Part II

Modules

Authors: Roland Hischier, Empa St. Gallen
Mischa Classen, Empa Dübendorf
Martin Lehmann, Empa St. Gallen
Wolfram Scharnhorst, Empa Dübendorf

Data: v2.0 (2007)

Hischier R., Classen M., Lehmann M. and Scharnhorst W. (2007) Life cycle inventories of Electric and Electronic Equipment: Production, Use and Disposal. ecoinvent report No. 18. Empa / Technology & Society Lab, Swiss Centre for Life Cycle Inventories, Dübendorf, 2007

© Swiss Centre for Life Cycle Inventories / 2007

i Table of Contents

1 INTRODUCTION 1

2 PRINTED WIRING BOARDS 2

2.1 Introduction 2
2.2 Production of Printed Wiring Boards 3
2.2.1 Material Characterisation & Market 3
2.2.2 Use & Application 4
2.2.3 System Characterisation 5
2.2.4 Datasets “Printed Wiring Board, surface mount, at plant” 9
2.2.5 Datasets “Printed Wiring Board, through-hole, at plant” 22
2.3 Mounting of Printed Wiring Boards 37
2.3.1 Introduction 37
2.3.2 Infrastructure for Printed Wiring Board Mounting 38
2.3.3 Soldering materials 50
2.3.4 Mounting activities 61
2.3.5 Mounted Printed Wiring Boards 71
2.3.6 Flux for wave soldering 103

3 CABLES 107

3.1 Introduction 107
3.2 General Product Information & Market 107
3.2.1 Direct Current and Electric conductors 107
3.2.2 Cable construction 108
3.2.3 Computer power cable 112
3.2.4 Network cable 113
3.2.5 Printer cable 116
3.2.6 Ribbon cable 118
3.3 System Characterisation 120
3.4 Use & Application 123
3.5 Datasets “cable, connector for computer, without plugs” and “plugs, inlet and outlet, for computer cable” 123
3.5.1 Dataset description and meta information 123
3.5.2 Life Cycle inventory and General Flow information 125
3.6 Datasets “cable, network cable, category 5, without plugs” and “plugs, inlet and outlet, for network cable” 130
3.6.1 Dataset description and meta information 130
3.6.2 Life Cycle inventory and General Flow information 132
3.7 Datasets “cable, printer cable, without plugs” and “plugs, inlet and outlet, for printer cable” 136
3.7.1 Dataset description and meta information 136
3.7.2 Life Cycle inventory and General Flow information 138
3.8 Dataset “ribbon cable, 20-pin, with plugs, at plant” 143
3.8.1 Dataset description and meta information 143
3.8.2 Life Cycle inventory and General Flow information 144

4 BATTERIES 149

4.1 Introduction 149
4.2 Material Characterisation & Market 149
4.3 Use & Application 151
4.4 System Characterisation 151
4.5 Battery plant 152
4.6 NiMH rechargable batteries for laptop applications 152
4.6.1 Dimensioning of the reference product 153
4.6.2 Dataset “Electrode, positive, $LaNi_5$, at plant” 157
4.6.3 Dataset “Electrode, negative, Ni, at plant” 158
4.6.4 Dataset “Electrolyte, KOH (30%), LiOH additive, at plant” 159
4.6.5 Dataset “Battery, NiMH, rechargable, prismatic, at plant” 159
4.6.6 Data uncertainty 162
4.7 LiIo rechargable batteries for laptop applications 171
4.7.1 Dimensioning of the reference product 171
4.7.2 Dataset “Electrode, positive, $LiMn_2O_4$, at plant” 175
4.7.3 Dataset “Electrode, negative, LiC_6, at plant” 177
4.7.4 Dataset “Battery, LiIo, rechargable, prismatic, at plant” 177
4.7.5 Data “Electrolyte, 4-Fluoro-1.3-dioxolan-2-one, at plant” 180
4.7.6 Data uncertainty 180

5 TONER 187

5.1 Introduction 187
5.2 Material Characterisation, Production & Market 187
5.3 Use & Application 188
5.4 System Characterisation 189
5.5 Production of Toner Powder 190
5.5.1 Processes of Toner Production 191
5.5.2 Life cycle inventory of “Toner, black, powder, at plant” in ecoinvent 192
5.5.3 Life cycle inventory of “Toner, colour, powder, at plant” in ecoinvent 193
5.5.4 Data quality and uncertainty adjustments 194
5.6 Production of Toner Cartridges 197
5.6.1 Manufacturing process and components 197
5.6.2 Life cycle inventory of monochrome and coloured toner cartridges. 199
5.6.3 Data quality and uncertainty adjustments 201
5.7 Toner, used for printing 204
5.7.1 Life Cycle inventory 206
5.7.2 Data quality and uncertainty adjustments 208

6 DRIVES 211

6.1 Introduction 211
6.1.1 Hard Disk Drive (HDD) 211
6.1.2 CD-ROM Drive / DVD-ROM Drive 217
6.1.3 System Characterisation 221
6.1.4 Use & Application 223
6.2 Dataset “HDD, desktop computer, at plant” 223
6.2.1 Dataset description and meta information 223
6.2.2 Life Cycle inventory and General Flow Information 226

6.3 Dataset “HDD, laptop computer, at plant” 229
6.3.1 Dataset description and meta information 229
6.3.2 Life Cycle inventory and General Flow Information 232
6.4 Dataset “CD-ROM/DVD-ROM drive, desktop computer, at plant” 236
6.4.1 Dataset description and meta information 236
6.4.2 Life Cycle inventory and General Flow Information 240
6.5 Dataset “CD-ROM/DVD-ROM drive, laptop computer, at plant” 245
6.5.1 Dataset description and meta information 245
6.5.2 Life Cycle inventory and General Flow Information 250

7 POWER SUPPLY UNIT (PSU) 256

7.1 Introduction 256
7.2 System characterisation 256
7.3 Life Cycle Inventories 257
7.3.1 Dataset “power supply unit, at plant” 257
7.3.2 Dataset “fan, at plant” 258

8 REFERENCES 262

1 Introduction

This part of the report describes the datasets for the more complex pieces – i.e. printed wiring boards (bare board, mounting process, mounted printed wiring boards), cables, batteries, toner modules, drives (harddisk drive, DVD/CD-ROM drive), and the power supply unit for desktop computers.

2 Printed Wiring Boards

2.1 Introduction

This chapter here documents the manufacturing as well as the subsequent mounting of printed wiring boards (PWB).

In the manufacturing, two different types of PWB are distinguished – PWB for the through-hole technology (-> dataset “Printed Wiring Boards, through-hole, at plant”) as well as PWB for the surface mounting technology (-> dataset “Printed Wiring Board, surface mount, at plant”) of electronic components like e.g. integrated circuits (IC). The PWB manufacturing is thereby inventoried excluding the manufacturing of these components (for the manufacturing of these components: see part I of this report here), as well as the mounting – which is described in the second part of this chapter here (i.e. in chapter 2.3). The recycling of such electronic components is also exluded here – this activity is described, together with the recycling and disposal routes of devices and other components in part V of this report here.

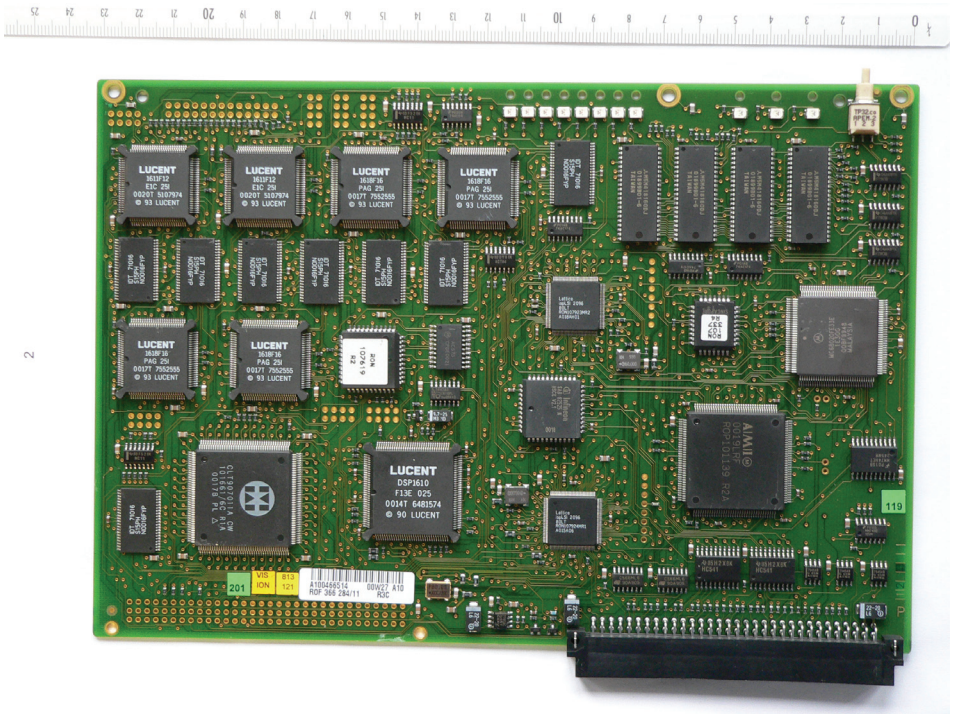


Fig. 2.1 **Example of a printed wiring board (PWB), mounted with integrated circuits (IC), as used in a mobile laptop application (picture: Empa)**

Due to the fact that the European **Restriction of Hazardous Substances Directive** (RoHS) requested from industry to eliminate lead from their products only by July 1, 2006, for each of the two PWB types both cases are still inventoried – i.e. by establishing a dataset with a Pb-containing surface finishing as well as one with a Pb-free surface. Hence, a total of three datasets (Pb-containing / Pb-free / mix) are established for each of the two PWB types mentioned above.

2.2 Production of Printed Wiring Boards

2.2.1 Material Characterisation & Market

Typically, a printed wiring board (PWB) consists of a number of electric current conducting and non-conducting layers which are sandwiched together, as shown for a 4 layer PWB in Fig. 2.2.

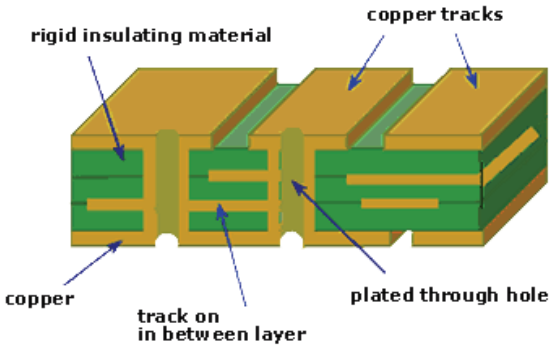


Fig. 2.2 Cross sectional sketch of a 4 layer PWB (adopted from MacCallum & Edgar (2006)).

Depending on the intended application, PWB can have different board constructions (rigid, flex and rigid-flex (cf.: Jawitz (1997) and Keating (1999)) as well as IC mounting techniques (through-hole, surface mounted and wired, surface mounted with solder ball, and surface mounted leadless (Klingenstein et al. (2004)). Rigid PWBs can be further split up according to Hinton (1997) into the following types:

- single-sided board,
- double-sided board,
- multilayer board without blind or buried vias,
- multilayered boards with blind and/or buried vias,
- multilayer metal-core boards without blind and buried vias, and
- multilayer metalcore boards with blind and/or buried vias.

Here, rigid PWB of the following two constructions is selected as representative for PWB applications in the ICT domain:

- PWB, prepared for through-hole mounting
- PWB, prepared for surface mounting

The main components / materials of a PWB are the (1 up to 24) conductive layers and the insulating material in-between these various conductive layers. For the conductive layers copper (foil) is used. As insulating material various types of composite are used – whereof the most common ones are:

- **FR-2** (flame-retardant 2): a synthetic resin bonded paper. It is a composite material made out of paper that is impregnated with a plasticized phenol formaldehyde resin
- **FR-4** (flame-retardant 4): a composite of a resin epoxy reinforced with a woven fibre glass matrix

The most common substrate for single-sided PCBs is FR-2 as it is cheap and easy to drill but is prone to cracking and is not good for making plated through-hole boards. Double sided and multilayer boards tend thus to use FR-4. [1]

In 2006, most of the PWB assembly processes took place in China (12.6 Billion US-$), followed by Japan (11.5), Taiwan (6.9) and North America (5.1). The forecast for 2007 estimates an increase in the production in China (14.1), Japan (12.1) and Taiwan (7.4). The production amount in North America will continue to stagnate and thus the falling trend in share of North America since the end of the past century will continue (Custer (2006)).

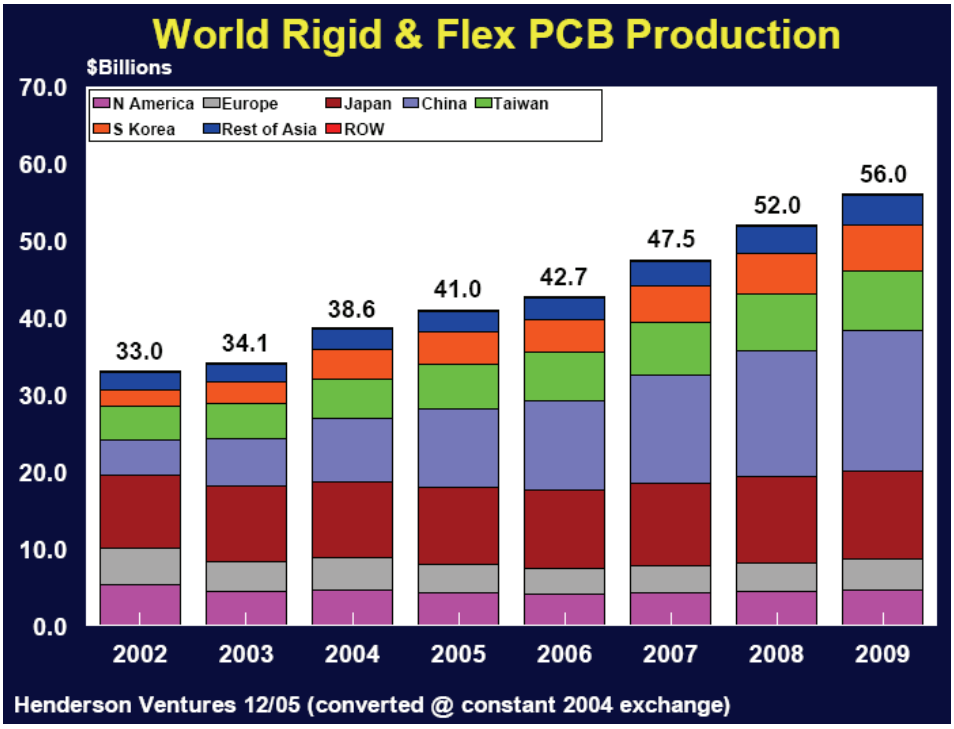


Fig. 2.3 PWB production amounts 2002-2004 and forecast 2005-2009 (figure from Custer (2006)).

Within the production of rigid PWB, the most often used types are multilayer PWB (60%), followed by the double-sided glass-filled PWB (16%) (Custer (2000)). According to Jawitz (1997), through-hole PWB are mainly single- or double-sided PWB while most of the multilayer PWB are used in the surface mount technology.

Hence, for the ecoinvent data v2, a multilayer, surface mount PWB and a double-sided, through-hole PWB are taken into account.

2.2.2 Use & Application

Key application of the inventoried PWBs are ICT hardware applications (-> multilayer, surface mount PWB), resp. industry applications as well as simple ICT applications (-> double-sided, through-hole PWB). Not considered are flexible PWB as well as further, special PWB types that are used for other applications (e.g. medical applications, military applications like aerospace, etc.).

[1] Wikipedia: Printed Circuit Board (http://en.wikipedia.org/wiki/pritned_circuit_board), assessed August 3, 2007.

2.2.3 System Characterisation

Datasets for the most important rigid PWB types – i.e. surface mount, multilayer PWB / double-sided, through-hole PWB – are established. The functional unit of all datasets is "1 m^2 of un-mounted printed wiring board". A typical application of the inventoried PWB types can be found in the desktop computer – having usually several types of multilayer PWB inside (mainboard, but also graphic card, sound card, etc.) as well as a through-hole PWB as part of the power supply unit. Other applications may require different PWB types and systems resulting in different manufacturing technologies (cf. Jawitz (1997), Coombs (2001)).

According to Williams (1998b), "printed wiring boards are the interconnective electrical framework and physical structure that hold together the various electronic components". This part of the report documents the inventory of the manufacturing of PWB. The dataset represents, as all other ecoinvent datasets, a gate-to-gate inventory, ranging until the finally assembled PWB ready for the mounting of ICs and other components. Technically, the data are representative for the group of rigid boards, i.e. non-flexible and without flexible appendices (McKeeby & Phillips (1997)). From its layer factor the inventoried PWB are a 6-layer multilayer PWB for surface mount technology which is typical for computer hardware applications, resp. a double-sided PWB for through-hole mounting that is typical for e.g. simpler ICT applications (like the internal power supply unit of a desktop computer) or for industrial control applications.

In Fig. 2.4, an overview of the different production steps within the production of different types of PWB is shown. The here inventoried manufacturing and assembly processes are based on current technologies and are representative for the global production. Thereby the data sets only cover the technology to manufacture the types of PWB specified above – i.e. a multilayer, surface mount PWB as well as a double-sided through-hole PWB (the left and the middle row in Fig. 2.4).

Within the here developed datasets, the individual production steps are not explicitely modelled, instead aggregated data are shown. Emissions to air and water are as comprehensible as possible considered. Defective and thus non-marketable PWB from the production are indirectly covered with the yield of the various input materials. Various cleaning substances, thermal energy, electricity and the consumption of water are inventoried. Likewise, the infrastructure is taken into account. Transports of the input materials to the PWB production site are included – not considered are administration processes like office management and business travelling.

The datasets represent global average data, based on European data, valid for the production period 2003-2006. Main data sources used are the environmental reports of several European PWB producer (AT&S AG (2006), hmp (2006), SEAG (2006)) as well as material specifications of PWB (ZVEI (2006)) as well as further literature sources.

The respective meta information of the datasets of printed wiring boards can be found in Tab. 2.1.

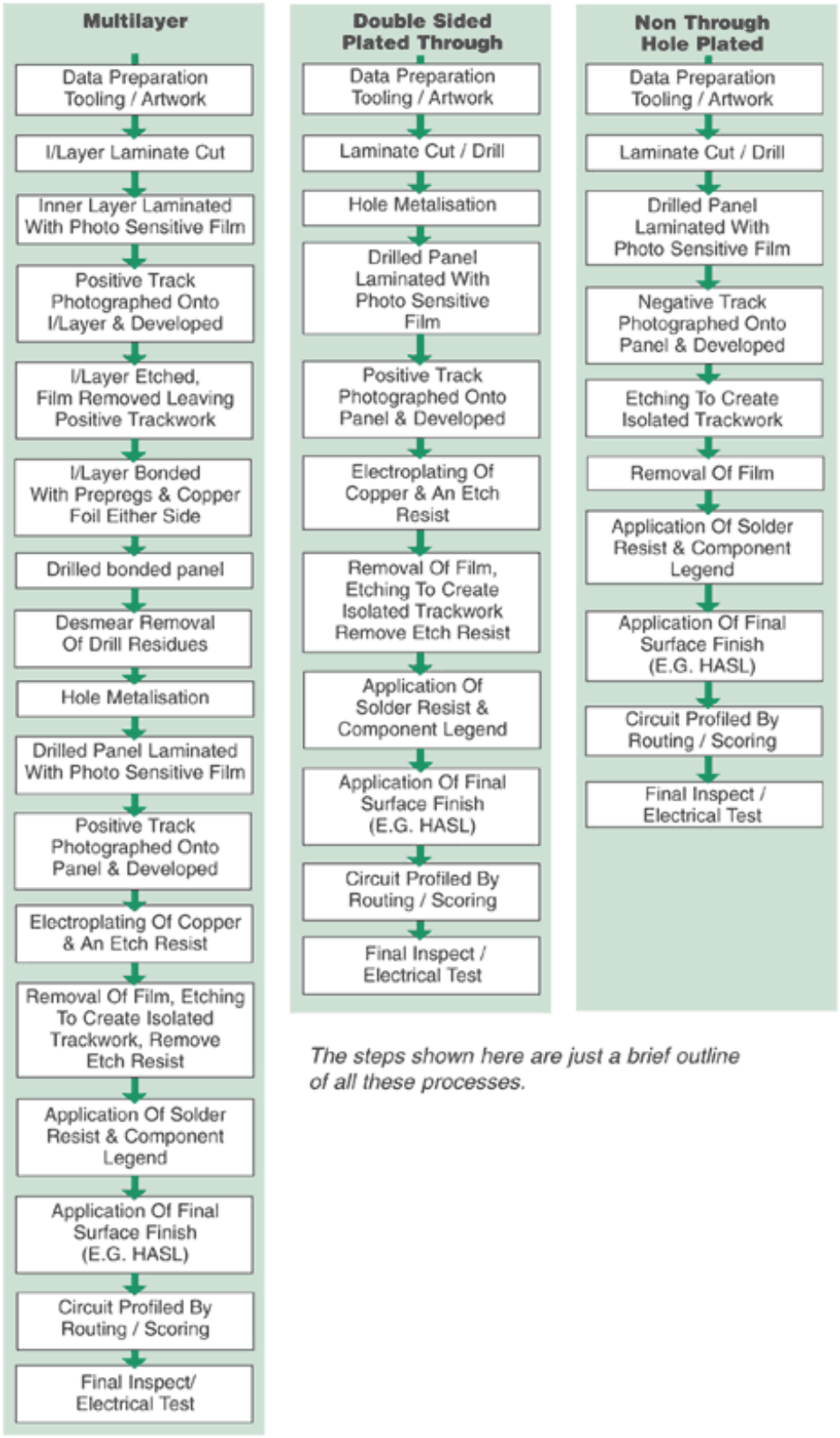


Fig. 2.4 PWB production scheme (figure taken from http://www.alrpcbs.co.uk/pages/technical_process.asp).

Tab. 2.1 ecoinvent meta information for the processes for the production of PWB prepared for surface mounting and for through-hole mounting of ICs, respectively.

Name	Printed Wiring Board, surface mount, lead containing surface, at plant	Printed Wiring Board, surface mount, lead-free surface, at plant
Location	GLO	GLO
Infrastructure Process	0	0
Unit	m^2	m^2
Dataset Version	2.0	2.0
Included Processes	The dataset covers the assembly of a PWB prepared for surface mounting of components. In this dataset (raw) materials, infrastructure, energy consumption, emissions to air and water and waste amounts from the production of 1 m^2 of board are taken into account. Not included into this dataset is the mounting of the PWB.	The dataset covers the assembly of a PWB prepared for surface mounting of components. In this dataset (raw) materials, infrastructure, energy consumption, emissions to air and water and waste amounts from the production of 1 m^2 of board are taken into account. Not included into this dataset is the mounting of the PWB.
Amount	1	1
Local Name	Leiterplatte, surface mount, Pb-haltige Oberfläche, ab Werk	Leiterplatte, surface mount, bleifreie Oberfläche, ab Werk
Synonyms		
General Comment	The functional unit represents 1 m^2 of a 6-layer FR-4 PWB, HAL (Sn-Pb) surface finished, with soldermask, for surface mount applications, without mounted components. It is designed to be used in ICT applications. Process data are taken from environmental reports of 3 German PWB producers, plus from literature. The described PWB has a square weight of 3.26 kg/m^2.	The functional unit represents 1 m^2 of a 6-layer FR-4 PWB, Pb-free surface finished (mixture of different finishing methods), with soldermask, for surface mount applications, without mounted components. It is designed to be used in ICT applications. Process data are taken from environmental reports of 3 German PWB producers, plus from literature. The described PWB has a square weight of 3.26 kg/m^2.
Start Date	2003	2003
End Date	2006	2006
Data valid for entire period	1	1
Geography Text	This dataset is based on information from European producers that are seen as representative for the global situation.	This dataset is based on information from European producers that are seen as representative for the global situation.
Technology Text	Dataset comprises the following steps of PWB production: substrate preparation, imaging, exposure, etching, sandwiching, activation and accelaration steps as well as copper plating, cleaning, oxidification, dry vacuum lamination, micro etching, hot air levelling.	Dataset comprises the following steps of PWB production: substrate preparation, imaging, exposure, etching, sandwiching, activation and accelaration steps as well as copper plating, cleaning, oxidification, dry vacuum lamination, micro etching, surface finishing.
Representativeness		
Production Volume	$ 18.9315 Billion in 1998 (includes all rigid PWB)	$ 18.9315 Billion in 1998 (includes all rigid PWB)
Sampling Procedure	literature	literature
Extrapolations	see Geography and Technology	see Geography and Technology
Uncertainty Adjustments	none	none

Tab. 2.1 (Cont.) ecoinvent meta information for the processes for the production of PWB prepared for surface mounting and for through-hole mounting of ICs, respectively.

Name	Printed Wiring Board, through-hole, lead containing surface, at plant	Printed Wiring Board, through-hole, lead-free surface, at plant
Location	GLO	GLO
Infrastructure Process	0	0
Unit	m^2	m^2
Dataset Version	2.0	2.0
Included Processes	The dataset covers the assembly of a PWB prepared for through-hole mounting of components. In this dataset (raw) materials, infrastructure, energy consumption, emissions to air and water and waste amounts from the production of 1 m^2 of board are taken into account. Not included into this dataset is the mounting of the PWB.	The dataset covers the assembly of a PWB prepared for surface mounting of components. In this dataset (raw) materials, infrastructure, energy consumption, emissions to air and water and waste amounts from the production of 1 m^2 of board are taken into account. Not included into this dataset is the mounting of the PWB.
Amount	1	1
Local Name	Leiterplatte, through-hole, Pb-haltige Oberfläche, ab Werk	Leiterplatte, through-hole, bleifreie Oberfläche, ab Werk
Synonyms		
General Comment	The functional unit represents 1 m^2 of a 2-layer FR-4 PWB, HAL (Sn-Pb) surface finished, with soldermask, for through-hole mount applications, without mounted components. It is designed to be used in industry electronics and simple ICT applications. Process data are taken from environmental reports of 2 German PWB producers, plus from literature. The described PWB has a square weight of 3.08 kg/m^2.	The functional unit represents 1 m^2 of a 2-layer FR-4 PWB, lead-free surface finished (mixture of various finishing methods), with soldermask, for through-hole mount applications, without mounted components. It is designed to be used in industry electronics and simple ICT applications. Process data are taken from environmental reports of 2 German PWB producers, plus from literature. The described PWB has a square weight of 3.08 kg/m^2.
Start Date	2003	2003
End Date	2006	2006
Data valid for entire period	1	1
Geography Text	This dataset is based on information from European producers that are seen as representative for the global situation.	This dataset is based on information from European producers that are seen as representative for the global situation.
Technology Text	Dataset comprises the following steps of PWB production: substrate preparation, imaging, exposure, etching, sandwiching, via opening, desmearing, activation and accelaration steps as well as via filling, second imaging, exposure, copper plating, cleaning, oxidification, dry vacuum lamination, micro etching, hot air leveling.	Dataset comprises the following steps of PWB production: substrate preparation, imaging, exposure, etching, sandwiching, via opening, desmearing, activation and accelaration steps as well as via filling, second imaging, exposure, copper plating, cleaning, oxidification, dry vacuum lamination, micro etching, surface finishing.
Representativeness		
Production Volume	$ 18.9315 Billion in 1998 (includes all rigid PWB)	$ 18.9315 Billion in 1998 (includes all rigid PWB)
Sampling Procedure	literature	Literature
Extrapolations	see Geography and Technology	see Geography and Technology
Uncertainty Adjustments	none	None

Tab. 2.1 (Cont.) ecoinvent meta information for the processes for the production of PWB prepared for surface mounting and for through-hole mounting of ICs, respectively.

Name	Printed Wiring Board, surface mount, at plant	Printed Wiring Board, through-hole, at plant
Location	GLO	GLO
Infrastructure Process	0	0
Unit	m^2	m^2
Dataset Version	2.0	2.0
Included Processes	The dataset represents a 50:50 mixture of the datasets "printed wiring board, surface mount, Pb-containing surface, at plant" and "printed wiring board, surface mount, Pb-free surface, at plant"	The dataset represents a 50:50 mixture of the datasets "printed wiring board, through-hole, Pb-containing surface, at plant" and "printed wiring board, through-hole, Pb-free surface, at plant"
Amount	1	1
Local Name	Leiterplatte, surface mount, ab Werk	Leiterplatte, through-hole, ab Werk
Synonyms		
General Comment	The functional unit represents 1 m^2 of a 6-layer FR-4 PWB, surface finished (mixture of Pb-containing and Pb-free methods), with soldermask, for surface mount applications, without mounted components. It is designed to be used in ICT applications.	The functional unit represents 1 m^2 of a 2-layer FR-4 PWB, surface finished (mixture of Pb-containing and Pb-free methods), with soldermask, for through-hole mount applications, without mounted components. It is designed to be used in industry electronics and simple ICT applications.
Start Date	2003	2003
End Date	2006	2006
Data valid for entire period	1	1
Geography Text	This dataset is based on information from European producers that are seen as representative for the global situation.	This dataset is based on information from European producers that are seen as representative for the global situation.
Technology Text	See included processes for the various surface finishing techniques.	See included processes for the various surface finishing techniques.
Representativeness		
Production Volume	$ 18.9315 Billion in 1998 (includes all rigid PWB)	$ 18.9315 Billion in 1998 (includes all rigid PWB)
Sampling Procedure	Mixture of surface finishing based on assumption	Mixture of surface finishing based on assumption
Extrapolations	see Geography and Technology	see Geography and Technology
Uncertainty Adjustments	none	None

2.2.4 Datasets "Printed Wiring Board, surface mount, at plant"

As basis a 1.6 mm thick 6-layer double-sided PWB, with surface finishing and soldermask, unmounted but prepared for surface mounting of electronic components is selected. All here described datasets have the functional unit "1 m^2", based on a square weight of 3.26 kg (ZVEI (2006)). In details, the following datasets are established:

- **"printed wiring board, surface mount, at plant"**: 50:50-mixture (due to a lack of more precise information) of the two following datasets;

- **"printed wiring board, surface mount, lead-containing surface, at plant"**: a 1.6 mm thick 6-layer PWB with a hot air solder leveling (HAL) surface finishing with a tin-lead-mixture (7.2 g Sn and 4.23 g Pb per m^2 PWB);
- **"printed wiring board, surface mount, lead-free surface, at plant"**: a 1.6 mm thick 6-layer PWB with a mixture of several Pb-free surface finishing methods (US EPA (2000) and ZVEI (2006)). Due to a lack of more specific information, the contribution to these various finishing methods is based on own assumptions, resulting in the following distribution:
  - 30% hot air solder leveling (HAL) with tin only (7.19 g/m^2 PWB);
  - 30% immersion tin (1.63 g/m^2 PWB);
  - 30% immersion silver (1.63 g/m^2 PWB), and
  - 10% electroless nickel / gold (7.36 g Ni and 1.47 g Au per m^2 PWB).

System Characterisation

The three datasets comprise the input of the raw materials, the consumption of energy (electricity and heat), the used infrastructure and the transport efforts as well as the produced waste and emissions. Main data sources are material data sheets of this type of PWB (established within ZVEI (2006)), the environmental reports of several PWB producers (hmp (2006), SEAG (2006), and AT&S AG (2006), but only data from Leoben plant), supported by punctual information from literature (e.g. US EPA (1995) or US EPA (2000)).

Life Cycle inventory

Raw materials (cores, prepreg, copper foil)

According to AT&S AG (2006), the yield of the process in Leoben is below 90%, thus a yield of 88% is assumed due to a lack of more precise information. The values for cores, prepreg and copper foil is then calculated accordingly, based on the total consumption figures in AT&S AG (2006) for the years 2003 to 2006 and the calculated square weight of 3.26 kg (average value for 6-layer, surface coated, FR-4 PWB according to ZVEI (2006)). Hereby cores and prepreg are represented by the dataset for glass-fibre reinforced polyester.

Raw materials (surface finishing)

The value for the respective surface finishing technology (see above) is taken from the calculations for 6-layer, surface coated, FR-4 PWB with ZVEI (2006). In the same way, the soldermask finishing is calculated and represented here, by using "phenolic resin" as a proxy. Due to a lack of further information, for all these inputs a yield of 95% is assumed.

Energy

Electricity and natural gas are used as energy carriers in the PWB production – steam and compressed air is produced internally out of these energy carriers. The average from the reported values in AT&S AG (2006), hmp (2006) and SEAG (2006) is used, taking into account the above described yield for the core materials.

Process chemicals (auxiliaries)

A variety of different chemical substances are used within the process chain of the PWB production. The values are taken from the Leoben plant in AT&S AG (2006), representing an average of the production years 2003 to 2006 – and taking into account the above described process yield for the core materials.

Emissions to air

In AT&S AG (2006), values for emissions into air from the Leoben plant are reported, split up into three different types of emissions (organic carbon, aerosols of acids/bases, dust). Due to a lack of more precise information, these available data are used in the following way in order to inventorize the emissions to air from the PWB production:

- *organic carbon (from resist input):* due to lack of more precise information, the dataset "NMVOC, unspecified" is used herefore;
- *aerosols of acids/bases:* based on the input of auxiliaries (HCl, NaOH, H_2O_2 and H_2SO_4), the following distribution in the aerosol emissions is calculated: 58% HCl, 30% NaOH, 7% H_2O_2 and the remaining 5% H_2SO_4 (assuming an equal transfer into air for all these substances),
- *dust:* due to a lack of data, a split into 75% $PM_{2.5}$ and 25% $PM_{2.5-10}$ is assumed here.

No metal emissions are reported in AT&S AG (2006) although, according to US EPA (1995), Pb as well as Cu can occur as emissions to air. The latter emissions (i.e. Cu) are primarily attributable to the electroplating process as well as to via-drilling and deburring (Wadden et al. (1995), Williams (1998a), and USEPA (1995)). The load of copper to air is calculated based on an assumed annual PWB yield of 292'000 m^2 and a Cu release to air of 3205 lb/year (US EPA (1995)). The Pb emissions on the other handside are attributable to HAL application (MIGA (2004)), via-drilling, deburring and solder coating (Wallenberger et al. (2004), USEPA (1995)) in case of Pb-containing PWB. The load of lead to air is calculated based on an assumed annual PWB yield of 292'000 m^2 and a Pb release to air of 1000 lb/year (US EPA (1995)).

Last but not least, it is assumed, that 100% of the electricity consumed is converted to waste heat. In accordance with the general rules for ecoinvent, it is assumed that 100% of the waste heat is released to the air.

Emissions to water & Water input

In AT&S AG (2006), Leoben plant, discharge values (in mg/L) for a couple of heavy metals, COD, AOX and fluorine emissions are reported. It is assumed that these values correspond to the discharge from the internal WWTP (waste water treatment plant) to the river. Accordingly, by using the amount of water released via internal WWTP, these discharge values are transformed into releases per m^2 of produced PWB.

Furthermore it is assumed that BOD = COD, and the value for BOD is included into these datasets accordingly. Due to a lack of information, no values for DOC and TOC are reported.

Waste

In AT&S AG (2006), Leoben plant, values for different types of waste are reported. Due to a lack of more precise information, these available data are used in the following way in order to inventorize the waste produced during the PWB production:

- *waste to recycling:* this amount is – in accordance with the ecoinvent methodology (more details, see Frischknecht et al. (2007)) – not further taken into account;
- *harmful waste:* due to a lack of more specific information, the general dataset "disposal, hazardous waste, to hazardous waste incineration" is used;
- *copper chloride:* it is assumed that this substance is recycled, hence its amount is – in accordance with the ecoinvent methodology (Frischknecht et al. (2007)) – not further taken into account;
- *sludge from galvanisation, FeOH:* due to a lack of more specific information, the general dataset "disposal, sluge, pig iron production, to residual material landfill" is used;
- *organic waste:* (biogenic waste – according to the German version of the report) it is assumed that this waste is recycled (e.g by composting), hence its amount is – in accordance with the ecoinvent methodology (Frischknecht et al. (2007)) – not further taken into account;
- *garbage (municipal waste):* the dataset "disposal, municipal waste, to municipal incineration" is used;
- *plastic dispersion:* due to a lack of more specific information, the general dataset "disposal, emulsion paint, to municipal incineration" is used.

Transport

Due to a lack of specific information, standard transport distances and means according to the ecoinvent methodology (see Frischknecht et al. (2007)) are used.

Infrastructure and land-use

Due to a lack of specific information, the infrastructure dataset "electronic component plant" is used here (more details about this infrastructure dataset, see chapter 2 in part I of this report).

Data Uncertainty

The uncertainty scores established according to the method used in the ecoinvent project (see Frischknecht et al. (2007)) include reliability, completeness, temporal correlation, geographical correlation, further technological correlation and sample size. The datasets represent a 6-layer, FR-4 PWB with surface finishing and soldermask of 1.6 mm thickness. The data are based on the information from 3 European PWB producers as well as on further literature, resulting in respective uncertainty values. Transportation and infrastructure are rough estimations having accordingly higher uncertainties.

The resulting unit processes are shown in Tab. 2.2 (on page 13) for the PWB with Pb-containing surface finishing, in Tab. 2.3 (on page 17) for the PWB with Pb-free surface finishing and in Tab. 2.4 (on page 21) for the unspecified mix data of these two datasets.

Tab. 2.2 Unit process inventories of the datasets "printed wiring board, surface mount, lead-containing surface, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Water (process)	⇨	printed wiring board, surface mount, lead-free surface, at plant				all water, not reported as pure water	resource	in water			Water, unspecified natural origin	5.58E+00	m3	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
Water (ultrapure)	⇨						water supply	production	No	GLO	water, ultrapure, at plant	1.09E+03	kg	average over 3 years from 3 European producer	1	1.13	average data over 3 years from 3 European PWB producer
natural gas	⇨						natural gas	heating systems	No	RER	heat, natural gas, at industrial furnace >100kW	3.79E+02	MJ	average over 3 years from 3 European producer	1	1.13	average data over 3 years from 3 European PWB producer
electricity	⇨						electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	3.26E+02	kWh	average over 3 years from 3 European producer	1	1.13	average data over 3 years from 3 European PWB producer
cores (incl. Composite)	⇨					glass fibre reinforced polyester used as a proxy	plastics	others	No	RER	glass fibre reinforced plastic, polyester resin, hand lay-up, at plant	9.81E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
prepreg	⇨					glass fibre reinforced polyester used as a proxy	plastics	others	No	RER	glass fibre reinforced plastic, polyester resin, hand lay-up, at plant	9.08E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
copper foil (material)	⇨						metals	extraction	No	RER	copper, at regional storage	1.82E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
copper foil (process)	⇨						metals	processing	No	RER	sheet rolling, copper	1.82E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
copper balls	⇨						metals	extraction	No	RER	copper, at regional storage	1.06E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
resist	⇨					25% novolak - using phenolic resin as proxy	paintings	production	No	RER	phenolic resin, at plant	1.67E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
resist	⇨					75% solvent	chemicals	organics	No	RER	dipropylene glycol monomethyl ether, at plant	5.01E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
hydrochloric acid	⇨						chemicals	inorganics	No	RER	hydrochloric acid, 30% in H_2O, at plant	1.36E+01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
sodium hydroxide	⇨						chemicals	inorganics	No	RER	sodium hydroxide, 50% in H_2O, production mix, at plant	6.97E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer

continued ▼

Tab. 2.2 (Cont.) Unit process inventories of the datasets "printed wiring board, surface mount, lead-containing surface, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
				▼ continued													
hydrogen peroxide	⇨	printed wiring board, surface mount, lead-free surface, at plant					chemicals	inorganics	No	RER	hydrogen peroxide, 50% in H2O, at plant	1.77E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
salt	⇨						chemicals	inorganics	No	RER	sodium chloride, powder, at plant	5.11E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
iron III chloride	⇨						chemicals	inorganics	No	CH	iron (III) chloride, 40% in H2O, at plant	8.61E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
sulphuric acid	⇨						chemicals	inorganics	No	RER	sulphuric acid, liquid, at plant	1.17E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
nickel	⇨						metals	extraction	No	GLO	nickel, 99.5%, at plant	7.75E-04	kg	amount according to ZVEI umbrella specification of PWB	1	1.24	average from several ZVEI umbrella specifications for PWB
gold	⇨						metals	extraction	No	RER	gold, at regional storage	1.55E-04	kg	amount according to ZVEI umbrella specification of PWB	1	1.24	average from several ZVEI umbrella specifications for PWB
tin	⇨						metals	extraction	No	RER	tin, at regional storage	2.27E-03	kg	amount according to ZVEI umbrella specification of PWB	1	1.24	average from several ZVEI umbrella specifications for PWB
silver, immersion	⇨						metals	extraction	No	RER	silver, at regional storage	5.15E-04	kg	amount according to ZVEI umbrella specification of PWB	1	1.24	average from several ZVEI umbrella specifications for PWB
tin, immersion	⇨						metals	extraction	No	RER	tin, at regional storage	5.15E-04	kg	amount according to ZVEI umbrella specification of PWB	1	1.24	average from several ZVEI umbrella specifications for PWB
solder mask	⇨					novolak - using phenolic resin as proxy	paintings	production	No	RER	phenolic resin, at plant	4.64E-02	kg	amount according to ZVEI umbrella specification of PWB	1	1.24	average from several ZVEI umbrella specifications for PWB
Transport (part by lorry)	⇨						transport systems	road	No	RER	transport, lorry >16t, fleet average	3.22E+00	tkm	standard distances	1	2.09	(4,5,na,na,na,na,5); standard distances
Transport (part by train)	⇨						transport systems	train	No	RER	transport, freight, rail	1.93E+01	tkm	standard distances	1	2.09	(4,5,na,na,na,na,5); standard distances
Infrastructure	⇨						electronics	component	Yes	GLO	electronic component production plant	2.00E-08	unit	rough estimation	1	3.77	(4,5,1,3,5,4,9); rough assumption
continued ▼			⇨	dangerous waste		general module for hazardous waste incineration used as proxy	waste management	hazardous waste incineration	No	CH	disposal, hazardous waste, 25% water, to hazardous waste incineration	1.39E+01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer

Tab. 2.2 (Cont.) Unit process inventories of the datasets "printed wiring board, surface mount, lead-containing surface, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
▼ continued		printed wiring board, surface mount, lead-free surface, at plant	⇨	sludge from galvanisation		treatment of sludge from pig iron used as proxy	waste management	residual material landfill	No	CH	disposal, sludge, pig iron production, 8.6%water, to residual material landfill	4.12E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
			⇨	municipal waste			waste management	municipal incineration	No	CH	disposal, municipal solid waste, 22.9%water, to municipal incineration	4.63E-02	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
			⇨	biogenic waste		treatment of municipal solid waste used as proxy						5.95E-03	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
			⇨	plastic dispersion		emulsion paint incineration used as proxy	waste management	municipal incineration	No	CH	disposal, emulsion paint, 0% water, to municipal incineration	1.82E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
			⇨	waste heat			air	high population density			Heat, waste	1.18E+03	MJ	calculated from the electricity input	1	1.27	(2,4,3,3,1,5,13); calculated, from electricity input
			⇨	C, organic, to air			air	high population density			NMVOC, non-methane volatile organic compounds, unspecified origin	4.27E-02	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
			⇨	acidic / basic aerosols, to air		58%as hydrochloric acid	air	high population density			Hydrogen chloride	2.86E-03	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
			⇨	acidic / basic aerosols, to air		30%as sodium hydroxide	air	high population density			Sodium hydroxide	1.48E-03	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
			⇨	acidic / basic aerosols, to air		7%as hydrogen peroxide	air	high population density			Hydrogen peroxide	3.45E-04	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
			⇨	acidic / basic aerosols, to air		5%as sulfuric acid	air	high population density			Sulfuric acid	2.46E-04	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
			⇨	copper, to air			air	high population density			Copper	4.98E-03	kg	calculated, based on total release in USA	1	3.05	calculated from total release in USA
			⇨	dust, to air		75%as PM 2.5	air	high population density			Particulates, < 2.5 um	3.37E-04	kg	average over 3 years from 1 European producer	1	3.03	average data over 3 years from 1 European PWB producer
continued ▼			⇨	dust (II), to air		25%as PM 2.5-10	air	high population density			Particulates, > 2.5 um, and < 10um	1.12E-04	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer

Tab. 2.2 (Cont.) Unit process inventories of the datasets "printed wiring board, surface mount, lead-containing surface, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
▼ continued		printed wiring board, surface mount, lead-free surface, at plant	⇧	arsenic, to water			water	river			Arsenic, ion	2.18E-06	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇧	cadmium ion, to water			water	river			Cadmium, ion	1.84E-05	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇧	chromium ion, to water			water	river			Chromium, ion	5.22E-05	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇧	copper ion, to water			water	river			Copper, ion	1.75E-04	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇧	mercury ion, to water			water	river			Mercury	6.09E-07	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇧	nickel ion, to water			water	river			Nickel, ion	6.09E-05	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇧	zinc ion, to water			water	river			Zinc, ion	5.14E-05	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇧	AOX			water	river			AOX, Adsorbable Organic Halogen as Cl	1.34E-04	kg	average over 3 years from 1 European producer	1	1.53	average data over 3 years from 1 European PWB producer
			⇧	COD			water	river			COD, Chemical Oxygen Demand	8.17E-02	kg	average over 3 years from 1 European producer	1	1.53	average data over 3 years from 1 European PWB producer
			⇧	BOD			water	river			BOD5, Biological Oxygen Demand	8.17E-02	kg	average over 3 years from 1 European producer	1	1.53	average data over 3 years from 1 European PWB producer
			⇧	fluoride, to water			water	river			Fluoride	3.76E-04	kg	average over 3 years from 1 European producer	1	1.53	average data over 3 years from 1 European PWB producer
			⇧	product			electronics	module	No	GLO	printed wiring board, surface mount, lead-free surface, at plant	1.00E+00	m2		1		

Tab. 2.3 Unit process inventories of the datasets "printed wiring board, surface mount, lead-free surface, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Water (process)	⇨	printed wiring board, surface mount, lead-containing surface, at plant				all water, not reported as pure water	resource	in water			Water, unspecified natural origin	5.58E+00	m3	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
Water (ultrapure)	⇨						water supply	production	No	GLO	water, ultrapure, at plant	1.09E+03	kg	average over 3 years from 3 European producer	1	1.13	average data over 3 years from 3 European PWB producer
natural gas	⇨						natural gas	heating systems	No	RER	heat, natural gas, at industrial furnace >100kW	3.79E+02	MJ	average over 3 years from 3 European producer	1	1.13	average data over 3 years from 3 European PWB producer
electricity	⇨						electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	3.26E+02	kWh	average over 3 years from 3 European producer	1	1.13	average data over 3 years from 3 European PWB producer
cores (incl. Composite)	⇨					glass fibre reinforced polyester used as a proxy	plastics	others	No	RER	glass fibre reinforced plastic, polyester resin, hand lay-up, at plant	9.81E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
prepreg	⇨					glass fibre reinforced polyester used as a proxy	plastics	others	No	RER	glass fibre reinforced plastic, polyester resin, hand lay-up, at plant	9.08E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
copper foil (material)	⇨						metals	extraction	No	RER	copper, at regional storage	1.82E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
copper foil (process)	⇨						metals	processing	No	RER	sheet rolling, copper	1.82E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
copper balls	⇨						metals	extraction	No	RER	copper, at regional storage	1.06E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
resist	⇨					25% novolak - using phenolic resin as proxy	paintings	production	No	RER	phenolic resin, at plant	1.67E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
resist	⇨					75% solvent	chemicals	organics	No	RER	dipropylene glycol monomethyl ether, at plant	5.01E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
hydrochloric acid	⇨						chemicals	inorganics	No	RER	hydrochloric acid, 30% in H_2O, at plant	1.36E+01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
sodium hydroxide	⇨						chemicals	inorganics	No	RER	sodium hydroxide, 50% in H_2O, production mix, at plant	6.97E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer

continued ▼

Tab. 2.3 (Cont.) Unit process inventories of the datasets "printed wiring board, surface mount, lead-free surface, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
				▼ continued													
hydrogen peroxide	⇨	printed wiring board, surface mount, lead-containing surface, at plant					chemicals	inorganics	No	RER	hydrogen peroxide, 50% in H2O, at plant	1.77E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
salt	⇨						chemicals	inorganics	No	RER	sodium chloride, powder, at plant	5.11E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
iron III chloride	⇨						chemicals	inorganics	No	CH	iron (III) chloride, 40 % in H2O, at plant	8.61E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
sulphuric acid	⇨						chemicals	inorganics	No	RER	sulphuric acid, liquid, at plant	1.17E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
lead	⇨						metals	extraction	No	GLO	nickel, 99.5%, at plant	4.45E-03	kg	amount according to ZVEI umbrella specification of PWB	1	1.24	average from several ZVEI umbrella specifications for PWB
tin	⇨						metals	extraction	No	RER	tin, at regional storage	7.58E-03	kg	amount according to ZVEI umbrella specification of PWB	1	1.24	average from several ZVEI umbrella specifications for PWB
solder mask	⇨					novolak - using phenolic resin as proxy	paintings	production	No	RER	phenolic resin, at plant	4.64E-02	kg	amount according to ZVEI umbrella specification of PWB	1	1.24	average from several ZVEI umbrella specifications for PWB
Transport (part by lorry)	⇨						transport systems	road	No	RER	transport, lorry >16t, fleet average	3.22E+00	tkm	standard distances	1	2.09	(4,5,na,na,na,na,5); standard distances
Transport (part by train)	⇨						transport systems	train	No	RER	transport, freight, rail	1.93E+01	tkm	standard distances	1	2.09	(4,5,na,na,na,na,5); standard distances
Infrastructure	⇨						electronics	component	Yes	GLO	electronic component production plant	2.00E-08	unit	rough estimation	1	3.77	(4,5,1,3,5,4,9); rough assumption
			⇨	dangerous waste		general module for hazardous waste incineration used as proxy	waste management	hazardous waste incineration	No	CH	disposal, hazardous waste, 25% water, to hazardous waste incineration	1.39E+01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
			⇨	sludge from galvanisation		treatment of sludge from pig iron used as proxy	waste management	residual material landfill	No	CH	disposal, sludge, pig iron production, 8.6% water, to residual material landfill	4.12E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
continued ▼			⇨	municipal waste			waste management	municipal incineration	No	CH	disposal, municipal solid waste, 22.9% water, to municipal incineration	4.63E-02	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer

Tab. 2.3 (Cont.) Unit process inventories of the datasets "printed wiring board, surface mount, lead-free surface, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
▼ continued		printed wiring board, surface mount, lead-containing surface, at plant	⇨	biogenic waste		treatment of municipal solid waste used as proxy						5.95E-03	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
			⇨	plastic dispersion		emulsion paint incineration used as proxy	waste management	municipal incineration	No	CH	disposal, emulsion paint, 0% water, to municipal incineration	1.82E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
			⇨	waste heat			air	high population density			Heat, waste	1.18E+03	MJ	calculated from the electricity input	1	1.27	(2,4,3,3,1,5,13); calculated, from electricity input
			⇨	C, organic, to air			air	high population density			NMVOC, non-methane volatile organic compounds, unspecified origin	4.27E-02	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
			⇨	acidic / basic aerosols, to air		58% as hydrochloric acid	air	high population density			Hydrogen chloride	2.86E-03	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
			⇨	acidic / basic aerosols, to air		30% as sodium hydroxide	air	high population density			Sodium hydroxide	1.48E-03	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
			⇨	acidic / basic aerosols, to air		7% as hydrogen peroxide	air	high population density			Hydrogen peroxide	3.45E-04	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
			⇨	acidic / basic aerosols, to air		5% as sulfuric acid	air	high population density			Sulfuric acid	2.46E-04	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
			⇨	copper, to air			air	high population density			Copper	4.98E-03	kg	calculated, based on total release in USA	1	3.05	calculated from total release in USA
			⇨	lead, to air			air	high population density			Lead	1.55E-03	kg	calculated, based on total release in USA	1	3.05	calculated from total release in USA
			⇨	dust, to air		75% as PM 2.5	air	high population density			Particulates, < 2.5 um	3.37E-04	kg	average over 3 years from 1 European producer	1	3.03	average data over 3 years from 1 European PWB producer
			⇨	dust (II), to air		25% as PM 2.5-10	air	high population density			Particulates, > 2.5 um, and < 10um	1.12E-04	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
continued ▼			⇨	arsenic, to water			water	river			Arsenic, ion	2.18E-06	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer

Tab. 2.3 (Cont.) Unit process inventories of the datasets "printed wiring board, surface mount, lead-free surface, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
▼ continued		printed wiring board, surface mount, lead-containing surface, at plant	⇧	cadmium ion, to water			water	river			Cadmium, ion	1.84E-05	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇧	chromium ion, to water			water	river			Chromium, ion	5.22E-05	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇧	copper ion, to water			water	river			Copper, ion	1.75E-04	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇧	mercury ion, to water			water	river			Mercury	6.09E-07	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇧	nickel ion, to water			water	river			Nickel, ion	6.09E-05	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇧	lead ion, to water			water	river			Lead	5.51E-05	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇧	zinc ion, to water			water	river			Zinc, ion	5.14E-05	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇧	AOX			water	river			AOX, Adsorbable Organic Halogen as Cl	1.34E-04	kg	average over 3 years from 1 European producer	1	1.53	average data over 3 years from 1 European PWB producer
			⇧	COD			water	river			COD, Chemical Oxygen Demand	8.17E-02	kg	average over 3 years from 1 European producer	1	1.53	average data over 3 years from 1 European PWB producer
			⇧	BOD			water	river			BOD5, Biological Oxygen Demand	8.17E-02	kg	average over 3 years from 1 European producer	1	1.53	average data over 3 years from 1 European PWB producer
			⇧	fluoride, to water			water	river			Fluoride	3.76E-04	kg	average over 3 years from 1 European producer	1	1.53	average data over 3 years from 1 European PWB producer
			⇧	product			electronics	module	No	GLO	printed wiring board, surface mount, lead-containing surface, at plant	1.00E+00	m2		1		

Tab. 2.4 Unit process inventories of the datasets "printed wiring board, surface mount, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Pb-containing type	⇩	printed wiring board, surface mount, at plant					electronics	module	No	GLO	printed wiring board, surface mount, lead-free surface, at plant	5.00E-01	m2	assumption	1	1.30	rough assumption
Pb-free type	⇩						electronics	module	No	GLO	printed wiring board, surface mount, lead-containing surface, at plant	5.00E-01	m2	assumption	1	1.30	rough assumption
			⇩	PWB, surface mount			electronics	module	No	GLO	printed wiring board, surface mount, at plant	1.00E+00	m2		1		

2.2.5 Datasets "Printed Wiring Board, through-hole, at plant"

As reference a 1.6 mm thick 2-layer FR-4 PWB, with surface finishing and soldermask, unmounted but prepared for through-hole mounting of electronic components is selected. All here described datasets have the reference flow "1 m^2", based on a square weight of 3.08 kg (ZVEI (2006)). In details, the following datasets are established:

- **"printed wiring board, through-hole, at plant"**: 50:50-mixture (due to a lack of more precise information) of the two following datasets;
- **"printed wiring board, through-hole, lead-containing surface, at plant"**: a 1.6 mm thick 2-layer FR-4 PWB with a hot air solder leveling (HAL) surface finishing with a tin-lead-mixture (6.79 g Sn and 3.99 g Pb per m^2 PWB);
- **"printed wiring board, through-hole, lead-free surface, at plant"**: a 1.6 mm thick 6-layer FR-4 PWB with a mixture of Pb-free HAL and immersion silver as surface finishing methods (US EPA (2000) and ZVEI (2006)). Due to a lack of more specific information, the following distribution is assumed here:
  - 50% as hot air solder leveling (HAL) with tin only (with 6.78 g/m^2 PWB), and
  - 50% immersion silver (with 1.54 g/m^2 PWB).

