Low pop. density	1.15	0.27	1.42

Gross Employment for Incineration of 1 tonne glass

Jobs per 1000 tonne per annum	Collection	Incinerator management / operation	Total
High pop. density	1.2	0.27	1.47
Low pop. density	1.15	0.27	1.42

Gross Employment , kerbside collection and sorting of PET bottles

Jobs per 1000 tonne per annum	Collection	Sorting	Transport from sorting to reprocessing	Total
High pop. density	14.7	0.71	0.19	**15.6**
Low pop. density	17.7	0.71	0.19	**18.6**

Gross Employment , bring scheme collection and sorting of PET bottles

Jobs per 1000 tonne per annum	Transport, bring bank to sorting	Sorting	Transport from sorting to reprocessing	Total
High pop. density	3.2	0.71	0.19	4.1
Low pop. density	3.8	0.71	0.19	4.7

Gross Employment , kerbside collection and sorting of steel packaging

Jobs per 1000 tonne per annum	Collection	Sorting	Transport from sorting plant to reprocessor	Total
High population density	4.8	0.53	0.1	5.43
Low population density	5.8	0.53	0.1	6.43

Gross Employment , bring scheme collection and sorting of steel packaging

Jobs per 1000 tonne per annum	Transport from bring bank to sorting plant	Sorting	Transport from sorting plant to reprocessor	Total
High population density	1	0.53	0.1	1.63
Low population density	1.2	0.53	0.1	1.83

Gross Employment , kerbside collection and sorting of rigid and semi-rigid aluminium packaging

Jobs per 1000 tonne per annum	Collection	Sorting	Transport from sorting plant to reprocessor	Total
High population density	10.3	0.03	0.68	11.01
Low population density	12.4	0.03	0.68	13.11

Gross Employment , bring scheme collection and sorting of rigid and semi-rigid aluminium packaging

Jobs per 1000 tonne per annum	Transport from bring bank to sorting plant	Sorting	Transport from sorting plant to reprocessor	Total
High population density	2.1	0.03	0.68	2.81
Low population density	2.6	0.03	0.68	3.31

Gross Employment , kerbside collection and sorting of Paper & Board packaging

Jobs per 1000 tonne per annum	Collection	Sorting	Transport from sorting plant to reprocessor	Total
High population density	2.6	n.a.	0.03	2.63
Low population density	3.1	n.a.	0.03	3.13

Gross Employment , bring scheme collection and sorting of Paper & Board packaging

Jobs per 1000 tonne per annum	Transport from bring bank to sorting plant	Sorting	Transport from sorting plant to reprocessor	Total
High population density	0.3	n.a.	0.03	0.33
Low population density	0.4	n.a.	0.03	0.43

Gross Employment , kerbside collection and sorting of Liquid Beverage Cartons (incineration of rejects)

Jobs per 1000 tonne per annum	Collection	Sorting	Transport from sorting plant to reprocessor	incineration of rejects (jobs/1000t rejects per annum)	Total
High population density	8.4	0.7	0.14	0.07	9.31
Low population density	10.1	0.7	0.14	0.07	11.01

Gross Employment , bring scheme collection and sorting of Liquid Beverage Cartons (incineration of rejects)

Jobs per 1000 tonne per annum	Transport from bring bank to sorting plant	Sorting	Transport from sorting plant to reprocessor	incineration of rejects (jobs/1000t rejects per annum)	Total
High pop. density	1.8	0.7	0.14	0.07	2.71
Low pop. density	2.2	0.7	0.14	0.07	3.11

Gross Employment , kerbside collection and sorting of Liquid Beverage Cartons (landfilling of rejects)

Jobs per 1000 tonne of LBC per annum	Collection	Sorting	Transport from sorting plant to reprocessor	landfilling of rejects (jobs/1000t rejects per annum)	Total
High population density	8.4	0.7	0.14	0.03	9.27
Low population density	10.1	0.7	0.14	0.03	10.97

Gross Employment , bring scheme collection and sorting of Liquid Beverage Cartons (landfilling of rejects)

Jobs per 1000 tonne of LBC per annum	Transport from bring bank to sorting plant	Sorting	Transport from sorting plant to reprocessor	landfilling of rejects (jobs/1000t rejects per annum)	Total
High pop. density	1.8	0.7	0.14	0.03	2.67
Low pop. density	2.2	0.7	0.14	0.03	3.07

Gross Employment , bring scheme collection and sorting of Glass (landfilling of rejects)

Jobs per 1000 tonne per annum	Transport from bring bank to sorting plant	Transport from sorting plant to reprocessor	Total
High pop. density	0.3	0.061	0.036
Low pop. density	0.3	0.061	0.036

2 COMMERCIAL AND INDUSTRIAL CASE STUDIES

Gross Employment, Landfilling 1 tonne C&I films

	Collection	Landfill management / operation	Total
Jobs per 1000 tonne per annum	1.2	0.1	1.3

Gross Employment for Incineration of 1 tonne C&I films

	Collection	Incinerator management / operation	Total
Jobs per 1000 tonne per annum	1.2	0.27	1.47

Gross Employment for Recycling of 1 tonne C&I films

	Collection	Total
Jobs per 1000 tonne per annum	1.2	1.2

Gross Employment, Landfilling 1 tonne C&I corrugated board

	Collection	Landfill management / operation	Total
Jobs per 1000 tonne per annum	1.2	0.1	1.3

Gross Employment for Incineration of 1 tonne C&I corrugated board

	Collection	Incinerator management / operation	Total
Jobs per 1000 tonne per annum	1.2	0.27	1.47

Gross Employment for Recycling of 1 tonne C&I corrugated board

	Collection	Total
Jobs per 1000 tonne per annum	1.2	1.2

Annex 6: Packaging mix by Member State

1 INTRODUCTION

It is assumed that the optimal recycling rate in a Member State is a function of the packaging mix in that Member State, as some packaging materials/applications will be easier to recycle than others. Therefore the packaging mix in each Member State must be determined in order to calculate the Member State's optimal recycling target.

2 DATA SOURCES AND EXTRAPOLATION RULES

The main data sources are:

- Member State's official declarations for 1997 and 1998
- Data provided by the national compliance schemes (1998-1999-2000)
- Reports and interview from/of European Material Federations (APME, FEVE)
- Additional input from local consultants where possible

Where data are missing, extrapolation rules are derived from the report "The Facts: A European cost/benefit perspective" commissioned by ERRA in 1998, e.g. for the split between industrial & commercial packaging and household packaging. The following assumptions are made

- the ratios between industrial and household packaging applications remain unchanged up to 2000
- the ratios between material applications are the best forecast where no other data is available
- for industrial packaging, distribution between packaging material applications is assumed to be the same in the south countries (Italy, Greece, Portugal and Spain)
- data for 1998 or 1999 provide a reasonable forecast for 2000

Member State	Source	Comment
Austria	"Bundesabfallwirtschaftsplan" 1998 Member State declaration, 1998	Data reviewed by the Compliance Scheme
Belgium	Fost Plus, 2000 Val-I-Pac, 1999	Data provided and reviewed by Compliance Scheme Extrapolation from Annual report and interview
Denmark	DEPA = Miljostyrelsen, 1998	Data provided by COWI
Finland	PYR, 2000	Data reviewed by the Compliance Scheme Shops packaging waste are considered as industrial packaging waste Extrapolation based on ERRA and APME reports when no data available.
France	Eco-Emballages, 1998	Data reviewed by Eco-emballages
Germany	GVM Gesallschaft für Verpackungsmarktforschung mbH, 1998	Data reviewed by the Compliance Scheme
Greece	Forecast for 2000	Data provided by Ecopolis
Ireland	National Waste database report 1998, Environmental Protection Agency	Data reviewed by the Compliance Scheme
Italy	CONAI, 2000	Data reviewed by the Compliance Scheme
Luxembourg	Valorlux	Data reviewed by the Compliance Scheme
The Netherlands		Data reviewed by the Compliance Scheme
Portugal	Sociedade Ponto Verde, 1999 PLASTVAL, 1999	Data collected by IDOM
Spain	ECOEMBALAJES ESPAÑA, S.A ECOVIDRIO	Data reviewed by the Compliance Scheme Data collected by IDOM and interview of Ecoembes.
Sweden	Member State declaration, 1998 Interview of RVF Svenska Renhållningsverksföreningen, The Swedish Association of Waste Management	
UK	Increasing recovery and recycling of packaging waste in the UK The Challenge Ahead: A forward Look for Planning Purposes, DETR (version under production)	Plastic packaging amount are split between application according to APME ratios Data reviewed by the Compliance Scheme