System Characterisation

The three datasets comprise the input of the raw materials, the consumption of energy (electricity and heat), the used infrastructure and the transport efforts as well as the produced waste and emissions. Main data sources for these datasets are material data sheets of this type of PWB (established within ZVEI (2006)), the environmental reports of several PWB producers (AT&S AG (2006) - Fehring plant, and hmp (2006)), supported by punctual information from literature (e.g. US EPA (1995), or US EPA (2000)).

Life Cycle inventory

Raw materials (cores, copper foil)

According to AT&S AG (2006), Fehring plant, the input amount of base materials (average of the production from 2003 to 206) into the process of the Fehring plant is about 3.35 kg per m^2 of PWB. Assuming an average square weight of 3.08 kg (average value for 2-layer, surface coated, FR-4 PWB according to ZVEI (2006)) for the produced PWB, this leads to a yield of 91.6%.

For the split into the actual core material and the outer copper foils, the values for 2-layer, surface coated, FR-4 PWB according to ZVEI (2006) are used. Hereby the amount of cores is represented by the dataset for glass-fibre reinforced polyester.

Raw materials (surface finishing)

The value for the respective surface finishing technology (see above) are taken from the calculations for 2-layer, surface coated, FR-4 PWB with ZVEI (2006). In the same way, the soldermask finishing is calculated and represented, by using "phenolic resin" as a proxy.

Energy

Electricity and natural gas plus light fuel oil are used as energy carriers. The average from the reported values in AT&S AG (2006), Fehring plant, and hmp (2006) is used.

Process chemicals (auxiliaries)

A variety of different chemical substances are used within the process chain of PWB production. The values used here are taken from AT&S AG (2006), Fehring plant, representing an average of the production years 2003 to 2006. However, about two third of the used chemicals are reported in the sum category "chemicals" and not further specified. In order to get this part of the used chemicals included into the ecoinvent dataset, the reported amount is split up – based on internal calculations and literature sources – into the following fractions:

- *81% potassium carbonate*: main material used in order to remove residuals of photo resist matter and to wash the unexposed solder masks from the final board (Goldman (1997));
- *14% sodium persulfate*: base material in order to etch the copper layer (Hayes (1997));
- *5% ammonium chloride*: a base component of the HAL flux (Goodell (1997));
- *0.5% (each) ethanol and defoamer*: a base component of the HAL flux remover resp. protection against organic contaminants (see e.g. Galgoci et al. (2005)).

The reported value of paints and solvents is assumed to be 50% paints (represented by the dataset "acrylic varnish, 87.5% in H2O") and 50% solvent (represented by the dataset "isopropanol").

Emissions to air

In AT&S AG (2006), Fehring plant, values for emissions into air are reported, split up into two different types of emissions (organic carbon / aerosols of acids/bases). Due to a lack of more precise information, these available data are used in the following way in order to inventorize the emissions to air from the PWB production:

- *organic carbon:* due to a lack of more precise information, the dataset "NMVOC, unspecified" is used herefore;
- *aerosols of acids/bases:* based on the input of auxiliaries (HCl, NaOH, H_2O_2 and H_2SO_4), the following distribution in the aerosol emissions is calculated: 64% HCl, 17% NaOH, 9% H_2O_2 and the remaining 9% H_2SO_4 (assuming an equal transfer into air of all these substances),

No metal emissions are reported in AT&S AG (2006) although, according to US EPA (1995), Pb as well as Cu can occur as emissions to air. The latter emissions (i.e. Cu) are primarily attributable to the electroplating process as well as to via-drilling and deburring (Wadden et al. (1995), Williams (1998a), and USEPA (1995)). The load of copper to air is calculated based on an assumed annual PWB yield of 292'000 m2 and a Cu release to air of 3205 lb/year (US EPA (1995)). The Pb emissions on the other side are attributable to HAL application (MIGA (2004)), via-drilling, deburring and solder coating (Wallenberger et al. (2004), USEPA (1995)) in case of Pb-containing PWB. The load of lead to air is calculated based on an assumed annual PWB yield of 292'000 m^2 and a Pb release to air of 1000 lb/year (US EPA (1995)).

Last but not least, it is assumed, that 100% of the electricity consumed is converted to waste heat. In accordance with the general rules for ecoinvent, it is assumed that 100% of the waste heat is released to the air.

Emissions to water & Water input

In AT&S AG (2006), Fehring plant, discharge values (in mg/L) for a couple of heavy metals and COD are reported. These values correspond to the discharge from the internal WWTP (waste water treatment plant) to the river. Accordingly, by using the amount of water released via internal WWTP, these discharge values are transformed into releases per m^2 of produced PWB. For As, Cd, Cr, Hg, AOX and Fluorine only the Leoben plant (-> multilayer PWB) reports values. Due to the fact that the processing for either of the PWB examined is rather similar, the values from the multilayer PWB are used also in this dataset here.

Furthermore it is assumed that BOD = COD, and the value for BOD is included into these datasets accordingly. Due to a lack of information, no values for DOC and TOC can be reported here.

Waste

In AT&S AG (2006), values for the different types of waste produced at the Fehring plant are reported. Due to a lack of more precise information, these available data are used in the following way in order to inventory the waste produced during the through-hole PWB production:

- *paper waste / plastics waste / PWB waste:* all this waste is recycled, hence this amount is – in accordance with the methodology of ecoinvent (more details, see Frischknecht et al. (2007)) – not further taken into account;
- *harmful waste:* due to a lack of more specific information, the general dataset "disposal, hazardous waste, to hazardous waste incineration" is used;
- *copper chloride:* it is assumed that this substance can be recycled, hence its amount is – in accordance with the methodology of ecoinvent (Frischknecht et al. (2007)) – not further taken into account;
- *sludge from WWTP:* due to a lack of more specific information, the general dataset "disposal, sluge from steel rolling" is used due to the fact that this dataset represents a sludge issue of a WWTP;
- *organic solvents / resins / paints:* due to a lack of more specific information, the dataset "disposal, solvent mixture, to hazardous waste incineration" is used;
- *organic waste:* (biogenic waste – according to the German version of the report) it is assumed that this waste can be recycled (e.g by composting), hence its amount is – in accordance with the methodology of ecoinvent (Frischknecht et al. (2007)) – not further taken into account;
- *garbage (municipal waste):* the dataset "disposal, municipal waste, to municipal incineration" is used;

Transport

Due to a lack of specific information, standard transport distances and means according to the ecoinvent methodology (see Frischknecht et al. (2007)) are used.

Infrastructure and land-use

Due to a lack of specific information, the infrastructure dataset "electronic component plant" is used here (more details about this infrastructure dataset, see chapter 2 in part I of this report).

Data Uncertainty

The uncertainty scores established according to the method used in the ecoinvent project (see Frischknecht et al. (2007)) include reliability, completeness, temporal correlation, geographical correlation, further technological correlation and sample size. The datasets represent a 6-layer, FR-4 PWB with surface finishing and soldermask of 1.6 mm thickness. The data are based on the information from 2 European PWB producers as well as on further literature, resulting in respective uncertainty values. Transportation and infrastructure are rough estimations having accordingly higher uncertainties.

The resulting unit processes are shown in Tab. 2.5 (on page 26) for the PWB with Pb-containing surface finishing, in Tab. 2.6 (on page 31) for the PWB with Pb-free surface finishing and in Tab. 2.7 (on page 34) for the unspecified mix data of these two other datasets.

Tab. 2.5 Unit process inventories of the datasets "printed wiring board, through-hole, lead-containing surface, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Water (process)	⇨	printed wiring board, through-hole, lead-containing surface, at plant					water supply	production	No	RER	tap water, at user	3.08E+02	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
Water (ultrapure)	⇨						water supply	production	No	GLO	water, ultrapure, at plant	2.05E-01	kg	average over 3 years from 2 European producer	1	1.13	average data over 3 years from 3 European PWB producer
natural gas	⇨						natural gas	heating systems	No	RER	heat, natural gas, at industrial furnace >100kW	1.26E+02	MJ	average over 3 years from 3 European producer	1	1.13	average data over 3 years from 3 European PWB producer
light fuel oil	⇨						oil	heating systems	No	RER	heat, light fuel oil, at industrial furnace 1MW	7.55E-01	MJ	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
electricity	⇨						electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	9.46E+01	kWh	average over 3 years from 3 European producer	1	1.13	average data over 3 years from 3 European PWB producer
cores (incl. Composite)	⇨					glass fibre reinforced polyester used as a proxy	plastics	others	No	RER	glass fibre reinforced plastic, polyester resin, hand lay-up, at plant	2.99E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
copper foil (material)	⇨						metals	extraction	No	RER	copper, at regional storage	3.58E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
copper foil (process)	⇨						metals	processing	No	RER	sheet rolling, copper	1.82E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
copper balls	⇨						metals	extraction	No	RER	copper, at regional storage	3.94E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
resist	⇨					25%novolak - using phenolic resin as proxy	paintings	production	No	RER	phenolic resin, at plant	1.82E-02	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
resist	⇨					75%solvent	chemicals	organics	No	RER	dipropylene glycol monomethyl ether, at plant	5.46E-02	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
hydrochloric acid	⇨						chemicals	inorganics	No	RER	hydrochloric acid, 30%in H2O, at plant	1.61E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
sodium hydroxide	⇨						chemicals	inorganics	No	RER	sodium hydroxide, 50%in H2O, production mix, at plant	4.34E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer

continued ▼

Tab. 2.5 (Cont.) Unit process inventories of the datasets "printed wiring board, through-hole, lead-containing surface, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
				▼ continued													
hydrogen peroxide	⇨	printed wiring board, through-hole, lead-containing surface, at plant					chemicals	inorganics	No	RER	hydrogen peroxide, 50% in H2O, at plant	2.39E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
salt	⇨						chemicals	inorganics	No	RER	sodium chloride, powder, at plant	3.27E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
iron III chloride	⇨						chemicals	inorganics	No	CH	iron (III) chloride, 40% in H2O, at plant	1.83E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
sulphuric acid	⇨						chemicals	inorganics	No	RER	sulphuric acid, liquid, at plant	2.39E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
paints / solvents	⇨					50% as "acrylic varnish"	paintings	production	No	RER	acrylic varnish, 87.5% in H2O, at plant	1.37E-01	kg	approximation, based on average over 3 years from 1 European producer	1	1.33	approximation, based on average data over 3 years from 1 European PWB producer
paints / solvents	⇨					50% as "isopropanol"	chemicals	organics	No	RER	isopropanol, at plant	1.37E-01	kg	approximation, based on average over 3 years from 1 European producer	1	1.33	approximation, based on average data over 3 years from 1 European PWB producer
chemicals (potassium carbonate)	⇨						chemicals	inorganics	No	GLO	potassium carbonate, at plant	3.78E+00	kg	assumption, based on literature (amount based on 1 European producer)	1	1.38	assumption - based on data from 1 European producer
chemicals (sodium persulfate)	⇨						chemicals	inorganics	No	GLO	sodium persulfate, at plant	6.54E-01	kg	assumption, based on literature (amount based on 1 European producer)	1	1.38	assumption - based on data from 1 European producer
chemicals (ammonium chloride)	⇨						chemicals	inorganics	No	GLO	ammonium chloride, at plant	1.87E+00	kg	assumption, based on literature (amount based on 1 European producer)	1	1.38	assumption - based on data from 1 European producer
chemicals (ethanol)	⇨						chemicals	organics	No	RER	ethanol from ethylene, at plant	2.34E-02	kg	assumption, based on literature (amount based on 1 European producer)	1	1.38	assumption - based on data from 1 European producer
chemicals (defoamer)	⇨					LLDPE used as proxy	plastics	polymers	No	RER	polyethylene, LLDPE, granulate, at plant	2.34E-02	kg	assumption, based on literature (amount based on 1 European producer)	1	1.38	assumption - based on data from 1 European producer
lead	⇨			▼ continued			metals	extraction	No	GLO	nickel, 99.5%, at plant	4.20E-03	kg	amount according to ZVEI umbrella specification of PWB	1	1.24	average from several ZVEI umbrella specifications for PWB

Tab. 2.5 (Cont.) Unit process inventories of the datasets "printed wiring board, through-hole, lead-containing surface, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
				▼ continued													
tin	⇨	printed wiring board, through-hole, lead-containing surface, at plant					metals	extraction	No	RER	tin, at regional storage	7.15E-03	kg	amount according to ZVEI umbrella specification of PWB	1	1.24	average from several ZVEI umbrella specifications for PWB
solder mask	⇨					novolak - using phenolic resin as proxy	paintings	production	No	RER	phenolic resin, at plant	4.38E-02	kg	amount according to ZVEI umbrella specification of PWB	1	1.24	average from several ZVEI umbrella specifications for PWB
Transport (part by lorry)	⇨						transport systems	road	No	RER	transport, lorry >16t, fleet average	1.53E+00	tkm	standard distances	1	2.09	(4,5,na,na,na,na,5); standard distances
Transport (part by train)	⇨						transport systems	train	No	RER	transport, freight, rail	9.21E+00	tkm	standard distances	1	2.09	(4,5,na,na,na,na,5); standard distances
Infrastructure	⇨						electronics	component	Yes	GLO	electronic component production plant	2.00E-08	unit	rough estimation	1	3.77	(4,5,1,3,5,4,9); rough assumption
			⇨	plastic waste			waste management	municipal incineration	No	CH	disposal, plastics, mixture, 15.3%water, to municipal incineration	2.27E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
			⇨	dangerous waste		general module for hazardous waste incineration used as proxy	waste management	hazardous waste incineration	No	CH	disposal, hazardous waste, 25%water, to hazardous waste incineration	1.96E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
			⇨	sludge from WWTP		treatment of sludge from steel rolling used as proxy	waste management	residual material landfill	No	CH	disposal, sludge from steel rolling, 20%water, to residual material landfill	7.43E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
			⇨	municipal waste			waste management	municipal incineration	No	CH	disposal, municipal solid waste, 22.9%water, to municipal incineration	9.27E-02	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
			⇨	biogenic waste		treatment of municipal solid waste used as proxy	waste management	municipal incineration	No	CH	disposal, municipal solid waste, 22.9%water, to municipal incineration	1.44E-03	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
			⇨	solvent, resin, paints		solvent mixture to hazardous waste incineration	waste management	hazardous waste incineration	No	CH	disposal, solvents mixture, 16.5%water, to hazardous waste incineration	1.09E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
			⇨	waste heat			air	high population density			Heat, waste	3.41E+02	MJ	calculated from the electricity input	1	1.27	(2,4,3,3,1,5,13); calculated, from electricity input
			⇨	C, organic, to air			air	high population density			NMVOC, non-methane volatile organic compounds, unspecified origin	8.52E-03	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
			⇨	acidic / basic aerosols, to air		64%as hydrochloric acid	air	high population density			Hydrogen chloride	2.94E-03	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
continued ▼																	

Tab. 2.5 (Cont.) Unit process inventories of the datasets "printed wiring board, through-hole, lead-containing surface, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
▼ continued		printed wiring board, through-hole, lead-containing surface, at plant	⇨	acidic / basic aerosols, to air		17% as sodium hydroxide	air	high population density			Sodium hydroxide	7.82E-04	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
			⇨	acidic / basic aerosols, to air		9% as hydrogen peroxide	air	high population density			Hydrogen peroxide	4.14E-04	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
			⇨	acidic / basic aerosols, to air		9% as sulfuric acid	air	high population density			Sulfuric acid	4.14E-04	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
			⇨	copper, to air			air	high population density			Copper	4.98E-03	kg	calculated, based on total release in USA	1	3.05	calculated from total release in USA
			⇨	lead, to air			air	high population density			Lead	1.55E-03	kg	calculated, based on total release in USA	1	3.05	calculated from total release in USA
			⇨	copper ion, to water			water	river			Copper, ion	2.07E-08	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇨	nickel ion, to water			water	river			Nickel, ion	8.00E-09	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇨	lead ion, to water			water	river			Lead	9.33E-09	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇨	zinc ion, to water			water	river			Zinc, ion	8.33E-09	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇨	COD			water	river			COD, Chemical Oxygen Demand	8.40E-05	kg	average over 3 years from 1 European producer	1	1.53	average data over 3 years from 1 European PWB producer
			⇨	BOD			water	river			BOD5, Biological Oxygen Demand	8.40E-05	kg	average over 3 years from 1 European producer	1	1.53	average data over 3 years from 1 European PWB producer
			⇨	arsenic, to water			water	river			Arsenic, ion	2.18E-06	kg	average over 3 years from 1 European multilayer producer	1	5.09	average data over 3 years from 1 European PWB producer
continued ▼			⇨	cadmium ion, to water			water	river			Cadmium, ion	1.84E-05	kg	average over 3 years from 1 European multilayer producer	1	5.09	average data over 3 years from 1 European PWB producer

Tab. 2.5 (Cont.) Unit process inventories of the datasets "printed wiring board, through-hole, lead-containing surface, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
▼ continued		printed wiring board, through-hole, lead-containing surface, at plant	↰	chromium ion, to water			water	river			Chromium, ion	5.22E-05	kg	average over 3 years from 1 European multilayer producer	1	5.09	average data over 3 years from 1 European PWB producer
			↰	mercury ion, to water			water	river			Mercury	6.09E-07	kg	average over 3 years from 1 European multilayer producer	1	5.09	average data over 3 years from 1 European PWB producer
			↰	AOX			water	river			AOX, Adsorbable Organic Halogen as Cl	1.34E-04	kg	average over 3 years from 1 European multilayer producer	1	1.61	average data over 3 years from 1 European PWB producer
			↰	fluoride, to water			water	river			Fluoride	3.76E-04	kg	average over 3 years from 1 European multilayer producer	1	1.61	average data over 3 years from 1 European PWB producer
			↰	product			electronics	module	No	GLO	printed wiring board, through-hole, lead-containing surface, at plant	1.00E+00	m2		1		

Tab. 2.6 Unit process inventories of the datasets "printed wiring board, through-hole, lead-free surface, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Water (process)	⇨	printed wiring board, through-hole, lead-free surface, at plant					water supply	production	No	RER	tap water, at user	3.08E+02	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
Water (ultrapure)	⇨						water supply	production	No	GLO	water, ultrapure, at plant	2.05E-01	kg	average over 3 years from 2 European producer	1	1.13	average data over 3 years from 3 European PWB producer
natural gas	⇨						natural gas	heating systems	No	RER	heat, natural gas, at industrial furnace >100kW	1.26E+02	MJ	average over 3 years from 3 European producer	1	1.13	average data over 3 years from 3 European PWB producer
light fuel oil	⇨						oil	heating systems	No	RER	heat, light fuel oil, at industrial furnace 1MW	7.55E-01	MJ	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
electricity	⇨						electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	9.46E+01	kWh	average over 3 years from 3 European producer	1	1.13	average data over 3 years from 3 European PWB producer
cores (incl. Composite)	⇨					glass fibre reinforced polyester used as a proxy	plastics	others	No	RER	glass fibre reinforced plastic, polyester resin, hand lay-up, at plant	2.99E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
copper foil (material)	⇨						metals	extraction	No	RER	copper, at regional storage	3.58E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
copper foil (process)	⇨						metals	processing	No	RER	sheet rolling, copper	1.82E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
copper balls	⇨						metals	extraction	No	RER	copper, at regional storage	3.94E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
resist	⇨					25%novolak - using phenolic resin as proxy	paintings	production	No	RER	phenolic resin, at plant	1.82E-02	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
resist	⇨					75%solvent	chemicals	organics	No	RER	dipropylene glycol monomethyl ether, at plant	5.46E-02	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
hydrochloric acid	⇨						chemicals	inorganics	No	RER	hydrochloric acid, 30%in H2O, at plant	1.61E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
sodium hydroxide	⇨						chemicals	inorganics	No	RER	sodium hydroxide, 50%in H2O, production mix, at plant	4.34E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer

continued ▼

Tab. 2.6 (Cont.) Unit process inventories of the datasets “printed wiring board, through-hole, lead-free surface, at plant (GLO)”

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
				▼ continued													
hydrogen peroxide	⇨	printed wiring board, through-hole, lead-free surface, at plant					chemicals	inorganics	No	RER	hydrogen peroxide, 50% in H2O, at plant	2.39E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
salt	⇨						chemicals	inorganics	No	RER	sodium chloride, powder, at plant	3.27E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
iron III chloride	⇨						chemicals	inorganics	No	CH	iron (III) chloride, 40% in H2O, at plant	1.83E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
sulphuric acid	⇨						chemicals	inorganics	No	RER	sulphuric acid, liquid, at plant	2.39E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
paints / solvents	⇨					50% as "acrylic varnish"	paintings	production	No	RER	acrylic varnish, 87.5% in H2O, at plant	1.37E-01	kg	approximation, based on average over 3 years from 1 European producer	1	1.33	approximation, based on average data over 3 years from 1 European PWB producer
paints / solvents	⇨					50% as "isopropanol"	chemicals	organics	No	RER	isopropanol, at plant	1.37E-01	kg	approximation, based on average over 3 years from 1 European producer	1	1.33	approximation, based on average data over 3 years from 1 European PWB producer
chemicals (potassium carbonate)	⇨						chemicals	inorganics	No	GLO	potassium carbonate, at plant	3.78E+00	kg	assumption, based on literature (amount based on 1 European producer)	1	1.38	assumption - based on data from 1 European producer
chemicals (sodium persulfate)	⇨						chemicals	inorganics	No	GLO	sodium persulfate, at plant	6.54E-01	kg	assumption, based on literature (amount based on 1 European producer)	1	1.38	assumption - based on data from 1 European producer
chemicals (ammonium chloride)	⇨						chemicals	inorganics	No	GLO	ammonium chloride, at plant	1.87E+00	kg	assumption, based on literature (amount based on 1 European producer)	1	1.38	assumption - based on data from 1 European producer
chemicals (ethanol)	⇨						chemicals	organics	No	RER	ethanol from ethylene, at plant	2.34E-02	kg	assumption, based on literature (amount based on 1 European producer)	1	1.38	assumption - based on data from 1 European producer
chemicals (defoamer)	⇨					LLDPE used as proxy	plastics	polymers	No	RER	polyethylene, LLDPE, granulate, at plant	2.34E-02	kg	assumption, based on literature (amount based on 1 European producer)	1	1.38	assumption - based on data from 1 European producer
tin	⇨			▼ continued			metals	extraction	No	RER	tin, at regional storage	3.57E-03	kg	amount according to ZVEI umbrella specification of PWB	1	1.24	average from several ZVEI umbrella specifications for PWB

Tab. 2.6 (Cont.) Unit process inventories of the datasets "printed wiring board, through-hole, lead-free surface, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
				▼ continued													
silver, immersion	⇦	printed wiring board, through-hole, lead-free surface, at plant					metals	extraction	No	RER	silver, at regional storage	8.11E-04	kg	amount according to ZVEI umbrella specification of PWB	1	1.24	average from several ZVEI umbrella specifications for PWB
solder mask	⇦					novolak - using phenolic resin as proxy	paintings	production	No	RER	phenolic resin, at plant	4.38E-02	kg	amount according to ZVEI umbrella specification of PWB	1	1.24	average from several ZVEI umbrella specifications for PWB
Transport (part by lorry)	⇦						transport systems	road	No	RER	transport, lorry >16t, fleet average	1.53E+00	tkm	standard distances	1	2.09	(4,5,na,na,na,na,5); standard distances
Transport (part by train)	⇦						transport systems	train	No	RER	transport, freight, rail	9.18E+00	tkm	standard distances	1	2.09	(4,5,na,na,na,na,5); standard distances
Infrastructure	⇦						electronics	component	Yes	GLO	electronic component production plant	2.00E-08	unit	rough estimation	1	3.77	(4,5,1,3,5,4,9); rough assumption
			⇦	plastic waste			waste management	municipal incineration	No	CH	disposal, plastics, mixture, 15.3%water, to municipal incineration	2.27E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
			⇦	dangerous waste		general module for hazardous waste incineration used as proxy	waste management	hazardous waste incineration	No	CH	disposal, hazardous waste, 25%water, to hazardous waste incineration	1.96E+00	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
			⇦	sludge from WWTP		treatment of sludge from steel rolling used as proxy	waste management	residual material landfill	No	CH	disposal, sludge from steel rolling, 20%water, to residual material landfill	7.43E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
			⇦	municipal waste			waste management	municipal incineration	No	CH	disposal, municipal solid waste, 22.9%water, to municipal incineration	9.27E-02	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
			⇦	biogenic waste		treatment of municipal solid waste used as proxy	waste management	municipal incineration	No	CH	disposal, municipal solid waste, 22.9%water, to municipal incineration	1.44E-03	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
			⇦	solvent, resin, paints		solvent mixture to hazardous waste incineration	waste management	hazardous waste incineration	No	CH	disposal, solvents mixture, 16.5%water, to hazardous waste incineration	1.09E-01	kg	average over 3 years from 1 European producer	1	1.16	average data over 3 years from 1 European PWB producer
			⇦	waste heat			air	high population density			Heat, waste	3.41E+02	MJ	calculated from the electricity input	1	1.27	(2,4,3,3,1,5,13); calculated, from electricity input
			⇦	C, organic, to air			air	high population density			NMVOC, non-methane volatile organic compounds, unspecified origin	8.52E-03	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
			⇦	acidic / basic aerosols, to air		64%as hydrochloric acid	air	high population density			Hydrogen chloride	2.94E-03	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
continued ▼																	

Tab. 2.6 (Cont.) Unit process inventories of the datasets "printed wiring board, through-hole, lead-free surface, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
▼ continued		printed wiring board, through-hole, lead-free surface, at plant	⇦	acidic / basic aerosols, to air		17% as sodium hydroxide	air	high population density			Sodium hydroxide	7.82E-04	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
			⇦	acidic / basic aerosols, to air		9% as hydrogen peroxide	air	high population density			Hydrogen peroxide	4.14E-04	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
			⇦	acidic / basic aerosols, to air		9% as sulfuric acid	air	high population density			Sulfuric acid	4.14E-04	kg	average over 3 years from 1 European producer	1	2.03	average data over 3 years from 1 European PWB producer
			⇦	copper, to air			air	high population density			Copper	4.98E-03	kg	calculated, based on total release in USA	1	3.05	calculated from total release in USA
			⇦	copper ion, to water			water	river			Copper, ion	2.07E-08	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇦	nickel ion, to water			water	river			Nickel, ion	8.00E-09	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇦	zinc ion, to water			water	river			Zinc, ion	8.33E-09	kg	average over 3 years from 1 European producer	1	5.03	average data over 3 years from 1 European PWB producer
			⇦	COD			water	river			COD, Chemical Oxygen Demand	8.40E-05	kg	average over 3 years from 1 European producer	1	1.53	average data over 3 years from 1 European PWB producer
			⇦	BOD			water	river			BOD5, Biological Oxygen Demand	8.40E-05	kg	average over 3 years from 1 European producer	1	1.53	average data over 3 years from 1 European PWB producer
			⇦	arsenic, to water			water	river			Arsenic, ion	2.18E-06	kg	average over 3 years from 1 European multilayer producer	1	5.09	average data over 3 years from 1 European PWB producer
			⇦	cadmium ion, to water			water	river			Cadmium, ion	1.84E-05	kg	average over 3 years from 1 European multilayer producer	1	5.09	average data over 3 years from 1 European PWB producer
continued ▼			⇦	chromium ion, to water			water	river			Chromium, ion	5.22E-05	kg	average over 3 years from 1 European multilayer producer	1	5.09	average data over 3 years from 1 European PWB producer

Tab. 2.6 (Cont.) Unit process inventories of the datasets "printed wiring board, through-hole, lead-free surface, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
▼ continued		printed wiring board, through-hole, lead-free surface, at plant	⇩	mercury ion, to water			water	river			Mercury	6.09E-07	kg	average over 3 years from 1 European multilayer producer	1	5.09	average data over 3 years from 1 European PWB producer
			⇩	AOX			water	river			AOX, Adsorbable Organic Halogen as Cl	1.34E-04	kg	average over 3 years from 1 European multilayer producer	1	1.61	average data over 3 years from 1 European PWB producer
			⇩	fluoride, to water			water	river			Fluoride	3.76E-04	kg	average over 3 years from 1 European multilayer producer	1	1.61	average data over 3 years from 1 European PWB producer
			⇩	product			electronics	module	No	GLO	printed wiring board, through-hole, lead-free surface, at plant	1.00E+00	m2		1		

Tab. 2.7 Unit process inventories of the datasets "printed wiring board, through-hole, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Pb-containing type	⇩	printed wiring board, through-hole, at plant					electronics	module	No	GLO	printed wiring board, through-hole, lead-free surface, at plant	5.00E-01	m2	assumption	1	1.30	rough assumption
Pb-free type	⇩						electronics	module	No	GLO	printed wiring board, through-hole, lead-containing surface, at plant	5.00E-01	m2	assumption	1	1.30	rough assumption
			⇩	PWB, surface mount			electronics	module	No	GLO	printed wiring board, through-hole, at plant	1.00E+00	m2		1		

2.3 Mounting of Printed Wiring Boards

2.3.1 Introduction

In this chapter, the mounting process of these printed wiring boards (PWB) is described. Mounting – sometimes also described as "populating" of a PWB – means to fix and connect various components (capacitors, resistors, transistors, integrated circuits, etc.) to the circuits on the PWB.

As it is shown in Fig. 7.1 below, separate datasets for the mounting process itself, the used solder materials, the infrastructure (plant, facilities) and some auxiliaries are established in order to get in the end several examples of mounted PWB datasets.

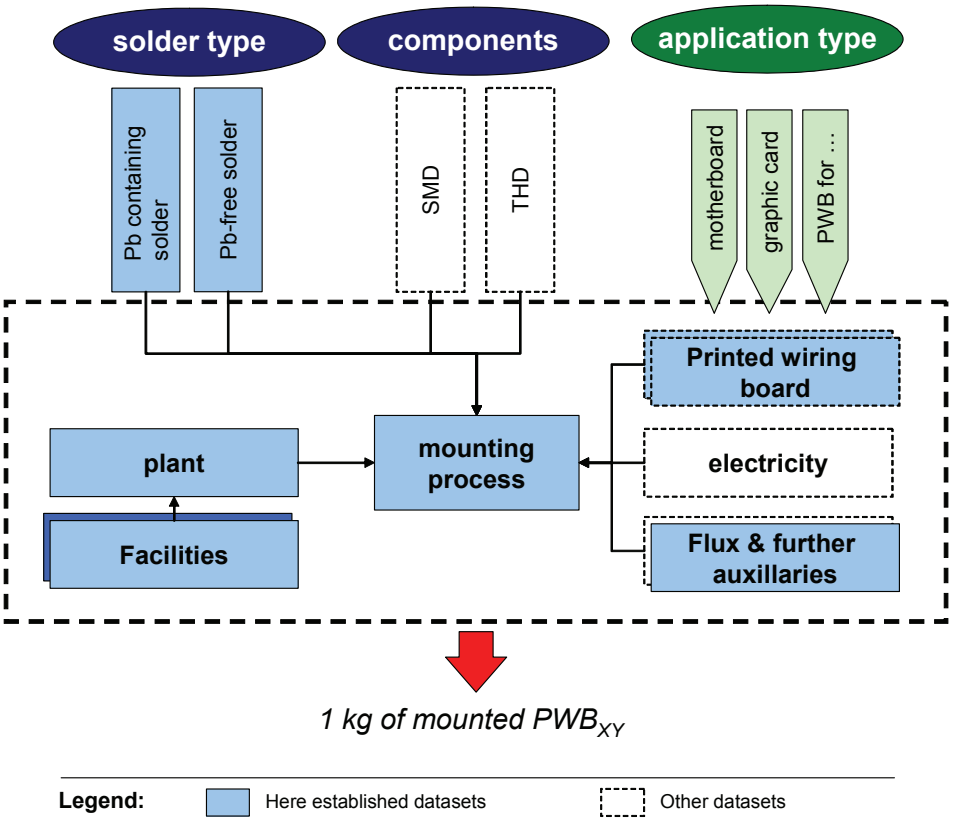


Fig. 2.5 Product system of the mounting process & its various parameters – resulting in a variety of different datasets for mounted printed wiring boards (SMD= surface mounted devices / THD= through-hole devices)

This distinction between solder materials, the mounting process and the resulting mounted PWB allows a flexible use of the data. The following datasets are established in this chapter:

- **Infrastructure:** (see chapter 2.3.2) Datasets of the mounting plant as well as for the mounting equipment in the case of surface mount technology (SMT) and through-hole technology (THT) are established.
- **Solder materials:** (see chapter 2.3.3) Datasets for lead-free and lead containing solder material, used in the electronics industry, are established. In each case, datasets for two different forms – one used for surface mount components, the other one for through-hole components – are established.
- **Mounting activities:** (see chapter 2.3.4) Separate datasets for SMT and THT with both types of solder materials (i.e. Pb-free, Pb-containing) – resulting in a total of 4 different mounting datasets – are established.

- **Mounted printed wiring boards:** (see chapter 2.3.5) In order to clearly show the use of the above described various datasets, example datasets of various PWB types are established and described. For each one of these PWB types described, a Pb-free, a Pb-containing and a mix of both is established – taking the mix datasets as reference datasets within the electronic devices established in this project here (see part III).

2.3.2 Infrastructure for Printed Wiring Board Mounting

The mounting activities do not request the same technical standards (e.g. clean room technology, etc.) as it is requested for the production of the components as well as the unmounted printed wiring board. Hence – in order to not overestimate the impact of the infrastructure, specific datasets of the mounting plant and the respective machinery park used inside this plant are established.

The information about the plant itself is based on own assumptions (from a plant visit in Switzerland) and on various information about Asian production sites, taken from the website www.alibaba.com. The meta information of the various datasets of the infrastructure for the mounting of printed wiring boards can be found in Tab. 7.1.

Tab. 2.8 Ecoinvent meta information for the datasets of the printed wiring board mounting infrastructure (plant and facilities) within the database.

Name	printed wiring board mounting facilities, SMT type	printed wiring board mounting facilities, THT type
Location	GLO	GLO
Infrastructure Process	1	1
Unit	Unit	unit
Dataset Version	2.0	2.0
Included Processes	This module includes material, production efforts (material treatment processes), transport efforts and the infrastructure for the production of all the machineries used for the mouning of surface mount components onto a printed wiring board. No information about emissions (air, water) and waste are included.	This dataset includes material, production efforts (material treatment processes), transport efforts and the infrastructure for the production of all the machineries used for the mouning of through-hole mounted components onto a printed wiring board. No information about emissions (air, water) and waste are included.
Amount	1	1
Local Name	Anlage, Leiterplattenbestückung, Typ SMT	Anlage, Leiterplattenbestückung, Type THT
Synonyms		
General Comment	The data represent an example of a SMT mounting line – comprising 3 small component placing machines, 2 big components placing machines, 1 inspection device and 1 reflow oven. Total weight data are taken from producer information of such machines. Composition, infrastructure and production efforts are based on own assumptions. The dataset represents a production line with a total weight of 19’300 kg.	The data represent an example of a THT mounting line – with a manual insertion of the components, followed by a wave solder machine. Total weight data are taken from producer information of such machines. Composition, infrastructure and production efforts are based on own assumptions. The dataset represents a production line with a total weight of 1’600 kg.
Start Date	2005	2005
End Date	2005	2005
Data valid for entire period	1	1
Geography Text	Data represent a global valid composition of a SMT mounting line.	Data represent a global valid composition of a THT mounting line.
Technology Text	Typical data of current machines sold for the mounting of SMD components (see general comments).	Typical data of current machines sold for the mounting of THT components (see general comments).
Representativeness	see Technology	see Technology
Production Volume	-	-
Sampling Procedure	Literature & own estimations	Literature & own estimations
Extrapolations	see Geography and Technology	see Geography and Technology
Uncertainty Adjustments	None	None

Tab. 7.1 (Cont.) Ecoinvent meta information for the datasets of the power supply unit for Desktop PC within the database.

Name	**printed wiring board mounting plant**
Location	GLO
Infrastructure Process	1
Unit	Unit
Dataset Version	2.0
Included Processes	This module includes land use, buildings and facilities (machinery, cables, etc.) as well as the respective disposal activities of a plant for printed wiring board mounting.
Amount	1
Local Name	Fabrik, Leiterplattenbestückung
Synonyms	
General Comment	The functional unit represents a production site for the mounting of printed wiring boards, comprising 6 SMT lines and 5 THT lines. Process data based on own estimations, using rough information about Asian plants. The here described plant has an assumed output of 60'000 m2 or 192'000 kg per year over a time span of 25 years.
Start Date	2005
End Date	2005
Data valid for entire period	1
Geography Text	This dataset relates to the global situation.
Technology Text	Up-to-date SMT and THT mounting plant, based on information from literature & a plant visit in Switzerland
Representativeness	see Technology
Production Volume	-
Sampling Procedure	Literature & own estimations
Extrapolations	see Geography and Technology
Uncertainty Adjustments	None

Dataset "Printed wiring board mounting plant"

System characterisation

For the infrastructure of the printed wiring board mounting plant datasets for the construction and dismantling of the different buildings as well as the technical equipment are used. Further the land use of the plant site is also included. In the dataset no emissions or wastes are included. The dataset represents a combined SMT and THT mounting plant as in more complex PWB constructions (like e.g. for computer motherboards) usually a mixture of these two techniques is currently used.

Life Cycle Inventory

Based on the description of several PC motherboard mounting facilities in China (data from website http://www.alibaba.com), reporting (factory) production sites of 3'000 to 11'000 m2 – a surface for the production of 5'000 m^2 is assumed here, represented by the dataset "building hall" reported in Kellenberger et al. (2007). In addition, the authors assume (based on experiences for the paper production site – reported in Hischier (2007)) that this represents only 50% of the overall surface of the production site – the remaining part is spread into 20% administration buildings (represented by the dataset „building, multi storey" reported in the same report), 20% internal streets and parking areas (represented by the dataset „roads, company, internal" described in Spielmann et al. (2007)). Further it is assumed that the administration buildings have an average height of 10 m. With his assumptions $2.0 * 10^4$ m^3 of multiple story building volume and $5.0 * 10^3$ m^2 of building hall area is calculated for the whole mounting site. The internal streets and parkings account for a total surface of 0.2 ha. The remaining 10% are considered as green area.

The type of land use before the occupation as industrial area is not known (i.e. reported as "transformation from unknown"). A further parameter concerning land use is the time that is used to Construction and to Dismantling of the whole plant. It is assumed to last for 12 month each.

In addition, it is assumed that the life time of all buildings, the street and parking surface will be, similar like the total assumed occupation time, about 25 years. Hence, no replacement occurs during this here assumed occupation time (production time). The final dismanteling of the buildings is already included into the datasets used, while for the streets it is assumed that all material can be recycled and therefore no dismanteling dataset is shown for this part of the infrastructure.

Concerning the equipment within the production hall, only the actual production machines are taken into account – all further kind of supporting parts (e.g. piplines for process media, data cables, etc.), are disregarded. For the number of production lines – information from the above mentioned website of Chinese PWB mounting companies is used, resulting in 6 SMT production lines and 5 THT production lines – production lines that are described further down in this chapter here. As all these production lines are assumed to have a life-span of only 10 years, 2.5 times these amounts have to be taken into account here.

Data Uncertainty and Input Data for Database ecoinvent

The uncertainty scores established according to the method used in the ecoinvent project (see Frischknecht et al. (2007)) include reliability, completeness, temporal correlation, geographical correlation, further technological correlation and sample size. The dataset is only a rough estimation of the actual infrastructure used for the production of all the different electronic components, based mainly on estimations from the author. Hence, the respective uncertainty values are accordingly high.

The resulting unit process "Printed wiring board mounting plant" is shown in Tab. 2.9 on the next page.

Tab. 2.9 Dataset "Electronic component production plant"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
land use (industrial area)	⇨	printed wiring board mounting plant					resource	land			Occupation, industrial area, built up	2.25E+05	m2a	own assumption	1	1.67	(4,5,1,3,1,5,7); own estimation, based on overall information from several chinese producers
land use (green area)	⇨						resource	land			Occupation, industrial area, vegetation	2.50E+04	m2a	own assumption	1	1.67	(4,5,1,3,1,5,7); own estimation, based on overall information from several chinese producers
land transformation (built area)	⇨						resource	land			Transformation, to industrial area, built up	9.00E+03	m2	own assumption	1	2.14	(4,5,1,3,1,5,8); own estimation, based on overall information from several chinese producers
land transformation (green area)	⇨						resource	land			Transformation, to industrial area, vegetation	1.00E+03	m2	own assumption	1	2.14	(4,5,1,3,1,5,8); own estimation, based on overall information from several chinese producers
land transformation (original land)	⇨						resource	land			Transformation, from unknown	1.00E+04	m2	own assumption	1	2.14	(4,5,1,3,1,5,8); own estimation, based on overall information from several chinese producers
land use (construction / disposal time)	⇨						resource	land			Occupation, construction site	2.00E+04	m2a	own assumption	1	1.67	(4,5,1,3,1,5,7); own estimation, based on overall information from several chinese producers
production hall	⇨						construction processes	buildings	Yes	CH	building, hall	5.00E+03	m2	own assumption	1	3.09	(4,5,na,na,na,na,9); rough estimation
office buildings	⇨						construction processes	buildings	Yes	RER	building, multi-storey	2.00E+04	m3	own assumption	1	3.09	(4,5,na,na,na,na,9); rough estimation
internal road & parking places	⇨			continued ▼			transport systems	road	Yes	CH	roads, company, internal	5.00E+04	m2a	own assumption	1	3.09	(4,5,na,na,na,na,9); rough estimation

Tab. 2.9 (Cont.) Dataset "Electronic component production plant"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Equipment SMT production	⇧	printed wiring board mounting plant		▼ continued			electronics	module	Yes	GLO	printed wiring board mounting facilities, SMT type	1.50E+01	unit	own assumption	1	3.14	(4,5,1,3,1,5,9); estimation, based on Locascio (2000) and own plant visit
Equipment THT production	⇧						electronics	module	Yes	GLO	printed wiring board mounting facilities, THT type	1.25E+01	unit	own assumption	1	3.14	(4,5,1,3,1,5,9); estimation, based on Locascio (2000) and own plant visit
			⇧	WEEE of equipment		disposal of the equipment (machinery) as WEEE - assuming 19'300 kg/unit (SMT) resp. 1'600 kg/unit (THT)	waste management	recycling	No	CH	disposal, industrial devices, to WEEE treatment	3.10E+05	kg	calculated from the input of equipment	1	3.14	(4,5,1,3,1,5,9); calculated from input of equipment
			⇧	PWB mounting plant			electronics	module	Yes	GLO	printed wiring board mounting plant	1.00E+00	unit		1	0.00	

Datasets "printed wiring board facilities"

System characterisation

Datasets, representing the various types of machineries used for the mounting of printed wiring boards with components by the surface mount as well as the through-hole technology are established.

According to Locascio (2000), a typical SMT mounting line comprises the following types of machines: screen print machine, small component placement machine(s), large component placement machine(s), inspection equipment and at the end a reflow oven. For a THT mounting line, usually just a wave solder machine is requested. In Fig. 2.6, a typical production line for the combined use of SMT and THT mounting is shown.

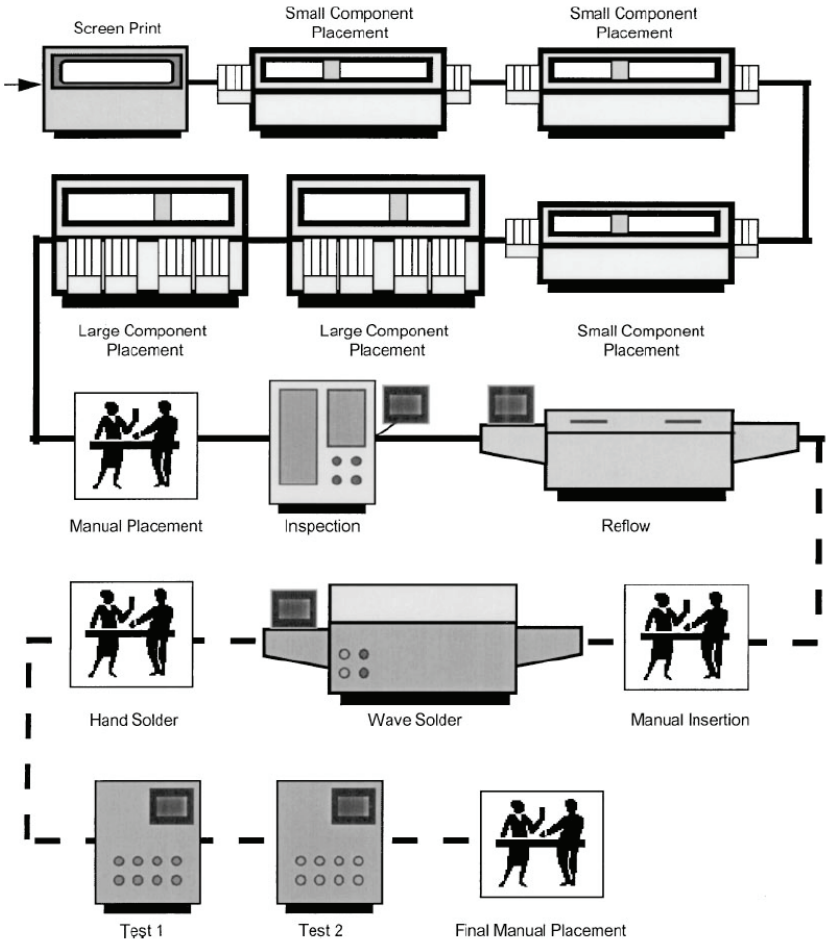


Fig. 2.6 Typical automated electronics assembly line: The solid line is a conveyor, the dashed line represents flow for batch processing (figure taken from Locascio (2000)).

For this complete mounting line, two datasets are established. While one dataset represents the wave solder machine used for the THT mounting, the other dataset represents all machineries used in the case of SMT mounting – i.e. represents 5 placement machines, 1 inspection machine and 1 reflow oven. In both cases, the established datasets contain information about the main materials used as well as the most important processing steps. No emissions are included.

Life Cycle Inventory

A big variety of different companies is producing this kind of machines. However, although you can find like this a variety of information about size and funcionalities of the various equipment parts used for the mounting process – none of these sites contain also information about the material weight and content of the respectice equipment. The following equipment information is used in order to establish the two datasets:

- **Placement machines for small components** – various machines from several producers (i.e. MYDATA, Panasonic) are taken into account, having a weight between 3'400 and 4'800 kg. An average weight of 4'100 kg/machine is used for ecoinvent;
- **Placement machines for big components** – similar to the above machine, various machines from several producers (i.e. MYDATA, Panasonic) are taken into account, having a weight between 1'900 and 3'200 kg. An average weight of 2'600 kg/machine is used for ecoinvent;
- **Inspection machines SMT mounting** – various machines from one producer (Panasonic) are taken into account, having a weight between 650 and 1'100 kg. An average weight of 800 kg/machine is used for ecoinvent;
- **Reflow oven** – various machines from one producer (Novastar) are taken into account, having a weight between 700 and 1'450 kg. An average weight of 1'000 kg/machine is used for ecoinvent;
- **Wave solder machine** – various machines from several producers (i.e. Tamura, Deksmt) are taken into account, having a weight between 1'100 and 2'000 kg. An average weight of 1'600 kg/machine is used for ecoinvent.

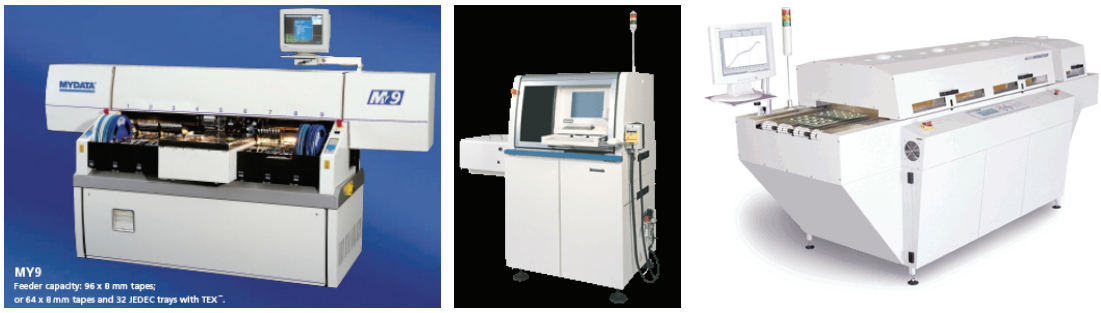


Fig. 2.7 **Examples of Mounting facilities – Component placement machine MYDATA MY-9 (left), Inspection machine PANASONIC IPV (center) and Reflow oven NOVASTAR 2000HC (right) – pictures taken from the respective homepage of the producer (www.mydata.com / www.panasonicfa.com / www.novastarinc.com)**

Based on these information sources, the following assumptions and estimations are used in order to establish the datasets "printed wiring board mounting facilities, SMT type" and "printed wiring board mounting facilities, THT type":

- **Raw materials (for SMT type)**: Based on the above described examples, a total weight of 19'300 kg is assumed for the complete SMT production line. Thereof, 17'000 kg are metals (80% low-alloyed steel – 20% chromium steel), 1'500 kg plastics (HDPE), 100 kg glass and the remaining 300 kg various electronic elements for controlling (250 kg of mounted wiring boards, 50 kg of cables).

- **Raw materials (for THT type)**: Based on the above described examples, an average weight of 1'600 kg is assumed for the wave solder machine. Thereof, 1'200 kg are metals (80% low-alloyed steel – 20% chromium steel), 100 kg plastics (HDPE), 200 kg glass and the remaining 100 kg various electronic elements for controlling (80 kg of mounted wiring boards, 20 kg of cables).
- **Auxiliaries & Packaging materials (both types)**: Due to a lack of respective information, no such flows are taken into account.
- **Energy (both types)**: No information about energy consumption is given in the examined sources. As an indirect mean, the following material processing steps are taken into account within this dataset here:
  - 80% of steel processed with dataset "section bar rolling, steel";
  - 20% of steel processed with dataset "sheet rolling, chromium steel";
  - All plastics processed with dataset "injection moulding".
- **Transport (both types)**: Due to a lack of specific information, standard transport distances and means according to the ecoinvent methodology (see Frischknecht et al. (2007)) are used here.
- **Infrastructure and land-use (both types)**: Due to a lack of specific information, the infrastructure dataset established for the production of cars (dataset "road vehicle plant" – reported in Spielmann et al. (2007)) is used as a proxy.
- **Emissions to air & water, waste (both types)**: Due to a lack of respective information, no such flows are taken into account.

Data Uncertainty and Input Data for Database ecoinvent

The uncertainty scores established according to the method used in the ecoinvent project (see Frischknecht et al. (2007)) include reliability, completeness, temporal correlation, geographical correlation, further technological correlation and sample size. Both datasets are a very rough estimation of the respective machineries used for the mounting procedure, based on weight information from several types of equipment. Hence, the respective uncertainty values are accordingly high.

The resulting unit process raw data of "printed wiring board mounting facilities, SMT type" and "printed wiring board mounting facilities, THT type" are shown in Tab. 2.10 and Tab. 2.11.

Tab. 2.10 Dataset "printed wiring board mounting facilities, SMT type"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
low-alloyed steel	⇨	printed wiring board mounting facilities, SMT type					metals	extraction	No	RER	steel, low-alloyed, at plant	1.36E+04	kg	Estimation - based on various examples of equipment	1	1.38	(4,2,1,1,3,5,3); estimation, based on partial information from a similar machine
chromium steel	⇨						metals	extraction	No	RER	chromium steel 18/8, at plant	3.40E+03	kg	Estimation - based on various examples of equipment	1	1.38	(4,2,1,1,3,5,3); estimation, based on partial information from a similar machine
plastics	⇨						plastics	polymers	No	RER	polyethylene, HDPE, granulate, at plant	1.50E+03	kg	Estimation - based on various examples of equipment	1	1.38	(4,2,1,1,3,5,3); estimation, based on partial information from a similar machine
glass	⇨						glass	construction	No	RER	flat glass, uncoated, at plant	5.00E+02	kg	Estimation - based on various examples of equipment	1	1.38	(4,2,1,1,3,5,3); estimation, based on partial information from a similar machine
electronics	⇨						electronics	module	No	GLO	printed wiring board, mixed mounted, unspec., solder mix, at plant	2.50E+02	kg	Estimation - based on various examples of equipment	1	1.38	(4,2,1,1,3,5,3); estimation, based on partial information from a similar machine
cables	⇨						electronics	component	No	GLO	cable, network cable, category 5, without plugs, at plant	1.39E+03	m	Estimation - based on various examples of equipment	1	1.38	(4,2,1,1,3,5,3); estimation, based on partial information from a similar machine
processing of steel	⇨						metals	processing	No	RER	section bar rolling, steel	1.36E+04	kg	calculated from estimated amount of low-alloyed steel	1	1.38	(4,2,1,1,3,5,3); estimation, based on partial information from a similar machine
processing of chromium steel	⇨						metals	processing	No	RER	sheet rolling, chromium steel	3.40E+03	kg	calculated from estimated amount of chromium steel	1	1.38	(4,2,1,1,3,5,3); estimation, based on partial information from a similar machine
processing of plastics	⇨						plastics	processing	No	RER	injection moulding	1.50E+03	kg	calculated from estimated plastics amount	1	1.38	(4,2,1,1,3,5,3); estimation, based on partial information from a similar machine
infrastructure	⇨			continued ▼			transport systems	road	Yes	RER	road vehicle plant	9.09E-07	unit	proxy	1	3.77	(4,5,1,3,5,4,9); rough estimation of infrastructure

Tab. 2.10 (Cont.) Dataset "printed wiring board mounting facilities, SMT type"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
transport, train	⇧	printed wiring board mounting facilities, SMT type		▼ continued			transport systems	train	No	RER	transport, freight, rail	3.86E+03	tkm	standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, road	⇧						transport systems	road	No	RER	transport, lorry >16t, fleet average	1.93E+03	tkm	standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
			⇧	PWB mounting facility			electronics	module	Yes	GLO	printed wiring board mounting facilities, SMT type	1.00E+00	unit		1	0.00	

Tab. 2.11 Dataset "printed wiring board mounting facilities, THT type"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
low-alloyed steel	⇧	printed wiring board mounting facilities, THT type					metals	extraction	No	RER	steel, low-alloyed, at plant	9.60E+02	kg	Estimation - based on various examples of equipment	1	1.38	(4,2,1,1,3,5,3); estimation, based on partial information from a similar machine
chromium steel	⇧						metals	extraction	No	RER	chromium steel 18/8, at plant	2.40E+02	kg	Estimation - based on various examples of equipment	1	1.38	(4,2,1,1,3,5,3); estimation, based on partial information from a similar machine
plastics	⇧						plastics	polymers	No	RER	polyethylene, HDPE, granulate, at plant	1.00E+02	kg	Estimation - based on various examples of equipment	1	1.38	(4,2,1,1,3,5,3); estimation, based on partial information from a similar machine
glass	⇧						glass	construction	No	RER	flat glass, uncoated, at plant	2.00E+02	kg	Estimation - based on various examples of equipment	1	1.38	(4,2,1,1,3,5,3); estimation, based on partial information from a similar machine
electronics	⇧						electronics	module	No	GLO	printed wiring board, mixed mounted, unspec., solder mix, at plant	8.00E+01	kg	Estimation - based on various examples of equipment	1	1.38	(4,2,1,1,3,5,3); estimation, based on partial information from a similar machine
cables	⇧			▼ continued			electronics	component	No	GLO	cable, network cable, category 5, without plugs, at plant	5.56E+02	m	Estimation - based on various examples of equipment	1	1.38	(4,2,1,1,3,5,3); estimation, based on partial information from a similar machine

Tab. 2.11 (Cont.) Dataset "printed wiring board mounting facilities, THT type"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
processing of steel	⇧	printed wiring board mounting facilities, THT type		▼ continued			metals	processing	No	RER	section bar rolling, steel	9.60E+02	kg	calculated from estimated amount of low-alloyed steel	1	1.38	(4,2,1,1,3,5,3); estimation, based on partial information from a similar machine
processing of chromium steel	⇧						metals	processing	No	RER	sheet rolling, chromium steel	2.40E+02	kg	calculated from estimated amount of chromium steel	1	1.38	(4,2,1,1,3,5,3); estimation, based on partial information from a similar machine
processing of plastics	⇧						plastics	processing	No	RER	injection moulding	1.00E+02	kg	calculated from estimated plastics amount	1	1.38	(4,2,1,1,3,5,3); estimation, based on partial information from a similar machine
infrastructure	⇧						transport systems	road	Yes	RER	road vehicle plant	9.09E-07	unit	proxy	1	3.77	(4,5,1,3,5,4,9); rough estimation of infrastructure
transport, train	⇧						transport systems	train	No	RER	transport, freight, rail	3.20E+02	tkm	standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, road	⇧						transport systems	road	No	RER	transport, lorry >16t, fleet average	1.60E+02	tkm	standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
			⇧	PWB mounting facility			electronics	module	Yes	GLO	printed wiring board mounting facilities, THT type	1.00E+00	unit		1	0.00	

2.3.3 Soldering materials

A **soldering material** or a **solder** is a fusible metal alloy, with a melting point or melting range of 180-190°C (360-370 °F), which is melted to join metallic surfaces, especially in the fields of electronics and plumbing, in a process called soldering.[2]

The following types of solder can be distinguished:

- **Lead solder:** most often, a mixture of 63% tin and 37% lead is used in this case, due to the fact that this mixture has the lowest melting point, a melting point that is close to the above mentioned 180°C.
- **Hard solder:** these materials are usually used for the brazing process and have thus a higher melting point. From the composition side, this type usually contains copper and/or silver.
- **Lead-free solder:** As an answer on the European legislation – introduced with the RoHS (Directive of the Restriction of Hasardous Substances). A variety of different metals and metal alloys are used in order to fulfil the RoHS, requesting no lead in electronic systems. Some examples of commonly used Pb-free solders are
  - **Tin-Copper solders** (e.g. Sn99.2Cu0.8) – used mainly in wave applications as a low-cost substitute of the lead containing solders
  - **Tin-silver-copper (SAC) solders** – usable in both forms – i.e. as bar and in a paste environment. Examples are Sn95.5Ag3.9Cu0.6 (SAC396) or Sn96.5Ag3.0Cu0.5 (SAC305).
  - **Bismuth-containing solders** (e.g. Sn42.0Bi57.0Ag1.0)

System Characterisation

As RoHS requests from industry to eliminate lead from their products only by July 1, 2006, the datasets cover in ecoinvent data v2.0 Pb-containing solder as well as Pb-free solder.

According to Geibig & Socolof (2005), the most often used Pb-containing solder in the electronics industry is the standard SnPb solder, i.e. Sn63Pb37 – containing 63% of Sn and 37% of Pb. In the field of the Pb-free solder materials, the electronics industry seems – according to the same literature source – to opt for the SAC solders, i.e. the Tin-Silver-Copper system. Within these SAC solders, the solder SAC396 (containing 95.5% of Sn, 3.9% of Ag and 0.6% of Cu) is chosen – being indicated as one of the most often used SAC solders in the electronics industry. For each of the two solders, datasets for the two different PWB are established in this project here (see chapter 2.3.3) – i.e. a solder paste for surface mount technology, and a solder bar for through-hole technology are distinguished. Actually, the production of these two types of solders is linked – as the solder bar is used as starting material for the production of solder paste. A more detailed overview of the various process steps – as explained e.g. in Alvarado Ascencio & Madsen (2005) – can be found in Fig. 2.8.

[2] Wikipedia: Solder and Soldering (http://en.wikipedia.org/wiki/solder and http://en.wikipedia.org/wiki/soldering), accessed June 29, 2007

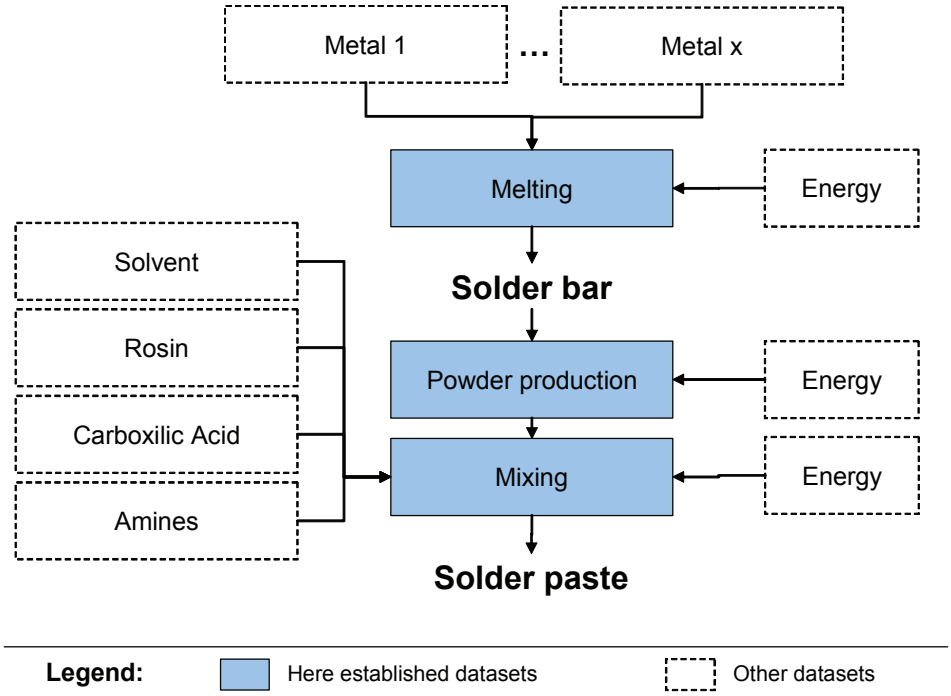


Fig. 2.8 **schematic overview of the various process steps in the production of solder bar and solder paste (according to figure 3 in Alvarado Ascencio & Madsen (2005))**

All in all this ends up with 4 different datasets – two bars and two paste systems (for each Pb-free and Pb-containing solders). All these datasets are based on information representing current solder materials used in the electronics industry. The used data sources are Alvarado Ascencio & Madsen (2005), and Geibig & Socolof (2005), representing LCA studies of solders and soldering processes as well as general information about these solder materials.

They represent solders that have been in use in the last couple of years as well as today. The studies and data sources are based on general information – being valid on a global scale – hence, the here developed data can be considered as globally vaild data.

The respective meta information of the various datasets of solder materials can be found in Tab. 2.12.

Tab. 2.12 ecoinvent meta information for the different soldering materials within the database.

Name	solder, bar, Sn63Pb37, for electronics industry, at plant	solder, paste, Sn63Pb37, for electronics industry, at plant
Location	GLO	GLO
Infrastructure Process	0	0
Unit	kg	kg
Dataset Version	2.0	2.0
Included Processes	This dataset includes raw material input, energy consumption and emissions (air), as well as an estimation of the efforts for transportation and of the infrastructure for the production of solder bar.	This dataset includes raw material input, auxillaries input, energy consumption and emissions (air), as well as an estimation of the efforts for transportation and of the infrastructure for the production of solder paste.
Amount	1	1
Local Name	Lot, Drahtform, Sn63Pb37, für Elektronikindustrie, ab Werk	Lot, Paste, Sn63Pb37, für Elektronikindustrie, ab Werk
Synonyms		
General Comment	Data are based on literature (report from a European research project in the field of lead-free soldering). Infrastructure and transportation efforts are based on own assumptions.	Data are based on literature (report from a European research project in the field of lead-free soldering). Infrastructure and transportation efforts are based on own assumptions.
Start Date	2005	2005
End Date	2005	2005
Data valid for entire period	1	1
Geography Text	Data represent global valid composition data for Pb-containing solder bar, used in the electronics industry.	Data represent global valid composition data for Pb-containing solder paste, used in the electronics industry.
Technology Text	Typical solder material for the electronics industry. Production through melting process out of respective metals. Data based on literature.	Typical solder material for the electronics industry. Production by melting (of solder bar), atomizing & sieving, followed by mixing with the respective flux. Data based on literature.
Representativeness	see General Comments	see General Comments
Production Volume	-	-
Sampling Procedure	own estimation	own estimation
Extrapolations	see Geography & Technology	see Geography & Technology
Uncertainty Adjustments	None	None

Tab. 2.12 (Cont.) ecoinvent meta information for the different soldering materials within the database.

Name	solder, bar, Sn95.5Ag3.9Cu0.6, for electronics industry, at plant	solder, paste, Sn95.5Ag3.9Cu0.6, for electronics industry, at plant
Location	GLO	GLO
Infrastructure Process	0	0
Unit	kg	Kg
Dataset Version	2.0	2.0
Included Processes	This dataset includes raw material input, energy consumption and emissions (air), as well as an estimation of the efforts for transportation and of the infrastructure for the production of solder bar.	This dataset includes raw material input, auxillaries input, energy consumption and emissions (air), as well as an estimation of the efforts for transportation and of the infrastructure for the production of solder paste.
Amount	1	1
Local Name	Lot, Drahtform, Sn95.5Ag3.9Cu0.6, für Elektronikindustrie, ab Werk	Lot, Paste, Sn95.5Ag3.9Cu0.6, für Elektronikindustrie, ab Werk
Synonyms		
General Comment	Data are based on literature (report from a European research project in the field of lead-free soldering). Infrastructure and transportation efforts are based on own assumptions.	Data are based on literature (report from a European research project in the field of lead-free soldering). Infrastructure and transportation efforts are based on own assumptions.
Start Date	2005	2005
End Date	2005	2005
Data valid for entire period	1	1
Geography Text	Data represent global valid composition data for Pb-free solder bar, used in the electronics industry.	Data represent global valid composition data for Pb-free solder paste, used in the electronics industry.
Technology Text	Typical solder material for the electronics industry. Production through melting process out of respective metals. Data based on literature.	Typical solder material for the electronics industry. Production by melting (of solder bar), atomizing & sieving, followed by mixing with the respective flux. Data based on literature.
Representativeness	see General Comments	see General Comments
Production Volume	-	-
Sampling Procedure	own estimation	own estimation
Extrapolations	see Geography & Technology	see Geography & Technology
Uncertainty Adjustments	None	None

Datasets Pb-containing solder

These datasets describe the material input and production efforts for the production of solder bar and solder paste of the type Sn63Pb37. The datasets have the functional unit “1 kg of soldering material”.

System Characterization

The two datasets comprise the input of the raw materials (i.e. tin and lead), the consumption of energy (electricity and heat), the used infrastructure and the transport efforts as well as the produced emissions. Main data source is Alvarado Ascencio & Madsen (2005), supported by punctual information in Geibig & Socolof (2005).

Life Cycle inventory

The various above mentioned, from the datasets covered aspects are taken into account based on the following information:

- **Raw materials**: According to Alvarado Ascencio & Madsen (2005), the process of solder bar production doesn't produce any material losses – hence, the input of the raw materials (tin resp. lead – for each one the dataset "from regional storage") is equal to the proportions that these metals have in the solder material – i.e. 0.63 kg of tin and 0.37 kg of lead. For the solder paste, a composition of 90% solder material (tin, lead) and 10% flux (as carrier material) is used here, based on Geibig & Socolof (2005).

- **Energy**: In Alvarado Ascencio & Madsen (2005) electricity and natural gas consumption of the various process steps (alloy production, powder production and paste production) are reported per kg of produced soldering material. This information is used in ecoinvent.

- **Emissions to air**: In Alvarado Ascencio & Madsen (2005), worst cases are assumed by using the maximum levels stated in legislation. Due to a lack of further information, these data are used as well. For the reported dust amount, a split into the three size categories >10 um, between 2.5 and 10 um and <2.5 um, is established in accordance with the quality guidelines of ecoinvent (see Frischknecht et al. (2007)) – resulting in 35% $PM_{2.5}$, 45% $PM_{2.5\text{-}10}$ and the remaining 20% $PM_{>10}$ (based on the particule size distribution in the aluminium industry).

  Furthermore, it is assumed, that 100% of the electricity consumed is converted to waste heat. In accordance with the general rules for ecoinvent, it is assumed that 100% of the waste heat is released to the air.

- **Emissions to water & Water input**: Due to a lack of respective information, it is assumed here that no water is used within this process here and no emissions to water are produced.

- **Waste**: For the first production step (i.e. the melting of the alloy and the subsequent solder bar production) it is assumed that all waste metals are recovered and given back into the process (i.e. an internal recycling system) – hence, no waste is produced within this process. In the second part (i.e. powder production & melting with flux in order to produce a solder paste), Alvarado Ascencio & Madsen (2005) reports a loss (so-called dross) of 10%. Due to a lack of further information, this value is used here.

- **Transport**: Due to a lack of specific information, standard transport distances and means according to the ecoinvent methodology (see Frischknecht et al. (2007)) are used here.

- **Infrastructure and land-use**: Due to a lack of specific information, the infrastructure dataset "aluminium casting, plant" is used here like in the dataset "brazing solder, cadmium free, at plant" (see Classen et al. (2007)).

Data Uncertainty and Input Data for Database ecoinvent

The uncertainty scores established according to the method used in the ecoinvent project (see Frischknecht et al. (2007)) include reliability, completeness, temporal correlation, geographical correlation, further technological correlation and sample size. The datasets represent one of the most often used Pb-containing solder material in the two main forms (bar, paste). Data are taken from a European LCA study (Alvarado Ascencio & Madsen (2005)) resulting in respective uncertainty values. Transportation and infrastructure are rough estimations having accordingly higher uncertainties.

The resulting unit processes are shown in Tab. 2.13 (on page 57) for the solder bar resp. in Tab. 2.14 (on page 58) for the solder paste form.

Datasets Pb-free solder

These datasets describe the material input and production efforts for the production of solder bar and solder paste of the type SAC396 – i.e. a SnAgCu solder with 95.5% Sn, 3.9% Ag and the remaining 0.6% Cu. The datasets have the functional unit "1 kg of soldering material".

System Characterization

The two datasets comprise the input of the raw materials (i.e. tin and lead), the consumption of energy (electricity and heat), the used infrastructure and the transport efforts as well as the produced emissions. Main data source for these datasets here is Alvarado Ascencio & Madsen (2005), supported by punctual information in Geibig & Socolof (2005).

Life Cycle inventory

The various covered aspects are taken into account based on the following information:

- **Raw materials**: According to Alvarado Ascencio & Madsen (2005), the process of solder bar production doesn't produce any material losses – hence, the input of the raw materials (tin, silver and copper – for each one the dataset "from regional storage") is equal to the proportions that these metals have in the solder material – i.e. 0.955 kg of tin, 0.039 kg of silver and 0.006 kg of copper. For the solder paste, a composition of 89% solder material (SnAgCu) and 11% flux is used here, based on Geibig & Socolof (2005).

- **Energy**: In Alvarado Ascencio & Madsen (2005) electricity and natural gas consumption of the various process steps (alloy production, powder production and paste production) are reported per kg of produced soldering material. This information is used in ecoinvent.

- **Emissions to air**: In Alvarado Ascencio & Madsen (2005), worst cases are assumed by using the maximum levels stated in legislation. Due to a lack of further information, these data are used. For the reported amount of dust, a split into the three size categories >10 um, between 2.5 and 10 um and <2.5 um, established in accordance with the ecoinvent quality guidelines (see Frischknecht et al. (2007)) – resulting in 35% $PM_{2.5}$, 45% $PM_{2.5\text{-}10}$ and the remaining 20% $PM_{>10}$ (based on the particule size distribution in the aluminium industry).

  Furthermore, it is assumed, that 100% of the electricity consumed is converted to waste heat. In accordance with the general ecoinvent rules, it is assumed that 100% of the waste heat is released to the air.

- **Emissions to water & Water input**: Due to a lack of respective information, it is assumed that no water is used within this process and no emissions to water are produced.

- **Waste**: For the first production step (i.e. the melting of the alloy and the subsequent solder bar production) it is assumed that all waste metals are recovered and given back into the process (i.e. an internal recycling system) – hence, no waste is produced within this process. In the second part (i.e. powder production & melting with flux in order to produce a solder paste), Alvarado Ascencio & Madsen (2005) report a loss (so-called dross) of 10%. Due to a lack of further information, this value is used here.

- **Transport**: Due to a lack of specific information, standard transport distances and means according to the ecoinvent methodology (see Frischknecht et al. (2007)) are applied.

- **Infrastructure and land-use**: Due to a lack of specific information, the infrastructure dataset "aluminium casting, plant" is used here like in the dataset "brazing solder, cadmium free, at plant" (see Classen et al. (2007)).

Data Uncertainty and Input Data for Database ecoinvent

The uncertainty scores established according to the method used in the ecoinvent project (see Frischknecht et al. (2007)) include reliability, completeness, temporal correlation, geographical correlation, further technological correlation and sample size. The datasets represent one of the most often used Pb-free solder material in its two main forms (bar, paste). The data are taken from a European LCA study (Alvarado Ascencio & Madsen (2005)) resulting in respective uncertainty values. Transportation and infrastructure are rough estimations having accordingly higher uncertainties.

The resulting unit process raw data are shown in Tab. 2.15 (on page 59) of the solder bar and in Tab. 2.16 (on page 60) of the solder paste form.

Tab. 2.13 Unit process inventory of the dataset "solder, bar, Sn63Pb37, for electronics industry, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Tin	⇨	solder, bar, Sn63Pb37, for electronics industry, at plant					metals	extraction	No	RER	tin, at regional storage	6.30E-01	kg	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
Lead	⇨						metals	extraction	No	RER	lead, at regional storage	3.70E-01	kg	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
electricity for alloy production	⇨						electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	1.61E-01	kWh	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,2); data from literature
natural gas (heat) for alloy production	⇨						natural gas	heating systems	No	RER	heat, natural gas, at industrial furnace >100kW	1.82E+00	MJ	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,1); data from literature
infrastructure	⇨					"aluminium casting, plant" as proxy - corrected by density (Al 2700 kg/m3 - Solder 8800 kg/m3)	metals	extraction	Yes	RER	aluminium casting, plant	4.73E-11	unit	calculation / estimation	1	3.77	(4,5,1,3,5,4,9); rough estimation of infrastructure
transport, rail	⇨						transport systems	road	No	RER	transport, lorry >16t, fleet average	2.00E-01	tkm	standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, road	⇨						transport systems	train	No	RER	transport, freight, rail	1.00E-01	tkm	standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
			⇨	waste heat			air	high population density			Heat, waste	5.80E-01	MJ	calculated from the electricity input	1	1.22	(2,3,1,3,1,5,13); calculated from electricity input
			⇨	dust to air		distribution from aluminium production used (i.e. 35%)	air	high population density			Particulates, < 2.5 um	6.08E-06	kg	dust amount according to Alvarado (2005)	1	3.05	(2,3,1,3,1,5,27); data from literature
			⇨	dust to air		distribution from aluminium production used (i.e. 45%)	air	high population density			Particulates, > 2.5 um, and < 10um	7.81E-06	kg	dust amount according to Alvarado (2005)	1	3.05	(2,3,1,3,1,5,27); data from literature
			⇨	dust to air		distribution from aluminium production used (i.e. 20%)	air	high population density			Particulates, > 10 um	3.47E-06	kg	dust amount according to Alvarado (2005)	1	3.05	(2,3,1,3,1,5,27); data from literature
			⇨	Sn to air			air	high population density			Tin	2.80E-07	kg	maximum emission levels according to Alvarado (2005)	1	1.57	(2,3,1,3,1,5,31); data from literature
			⇨	Pb to air			air	high population density			Lead	1.54E-06	kg	maximum emission levels according to Alvarado (2005)	1	1.57	(2,3,1,3,1,5,31); data from literature
			⇨	solder bar, Pb-containing			metals	extraction	No	GLO	solder, bar, Sn63Pb37, for electronics industry, at plant	1.00E+00	kg		1	0.00	

Tab. 2.14 Unit process inventory of the dataset "solder, paste, Sn63Pb37, for electronics industry, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Tin	⇨	solder, paste, Sn63Pb37, for electronics industry, at plant					metals	extraction	No	GLO	solder, bar, Sn63Pb37, for electronics industry, at plant	1.00E+00	kg	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
electricity for powder production	⇨						electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	1.50E+00	kWh	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,2); data from literature
natural gas (heat) for powder production	⇨						natural gas	heating systems	No	RER	heat, natural gas, at industrial furnace >100kW	5.45E+01	MJ	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,1); data from literature
Electricity for paste production	⇨						electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	1.68E+00	kWh	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,2); data from literature
Solvent	⇨					Isopropanol used as proxy	chemicals	organics	No	RER	isopropanol, at plant	4.60E-02	kg	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
Rosin	⇨					rosin size used as proxy	chemicals	organics	No	RER	rosin size, in paper production, at plant	4.60E-02	kg	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
carboxylic acid	⇨					formic acid (as one type of carboxylic acid) used as proxy	chemicals	organics	No	RER	formic acid, at plant	5.00E-03	kg	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
amines	⇨					ethanolamine (as one type of amine) used as a proxy	chemicals	organics	No	RER	monoethanolamine, at plant	3.00E-03	kg	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
transport	⇨						transport systems	road	No	RER	transport, lorry >16t, fleet average	6.00E-02	tkm	standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport	⇨						transport systems	train	No	RER	transport, freight, rail	1.00E-02	tkm	standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
			⇨	dross		disposal of a tin sheet as a proxy	waste management	sanitary landfill	No	CH	disposal, tin sheet, 0% water, to sanitary landfill	1.00E-01	kg	amount according to Alvarado (2005)	1	2.06	(2,3,1,3,1,5,8); data from literature
			⇨	waste heat			air	high population density			Heat, waste	1.14E+01	MJ	calculated from the electricity input	1	1.22	(2,3,1,3,1,5,13); calculated from electricity input
			⇨	dust to air		distribution from aluminium production used (i.e. 35%)	air	high population density			Particulates, < 2.5 um	5.57E-04	kg	dust amount according to Alvarado (2005)	1	3.05	(2,3,1,3,1,5,27); data from literature
			⇨	dust to air		distribution from aluminium production used (i.e. 45%)	air	high population density			Particulates, > 2.5 um, and < 10um	7.16E-04	kg	dust amount according to Alvarado (2005)	1	3.05	(2,3,1,3,1,5,27); data from literature
			⇨	dust to air		distribution from aluminium production used (i.e. 20%)	air	high population density			Particulates, > 10 um	3.18E-04	kg	dust amount according to Alvarado (2005)	1	3.05	(2,3,1,3,1,5,27); data from literature
			⇨	Sn to air			air	high population density			Tin	2.97E-04	kg	maximum emission levels according to Alvarado (2005)	1	1.57	(2,3,1,3,1,5,31); data from literature
			⇨	Pb to air			air	high population density			Lead	3.68E-04	kg	maximum emission levels according to Alvarado (2005)	1	1.57	(2,3,1,3,1,5,31); data from literature
			⇨	solder paste, Pb-containing			metals	extraction	No	GLO	solder, paste, Sn63Pb37, for electronics industry, at plant	1.00E+00	kg		1	0.00	

Tab. 2.15 Unit process inventory of the dataset "solder, bar, Sn95.5Ag3.9Cu0.6, for electronics industry, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Tin	⇧	solder, bar, Sn95.5Ag3.9Cu0.6, for electronics industry, at plant					metals	extraction	No	RER	tin, at regional storage	9.55E-01	kg	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
Silver	⇧						metals	extraction	No	RER	silver, at regional storage	3.90E-02	kg	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
Copper	⇧						metals	extraction	No	RER	copper, at regional storage	6.00E-03	kg	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
electricity for alloy production	⇧						electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	1.61E-01	kWh	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,2); data from literature
natural gas (heat) for alloy production	⇧						natural gas	heating systems	No	RER	heat, natural gas, at industrial furnace >100kW	2.54E+00	MJ	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,1); data from literature
infrastructure	⇧					"aluminium casting, plant" as proxy - corrected by density (Al 2700 kg/m3 - Solder 8800 kg/m3)	metals	extraction	Yes	RER	aluminium casting, plant	4.73E-11	unit	calculation / estimation	1	3.77	(4,5,1,3,5,4,9); rough estimation of infrastructure
transport, rail	⇧						transport systems	road	No	RER	transport, lorry >16t, fleet average	2.00E-01	tkm	standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, road	⇧						transport systems	train	No	RER	transport, freight, rail	1.00E-01	tkm	standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
			⇧	waste heat			air	high population density			Heat, waste	5.80E-01	MJ	calculated from the electricity input	1	1.22	(2,3,1,3,1,5,13); calculated from electricity input
			⇧	dust to air		distribution from aluminium production used (i.e. 35%)	air	high population density			Particulates, < 2.5 um	6.08E-06	kg	dust amount according to Alvarado (2005)	1	3.05	(2,3,1,3,1,5,27); data from literature
			⇧	dust to air		distribution from aluminium production used (i.e. 45%)	air	high population density			Particulates, > 2.5 um, and < 10um	7.81E-06	kg	dust amount according to Alvarado (2005)	1	3.05	(2,3,1,3,1,5,27); data from literature
			⇧	dust to air		distribution from aluminium production used (i.e. 20%)	air	high population density			Particulates, > 10 um	3.47E-06	kg	dust amount according to Alvarado (2005)	1	3.05	(2,3,1,3,1,5,27); data from literature
			⇧	Sn to air			air	high population density			Tin	2.80E-07	kg	maximum emission levels according to Alvarado (2005)	1	1.57	(2,3,1,3,1,5,31); data from literature
			⇧	solder bar, Pb-free			metals	extraction	No	GLO	solder, bar, Sn95.5Ag3.9Cu0.6, for electronics industry, at plant	1.00E+00	kg		1	0.00	

Tab. 2.16 Unit process inventory of the dataset "solder, paste, Sn95.5Ag3.9Cu0.6, for electronics industry, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Tin	⇨	solder, paste, Sn95.5Ag3.9Cu0.6, for electronics industry, at plant					metals	extraction	No	GLO	solder, bar, Sn95.5Ag3.9Cu0.6, for electronics industry, at plant	9.89E-01	kg	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
electricity for powder production	⇨						electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	1.80E+00	kWh	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,2); data from literature
natural gas (heat) for powder production	⇨						natural gas	heating systems	No	RER	heat, natural gas, at industrial furnace >100kW	5.45E+01	MJ	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,1); data from literature
Electricity for paste production	⇨						electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	1.68E+00	kWh	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,2); data from literature
Solvent	⇨					Isopropanol used as proxy	chemicals	organics	No	RER	isopropanol, at plant	5.10E-02	kg	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
Rosin	⇨					rosin size used as proxy	chemicals	organics	No	RER	rosin size, in paper production, at plant	5.10E-02	kg	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
carboxylic acid	⇨					formic acid (as one type of carboxylic acid) used as proxy	chemicals	organics	No	RER	formic acid, at plant	5.00E-03	kg	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
amines	⇨					ethanolamine (as one type of amine) used as a proxy	chemicals	organics	No	RER	monoethanolamine, at plant	3.00E-03	kg	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
transport	⇨						transport systems	road	No	RER	transport, lorry >16t, fleet average	6.60E-02	tkm	standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport	⇨						transport systems	train	No	RER	transport, freight, rail	1.10E-02	tkm	standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
			⇨	dross		disposal of a tin sheet as a proxy	waste management	sanitary landfill	No	CH	disposal, tin sheet, 0% water, to sanitary landfill	9.90E-02	kg	amount according to Alvarado (2005)	1	2.06	(2,3,1,3,1,5,8); data from literature
			⇨	waste heat			air	high population density			Heat, waste	1.25E+01	MJ	calculated from the electricity input	1	1.22	(2,3,1,3,1,5,13); calculated from electricity input
			⇨	dust to air		distribution from aluminium production used (i.e. 35%)	air	high population density			Particulates, < 2.5 um	5.57E-04	kg	dust amount according to Alvarado (2005)	1	3.05	(2,3,1,3,1,5,27); data from literature
			⇨	dust to air		distribution from aluminium production used (i.e. 45%)	air	high population density			Particulates, > 2.5 um, and < 10um	7.16E-04	kg	dust amount according to Alvarado (2005)	1	3.05	(2,3,1,3,1,5,27); data from literature
			⇨	dust to air		distribution from aluminium production used (i.e. 20%)	air	high population density			Particulates, > 10 um	3.18E-04	kg	dust amount according to Alvarado (2005)	1	3.05	(2,3,1,3,1,5,27); data from literature
			⇨	Sn to air			air	high population density			Tin	2.97E-04	kg	maximum emission levels according to Alvarado (2005)	1	1.57	(2,3,1,3,1,5,31); data from literature
			⇨	Solder paste, Pb-free			metals	extraction	No	GLO	solder, paste, Sn95.5Ag3.9Cu0.6, for electronics industry, at plant	1.00E+00	kg		1	0.00	

2.3.4 Mounting activities

According to Boulanger (2001), the electronics assemblies can be grouped into three major categories – through-hole, surface mount and mixed technology.Datasets for the first two categories (through-hole and surface mount) are established – allowing at the same time also covering the mixed technology (being any mixture of the two other types).

System Characterisation

Similar as for the soldering materials, the data in ecoinvent contain as well the above described two mounting types for Pb-containing solder as well as for Pb-free solder.

According to Geibig & Socolof (2005), "the process of solder application differs for paste and bar solders." This difference is similar to the two technologies distinguished in Boulanger (2001), as paste solder is used for surface mount technology in a so-called reflow process – while bar solder is used in a so-called wave soldering process for through-hole mounting. Fig. 2.9 shows an overview of the different process steps of these two mounting technologies.

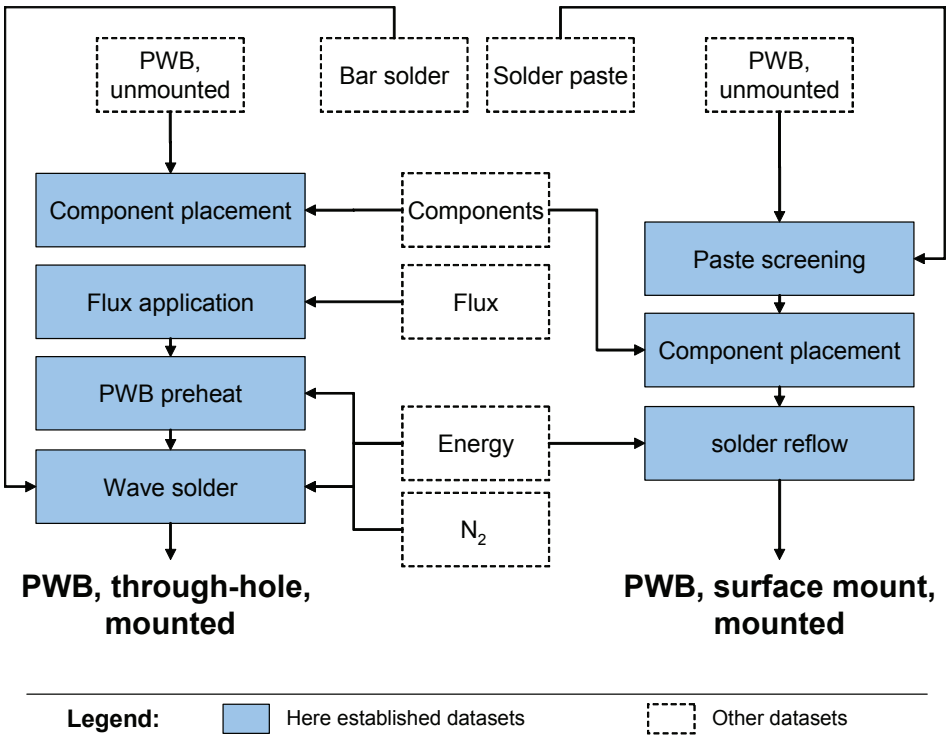


Fig. 2.9 schematic overview of the various process steps in the wave solder technologies (left) and the reflow solder technology (right) for the mounting of printed wiring boards (according to Geibig & Socolof (2005))

In total 4 different datasets – two through-hole mounting and two surface mounting datasets (for each one Pb-free and one Pb-containing) – are established here. All these datasets are based on information representing current mounting activities in the electronics industry. The used data sources are Alvarado Ascencio & Madsen (2005) and Geibig & Socolof (2005), representing LCA studies of solders and soldering processes as well as general information about the mounting of PWBs.

They represent mounting activities from the last couple of years until today. The studies and data sources are based on general information – valid on a global scale – hence, the here developed data can be considered as globally valid data.

The respective meta information for the various datasets of solder materials can be found in Tab. 2.17.

Tab. 2.17 ecoinvent meta information for the different mounting processes within the database.

Name	**mounting, surface mount technology, Pb-containing solder**	**mounting, surface mount technology, Pb-free solder**
Location	GLO	GLO
Infrastructure Process	0	0
Unit	m2	m2
Dataset Version	2.0	2.0
Included Processes	This dataset includes soldering material input, energy consumption and waste, as well as an estimation of emissions to air, the efforts for transportation and of the infrastructure for the mounting process of surface mount components. Input of PWB and components are not included in this dataset.	This dataset includes soldering material input, energy consumption and waste, as well as an estimation of emissions to air, the efforts for transportation and of the infrastructure for the mounting process of surface mount components. Input of PWB and components are not included in this dataset.
Amount	1	1
Local Name	Bestückung, Surface mount Technologie, Pb-haltiges Lot	Bestückung, Surface mount Technologie, bleifreies Lot
Synonyms		
General Comment	Data are based on literature (report from a European research project in the field of lead-free soldering). Infrastructure and transportation efforts are based on own assumptions.	Data are based on literature (report from a European research project in the field of lead-free soldering). Infrastructure and transportation efforts are based on own assumptions.
Start Date	2005	2005
End Date	2005	2005
Data valid for entire period	1	1
Geography Text	Data from a European study- representing global valuable values for the mounting activities in the electronics industry.	Data from a European study- representing global valuable values for the mounting activities in the electronics industry.
Technology Text	Information from two global electronics producing companies in the framework of a European study.	Information from two global electronics producing companies in the framework of a European study.
Representativeness	see General Comments	see General Comments
Production Volume	-	-
Sampling Procedure	own estimation	own estimation
Extrapolations	see Geography & Technology	see Geography & Technology
Uncertainty Adjustments	None	None

Tab. 2.17 (Cont.) ecoinvent meta information for the different mounting processes within the database.

Name	mounting, through-hole technology, Pb-containing solder	mounting, through-hole technology, Pb-free solder
Location	GLO	GLO
Infrastructure Process	0	0
Unit	m2	m2
Dataset Version	2.0	2.0
Included Processes	This dataset includes soldering material input, energy consumption and waste, as well as an estimation of emissions to air, the efforts for transportation and of the infrastructure for the mounting process of through-hole components. Input of PWB and components are not included in this dataset.	This dataset includes soldering material input, energy consumption and waste, as well as an estimation of emissions to air, the efforts for transportation and of the infrastructure for the mounting process of through-hole components. Input of PWB and components are not included in this dataset.
Amount	1	1
Local Name	Bestückung, Through-hole Technologie, Pb-haltiges Lot	Bestückung, Through-hole Technologie, bleifreies Lot
Synonyms		
General Comment	Data are based on literature (report from a European research project in the field of lead-free soldering). Infrastructure and transportation efforts are based on own assumptions.	Data are based on literature (report from a European research project in the field of lead-free soldering). Infrastructure and transportation efforts are based on own assumptions.
Start Date	2005	2005
End Date	2005	2005
Data valid for entire period	1	1
Geography Text	Data from a European study- representing global valuable values for the mounting activities in the electronics industry.	Data from a European study- representing global valuable values for the mounting activities in the electronics industry.
Technology Text	Information from two global electronics producing companies in the framework of a European study.	Information from two global electronics producing companies in the framework of a European study.
Representativeness	see General Comments	see General Comments
Production Volume	-	-
Sampling Procedure	own estimation	own estimation
Extrapolations	see Geography & Technology	see Geography & Technology
Uncertainty Adjustments	None	None

Datasets surface mounting (reflow soldering)

These datasets describe the soldering material input and production efforts for the mounting of surface mount components on a PWB, using the so-called reflow soldering technique. The datasets have the functional unit "1 m^2 of mounted PWB".

System Characterization

The two datasets comprise the input of the soldering material, the consumption of electricity, the used infrastructure and the transport efforts as well as the produced emissions and waste. Main data source is Alvarado Ascencio & Madsen (2005).

Life Cycle inventory

The various covered aspects are taken into account based on the following information:

- **Soldering material**: In Alvarado Ascencio & Madsen (2005), average values from several different PWB mounting trials (on laboratory scale) are reported on a "per m^2 PWB" basis. Due to a lack of further information, these values are used as average values for mounting activities in the electronics production.
- **Energy**: In Alvarado Ascencio & Madsen (2005), average values from several different PWB mounting trials (on laboratory scale) are reported on a "per m^2 PWB" basis. These values are used.
- **Emissions to air**: It is assumed that the non-metal parts of the solder paste will be emitted during the reflow heating as emissions to air. Due to a lack of respective information, 100% of these substances are taken as emission to air. Furthermore, it is assumed, that 100% of the electricity consumed is converted to waste heat. In accordance with the general rules for ecoinvent, it is assumed that 100% of the waste heat is released to the air.
- **Emissions to water & Water input**: According to a plant visit by the author, no water is used in this process – hence, there is neither a water consumption nor are there any emissions to water.
- **Waste**: In Alvarado Ascencio & Madsen (2005), average values of losses (dross) from several different PWB mounting trials (on laboratory scale) are reported on a "per m^2 PWB" basis. Due to a lack of further information, these values are used as average values for mounting activities in the electronics production.
- **Transport**: Due to a lack of information, standard transport distances and means are used.
- **Infrastructure and land-use**: The in chapter 2.3.2 described PWB mounting facility is used here, assuming an output of ca. 60'000 m^2 or 192'000 kg per year during 25 years.

Data Uncertainty and Input Data for Database ecoinvent

The uncertainty scores established according to the method used in the ecoinvent project (see Frischknecht et al. (2007)) include reliability, completeness, temporal correlation, geographical correlation, further technological correlation and sample size. The datasets represent average conditions out of five different laboratory scale trials in two European electronic devices producing companies. The data are taken from a European LCA study (Alvarado Ascencio & Madsen (2005)) resulting in respective uncertainty values. Transportation and infrastructure are rough estimations having accordingly higher uncertainties.

The resulting unit processes are shown in Tab. 2.18 (on page 67) for the mounting activities with Pb-containing solder resp. in Tab. 2.19 (on page 68) for the activities with Pb-free solder.

Datasets through-hole mounting (wave soldering)

The datasets describe the soldering material input and production efforts for the mounting of through-hole components on a PWB, using the so-called wave soldering technique. The datasets have the functional unit "1 m^2 of mounted PWB".

System Characterization

The two datasets comprise the input of the soldering material, the consumption of electricity, the input of further process materials (flux, nitrogen), the used infrastructure and the transport efforts as well as the produced emissions and waste. Main data sources are Alvarado Ascencio & Madsen (2005), Geibig & Socolof (2005), and Theriault & Rahn (2002).

Life Cycle inventory

The various covered aspects are taken into account based on the following information:

- **Soldering material**: In Alvarado Ascencio & Madsen (2005), average values from several different PWB mounting trials (on laboratory scale) are reported on a "per m^2 PWB" basis. Due to a lack of further information, these values are used as average values for mounting activities in the electronics production.

- **Process materials**: Wave soldering has as additional input a flux (for the preparation of the PWB) and gaseous nitrogen (in order to have an oxygen-free atmosphere for the soldering process). In Alvarado Ascencio & Madsen (2005), no such information is given – hence other data sources are used here. For the flux consumption, data from Geibig & Socolof (2005) are used, representing results from test mounting activities in the framework of the US-EPA study. For the nitrogen consumption, Theriault & Rahn (2002) reports consumption values in function of the produced dross. Due to a lack of further information, these values are used here as average values for mounting activities in the electronics production.

- **Energy**: In Alvarado Ascencio & Madsen (2005), average values from several different PWB mounting trials (on laboratory scale) are reported on a "per m^2 PWB" basis. These values are used.

- **Emissions to air**: It is assumed that the consumed flux will be emitted during the heating process as emissions to air. Due to a lack of respective information, 100% of these flux input are taken as emission to air. Furthermore, it is assumed, that 100% of the electricity consumed is converted to waste heat. In accordance with the general rules for ecoinvent, it is assumed that 100% of the waste heat is released to the air.

- **Emissions to water & Water input**: According to a plant visit from the author, no water is used in this process – hence, there is neither a water consumption nor are there any emissions to water.

- **Waste**: In Alvarado Ascencio & Madsen (2005), average values of losses (dross) from several different PWB mounting trials (on laboratory scale) are reported on a "per m^2 PWB" basis. Due to a lack of further information, these values are used here as average values for mounting activities in the electronics production.

- **Transport**: Due to a lack of specific information, standard transport distances and means according to the ecoinvent methodology (see Frischknecht et al. (2007)) are used here.

- **Infrastructure and land-use**: The in chapter 2.3.2 described PWB mounting facility is used here, assuming an output of ca. 9'200 m2 or 37'000 kg per year over a time span of 25 years.

Data Uncertainty and Input Data for Database ecoinvent

The uncertainty scores established according to the method used in the ecoinvent project (see Frischknecht et al. (2007)) include reliability, completeness, temporal correlation, geographical correlation, further technological correlation and sample size. The datasets represent average conditions out of five different laboratory scale trials in two European electronic devices producing companies as well as information from further experiments. The data are taken from a European LCA study (Alvarado Ascencio & Madsen (2005)) as well as from a US-study (Geibig & Socolof (2005)) resulting in respective uncertainty values. Transportation and infrastructure are rough estimations having accordingly higher uncertainties.

The resulting unit processes are shown in Tab. 2.20 (on page 69) for the mounting activities with Pb-containing solder resp. in Tab. 2.21 (on page 70) for the activities with Pb-free solder.