Year 2000 unit: kt	Material	Application	AUT	BE	DK	FI	FR	DE	GK	IE	IT	LU	NL	PO	SP	SE	UK
Industrial waste	Plastics	LDPE films	55	42	51	22	260	384	28	13	261	2	92	24	125	19	273
		Other	20	49	58	26	470	486	102	39	330	3	163	0	286	21	314
		total	75	91	109	48	730	870	129	52	591	5	256	24	411	40	587
	Wood	all appl.	60	168	84	0	1 690	1 969	38	0	2 295	9	379	7	443	0	670
	Steel	all appl.	4	56	11	18	280	654	108	10	223	3	118	20	43	53	217
	Cardboard	all appl.	384	371	314	192	3 100	4 350	403	242	2 875	19	1 128	75	1 627	370	3 373
	glass	all appl.	47	4	0	6	960	88	118	52	60	0	23	22	0	60	350
	Other	all appl.	0	14	0	0	0	0	22	31	0	1	0	4	177	0	40
Total Industrial			**570**	**704**	**518**	**264**	**6 760**	**7 930**	**818**	**387**	**6 043**	**36**	**1 905**	**152**	**2 702**	**523**	**5 237**
Household waste	Plastics	PET bottles	20	44	5	6	250	100	34	11	426	2	67	106	159	19	252
		PE films	24	43	20	17	140	175	25	11	248	2	59	98	130	25	190
		HDPE bottles	24	18	17	15	100	152	21	9	215	1	51	75	112	22	183
		other	44	57	21	0	412	201	152	86	420	2	58	10	200	27	459
		Total	112	162	63	37	902	628	232	117	1 309	7	235	289	601	94	1 084
	Steel	all appl.	69	80	37	12	350	358	87	21	247	2	92	81	235	9	533
	Aluminium	all appl.	9	14	7	2	36	62	14	8	57	1	10	15	41	8	108
	Metals	Al + steel	81	93.5	44	14	386	421	101	29	304	3	109	96	276	17	641
	Wood	all appl.			9		10				109				0		
	Cardboard	all appl.	98	153	121	18	872	978	302	50	1 300	11	447	198	828	150	420
	composites	liquid beverage cartons	23	20	0	29	120	209	25	8	10	1	47	12	117	40	51
		mainly based on plastic	4	3	1	4	18	32	4	1	2	0	7	2	18	6	7
		mainly based on cardboard	5	5	1	6	28	48	6	2	2	0	11	3	27	9	11
		mainly based on Al.	3	2	1	0	15	26	3	1	1	1	6	2	15	5	6
		Total	35	30	3	40	181	315	38	12	15	2	70	18	176	61	75
	Glass	all appl.	183	330	176	50	2 550	3 512	145	59	2 189	17	436	314	1 523	111	1 848
	Other	all appl.						14		32					19		
Total Household			**506**	**768**	**416**	**160**	**4 901**	**5 867**	**818**	**300**	**5 227**	**40**	**1 291**	**915**	**3 423**	**433**	**4 068**

Total HH + industrial	Material	AUT	BE	DK	FI	FR	DE	GK	IE	IT	LU	NL	PO	SP	SE	UK
	Glass	230	334	176	56	3 510	3 600	263	111	2 249	17	459	336	1 523	171	2 198
	Plastic	191	256	173	89	1 650	1 530	365	170	1 902	12	498	315	1 029	140	1 678
	Paper and board	510	548	436	246	4 120	5 585	735	302	4 187	32	1 633	287	2 598	570	3 855
	Metals	85	152	56	32	681	1 100	212	40	528	7	226	118	334	75	864
	Wood	60	168	93	0	1 700	1 969	38	0	2 404	9	379	7	443	0	670
	Other	0	14	0	0	0	14	22	63	0	1	0	4	196	0	40
	Total	1 076	1 472	934	423	11 661	13 798	1 635	686	11 270	77	3 195	1 067	6 125	956	9 305

Annex 7: Environmental data sources

Environmental data for background systems

LCI data for the environmental analysis has been derived from the following sources:

	Data Source	Comments
Transport steps		
Vehicle emissions	*"Life Cycle Inventory Development for Waste Management Operations: Waste Transport and Other Vehicle Use",* UK Environment Agency 2000	Data collected and reported by Latham S & Mudge G (Transport Research Laboratory), 1997 as research contractors to the UK Environment Agency
Electricity and other energies	Calculated from *"Life cycle inventories of energy systems",* ETH, Zurich, 1994	
Raw materials	Various sources including: *"Life cycle inventories of energy systems",* ETH, Zurich, 1994	

Environmental data related to PET bottles from household sources

LCI data for the environmental analysis has been derived from the following sources:

	Original Data Source	Comments
	Waste management	
Landfilling of rigid plastics	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Landfill"*, UK Environment Agency 2000	Data collected and reported by RG Gregory, AJ Revans & G Attenborough (WS Atkins Consultants Ltd), 1997 as research contractors to the UK Environment Agency
Rigid plastics incineration	RDC and Pira International 2000	Data reworked by P Dobson, Pira International, and Bernard de Caevel, RDC from various sources: *"Life Cycle Inventory Development for Waste Management Operations: Incineration"*, UK Environment Agency 2000 *"Integrated Solid Waste Management: A Life cycle inventory"*, PR White, M Franke and P Hindle, 1995 *"Specific processing costs of waste materials in a MSWcombustion facility"*, ir. L.P.M Rijpkema and Dr.ir.J.A. Zeevalkink,TNO 1996
	Material recycling	
Sorting	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Waste Collection and Separation"*, UK Environment Agency 2000	Data collected and reported by Vip Patel (Aspinwall and Co.), 1997 as research contractors to the UK Environment Agency
Baling	Derived from *"Life Cycle Assessment of Packaging Systems for Beer and Soft Drinks, Disposable PET Bottles"*, Danish Environmental Protection Agency, 1998	
Recycling – Regranulation	*"Life Cycle Assessment of Packaging Systems for Beer and Soft Drinks, Disposable PET Bottles"*, Danish Environmental Protection Agency, 1998	
PET (bottle grade and amorphous)	*"Ecoprofiles of the European plastics industry Report 8: Polyethylene terephthalate"*, APME, 1995	

Environmental data related to Paper & board packaging from household sources

LCI data for the environmental analysis has been derived from the following sources:

	Data Source	Comments
	Waste mangement	
Landfilling of paper	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Landfill"*, UK Environment Agency 2000	Data collected and reported by RG Gregory, AJ Revans & G Attenborough (WS Atkins Consultants Ltd), 1997 as research contractors to the UK Environment Agency
Paper incineration	RDC and Pira International 2000	Data reworked by P Dobson, Pira International, and Bernard de Caevel, RDC from various sources: *"Life Cycle Inventory Development for Waste Management Operations: Incineration"*, UK Environment Agency 2000 *"Integrated Solid Waste Management: A Life cycle inventory"*, PR White, M Franke and P Hindle, 1995
	Material recycling	
Sorting	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Waste Collection and Separation"*, UK Environment Agency 2000	Data collected and reported by Vip Patel (Aspinwall and Co.), 1997 as research contractors to the Environment Agency
Testliner production	Derived from *"European Database for Corrugated Board Life Cycle Studies"*, FEFCO, Groupemont Ondule and Kraft Institute, 1997	
Kraftliner production	Derived from *"European Database for Corrugated Board Life Cycle Studies"*, FEFCO, Groupemont Ondule and Kraft Institute, 1997	

Environmental data related to corrugated board packaging from industrial sources

LCI data for the environmental analysis has been derived from the following sources:

	Data Source	Comments
	Waste management	
Landfilling of paper	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Landfill",* UK Environment Agency 2000	Data collected and reported by RG Gregory, AJ Revans & G Attenborough (WS Atkins Consultants Ltd), 1997 as research contractors to the UK Environment Agency
Paper incineration	RDC and Pira International 2000	Data reworked by P Dobson, Pira International, and Bernard de Caevel, RDC from various sources: *"Life Cycle Inventory Development for Waste Management Operations: Incineration",* UK Environment Agency 2000 *"Integrated Solid Waste Management: A Life cycle inventory",* PR White, M Franke and P Hindle, 1995
	Material recycling	
Testliner production	Derived from *"European Database for Corrugated Board Life Cycle Studies",* FEFCO, Groupemont Ondule and Kraft Institute, 1997	
Kraftliner production	Derived from *"European Database for Corrugated Board Life Cycle Studies",* FEFCO, Groupemont Ondule and Kraft Institute, 1997	