Tab. 2.18 Unit process inventory of the dataset "mounting, surface mount technology, Pb-containing solder (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Solder paste, type SnPb	⇧	mounting, surface mount technology, Pb-containing solder				amount equals to used solder plus 7% dross (= losses) according to Alvarado (2005)	metals	extraction	No	GLO	solder, paste, Sn63Pb37, for electronics industry, at plant	8.06E-02	kg	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
electricity	⇧						electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	3.36E+00	kWh	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,2); data from literature
infrastructure	⇧						electronics	module	Yes	GLO	printed wiring board mounting plant	2.08E-07	unit	own estimation	1	3.77	(4,5,1,3,5,4,9); rough estimation of infrastructure
transport, paste, by lorry	⇧						transport systems	road	No	RER	transport, lorry >16t, fleet average	1.61E-02	tkm	standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, paste, by train	⇧						transport systems	train	No	RER	transport, freight, rail	8.06E-03	tkm	standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
			⇧	dross		disposal of a tin sheet as a proxy	waste management	sanitary landfill	No	CH	disposal, tin sheet, 0% water, to sanitary landfill	5.65E-03	kg	amount according to Alvarado (2005)	1	2.06	(2,3,1,3,1,5,8); data from literature
			⇧	waste heat			air	high population density			Heat, waste	1.21E+01	MJ	calculated from the electricity input	1	1.22	(2,3,1,3,1,5,13); calculated from electricity input
			⇧	isopropanol to air			air	high population density			2-Propanol	3.45E-03	kg	amount calculated from flux used in solder paste (data Alvarado (2005))	1	2.10	(4,3,1,3,1,5,23); calculated from input of flux material
			⇧	rosin to air		formaldehyde used as a proxy (as this is a possible airborne product out of rosin)	air	high population density			Formaldehyde	3.45E-03	kg	amount calculated from flux used in solder paste (data Alvarado (2005))	1	2.10	(4,3,1,3,1,5,23); calculated from input of flux material
			⇧	carboxylic acid to air		similar to input, formic acid used as proxy	air	high population density			Formic acid	3.75E-04	kg	amount calculated from flux used in solder paste (data Alvarado (2005))	1	2.10	(4,3,1,3,1,5,23); calculated from input of flux material
			⇧	amine to air		similar to input, ethanolamine used as proxy	air	high population density			Monoethanolamine	2.25E-04	kg	amount calculated from flux used in solder paste (data Alvarado (2005))	1	2.10	(4,3,1,3,1,5,23); calculated from input of flux material
			⇧	mounting process			electronics	module	No	GLO	mounting, surface mount technology, Pb-containing solder	1.00E+00	m2		1	0.00	

Tab. 2.19 Unit process inventory of the dataset "mounting, surface mount technology, Pb-free solder (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Solder paste, type SnAgCu	⇧	mounting, surface mount technology, Pb-free solder				amount equals to used solder plus 7% dross (=losses) according to Alvarado (2005)	metals	extraction	No	GLO	solder, paste, Sn95.5Ag3.9Cu0.6, for electronics industry, at plant	8.06E-02	kg	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
electricity	⇧						electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	4.32E+00	kWh	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,2); data from literature
infrastructure	⇧						electronics	module	Yes	GLO	printed wiring board mounting plant	2.08E-07	unit	own estimation	1	3.77	(4,5,1,3,5,4,9); rough estimation of infrastructure
transport, paste, by lorry	⇧						transport systems	road	No	RER	transport, lorry >16t, fleet average	1.61E-02	tkm	standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, paste, by train	⇧						transport systems	train	No	RER	transport, freight, rail	8.06E-03	tkm	standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
			⇧	dross		disposal of a tin sheet as a proxy	waste management	sanitary landfill	No	CH	disposal, tin sheet, 0% water, to sanitary landfill	5.65E-03	kg	amount according to Alvarado (2005)	1	2.06	(2,3,1,3,1,5,8); data from literature
			⇧	waste heat			air	high population density			Heat, waste	1.56E+01	MJ	calculated from the electricity input	1	1.22	(2,3,1,3,1,5,13); calculated from electricity input
			⇧	isopropanol to air			air	high population density			2-Propanol	3.83E-03	kg	amount calculated from flux used in solder paste (data Alvarado (2005))	1	2.10	(4,3,1,3,1,5,23); calculated from input of flux material
			⇧	rosin to air		formaldehyde used as a proxy (as this is a possible airborne product out of rosin)	air	high population density			Formaldehyde	3.83E-03	kg	amount calculated from flux used in solder paste (data Alvarado (2005))	1	2.10	(4,3,1,3,1,5,23); calculated from input of flux material
			⇧	carboxylic acid to air		similar to input, formic acid used as proxy	air	high population density			Formic acid	3.75E-04	kg	amount calculated from flux used in solder paste (data Alvarado (2005))	1	2.10	(4,3,1,3,1,5,23); calculated from input of flux material
			⇧	amine to air		similar to input, ethanolamine used as proxy	air	high population density			Monoethanolamine	2.25E-04	kg	amount calculated from flux used in solder paste (data Alvarado (2005))	1	2.10	(4,3,1,3,1,5,23); calculated from input of flux material
			⇧	mounting process			electronics	module	No	GLO	mounting, surface mount technology, Pb-free solder	1.00E+00	m2		1	0.00	

Tab. 2.20 Unit process inventory of the dataset "mounting, through-hole technology, Pb-containing solder (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Solder bar, type SnPb, for wave soldering	⇨	mounting, through-hole technology, Pb-containing solder				amount equals to used solder plus 29% dross (= losses) according to Alvarado (2005)	metals	extraction	No	GLO	solder, bar, Sn63Pb37, for electronics industry, at plant	4.23E-01	kg	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
electricity	⇨						electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	3.94E+00	kWh	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,2); data from literature
solder flux	⇨						chemicals	inorganics	No	GLO	flux, wave soldering, at plant	2.20E-01	kg	amount according to Geibig (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
nitrogen	⇨						chemicals	inorganics	No	RER	nitrogen, liquid, at plant	1.67E+02	kg	amount estimated in Theriault (2002)	1	1.23	(2,3,2,3,1,5,3); data from literature
infrastructure	⇨						electronics	module	Yes	GLO	printed wiring board mounting plant	2.08E-07	unit	own estimation	1	3.77	(4,5,1,3,5,4,9); rough estimation of infrastructure
transport, paste, by lorry	⇨						transport systems	road	No	RER	transport, lorry >16t, fleet average	8.45E-02	tkm	standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, paste, by train	⇨						transport systems	train	No	RER	transport, freight, rail	4.23E-02	tkm	standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
			⇨	dross		disposal of a tin sheet as a proxy	waste management	sanitary landfill	No	CH	disposal, tin sheet, 0% water, to sanitary landfill	1.23E-01	kg	amount according to Alvarado (2005)	1	2.06	(2,3,1,3,1,5,8); data from literature
			⇨	waste heat			air	high population density			Heat, waste	1.42E+01	MJ	calculated from the electricity input	1	1.22	(2,3,1,3,1,5,13); calculated from electricity input
			⇨	flux, to air		as 100% isopropanol	air	high population density			2-Propanol	2.20E-01	kg	amount calculated from flux used (data Geibig (2005))	1	2.10	(4,3,1,3,1,5,23); calculated from input of flux material
			⇨	mounting process			electronics	module	No	GLO	mounting, through-hole technology, Pb-containing solder	1.00E+00	m2		1	0.00	

Tab. 2.21 Unit process inventory of the dataset "mounting, through-hole technology, Pb-free solder (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Solder bar, type SnAgCu, for wave soldering	⇧	mounting, through-hole technology, Pb-free solder				amount equals to used solder plus 29% dross (= losses) according to Alvarado (2005)	metals	extraction	No	GLO	solder, bar, Sn95.5Ag3.9Cu0.6, for electronics industry, at plant	4.23E-01	kg	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
electricity	⇧						electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	6.76E+00	kWh	amount according to Alvarado (2005)	1	1.22	(2,3,1,3,1,5,2); data from literature
solder flux	⇧						chemicals	inorganics	No	GLO	flux, wave soldering, at plant	2.51E-01	kg	amount according to Geibig (2005)	1	1.22	(2,3,1,3,1,5,3); data from literature
nitrogen	⇧						chemicals	inorganics	No	RER	nitrogen, liquid, at plant	7.43E+01	kg	amount estimated in Theriault (2002)	1	1.23	(2,3,2,3,1,5,3); data from literature
infrastructure	⇧						electronics	module	Yes	GLO	printed wiring board mounting plant	2.08E-07	unit	own estimation	1	3.77	(4,5,1,3,5,4,9); rough estimation of infrastructure
transport, paste, by lorry	⇧						transport systems	road	No	RER	transport, lorry >16t, fleet average	8.45E-02	tkm	standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, paste, by train	⇧						transport systems	train	No	RER	transport, freight, rail	4.23E-02	tkm	standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
			⇧	dross		disposal of a tin sheet as a proxy	waste management	sanitary landfill	No	CH	disposal, tin sheet, 0% water, to sanitary landfill	1.23E-01	kg	amount according to Alvarado (2005)	1	2.06	(2,3,1,3,1,5,8); data from literature
			⇧	waste heat			air	high population density			Heat, waste	2.43E+01	MJ	calculated from the electricity input	1	1.22	(2,3,1,3,1,5,13); calculated from electricity input
			⇧	flux, to air		as 100% isopropanol	air	high population density			2-Propanol	2.51E-01	kg	amount calculated from flux used (data Geibig (2005))	1	2.10	(4,3,1,3,1,5,23); calculated from input of flux material
			⇧	mounting process			electronics	module	No	GLO	mounting, through-hole technology, Pb-free solder	1.00E+00	m2		1	0.00	

2.3.5 Mounted Printed Wiring Boards

General Procedure

Based on the information given in the preceding chapters (i.e. chapter 2.2 to 2.3.4), and using the data for the various components (described in part I of this report), it is possible for each user of the ecoinvent database system to establish actually datasets of any kind of mounted printed wiring board. The connection of these various datasets is established according to the following scheme:

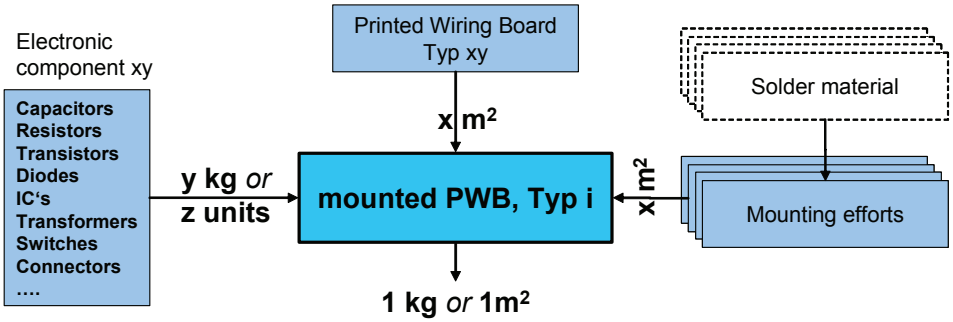


Fig. 2.10 General procedure in order to establish a dataset of a mounted printed wiring board.

The scheme in Fig. 2.10 shows that actually the only dataset directly necessary from this part of the report here is one of the datasets describing the mounting activites (as described in chapter 2.3.4); the choice of the solder material (Pb-free or not ?) will influence the preceding described choice – but in the end, the solder material is an input of the dataset of the mounting efforts. Further important inputs in a dataset of a mounted PWB are the printed wiring board (described in chapter 2.2) – like the mounting efforts, this data input is expressed in m^2 – as well as the various components that are on the PWB. For the latter ones, the datasets are in kg, but the number of them can be used as well (as the different components described in part I of this report here all report their respective weight per unit). In the end, the resulting dataset of a mounted PWB can either be in m2 or in kg (by using the surface weight of PWB, as indicated in chapter 2.2).

In order to provide the in this report described devices (i.e. desktop PC, laptop, printer) with adequate datasets about the contained mounted printed wiring boards, several datasets for mounted printed wiring boards have also been established here and are described in the following.

System Characterisation

Various datasets of mounted PWB are established as described above (and shown in Fig. 2.10) in order to adequately model the devices in this report here – in details the following datasets are established:

- Motherboard of a desktop personal computer
- Motherboard of a laptop computer
- Mounted PWB of a power supply unit (for a desktop PC)
- Unspecified, mounted PWB (for surface mount type and through-hole type)

Each of the above mentioned types of PWB could be established with Pb-containing as well as Pb-free solder material – as the European RoHS directive bans lead only since Mid of 2006. As the data repre-

sent the situation in 2004/2005 – it has to be assumed that models with both types of solder materials are on the market.

In order to deal with this fact, for each of the above mentioned four types of PWB three different datasets have been established – one with Pb-containing solder, one with Pb-free solder and the third one as a mix of the first two. In addition, in case of unspecified PWB another mix dataset is established, representing a mixture of solder material and a mixture of mounting technologies (i.e. a mix of surface-mount and through-hole technologies). In total, 13 different datasets of mounted PWB are established– as shown in Fig. 2.11. The in bright yellow and bold writings indicated datasets are those datasets used within the ecoinvent datasets for the devices in part III of this report.

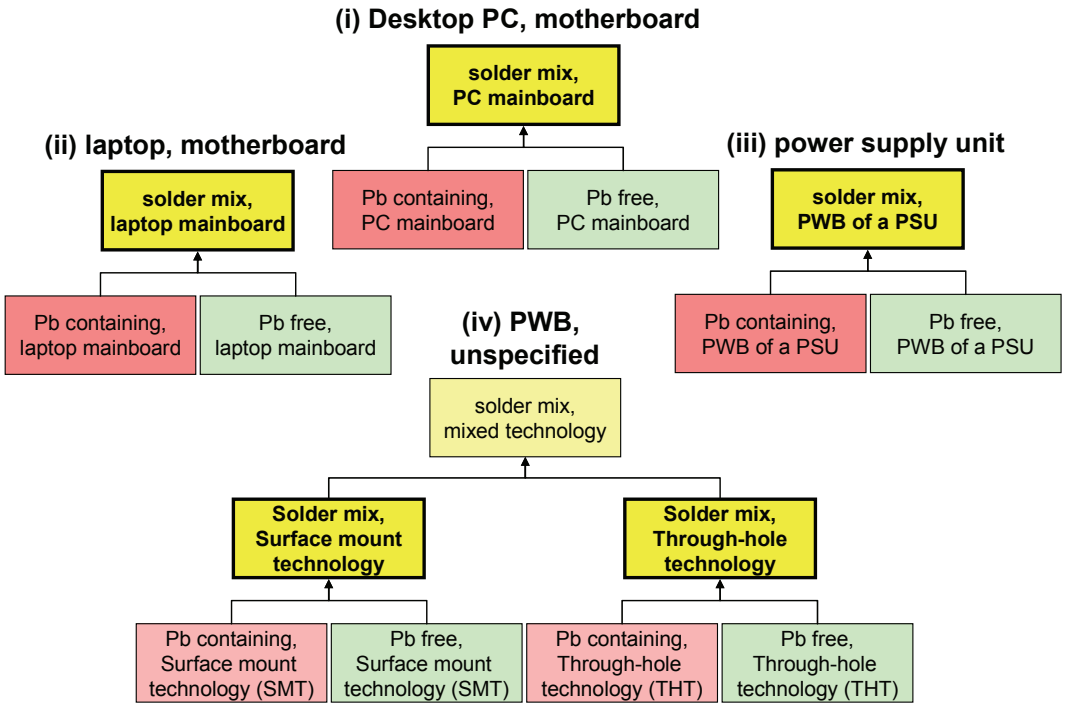


Fig. 2.11 Scheme of the here established dataset of mounted PWB. The datasets used within the devices of this report are highlighted in yellow/bold writings.

However it is very difficult to find actual information about the composition of the here required different types of mounted PWB. Thus, all these datasets are based on information from actual devices as well as on information from literature. These latter data sources are mainly Kemna et al. (2005) and Behrendt et al. (1998), representing example compositions of electronic devices (PC, TV). Some example picture of PWB are shown in Fig. 2.12.

The respective meta information of the different types of mounted PWB can be found in Tab. 2.22.

Fig. 2.12 **Photos of PWB. From top left (No.1) to down right (No.10) it is shown: [1] graphic card (photo: Empa); [2+3] network cards (photos: Empa); [4] Laptop motherboard (photo from wiki.laptop.org); [5] Intel PII motherboard (photo: Empa); [6] Intel P4 motherboard (photo: Empa); [7] Laptop motherboard (photo from www.neothermic.com/laptop); [8] 256KB memory card (photo: Empa); [9] interface card, unspecified (photo: Empa); [10] Power Supply Unit, Intel PII computer (photo: Empa)**

Tab. 2.22 Ecoinvent meta information for the various mounted PWB datasets within the database.

Name	printed wiring board, mounted, Desktop PC mainboard, Pb containing, at plant	printed wiring board, mounted, Desktop PC mainboard, Pb free, at plant	printed wiring board, mounted, Laptop PC mainboard, Pb containing, at plant	printed wiring board, mounted, Laptop PC mainboard, Pb free, at plant	printed wiring board, surface mounted, unspec., Pb containing, at plant	printed wiring board, surface mounted, unspec., Pb free, at plant	printed wiring board, through-hole mounted, unspec., Pb containing, at plant	printed wiring board, through-hole mounted, unspec., Pb free, at plant
Location	GLO	GLO	GLO	GLO	GLO	GLO	GLO	GLO
Infrastructure Process	0	0	0	0	0	0	0	0
Unit	kg	kg	kg	kg	kg	kg	kg	kg
Dataset Version	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Included Processes	This dataset covers component input and production efforts (incl. PWB waste due to failure in mounting) for the production of Desktop PC mainboards, using Pb-containing solder material.	This dataset covers component input and production efforts (incl. PWB waste due to failure in mounting) for the production of Desktop PC mainboards, using Pb-free solder material.	This dataset covers component input and production efforts (incl. PWB waste due to failure in mounting) for the production of Laptop PC mainboards, using Pb-containing solder material.	This dataset covers component input and production efforts (incl. PWB waste due to failure in mounting) for the production of Laptop PC mainboards, using Pb-free solder material.	This dataset covers component input and production efforts (incl. PWB waste due to failure in mounting) for the production of an unspecified, surface mounted, PWB, using Pb-containing solder material.	This dataset covers component input and production efforts (incl. PWB waste due to failure in mounting) for the production of an unspecified, surface mounted, PWB, using Pb-free solder material.	This dataset covers component input and production efforts (incl. PWB waste due to failure in mounting) for the production of an unspecified, through-hole mounted, PWB, using Pb-containing solder material.	This dataset covers component input and production efforts (incl. PWB waste due to failure in mounting) for the production of an unspecified, through-hole mounted, PWB, using Pb-free solder material.
Amount	1	1	1	1	1	1	1	1
Local Name	Leiterplatte, bestückt, Desktop PC Mainboard, Pb haltig, ab Werk	Leiterplatte, bestückt, Desktop PC Mainboard, Pb frei, ab Werk	Leiterplatte, bestückt, Laptop PC Mainboard, Pb haltig, ab Werk	Leiterplatte, bestückt, Laptop PC Mainboard, Pb frei, ab Werk	Leiterplatte, Surface mount bestückt, unspez., Pb haltig, ab Werk	Leiterplatte, Surface mount bestückt, unspez., Pb frei, ab Werk	Leiterplatte, Through-hole bestückt, unspez., Pb haltig, ab Werk	Leiterplatte, Through-hole bestückt, unspez., Pb frei, ab Werk
Synonyms								
General Comment	The data represent a typical Desktop PC mainboard, used in modem computers. Material data are taken from the literature and own dismantling activities. Infrastructure and production efforts are based on own assumptions.	The data represent a typical Desktop PC mainboard, used in modem computers. Material data are taken from the literature and own dismantling activities. Infrastructure and production efforts are based on own assumptions.	The data represent a typical Lsptop PC mainboard, used in modern computers. Material data are taken from the literature plus from own estimations and assumptions. Infrastructure and production efforts are based on own assumptions.	The data represent a typical Lsptop PC mainboard, used in modern computers. Material data are taken from the literature plus from own estimations and assumptions. Infrastructure and production efforts are based on own assumptions.	The data represent an unspecified, surface-mounted, PWB , used in electronic devices. Material data are based on literature and own dismantling activities. Infrastructure and production efforts are based on own assumptions.	The data represent an unspecified, surface-mounted, PWB , used in electronic devices. Material data are based on literature and own dismantling activities. Infrastructure and production efforts are based on own assumptions.	The data represent an unspecified, through-hole mounted, PWB , used in electronic and electric devices. Material data are based on literature and own dismantling activities. Infrastructure and production efforts are based on own assumptions.	The data represent an unspecified, through-hole mounted, PWB , used in electronic and electric devices. Material data are based on literature and own dismantling activities. Infrastructure and production efforts are based on own assumptions.
StartDate	2005	2005	2005	2005	2005	2005	2005	2005
EndDate	2005	2005	2005	2005	2005	2005	2005	2005
DataValidForEntirePeriod	1	1	1	1	1	1	1	1
Geography Text	Data represent a global valuable composition of Desktop PC mainboards.	Data represent a global valuable composition of Desktop PC mainboards.	Data represent a global valuable composition of Laptop PC mainboards.	Data represent a global valuable composition of Laptop PC mainboards.	Data represent a global valuable example for a unspecified, surface mounted, PWB.	Data represent a global valuable example for a unspecified, surface mounted, PWB.	Data represent a global valuable example for a unspecified, through-hole mounted, PWB.	Data represent a global valuable example for a unspecified, through-hole mounted, PWB.
Technology Text	average PWB mounting technology (solder paste production line)	average PWB mounting technology (solder paste production line)	average PWB mounting technology (solder paste production line)	average PWB mounting technology (solder paste production line)	average PWB mounting technology (solder paste production line)	average PWB mounting technology (solder paste production line)	average PWB mounting technology (wave soldering)	average PWB mounting technology (wave soldering)
Representativeness								
Production Volume								
Sampling Procedure	literature & own dismantling	literature & own dismantling	literature & own estimations	literature & own estimations	literature & own estimations	literature & own estimations	literature & own estimations	literature & own estimations
Extrapolations	see Geography & Technology	see Geography & Technology	see Geography & Technology	see Geography & Technology	see Geography & Technology	see Geography & Technology	see Geography & Technology	see Geography & Technology
Uncertainty Adjustments	None	None	None	None	None	None	None	None

Tab. 2.22 (Cont.) Ecoinvent meta information for the various mounted PWB datasets within the database.

Name	printed wiring board, power supply unit desktop PC, Pb containing, at plant	printed wiring board, power supply unit desktop PC, Pb free, at plant	printed wiring board, mounted, Desktop PC mainboard, at plant	printed wiring board, mounted, Laptop PC mainboard, at plant	printed wiring board, mixed mounted, unspec., solder mix, at plant	printed wiring board, through-hole mounted, unspec., solder mix, at plant	printed wiring board, surface mounted, unspec., solder mix, at plant	printed wiring board, power supply unit desktop PC, solder mix, at plant
Location	GLO	GLO	GLO	GLO	GLO	GLO	GLO	GLO
Infrastructure Process	0	0	0	0	0	0	0	0
Unit	kg	kg	kg	kg	kg	kg	kg	kg
Dataset Version	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Included Processes	This dataset covers component input and production efforts (incl. PWB waste due to failure in mounting) for the production of a PWB used in the power supply unit of a desktop PC, using Pb-containing solder material.	This dataset covers component input and production efforts (incl. PWB waste due to failure in mounting) for the production of a PWB used in the power supply unit of a desktop PC, using Pb-free solder material.	This dataset represents a mix of Pb-containing and Pb-free soldered Desktop PC mainboards. It includes processes of components mounting using lead and lead free solder technology.	This dataset represents a mix of Pb-containing and Pb-free soldered laptop PC mainboards. It includes processes of components mounting using lead and lead free solder technology.	This dataset represents a mix of the two mounting technologies (surface mount / through-hole mount); using for each of them a dataset representing a solder mix of Pb-containing and Pb-free solder. It includes processes of components mounting using lead and lead free solder technology.	This dataset represents a mix of Pb-containing and Pb-free soldered unspecified through-hole mounted PWB. It includes processes of components mounting using lead and lead free solder technology.	This dataset represents a mix of Pb-containing and Pb-free soldered unspecified surface mounted PWB. It includes processes of components mounting using lead and lead free solder technology.	This dataset represents a mix of Pb-containing and Pb-free soldered PWBs used in the power supply unit (PSU) of a Desktop PC. In includes only these two distinguished soldering processes as input.
Amount	1	1	1	1	1	1	1	1
Local Name	Leiterplatte, Stromversorgungseinheit PC, Pb haltig, ab Werk	Leiterplatte, Stromversorgungseinheit PC, Pb frei, ab Werk	Leiterplatte, bestückt, Desktop PC Mainboard, ab Werk	Leiterplatte, bestückt, Laptop PC Mainboard, ab Werk	Leiterplatte, gemischt bestückt, unspez., Lot-Mix, ab Werk	Leiterplatte, Through-hole bestückt, unspez., Lot-Mix, ab Werk	Leiterplatte, Surface mount bestückt, unspez., Lot-Mix, ab Werk	Leiterplatte, Stromversorgungseinheit PC, Lot-Mix, ab Werk
Synonyms								
General Comment	The data represent the PWB of a power supply unit, used in modern Desktop PCs. Material data are based on own dismantling activities. Infrastructure and production efforts are based on own assumptions.	The data represent the PWB of a power supply unit, used in modern Desktop PCs. Material data are based on own dismantling activities. Infrastructure and production efforts are based on own assumptions.	Data are based on own assumption - assuming that in 2005 70% of all desktop PC mainboards are produced, using Pb-free solder materials.	Data are based on own assumption - assuming that in 2005 70% of all laptop PC mainboards are produced, using Pb-free solder materials.	Data are based on own assumption - assuming a 50:50 mix between the two technologies (through-hole, surface mount)	Data are based on own assumption - assuming that in 2005 70% of all through-hole mounted PWB are produced, using Pb-free solder materials.	Data are based on own assumption - assuming that in 2005 70% of all surface mounted PWB are produced, using Pb-free solder materials.	Due to a lack of respective information, a 50/50 mixture of the two solder technologies is assumed here.
StartDate	2005	2005	2005	2005	2005	2005	2005	2005
EndDate	2005	2005	2005	2005	2005	2005	2005	2005
DataValidForEntirePeriod	1	1	1	1	1	1	1	1
Geography Text	Data represent a global valuable composition of PWB in a power supply unit.	Data represent a global valuable composition of PWB in a power supply unit.	Own estimation - used for the global average	Own estimation - used for the global average	Own estimation - used for the global average	Own estimation - used for the global average	Own estimation - used for the global average	Own estimation - used for the global average
Technology Text	average PWB mounting technology (wave soldering)	average PWB mounting technology (wave soldering)	Dataset represents the mix of lead and lead-free mounting of motherboards.	Dataset represents the mix of lead and lead-free mounting of motherboards.	Dataset represents the mix of lead and lead-free mounting of unspecified PWBs.	Dataset represents the mix of lead and lead-free mounting of through-hole mounted PWBs.	Dataset represents the mix of lead and lead-free mounting of surface mount PWBs.	average PWB mounting technology (wave soldering)
Representativeness								
Production Volume			-	-	-	-	-	-
Sampling Procedure	own dismanlting	own dismantling	own estimation	own estimation	own estimation	own estimation	own estimation	own estimation
Extrapolations	see Geography & Technology	see Geography & Technology	see Geography & Technology	see Geography & Technology	see Geography & Technology	see Geography & Technology	see Geography & Technology	see Geography & Technology
Uncertainty Adjustments	None	None	None	None	None	None	None	None

Datasets Desktop PC motherboard

These datasets describe the average composition and production efforts for a motherboard used in a desktop PC. The datasets (for further details – see beginning of this chapter here) have all the functional unit "1 kg of motherboard".

System Characterization

The dataset comprises the input of the printed wiring board and its components (i.e. the composition of the PWB) as well as the mounting efforts (see chapter 2.3.4). This latter one contains all further inputs and outputs – i.e. the consumption of soldering material, of energy and of further auxiliaries, the used infrastructure as well as the produced emissions and the amounts of waste. In case of a motherboard, surface as well as through-hole mounted components can be found. Main data sources for the composition of PWB used as a motherboard in a desktop PC is Kemna et al. (2005) plus own estimations, based on own dismantling activities (PWB shown in Fig. 2.12).

Life Cycle inventory

The established datasets include as only direct input the materials – i.e. PWB and all the components mounted on it. Based on the PWB composition reported in Kemna et al. (2005), chapter "personal computer" and additional estimations, the detailed composition of a Desktop PC motherboard is established. All this is summarized in Tab. 7.2.

Tab. 2.23 Material specification of a typical Desktop PC motherboard (data sources: see text)

Data according to Kemna (2005)	[%]		Data Desktop PC		
PWB, not mounted	35	--►	PWB, unmounted	8.79E-02	m2
ports, slots, incl. LED package	24	--►	connectors, PCI bus type	1.80E-01	kg
			connectors, peripherical type	6.00E-02	kg
caps & coils (power components)	28	--►	electrolyt capacitor	1.79E-01	kg
			tantalum capacitor	4.48E-02	kg
			wired transistors	4.48E-02	kg
			coils	1.12E-02	kg
IC's CPU & other IC	10	--►	IC, logic type	8.00E-02	kg
			IC, memory type	2.00E-02	kg
SMD, incl. LED	2.4	--►	resistors, SMD type	1.08E-02	kg
			capacitors, SMD type	1.08E-02	kg
			diodes, SMD type	1.68E-03	kg
			LED	7.20E-04	kg
solder	0.6	--►	mounting activities, SMT	7.47E-02	m2
			mounting activities, THT	1.32E-02	m2

Data Uncertainty and Input Data for Database ecoinvent

The uncertainty scores established according to the method used in the ecoinvent project (see Frischknecht et al. (2004)) include reliability, completeness, temporal correlation, geographical correlation, further technological correlation and sample size. The datasets represent a typical desktop PC motherboard, based on composition information in Kemna et al. (2005) as well as own dismantling activities. Hence, the uncertainty values are estimated accordingly.

The resulting unit process raw data of 1 kg of a desktop PC motherboard are shown in Tab. 2.28 (on page 82) for the Pb-containing solder, in Tab. 2.29 (on page 84) for Pb-free solder and in Tab. 2.30 (on page 86) for a 30:70 solder mix.

Datasets Laptop motherboard

These datasets describe the average composition and production efforts of a motherboard used in a laptop PC. The three datasets (for further details – see beginning of this chapter here) have all the functional unit "1 kg of motherboard".

System Characterization

The dataset comprises the input of the printed wiring board and its components (i.e. the population of the PWB) as well as the mounting efforts (see chapter 2.3.4). This latter one contains all further inputs and outputs – i.e. the consumption of soldering material, of energy and of further auxiliaries, the used infrastructure as well as the produced emissions and waste amounts. In case of a motherboard, surface mounted as well as through-hole mounted components can be found. Taking Kemna et al. (2005), reporting the average composition for a desktop computer, plus own assumptions / estimations (reported e.g. in the photos from Fig. 2.12) results in the used average composition.

Life Cycle inventory

As just mentioned above, the datasets include as only direct input the materials – i.e. PWB and all the components mounted on it. Based on the distribution reported in Kemna et al. (2005), chapter "personal computer" and additional estimations, the detailed composition of a Laptop PC motherboard is derived from the above established composition of a Desktop PC. All this is summarized in Tab. 2.24.

Data Uncertainty and Input Data for Database ecoinvent

The uncertainty scores established according to the method used in the ecoinvent project (see Frischknecht et al. (2004)) include reliability, completeness, temporal correlation, geographical correlation, further technological correlation and sample size. The datasets represent a typical laptop PC motherboard, based on approximations from information about a Desktop PC in Kemna et al. (2005). Hence, the uncertainty values are estimated accordingly.

The resulting unit process raw data of 1 kg of a Laptop PC motherboard are shown in Tab. 2.32 (on page 87) for the Pb-containing solder, in Tab. 2.33 (on page 88) for Pb-free solder and in Tab. 2.31 (on page 86) for a 30:70 solder mix.

Tab. 2.24 Material specification of a typical Laptop PC motherboard (data sources: see text)

Data Desktop PC		Data Laptop PC		
PWB, unmounted	--►	PWB, unmounted	1.56E-01	m2
connectors, PCI bus type	--►	connectors, PCI bus type	3.20E-02	kg
connectors, peripherical type		connectors, peripherical type	4.30E-02	kg
electrolyt capacitor		electrolyt capacitor	-	kg
tantalum capacitor	--►	tantalum capacitor	-	kg
wired transistors		transistors, SMD type	8.00E-03	kg
coils		coils	-	kg
IC, logic type	--►	IC, logic type	1.42E-01	kg
IC, memory type		IC, memory type	1.06E-01	kg
resistors, SMD type		resistors, SMD type	1.90E-02	kg
capacitors, SMD type	--►	capacitors, SMD type	2.70E-02	kg
diodes, SMD type		diodes, SMD type	3.00E-03	kg
LED		LED	1.00E-03	kg
mounting activities, SMT	--►	mounting activities, SMT	1.32E-01	m2
mounting activities, THT		mounting activities, THT	2.34E-02	m2

Dataset of the Printed Wiring Board of a Power Supply Unit

The datasets describe a typical composition as well as the respective production efforts for the PWB of a power supply unit (PSU), as used in a desktop PC. The three distinguished datasets (for further details – see chapter 0) have all the functional unit "1 kg of mounted PWB".

System Characterization

The datasets comprise the input of the printed wiring board and its components (i.e. the population of the PWB) as well as the mounting efforts (see chapter 2.3.4). This latter one contains all further inputs and outputs – i.e. the consumption of soldering material, of energy and of further auxiliaries, the used infrastructure as well as the produced emissions and waste amounts. In case of a PSU, only through-hole mounted components can be found. Starting point for the composition of this PWB here are own dismantling activities of a PSU of a Intel PII Desktop PC (shown on photo No. 10 in Fig. 2.12).

Life Cycle inventory

As just mentioned above, the datasets include as only direct input the materials – i.e. PWB and all the components mounted on it. From the dismantling activities at Empa, the composition reported in Tab. 2.25 (on the next page) is derived for the PWB of a PSU.

Data Uncertainty and Input Data for Database ecoinvent

The uncertainty scores established according to the method used in the ecoinvent project (see Frischknecht et al. (2004)) include reliability, completeness, temporal correlation, geographical correlation, further technological correlation and sample size. The datasets represent a typical PWB of a desktop PC power supply unit, based on own dismantling activities. Hence, the uncertainty values are estimated accordingly.

The resulting unit processes for 1 kg of a PWB of a PSU are shown in Tab. 2.34 (on page 90) for the Pb-containing solder, in Tab. 2.35 (on page 92) for Pb-free solder and in Tab. 2.36 (on page 94) for a 50:50 solder mix.

Tab. 2.25 Material specification for a typical PWB of a power supply unit in a desktop PC (data sources: see text)

PSU (own dismantling)		
PWB, unmounted	4.82E-02	m2
capacitors, film type	2.21E-02	kg
capacitor, electrolyt (big)	7.24E-02	kg
capacitor, electrolyt (small)	4.28E-02	kg
capacitors, others	2.45E-02	kg
resistors	1.19E-02	kg
inductor, ring core	2.51E-01	kg
transformer, big	1.90E-01	kg
transformer, small	6.03E-02	kg
IC, logic type	3.03E-03	kg
transistors, wired, big	3.54E-02	kg
transistors, wired, small	1.76E-03	kg
diodes	6.37E-03	kg
other components		kg
cable		kg
cooling sheets (metal)	1.30E-01	kg
mounting activities, THT	4.82E-02	m2

Datasets Printed Wiring Boards, mounted, unspecified

The datasets describe the average composition and production efforts for unspecified mounted PWB – either with surface mount components (3 datasets), with through-hole components (3 datasets) as well as a unspecified, mixed technology, dataset (for further details – see chapter 0). These datasets have all the functional unit "1 kg of mounted PWB".

System Characterization

Each of these datasets comprises the input of the printed wiring board and its components (i.e. the population of the PWB) as well as the mounting efforts (see chapter 2.3.4). This latter one contains all further inputs and outputs – i.e. the consumption of soldering material, of energy and of further auxiliaries, the used infrastructure as well as the produced emissions and the amounts of waste.

Life Cycle inventory

All datasets include as only direct input the materials – i.e. PWB and all the components mounted on it. For the surface mount technology, the distribution in Kemna et al. (2005), chapter "personal computer", is used as starting point. By using additional estimations, a detailed composition of a non-specified surface mount PWB has been established, based on the above described composition data for Desktop PC and Laptop PC. The resulting composition is summarized in Tab. 2.26.

Tab. 2.26 Material specification of an unspecified surface mounted PWB (data sources: see text)

Data Desktop PC		Data Laptop PC		PWB, SMT, unspecified		
PWB, unmounted	--►	PWB, unmounted	--►	PWB, unmounted	1.86E-01	m2
connectors, PCI bus type	--►	connectors, PCI bus type	--►	connectors, PCI bus type	1.90E-02	kg
connectors, peripherical type		connectors, peripherical type		connectors, peripherical type	-	kg
electrolyt capacitor		electrolyt capacitor		electrolyt capacitor	-	kg
tantalum capacitor	--►	tantalum capacitor	--►	tantalum capacitor	-	kg
wired transistors		transistors, SMD type		transistors, SMD type	1.00E-02	kg
coils		coils		coils	-	kg
IC, logic type	--►	IC, logic type	--►	IC, logic type	1.70E-01	kg
IC, memory type		IC, memory type		IC, memory type	-	kg
resistors, SMD type		resistors, SMD type		resistors, SMD type	2.30E-02	kg
capacitors, SMD type	--►	capacitors, SMD type	--►	capacitors, SMD type	3.20E-02	kg
diodes, SMD type		diodes, SMD type		diodes, SMD type	4.00E-03	kg
LED		LED		LED	1.00E-03	kg
mounting activities, SMT	--►	mounting activities, SMT	--►	mounting activities, SMT	1.86E-01	m2
mounting activities, THT		mounting activities, THT		mounting activities, THT	-	m2

Tab. 2.27 Material specification of an unspecified through-hole mounted PWB (data sources: see text)

TV (Beherendt, 1998)	[g]	PSU (own dismantling)				PWB, THT, unspecified		
PWB, not mounted	330	PWB, unmounted	4.82E-02	m2	--►	PWB, unmounted	5.72E-02	m2
capacitors	207	capacitors, film type	2.21E-02	kg		capacitors, film type	7.49E-02	kg
		capacitor, electrolyt (big)	7.24E-02	kg	--►	capacitor, electrolyt (big)	3.62E-02	kg
		capacitor, electrolyt (small)	4.28E-02	kg		capacitor, electrolyt (small)	2.14E-02	kg
		capacitors, others	2.45E-02	kg		capacitors, others	1.23E-02	kg
resistors	46	resistors	1.19E-02	kg	--►	resistors	2.01E-02	kg
inductors / transformers	645	inductor, ring core	2.51E-01	kg		inductor, ring core choke type	3.24E-01	kg
		transformer, big	1.90E-01	kg	--►	transformer, high voltage	9.48E-02	kg
		transformer, small	6.03E-02	kg		transformer, low voltage	3.01E-02	kg
IC	52	IC, logic type	3.03E-03	kg	--►	IC, logic type	1.76E-02	kg
transistors	26	transistors, wired, big	3.54E-02	kg		transistors, wired, big	2.57E-02	kg
		transistors, wired, small	1.76E-03	kg	--►	transistors, wired, small	8.78E-04	kg
diodes	9	diodes	6.37E-03	kg	--►	diodes	5.96E-03	kg
other components	157	other components		kg				
cable	727	cable		kg	--►	cable	*not included*	
cooling sheets (metal)	306	cooling sheets (metal)	1.30E-01	kg	--►	cooling sheets (metal)	1.60E-01	kg
		mounting activities, THT	4.82E-02	m2		mounting activities, THT	5.72E-02	m2
Total	2505	Total		kg				

For the through-hole technology, an unspecified PWB composition is established, taking the data for the PWB of a television (according to Behrendt et al. (1998)) and the data of the PWB of a power supply unit of a Intel PII desktop PC (according to dismantling activities at Empa – as described in details here). From these two datasets an average dataset is established by not taking into account the amount of cables used (as this is usually taken into account separately from the mounted PWB) and by assuming for the amount of "other components" in Behrendt et al. (1998) an average distribution of the remaining part of the TV PWB. All this is summarized in Tab. 2.27.

Data Uncertainty and Input Data for Database ecoinvent

The uncertainty scores established according to the method used in the ecoinvent project (see Frischknecht et al. (2004)) include reliability, completeness, temporal correlation, geographical correlation, further technological correlation and sample size. The datasets represent one possibility for unspecified PWB compositions (either with surface mount technology, or with through-hole technology), based on own assumptions, starting from information about a Desktop PC in Kemna et al. (2005). Hence, the uncertainty values are estimated accordingly.

The resulting unit process raw data of 1 kg of an unspecified, mounted PWB are shown in:

- Tab. 2.37 (on page 90): surface mounted PWB with Pb-containing solder;
- Tab. 2.38 (on page 96): surface mounted PWB with Pb-free solder;
- Tab. 2.39 (on page 97): through-hole mounted PWB with Pb-containing solder;
- Tab. 2.40 (on page 99): through-hole mounted PWB with Pb-free solder;
- and in Tab. 2.41 to Tab. 2.43 (on page 101ff) of solder mix datasets of the two technologies as well as a technology mix dataset of these two datasets (in each case based on 50:50 solder mix).

Tab. 2.28 Unit process inventory of the dataset "printed wiring board, mounted, Desktop PC mainboard, Pb containing, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
PWB, unmounted	⇨	printed wiring board, mounted, Desktop PC mainboard, Pb containing, at plant					electronics	module	No	GLO	printed wiring board, surface mount, lead-containing surface, at plant	1.10E-01	m2	according to Kemna (2005)	1	1.22	(1,3,1,3,1,5,3); data from literature
mounting efforts, SMD components	⇨					Assuming 85%SMT mounting - 15%THT mounting	electronics	module	No	GLO	mounting, surface mount technology, Pb-containing solder	9.31E-02	m2	Alvarado (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
mount efforts, THD components	⇨					Assuming 85%SMT mounting - 15%THT mounting	electronics	module	No	GLO	mounting, through-hole technology, Pb-containing solder	1.64E-02	m2	Alvarado (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
connectors	⇨						electronics	component	No	GLO	connector, PCI bus, at plant	1.84E-01	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
connectors (II)	⇨						electronics	component	No	GLO	connector, computer, peripherical type, at plant	6.12E-02	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
coils	⇨						electronics	component	No	GLO	inductor, ring core choke type, at plant	1.14E-02	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
IC, logic type	⇨						electronics	component	No	GLO	integrated circuit, IC, logic type, at plant	8.16E-02	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
IC, memory type	⇨						electronics	component	No	GLO	integrated circuit, IC, memory type, at plant	2.04E-02	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
resistors, SMD type	⇨						electronics	component	No	GLO	resistor, SMD type, surface mounting, at plant	1.10E-02	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
capacitors, SMD type	⇨						electronics	component	No	GLO	capacitor, SMD type, surface-mounting, at plant	1.10E-02	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
capacitors, electrlyte type	⇨						electronics	component	No	GLO	capacitor, electrolyte type, < 2cm height, at plant	1.83E-01	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
capacitors, tantalum type	⇨						electronics	component	No	GLO	capacitor, Tantalum-, through-hole mounting, at plant	4.57E-02	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
LED	⇨			continued ▼			electronics	component	No	GLO	light emitting diode, LED, at plant	7.35E-04	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions

Tab. 2.28 (Cont.) Unit process inventory of the dataset "printed wiring board, mounted, Desktop PC mainboard, Pb containing, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Diodes, SMD type	⇧	printed wiring board, mounted, Desktop PC mainboard, Pb containing, at plant		▼ continued			electronics	component	No	GLO	diode, glass-, SMD type, surface mounting, at plant	1.71E-03	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
transistors, wired, small	⇧						electronics	component	No	GLO	transistor, wired, small size, through-hole mounting, at plant	4.57E-02	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
transport, components, by lorry	⇧						transport systems	road	No	RER	transport, lorry >16t, fleet average	1.33E-01	tkm	assumptions & standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, components, by train	⇧						transport systems	train	No	RER	transport, freight, rail	1.43E-01	tkm	assumptions & standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, components, by freight ship	⇧						transport systems	ship	No	OCE	transport, transoceanic freight ship	8.06E-01	tkm	own assumptions (see report)	1	2.09	(4,5,na,na,na,na,5); standard distances
			⇧	failed PWB to PWB treatment (WEEE)			waste management	recycling	No	GLO	disposal, treatment of printed wiring boards	2.04E-02	kg	amount based on a European PWB mounting company	1	3.06	(3,3,1,3,1,5,9); information from a European PWB mounting company
			⇧	mounted PWB			electronics	module	No	GLO	printed wiring board, mounted, Desktop PC mainboard, Pb containing, at plant	1.00E+00	kg		1	0.00	

Tab. 2.29 Unit process inventory of the dataset "printed wiring board, mounted, Desktop PC mainboard, Pb free, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
PWB, unmounted	⇨	printed wiring board, mounted, Desktop PC mainboard, Pb free, at plant					electronics	module	No	GLO	printed wiring board, surface mount, lead-free surface, at plant	1.10E-01	m2	according to Kemna (2005)	1	1.22	(1,3,1,3,1,5,3); data from literature
mounting efforts, SMD components	⇨					Assuming 85%SMT mounting - 15%THT mounting	electronics	module	No	GLO	mounting, surface mount technology, Pb-free solder	9.31E-02	m2	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
mount efforts, THD components	⇨					Assuming 85%SMT mounting - 15%THT mounting	electronics	module	No	GLO	mounting, through-hole technology, Pb-free solder	1.64E-02	m2	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
connectors	⇨						electronics	component	No	GLO	connector, PCI bus, at plant	1.84E-01	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
connectors (II)	⇨						electronics	component	No	GLO	connector, computer, peripherical type, at plant	6.12E-02	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
coils	⇨						electronics	component	No	GLO	inductor, ring core choke type, at plant	1.14E-02	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
IC, logic type	⇨						electronics	component	No	GLO	integrated circuit, IC, logic type, at plant	8.16E-02	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
IC, memory type	⇨						electronics	component	No	GLO	integrated circuit, IC, memory type, at plant	2.04E-02	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
resistors, SMD type	⇨						electronics	component	No	GLO	resistor, SMD type, surface mounting, at plant	1.10E-02	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
capacitors, SMD type	⇨						electronics	component	No	GLO	capacitor, SMD type, surface-mounting, at plant	1.10E-02	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
capacitors, electrlyte type	⇨						electronics	component	No	GLO	capacitor, electrolyte type, < 2cm height, at plant	1.83E-01	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
capacitors, tantalum type	⇨						electronics	component	No	GLO	capacitor, Tantalum-, through-hole mounting, at plant	4.57E-02	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
LED	⇨			continued ▼			electronics	component	No	GLO	light emitting diode, LED, at plant	7.35E-04	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions

Tab. 2.29 (Cont.) Unit process inventory of the dataset "printed wiring board, mounted, Desktop PC mainboard, Pb free, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Diodes, SMD type	⇩	printed wiring board, mounted, Desktop PC mainboard, Pb free, at plant		▼ continued			electronics	component	No	GLO	diode, glass-, SMD type, surface mounting, at plant	1.71E-03	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
transistors, wired, small	⇩						electronics	component	No	GLO	transistor, wired, small size, through-hole mounting, at plant	4.57E-02	kg	Kemna (2005) plus own assumptions	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
transport, components, by lorry	⇩						transport systems	road	No	RER	transport, lorry >16t, fleet average	1.33E-01	tkm	assumptions & standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, components, by train	⇩						transport systems	train	No	RER	transport, freight, rail	1.43E-01	tkm	assumptions & standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, components, by freight ship	⇩						transport systems	ship	No	OCE	transport, transoceanic freight ship	8.06E-01	tkm	own assumptions (see report)	1	2.09	(4,5,na,na,na,na,5); standard distances
			⇩	failed PWB to PWB treatment (WEEE)			waste management	recycling	No	GLO	disposal, treatment of printed wiring boards	2.04E-02	kg	amount based on a European PWB mounting company	1	3.06	(3,3,1,3,1,5,9); information from a European PWB mounting company
			⇩	mounted PWB			electronics	module	No	GLO	printed wiring board, mounted, Desktop PC mainboard, Pb free, at plant	1.00E+00	kg		1	0.00	

Tab. 2.30 Unit process inventory of the dataset "printed wiring board, mounted, Desktop PC mainboard, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
lead free mounted mainboard	⇩	printed wiring board, mounted, Desktop PC	⇩	mounted PC mainboard, solder mix			electronics	module	No	GLO	printed wiring board, mounted, Desktop PC mainboard, Pb free, at plant	7.00E-01	kg	rough estimation	1	1.30	(4,5,1,na,na,na,3); own estimation
lead containing mounted mainboard	⇩						electronics	module	No	GLO	printed wiring board, mounted, Desktop PC mainboard, Pb containing, at plant	3.00E-01	kg	rough estimation	1	1.30	(4,5,1,na,na,na,3); own estimation
							electronics	module	No	GLO	printed wiring board, mounted, Desktop PC mainboard, at plant	1.00E+00	kg		1	0.00	

Tab. 2.31 Unit process inventory of the dataset "printed wiring board, mounted, Laptop PC mainboard, at plant (GLO)"

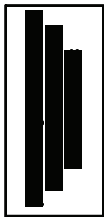
General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
lead free mounted laptop mainboard	⇩	printed wiring board, mounted, Laptop PC mainboard, at plant	⇩	mounted laptop mainboard, solder mix			electronics	module	No	GLO	printed wiring board, mounted, Laptop PC mainboard, Pb free, at plant	7.00E-01	kg	rough estimation	1	1.30	(4,5,1,na,na,na,3); own estimation
lead containing mounted laptop mainboard	⇩						electronics	module	No	GLO	printed wiring board, mounted, Laptop PC mainboard, Pb containing, at plant	3.00E-01	kg	rough estimation	1	1.30	(4,5,1,na,na,na,3); own estimation
							electronics	module	No	GLO	printed wiring board, mounted, Laptop PC mainboard, at plant	1.00E+00	kg		1	0.00	

Tab. 2.32 Unit process inventory of the dataset "printed wiring board, mounted, Laptop PC mainboard, Pb containing, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
PWB, unmounted	⇨	printed wiring board, mounted, Laptop PC mainboard, Pb containing, at plant					electronics	module	No	GLO	printed wiring board, surface mount, lead-containing surface, at plant	1.94E-01	m2	estimation, based on own assumptions and Kemna (2005)	1	1.22	(1,3,1,3,1,5,3); data from literature
mounting efforts, SMD components	⇨					Assuming 85%SMT mounting - 15%THT mounting	electronics	module	No	GLO	mounting, surface mount technology, Pb-containing solder	1.65E-01	m2	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
mount efforts, THD components	⇨					Assuming 85%SMT mounting - 15%THT mounting	electronics	module	No	GLO	mounting, through-hole technology, Pb-containing solder	2.91E-02	m2	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
connectors	⇨						electronics	component	No	GLO	connector, PCI bus, at plant	3.27E-02	kg	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
connectors (II)	⇨						electronics	component	No	GLO	connector, computer, peripherical type, at plant	4.39E-02	kg	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
IC, logic type	⇨						electronics	component	No	GLO	integrated circuit, IC, logic type, at plant	1.45E-01	kg	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
IC, memory type	⇨						electronics	component	No	GLO	integrated circuit, IC, memory type, at plant	1.08E-01	kg	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
resistors, SMD type	⇨						electronics	component	No	GLO	resistor, SMD type, surface mounting, at plant	1.94E-02	kg	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
capacitors, SMD type	⇨						electronics	component	No	GLO	capacitor, SMD type, surface-mounting, at plant	2.76E-02	kg	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
LED	⇨						electronics	component	No	GLO	light emitting diode, LED, at plant	1.02E-03	kg	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
Diodes, SMD type	⇨						electronics	component	No	GLO	diode, glass-, SMD type, surface mounting, at plant	3.06E-03	kg	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
transistors, SMD type	⇨						electronics	component	No	GLO	transistor, SMD type, surface mounting, at plant	8.16E-03	kg	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
transport, components, by lorry	⇨						transport systems	road	No	RER	transport, lorry >16t, fleet average	1.33E-01	tkm	assumptions & standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, components, by train	⇨						transport systems	train	No	RER	transport, freight, rail	1.43E-01	tkm	assumptions & standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances

continued ▼

Tab. 2.32 (Cont.) Unit process inventory of the dataset "printed wiring board, mounted, Laptop PC mainboard, Pb containing, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
transport, components, by freight ship	⇩			▼ continued			transport systems	ship	No	OCE	transport, transoceanic freight ship	8.06E-01	tkm	own assumptions (see report)	1	2.09	(4,5,na,na,na,na,5); standard distances
			⇩	failed PWB to PWB treatment (WEEE)			waste management	recycling	No	GLO	disposal, treatment of printed wiring boards	2.04E-02	kg	amount based on a European PWB mounting company	1	3.06	(3,3,1,3,1,5,9); information from a European PWB mounting company
			⇩	mounted PWB			electronics	module	No	GLO	printed wiring board, mounted, Laptop PC mainboard, Pb containing, at plant	1.00E+00	kg		1	0.00	

Tab. 2.33 Unit process inventory of the dataset "printed wiring board, mounted, Laptop PC mainboard, Pb free, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
PWB, unmounted	⇩	printed wiring board, mounted, Laptop PC mainboard, Pb free, at plant					electronics	module	No	GLO	printed wiring board, surface mount, lead-free surface, at plant	1.94E-01	m2	estimation, based on own assumptions and Kemna (2005)	1	1.22	(1,3,1,3,1,5,3); data from literature
mounting efforts, SMD components	⇩					Assuming 85%SMT mounting - 15%THT mounting	electronics	module	No	GLO	mounting, surface mount technology, Pb-free solder	1.65E-01	m2	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
mount efforts, THD components	⇩					Assuming 85%SMT mounting - 15%THT mounting	electronics	module	No	GLO	mounting, through-hole technology, Pb-free solder	2.91E-02	m2	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
connectors	⇩						electronics	component	No	GLO	connector, PCI bus, at plant	3.27E-02	kg	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
connectors (II)	⇩			▼ continued			electronics	component	No	GLO	connector, computer, peripherical type, at plant	4.39E-02	kg	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions

Tab. 2.33 (Cont.) Unit process inventory of the dataset "printed wiring board, mounted, Laptop PC mainboard, Pb free, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
				▼ continued													
IC, logic type	⇦	printed wiring board, mounted, Laptop PC mainboard, Pb free, at plant					electronics	component	No	GLO	integrated circuit, IC, logic type, at plant	1.45E-01	kg	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
IC, memory type	⇦						electronics	component	No	GLO	integrated circuit, IC, memory type, at plant	1.08E-01	kg	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
resistors, SMD type	⇦						electronics	component	No	GLO	resistor, SMD type, surface mounting, at plant	1.94E-02	kg	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
capacitors, SMD type	⇦						electronics	component	No	GLO	capacitor, SMD type, surface-mounting, at plant	2.76E-02	kg	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
LED	⇦						electronics	component	No	GLO	light emitting diode, LED, at plant	1.02E-03	kg	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
Diodes, SMD type	⇦						electronics	component	No	GLO	diode, glass-, SMD type, surface mounting, at plant	3.06E-03	kg	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
transistors, SMD type	⇦						electronics	component	No	GLO	transistor, SMD type, surface mounting, at plant	8.16E-03	kg	own assumptions, starting from Kemna (2005)	1	1.24	(3,3,1,3,1,5,3); data from literature plus own assumptions
transport, components, by lorry	⇦						transport systems	road	No	RER	transport, lorry >16t, fleet average	1.33E-01	tkm	assumptions & standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, components, by train	⇦						transport systems	train	No	RER	transport, freight, rail	1.43E-01	tkm	assumptions & standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, components, by freight ship	⇦						transport systems	ship	No	OCE	transport, transoceanic freight ship	8.06E-01	tkm	own assumptions (see report)	1	2.09	(4,5,na,na,na,na,5); standard distances
			⇦	failed PWB to PWB treatment (WEEE)			waste management	recycling	No	GLO	disposal, treatment of printed wiring boards	2.04E-02	kg	amount based on a European PWB mounting company	1	3.06	(3,3,1,3,1,5,9); information from a European PWB mounting company
			⇦	mounted PWB			electronics	module	No	GLO	printed wiring board, mounted, Laptop PC mainboard, Pb free, at plant	1.00E+00	kg		1	0.00	

Tab. 2.34 Unit process inventory of the dataset “printed wiring board, power supply unit, Pb containing, at plant (GLO)”

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
PWB, unmounted	⇦	printed wiring board, power supply unit desktop PC, Pb containing, at plant					electronics	module	No	GLO	printed wiring board, through-hole, lead-containing surface, at plant	4.92E-02	m2	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
mounting efforts, through-hole components	⇦						electronics	module	No	GLO	mounting, through-hole technology, Pb-containing solder	4.92E-02	m2	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
capacitor, film type	⇦						electronics	component	No	GLO	capacitor, film, through-hole mounting, at plant	2.26E-02	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
capacitor, electrolyte (big)	⇦						electronics	component	No	GLO	capacitor, electrolyte type, > 2cm height, at plant	7.39E-02	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
capacitor, electrolyte (small)	⇦						electronics	component	No	GLO	capacitor, electrolyte type, < 2cm height, at plant	4.37E-02	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
capacitors, others	⇦						electronics	component	No	GLO	capacitor, unspecified, at plant	2.50E-02	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
resistors	⇦						electronics	component	No	GLO	resistor, metal film type, through-hole mounting, at plant	1.21E-02	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
inductor, ring choke	⇦						electronics	component	No	GLO	inductor, ring core choke type, at plant	2.56E-01	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
transformer, high voltage	⇦						electronics	component	No	GLO	transformer, high voltage use, at plant	1.94E-01	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
transformer, low voltage	⇦						electronics	component	No	GLO	transformer, low voltage use, at plant	6.15E-02	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
IC, logic type	⇦						electronics	component	No	GLO	integrated circuit, IC, logic type, at plant	3.09E-03	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
transistors, wired, big	⇦						electronics	component	No	GLO	transistor, wired, big size, through-hole mounting, at plant	3.61E-02	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
transistors, wired, small	⇦						electronics	component	No	GLO	transistor, wired, small size, through-hole mounting, at plant	1.80E-03	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
diodes	⇦			continued ▼			electronics	component	No	GLO	diode, glass-, through-hole mounting, at plant	6.50E-03	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU

Tab. 2.34 (Cont.) Unit process inventory of the dataset "printed wiring board, power supply unit, Pb containing, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
aluminium (heat sink)	⇩	printed wiring board, power supply unit desktop PC, Pb containing, at plant		▼ continued			metals	extraction	No	RER	aluminium, production mix, wrought alloy, at plant	1.30E-01	kg	own dismanlting activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
aluminium (heat sink), processing	⇩						metals	processing	No	RER	section bar extrusion, aluminium	1.30E-01	kg	own dismanlting activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
transport, components, by lorry	⇩						transport systems	road	No	RER	transport, lorry >16t, fleet average	1.33E-01	tkm	assumptions & standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, components, by train	⇩						transport systems	train	No	RER	transport, freight, rail	1.43E-01	tkm	assumptions & standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, components, by freight ship	⇩						transport systems	ship	No	OCE	transport, transoceanic freight ship	8.06E-01	tkm	own assumptions (see report)	1	2.09	(4,5,na,na,na,na,5); standard distances
			⇩	failed PWB to PWB treatment (WEEE)			waste management	recycling	No	GLO	disposal, treatment of printed wiring boards	2.04E-02	kg	amount based on a European PWB mounting company	1	3.06	(3,3,1,3,1,5,9); information from a European PWB mounting company
			⇩	mounted PWB			electronics	module	No	GLO	printed wiring board, power supply unit desktop PC, Pb containing, at plant	1.00E+00	kg		1	0.00	

Tab. 2.35 Unit process inventory of the dataset "printed wiring board, power supply unit, Pb free, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
PWB, unmounted	⇦	printed wiring board, power supply unit desktop PC, Pb free, at plant					electronics	module	No	GLO	printed wiring board, through-hole, lead-free surface, at plant	4.92E-02	m2	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
mounting efforts, through-hole components	⇦						electronics	module	No	GLO	mounting, through-hole technology, Pb-free solder	4.92E-02	m2	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
capacitor, film type	⇦						electronics	component	No	GLO	capacitor, film, through-hole mounting, at plant	2.26E-02	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
capacitor, electrolyte (big)	⇦						electronics	component	No	GLO	capacitor, electrolyte type, > 2cm height, at plant	7.39E-02	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
capacitor, electrolyte (small)	⇦						electronics	component	No	GLO	capacitor, electrolyte type, < 2cm height, at plant	4.37E-02	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
capacitors, others	⇦						electronics	component	No	GLO	capacitor, unspecified, at plant	2.50E-02	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
resistors	⇦						electronics	component	No	GLO	resistor, metal film type, through-hole mounting, at plant	1.21E-02	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
inductor, ring choke	⇦						electronics	component	No	GLO	inductor, ring core choke type, at plant	2.56E-01	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
transformer, high voltage	⇦						electronics	component	No	GLO	transformer, high voltage use, at plant	1.94E-01	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
transformer, low voltage	⇦						electronics	component	No	GLO	transformer, low voltage use, at plant	6.15E-02	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
IC, logic type	⇦						electronics	component	No	GLO	integrated circuit, IC, logic type, at plant	3.09E-03	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
transistors, wired, big	⇦						electronics	component	No	GLO	transistor, wired, big size, through-hole mounting, at plant	3.61E-02	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
transistors, wired, small	⇦						electronics	component	No	GLO	transistor, wired, small size, through-hole mounting, at plant	1.80E-03	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
diodes	⇦			continued ▼			electronics	component	No	GLO	diode, glass-, through-hole mounting, at plant	6.50E-03	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU

Tab. 2.35 (Cont.) Unit process inventory of the dataset "printed wiring board, power supply unit, Pb free, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
aluminium (heat sink)	↰	printed wiring board, power supply unit desktop PC, Pb free, at plant		▼ continued			metals	extraction	No	RER	aluminium, production mix, wrought alloy, at plant	1.30E-01	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
aluminium (heat sink), processing	↰						metals	processing	No	RER	section bar extrusion, aluminium	1.30E-01	kg	own dismantling activities	1	1.31	(2,5,1,3,1,5,3); own dismantling activities of a Intel PII Desktop PC PSU
transport, components, by lorry	↰						transport systems	road	No	RER	transport, lorry >16t, fleet average	1.33E-01	tkm	assumptions & standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, components, by train	↰						transport systems	train	No	RER	transport, freight, rail	1.43E-01	tkm	assumptions & standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, components, by freight ship	↰						transport systems	ship	No	OCE	transport, transoceanic freight ship	8.06E-01	tkm	own assumptions (see report)	1	2.09	(4,5,na,na,na,na,5); standard distances
			↰	failed PWB to PWB treatment (WEEE)			waste management	recycling	No	GLO	disposal, treatment of printed wiring boards	2.04E-02	kg	amount based on a European PWB mounting company	1	3.06	(3,3,1,3,1,5,9); information from a European PWB mounting company
			↰	mounted PWB			electronics	module	No	GLO	printed wiring board, power supply unit desktop PC, Pb free, at plant	1.00E+00	kg		1	0.00	

Tab. 2.36 Unit process inventory of the dataset "printed wiring board, power supply unit, solder mix, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Pb containing solder	↓	printed wiring board, power supply unit desktop PC, solder					electronics	module	No	GLO	printed wiring board, power supply unit desktop PC, Pb containing, at plant	3.00E-01	kg	rough estimation	1	1.30	(4,5,1,na,na,na,3); own estimation
Pb-free solder	↓						electronics	module	No	GLO	printed wiring board, power supply unit desktop PC, Pb free, at plant	7.00E-01	kg	rough estimation	1	1.30	(4,5,1,na,na,na,3); own estimation
			↓	Pb-containing solder for mounted printed wiring board			electronics	module	No	GLO	printed wiring board, power supply unit desktop PC, solder mix, at plant	1.00E+00	kg		1	0.00	

Tab. 2.37 Unit process inventory of the dataset "printed wiring board, surface mounted, unspec., Pb containing, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
PWB, unmounted	⇦	printed wiring board, surface mounted, unspec., Pb containing, at plant					electronics	module	No	GLO	printed wiring board, surface mount, lead-containing surface, at plant	2.32E-01	m2	assumptions / analogies, starting from Kemna (2005)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
mounting efforts, SMD components	⇦						electronics	module	No	GLO	mounting, surface mount technology, Pb-containing solder	2.32E-01	m2	assumptions / analogies, starting from Kemna (2005)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
connectors	⇦						electronics	component	No	GLO	connector, PCI bus, at plant	1.94E-02	kg	assumptions / analogies, starting from Kemna (2005)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
IC, logic type	⇦						electronics	component	No	GLO	integrated circuit, IC, logic type, at plant	1.73E-01	kg	assumptions / analogies, starting from Kemna (2005)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
resistors, SMD type	⇦						electronics	component	No	GLO	resistor, SMD type, surface mounting, at plant	2.35E-02	kg	assumptions / analogies, starting from Kemna (2005)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
capacitors, SMD type	⇦						electronics	component	No	GLO	capacitor, SMD type, surface-mounting, at plant	3.27E-02	kg	assumptions / analogies, starting from Kemna (2005)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
LED	⇦						electronics	component	No	GLO	light emitting diode, LED, at plant	1.02E-03	kg	assumptions / analogies, starting from Kemna (2005)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
Diodes, SMD type	⇦						electronics	component	No	GLO	diode, glass-, SMD type, surface mounting, at plant	4.08E-03	kg	assumptions / analogies, starting from Kemna (2005)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
transistors, SMD type	⇦						electronics	component	No	GLO	transistor, SMD type, surface mounting, at plant	1.02E-02	kg	assumptions / analogies, starting from Kemna (2005)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
transport, components, by lorry	⇦						transport systems	road	No	RER	transport, lorry >16t, fleet average	1.33E-01	tkm	assumptions & standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, components, by train	⇦						transport systems	train	No	RER	transport, freight, rail	1.43E-01	tkm	assumptions & standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, components, by freight ship	⇦						transport systems	ship	No	OCE	transport, transoceanic freight ship	8.06E-01	tkm	own assumptions (see report)	1	2.09	(4,5,na,na,na,na,5); standard distances
			⇦	failed PWB to PWB treatment (WEEE)			waste management	recycling	No	GLO	disposal, treatment of printed wiring boards	2.04E-02	kg	amount based on a European PWB mounting company	1	3.06	(3,3,1,3,1,5,9); information from a European PWB mounting company
			⇦	mounted PWB			electronics	module	No	GLO	printed wiring board, surface mounted, unspec., Pb containing, at plant	1.00E+00	kg		1	0.00	

Tab. 2.38 Unit process inventory of the dataset "printed wiring board, surface mounted, unspec., Pb free, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
PWB, unmounted	⇦	printed wiring board, surface mounted, unspec., Pb free, at plant					electronics	module	No	GLO	printed wiring board, surface mount, lead-free surface, at plant	2.32E-01	m2	assumptions / analogies, starting from Kemna (2005)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
mounting efforts, SMD components	⇦						electronics	module	No	GLO	mounting, surface mount technology, Pb-free solder	2.32E-01	m2	assumptions / analogies, starting from Kemna (2005)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
connectors	⇦						electronics	component	No	GLO	connector, PCI bus, at plant	1.94E-02	kg	assumptions / analogies, starting from Kemna (2005)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
IC, logic type	⇦						electronics	component	No	GLO	integrated circuit, IC, logic type, at plant	1.73E-01	kg	assumptions / analogies, starting from Kemna (2005)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
resistors, SMD type	⇦						electronics	component	No	GLO	resistor, SMD type, surface mounting, at plant	2.35E-02	kg	assumptions / analogies, starting from Kemna (2005)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
capacitors, SMD type	⇦						electronics	component	No	GLO	capacitor, SMD type, surface-mounting, at plant	3.27E-02	kg	assumptions / analogies, starting from Kemna (2005)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
LED	⇦						electronics	component	No	GLO	light emitting diode, LED, at plant	1.02E-03	kg	assumptions / analogies, starting from Kemna (2005)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
Diodes, SMD type	⇦						electronics	component	No	GLO	diode, glass-, SMD type, surface mounting, at plant	4.08E-03	kg	assumptions / analogies, starting from Kemna (2005)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
transistors, SMD type	⇦						electronics	component	No	GLO	transistor, SMD type, surface mounting, at plant	1.02E-02	kg	assumptions / analogies, starting from Kemna (2005)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
transport, components, by lorry	⇦						transport systems	road	No	RER	transport, lorry >16t, fleet average	1.33E-01	tkm	assumptions & standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, components, by train	⇦						transport systems	train	No	RER	transport, freight, rail	1.43E-01	tkm	assumptions & standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, components, by freight ship	⇦						transport systems	ship	No	OCE	transport, transoceanic freight ship	8.06E-01	tkm	own assumptions (see report)	1	2.09	(4,5,na,na,na,na,5); standard distances
			⇦	failed PWB to PWB treatment (WEEE)			waste management	recycling	No	GLO	disposal, treatment of printed wiring boards	2.04E-02	kg	amount based on a European PWB mounting company	1	3.06	(3,3,1,3,1,5,9); information from a European PWB mounting company
			⇦	mounted PWB			electronics	module	No	GLO	printed wiring board, surface mounted, unspec., Pb free, at plant	1.00E+00	kg		1	0.00	

Tab. 2.39 Unit process inventory of the dataset "printed wiring board, through-hole mounted, unspec., Pb containing, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
PWB, unmounted	⇨	printed wiring board, through-hole mounted, unspec., Pb containing, at plant					electronics	module	No	GLO	printed wiring board, through-hole, lead-containing surface, at plant	5.84E-02	m2	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
mounting efforts, through-hole components	⇨						electronics	module	No	GLO	mounting, through-hole technology, Pb-containing solder	5.84E-02	m2	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
capacitor, film type	⇨						electronics	component	No	GLO	capacitor, film, through-hole mounting, at plant	7.64E-02	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
capacitor, electrolyte (big)	⇨						electronics	component	No	GLO	capacitor, electrolyte type, > 2cm height, at plant	3.69E-02	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
capacitor, electrolyte (small)	⇨						electronics	component	No	GLO	capacitor, electrolyte type, < 2cm height, at plant	2.18E-02	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
capacitors, others	⇨						electronics	component	No	GLO	capacitor, unspecified, at plant	1.26E-02	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
resistors	⇨						electronics	component	No	GLO	resistor, metal film type, through-hole mounting, at plant	2.05E-02	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
inductor, ring choke	⇨						electronics	component	No	GLO	inductor, ring core choke type, at plant	3.31E-01	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
transformer, high voltage	⇨						electronics	component	No	GLO	transformer, high voltage use, at plant	9.67E-02	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
transformer, low voltage	⇨						electronics	component	No	GLO	transformer, low voltage use, at plant	3.07E-02	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
IC, logic type	⇨						electronics	component	No	GLO	integrated circuit, IC, logic type, at plant	1.80E-02	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
transistors, wired, big	⇨						electronics	component	No	GLO	transistor, wired, big size, through-hole mounting, at plant	2.62E-02	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
transistors, wired, small	⇨						electronics	component	No	GLO	transistor, wired, small size, through-hole mounting, at plant	8.96E-04	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
diodes	⇨						electronics	component	No	GLO	diode, glass-, through-hole mounting, at plant	6.08E-03	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling

continued ▼

Tab. 2.39 (Cont.) Unit process inventory of the dataset "printed wiring board, through-hole mounted, unspec., Pb containing, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
aluminium (heat sink)	↰	printed wiring board, through-hole mounted, unspec., Pb containing, at plant		▼ continued			metals	extraction	No	RER	aluminium, production mix, wrought alloy, at plant	1.60E-01	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
aluminium (heat sink), processing	↰						metals	processing	No	RER	section bar extrusion, aluminium	1.60E-01	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
transport, components, by lorry	↰						transport systems	road	No	RER	transport, lorry >16t, fleet average	1.33E-01	tkm	assumptions & standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, components, by train	↰						transport systems	train	No	RER	transport, freight, rail	1.43E-01	tkm	assumptions & standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, components, by freight ship	↰						transport systems	ship	No	OCE	transport, transoceanic freight ship	8.06E-01	tkm	own assumptions (see report)	1	2.09	(4,5,na,na,na,na,5); standard distances
			↰	failed PWB to PWB treatment (WEEE)			waste management	recycling	No	GLO	disposal, treatment of printed wiring boards	2.04E-02	kg	amount based on a European PWB mounting company	1	3.06	(3,3,1,3,1,5,9); information from a European PWB mounting company
			↰	mounted PWB			electronics	module	No	GLO	printed wiring board, through-hole mounted, unspec., Pb containing, at plant	1.00E+00	kg		1	0.00	

Tab. 2.40 Unit process inventory of the dataset "printed wiring board, through-hole mounted, unspec., Pb free, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
PWB, unmounted	⇨	printed wiring board, through-hole mounted, unspec., Pb free, at plant					electronics	module	No	GLO	printed wiring board, through-hole, lead-free surface, at plant	5.84E-02	m2	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
mounting efforts, through-hole components	⇨						electronics	module	No	GLO	mounting, through-hole technology, Pb-free solder	5.84E-02	m2	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
capacitor, film type	⇨						electronics	component	No	GLO	capacitor, film, through-hole mounting, at plant	7.64E-02	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
capacitor, electrolyte (big)	⇨						electronics	component	No	GLO	capacitor, electrolyte type, > 2cm height, at plant	3.69E-02	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
capacitor, electrolyte (small)	⇨						electronics	component	No	GLO	capacitor, electrolyte type, < 2cm height, at plant	2.18E-02	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
capacitors, others	⇨						electronics	component	No	GLO	capacitor, unspecified, at plant	1.26E-02	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
resistors	⇨						electronics	component	No	GLO	resistor, metal film type, through-hole mounting, at plant	2.05E-02	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
inductor, ring choke	⇨						electronics	component	No	GLO	inductor, ring core choke type, at plant	3.31E-01	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
transformer, high voltage	⇨						electronics	component	No	GLO	transformer, high voltage use, at plant	9.67E-02	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
transformer, low voltage	⇨						electronics	component	No	GLO	transformer, low voltage use, at plant	3.07E-02	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
IC, logic type	⇨						electronics	component	No	GLO	integrated circuit, IC, logic type, at plant	1.80E-02	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
transistors, wired, big	⇨						electronics	component	No	GLO	transistor, wired, big size, through-hole mounting, at plant	2.62E-02	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
transistors, wired, small	⇨						electronics	component	No	GLO	transistor, wired, small size, through-hole mounting, at plant	8.96E-04	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
diodes	⇨			continued ▼			electronics	component	No	GLO	diode, glass-, through-hole mounting, at plant	6.08E-03	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling

Tab. 2.40 (Cont.) Unit process inventory of the dataset "printed wiring board, through-hole mounted, unspec., Pb free, at plant (GLO)"

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
aluminium (heat sink)	⇦	printed wiring board, through-hole mounted, unspec., Pb free, at plant		▼ continued			metals	extraction	No	RER	aluminium, production mix, wrought alloy, at plant	1.60E-01	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
aluminium (heat sink), processing	⇦						metals	processing	No	RER	section bar extrusion, aluminium	1.60E-01	kg	average from TV and PSU (Beherendt 1998 & Empa)	1	1.32	(3,5,1,3,1,5,3); own assumptions - from literature & dismantling
transport, components, by lorry	⇦						transport systems	road	No	RER	transport, lorry >16t, fleet average	1.33E-01	tkm	assumptions & standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, components, by train	⇦						transport systems	train	No	RER	transport, freight, rail	1.43E-01	tkm	assumptions & standard distances according to Frischknecht et al. (2004)	1	2.09	(4,5,na,na,na,na,5); standard distances
transport, components, by freight ship	⇦						transport systems	ship	No	OCE	transport, transoceanic freight ship	8.06E-01	tkm	own assumptions (see report)	1	2.09	(4,5,na,na,na,na,5); standard distances
			⇦	failed PWB to PWB treatment (WEEE)			waste management	recycling	No	GLO	disposal, treatment of printed wiring boards	2.04E-02	kg	amount based on a European PWB mounting company	1	3.06	(3,3,1,3,1,5,9); information from a European PWB mounting company
			⇦	mounted PWB			electronics	module	No	GLO	printed wiring board, through-hole mounted, unspec., Pb free, at plant	1.00E+00	kg		1	0.00	

Tab. 2.41 Unit process inventory of the dataset “printed wiring board, surface mounted, unspec., solder mix, at plant (GLO)”

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Pb containing solder	↑	printed wiring board, surface mounted, unspec., solder mix, at					electronics	module	No	GLO	printed wiring board, surface mounted, unspec., Pb containing, at plant	3.00E-01	kg	rough estimation	1	1.30	(4,5,1,na,na,na,3); own estimation
Pb-free solder	↑						electronics	module	No	GLO	printed wiring board, surface mounted, unspec., Pb free, at plant	7.00E-01	kg	rough estimation	1	1.30	(4,5,1,na,na,na,3); own estimation
			↑	Pb-containing solder for mounted printed wiring board			electronics	module	No	GLO	printed wiring board, surface mounted, unspec., solder mix, at plant	1.00E+00	kg		1	0.00	

Tab. 2.42 Unit process inventory of the dataset “printed wiring board, through-hole mounted, unspec., solder mix, at plant (GLO)”

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Pb-containing solder	↑	printed wiring board, through-hole mounted, unspec., solder mix, at					electronics	module	No	GLO	printed wiring board, through-hole mounted, unspec., Pb containing, at plant	3.00E-01	kg	rough estimation	1	1.30	(4,5,1,na,na,na,3); own estimation
Pb-free solder	↑						electronics	module	No	GLO	printed wiring board, through-hole mounted, unspec., Pb free, at plant	7.00E-01	kg	rough estimation	1	1.30	(4,5,1,na,na,na,3); own estimation
			↑	lead-free mounted printed wiring board			electronics	module	No	GLO	printed wiring board, through-hole mounted, unspec., solder mix, at plant	1.00E+00	kg		1	0.00	

Tab. 2.43 Unit process inventory of the dataset “printed wiring board, mixed mounted, unspec., solder mix, at plant (GLO)”

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
through-hole mounted PWB	↓	printed wiring board, mixed mounted, unspec.,	↓	mounted PWB, unspec., solder mix			electronics	module	No	GLO	printed wiring board, through-hole mounted, unspec., solder mix, at plant	5.00E-01	kg	rough estimation	1	1.30	(4,5,1,na,na,na,3); own estimation
surface mounted PWB	↓						electronics	module	No	GLO	printed wiring board, surface mounted, unspec., solder mix, at plant	5.00E-01	kg	rough estimation	1	1.30	(4,5,1,na,na,na,3); own estimation
							electronics	module	No	GLO	printed wiring board, mixed mounted, unspec., solder mix, at plant	1.00E+00	kg		1	0.00	

2.3.6 Flux for wave soldering

System characterisation

In the through-hole mounting technology, cleaning with a special flux is done after placement of the components, before the actual soldering process takes place. In soldering of metals, flux serves a threefold purpose: it removes oxidation from the surfaces to be soldered, it seals out air thus preventing further oxidation, and by facilitating amalgamation improves wetting characteristics of the liquid solder.[3]

Information source is the Material Safety Data Sheet (MSDS) of a producer of wave solder fluxes (Indium Coorperation (2004)). The meta information of this dataset can be found in Tab. 2.44.

Tab. 2.44 ecoinvent meta information of the dataset of wave solder flux within the database.

Name	**flux, wave soldering, at plant**
Location	GLO
Infrastructure Process	1
Unit	kg
Dataset Version	2.0
Included Processes	This dataset includes only the raw materials (i.e. the main ingredients) of an example of a wave solder flux. No information about mixing efforts, waste and emissions produced, used infrastructure and transport are included.
Amount	1
Local Name	Flussmittel, Wellenlöten, ab Werk
Synonyms	
General Comment	This is a rough dataset for a flux used in the wave solder process of the electronics industry. The dataset contains only information about the ingredients.
Start Date	2005
End Date	2005
Data valid for entire period	1
Geography Text	This dataset relates to the global situation.
Technology Text	Dataset represents one example of a mixture used as wave solder flux in the electronics industry
Representativeness	see Technology
Production Volume	-
Sampling Procedure	Literature & own estimations
Extrapolations	see Geography and Technology
Uncertainty Adjustments	None

[3] Wikipedia: Solder and Soldering (http://en.wikipedia.org/wiki/solder and http://en.wikipedia.org/wiki/soldering), accessed June 29, 2007

Life Cycle Inventory

The dataset includes ingredients inputs and no process efforts (i.e. energy consumption, auxiliaries, etc.), no emissions or wastes, no infrastructure and no transport efforts. The dataset represents an example of a currently used wave solder flux.

Data Uncertainty and Input Data for Database ecoinvent

The uncertainty scores established according to the method used in the ecoinvent project (see Frischknecht et al. (2007)) include reliability, completeness, temporal correlation, geographical correlation, further technological correlation and sample size. The dataset is a very rough estimation of a currently used wave solder flux, based on information in a MSDS of a producer (Indium Coorperation (2004)). Hence, the respective uncertainty values are accordingly high.

The resulting unit process raw data of “flux, wave soldering, at plant (GLO)” is shown in Tab. 2.45.

Tab. 2.45 Dataset “flux, wave soldering, at plant (GLO)”

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
isopropanol	⇩	flux, wave soldering, at plant					chemicals	organics	No	RER	isopropanol, at plant	8.00E-01	kg	Composition of a Wave Solder flux (Indium 2004)	1	1.24	(2,4,1,3,1,5,3); Data from MSDS of a wave soldering flux producer
prioprietary ingredients	⇩					dataset "chemicals, organic, unspecified" as proxy used	chemicals	organics	No	GLO	chemicals organic, at plant	1.00E-01	kg	Composition of a Wave Solder flux (Indium 2004)	1	1.24	(2,4,1,3,1,5,3); Data from MSDS of a wave soldering flux producer
polyol	⇩						plastics	monomers	No	RER	polyols, at plant	1.00E-01	kg	Composition of a Wave Solder flux (Indium 2004)	1	1.24	(2,4,1,3,1,5,3); Data from MSDS of a wave soldering flux producer
			⇩	flux for wave soldering			chemicals	inorganics	No	GLO	flux, wave soldering, at plant	1.00E+00	kg		1	0.00	

3 Cables

3.1 Introduction

This Chapter presents the datasets of four different types of cables used to connect computers to an electric power source, to the network environment, or to a peripherial. It includes inventories on a computer power cable, a network cable, a printer cable and a ribbon cable. The plugs for the respective cables are described by their own dataset (1 unit of plugs), whereas the cord part is expressed by the functional unit 1 m. This allows the user to specify a cable with any particular length, as long as the plugs are of similar weight and structure.

Information is given on the basics of electric conductors (Chapter 3.2), the characteristics of cable construction materials (Chapter 3.2), the cable manufacturing process (Chapter 3.2), the system characterisation including the description of functional units, sources, configuration of datasets (Chapter 3.3), as well as the use and application of the cable datasets (Chapter 3.4).

Chapters 3.5 to 3.8 describe the specific datasets, address the relevant meta information, and present the general flow sheets with uncertainty information, sources and values.

3.2 General Product Information & Market

Early telegraph systems is the first forms of electrical cabling but transmitted only small amounts of power. The first power distribution system developed by Thomas Edison used copper rods, wrapped in jute and placed in rigid pipes filled with a bituminous compound. Although vulcanized rubber had been patented by Charles Goodyear in 1844, it is not applied to cable insulation until the 1880s, when it is used for lighting circuits [4].

In the 19th century and early 20th century, cable is often insulated using cloth, rubber and even paper. Plastic materials are generally used today, except for high reliability power cables. There are four types of plastic insulation used in telecommunications cables today: solid, cellular, foam skin and skin-foam-skin [5].

In 2004 some of the leading global producers of cable products included Draka, General Cable, Nexans, Prysmian, Hesfibel Co Sumitomo Electric Industries, Furukawa Electric, Hitachi Cable, Southwire, Marmon Group, LS Cable, LEONI, Fujikura, Tyco, Walsin Lihwa and Wilms Group [5].

3.2.1 Direct Current and Electric conductors

All conductors contain movable electric charges which will move when an electric potential difference (measured in volts) is applied across separate points on a wire (etc.) made from the material. This flow of charge (measured in amperes) is what is meant by *electric current*. In most materials, the amount of current is proportional to the voltage (Ohm's Law) provided the temperature remains constant and the material remains in the same shape and state. The ratio between the voltage and the current is called the resistance (measured in ohms) of the object between the points where the voltage is applied. The resistance across a standard mass (and shape) of a material at a given temperature is called the resistivity of the material. The inverse of resistance and resistivity is conductance and conductivity [6].

Most familiar conductors are metallic. Copper is the most common material for electrical wiring, and gold for high-quality surface-to-surface contacts. However, there are also many non-metallic conductors, including graphite, solutions of salts, and all plasmas [6].

---

[4] Wikipedia: Power cable (http://en.wikipedia.org/wiki/Power_cable), accessed April 2007.

[5] Wikipedia: Cable (http://en.wikipedia.org/wiki/Cable), accessed April 2007.

[6] Wikipedia: Electrical Conductors (http://en.wikipedia.org/wiki/Electrical_Conductors), accessed April 2007.

Non-conducting materials lack mobile charges, and so resist the flow of electric current, generating heat. In fact, all materials offer some resistance and warm up when a current flows. Thus, proper design of an electrical conductor takes into account the temperature that the conductor needs to be able to endure without damage, as well as the quantity of electrical current [6].

For the purpose of electronics and electrical engineering, materials are classified according to their electrical resistance, which describes how readily they allow electric current to pass when a voltage is applied. Apart from conductors, materials are classed as insulators (very poor conductors), semiconductors (basically, materials whose ability to conduct electricity can be controlled), and superconductors which offer no significant electrical resistance, allowing circular currents, once established, to flow indefinitely [3].

3.2.2 Cable construction

Modern power cables come in a variety of sizes, materials, and types, each particularly adapted to its uses. Large single insulated conductors are also called power cables in the trade. ***Conductors*** are usually made of copper or aluminum wires, or may be composite conductors with steel strands at their core. Conductors are usually stranded for flexibility, but small cables may use solid conductors [7]. Alloys of copper are used for applications needing higher strength, or longer flex life, or greater reliability. These alloys are normally Cadmium bronze (also known as Cadmium copper). Less frequently used alloys are Cadmium chromium copper, Phosphor bronze, and Silicone bronze (Virginia Plastics (2007)).

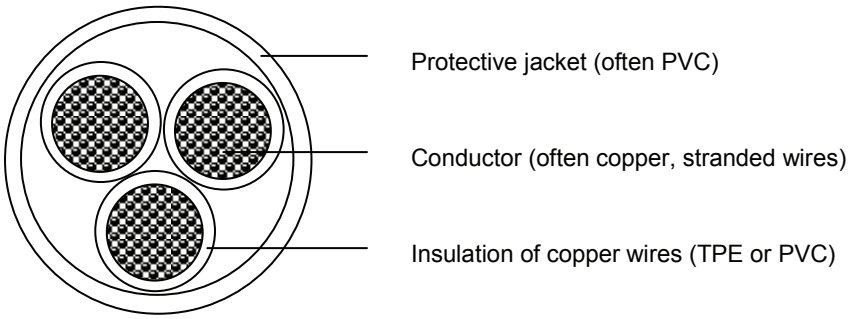


Fig. 3.1 Cross-section and parts materials of a standard electric cable/wire

Conductors in a cable may be of different sizes. Thereby, each conductor has its own electrical insulation (see Fig. 3.1). ***Insulations*** available are (Virginia Plastics (2004b)):

- Polyamides and alloys
- Copolyesters and alloys
- TPEs (thermoplastic elastomers)
- Polyolefins
- Fluoropolymers such as TFE, FEP, ETFE, ECTFE
- Foamed fluoropolymers of TFE or FEP
- PVCs
- Low-smoke polymers and elastomers
- Highly flame retardant versions of the materials mentioned

[7] Wikipedia Contributors (2007) Power cable. Wikipedia, The Free Encyclopedia. Retrieved April 2007 from http://en.wikipedia.org/w/index.php?title=Power_cable&oldid=102431006

The cable may include uninsulated conductors used for the circuit neutral or for ground (earth) connection.

The overall assembly may be round or flat. Electrical cables may be made more flexible by ***stranding the wires***. In this process, smaller individual wires are twisted or braided together to produce larger wires that are more flexible than solid wires of similar size. Bunching small wires before concentric stranding adds the most flexibility. A thin coat of a specific material (usually tin, but it could be silver, gold and other materials and of course the wire can be unplated - with no coating material) on the individual wires provides lubrication for longest life. Tight lays during stranding makes the cable extensible (CBA - as in telephone handset cords) [8]. Special purpose power cables for overhead or vertical use may have additional elements such as steel or Kevlar structural supports.

The ***contacts*** in electrical connectors are also commonly gold plated or gold flashed (over nickel). Contrary to popular belief, this is not done because gold is a better conductor. Instead, it is done because gold is very resistant to the surface corrosion that is commonly suffered by copper, silver, or tin/lead alloys. This corrosion would have a very detrimental effect on connection quality over time; gold plating avoids that [9].

Cables can be strengthened with the addition of reinforcing fibres such as aramid. Generally speaking, cables can have the following *shielding* features (Virginia Plastics (2004b)):

- Shielding (sheath) is offered for individual conductors, twisted pairs, over inner bundles or on the overall cable
- Shields can be spiral wrapped strands, single or double sided foil, braided, or any combination thereof
- Foil shields maintain positive contact with drain wire to provide efficient grounding means
- Foil shields typically provide 100% coverage with a nominal 10% overlap
- Spiral wrapped strand shields and braided shields typically provide 90% coverage nominal

Some power cables for outdoor overhead use may have no overall *sheath (or jacket)*. Other cables may have a plastic or metal sheath enclosing all the conductors. The materials for the sheath will be selected according to the intended application, and may be specially resistant to water, oil, sunlight, underground conditions, chemical vapours, impact, or high temperatures. Cables intended for underground use or direct burial in earth will have heavy plastic sheaths, may be protected by a lead sheath, or may require special direct-buried construction. Where cables must run where exposed to impact damage, they are protected with flexible steel tape or wire armor, which may also be covered by a water resistant jacket [10]. Tab. 3.1 shows more specific information on available materials for jackets in cables.

[8] Wikipedia: Cable (http://en.wikipedia.org/wiki/cable), accessed April 2007.

[9] Wikipedia: Electrical Conductors (http://en.wikipedia.org/wiki/cable), accessed April 2007.

[10] Wikipedia: Power cable (http://en.wikipedia.org/wiki/power_cable), accessed April 2007.

Tab. 3.1 Materials for inner and outer jackets (source: Virginia Plastics (2004b))

Available Materials for Inner and Outer Jackets of Cables:

- Low smoke, zero-halogen elastomers and polymers
- Vinyl-rubber copolymers
- Fluoropolymers
- PVC
- Polyamides and alloys
- Copolyesters and alloys
- TPEs (thermoplastic elastomers)
- TPUs or PURs (thermoplastic urethanes)

Each of the various insulation and jacket materials shows key properties that are crucial for the application and purpose of the cable. For detailed properties Fig. 3.2 can be consulted.

Cable manufacturing

Cable manufacturing is a process that typically is as follows (Virginia Plastics (2004b)):

- *Insulation* of copper conductors or optical fibres with selected polymer(s)
- If specified, *shielding* of insulated copper conductors (based on cable design)
- If specified, *twisting* of insulated conductors into pairs or triplets or quads (based on cable design)
- If specified, *shielding* of insulated pairs, triplets, or quads (based on cable design)
- *Cabling* of insulated conductors and/or pairs, triplets, quads into groups (based on cable design)
- If specified, *shielding* of group(s) of conductors/pairs/triplets (based on cable design)
- *Cabling* of together unshielded and shielded groups of conductors into the cable bundle
- If specified, overall *shielding* of cable bundle (based on cable design)
- If specified, application of separation barriers around cable bundle and/or overall shield
- *Jacketing* over cable bundle or shielded cable bundle with selected polymer
- Perform outgoing QA *testing* (tests based on cable design)

An interesting aspect of cable production is of course the total electric power consumption for cable manufacturing. Some information on this can be obtained from the Environmental Product Declaration published by Nichigoh (2006)). The EPD publication refers to the electric power consumption of most of the process steps carried out for the production of the "ECO-FLEC 14000T(600)" cable with a nominal cross-section of 2.5 mm, an insulation weight of 79.2 kg/km, and a sheath weight of 104.2 kg/km. The total power consumption is calculated for the processes 4 (Insulation extrusion), 5 (Winding), 6 (Twisting) and 8 (Sheath coating) of the cable production (compare Fig. 3.15). Process 3 (Conductor twisting) and 7 (Shielding) are not applicable for this type of cable.

The total sum of internal process electric power consumption is 93.54 kWh per km of ECO-FLEC cable, with the subtotals of 29.51 kWh/km for insulation extrusion, 12.48 kWh/km for winding, 1.56 kWh/km for twisting, and 49.99 kWh/km for sheath coating. According to Nichigoh (2006), the insulation extrusion and especially the sheath coating are the dominat processes consuming electric energy. This information has been used in the inventory of the 7 cable datasets (Chapters 3.5 to 3.8).

		MATERIAL											
		Polyethylenes (PEs)	Polypropylenes (PPs)	Polyvinylchlorides (PVCs)	Polyesters Co-Polyesters	O-Elastomers (TPEs)	S-Elastomers (TPEs)	Vinyl Rubber (C75)	ETFE or ECTFE Fluoropolymers	TFEs	FEPs	Polyurethanes* (TPUs or PURs)	Polymides
PROPERTY	Relative weight (density)	Very Light	Very Light	Medium	Light to Medium	Light to Medium	Light to Medium	Medium	Heavy	Very Heavy	Very Heavy	Light to Medium	Light
	Dielectric strength	Very High	High	Moderate	High	High	High	Moderate	Moderate	High	High	Poor	Moderate
	Long term typical max operating temperature, °C	80	90	105	125	125	125	105	150	200	200	90	105
	Flame Retardancy, unmodified material	Poor	Poor	Excellent	Moderate	Poor	Poor	Not Available	Excellent	Excellent	Excellent	Poor	Poor
	Flame Retardancy, modified material	Moderate	Very Good	Excellent	Very Good	Excellent	Moderate	Excellent	Excellent	Excellent	Excellent	Very Good	Good
	Smoke Density (Very Low is safest)	Moderate	Moderate	Very High	Moderate to High	Very Low to Moderate	Moderate to High	Moderate to High	Low	Low	Low	Moderate to High	Low to Moderate
	Smoke Toxicity (Very Low is safest)	Low to Moderate	Low to Moderate	Very High	Low to Moderate	Very Low to Moderate	Moderate to High	Moderate	Moderate	Moderate	Moderate	Moderate to High	Low
	Weatherability	Good	Good	Poor	Good	Excellent	Moderate	Excellent	Excellent	Excellent	Excellent	Excellent	Moderate
	Abrasion Resistance	Moderate	Moderate	Poor to Good	Excellent	Moderate to Good	Moderate to Good	Excellent	Excellent	Poor	Good	Excellent	Excellent
	Water Resistance	Excellent	Excellent	Good	Good	Excellent	Excellent	Moderate to Good	Excellent	Excellent	Excellent	Moderate	Poor to Moderate
	Acid Resistance	Excellent	Excellent	Good	Good to Very Good	Excellent	Excellent	Moderate	Excellent	Excellent	Excellent	Moderate	Poor to Moderate
	Alkali Resistance	Very Good	Excellent	Good	Moderate to Good	Good	Good	Moderate	Very Good	Excellent	Excellent	Moderate	Excellent
	Aliphatic Hydrocarbon Resistance	Moderate to Good	Good	Good	Good to Excellent	Good	Poor	Good to Very Good	Excellent	Excellent	Excellent	Good	Excellent
	Aromatic Hydrocarbon Resistance	Poor to Good	Moderate to Good	Poor	Moderate to Excellent	Moderate to Good	Poor	Poor	Excellent	Excellent	Excellent	Poor	Excellent
	Oils (reference)	Moderate to Good	Moderate to Good	Moderate	Good to Excellent	Moderate to Very Good	Poor	Good to Excellent	Excellent	Excellent	Excellent	Good to Very Good	Good
	Fuels (reference)	Moderate to Good	Good to Excellent	Good to Excellent	Very Good	Moderate to Good	Poor	Moderate to Good	Excellent	Excellent	Excellent	Moderate to Good	Good to Excellent

*Polyurethanes are suitable for jackets only

© 2004 - Virginia Plastics Company, Inc

Fig. 3.2 Conductor insulation and jacket materials key properties (source: Virginia Plastics (2004a))

The Environmental Report by the Draka Norsk Kabel AS in Norway (Draka (2004)) mentiones an electric power consumption of 27100 MWh for the production of 175000 km of cables. This converts to 0.15 kWh/m of cable, which is about 150% of the value (0.094kWh/m) found in Nichigoh (2006). The difference in these numbers can be explained by the fact that Draka Norsk Kabel is producing a wide range of cable types including oil, gas, marine cables, optical fibre cables as well as power, installation and control cables [11]. The production of oil and marine cables naturally implies a higher consumption of electricity due to the higher input of metal sheats compared to cables in the ICT sector.

For this reason, the electricity values for all the cable datasets have been taken from the publication by Nichigoh (2006) representing more of a computer type cable.

3.2.3 Computer power cable

A computer power cable (or power cord or mains cable) is a cable that temporarily connects an electrical appliance to an electrical power source. The term is generally used for cables using a power plug to connect to a single-phase alternating current power source at "mains voltage" (100 to 240 volts, depending on the location). The term ‘cord set’ is also used to distinguish those cords that include connectors molded to the cord at each end [12].

Power cords from those countries that use 110 V mains supply (mainly the United States, Canada, parts of South America and Japan) tend to be bulkier than the mains cables used in the rest of the world, because of the higher currents required to deliver the same power (watts) at 110 V compared to 230 V. A few examples of cables and plugs shown in Fig. 3.3 give a picture of the diversity of international power cords [12].

Power cables may be either fixed or detachable from the appliance. In the case of detachable leads (plugs), the appliance end of the power cord has a socket (female connector) rather than a plug (male connector) to link it to the appliance, to avoid the dangers from having a live protruding pin. Cords may also have twist-locking features, or other attachments to prevent accidental disconnection at one or both ends [12].

Fig. 3.3 Different power cord systems in the world. From top left to bottom right: Indian, Australian, Japanese, European, South African and Swiss system (source: DataPro; www.datapro.net/images/9216.jpg etc.)

[11] Draka Norsk Kabel AS. Products. Retrieved May 2007 from http://www.draka.no/drakanorway/html/index1.htm

[12] Wikipedia: Power cord (http://en.wikipedia.org/wiki/Power_cord), accessed April 2007.

The dismantled computer power cable in Fig. 3.4 used to establish the ecoinvent dataset (Chapter 3.5) represents the Swiss system. This computer power cord is designed to provide 220-240 volt power to a PC or Macintosh type computer or peripheral. It is used in most parts of Switzerland (the French power cord may also be used in Switzerland in some places). The CPU (computer) side has a 3-prong "PC" power type bevelled connector; the wall end has a Swiss type 220-volt outlet connector (see Fig. 3.3; Swiss system at bottom right).

A three-conductor cord with a suitable power plug for the locality in which the appliance is used on one end and a C13 line socket on the other is commonly called an "IEC cord." IEC stands for International Electrotechnical Commission, which is a standards organisation dealing with electrical, electronic and related technologies. IEC cords are used to power many pieces of electronic equipment other than computers, for example instrument amplifiers and professional or private audio equipment [13].

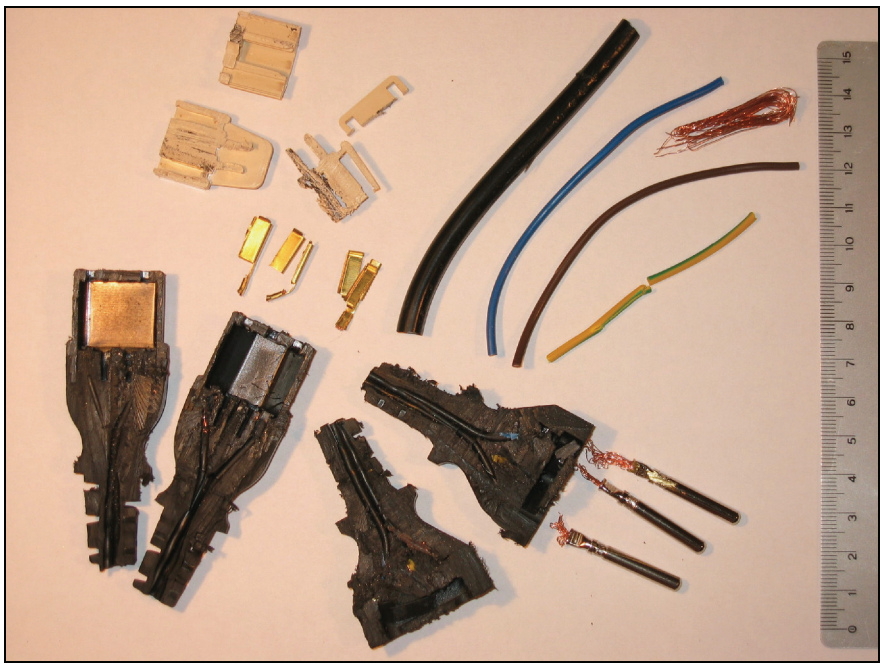


Fig. 3.4 Components of the Computer Power Cable under study (Source: EMPA St. Gallen)

3.2.4 Network cable

Category 5 cable, commonly known as Cat 5 (Fig. 3.5), is an unshielded twisted pair cable type designed for high signal integrity. Category 5 has been superseded by the Category 5e specification. This type of cable is often used in structured cabling for computer networks such as Ethernet, although it is also used to carry many other signals such as basic voice services, token ring, and ATM (Asynchrone Transfere Mode, at up to 155 Mbit/s, over short distances) [14].

[13] Wikipedia: IEC Connector (http://en.wikipedia.org/wiki/IEC_connector), accessed April 2007.

[14] Wikipedia: Category 5 Cable (http://en.wikipedia.org/wiki/Category_5_Cable), accessed April 2007.

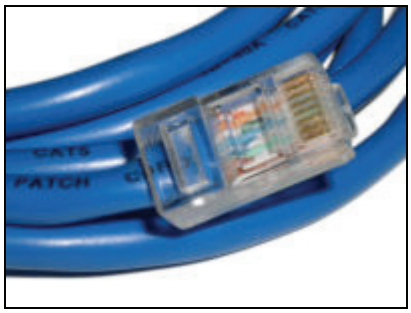


Fig. 3.5 Cat5 patch network or patch cable with plug (source: Wikipedia[15])

Category 5 cable includes four twisted pairs in a single cable jacket. This use of balanced lines helps preserve a high signal-to-noise ratio despite interference from both external sources and other pairs (this latter form of interference is called crosstalk) [15].

Patch cables come in two varieties, straight through or reversed. One application of patch cables is for patching between modular patch panels in system centers. This is the straight through variety. Another application is to connect workstation equipment to the wall jack, and these could be eitherstraight through or reversed depending upon the manufacturer. Reversed cables are normally used for voice systems.

Cable types, connector types and cabling topologies are defined by TIA/EIA-568-B. TIA/EIA-568-B represents a set of three standards that address commercial building cabling for telecommunications products and services. The TIA/EIA-568-B standards is first published in 2001. Perhaps the best known feature of TIA/EIA-568-B.1-2001 is the pin/pair assignments for eight-conductor 100-ohm balanced twisted pair cabling. These assignments are named T568A and T568B and they define the pinout, or order of connections, for wires in 8P8C eight-pin modular connector plugs and jacks [15, 16]. Fig. 3.6 shows the assignment of wire pairs in a category 5 patch cable (with RJ45 plugs).

[15] Wikipedia: Category 5 Cable (http://en.wikipedia.org/wiki/Category_5_cable), accessed April 2007.

[16] Wikipedia: TIA/EIA-568-B (http://en.wikipedia.org/wiki/TIA/EIA-568-B), accessed April 2007.

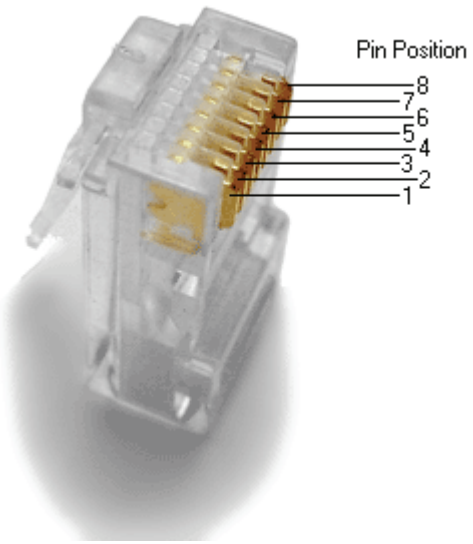
Pin	T568A Pair	T568B Pair	Wire	T568A Colour	T568B Colour	Pins on plug face (jack is reversed)
1	3	2	tip	white/green stripe	white/orange stripe	
2	3	2	ring	green solid	orange solid	
3	2	3	tip	white/orange stripe	white/green stripe	
4	1	1	ring	blue solid	blue solid	
5	1	1	tip	white/blue stripe	white/blue stripe	
6	2	3	ring	orange solid	green solid	
7	4	4	tip	white/brown stripe	white/brown stripe	
8	4	4	ring	brown solid	brown solid	

Fig. 3.6 **The assignments of wire pairs to plug and jack pins (RJ45 wiring) (source: Wikipedia; http://en.wikipedia.org/wiki/TIA/EIA-568-B)**

The network cable represented in the ecoinvent dataset is displayed in Fig. 3.7 (all dismantled) and Fig. 3.8, and consists of the following parts (in the order from inside to outside of the cable):

- conductor(s) in twisted pairs
- insulation
- double shield: PE-sheet and tinned copper braid
- jacket
- two RJ45 plugs: with strain relief, contacts 50 µm gold plated

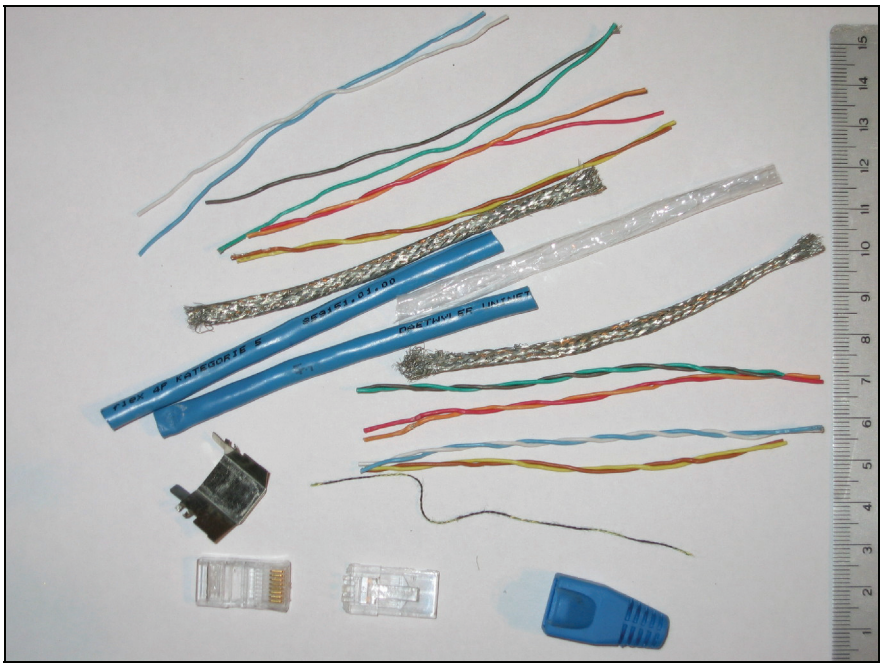


Fig. 3.7 Components of the Network Cable under study (source: EMPA St. Gallen)

Fig. 3.8 The inventoried network cable Uninet flex 4P by Daetwyler (2006).

3.2.5 Printer cable

A printer cable refers to the cable that carries data between a computer and a printer. There are many different types of printer cables, for example:

- Serial
- Parallel
- Fire wire
- USB

Parallel ports are not built in most new computers anymore, but are still part of the majority of computers currently in use. For new laptops and PCs with parallel port printers and scanners, USB adapters are available, commonly through docking stations [17] and [18] Fig. 3.9 and Fig. 3.10 display the kind of printer cable represented in the ecoinvent dataset in Chapter 3.7.

[17] Wikipedia: Printer cable (http://en.wikipedia.org/wiki/Printer_cable), accessed April 2007.

[18] Wikipedia: Parallel port (http://en.wikipedia.org/wiki/Parallel_port), accessed April 2007.

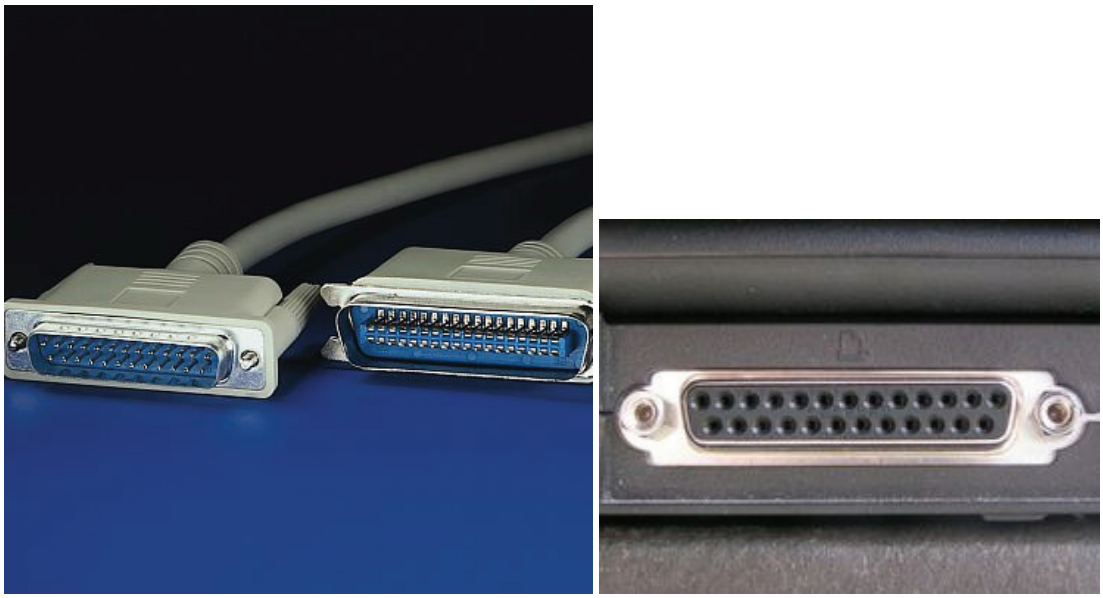


Fig. 3.9 **Roline Printer cable and the matching DB-25 parallel printer port on the back of a laptop (source: http://www.reset.bg/catalog/images/roline_11_01_1060.jpg and Wikipedia: http://en.wikipedia.org/w/index.php?title=Parallel_port&oldid=107501649)**

The key features of this specific printer cable are (partsdata (2007)):

- parallel printer cable for PC
- bidirectional
- Cen 36 male to DB 25 female
- length 5m
- 25 cores
- connection 1:1
- long thumb screws (DB 25)
- shielded cable (foil)
- molded plugs with strain relief
- for standard printers (ink jet, laser, impact printers)
- not to use with IEEE 1284 printers (high speed EPP mode)

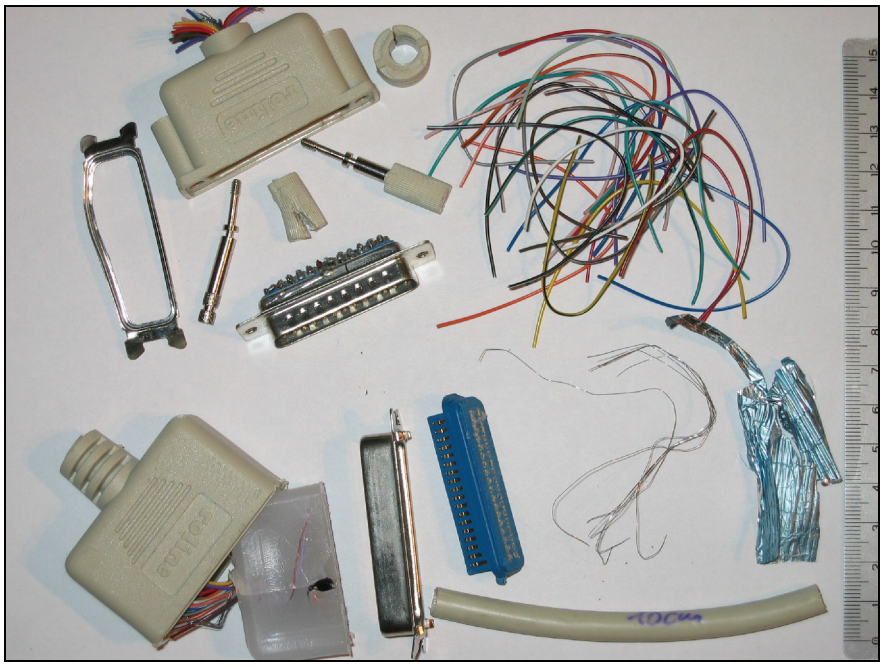


Fig. 3.10 The Printer Cable represented in the ecoinvent dataset (source: EMPA St. Gallen)

The contacts of the male plugs can be in form of phosphor-bronze, nickel seating or hard gold-plated (Leunig (2007)). Fig. 3.11 shows the plugs of a parallel printer cable for a PC.

Fig. 3.11 Parallel printer cable for PC with Centronics 36 male and DSub 25 female plugs (source: partsdata (2007))

3.2.6 Ribbon cable

A ribbon cable is a cable with many conducting wires running parallel to each other on the same flat plane. As a result the cable is wide and flat rather than round. Its name comes from the resemblance of the cable to a piece of ribbon (which is likewise wide and flat). Generally the cable is marked with a red stripe along one edge, although rainbow coloured cables are also made, which are helpful if only one end of the cable is terminated with an IDC connector (Fig. 3.12). In order to avoid damage to hardware due to ribbon cables plugged in the wrong way, the red stripe designates the first wire of the cable, indicating the correct position to plug the cable into its corresponding socket. The order of colours in a rainbow coloured cable is the same as the electronic colour code. (Brown is pin 1 or pin 11 or pin 21 etc. Red is pin 2 or pin 12 or pin 22 etc.) [19].

Ribbon cables are commonly seen for internal peripherals in computers, such as hard drives, CD drives and floppy drives. On some older computer systems they is commonly used for external connections as well.

[19] Wikipedia: Ribbon cable (http://en.wikipedia.org/wiki/Ribbon_cable), accessed April 2007.

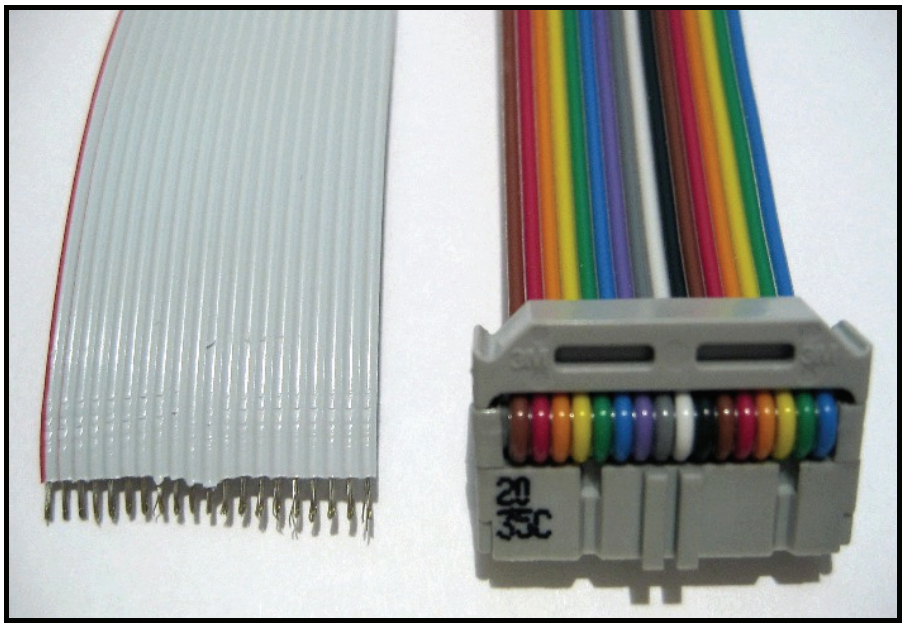


Fig. 3.12 20-pin Ribbon cables with IDC connector (source: Wikipedia[20])

Ribbon cables are usually specified by two numbers: the spacing or *pitch* of the conductors and the number of conductors or *ways*. Conventionally a spacing of 0.05 inch (1.27 mm) is the norm allowing for a two row connector with a pin spacing of 0.1 inch (2.54 mm). This size is still common today in floppy cables and older ATA cables as well as many more special applications [20]. AT Attachment (ATA) is a standard interface for connecting storage devices such as hard disks and CD-ROM drives inside personal computers (Fig. 3.13).

Fig. 3.13 ATA connector for ribbon cables (source: Wikipedia[21])

The high-speed ATA cable used for ULTRA-ATA 66 and above has 0.025 inch (0.64 mm) pitch and 80 ways. The 40 pin connection is still used but with special connectors that ground every other wire in the 80 way cable. Finer pitches, as small as 0.3 mm, are found in portable

[20] Wikipedia: Ribbon cable (http://en.wikipedia.org/wiki/Ribbon_cable), accessed April 2007.

[21] Wikipedia: Ribbon cable (http://en.wikipedia.org/wiki/Ribbon_cable), accessed April 2007.

electronic equipment such as laptops, however portable electronic equipment usually uses FFC (Flexible Flat Cables) [22].

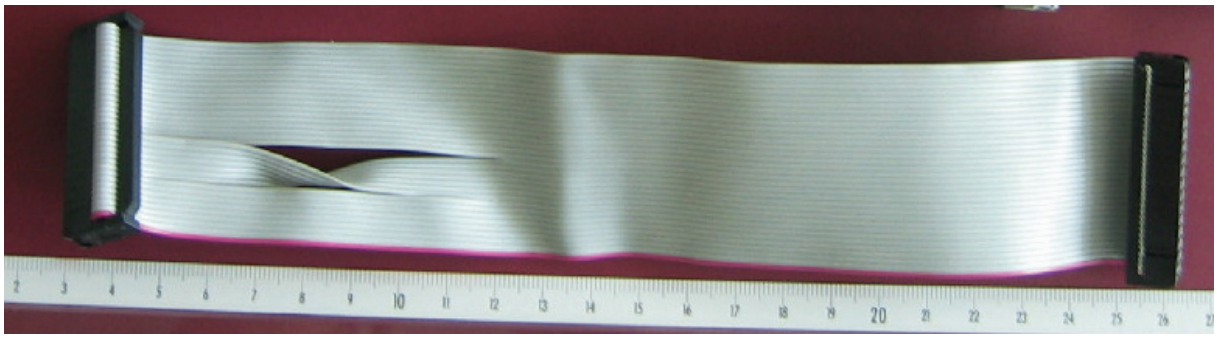


Fig. 3.14 The inventoried 20-pin Ribbon cable under study (source: EMPA St. Gallen)

3.3 System Characterisation

Study object:

In the framework of new ecoinvent datasets in the field of electronics, the following datasets for cables/conductors with their respective plugs are inventoried:

Tab. 3.2 Cable datasets established for this ecoinvent report

Name of dataset	Unit	Region	Chapter
cable, connector for computer, without plugs, at plant,	m	GLO	3.5
plugs, inlet and outlet, for computer cable, at plant	unit	GLO	3.5
cable, network cable, category 5, without plugs, at plant	m	GLO	3.6
plugs, inlet and outlet, for network cable, at plant	unit	GLO	3.6
cable, printer cable, without plugs, at plant	m	GLO	3.7
plugs, inlet and outlet, for printer cable, at plant	unit	GLO	3.7
cable, ribbon cable, 20-pin, with plugs, at plant	kg	GLO	3.8

The inventories include all input and output data of the production stage of the different cables and plugs (materials, energy for assembly, transport, infrastructure, and emissions (if any)).

Functional unit(s):

The cable datasets are established the following way (see Tab. 3.2): On the one hand 1 m of cable is inventoried, on the other hand 1 unit (normally a set of inlet and outlet plugs) of plugs. This allows the ecoinvent user to describe a specific cable of individual length. In case of the ribbon cable, the dataset has the functional unit 1 kg, as there are both cords and plugs included in the same dataset.

[22] Wikipedia: Ribbon cable (http://en.wikipedia.org/wiki/Ribbon_cable), accessed April 2007.

Sources & Representativeness:

Although there is a large variety of all kinds of cables of each type, specific data for the inventory of these four cables is quite rare. Where possible, the applied data of the cables is taken from Environmental Product Declarations from the Internet (computer cable). Additionally, some defective cables is cut up for exact weight measurements of the different components and materials. This is carried out at the Swiss Federal Laboratories for Materials Testing and Research (EMPA).

The cable industry is a global business nowadays, and cables for computers and printers are spread throughout all regions of the world, naturally coupled to the availability of electronic equipment. For this reason, the datasets for cables and plugs are valid globally (GLO). However, as there are dozens if not hundreds of producer companies in the world, and numerous different brands and types of cables and plugs, it is impossible to describe an "average" cable with one single dataset. The changing systems for plug points and voltage in different parts of the world have caused as many different designs of plugs and sockets (see e.g. Fig. 3.3). Yet, the authors tried to picture cables that are a) widely spread, b) world-wide available and c) not older than 2-4 years.

Configuration of datasets:

As mentioned above, the cable datasets include materials (metals, plastics), required manufacturing processes (moulding, rolling or extruding of materials into shapes), electricity for the assembly, transport from regional storage to production site (on the basis of ecoinvent standard transport distances), emissions to air, water (industrial water) and soil (if information available), plastic and rubber wastes, and the infrastructure of the cable production plant. Fig. 3.15 shows the different process steps looked at within the system boundaries of a cable production process (Nichigoh (2006)).

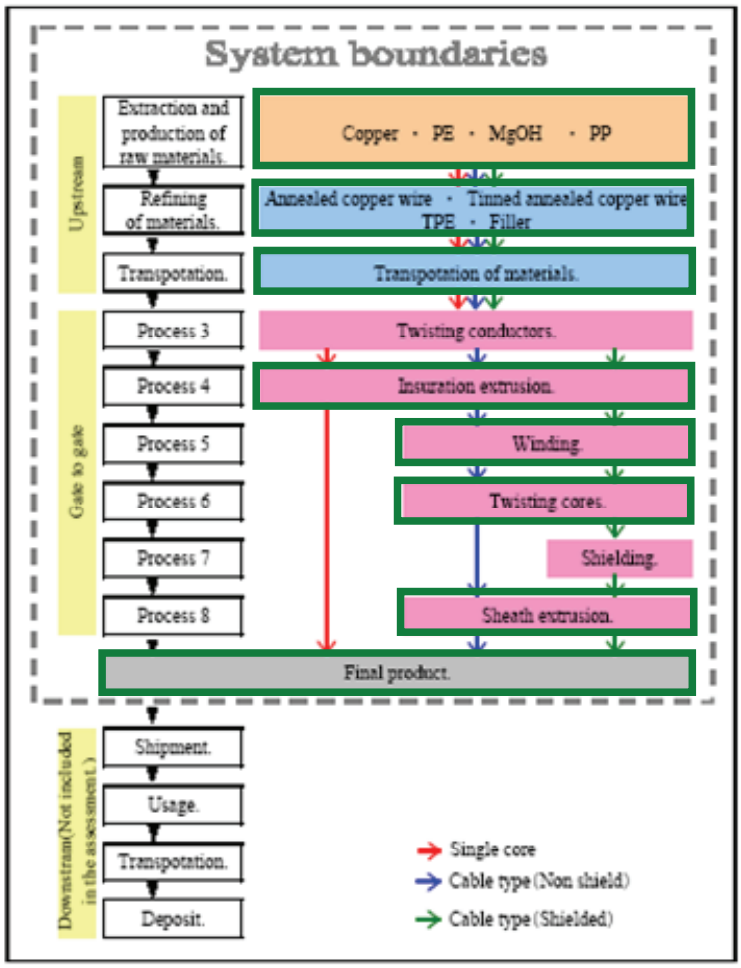


Fig-2. Life cycle flow

Fig. 3.15 Life cycle flow chart and system boundaries of wires and cables; the green-framed process steps are represented in the ecoinvent cable datasets (source: Nichigoh (2006))

Time period:

The data applied on the cable datasets originate mainly from the years 2000 to 2006. All of the cables are still sold and used as computer, Internet, and printer connectors. Except for the described 20-pin ribbon cable that is/is mainly used for floppy disk connections. Modern ribbon cables are normally 40-pin, or then 80-pin constructions and therefore vary in length and width. Though, these 40- and 80-pin cables can be inventoried rather easily by applying the information given on the 20-pin ribbon cable dataset (in kg). The weight proportion of insulated wires and plugs remains the same and therefore a possible mistake is marginal. Generally speaking, the inventoried cables represent products that are currently in use in the majority of the world-wide computer and printer stocks.

Sampling procedure:

First of all, a literature and Internet survey is carried out. Cable producers describe the materials used in their products very well, though one rarely finds exact material contents mentioned. Cable manufacturing description, supported by information on energy consumption, emissions and waste, is also hard to find. However, one technical datasheet and Environmental Product Declaration (EPD) Nichigoh (2006) and an Environmental Report by Draka (2004) brought some useful information.

In order to get exact and trustful information, the 4 cable types is sawn or cut up to weigh the different materials and components at EMPA Laboratories. The materials is classified with some help of material and electronic experts at EMPA, and manufacturing processes is discussed.

3.4 Use & Application

The seven datasets listed in Chapter 3.3 can be applied to describe the production of computer cable, network cable, printer cable and ribbon cable. The datasets describe the cabling systems for computers and printers in small and medium sized offices and in home environments. Where plug systems differ remarkably from the plugs described, new material contents per unit of plug have to be calculated and combined with the inventoried cable (per meter). Hence, this transparent configuration allows the user also to describe case-specific cable compositions.

The cable material datasets are constructed from other ecoinvent datasets for metals, plastics and coatings. The applied process datasets (e.g. extrusion of plastic, injection moulding, and contour brass) are also ecoinvent datasets, as well as the electricity input, the transportation by road and rail, the water input, the emission and the infrastructure.

These cable datasets are applicable for any region in the world, as they are coupled to computers and printers, which are produced in different continents by world-wide running companies. For this reason all the datasets provided for cables and plugs are valid in the global context (GLO).

3.5 Datasets “cable, connector for computer, without plugs” and “plugs, inlet and outlet, for computer cable”

3.5.1 Dataset description and meta information

The datasets “cable, connector for computer, without plugs” and “plugs, inlet and outlet, for computer cable” illustrate the “gate-to-gate” manufacturing process of an electric computer cable. The functional units for the datasets are 1 m of computer cable, and 1 unit of plugs.

The described product (a Swiss system cable, with 0.75 mm^2 cross-section, Type H05VV-F, LS-60, and 3 conductor pins (see Fig. 3.3 and Fig. 3.4)) is of recent date and designed to handle 10A and ca. 250V. The total weight of 1 m of computer power cable is 0.065 kg (without plugs). Major contributions to the weight of the cable part (without plugs!) are coming from the PVC jacket, and the copper wires. The inlet and outlet plugs consist mainly of soft plastic (PVC), brass and hard plastic holders (HDPE) around the pins. The total weight of the plugs is 0.0293 kg for the inlet respectively 0.0292 kg for the outlet. The different power cord systems (plugs) existing in the world do not vary much in material input, and therefore a globally valid dataset (GLO) is justifiable.

More information on the two computer cable datasets can be retrieved from the general flow information sheet in Fig. 3.16 to Fig. 3.19, as well as the meta information presented in Tab. 3.3.

For the material input of the computer cable, general information could be retrieved from the EPD published by Nichigoh (2006). Information on process material inputs like propane, water or fuel oil is retrieved from the Environmental Report by the Draka Norsk Kabel Company (Draka (2004)), the same applies for process emissions like VOC, methanol and the hazardous waste.

Tab. 3.3 ecoinvent meta information for the computer cable dataset(s)

Name	cable, connector for computer, without plugs, at plant	plugs, inlet and outlet, for computer cable, at plant
Location	GLO	GLO
Infrastructure Process	0	0
Unit	m	unit
Dataset Version	2.0	2.0
Included Processes	Describes the production of a typical electric cable (connector) for a desktop computer. Calculated per 1 m of connector. Included are the materials copper, TPE (elastomere) and PVC with their respective manufacturing processes. The infrastructure is calculated via the proxy "printed wiring board mounting plant". Further inventoried are the electricity for the assembly of the connector, the fuel oil, propane and water input, the disposal of plastic and rubber parts, the VOC and methanol emissions created during the processing, plus the road and rail transportation for input materials from the regional storage to the production site. The accummulated hazardous waste is also reported.	Describes the production of a typical set of inlet and outlet plugs for a computer power cord. Calculated per 1 unit of plugs, which is per definition 1 inlet and 1 outlet plug. Included are the materials PVC, HDPE, brass, and copper with their respective manufacturing processes. The infrastructure is calculated via the proxy "printed wiring board mounting plant". Further inventoried are the electricity for the assembly of the plugs, plus the road and rail transportation for input materials from the regional storage to the production site. Water input, emissions and waste are attributed to the electric cable represented in a different dataset.
Amount	1	1
Local Name	Kabel, Stromkabel für Computer, ohne Stecker, ab Werk	Stecker, Schuko- und Kaltgerätestecker für Computerkabel, ab Werk
Synonyms	Power cord//Mains cable//Power cable//Mains lead//Flex//Electric cable//Line//String//Wire//Strand	Connector//Male//Female
General Comment	This dataset can be applied to describe the production of a typical power cord/connector for computers. The total weight of 1 m of connector is 0.065 kg (without the belonging plugs). The information for this dataset is based on weighing, measurements and analysis at EMPA Laboratories.	This dataset can be applied to describe the production of a typical set of plugs (inlet and outlet) for an electric computer cable. The total weight of the inlet plug (with pins) is 0.0293 kg and 0.0292 kg for the outlet plug. The information for this dataset is based on weighing, measurements and analysis at EMPA Laboratories.
Start Date	2000	2000
End Date	2006	2006
Data valid for entire period	1	1
Geography Text	The data describes a typical computer cable in 2006. The kind of cable is produced by international manufacturers and available all over the world. Therefore a global dataset is justifiable.	The data describes a typical set of plugs for a computer cable in 2006. Plugs and cable are produced by international manufacturers and available all over the world. Therefore a global dataset is justifiable.
Technology Text	The manufacturing process is inventoried through wire drawing and extrusion of insulation and jacket (TPE, PVC) around wire.	The manufacturing process is inventoried through wire drawing, injection moulding, contouring (brass), and tin coating (of copper wire).
Representativeness	unknown	unknown
Production Volume	unknown	unknown
SamplingProcedure	Weighing and measuring of materials. Literature for electricity consumption (assembly), emissions and waste.	Weighing and measuring of materials. Literature for electricity consumption (assembly).
Extrapolations	see Geography and Technology	see Geography and Technology

Uncertainty Adjustments	see Geography and Technology	see Geography and Technology

3.5.2 Life Cycle inventory and General Flow information

The layout of the datasets “cable, connector for computer, without plugs” and “plugs, inlet and outlet, for computer cable” with general flow information, remarks, sources, values and uncertainty information are shown in Fig. 3.16 to Fig. 3.19 below.

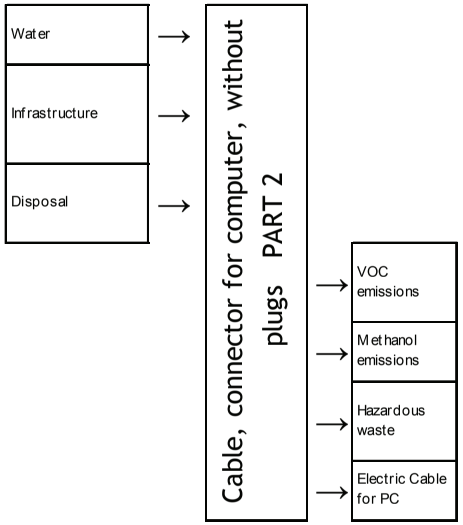
Data Uncertainty and Input Data for Database ecoinvent

The datasets represent a typical electric computer cable (or power cord) with inlet and outlet plugs. The data are mainly based on weighing and calculations of a Swiss type computer cable at EMPA laboratories, supported by EPD information (Nichigoh (2006)). The fact that this typical computer cable does not represent the majority of world-wide available computer cables has been accounted for in the uncertainties of the dataset.

There is no direct natural resource input to the datasets “Cable, connector for computer, without plugs” and “Plugs, inlet and outlet, for computer cable”. The infrastructure for the computer cable and plug production has been taken into account and has been calculated via the annual production volume for a printed wiring board mounting plant described in Chapter 2.3.2. Further balanced for this computer cable dataset are process water, propane and fuel oil input, plastic and rubber disposal, direct air emissions of VOC and methanol, as well as hazardous waste. This information is retrieved from the Environmental Report by the Draka Norsk Kabel Company Draka (2004).

General Flow information							Representation in ecoinvent								Uncertainty		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent		Unit	Source	Type	StDv 95%	General Comment
Conductor	→	Cable, connector for computer, without plugs PART 1				Conductor material: Copper 1.95 g for 3 conductor per 10 cm	metals	extraction	No	RER	copper, at regional storage	1.95E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Wire drawing	→					Wire drawing process	metals	processing	No	RER	wire drawing, copper	1.95E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
TPE insulation copper wires	→					Insulation is TPE elastomer; includes PVC, polyurethane and synthetic rubber: 1.29 g for 3 wires per 10 cm insulation	insulation materials	production	No	DE	tube insulation, elastomere, at plant	1.29E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Extrusion of TPE	→					Extrusion of TPE elastomere into shape	plastics	processing	No	RER	extrusion, plastic pipes	1.29E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Protective jacket	→					Black jacket made out of PVC; 3.25 g per 10 cm of jacket	plastics	polymers	No	RER	polyvinylchloride, at regional storage	3.25E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Extrusion of PVC	→					Extrusion of PVC-jacket	plastics	processing	No	RER	extrusion, plastic pipes	3.25E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Transportation road	→					Road transportation of materials to manufacturing site	transport systems	road	No	RER	transport, lorry >16t, fleet average	6.49E-03	tkm	ecoinvent standard transport distances	1	2.07	(3,4,1,3,1,5,5)
Transportation rail	→					Rail transportation of materials to manufacturing site	transport systems	train	No	RER	transport, freight, rail	1.30E-02	tkm	ecoinvent standard transport distances	1	2.07	(3,4,1,3,1,5,5)
Power consumption cable production	→					Internal process electric power consumption calculated by Nichigoh cable is 93.54 kWh/km; value given by Draka Norsk Kabel SA is 154.8 kWh/km (former value taken)	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	9.35E-02	kWh	Nichigoh Cable (2004) and Draka Norsk Kabel SA (2004)	1	1.24	(2,4,1,3,1,5,2)
Fuel oil	→					Fuel oil for process heating; 278 t/18600 t cable; efficiency 95%; 1 MJ requires 0.025 kg heavy fuel oil; 1 m cable equals 0.065 kg	oil	heating systems	No	RER	heat, heavy fuel oil, at industrial furnace 1MW	4.07E-02	MJ	Draka Norsk Kabel AS (2004)	1	1.24	(2,4,1,3,1,5,1)
Propane	→					Propane used for processes and fire testing; 3450 kg/18600 t cable; 1 m cable equals 0.065 kg	oil	fuels	No	RER	propane/ butane, at refinery	1.21E-05	kg	Draka Norsk Kabel AS (2004)	1	1.24	(2,4,1,3,1,5,11)

Fig. 3.16 Unit process raw data of "cable, connector for computer, without plugs" and their representation in the ecoinvent database (PART 1)

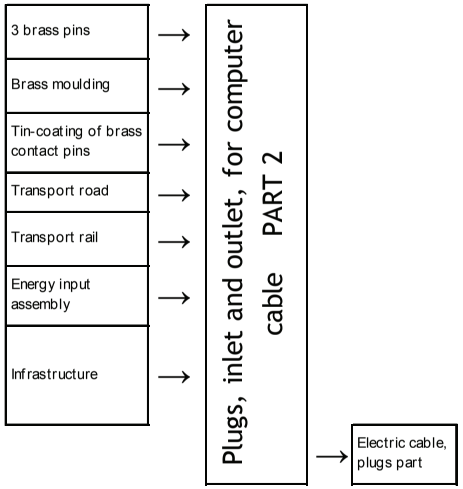


General Flow information							Representation in ecoinvent								Uncertainty		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent		Unit	Source	Type	StDv 95%	General Comment
Water	→	Cable, connector for computer, without plugs PART 2	→	VOC emissions		Water used for cooling, cleaning and sanitary purposes; 375100 m3/18600 t cable; 1m3 = 1000 kg water; 1m cable equals 0.065 kg	water supply	production	No	RER	tap water, at user	1.31E+00	kg	Draka Norsk Kabel AS (2004)	1	1.24	(2,4,1,3,1,5,3)
Infrastructure	→		→	Methanol emissions		Dataset "printed wiring board mounting plant" used as a proxy; annual production volume 192 t, life-span 25 y; value calculated per m	electronics	module	Yes	GLO	printed wiring board mounting plant	1.35E-08	unit	Assumed to be the same as 'printed wiring board mounting plant' (ecoinvent)	1	3.06	(2,4,1,3,1,5,9)
Disposal	→		→	Hazardous waste		Disposal of plastic and rubber; 470 t/18600 t of cable	waste management	municipal incineration	No	CH	disposal, plastics, mixture, 15.3%water, to municipal incineration	1.64E-03	kg	Draka Norsk Kabel AS (2004)	1	1.24	(2,4,1,3,1,5,6)
						VOC emissions to air; 1.8 tons for 18600 t of cable; 1m cable equals 0.065 kg	air	low population density			NM VOC, non-methane volatile organic compounds, unspecified origin	6.29E-06	kg	Draka Norsk Kabel AS (2004)	1	2.06	(1,4,1,3,1,5,23)
						Methanol emissions to air; 2.4 tons for 18600 t of cables; 1m cable equals 0.065 kg	air	low population density			Methanol	8.39E-06	kg	Draka Norsk Kabel AS (2004)	1	2.06	(1,4,1,3,1,5,23)
						57 tons of hazardous waste from 18600 t of cables; 1m cable equals 0.065 kg	waste management	hazardous waste incineration	No	CH	disposal, hazardous waste, 25%water, to hazardous waste incineration	1.99E-04	kg	Draka Norsk Kabel AS (2004)	1	1.24	(1,4,1,3,1,5,6)
						1m of standard computer cable, 0.75 mm2 cross section	electronics	component	No	GLO	cable, connector for computer, without plugs, at plant	1.00E+00	m				

Fig. 3.17 Unit process raw data of "cable, connector for computer, without plugs" and their representation in the ecoinvent database (PART 2)

General Flow information							Representation in ecoinvent									Uncertainty		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent		Unit	Source	Type	StDv 95%	General Comment
Socket for inlet plug	→	Plugs, inlet and outlet, for computer cable PART 1				Semi-soft, taken as PVC; 20.2 g	plastics	polymers	No	RER	polyvinylchloride, at regional storage	2.02E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Plastic moulding	→					Moulding of PVC plastic into form	plastics	processing	No	RER	injection moulding	2.02E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Plastic holder for brass contact pins	→					Hard plastic, taken as PE; 4 g	plastics	polymers	No	RER	polyethylene, HDPE, granulate, at plant	4.00E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Plastic moulding	→					Moulding of plastic into form	plastics	processing	No	RER	injection moulding	4.00E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Brass contacts	→					3 brass contacts in socket; total of 1.75 g	metals	extraction	No	CH	brass, at plant	1.75E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Brass rolling	→					Process of brass rolling for contacts	metals	processing	No	RER	contour, brass	1.75E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Socket for outlet plug	→					Semi-soft, taken as PVC; 19.8 g	plastics	polymers	No	RER	polyvinylchloride, at regional storage	1.98E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Plastic moulding	→					Moulding of PVC plastic into form	plastics	processing	No	RER	injection moulding	1.98E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Plastic holder for connectors	→					Hard plastic holders with holes for pins; taken as HDPE	plastics	polymers	No	RER	polyethylene, HDPE, granulate, at plant	1.12E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Plastic moulding	→					Moulding of plastic into form	plastics	processing	No	RER	injection moulding	1.12E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
3 conductor pieces	→					10 cm of all the 3 connectors are moulded into the inlet and outlet plugs	metals	extraction	No	RER	copper, at regional storage	3.23E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Wire drawing	→					Wire drawing of copper	metals	processing	No	RER	wire drawing, copper	3.23E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)

Fig. 3.18 Unit process raw data of "plugs, inlet and outlet, for computer cable" and their representation in the ecoinvent database (PART 1)



General Flow information							Representation in ecoinvent								Uncertainty		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent		Unit	Source	Type	StDv 95%	General Comment
3 brass pins	→	Plugs, inlet and outlet, for computer cable PART 2	→	Electric cable, plugs part		3 brass pins tin-coated	metals	extraction	No	CH	brass, at plant	8.40E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Brass moulding	→					Moulding of the 3 brass pins	metals	processing	No	RER	contour, brass	8.40E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Tin-coating of brass contact pins	→					Brass pins are tin-coated with 12 um of tin; zinc coating process as proxy; Pin surface=2pr(r+h), h=3cm, r=2mm	metals	processing	No	RER	zinc coating, pieces	4.02E-04	m2	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Transport road	→					Road transportation of materials from regional storage to manufacturing site	transport systems	road	No	RER	transport, lorry >16t, fleet average	5.85E-03	tkm	ecoinvent standard transport distances	1	2.07	(3,4,1,3,1,5,5)
Transport rail	→					Rail transportation of materials from regional storage to manufacturing site	transport systems	train	No	RER	transport, freight, rail	1.17E-02	tkm	ecoinvent standard transport distances	1	2.07	(3,4,1,3,1,5,5)
Energy input assembly	→					Assumed to be the same as for the Insulation extrusion for conductor; for 5 cm of plug; 29.51 kWh/km (Nichigoh)	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	1.48E-03	kWh	Nichigoh Cable (2004)	1	1.24	(2,4,1,3,1,5,2)
Infrastructure	→					Dataset "printed wiring board mounting plant" used as a proxy; annual production volume 192 t, life-span 25 y; value calculated per m	electronics	module	Yes	GLO	printed wiring board mounting plant	1.22E-08	unit	Assumed to be the same as 'printed wiring board mounting plant' (ecoinvent)	1	3.06	(2,4,1,3,1,5,9)
							electronics	component	No	GLO	plugs, inlet and outlet, for computer cable, at plant	1.00E+00	unit				

Fig. 3.19 Unit process raw data of "plugs, inlet and outlet, for computer cable" and their representation in the ecoinvent database (PART 2)

3.6 Datasets “cable, network cable, category 5, without plugs” and “plugs, inlet and outlet, for network cable”

3.6.1 Dataset description and meta information

The datasets “cable, network cable, category 5, without plugs” and “plugs, inlet and outlet, for network cable” illustrate the “gate-to-gate” manufacturing process of a network cable (or patch cable). The functional units for the datasets are 1 m of network cable, and 1 unit of plugs (two plugs).

The described product (network cable UNINET flex 4P produced by Daetwyler (see Fig. 3.5, Fig. 3.7 and Fig. 3.8) is of recent date and commonly in use. The total weight of 1 m of network cable is 0.036 kg (without plugs). Major contributions to the weight of the cable part (without plugs!) are coming from the PVC jacket, the tinned copper braid and the insulated fine copper wires. The inlet and outlet plugs consist mainly of soft PVC, brass/gold and hard plastic (HIPS) around the pins (Fig. 3.6 and Fig. 3.7). The total weight of two plugs (2 identical ones) is 0.0086 kg. The described network cable category 5 is spread all over the world and therefore a globally valid dataset (GLO) is justifiable.

More information on the network cable datasets can be retrieved from the general flow information sheet in Fig. 3.20 to Fig. 3.22, as well as the meta information presented in Tab. 3.4.

For the material input of the computer cable, general information could be found in the EPD published by (Nichigoh (2006)). Information on process material inputs like propane, water or fuel oil is retrieved from the Environmental Report by the Draka Norsk Kabel Company (Draka (2004)), the same applies for process emissions like VOC, methanol and the hazardous waste.

Tab. 3.4 ecoinvent meta information for the network cable dataset(s)

Name	cable, network cable, category 5, without plugs, at plant	plugs, inlet and outlet, for network cable, at plant
Location	GLO	GLO
Infrastructure Process	0	0
Unit	m	unit
Dataset Version	2.0	2.0
Included Processes	Describes the production of a typical network cable used with desktop or laptop computers. Calculated per 1 m of connector. Included are the materials copper, soft PVC, LDPE and tin (as coating) with their respective manufacturing processes. The infrastructure is calculated via the proxy "printed wiring board mounting plant". Further inventoried are the electricity for the assembly of the connector, the fuel oil, propane and water input, the disposal of plastic and rubber parts, the VOC and methanol emissions created during the processing, plus the road and rail transportation for input materials from the regional storage to the production site. The accummulated hazardous waste is also reported.	Describes the production of a typical set of inlet and outlet plugs of a computer network cable. Calculated per 1 unit of plugs, which is per definition 1 inlet and 1 outlet plug (identical in this case). Included are the materials PVC, HIPS and brass with their respective manufacturing processes. The infrastructure is calculated via the proxy "printed wiring board mouning plant". Further inventoried are the electricity for the assembly of the plugs, plus the road and rail transportation for input materials from the regional storage to the production site.
Amount	1	1
Local Name	Kabel, Netzwerkkabel, Kategorie 5, ohne Stecker, ab Werk	Stecker, für Netzwerkkabel, ab Werk
Synonyms	Patch cable//Patch cord	Connector
General Comment	This dataset can be applied to describe the production of a typical network cable for computers. The total weight of 1 m of network cable is 0.036 kg (without the belonging plugs). The information for this dataset is based on weighing, measurements and analysis at EMPA Laboratories.	This dataset can be applied to describe the production of a typical set of plugs (inlet and outlet) for a computer network cable. The total weight of the plugs (2 identical ones) is 0.0086 kg. The information for this dataset is based on weighing, measurements and analysis at EMPA Laboratories.
Start Date	2000	2000
End Date	2006	2006
Data valid for entire period	1	1
Geography Text	The data describes a typical network cable for computers in 2006. The kind of cable is produced by international manufacturers and available all over the world. Therefore a global dataset is justifiable.	The data describes a typical set of plugs for a computer network cable in 2006. Plugs and cable are produced by international manufacturers and available all over the world. Therefore a global dataset is justifiable.
Technology Text	The manufacturing process is represented by wire drawing (of copper), plastic extrusion (for LDPE and PVC), tin coating.	The manufacturing process is represented by injection moulding and contouring (brass).
Representativeness	unknown	unknown
Production Volume	unknown	unknown
SamplingProcedure	Weighing and measuring of materials. Literature for electricity consumption (assembly), emissions and waste.	Weighing and measuring of materials. Literature for electricity consumption (assembly).
Extrapolations	see Geography and Technology	see Geography and Technology
Uncertainty Adjustments	see Geography and Technology	see Geography and Technology

3.6.2 Life Cycle inventory and General Flow information

The layout of the datasets “cable, network cable, category 5, without plugs” and “plugs, inlet and outlet, for network cable” with general flow information, remarks, sources, values and uncertainty information are shown in Fig. 3.20 to Fig. 3.22 below.

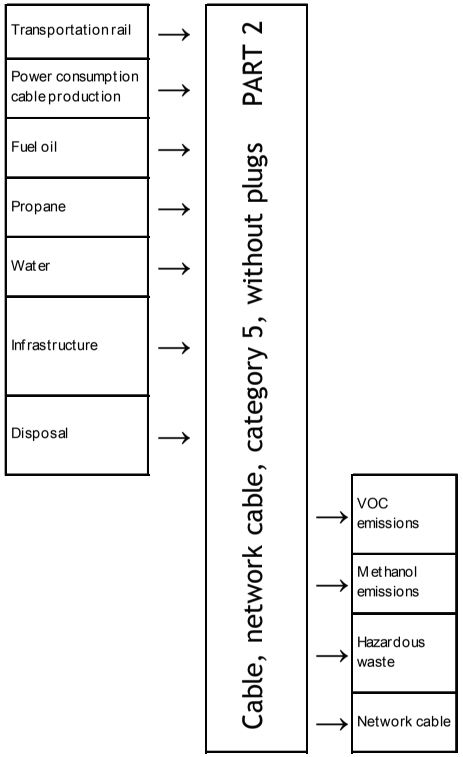
Data Uncertainty and Input Data for Database ecoinvent

The datasets represent a typical network computer cable (or power cord) and inlet and outlet plugs. The data are mainly based on weighing and calculations of a category 5 network cable at EMPA laboratories, supported by information by (Daetwyler (2006)). The fact that this typical network/patch cable does not represent the majority of world-wide available network cables has been accounted for in the uncertainties of the dataset inputs and outputs.

There is no direct natural resource input to the datasets “cable, network cable, category 5, without plugs” and “plugs, inlet and outlet, for network cable”. The infrastructure for the network cable and plug production has been taken into account and has been calculated via the annual production volume for a printed wiring board mounting plant described in Chapter 2.3.2. Further balanced for this network cable dataset are process water, propane and fuel oil input, plastic and rubber disposal, direct air emissions of VOC and methanol, as well as hazardous waste. This information is retrieved from the Environmental Report by the Draka Norsk Kabel Company Draka (2004).

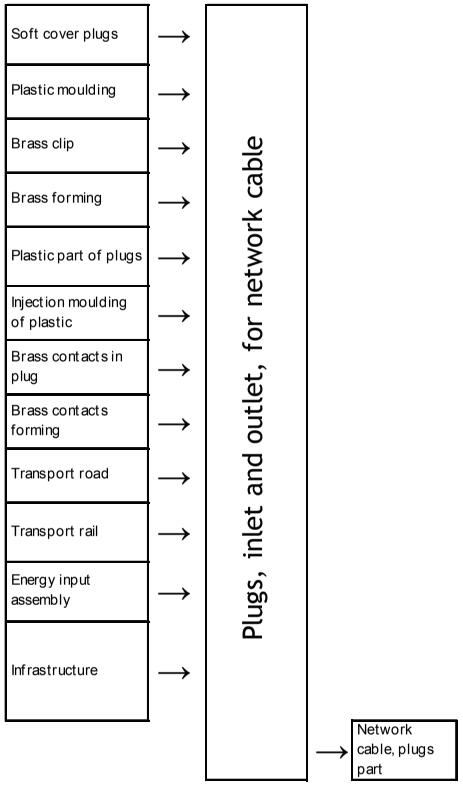
General Flow information							Representation in ecoinvent								Uncertainty		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent		Unit	Source	Type	StDv 95%	General Comment
Conductor	→	Cable, network cable, category 5, without plugs PART 1				8 thin (diameter < 1mm) copper conductors (twisted in pairs) in insulation; weight per insulated copper wire 12.5 g per m; ratio copper vs. Insulation material assumed to be 50:50	metals	extraction	No	RER	copper, at regional storage	6.25E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Wire drawing	→					Wire drawing process	metals	processing	No	RER	wire drawing, copper	6.25E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Insulation copper wires	→					Insulation made out of PVC	plastics	polymers	No	RER	polyvinylchloride, at regional storage	6.25E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Extrusion of PVC	→					Extrusion of PVC insulation	plastics	processing	No	RER	extrusion, plastic pipes	6.25E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
PE sheath	→					PE-foil around insulated wires; 1 g per 1 m	plastics	polymers	No	RER	polyethylene, LDPE, granulate, at plant	1.00E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Extrusion plastic film	→					Extrusion of LDPE into plastic film	plastics	processing	No	RER	extrusion, plastic film	1.00E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Tinned copper braid	→					Shielding braid made out of tinned copper; 12 g per 1m	metals	extraction	No	RER	copper, at regional storage	1.20E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Wire drawing	→					Wire drawing of copper into fine wires	metals	processing	No	RER	wire drawing, copper	1.20E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Tin-coating	→					Tin-coating of braid; layer of 1.5 micrometer; zinc-coating process as proxy	metals	processing	No	RER	zinc coating, pieces	3.77E-02	m2	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Protective jacket	→					Soft PVC jacket (blue)	plastics	polymers	No	RER	polyvinylchloride, at regional storage	1.05E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Extrusion of PVC	→					Extrusion of jacket PVC	plastics	processing	No	RER	extrusion, plastic pipes	1.05E-02	kg	Nichigoh Cable (2004)	1	1.24	(1,4,1,3,1,5,3)
Transportation road	→					Road transportation of materials to manufacturing site	transport systems	road	No	RER	transport, lorry >16t, fleet average	3.60E-03	tkm	ecoinvent standard transport distances	1	1.24	(1,4,1,3,1,5,3)

Fig. 3.20 Unit process raw data of "cable, network cable, category 5, without plugs" and their representation in the ecoinvent database (PART 1)



General Flow information							Representation in ecoinvent								Uncertainty		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent		Unit	Source	Type	StDv 95%	General Comment
Transportation rail	→	Cable, network cable, category 5, without plugs PART 2				Rail transportation of materials to manufacturing site	transport systems	train	No	RER	transport, freight, rail	7.20E-03	tkm	ecoinvent standard transport distances	1	1.24	(1,4,1,3,1,5,3)
Power consumption cable production	→					Internal process electric power consumption calculated by Nichigoh cable is 93.54 kWh/km	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	9.35E-02	kWh	Nichigoh Cable (2004)	1	1.24	(1,4,1,3,1,5,2)
Fuel oil	→					Fuel oil for process heating; 278 t/18600 t cable; efficiency 95%; 1 MJ requires 0.025 kg heavy fuel oil; 1 m cable equals 0.036 kg	oil	heating systems	No	RER	heat, heavy fuel oil, at industrial furnace 1MW	2.25E-02	MJ	Draka Norsk Kabel AS (2004)	1	1.24	(2,4,1,3,1,5,1)
Propane	→					Propane used for processes and fire testing; 3450 kg/18600 t cable; 1 m cable equals 0.036 kg	oil	fuels	No	RER	propane/ butane, at refinery	6.68E-06	kg	Draka Norsk Kabel AS (2004)	1	1.24	(2,4,1,3,1,5,11)
Water	→					Water used for cooling, cleaning and sanitary purposes; 375100 m3/18600 t cable; 1 m3 = 1000 kg water; 1 m cable equals 0.036 kg	water supply	production	No	RER	tap water, at user	7.26E-01	kg	Draka Norsk Kabel AS (2004)	1	1.24	(2,4,1,3,1,5,3)
Infrastructure	→					Dataset "printed wiring board mounting plant" used as a proxy; annual production volume 192 t, life-span 25 y; value calculated per m	electronics	module	Yes	GLO	printed wiring board mounting plant	7.49E-09	unit	Assumed to be the same as 'printed wiring board mounting plant' (ecoinvent)	1	3.06	(2,4,1,3,1,5,9)
Disposal	→					Disposal of plastic and rubber; 470 t/18600 t of cable; 1 m cable equals 0.036 kg	waste management	municipal incineration	No	CH	disposal, plastics, mixture, 15.3% water, to municipal incineration	9.10E-04	kg	Draka Norsk Kabel AS (2004)	1	1.24	(2,4,1,3,1,5,6)
			→	VOC emissions		VOC emissions to air; 1.8 tons for 18600 t of cable; 1 m cable equals 0.036 kg	air	low population density			NM VOC, non-methane volatile organic compounds, unspecified origin	3.48E-06	kg	Draka Norsk Kabel AS (2004)	1	2.06	(1,4,1,3,1,5,23)
			→	Methanol emissions		Methanol emissions to air; 2.4 tons for 18600 t of cables; 1 m cable equals 0.036 kg	air	low population density			Methanol	4.65E-06	kg	Draka Norsk Kabel AS (2004)	1	2.06	(1,4,1,3,1,5,23)
			→	Hazardous waste		57 tons of hazardous waste from 18600 t of cables; 1 m cable equals 0.036 kg	waste management	hazardous waste incineration	No	CH	disposal, hazardous waste, 25% water, to hazardous waste incineration	1.10E-04	kg	Draka Norsk Kabel AS (2004)	1	1.24	(1,4,1,3,1,5,6)
			→	Network cable		1 m of standard network cable	electronics	component	No	GLO	cable, network cable, category 5, without plugs, at plant	1.00E+00	m				

Fig. 3.21 Unit process raw data of "cable, network cable, category 5, without plugs" and their representation in the ecoinvent database (PART 2)



General Flow information							Representation in ecoinvent								Uncertainty		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent		Unit	Source	Type	StDv 95%	General Comment
Soft cover plugs	→	Plugs, inlet and outlet, for network cable				Network cable has two identical connectors with a total weight of 8.6 g; soft PVC for 2 plug covers; 1 plug cover weighs 2 g	plastics	polymers	No	RER	polyvinylchloride, at regional storage	4.00E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Plastic moulding	→					Plastic injection moulding of PVC into shape	plastics	processing	No	RER	injection moulding	4.00E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Brass clip	→					Metal clip inside plug made out of brass; weight per clip 1g	metals	extraction	No	CH	brass, at plant	2.00E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Brass forming	→					Brass forming into metal clip	metals	processing	No	RER	contour, brass	2.00E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Plastic part of plugs	→					Plastic plug made out of HIPS	plastics	polymers	No	RER	polystyrene, high impact, HIPS, at plant	2.18E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Injection moulding of plastic	→					Injection moulding of HIPS into shape	plastics	processing	No	RER	injection moulding	2.18E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Brass contacts in plug	→					8 gold plated contacts in plug; taken as brass	metals	extraction	No	CH	brass, at plant	4.22E-04	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Brass contacts forming	→					Forming of brass into contact shape	metals	processing	No	RER	contour, brass	4.22E-04	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Transport road	→					Road transportation of materials from regional storage to manufacturing site	transport systems	road	No	RER	transport, lorry >16t, fleet average	8.60E-04	tkm	ecoinvent standard transport distances	1	2.07	(3,4,1,3,1,5,5)
Transport rail	→					Rail transportation of materials from regional storage to manufacturing site	transport systems	train	No	RER	transport, freight, rail	1.72E-03	tkm	ecoinvent standard transport distances	1	2.07	(3,4,1,3,1,5,5)
Energy input assembly	→					Assumed to be the same as for the Insulation extrusion for conductor; for 3 cm of plug; 29.51 kWh/km (Nichigoh)	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	8.85E-04	kWh	Nichigoh Cable (2004)	1	1.24	(2,4,1,3,1,5,2)
Infrastructure	→					Dataset "printed wiring board mounting plant" used as a proxy; annual production volume 192 t, life-span 25 y; value calculated per m	electronics	module	Yes	GLO	printed wiring board mounting plant	1.79E-09	unit	Assumed to be the same as 'printed wiring board mounting plant' (ecoinvent)	1	3.06	(2,4,1,3,1,5,9)
			→	Network cable, plugs part			electronics	component	No	GLO	plugs, inlet and outlet, for network cable, at plant	1.00E+00	unit				

Fig. 3.22 Unit process raw data of "plugs, inlet and outlet, for network cable" and their representation in the ecoinvent database

3.7 Datasets “cable, printer cable, without plugs” and “plugs, inlet and outlet, for printer cable”

3.7.1 Dataset description and meta information

The datasets “cable, printer cable, without plugs” and “plugs, inlet and outlet, for printer cable” illustrate the “gate-to-gate” manufacturing process of a printer cable. The functional units for the datasets are 1 m of printer cable, and 1 unit of plugs (two plugs).