Environmental data related LDPE films from Commercial and Industrial Sources

LCI data for the environmental analysis has been derived from the following sources:

	Original Data Source	Comments
	Waste management	
Landfilling of flexible plastics	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Landfill"*, UK Environment Agency 2000	Data collected and reported by RG Gregory, AJ Revans & G Attenborough (WS Atkins Consultants Ltd), 1997 as research contractors to the UK Environment Agency
LDPE films to incineration	RDC and Pira International 2000	Data reworked by P Dobson, Pira International, and Bernard de Caevel, RDC from various sources: *"Life Cycle Inventory Development for Waste Management Operations: Incineration"*, UK Environment Agency 2000 *"Integrated Solid Waste Management: A Life cycle inventory"*, PR White, M Franke and P Hindle, 1995
	Material recycling	
Recycling processes	Derived from*: "Recycling and Recovery of Plastics from Packagings in Domestic Waste", Michael Heyde and Markus Kremer, LCA Documents, Vol 5, 1999*	Study carried out between 1994 and 1995
LLDPE	*"Ecoprofiles of the European plastics industry Report 8: Polyethylene terephthalate"*, APME, 1995	
LDPE	*"Ecoprofiles of the European plastics industry Report 8: Polyethylene terephthalate"*, APME, 1995	

Environmental data related Mixed plastics from household sources

LCI data for the environmental analysis has been derived from the following sources:

	Original Data Source	Comments
Waste management		
Landfilling of mixed plastics	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Landfill"*, UK Environment Agency 2000	Data collected and reported by RG Gregory, AJ Revans & G Attenborough (WS Atkins Consultants Ltd), 1997 as research contractors to the UK Environment Agency
Mixed plastics to incineration	RDC and Pira International 2000	Data reworked by P Dobson, Pira International, and Bernard de Caevel, RDC from various sources: *"Life Cycle Inventory Development for Waste Management Operations: Incineration"*, UK Environment Agency 2000 *"Integrated Solid Waste Management: A Life cycle inventory"*, PR White, M Franke and P Hindle, 1995
Material recycling		
Sorting and recycling processes	Derived from: *"Recycling and Recovery of Plastics from Packagings in Domestic Waste", Michael Heyde and Markus Kremer, LCA Documents, Vol 5, 1999*	Study carried out between 1994 and 1995
Pallisade (assumed to be wood construction material)	*"Life cycle inventories of energy systems"*, ETH, Zurich, 1994	
Other reprocessing		
Agglomeration and Blast furnace	Derived from: *"Recycling and Recovery of Plastics from Packagings in Domestic Waste", Michael Heyde and Markus Kremer, LCA Documents, Vol 5, 1999*	Study carried out between 1994 and 1995
Heating oil	*"Life cycle inventories of energy systems"*, ETH, Zurich, 1994	

Environmental data related to Glass beverage bottles from household sources

LCI data for the environmental analysis has been derived from the following sources:

	Original Data Source	Comments
	Waste management	
Landfilling of glass	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Landfill",* UK Environment Agency 2000	Data collected and reported by RG Gregory, AJ Revans & G Attenborough (WS Atkins Consultants Ltd), 1997 as research contractors to the UK Environment Agency
Glass to incineration	RDC and Pira International 2000	Data reworked by P Dobson, Pira International, and Bernard de Caevel, RDC from various sources: *"Life Cycle Inventory Development for Waste Management Operations: Incineration",* UK Environment Agency 2000 *"Integrated Solid Waste Management: A Life cycle inventory",* PR White, M Franke and P Hindle, 1995
	Material recycling	
Recycling processes and credit	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Recycling",* UK Environment Agency 2000	
Sorting	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Waste Collection and Separation",* UK Environment Agency 2000	Data collected and reported by Vip Patel (Aspinwall and Co.), 1997 as research contractors to the UK Environment Agency Data collected and reported by Vip Patel (Aspinwall and Co.), 1997 as research contractors to the Environment Agency