The described product (a parallel, DB25 ST/Cen36 ST (1.8 m), brand name “Roline” (see Fig. 3.9 and Fig. 3.10)) is manufactured some years back but is still commonly in use. The total weight of 1 m of printer cable is 0.072 kg (without plugs). Major contributions to the weight of the cable part (without plugs!) are the PVC jacket and the 25 fine copper wires, each being insulated with PVC. The inlet and outlet plugs consist mainly of a softer type plastic (LDPE), a harder type plastic (HIPS) around the contacts, and hard silicon to keep the fine wires in place in the outlet plug (Fig. 3.6 and Fig. 3.7). The total weight of the inlet plug is 0.0395 kg; the outlet plug weighs 0.050 kg. The described printer cable is spread all over the world and therefore a globally valid dataset (GLO) is justifiable.

More information on the printer cable datasets can be retrieved from the general flow information sheet in Fig. 3.23 to Fig. 3.26, as well as the meta information presented in Tab. 3.5.

For the material input of the computer cable, general information could be retrieved from the EPD published by (Nichigoh (2006)). Information on process material inputs like propane, water or fuel oil is retrieved from the Environmental Report by the Draka Norsk Kabel Company (Draka (2004)), the same applies for process emissions like VOC, methanol and the hazardous waste.

Tab. 3.5 ecoinvent meta information for the printer cable dataset(s)

Name	**cable, printer cable, without plugs, at plant**	**plugs, inlet and outlet, for printer cable, at plant**
Location	GLO	GLO
Infrastructure Process	0	0
Unit	m	unit
Dataset Version	2.0	2.0
Included Processes	Describes the production of a typical printer cable (connector). Calculated per 1 m of printer cable. Included are the materials copper, PVC, and aluminium with their attributed manufacturing processes like wire drawing or extrusion. The infrastructure is calculated via the proxy "printed wiring board mounting plant". Further inventoried are the electricity for the assembly of the connector, the fuel oil, propane and water input, the disposal of plastic and rubber parts, the VOC and methanol emissions created during the processing, plus the road and rail transportation for input materials from the regional storage to the production site. The accummulated hazardous waste is also reported.	Describes the production of a typical set of inlet and outlet plugs for a printer cable. Calculated per 1 unit of plugs, which is per definition 1 inlet and 1 outlet plug. Included are the materials PVC, LDPE, HDPE, silicone, low-alloyed steel, chromium steel, brass, and copper with their respective manufacturing processes. The infrastructure is calculated via the proxy "printed wiring board mounting plant". Further inventoried are the electricity used in the assembly of the plugs, plus the road and rail transportation for input materials from the regional storage to the production site.
Amount	1	1
Local Name	Kabel, Druckerkabel, ohne Stecker, ab Werk	Stecker, für Druckerkabel, ab Werk
Synonyms	Printer cord	Connector//Male//Female
General Comment	This dataset can be applied to describe the production of a typical printer cable to connect to the desktop or laptop computer. The total weight of 1 m of printer cable is 0.072 kg (without the belonging plugs). The information for this dataset is based on weighing, measurements and analysis at EMPA Laboratories.	This dataset can be applied to describe the production of a typical set of plugs (inlet and outlet) for a printer cable. The total weight of the inlet plug (with pins) is 0.0395 kg and 0.050 kg for the outlet plug (the one with holes). The information for this dataset is based on weighing, measurements and analysis at EMPA Laboratories.
Start Date	2000	2000
End Date	2006	2006
Data valid for entire period	1	1
Geography Text	The data describes a typical printer cable in 2006. The kind of printer cable is produced by international manufacturers and available all over the world. Therefore a global dataset is justifiable.	The data describes a typical set of plugs for a printer cable in 2006. Plugs and cable are produced by international manufacturers and available all over the world. Therefore a global dataset is justifiable.
Technology Text	The manufacturing process is represented through plastic extrusion (PVC), sheet rolling (aluminium), and wire drawing (copper).	The manufacturing process is inventoried through wire drawing, injection moulding, sheet rolling & hot rolling (steel), contouring (brass), and zinc coating (galvanising of steel).
Representativeness	unknown	unknown
Production Volume	unknown	unknown
Sampling Procedure	Weighing and measuring of materials. Literature for electricity consumption (assembly), emissions and waste.	Weighing and measuring of materials. Literature for electricity consumption (assembly).
Extrapolations	see Geography and Technology	see Geography and Technology

Uncertainty Adjustments	see Geography and Technology	see Geography and Technology

3.7.2 Life Cycle inventory and General Flow information

The layout of the datasets “cable, printer cable, without plugs” and “plugs, inlet and outlet, for printer cable” with general flow information, remarks, sources, values and uncertainty information are shown in Fig. 3.23 to Fig. 3.26 below.

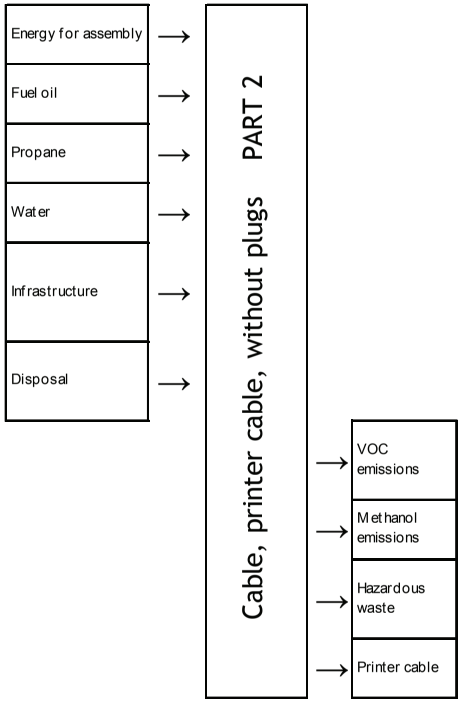
Data Uncertainty and Input Data for Database ecoinvent

The datasets represent a typical printer cable (parallel) and inlet and outlet plugs. The data are mainly based on weighing and calculations of a printer cable at EMPA laboratories. The fact that this typical printer cable does not represent the majority of world-wide available printer cables has been accounted for in the uncertainties of the inputs and outputs of the datasets.

There is no direct natural resource input to the datasets “Cable, printer cable, without plugs” and “Plugs, inlet and outlet, for printer cable”. The infrastructure for the printer cable and plug production has been taken into account and has been calculated via the annual production volume for a printed wiring board mounting plant described in Chapter 2.3.2. Further balanced for this printer cable dataset are process water, propane and fuel oil input, plastic and rubber disposal, direct air emissions of VOC and methanol, as well as hazardous waste. This information is retrieved from the Environmental Report by the Draka Norsk Kabel Company (Draka (2004)).

General Flow information							Representation in ecoinvent								Uncertainty		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent		Unit	Source	Type	StDv 95%	General Comment
Conductor	→	Cable, printer cable, without plugs PART 1				25 thin (diameter < 1mm) copper conductors in insulation; weight per insulated copper wire 36.8 g per m; ratio copper vs. Insulation material assumed to be 50:50	metals	extraction	No	RER	copper, at regional storage	1.84E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Wire drawing	→					Wire drawing process	metals	processing	No	RER	wire drawing, copper	1.84E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Insulation copper wires	→					Insulation made out of PVC	plastics	polymers	No	RER	polyvinylchloride, at regional storage	1.84E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Extrusion Insulation	→					Extrusion of PVC into shape	plastics	processing	No	RER	extrusion, plastic pipes	1.84E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Fine wire	→					Fine copper wire to absorb noise	metals	extraction	No	RER	copper, at regional storage	1.20E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Wire drawing	→					Drawing of fine wire	metals	processing	No	RER	wire drawing, copper	1.20E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Aluminium layer	→					Fine aluminium layer	metals	extraction	No	RER	aluminium, primary, at plant	9.00E-04	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Sheet rolling	→					Sheet rolling of aluminium into fine layer	metals	processing	No	RER	sheet rolling, aluminium	9.00E-04	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Protective jacket	→					Soft PVC jacket (cream color)	plastics	polymers	No	RER	polyvinylchloride, at regional storage	3.41E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Extrusion PVC	→					Extrusion of PVC into jacket shape	plastics	processing	No	RER	extrusion, plastic pipes	3.41E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Transportation road	→					Road transportation of materials to manufacturing site	transport systems	road	No	RER	transport, lorry >16t, fleet average	7.30E-03	tkm	ecoinvent standard transport distances	1	2.07	(3,4,1,3,1,5,5)
Transportation rail	→					Rail transportation of materials to manufacturing site	transport systems	train	No	RER	transport, freight, rail	1.46E-02	tkm	ecoinvent standard transport distances	1	2.07	(3,4,1,3,1,5,5)

Fig. 3.23 Unit process raw data of “cable, printer cable, without plugs” and their representation in the ecoinvent database (PART 1)

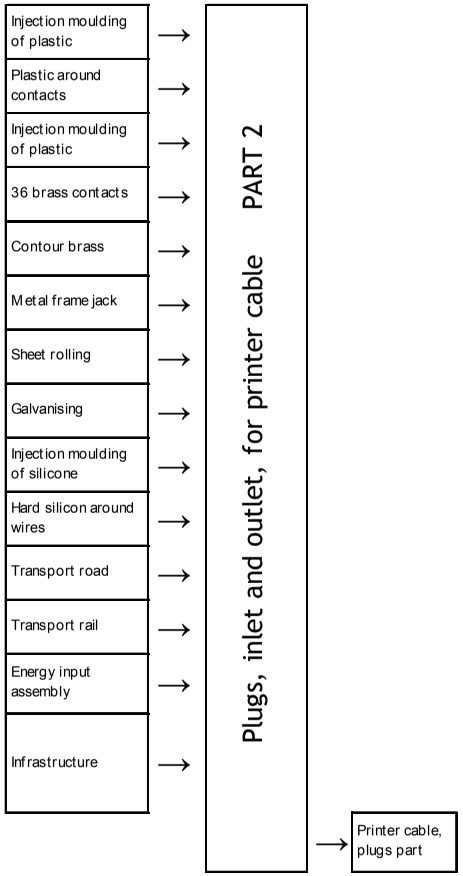


General Flow information							Representation in ecoinvent								Uncertainty		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent		Unit	Source	Type	StDv 95%	General Comment
Energy for assembly	→	Cable, printer cable, without plugs PART 2				Internal process electric power consumption calculated by Nichigoh cable is 93.54 kWh/km	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	9.35E-02	kWh	Nichigoh Cable (2004)	1	1.24	(2,4,1,3,1,5,2)
Fuel oil	→					Fuel oil for process heating; 278 t/18600 t cable; efficiency 95%; 1 MJ requires 0.025 kg heavy fuel oil; 1 m cable equals 0.072 kg	oil	heating systems	No	RER	heat, heavy fuel oil, at industrial furnace 1MW	4.51E-02	MJ	Draka Norsk Kabel AS (2004)	1	1.24	(2,4,1,3,1,5,1)
Propane	→					Propane used for processes and fire testing; 3450 kg/18600 t cable; 1 m cable equals 0.072 kg	oil	fuels	No	RER	propane/ butane, at refinery	1.34E-05	kg	Draka Norsk Kabel AS (2004)	1	1.24	(2,4,1,3,1,5,11)
Water	→					Water used for cooling, cleaning and sanitary purposes; 375100 m3/18600 t cable; 1 m3 = 1000 kg water; 1 m cable equals 0.072 kg	water supply	production	No	RER	tap water, at user	1.45E+00	kg	Draka Norsk Kabel AS (2004)	1	1.24	(2,4,1,3,1,5,3)
Infrastructure	→					Dataset "printed wiring board mounting plant" used as a proxy; annual production volume 192 t, life-span 25 y; value calculated per m	electronics	module	Yes	GLO	printed wiring board mounting plant	1.50E-08	unit	Assumed to be the same as 'printed wiring board mounting plant' (ecoinvent)	1	3.06	(2,4,1,3,1,5,9)
Disposal	→					Disposal of plastic and rubber; 470 t/18600 t of cable; 1 m cable equals 0.072 kg	waste management	municipal incineration	No	CH	disposal, plastics, mixture, 15.3%water, to municipal incineration	1.82E-03	kg	Draka Norsk Kabel AS (2004)	1	1.24	(2,4,1,3,1,5,6)
			→	VOC emissions		VOC emissions to air; 1.8 tons for 18600 t of cable; 1 m cable equals 0.072 kg	air	low population density			NM VOC, non-methane volatile organic compounds, unspecified origin	6.97E-06	kg	Draka Norsk Kabel AS (2004)	1	2.06	(1,4,1,3,1,5,23)
			→	Methanol emissions		Methanol emissions to air; 2.4 tons for 18600 t of cables; 1 m cable equals 0.072 kg	air	low population density			Methanol	9.29E-06	kg	Draka Norsk Kabel AS (2004)	1	2.06	(1,4,1,3,1,5,23)
			→	Hazardous waste		57 tons of hazardous waste from 18600 t of cables; 1 m cable equals 0.072 kg	waste management	hazardous waste incineration	No	CH	disposal, hazardous waste, 25%water, to hazardous waste incineration	2.21E-04	kg	Draka Norsk Kabel AS (2004)	1	1.24	(1,4,1,3,1,5,6)
			→	Printer cable		1 m of standard printer cable	electronics	component	No	GLO	cable, printer cable, without plugs, at plant	1.00E+00	m	Own calculation based on assumed life time			

Fig. 3.24 Unit process raw data of "cable, printer cable, without plugs" and their representation in the ecoinvent database (PART 2)

General Flow information							Representation in ecoinvent								Uncertainty		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent		Unit	Source	Type	StDv 95%	General Comment
Soft cover plugs	→	Plugs, inlet and outlet, for printer cable PART 1				25-pin plug; plastic; taken as LDPE; 0.0268 kg	plastics	polymers	No	RER	polyethylene, LDPE, granulate, at plant	2.68E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Plastic moulding	→					Moulding of plastic into form	plastics	processing	No	RER	injection moulding	2.68E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Metal plug copper pins	→					Copper wires running into 25 pins; tinned; 25 w-% of total plug weight of 9.25 g	metals	extraction	No	RER	copper, at regional storage	2.31E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Wire drawing	→					Wire drawing into fine copper pins	metals	processing	No	RER	wire drawing, copper	2.31E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Metal plug blue plastic	→					Plastic HDPE with 25 pins moulded in; 20 w-% of total plug weight of 9.25 g	plastics	polymers	No	RER	polyethylene, HDPE, granulate, at plant	1.85E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Injection moulding of plastic	→					Injection moulding of HDPE into jack	plastics	processing	No	RER	injection moulding	1.85E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Metal plug steel part	→					Low-alloyed steel zinc-plated; 55 w-% of total plug weight of 9.25 g	metals	extraction	No	RER	steel, low-alloyed, at plant	5.09E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Sheet rolling	→					Sheet rolling of low-alloyed steel	metals	processing	No	RER	sheet rolling, steel	5.09E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Galvanising	→					Galvanising of steel alloy; ca. 10 cm2 surface	metals	processing	No	RER	zinc coating, pieces	1.00E-03	m2	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Plastic part of thumb screws	→					Injection moulding of LDPE into shape for thumb screws	plastics	polymers	No	RER	polyethylene, LDPE, granulate, at plant	8.30E-04	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Injection moulding of plastic	→					LDPE plastic	plastics	processing	No	RER	injection moulding	8.30E-04	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Steel part of thumb screws	→					Chromium steel	metals	extraction	No	RER	chromium steel 18/8, at plant	2.61E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Steel forming	→					Steel forming into screw shape	metals	processing	No	RER	hot rolling, steel	2.61E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Plastic for 36-hole jack	→					36-hole jack; plastic part (creme-color); LDPE	plastics	polymers	No	RER	polyethylene, LDPE, granulate, at plant	2.51E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)

Fig. 3.25 Unit process raw data of "plugs, inlet and outlet, for printer cable" and their representation in the ecoinvent database (PART 1)



General Flow information							Representation in ecoinvent								Uncertainty		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent		Unit	Source	Type	StDv 95%	General Comment
						Injection moulding of LDPE into handle shape	plastics	processing	No	RER	injection moulding	2.51E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
						Blue plastic around contacts; HDPE	plastics	polymers	No	RER	polyethylene, HDPE, granulate, at plant	4.96E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
						Injection moulding of HDPE around contacts	plastics	processing	No	RER	injection moulding	4.96E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
						Contacts in jack out of brass	metals	extraction	No	CH	brass, at plant	1.40E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
						Shaping of brass for contacts	metals	processing	No	RER	contour, brass	1.40E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
						Low-alloyed steel zinc-plated; weight 6.45 g	metals	extraction	No	RER	steel, low-alloyed, at plant	6.45E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
						Sheet rolling of low-alloyed steel	metals	processing	No	RER	sheet rolling, steel	6.45E-03	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
						Galvanising of steel alloy; ca. 13 cm2 surface	metals	processing	No	RER	zinc coating, pieces	1.30E-03	m2	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
						Fine insulated wires moulded into hard silicone	chemicals	inorganics	No	RER	silicone product, at plant	1.22E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
						Injection moulding of silicone around wires	plastics	processing	No	RER	injection moulding	1.22E-02	kg	Own measurements (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
						Road transportation of materials from regional storage to manufacturing site	transport systems	road	No	RER	transport, lorry >16t, fleet average	3.95E-03	tkm	ecoinvent standard transport distances	1	2.07	(3,4,1,3,1,5,5)
						Rail transportation of materials from regional storage to manufacturing site	transport systems	train	No	RER	transport, freight, rail	7.90E-03	tkm	ecoinvent standard transport distances	1	2.07	(3,4,1,3,1,5,5)
						Assumed to be the same as for the Insulation extrusion for conductor; but for 5 cm of plug; 29.51 kWh/km (Nichigoh)	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	1.48E-03	kWh	Nichigoh Cable (2004)	1	1.24	(2,4,1,3,1,5,2)
						Dataset "printed wiring board mounting plant" used as a proxy; annual production volume 192 t, life-span 25 y; value calculated per m	electronics	module	Yes	GLO	printed wiring board mounting plant	1.86E-08	unit	Assumed to be the same as 'printed wiring board mounting plant' (ecoinvent)	1	3.06	(2,4,1,3,1,5,9)
							electronics	component	No	GLO	plugs, inlet and outlet, for printer cable, at plant	1.00E+00	unit				

Fig. 3.26 Unit process raw data of "plugs, inlet and outlet, for printer cable" and their representation in the ecoinvent database (PART 2)

3.8 Dataset “ribbon cable, 20-pin, with plugs, at plant”

3.8.1 Dataset description and meta information

The dataset “ribbon cable, 20-pin, with plugs” illustrates the “gate-to-gate” manufacturing process of a ribbon cable. The functional unit for the dataset is 1 kg of ribbon cable.

The described product (a typical 20-pin ribbon cable (see Fig. 3.12 and Fig. 3.14)) is manufactured in the beginning of the century and is still commonly installed in desktop computers. Major contributions to the weight of the ribbon cable are the 20 fine copper wires with their PVC insulation. The weight shares – all inputs are calculated per 1 kg of ribbon cable – are based on the 20-pin ribbon cable with 3.75 g PVC and 3.75 g tinned copper per 24 cm of cable. The inlet and outlet plugs (IDC connectors) consist mainly of hard plastic (HDPE) and gold-plated contacts. The described ribbon cable is connecting floppy disks and other drives to the PC mainboard. PCs are spread all over the world and therefore a globally valid dataset (GLO) is justifiable.

More information on the ribbon cable dataset can be retrieved from the general flow information sheet in Fig. 3.27, as well as the meta information presented in Tab. 3.6.

For the material input of the computer cable, general information could be retrieved from the EPD published by (Nichigoh (2006)). Information on process material inputs like propane, water or fuel oil is retrieved from the Environmental Report by the Draka Norsk Kabel Company (Draka (2004)), the same applies for process emissions like VOC, methanol and the hazardous waste.

Tab. 3.6 ecoinvent meta information for the ribbon cable dataset

Name	**cable, ribbon cable, 20-pin, with plugs, at plant**
Location	GLO
Infrastructure Process	0
Unit	kg
Dataset Version	2.0
Included Processes	Describes the production of a typical ribbon cable with connectors for a desktop computer. Calculated per 1 kg of ribbon cable. Included are the materials copper, brass, PVC and HDPE with their attributed manufacturing processes like wire drawing or extrusion. The infrastructure is calculated via the proxy "printed wiring board mounting plant". Further inventoried are the electricity for the assembly of the connector, the fuel oil, propane and water input, the disposal of plastic and rubber parts, the VOC and methanol emissions created during the processing, plus the road and rail transportation for input materials from the regional storage to the production site. The accummulated hazardous waste is also reported.
Amount	1
Local Name	Kabel, Flachbandkabel, 20 Pin, mit Stecker, ab Werk
Synonyms	
General Comment	This dataset can be applied to describe the production of a typical 20-way ribbon cable to connect drives to the motherboard of a computer. The total weight of 1 unit of ribbon cable (with connector) is 0.0242 kg and the length 0.24 m, whereof the plugs weigh 0.0167 kg and the 20-cores cable 0.0075 kg. These weights have been extrapolated to 1 kg of ribbon cable (factor 1/0.0242). The information for this dataset is based on calculations and analyses at EMPA Laboratories.
Start Date	2000
End Date	2006
Data valid for entire period	1
Geography Text	The data describes a typical ribbon cable in the years after 2000. The kind of ribbon cable is produced by international manufacturers and available all over the world. Therefore a global dataset is justifiable.
Technology Text	The manufacturing process is represented through plastic extrusion (for HDPE and PVC), tin-coating, contouring (brass), and wire drawing (copper).
Representativeness	unknown
Production Volume	unknown
Sampling Procedure	Weighing and measuring of materials. Literature for electricity consumption (assembly), emissions and waste.
Extrapolations	see Geography and Technology
Uncertainty Adjustments	see Geography and Technology

3.8.2 Life Cycle inventory and General Flow information

The layout of the dataset “cable, ribbon cable, 20-pin, with plugs” with general flow information, remarks, sources, values and uncertainty information are shown in Fig. 3.27 and Fig. 3.28 below.

Data Uncertainty and Input Data for Database ecoinvent

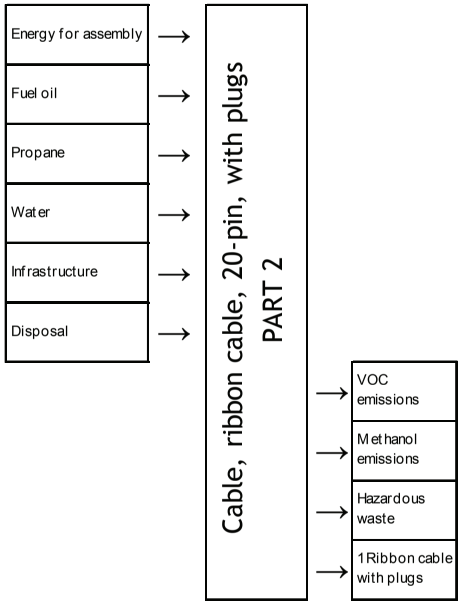
The datasets represent a typical 20-pin ribbon cable with plugs, calculated per 1 kg. The data are mainly based on measurements and calculations at EMPA laboratories. The fact that this typical rib-

bon cable does not represent the majority of world-wide available ribbon cables has been accounted for in the uncertainties of the dataset.

There is no direct natural resource input to the dataset “cable, ribbon cable, 20-pin, with plugs”. The infrastructure for the ribbon cable (with plug!) production has been taken into account and has been calculated via the annual production volume for a printed wiring board mounting plant described in Chapter 2.3.2. Further balanced for this ribbon cable dataset are process water, propane and fuel oil input, plastic and rubber disposal, direct air emissions of VOC and methanol, as well as hazardous waste. This information is retrieved from the Environmental Report by the Draka Norsk Kabel Company (Draka (2004)).

General Flow information							Representation in ecoinvent								Uncertainty		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent		Unit	Source	Type	StDv 95%	General Comment
Cable PVC jacket	→	Cable, ribbon cable, 20-pin, with plugs PART 1				Cable jacket for all the copper wires made out of PVC; insulation for 20 wires (each 24 cm long) with total weight of 3.75 g; total weight of ribbon cable including plugs 24.2 g; here calculated for 1kg of cable	plastics	polymers	No	RER	polyvinylchloride, at regional storage	1.55E-01	kg	Own measurements and calculations (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Extrusion of PVC	→					Extrusion of PVC for ribbon cable jacket	plastics	processing	No	RER	extrusion, plastic pipes	1.55E-01	kg	Own measurements and calculations (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Fine copper wires	→					Copper wires tin plated; diameter similar to network cable; 20 wires with total weight of 3.75 g	metals	extraction	No	RER	copper, at regional storage	1.55E-01	kg	Own measurements and calculations (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Wire drawing	→					Wire drawing of copper	metals	processing	No	RER	wire drawing, copper	1.55E-01	kg	Own measurements and calculations (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Tin plating of wires	→					Tin-coating of 20 wires; layer of 1.5 micrometer; zinc-coating process as proxy	metals	processing	No	RER	zinc coating, pieces	6.24E-01	m2	Own measurements and calculations (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
20-pin plug HDPE	→					Both plugs of ribbon cable made out of HDPE plastic; 16.6 g for 2 plugs	plastics	polymers	No	RER	polyethylene, HDPE, granulate, at plant	6.87E-01	kg	Own measurements and calculations (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Injection moulding of HDPE	→					Injection moulding of HDPE granulate into plug shape	plastics	processing	No	RER	injection moulding	6.87E-01	kg	Own measurements and calculations (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Brass contacts	→					20 contacts made out of brass	metals	extraction	No	CH	brass, at plant	3.31E-03	kg	Own measurements and calculations (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Contour brass	→					Infrastructure; assumed life time 6 years; photovoltaic factory as proxy	metals	processing	No	RER	contour, brass	3.31E-03	kg	Own measurements and calculations (EMPA St. Gallen)	1	1.24	(1,4,1,3,1,5,3)
Transportation road	→					Road transportation of materials to manufacturing site	transport systems	road	No	RER	transport, lorry >16t, fleet average	1.00E-01	tkm	ecoinvent standard transport distances	1	2.07	(3,4,1,3,1,5,5)
Transportation rail	→					Rail transportation of materials to manufacturing site	transport systems	train	No	RER	transport, freight, rail	2.00E-01	tkm	ecoinvent standard transport distances	1	2.07	(3,4,1,3,1,5,5)

Fig. 3.27 Unit process raw data of "cable, ribbon cable, 20-pin, with plugs" and their representation in the ecoinvent database (PART 1)



General Flow information							Representation in ecoinvent								Uncertainty		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent		Unit	Source	Type	StDv 95%	General Comment
						Internal process electric power consumption calculated by Nichigoh cable is 93.54 kWh/km	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	7.73E-01	kWh	Nichigoh Cable (2004)	1	1.24	(2,4,1,3,1,5,2)
						Fuel oil for process heating; 278 t/18600 t cable; efficiency 95%; 1 MJ requires 0.025 kg heavy fuel oil; calculated for 1 kg of cable	oil	heating systems	No	RER	heat, heavy fuel oil, at industrial furnace 1MW	6.26E-01	MJ	Draka Norsk Kabel AS (2004)	1	1.24	(2,4,1,3,1,5,1)
						Propane used for processes and fire testing; 3450 kg/18600 t cable; calculated for 1 kg of cable	oil	fuels	No	RER	propane/ butane, at refinery	1.85E-04	kg	Draka Norsk Kabel AS (2004)	1	1.24	(2,4,1,3,1,5,11)
						Water used for cooling, cleaning and sanitary purposes; 375100 m3/18600 t cable; 1 m3 = 1000 kg water; calculated for 1 kg of cable	water supply	production	No	RER	tap water, at user	2.02E+01	kg	Draka Norsk Kabel AS (2004)	1	1.24	(2,4,1,3,1,5,3)
						Dataset "printed wiring board mounting plant" used as a proxy; annual production volume 192 t, life-span 25 y	electronics	module	Yes	GLO	printed wiring board mounting plant	2.08E-07	unit	Assumed to be the same as 'printed wiring board	1	3.06	(2,4,1,3,1,5,9)
						Disposal of plastic and rubber; 470 t/18600 t of cable; calculated for 1 kg of cable	waste management	municipal incineration	No	CH	disposal, plastics, mixture, 15.3% water, to municipal incineration	2.53E-02	kg	Draka Norsk Kabel AS (2004)	1	1.24	(2,4,1,3,1,5,6)
						VOC emissions to air; 1.8 tons for 18600 t of cable; calculated for 1 kg of cable	air	low population density			NM VOC, non-methane volatile organic compounds,	9.68E-05	kg	Draka Norsk Kabel AS (2004)	1	2.06	(1,4,1,3,1,5,23)
						Methanol emissions to air; 2.4 tons for 18600 t of cables; calculated for 1 kg of cable	air	low population density			Methanol	1.29E-04	kg	Draka Norsk Kabel AS (2004)	1	2.06	(1,4,1,3,1,5,23)
						57 tons of hazardous waste from 18600 t of cables; calculated for 1 kg of cable	waste management	hazardous waste incineration	No	CH	disposal, hazardous waste, 25% water, to hazardous waste	3.06E-03	kg	Draka Norsk Kabel AS (2004)	1	1.24	(1,4,1,3,1,5,6)
							electronics	component	No	GLO	cable, ribbon cable, 20-pin, with plugs, at plant	1.00E+00	kg				

Fig. 3.28 Unit process raw data of "cable, ribbon cable, 20-pin, with plugs" and their representation in the ecoinvent database (PART 2)

4 Batteries

4.1 Introduction

This chapter documents the inventories of secondary[23], i.e. rechargeable, portable nickel-metal hydride (NiMH) and lithium-ion (LiIo) batteries. Key application of the here inventoried batteries is the energy supply in laptop computers. Both data sets (the NiMH and the LiIo rechargable battery, respectively) are primarily based on the handbook of batteries (Linden & Reddy (2002)) and the HITACHI MAXELL Environmental Report 2003 (MAXELL (2003)). In addition, own measurements of a rechargable Fujitsu-Siemens LiIo-battery type as used in Lifebook S-series (model: 6120D) is performed.

Most of the production processes base upon proprietary manufacturing technologies and environmental data are hardly available. Also, the battery technologies of the same electrode materials (e.g. LiIo or NiMH type) differ in terms of design and electrode composition in function of the mobile application they are intended to be used for. For this reason, the here inventoried battery data sets represent typical examples of energy supply solutions for mobile applications with focus on laptop applications. Neither the use nor their End-of-Life (EoL) treatment are part of these datasets here.

4.2 Material Characterisation & Market

In principle, all types of batteries that function by converting chemical energy stored in the electrode materials into electrical energy through electrochemical oxidation/reduction (Linden (2002)) consist of a rather similar construction as shown in Fig. 1.1.

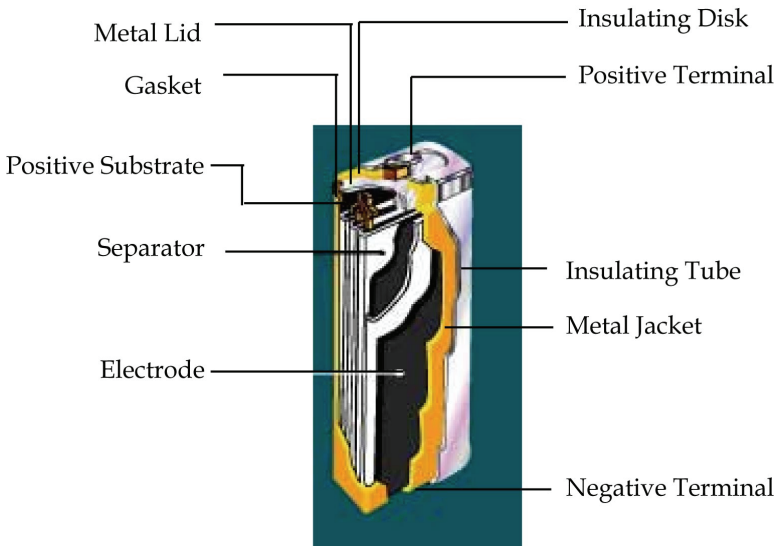


Fig. 4.1 Sketch of a prismatic battery with the typical elements denoted (adopted from Linden & Magnusen (2002) and W.L. Gore & Associates Inc. (2006))

Whereas battery elements such as housing, contacts, etc. consist of more or less the same materials (namely the moulds made of steel and plastic and the contacts primarily made of copper), there exist different electrode material compositions for NiMH and LiIo rechargable batteries (Fetcenko (2002), Linden & Magnusen (2002)). In Tab. 4.1 the major electrode material compositions are compiled.

[23] A **secondary** battery is an electrochemical cell in which the electrochemical reaction is readily reversible (**primary** batteries are not rechargeable).

Tab. 4.1 Examples of typical electrode compositions (taken from Fetcenko (2002), Linden & Magnusen (2002)).

NiMH-Batteries		LiIo-Batteries	
	$LaNi_5$		$LiCoO_2$
	$La_{5.7}Ce_{8.0}Pr_{0.8}Nd_{2.3}Ni_{59.2}Co_{12.2}Mn_{6.8}Al_{5.2}$ [a]	+	$LiNiO_2$
	$La_{10.5}Ce_{4.3}Pr_{0.5}Nd_{1.3}Ni_{60.1}Co_{12.7}Mn_{5.9}Al_{4.7}$ [a]		$LiMn_2O_4$
+	TiZr		$Li_{0.5}C_6$
	$V_{18}Ti_{15}Zr_{18}Ni_{29}Cr_5Co_7Mn_8$ [b]		LiC_6
	$V_5Ti_9Zr_{26.7}Ni_{38}Cr_5Mn_{16}Sn_{0.3}$ [b]	-	$LiWO_2$
	$V_5Ti_9Zr_{26.2}Ni_{38}Cr_{3.5}Co_{1.5}Mn_{15.6}Al_{0.4}Sn_{0.8}$ [b]		$LiMoO_2$
-	$Ni_{94}Co_3Zn_3$ [c]		$LiTiS_2$

[a] Both species represent the so-called AB_5 type. Figures indicate atomic percent

[b] All three species represent the so-called AB_2 type. Figures indicate atomic percent

[c] Figures indicate weight percent

The following electrode compositions are selected here for the inventoried NiMH and LiIo rechargable batteries (Reddy & Hossain (2002)):

- **NiMH** rechargable battery: positive electrode: **$LaNi_5$**; negative electrode: **$Ni_{94}Co_3Zn_3$**
- **LiIo** rechargable battery: positive electrode: **$LiMn_2O_4$**; negative electrode: **LiC_6**

Basic input materials of the inventoried rechargable batteries are thus:

- **NiMH**: Mischmetal, Ni, Co, Zn, Polyurethane, plus auxiliary materials consumed in the manufacturing processes.
- **LiIo**: Li_2Co_3, MnO_2, Li, C, plus auxiliary materials consumed in the manufacturing processes.

A detailed compilation of all materials is given in chapter 1.4 (System Characterisation). Other rechargable batteries like nickel-cadmium are not considered as their importance is drastically dropping (BAJ (2006), EPBA (2006), Buchmann (2004)). Fuel cells are neither taken into account due to the fact that they are still in a developing stage. First successful tests for energy supply have been made (see e.g. Arakawa (2005)) but they are currently not available on the market.

Most of the assembly processes today take place in the Asean region like Japan, China and Korea (Buchmann (2004)). However, the key markets (in terms of regions) are North America, Asia and Europe (BAJ (2006), Buchmann (2004)). In context of a growing volume of energy consuming mobile devices like laptops, notebooks, mobile phones, and personal digital assistants (PDA's) a further on increasing demand is expected in a near future (Buchmann (2004)). Thereby a transition trend from nickel-cadmium to NiMH to LiIo and further on to Li-polymer rechargable batteries becomes apparent, with nickel-cadmium rechargable batteries vanishing rapidly within the very next years and LiIo- and Li-polymer rechargable batteries just now becoming mature for the market.

Unisonous reports document a very heterogeneous recycling behaviour in Europe with Austria being the leader in taking back and recycling batteries and Great Britain being one of those countries where only a marginal fraction of the sold batteries are recycled (Aighton (2003)). In North America, 2.4 Mio pounds of all rechargable batteries is collected within a special RBRC programm (Brown & Gabor (2006)) – an amount that is however still very small compared with all the sold mobile appliances that use this type of energy supply.

4.3 Use & Application

According to recent forecasts there will be a trend towards increasing application of mobile devices requiring mobile energy supply solutions (c.f. Delpho (2005), Schullitz (2001) and GSMAssociation (2006)). The recent statistics unisonously indicate that nickel-cadmium solutions for mobile communiation equipment are nearly phased out and that NiMH solutions are increasingly replaced by LiIo and lithium polymer alternatives (c.f. EPBA (2006) and Buchmann (2004)). Key driver of this evolution is the demand for mobile energy supply solutions enabling long-term autnomous operation of electronic devices (Linden & Magnusen (2002)).

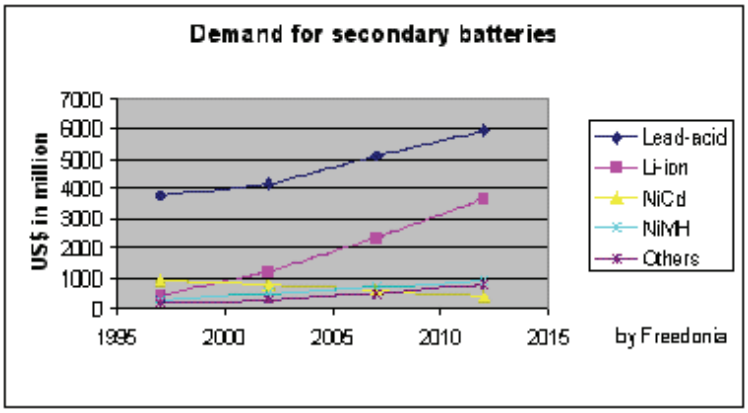


Fig. 4.2 **Worldwide demand (and forecasted demand) for secondary, i.e. rechargeable, batteries (graph taken from http://www.batteriesdigest.com/global_battery_market_growth.htm).**

4.4 System Characterisation

This part documents the inventories for the manufacturing of NiMH- and LiIo-rechargable batteries as well as the subsequent production steps (electrodes, electrolytes, …). The inventoried datasets represent global averages with focus on Japan and the data are valid for the period of 2002 to 2006.

The inventoried rechargable battery types are used when analysing the life cycle of laptop applications. Technically, the battery belongs to the group of secondary batteries (i.e. rechargable batteries). From its form factor the inventoried battery types are prismatic which is typical for mobile applications.

Fig. 4.3 **Example of a prismatic NiMH laptop rechargable battery (picture taken from http://www.amazon.co.uk/gp/product/B000F2BT1W/ref=pd_rvi_gw_1/026-4481762-8244443?ie=UTF8)**

The data sets „Battery, LiIo, rechargable, prismatic, at plant" and "Battery, NiMH, rechargable, prismatic, at plant" are covering final assemblies of the batteries, as well as the manufacturing of semi-finished products like subtrates, positive and negative terminals, separator lamina, insulation and housing components. The manufacturing of the electrodes (i.e. positive electrode of $LaNi_5$-type in case of a

NiMH rechargable battery and of $LiMn_2O_4$-type in case if a LiIo rechargable battery, resp. negative electrode of Ni-type in case of a NiMH rechargable battery and of LiC_6-type in case of a LiIo battery) as well as the manufacturing of the electrolyte are reported in separate datasets.

Emissions to air, soil and water as well as the production of by-products are only partly considered and rely solely on the HITACHI environmental report (MAXELL (2003)).

By-products, for example defective and thus non-marketable batteries, are not covered.

As auxiliary products requested in the battery assembly process thermal energy, electricity and the consumption of water are inventoried. Other auxiliaries potentially used are not considered due to missing knowledge. Also not included are transportation and administration processes, like office management and travels.

The inventoried manufacturing and assembly processes base on technologies typical for 2002-2006 and represent a global average with focus on Japanese conditions. The data sets only cover the technology to manufacture the types of rechargable batteries defined above. Also, the typical application of the inventoried battery types is energy supply for laptop applications. Other applications may require different battery types and systems resulting in different manufacturing technologies (cf. Linden & Reddy (2002)).

Key sources for the inventory of NiMH- and LiIo-rechargable batteries is: MAXELL (2003). Linden & Reddy (2002), Linden & Magnusen (2002), Ehrlich (2002), Fetcenko (2002), Reddy & Hossain (2002), Striebel et al. (2001), GFS Chemicals Inc. (2004), Joubert et al. (2002), Zabel et al. (1983), Freitas (2001), Jayashree & Kamath (2001), Subbaiah et al. (2002), Sakai et al. (1992), Li et al. (2004), Braun et al. (2001), Buchmann (2005), European Portable Battery Association (2000). Further background data is adopted from Freitas (2001), Dixit et al. (1996), Jayashree & Kamath (2001), Subbaiah et al. (2002), and Joubert et al. (2002).

Aisde the above mentioned literature, the technical data of NiMH-rechargable battery as applied in notebooks of the Fujitsu-Siemens C-series[24] and own measurements of a LiIo-rechargable battery as applied in a Fujitsu-Siemens S-series notebook (model: S6120D) (Fujitsu-Siemens (2005)) is used to specify a typical average size of a NiMH-rechargable battery applied in a notebook.

4.5 Battery plant

According to MAXELL (2003), the total surface area of the Osaka site is about 75'562 m^2. The total floor space of all buildings is about 38'900 m^2. In the same time, there is no information – neither in literature, nor in the internet – available concerning the faciltities inside such a plant. Hence, instead of developing a proper dataset for the battery plant, the dataset "facilities precious metal refinery" is used as a proxy.

4.6 NiMH rechargable batteries for laptop applications

The described inventory of the manufacturing of a NiMH rechargable battery for laptop applications is conceptualised as a series of unit processes comprising the manufacturing of the negative and the positive electrode, the electrolyte and the final assembly of the NiMH rechargable battery. In Fig. 4.4 a schematic view of the different parts is shown.

[24] Fujitsu Siemens LifeBook C4135 NiMH, 2-Power Laptop Battery 4500mAh (http:/www.amazon.co.uk/gp/product/B000F2-BT1W/ref=pdf_rvi_gw_1/026-4481762-8244443?ie=UTF8), accessed October 12, 2006.

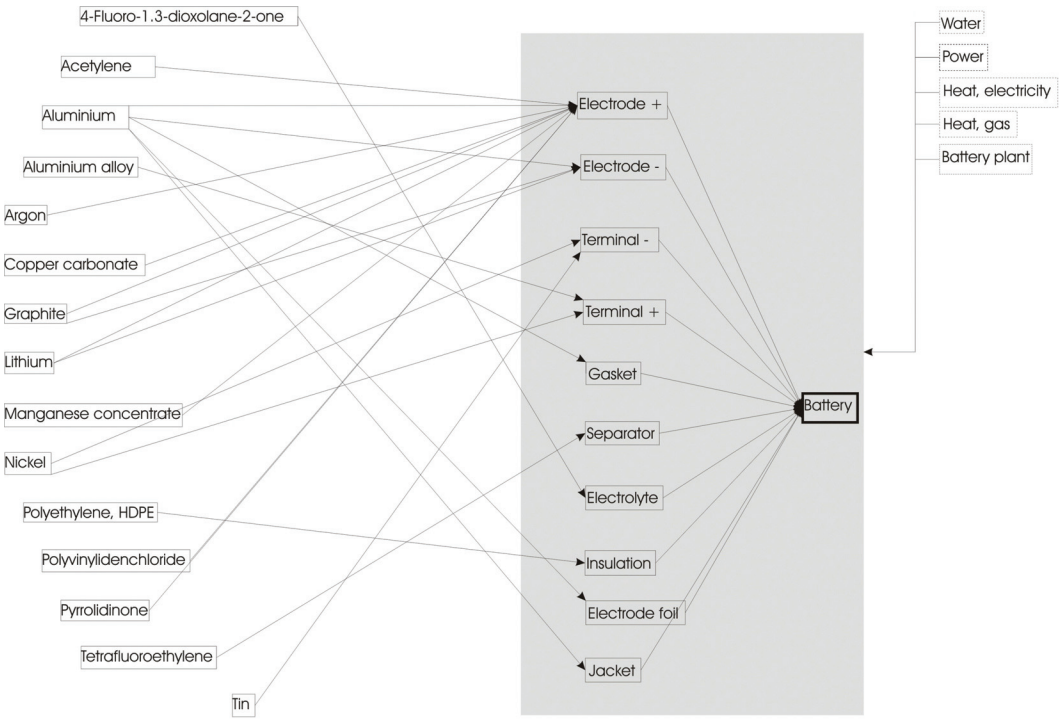


Fig. 4.4 **Scheme of input flows of the dataset "Battery, LiIo, rechargable, prismatic, at plant". Production auxiliaries (like chemicals) and emissions are not shown.**

4.6.1 Dimensioning of the reference product

As reference product a NiMH battery package as used in a Fujitsu-Siemens laptop (model: C4135 see Fig. 4.3) is selected. The specification of this type of battery package is shown in Tab. 4.2. For simplification it is approximated that the battery package consisted of only one large sized battery cell. Technologically a battery cell consists of a multilayered assembly of coats sandwiched to each other and wound eiter circular or prismatically around a virtual axis (see Fig. 4.6). The size of this wound layer assembly is specified based on approximations for single cell layer assembly as contained in a LiIo rechargable battery as used in Fujitsu-Siemens laptops (model: S6120D) depicted in Fig. 4.6 (Fujitsu-Siemens (2005)).

Tab. 4.2 **Specifications of the selected reference product (Data taken from Amazon.co.uk[25])**

	NiMH battery package
Model	UBP0767B
Size (W x D x H [mm])	138.00 x 105.00 x 20.00
Weight [kg]	0.591
Capacity [mAh]	4500
Number of cells	1

The mass of the entire multilayer cell assembly of the considered reference NiMH rechargable battery package is approximated based upon size approximations for the above noted LiIo battery model and is made as follows:

[25] Fujitsu Siemens LifeBook C4135 NiMH, 2-Power Laptop Battery 4500mAh (http:/www.amazon.co.uk/gp/product/B000F2-BT1W/ref=pdf_rvi_gw_1/026-4481762-8244443?ie=UTF8), accessed October 12, 2006.

-> Cell layer assembly length (LiIo rechargable battery):	100.00 mm
-> Cell layer assembly width (LiIo rechargable battery):	60.00 mm
-> Battery length (LiIo rechargable battery):	128.00 mm
-> Battery width (LiIo rechargable battery):	77.00 mm
-> Battery length (NiMH rechargable battery):	138.00 mm

The calculation is then performed as follows:

<- Cell layer assembly length (NiMH rechargable battery):

100.00 mm / 128.00 mm = 78.125%

138.00 mm *0.781 = 107.81 mm

<- Cell layer assembly width (NiMH rechargable battery):

60.00 mm / 77.00 mm = 77.922%

105.00 mm *0.779 = 81.81 mm

The thickness (i.e. the depth) of the single unwound layer compartments is approximated with 0.15 mm (cf.: Linden & Magnusen (2002)). Accordingly the single layers are dimensioned as follows (W x D x H): 81.81 mm x 0.15 mm x 107.81 mm.

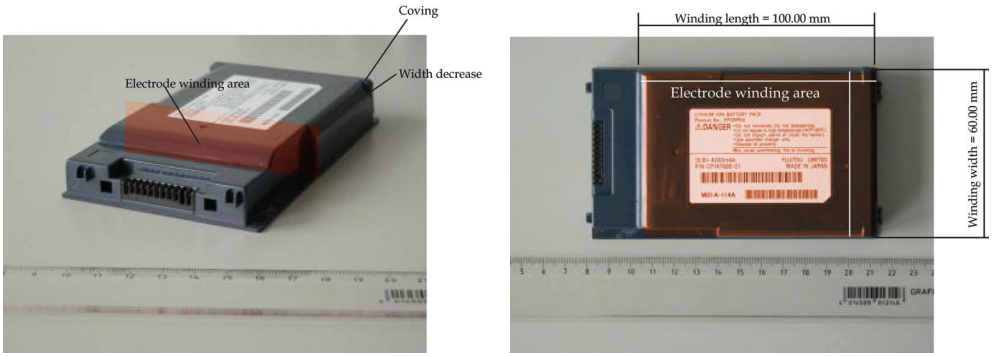


Fig. 4.5 **To the left: estimation of the winding size (width and depth based upon measurments). To the right: approximation of the width decrease in dependence upon the coving on the corners and the increasing winding width with increasing number of windings.**

According to Reddy & Hossain (2002) such a multilayer package consists of 5 individual layers, namely positive and negative electrode, separator and electrolyte layer. The thickness of the entire prismatically wound multilayer assembly is approximated to 13.5 mm. Adopting the above defined thickness for a single layer (0.15 mm), the entire prismatically wound multilayer assembly consists in total of 90 individual layers and 18 windings (with each time 5 individual layers).

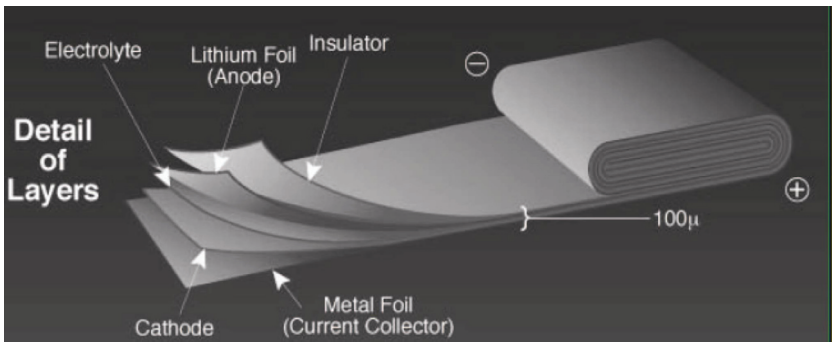


Fig. 4.6 Drawing of a twisted Lilo electrode package (adopted from Reddy & Hossain (2002)).

For this type of battery package, the following itemized datasets have been established:

- "*Electrode, positive, LaNi5, at plant*": production of the positive electrode chosen for the here established dataset of a NiMH rechargable battery package
- "*Electrode, negative, Ni, at plant*": production of the negative electrode chosen for the here established dataset of a NiMH rechargable battery package
- "*Electrolyte, KOH, LiOH additive, at plant*": production of the electrolyte chosen for the here established dataset of a NiMH rechargable battery package
- "*Battery, NiMH, rechargable, prismatic, at plant*": production of all further components of a NiMH rechargable battery package (separator, housing, inner lining, positive substrate, terminals, contacts,) as well as the efforts (energy & water consumption) for the final assembly of the battery package

The metadata of these various datasets for the NiMH battery are given in Tab. 4.3 and Tab. 4.4, their exchanges are shown in Fig. 4.7 to Fig. 4.10.

Tab. 4.3 ecoinvent meta information of the processes for the production of NiMH-rechargable batteries.