Environmental data related to aluminium beverage, rigid and semi-rigid from household sources

LCI data for the environmental analysis has been derived from the following sources:

	Original Data Source	**Comments**
	Waste management	
Landfilling of aluminium	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Landfill"*, UK Environment Agency 2000	Data collected and reported by RG Gregory, AJ Revans & G Attenborough (WS Atkins Consultants Ltd), 1997 as research contractors to the UK Environment Agency
Aluminium to incineration	RDC and Pira International 2000	Data reworked by P Dobson, Pira International, and Bernard de Caevel, RDC from various sources: *"Life Cycle Inventory Development for Waste Management Operations: Incineration"*, UK Environment Agency 2000 *"Integrated Solid Waste Management: A Life cycle inventory"*, PR White, M Franke and P Hindle, 1995
	Material recycling	
Recycling processes and virgin production	Derived from *"Environmental Profile Report for the European Aluminium Industry"*, European Aluminium Association, April 2000	
Sorting and baling	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Waste Collection and Separation"*, UK Environment Agency 2000	Data collected and reported by Vip Patel (Aspinwall and Co.), 1997 as research contractors to the UK Environment Agency

Environmental data related to steel from household sources

LCI data for the environmental analysis has been derived from the following sources:

	Original Data Source	Comments
Waste management		
Landfilling of steel	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Landfill"*, UK Environment Agency 2000	Data collected and reported by RG Gregory, AJ Revans & G Attenborough (WS Atkins Consultants Ltd), 1997 as research contractors to the UK Environment Agency
Steel to incineration	RDC and Pira International 2000	Data reworked by P Dobson, Pira International, and Bernard de Caevel, RDC from various sources: *"Life Cycle Inventory Development for Waste Management Operations: Incineration"*, UK Environment Agency 2000 *"Integrated Solid Waste Management: A Life cycle inventory"*, PR White, M Franke and P Hindle, 1995
Material recycling		
Recycling processes and virgin production	Derived from *«Ökobilanzdaten für Weissblech und ECCS »* ; Informationszentrum Weissblech ; October 1995	
Sorting and baling	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Waste Collection and Separation"*, UK Environment Agency 2000	Data collected and reported by Vip Patel (Aspinwall and Co.), 1997 as research contractors to the UK Environment Agency

Environmental data related to LBC from household sources

LCI data for the environmental analysis has been derived from the following sources:

	Original Data Source	Comments
Waste management		
Landfilling of LBC	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Landfill"*, UK Environment Agency 2000	Data collected and reported by RG Gregory, AJ Revans & G Attenborough (WS Atkins Consultants Ltd), 1997 as research contractors to the UK Environment Agency The data for paper, aluminium and plastic film has been combined to represent LBC
LBC to incineration	RDC and Pira International 2000	Data reworked by P Dobson, Pira International, and Bernard de Caevel, RDC from various sources: *"Life Cycle Inventory Development for Waste Management Operations: Incineration"*, UK Environment Agency 2000 *"Integrated Solid Waste Management: A Life cycle inventory"*, PR White, M Franke and P Hindle, 1995 The data for paper, aluminium foil and plastic film has been combined to represent LBC
Material recycling		
Fibre recycling processes and credit	Derived from *"European Database for Corrugated Board Life Cycle Studies"*, FEFCO, Groupemont Ondule and Kraft Institute, 1997	Based on comparison of kraftliner production and testliner production
Incineration of rejects	RDC and Pira International 2000	Data reworked by P Dobson, Pira International, and Bernard de Caevel, RDC from various sources: *"Life Cycle Inventory Development for Waste Management Operations: Incineration"*, UK Environment Agency 2000 *"Integrated Solid Waste Management: A Life cycle inventory"*, PR White, M Franke and P Hindle, 1995 The data for aluminium foil and plastic film has been combined to represent LBC

Landfilling of rejects	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Landfill",* UK Environment Agency 2000	The data for aluminium and plastic film has been combined to represent LBC
Sorting and baling	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Waste Collection and Separation",* UK Environment Agency 2000	Data collected and reported by Vip Patel (Aspinwall and Co.), 1997 as research contractors to the UK Environment Agency

Environmental Data for Refillable and single trip PET bottles

LCI data for the environmental analysis has been derived from the following sources:

	Original Data Source	**Comments**
	Material production	
PET Bottle grade	*"Ecoprofiles of the European plastics industry Report 8: Polyethylene terephthalate",* APME, 1995	
HDPE	*"Ecoprofiles of the European plastics industry Report 3: Polyethylene and polypropolene"* , APME, 1993	
	Bottle production	
Preform and bottle production	Derived from *"Life cycle assessment of Packaging Systems for Beer and Soft Drinks, Refillable PET Bottles",* Environment Project No404, Danish Environmental Protection Agency, 1998	
	Crate production	
Crate production and grinding	*"Life cycle assessment of Packaging Systems for Beer and Soft Drinks, Refillable PET Bottles",* Environment Project No404, Danish Environmental Protection Agency, 1998	
	Reuse	
Washing & filling	*"Life cycle assessment of Packaging Systems for Beer and Soft Drinks, Refillable PET Bottles",* Environment Project No404, Danish Environmental Protection Agency, 1998	
	Waste management	
Landfilling of rigid plastics	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Landfill",* UK Environment Agency 2000	Data collected and reported by RG Gregory, AJ Revans & G Attenborough (WS Atkins Consultants Ltd), 1997 as research contractors to the UK Environment Agency
Rigid plastics incineration	RDC and Pira International 2000	Data reworked by P Dobson, Pira International, and Bernard de Caevel, RDC from various sources: *"Life Cycle Inventory Development for Waste Management Operations: Incineration",* UK Environment Agency 2000

		"Integrated Solid Waste Management: A Life cycle inventory", PR White, M Franke and P Hindle, 1995
Material recycling		
Sorting	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Waste Collection and Separation",* UK Environment Agency 2000	Data collected and reported by Vip Patel (Aspinwall and Co.), 1997 as research contractors to the UK Environment Agency
Baling	Derived from *"Life Cycle Assessment of Packaging Systems for Beer and Soft Drinks, Disposable PET Bottles",* Danish Environmental Protection Agency, 1998	
Recycling – Regranulation	*"Life Cycle Assessment of Packaging Systems for Beer and Soft Drinks, Disposable PET Bottles",* Danish Environmental Protection Agency, 1998	
PET (bottle grade and amorphous)	*"Ecoprofiles of the European plastics industry Report 8: Polyethylene terephthalate",* APME, 1995	

Environmental Data for Refillable and single trip Glass bottles

LCI data for the environmental analysis has been derived from the following sources:

	Original Data Source	**Comments**
	Material production	
HDPE	*"Ecoprofiles of the European plastics industry Report 3: Polyethylene and polypropolene"* , APME, 1993	
	Bottle production	
Glass bottle production	Derived from "BUWAL Env Series 250: Life Cycle Inventories for Packaging, BUWAL", BUWAL, 1999	
	Crate production	
Crate production and grinding	*"Life cycle assessment of Packaging Systems for Beer and Soft Drinks, Refillable Glass Bottles",* Environment Project No400, Danish Environmental Protection Agency, 1998	
	Reuse	
Washing & filling	*"Life cycle assessment of Packaging Systems for Beer and Soft Drinks, Refillable Glass Bottles",* Environment Project No400, Danish Environmental Protection Agency, 1998	
	Waste management	
Landfilling of glass	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Landfill",* UK Environment Agency 2000	Data collected and reported by RG Gregory, AJ Revans & G Attenborough (WS Atkins Consultants Ltd), 1997 as research contractors to the UK Environment Agency
Glass to incineration	RDC and Pira International 2000	Data reworked by P Dobson, Pira International, and Bernard de Caevel, RDC from various sources: *"Life Cycle Inventory Development for Waste Management Operations: Incineration",* UK Environment Agency 2000 *"Integrated Solid Waste Management: A Life cycle inventory",* PR White, M Franke and P Hindle, 1995

Material recycling		
Recycling processes and credit	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Recycling"*, UK Environment Agency 2000	
Sorting	Derived from *"Life Cycle Inventory Development for Waste Management Operations: Waste Collection and Separation"*, UK Environment Agency 2000	Data collected and reported by Vip Patel (Aspinwall and Co.), 1997 as research contractors to the UK Environment Agency