Name	**Battery, NiMH, rechargable, prismatic, at plant**	**Electrode, positive, LaNi5, at plant**
Location	GLO	GLO
Infrastructure Process	0	0
Unit	kg	kg
Included Processes	(Raw) materials, infrastructure, energy consumption and waste disposal for the production of a NiMH battery. No emissions to air or water are taken into account.	(Raw) materials, infrastructure and energy consumption for the production of the positive electrode for NiMH batteries. No emissions to air or water are taken into account.
Amount	1	1
Local Name	Batterie, NiMH, aufladbar, prismatisch, ab Werk	Elektrode, positiv, LaNi5, ab Werk
Synonyms	NiMH-akku	
General Comment	The functional unit represents 1 kg of a NiMH battery for laptop applications. A typical such NiMH battery has a weight of 0.591 kg. Process data is taken mainly from an environmental report of a battery producer as well as from literature. In addition own measurements of sizes and weights of batteries are used.	The functional unit represents 1 kg of the positive LaNi5 electrode material for the production of NiMH batteries. Process data is taken mainly from an environmental report of a battery producer as well as from literature. In addition own measurements of sizes and weights of batteries are used.
Start Date	2002	2002
End Date	2006	2006
Data valid for entire period	1	1
Geography Text	This dataset relates to the global situation.	This dataset relates to the global situation.
Technology Text	Construction details as described for NiMH-rechargable batteries and manufacturing conditions as documented in the environmental report is adopted.	Construction details as described for NiMH-rechargable batteries and manufacturing conditions as documented in the environmental report is adopted.
Representativeness	nn	nn
Production Volume	183’000 t in 2005 (own calculations)	
Sampling Procedure	Literature, measurements	Literature, measurements
Extrapolations	see Geography and Technology	see Geography and Technology
Uncertainty Adjustments	none	none

Tab. 4.4 (Cont.) ecoinvent meta information of the processes for the production of NiMH-rechargable batteries.

Name	Electrode, negative, Ni, at plant	Electrolyte, KOH, LiOH additive, at plant
Location	GLO	GLO
Infrastructure Process	0	0
Unit	kg	kg
Included Processes	(Raw) materials, infrastructure, energy consumption and waste disposal for the production of the negative electrode of NiMH batteries. No emissions to air or water are taken into account.	(Raw) materials, infrastructure and energy consumption for the production of the electrolyte for NiMH batteries. No emissions to air or water are taken into account.
Amount	1	1
Local Name	Elektrode, negativ, Ni, ab Werk	Elektrolyt, KOH, LiOH-zusatz, ab Werk
Synonyms		
General Comment	The functional unit represents 1 kg of the negative Ni electrode material for the production of NiMH batteries. Process data is taken mainly from an environmental report of a battery producer as well as from literature. In addition own measurements of sizes and weights of batteries are used.	The functional unit represents 1 kg of electrolyte material for the production of NiMH batteries. Process data is taken mainly from an environmental report of a battery producer as well as from literature. In addition own measurements of sizes and weights of batteries are used.
Start Date	2002	2002
End Date	2006	2006
Data valid for entire period	1	1
Geography Text	This dataset relates to the global situation.	This dataset relates to the global situation.
Technology Text	Construction details as described for NiMH-rechargable batteries and manufacturing conditions as documented in the environmental report is adopted.	Construction details as described for NiMH-rechargable batteries and manufacturing conditions as documented in the environmental report is adopted.
Representativeness		
Production Volume		
Sampling Procedure	Literature, measurements	Literature, measurements
Extrapolations	see Geography and Technology	see Geography and Technology
Uncertainty Adjustments	none	none

4.6.2 Dataset "Electrode, positive, $LaNi_5$, at plant"

Adopting the above determined electrode and battery dimensions this dataset covers the manufacturing of the positive battery electrode including the main input materials and the electrical energy consumed during the manufacturing of the positive electrode. Basic input materials are mischmetal (Sakai et al. (1992), Linden & Magnusen (2002)), tetrafluoroethylene (Linden & Magnusen (2002)), liquid hydrogen (Linden & Magnusen (2002), Sakai et al. (1992)) and nickel (Sakai et al. (1992)). Thereby liquid hydrogen is used to pulverise the mischmetal and nickel is used for particle coating (Sakai et al. (1992)). Tetrafluoroethylene is used to produce the electrode paste (Linden & Magnusen (2002)). Based on the specificitions of the here inventoried battery (see chapter 4.6.1) and adopting a density of 8310 kg/m3 for $LaNi_5$ (Joubert et al. (2002)) the total mass of $LaNi_5$ per kg NiMH rechargable battery package of 0.3348 kg $LaNi_5$ electrode is determined as follows:

<- 0.10781 m*0.08181 m*0.00015 m*8310 kg/m^3*18 = 0.1979 kg $LaNi_5$ / NiMH battery package

<- 0.1979 kg*1 kg / 0.591 kg = 0.3348 kg $LaNi_5$ / kg NiMH battery package

No direct emissions to air, soil and water associated with the assembly of the $LaNi_5$ electrode could be inventoried as no information is available with the exception of heat emission to air which is derived directly from the amount of electrical powere supplied during the electrode manufacturing process.

The relevant amount of infrastructure is determined adopting the information from the MAXELL (2003) environmental report. The following assumptions are made to approximate the infrastructure demand per kg $LaNi_5$ electrode:

-> $LaNi_5$ content per battery package:	0.3348 kg/kg NiMH battery package
-> Life time of the HITACHI Kyoto plant (own assumption):	50 years
-> Total battery package production capacity assumption for Kyoto in 2003 (own assumption):	1/3
-> Total NiMH battery package production capacity for Kyoto in 2003 (approx. from Fig.2):	0.4
-> Total consolidated net sales of batteries in 2003 (MAXELL (2003)):	65'532'000'000 ¥
-> Average price of a NiMH laptop battery package in 2006[26]:	98.89 £
-> Currency course ¥ <>CHF (exchange rate at Aug 25, 2006):	100 ¥ = 1.11 CHF
-> Currency course £ <> CHF (exchange rate at Oct 12, 2006):	1 £ = 2.44 CHF

The calculation is then performed as follows:

<- Single price of NiMH rechargable battery: 91.89 £ = 224.44 CHF

<- Conversion of consolidated net sales: 65'532'000'000 ¥ = 727'405'200 CHF

<- NiMH revenue fraction: 727'405'200 CHF * (1/3) * 0.4 = 96'987'360 CHF

<- Annual NiMH battery package production:

96'987'360 CHF / 224.44 CHF = 432'130 NiMH battery package/year

<- Annual $LaNi_5$ electrode production:

432'130 electrodes /year * 0.3348 kg $LaNi_5$ = 144'696 kg $LaNi_5$ / kg NiMH battery package

<- Infrastructure demand per kg $LaNi_5$ electrode:

1 plant/ (144'696 kg$LaNi_5$ electrode /year * 50 years) = 1.3822e-7 plants/kg $LaNi_5$

4.6.3 Dataset "Electrode, negative, Ni, at plant"

The amount of negative electrode ($Ni_{94}Co_3Zn_3$) has been calculated similarly as the mass of the positive electrode in the preceding chapter. Accordingly, this dataset covers the manufacturing of the negative electrode considering the main input materials as well as the electricity consumed to manufacture the negative electrode. Basic input materials are polyurethane foam, nickel, cobalt, zinc, sintered nickel, sodium hydroxide as well as thermal energy, water and electrical energy (Linden & Magnusen (2002), Freitas (2001), Jayashree & Kamath (2001), Subbaiah et al. (2002), Sakai et al. (1992)). Thereby, the polyurethane foam is used as a proxy for the construction of the nickel mesh (Linden & Magnusen (2002)). The nickel skeleton is accomplished by vapour deposition onto the polyurethane foam (Linden & Magnusen (2002)) and thereafter the polyurethane foam is removed and disposed of as waste in a landfill (Linden & Magnusen (2002)). The nickel-, cobalt- and zinc-composite is used- to physically load nickel oxyhdydroxide onto the nickel skeleton (Linden & Magnusen (2002), Freitas (2001)). The sodium hydroxide is used for degreasing the sintered nickel. Based on the specificitions of the here inventoried battery (see chapter 4.6.1) and using a density of 8908 kg/m3 for Ni the total mass of Ni per kg NiMH rechargable battery package of 0.3589 kg Ni electrode is determined.

No direct emissions to air, soil and water associated with the assembly of the Ni electrode could be inventoried as no information is available with the exception of heat emission to air which is derived directly from the amount of electrical powere supplied during the electrode manufacturing process. As

[26] Fujitsu Siemens LifeBook C4135 NiMH, 2-Power Laptop Battery 4500mAh (http:/www.amazon.co.uk/gp/product/B000F2-BT1W/ref=pdf_rvi_gw_1/026-4481762-8244443?ie=UTF8), accessed October 12, 2006.

waste only the polyurethane foam from the Ni skeleton assembly is considered (thermal treatement and final disposal).

The relevant amount of infrastructure is determined adopting the information from the MAXELL (2003) environmental report in a similar manner like for the positive LaNi5 electrode. This calculation is performed as follows:

<- Single price of NiMH rechargable battery: 91.89 £ = 224.44 CHF
<- Conversion of consolidated net sales: 65'532'000'000 ¥ = 727'405'200 CHF
<- NiMH revenue fraction: 727'405'200 CHF * (1/3) * 0.4 = 96'987'360 CHF
<- Annual NiMH battery package production:
96'987'360 CHF / 224.44 CHF = 432'130 NiMH battery package/year
<- Annual Ni electrode production:
432'130 Ni electrode /year * 0.3589 kg Ni = 155'113 kg Ni / kg NiMH battery package
<- Infrastructure demand per kg Ni electrode:
1 plant/ (155'113 kg Ni electrode /year * 50 years) = 1.2894e-7 plants/kg Ni

4.6.4 Dataset "Electrolyte, KOH (30%), LiOH additive, at plant"

The amount of electrolyte is calculated similarly like the mass of the electrodes. Accordingly, this dataset covers the main input materials and the electricity consumed to produce the electrolyte. Input materials are lithium, water and sodium hydroxide. In addition, oxygen, consumed in the oxidation of lithium, and water, used in the synthesis of LiOH from Li_2O, and representing auxiliary materials are taken into account (Linden & Magnusen (2002), Fetcenko (2002)). Based on the specificitions of the here inventoried battery (see chapter 4.6.1) and using a density of 2040 kg/m^3 for KOH the total mass of electrolyte per kg NiMH rechargable battery package is determined as 0.0822 kg electrolyte per kg of NiMH battery.

No direct emissions to air, soil and water associated with the production of the electrolyte could be inventoried as no information is available with the exception of heat emission to air which is derived directly from the amount of electrical power used during the manufacturing process.

The relevant amount of infrastructure is determined as follows:

-> Electrolyte content per battery package: 0.0822 kg/kg NiMH battery package
-> Life time of the Shenzen BAK Battery Co. plant (own assumption): 30 years
-> Total electrolyte throughput in 2003 (Shenzen BAK Battery Co. (2006)) 100'000

The calculation is then performed as follows:

<- 1 plant/ (1'000'000 electrolytes per day * 0.0822 kg electrolyte *50 years*365 d)

= 1.1109E-09 plants/kg electrolyte

4.6.5 Dataset "Battery, NiMH, rechargable, prismatic, at plant"

Housing

As basic input material of the housing of the battery, polycarbonate (PC) is inventoried with a thickness of 1.0 mm (own measurements and averaged over the entire mould) and a density of 1240 kg/m^3. No explicit information could be found on the separator production process. Thus, the processing is modelled by adopting the ecoinvent data set "injection moulding" and the material (Hischier (2007)). The calculation of the amount is performed as follows

<- Surface *S* = (0.138 m * 0.105 m * 2) + (0.105 m * 0.02 m * 2) + (0.138 m * 0.02 m * 2)

S * 0.001 m * 1240 kg/m^3 = 0.072 kg PC / NiMH battery package

0.071982 kg * 1 kg / 0.591 kg = 0.0812 kg PC/ kg NiMH battery package

Housing, inner lining (battery jacket)

The manufacturing of the battery jacket is modelled by inventorying steel (Classen et al. (2007)) as basic input material. The thickness of the steel jacket is set to 0.09 mm and the density of steel is 7850 kg/m^3. The calculation is performed as shown above, resulting in 0.046 kg steel/kg battery. No explicit information could be found on the lining production process but the processing of the jacket is modelled by adopting the ecoinvent data set "Sheet rolling, steel, at plant" plus the materials (Classen et al. (2007)). No other processes and related material and energy consumptions or emissions are inventoried.

Separator

This part is made out of polypropylene and polyethylene (Calábek et al. (2006), Noda et al. (2005), W.L. Gore & Associates Inc. (2003), Fetcenko (2002)). Using a density for PP of 920 kg/m^3 and for PE-LDPE of 910 kg/m^3 and assuming a share of PP and PE-LDPE composite of 50 Vol-% each, an amount of 0.01854 kg PP resp. 0.0183 kg LDPE result per kg of NiMH battery package. No explicit information could be found on the separator production process. Thus, the processing is modelled by adopting the ecoinvent data set "injection moulding" plus the materials (Hischier (2007)).

According to the literature (Noda et al. (2005)) acrylic acid is inventoried as additive (share: ≈ 7.22%) to the PP/PE-LDPE separator with an amount of 0.00093 kg per kg of NiMH battery packages. No further processes and related material and energy consumptions or emissions are inventoried.

Substrate

Nickel is inventoried as basic input material of the substrate ((Fetcenko (2002), Linden & Magnusen (2002)). The thickness of the substrate (see Fig. 4) alloy is assumed to be 0.1 mm and the density of nickel is 8908 kg/m^3. No explicit information could be found concerning the substrate production process, hence the processing of the substrate is modelled by adopting the ecoinvent data set "Sheet rolling, steel, at plant" (Classen et al. (2007)). No other processes and related material and energy consumptions or emissions are inventoried. The calculation of the amount is performed as follows:

<- (0.138 m * 0.105 m * 0.0001 m) * 2 + (0.105 m * 0.02 m * 0.0001 m) * 2 +

(0.138 m * 0.02 m * 0.0001 m) * 2 * 8908 kg/m^3 = 0.0266 kg Ni /NiMH battery package

0.0266 kg * 1 kg / 0.591 kg = 0.058 kg Ni/ kg NiMH battery package

Terminals (positive, negative)

Copper is inventoried as the basic input material for the negative and positive terminals (Linden & Reddy (2002)). The number of contacts is set to 12 (Fig. 7 to the right). Based on own measurements a size of (W x D x H): 2.00 mm x 0.00001 mm x 1.00 mm is determined. The density of copper is 8920 kg/m^3. No explicit information could be found concerning the substrate production process, hence the processing of the terminals is modelled by adopting the ecoinvent data set "Sheet rolling, copper, at plant" (Classen et al. (2007)). No other processes and related material and energy consumptions or emissions are inventoried. The calculation of the amount is performed as follows:

<- 0.002 m * 0.001 m * 0.0000001 m * 8920 kg/m^3 * 12

= 0.0000021408 kg Cu-contacts / NiMH battery package

<- 0.0000021408 kg * 1 kg / 0.591 kg = 3.622e-6 kg Cu / kg NiMH battery package

Contact plating

Zinc is inventoried as coating material applied to the positive and negative terminals (Linden & Reddy (2002)). It is assumed that the share of zinc amounts to 1 wt% of the terminal weights (made of copper) and is calculated to 3.6223e-8 kg zinc per kg NiMH battery package. The coating process including energy and auxiliary supply etc. is approximated by adopting the ecoinvent data set "zinc coating, pieces" (Classen et al. (2007)).

Final Assembly of NiMH battery package

To run the battery assmbly process four different auxiliary materials have been taken into account – thermal heat from natural gas, thermal heat from light fuel oil, electrical power and water. The amount of the four auxiliaries consumed during the battery assembly is calculated based on the information documented in MAXELL (2003).

For electrical power the following specifications (if not otherwise mentioned, from MAXELL (2003) is adopted and pre-assumptions made:

-> Total power consumption at HITACHI:	140'000'000 kWh
-> Total area of HTACHI plants:	721'000 m^2
-> Area of Kyoto work:	211'647 m^2
-> Total rechargable battery production capacity at Kyoto works:	1/3
-> Total NiMH battery package production capacity for Kyoto in 2003 (own approximation):	0.6
-> Total consolidated net sales of batteries in 2003):	65'532'000'000 ¥
-> Average price of a NiMH rechageable battery in 2006 [27]:	91.89 £
-> Currency course ¥ <>CHF (exchange rate at Aug 25, 2006):	100 ¥ = 1.11 CHF
-> Currency course £ <> CHF (exchange rate at Oct 12, 2006):	1 £ = 2.44 CHF

The calculation is then performed as follows:

<- Production area share of Kyoto plant: 211'647 m2 * 100% / 720'168 m2 = 29.4%

<- NiMH production area share of Kyoto plant: 29.4%* (1/3)*0.4 = 3.92%

<- Total annual power consumption for NiMH production:

3.92%*140'000'000 kWh/100% = 5'485'573 kWh

<- Conversion of GB-£ NiMH price into CHF: 91.89 £ = 224.44 CHF

<- Conversion of ¥-consolidated net sales into CHF: 65'532'000'000 ¥ = 727'405'200 CHF

<- Number of NiMH produced:

727'405'200 CHF * (1/3) * 0.4/ 224.44 CHF = 432'130 NiMH battery packages

<- Electrical power consumed per NiMH rechargable battery produced:

5'485'573 kWh / 432'130 NiMH battery package = 12.7 kWh / NiMH battery package

<- Electrical power consumed per kg NiMH rechargable battery produced:

12.7 kWh/ NiMH battery package * 1 kg / 0.591 kg = 21.5 kWh /kg NiMH battery package

Based on the above documented specifications and adopting the total annual thermal energy consumption at HITACHI of 1'349'000.00 L light fuel oil (MAXELL (2003)) the amount of thermal energy consumed per kg NiMH battery package is calculated as 8.4 MJ per kg batteries. Concerning the consumption of natural gas, a total consumption of 10'700'000 m^3 is reported in MAXELL (2003), resulting in 59.1 MJ of natural gas per kg NiMH battery packages.

[27] Fujitsu Siemens LifeBook C4135 NiMH, 2-Power Laptop Battery 4500mAh (http:/www.amazon.co.uk/gp/product/B000F2-BT1W/ref=pdf_rvi_gw_1/026-4481762-8244443?ie=UTF8), accessed October 12, 2006.

Last but not least, the amount of water is calculated adopting again the above made specifications and is approximated taking the annual water consumption at HITACHI of 1'190'000 m^3. This results in a consumption of 182.6 m^3 water per kg of battery packages.

Infrastructure

The infrastructure, i.e. the share of battery plant consumed to finally assemble 1 kg of NiMH rechargable battery packages is calculated adopting the above made specifications and assuming a life time of the battery plant of 50 years. Hence an amount of 7.831e-8 plants per kg battery packages results from this calculation.

4.6.6 Data uncertainty

The inventoried data set relies on the most recently available literature information reflecting NiMH rechargable battery technology for laptop applications as used in the past few years (2002-2006). Own available measurements are used to approximate the dimension of the key battery components. However, the dataset is subject to several limitations:

- No comprehensive and complete information about industrial battery production technologies;
- No environmental data (i.e. emissions, waste) directly associated with the battery manufacturing;
- No information concerning the consumption of auxiliaries.

According to the identified limitations the corresponding uncertainty is documented.

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Electrode, positive, LaNi5, at plant	G	battery, NiMH, rechargeable, prismatic, at plant				component, estimated based on the density assumption of 6.0 g/cm3 for metallhydride	electronics	component	No	GLO	Electrode, positive, LaNi5, at plant	3.35E-01	kg	Linden and Reddy, 2002; Freitas, 2001; Sakai et al., 1992	1	1.20	(3,4,3,2,1,3,4)
Electrode, negative, Ni, at plant	G					component, estimated based on the total volume of a NOKIA 3330 NiMH accu and the assumption that the electrolyte occupies about 40 %of the total accu volume	electronics	module	No	GLO	Electrode, negative, Ni, at plant	3.59E-01	kg	Linden and Reddy, 2002; Dixit et al., 1996; Freitas, 2001; Jayashree and Kamath, 2001; Subbaiah et al., 2002	1	1.20	(3,4,3,2,1,3,4)
Electrolyte, KOH (30%), LiOH additive, at plant	G					basic material of PP/PE separator (proxy, without PE), calculated based on JofPowerSources (check for 'JofPowerSources_Calábeket al_2005.pdf) and based on the physical dimension of a NOKIA 3330 NiMH accu	electronics	component	No	GLO	Electrolyte, KOH, LiOH additive, at plant	8.22E-02	kg	Linden and Reddy, 2002	1	1.20	(3,4,3,2,1,3,4)
Polypropylene, granulate, at plant	G						plastics	polymers	No	RER	polypropylene, granulate, at plant	1.85E-02	kg	NOKIA, 2006; Calábek et al., 2006	1	1.16	(3,4,1,2,1,3,4)
Polyethylene, LDPE, granulate, at plant	G						plastics	polymers	No	RER	polyethylene, LDPE, granulate, at plant	1.83E-02	kg	NOKIA, 2006; Calábek et al., 2006	1	1.16	(3,4,1,2,1,3,4)
processing Polypropylene and Polyethylene (LDPE)	G					additive to the PP separator, estimated based on a NOKIA 3330 accu (1%of the casing mass was assumed to be the mass of the acrylic acid additive)	plastics	processing	No	RER	injection moulding	3.69E-02	kg	NOKIA, 2006; Calábek et al., 2006	1	1.16	(3,4,1,2,1,3,4)
Acrylic acid, at plant	G					basic material for tube insulating (non-moulded), calculated based on measurements of a NOKIA 3330 accu	chemicals	organics	No	RER	acrylic acid, at plant	1.34E-03	kg		1	1.57	(5,5,1,2,1,3,4)
Polycarbonate, at plant	G			continued ▼			plastics	polymers	No	RER	polycarbonate, at plant	8.12E-02	kg	NOKIA, 2006	1	1.31	(4,5,1,2,1,3,4)

Fig. 4.7 Unit process inventories of the data set Battery, NiMH, rechargable, prismatic, at plant.

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Loca-tion	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
				▼ continued													
Steel, low-alloyed, at plant	S	battery, NiMH, rechargeable, prismatic, at plant				proxy for the jacket, gasket, lid basic material, estimated based on NOKIA 3330 accu	metals	extraction	No	RER	steel, low-alloyed, at plant	4.63E-02	kg	Linden and Reddy, 2002	1	1.31	(4,5,2,2,1,3,4)
Nickel, 99.5% at plant	S					proxy for the steel nickel for the positive substrate alloy, calculated based on measurments of a NOKIA 3330 accu	metals	extraction	No	GLO	nickel, 99.5% at plant	5.83E-02	kg	Linden and Reddy, 2002	1	1.31	(4,5,2,2,1,3,4)
processing of steel and nickel	S					proxy for the jacket, gasket, lid formation, and proxy for the steel nickel substrate alloy, estimated based on NOKIA 3330 accu	metals	processing	No	RER	sheet rolling, steel	1.05E-01	kg	Linden and Reddy, 2002	1	1.31	(4,5,2,2,1,3,4)
Copper, primary, at refinery	S					basic input material for terminal (negative, positive), calculated for both terminals based in measurments of a NOKIA 3330 accu	metals	extraction	No	RAS	copper, primary, at refinery	3.62E-06	kg	Linden and Reddy, 2002	1	1.13	(1,4,2,2,1,3,4)
Processing of copper	S					proxy for terminal (negative, positive) formation, estimated based on measurments of a NOKIA 3330 accu	metals	processing	No	RER	sheet rolling, copper	3.62E-06	kg	Linden and Reddy, 2002	1	1.13	(1,4,2,2,1,3,4)
Zinc for coating, at regional storage	S					coating for the terminals, estimated based on a NOKIA 3330 accu (1% of the terminal mass was assumed to be the mass of the coating)	metals	extraction	No	RER	zinc for coating, at regional storage	3.62E-08	kg	Linden and Reddy, 2002	1	1.57	(5,5,2,2,1,3,4)
coating process	S					zinc coating process	metals	processing	No	RER	zinc coating, pieces	4.81E-05	m2	Linden and Reddy, 2002	1	1.57	(5,5,2,2,1,3,4)
Electricity, high voltage, production UCTE, at grid	S			continued ▼		power needed for form the tube insulating, needed by the final accu manufacturer to run his facitlities (see HitachiMaxel Env Report 2003), estimated based on the HITACHI Env Report 2003 + the exchange rate Y <-> CHF 2006-02-22	electricity	production mix	No	UCTE	electricity, production mix UCTE	2.15E+01	kWh	HitachiMaxell Env Report 2003	1	1.13	(1,4,1,2,1,3,2)

Fig. 4.7 Unit process inventories of the data set Battery, NiMH, rechargable, prismatic, at plant. (Cont.)

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Loca-tion	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
				▼ continued													
Heat, light fuel oil, at industrial furnace 1MW		battery, NiMH, rechargeable, prismatic, at plant				needed by the final accu manufacturer to run his facitlities (see HitachiMaxel Env Report 2003), estimated based on the HITACHI Env Report 2003 + the exchange rate Y <-> CHF 2006-02-22	oil	heating systems	No	RER	heat, light fuel oil, at industrial furnace 1MW	8.41E+00	MJ	HitachiMaxell Env Report 2003	1	1.13	(1,4,1,2,1,3,1)
Water, decarbonised, at plant						water needed for cooling process water, needed by the final accu manufacturer to run hi facitlities (see HitachiMaxel Env Report 2003), estimated based on the HITACHI Env Report 2003 + the exchange rate Y <-> CHF 2006-02-22	water supply	production	No	RER	water, decarbonised, at plant	1.83E+02	kg	HitachiMaxell Env Report 2003	1	1.13	(1,4,1,2,1,3,11)
Heat, natural gas, at industrial furnace low-NOx >100kW						consumed by the final battery manufacturer (see Env Report HitachiMaxell 2003), estimated based on the HITACHI Env Report 2003 + the exchange rate Y <-> CHF 2006-02-22	natural gas	heating systems	No	RER	heat, natural gas, at industrial furnace low-NOx >100kW	5.91E+01	MJ	HitachiMaxell Env Report 2003	1	1.13	(1,4,1,2,1,3,1)
Battery Plant						as proxy, the precious metalls plant (see chapter xy) is used	electronics	Metals	Yes	SE	facilities precious metal refinery	7.83E-08	Unit	HitachiMaxell 2003	1		(2,4,1,2,1,3,9)
				Heat, waste, to air			air	unspecified			Heat, waste	7.73E+01	MJ		1	1.13	(1,4,1,2,1,3,13)
				Disposal, hazardous waste, 25% water, to hazardous waste incineration		estimated based on the HITACHI Env Report 2003 + the exchange rate Y <-> CHF 2006-02-22	waste management	hazardous waste incineration	No	CH	disposal, hazardous waste, 25%water, to hazardous waste incineration	8.84E-01	kg	HitachiMaxell Env Report 2003	1	1.52	(1,4,1,2,1,3,31)
			a	Battery, NiMH, rechargable, prismatic, at plant			electronics	module	No	GLO	battery, NiMH, rechargeable, prismatic, at plant	1.00E+00	kg		1	1.16	(3,4,1,2,1,3,3)

Fig. 4.7 Unit process inventories of the data set Battery, NiMH, rechargable, prismatic, at plant. (Cont.)

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Hydrogen, liquid, at plant	g	Electrode, positive, LaNi5, at plant				used for pulverisation of mischmetal and as compartment in NiH, estimated assuming a contained of 1m3 was filled for the mischmetal treatment	chemicals	inorganics	No	RER	hydrogen, liquid, at plant	7.05E-01	kg	Sakai et al., 1992; Linden and Reddy, 2002	1	1.93	(5,5,4,3,4,5,4)
Nickel, 99.5% at plant	g					for particle (LaNi5) coating, estimated based on the literature data given (10 wt % of electrode by Nickel coating)	metals	extraction	No	GLO	nickel, 99.5% at plant	1.00E-01	kg	Sakai et al., 1992; Linden and Reddy, 2002	1	1.63	(2,3,4,3,4,5,4)
Tetrafluoroethylene, at plant	g					fo the generation of electrode paste, estimated based on the literature data given (10 wt % of electrode by Nickel coating)	chemicals	inorganics	No	RER	tetrafluoroethylene, at plant	3.00E-02	kg	Linden and Reddy, 2002	1	1.63	(2,3,4,3,4,5,4)
Electricity, high voltage, production UCTE, at grid	g					for hot pressing of electrode paste	electricity	production mix	No	UCTE	electricity, high voltage, production UCTE, at grid	5.06E-03	kWh	Linden and Reddy, 2002	1	1.88	(5,5,2,3,4,5,2)
Mischmetal, at plant	g					proxy for mischmetal alloy used for the fabriaction of the electrode (La 30, Ce 52, Pr 5, Nd 13)	electronics	module	No	GLO	mixed metal, primary, at plant	8.70E-01	kg	Sakai et al., 1992; Linden and Reddy, 2002	1	1.59	(2,3,3,3,4,5,4)
Battery Plant	g					as proxy, the precious metalls plant (see chapter xy) is used	electronics	Metals	Yes	SE	facilities precious metal refinery	1.38E-07	Unit	HitachiMaxell 2003	1	3.12	(4,4,3,2,3,3,9)
			a	Electrode, positive, LaNiH, at plant		no direct emissions could be identified	electronics	component	No	GLO	Electrode, positive, LaNi5, at plant	1.00E+00	kg		1	#NV	
			a	Heat, waste, to air			air	unspecified			Heat, waste	1.82E-02	MJ		1	1.59	(2,3,3,2,3,3,31)

Fig. 4.8 Unit process inventory of the positive electrode used in a NiMH rechargable battery, prismatic

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Polyurethane, flexible foam, at plant	GB	Electrode, negative, Ni, at plant				as skeleton for Ni mesh, estimated based on the denstiy of PUR related to 1kg of NiOH electrode output	plastics	polymers	No	RER	Polyurethane, flexible foam, at plant	4.76E-03	kg	Freitas, 2001;Jayashree and Kamath, 2001; Subbaiah et al., 2002; Linden and Reddy, 2002	1	1.08	(2,1,2,1,1,1,4)
Nickel, 99.5% at plant	GB					for coating (e-deposition or chem. vapour deposition) of PUR, for NiOH synthesis, for physical NiOOH loading the Ni skeleton, estimated based on the information documented in	metals	extraction	No	GLO	Nickel, 99.5% at plant	9.40E-01	kg	Freitas, 2001;Jayashree and Kamath, 2001; Subbaiah et al., 2002; Linden and Reddy, 2002	1		(2,1,2,1,1,1,4)
Cobalt, at plant	GB					contained in the paste to physically load NiOOH onto the Ni skeleton, estimated on the information documented in the overall comment	metals	extraction	No	GLO	Cobalt, at plant	3.00E-02	kg	Freitas, 2001; Linden and Reddy, 2002	1		(2,2,2,2,1,1,4)
Zinc for coating, at regional storage	GB					contained in the paste to physically load NiOOH onto the Ni skeleton, estimated on the information documented in the overall comment	metals	extraction	No	RER	Zinc for coating, at regional storage	3.00E-02	kg	Freitas, 2001; Linden and Reddy, 2002	1		(2,2,2,2,1,1,4)
Sinter, Nickel, at plant	GB					proxy for sintering Ni	building components	windows	No	RER	Glazing, double (2-IV), U<1.1 W/m2K, laminated safety glass, at plant	1.32E+00	m2		1		(2,1,2,1,3,1,4)
Sodium hydroxide, 50% in H2O, production mix, at plant	GB					proxy for KOH solution used for the degreasing of sintered Ni, estimated based on the solubility of KOH in water and the total volume of 1kg NiOOH electrode and assuming that KOH bath is only 1 time applied	chemicals	inorganics	No	RER	Sodium hydroxide, 50% in H2O, production mix, at plant	1.68E-01	kg	Linden and Reddy, 2002	1		(5,5,5,5,4,5,4)
Electricity, high voltage, production UCTE, at grid	GB					for induction smelter heating, for galvanostatically immersing of NiOH into sintered Ni solution, only galvansing taken into account and estimated based on eocinvent data set listed in the comment	electricity	production mix	No	UCTE	Electricity, high voltage, production UCTE, at grid	3.41E-01	kWh		1		(4,4,2,2,3,3,2)
Heat, natural gas, at industrial furnace low-NOx >100kW	GB					for the drying process of the KOH treated and washed sintered Ni, estimated based on the document comments	natural gas	heating systems	No	RER	Heat, natural gas, at industrial furnace low-NOx >100kW	4.40E-01	MJ	Sakai et al., 1992	1		(2,2,2,2,1,3,1)

continued ▼

Fig. 4.9 Unit process inventory of the negative electrode used in a NiMH rechargable battery, prismatic

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Battery plant	g	Electrode, negative, Ni, at plant		▼ continued		as proxy, the precious metalls plant (see chapter xy) is used	electronics	Metals	Yes	SE	facilities precious metal refinery	1.29E-07	Unit		1		
			a	Electrode, negative, Ni, at plant			electronics	module	No	GLO	Electrode, negative, Ni, at plant	1.00E+00	kg		1		
			a	Disposal, polyurethane, 0.2%water, to municipal incineration			waste management	municipal incineration	No	CH	disposal, polyurethane, 0.2% water, to municipal incineration	4.76E-03	kg		1		
			a	Disposal, polyurethane, 0.2%water, to inert material landfill		disposal of the PUR incineration residuals, estimated based on the assumption that 36wt%remain	waste management	inert material landfill	No	CH	disposal, polyurethane, 0.2% water, to inert material landfill	1.71E-03	kg		1		(5,5,3,2,4,5,6)
			a	Heat, waste, to air			air	unspecified			Heat, waste	1.82E-02	MJ				1

Fig. 4.9 Unit process inventory of the negative electrode used in a NiMH rechargable battery, prismatic

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Sodium hydroxide, 50% in H2O, production mix, at plant	g	Electrolyte, KOH, LiOH additive, at plant	a	Electrolyte, KOH (30%), LiOH additive, at plant		proxy for KOH (30%)	chemicals	inorganics	No	RER	sodium hydroxide, 50% in H2O, production mix, at plant	9.83E-01	kg	Linden and Reddy, 2002	1	1.21	(1,2,1,1,1,5,3)
Lithium, at plant	g					Li additive, adopted from literature	chemicals	organics	No	GLO	lithium, at plant	1.70E-02	kg	Linden and Reddy, 2002	1	1.65	(4,4,3,2,4,5,3)
Water, completely softened, at plant	g					for the synthesis of LiOH from Li2O, estimated based on stöchiometric balance	water supply	production	No	RER	water, completely softened, at plant	9.92E-03	kg	Linden and Reddy, 2002	1	1.65	(4,4,3,2,4,5,11)
Electrolyte plant	g					chemical plant as proxy used	chemicals	organics	Yes	RER	chemical plant, organics	4.00E-10	unit	standard value according to Althaus et al. (2004)	1	3.77	(4,5,1,3,5,4,9); estimation
Oxygen, liquid, at plant	g					for the oxidation of Li to Li2O, estimated based on stöchiometric balance	chemicals	inorganics	No	RER	oxygen, liquid, at plant	8.81E-03	kg	Linden and Reddy, 2002	1	1.65	(4,4,3,2,4,5,11)
						no direct emissions could be identified	electronics	component	No	GLO	Electrolyte, KOH, LiOH additive, at plant	1.00E+00	kg		1	#NV	

Fig. 4.10 Unit process inventory of the electrolyte used in a NiMH rechargable battery, prismatic

4.7 LiIo rechargable batteries for laptop applications

The described inventory of the manufacturing of a LiIo rechargable battery for laptop applications is conceptualised as a series of unit processes comprising the manufacturing of the negative and the positive electrode, the electrolyte and the final assembly of the LiIo rechargable battery. In Fig. 4.11 a schematic view of the different parts inventorised is shown.

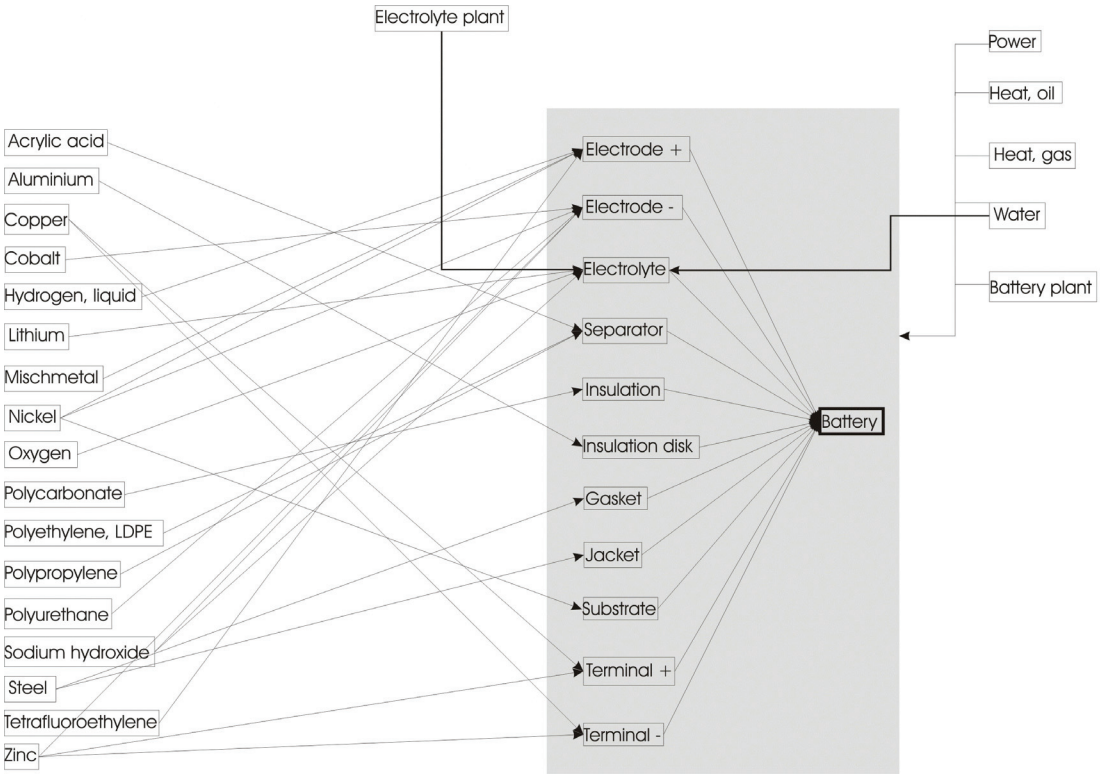


Fig. 4.11 Scheme of input flows of the dataset "Battery, NiMH, rechargable, prismatic, at plant". Production auxiliaries (like chemicals) and emissions are not shown.

4.7.1 Dimensioning of the reference product

A LiIo battery (model: FPCBP64 [28]) with a capacity of 4000 mAh as used in Fujitsu-Siemens laptops (model: Lifebook S6120D) is selected as reference product (see Fig. 4.12).

The total mass of the battery package is estimated based upon the mass of the single LiIo battery cells and the mass of the package housing. According to the specified capacity and the size of the entire battery package, it is assumed that 4 individual battery cells (reference model: CGP345010 Panasonic – see Fig. 4.13) are contained in the battery package. Physical and other relevant information of the selected reference cell type is documented in Matsushita Battery Industrial Co. (2002). The average thickness of the plastic housing (material: polyethylene, high density) of the battery package is set to 0.8 mm resulting in a housing mass of ~ 0.0217 kg per LiIo battery package. Accordingly, the mass of the entire battery package is determined with ~ 0.19 kg.

[28] PowerUp: Laptop Batteries & Power Products for Fujitsu Siemens LifeBook S6120D (http://www.computerbatteries.co.uk/-gb3/m/fujitsu-siemens/lifebook-s6120d.html), accessed October 19, 2006.

Tab. 4.5 Specifications of the selected reference product.

	Lilo battery package	Lilo battery cell
Model	FPCBP64	CGP345010
Size (W x D x H [mm])	128.00 x 77.00 x 20.00	34.00 x 10.30 x 49.80
Weight [kg]	0.19 (calculated)	0.042 (calculated)
Capacity [mAh]	4000	1400
Number of cells	4	-

Fig. 4.12 Example of a prismatic Lilo laptop rechargable battery.

Like in case of the NiMH rechargable battery cells, the electrode package of a LiIo rechargable battery cell consists of a multilayered electrode assembly (Fig. 14, to the left), which is wound around itself to finally form rectangular cells. The individual layers (i.e. positive and negative electrode, separators, electrolyte, etc.) are dimensioned as follows: width [mm] and height [mm] are set to 30.00 x 45.00 mm respectively. The thickness (i.e. the depth [mm]) of each layer is set to 0.1 mm and is assumed to be equal for each layer species (i.e. equal for positive and negative electrode, electrolytes and separators). In order to approximate the mass of the LiIo cell as specified in Matsushita Battery Industrial Co. (2002) it is assumed that the multilayered electrode assembly is wound 26 times (26 windings). Based on the above specifications the total mass of the wound multilayered electrode assembly is calculated to ~ 0.0309 kg. The housing of the wound electrode packages (i.e. the single cells) consisted of aluminium (density of 2700 kg/m^3) and again plastic (material: polyethylene, high density). The thickness of the aluminium part is set to 0.078 mm and the thickness of the plastic part is set to 0.8 mm. Accordingly, the total mass of the aluminium and and the plastic housing part of the LiIo battery cell is determined with ~ 0.01 kg and the total mass of a single LiIo rechargable battery cell is determined with 0.041 kg. Based on these specifications the mass of the entire LiIo rechargable battery package consisting of 4 cells is calculated to 0.19 kg (see Tab. 4.5).

The assembly process of the battery is documented below and quantitative information cover the consumption of thermal energy supplied from light fuel oil and natural gas, electrical power and water according to the conditions documented in MAXELL (2003). No information is found on emissions and by-products except for heat emission to air derived adequately from the amount of electricity consumed.

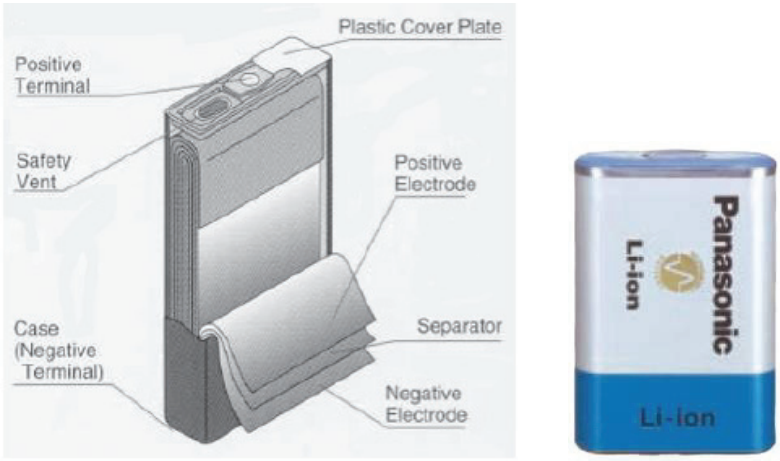


Fig. 4.13 Example of a prismatic LiIo rechargable battery cell (adopted from Ehrlich (2002) and Matsushita Battery Industrial Co. (2002)).

For this type of battery package, the following itemized datasets have been established:

- "*Electrode, positive, LIMn2O4, at plant*": production of the positive electrode chosen for the here established dataset of a LiIo rechargable battery package;
- "*Electrode, negative, LiC6, at plant*": production of the negative electrode chosen for the here established dataset of a LiIo rechargable battery package;
- "*Battery, LiIo, rechargable, prismatic, at plant*": production of all further components of a LiIo rechargable battery package (separator, housing, inner lining, positive substrate, terminals, contacts,) as well as the efforts (energy & water consumption) for the final assembly of this battery package.

The metadata of these three datasets of the LiIo rechargable battery package are given in Tab. 4.6 and Tab. 4.7, their exchanges are shown in Fig. 4.14 to Fig. 4.16.

Tab. 4.6 Ecoinvent meta information for the processes for the production of LiIo-rechargable batteries.

Name	**Battery, LiIo, rechargable, prismatic, at plant**
Location	GLO
Infrastructure Process	0
Unit	kg
Dataset Version	1.0
Included Processes	(Raw) materials, infrastructure, energy consumption and waste disposal for the production of a LiIo rechargable battery. No emissions to air or water are taken into account.
Amount	1
Local Name	Batterie, LiIo, aufladbar, prismatisch, ab Werk
Synonyms	LiIo-Akku
General Comment	The functional unit represents 1 kg of a LiIo rechargable battery for laptop applications. A typical such LiIo battery has a weight of 0.190 kg. Process data is taken mainly from an environmental report of a battery producer as well as from literature. In addition own measurements of sizes and weights of batteries are used.
Start Date	2002
End Date	2006
Data valid for entire period	1
Geography Text	This dataset relates to the global situation.
Technology Text	Construction details as described for LiIo-rechargable batteries and manufacturing conditions as documented in the environmental report is adopted.
Representativeness	
Production Volume	170’300 t (own calculations)
Sampling Procedure	Literature, measurements
Extrapolations	see Geography and Technology
Uncertainty Adjustments	None

Tab. 4.7 (Cont.) Ecoinvent meta information for the processes for the production of LiIo-rechargable batteries.

Name	Electrode, positive, LIMn2O4, at plant	Electrode, negative, LiC6, at plant
Location	GLO	GLO
Infrastructure Process	0	0
Unit	kg	kg
Dataset Version	1.0	1.0
Included Processes	(Raw) materials, infrastructure and energy consumption for the production of the positive electrode for LiIo recharable batteries. No emissions to air or water are taken into account.	(Raw) materials, infrastructure and energy consumption for the production of the negative electrode for LiIo recharable batteries. No emissions to air or water are taken into account.
Amount	1	1
Local Name	Elektrode, positiv, LiMn2O4, ab Werk	Elektrode, negativ, LiC6, ab Werk
Synonyms		
General Comment	The functional unit represents 1 kg of the positive LiMn2O4 electrode material for the production of LiIo rechargable batteries. Process data is taken mainly from an environmental report of a battery producer as well as from literature. In addition own measurements of sizes and weights of batteries are used.	The functional unit represents 1 kg of the negative LiC6 electrode material for the production of LiIo rechargable batteries. Process data is taken mainly from an environmental report of a battery producer as well as from literature. In addition own measurements of sizes and weights of batteries are used.
Start Date	2002	2002
End Date	2006	2006
Data valid for entire period	1	1
Geography Text	This dataset relates to the global situation.	This dataset relates to the global situation.
Technology Text	Construction details as described for LiIo-rechargable batteries and manufacturing conditions as documented in the environmental report is adopted.	Construction details as described for LiIo-rechargable batteries and manufacturing conditions as documented in the environmental report is adopted.
Representativeness		
Production Volume		
Sampling Procedure	Literature, measurements	Literature, measurements
Extrapolations	see Geography and Technology	see Geography and Technology
Uncertainty Adjustments	None	None

4.7.2 Dataset "Electrode, positive, $LiMn_2O_4$, at plant"

The preparation of $LiMn_2O_4$ positive electrodes of LiIo rechargable batteries has been inventoried based upon various laboratory reports (e.g.: Braun et al. (2001), G. Chen et al. (2005), Ehrlich (2002)). Based on the specificitions of the here inventoried battery (see chapter 4.7.1) the total mass of $LiMn_2O_4$ per kg LiIo rechargable battery package is determined as follows:

<- Size of single positive electrode layer (W x D x H): 30.00 x 0.1 x 45.00 mm

<- Thickness of single positive electrode layer: 0.0001 m

<- Mass of single positive electrode layer: 0.03 m x 0.045 m x 0.0001 m * 4400 kg/m^3 = 0.000594 kg

<- Total mass of all single positive electrode layers per cell:

0.000594 kg * 26 = 0.015444 kg $LiMn_2O_4$ / LiIo cell

<- Total mass of all single electrode layers per unit battery package:
0.015444 kg $LiMn_2O_4$ / LiIo cell * 4 = 0.061776 kg $LiMn_2O_4$ / 4 LiIo cells

<- Total mass per kg battery package:
0.061776 kg $LiMn_2O_4$ / 4 cells * 1 kg / 0.1897 kg = 0.3257 kg LiMn2O4 / kg LiIo battery package

Li_2CO_3, MnO_2, acetylene, graphite, polyvinyliden chloride, n-methyl pyrrolidone, lithium (as salt) and aluminium is inventoried as the key semi-finished products and helium and electricity is inventoried as key processing inputs (cf.: Braun et al. (2001)). The mass of the $LiMn_2O_4$ spinel is estimated based on the atomic weights of the single elements.

- The spinel is thereafter immersed in a solution of acetylene, graphite, polyvinylilden chloride and pyrrolidone in the ratio 90:2:4:4 (G. Chen et al. (2005), Braun et al. (2001)). According to the mixing ratio the respective masses is determined.
- According to Braun et al. (2001) the preparation of the electrode is continued by treatment in a helium filled glove box. It is assumed that this box had a volume of 1 m^3 and is saturated with helium, i.e. filled with 0.1785 kg. It is further assumed that the helium had to be replaced after the treatment of 1 kg spinel.
- The spinel treatment is finalised by sandwiching the spinel onto a lithium containing foil (cf.: Braun et al. (2001)). Assuming a foil thickness of 0.0001 m and using the density of lithium of 534 kg/m^3 as representative for the density of the entire foil composition the mass of the foil per kg $LiMn_2O_4$ is calculated.
- The treatment is completed by drying the $LiMn_2O_4$ spinel at 100°C and during 8 hours (cf.: Braun et al. (2001)). Assuming a furnace capacity of 1350 kg and a power consumption of 600 kW the electrical energy consumed per kg $LiMn_2O_4$ is calculated.

No direct emissions to air, soil and water associated with the assembly of the LiMn2O4 electrode could be inventoried as no information is available with the exception of heat emission to air which is derived directly from the amount of electrical powere supplied during the electrode manufacturing process.

The relevant amount of infrastructure is determined adopting the information from the MAXELL (2003) environmental report. The following assumptions are made to approximate the infrastructure demand per kg LiMn2O4 electrode:

-> $LiMn_2O_4$ content per battery package:	0.3257 kg/kg LiIo rechargable battery package
-> Life time of the HITACHI Kyoto plant (own approximation):	50 years
-> Total battery package production capacity; assumption for Kyoto in 2003	1/3
-> Total LiIo battery package production capacity for Kyoto in 2003 (according to Fig.2):	0.6
-> Total net sales of batteries in 2003 (MAXELL (2003)):	65'532'000'000 ¥
-> Average price of a LiIo battery package in 2006[29]:	103.45 $
-> Currency ourse ¥ <>CHF (exchange rate at Aug 25, 2006):	100 ¥ = 1.11 CHF
-> Currency course $ <> CHF (exchange rate at Sep 12, 2006):	1 $ = 1.32 CHF

The calculation is then performed as follows:

< Single price of LiIo rechargable battery:	103.45 $ = 136.554 CHF
< Conversion of consolidated net sales:	65'532'000'000 ¥ = 727'405'200 CHF

[29] Fujitsu FPCBP64 batteries & accessories (http://www.atbatt.com/laptop-batteries/b/Fujitsu/m/FPCBP64.asp), accessed October 19, 2006.

< LiIo revenue fraction: 727'405'200 CHF * (1/3) * 0.6 = 145'481'040 CHF
< Annual LiIo battery package production:
145'481'040 CHF / 136.554 CHF = 1'065'374 LiIo-battery packages/year

< Annual $LiMn_2O_4$ electrode production:
1'065'374 $LiMn_2O_4$ electrode/year * 0.3257 kg = 347'014 kg $LiMn_2O_4$ electrode/year
< Infrastructure demand per kg $LiMn_2O_4$ electrode:
1 plant/ (347'014 kg $LiMn_2O_4$ * 50 years) = 5.7634e-8 plants /kg $LiMn_2O_4$-electrode

4.7.3 Dataset "Electrode, negative, LiC_6, at plant"

Adopting the process of intercalation (Ehrlich (2002), Tossici et al. (1996), Tossici et al. (1997)) the process of manufacturing the negative electrode of the LiIo rechargable battery is inventoried. Different electrode configurations exist depending, e.g., on the application considered. The here inventoried negative electrode is of the type LiC_6 (cf.: Mizutani et al. (1997), Isaev et al. (1997) and Zabel et al. (1983)). Based on the specificitions of the here inventoried battery (see chapter 4.7.1) the total mass of LiC_6 per kg LiIo rechargable battery package is determined as 0.00789 kg LiC_6 / LiIo cell resp. 0.1664 kg LiC_6 / LiIo rechargable battery package.

According to the above quoted descriptions graphite and lithium as key input materials for the electrode body and an aluminium bonding layer, to which the LiC_6 electrode is sandwiched (cf.: Zuckerbrod et al. (2002)), is inventoried. The masses of lithium and graphite are estimated based on the respective atomic weights. The mass of the aluminium bonding layer is estimated to 0.24 kg per kg LiC_6 assuming a layer thickness of 0.1 mm and a layer surface area of 8889 cm^2 per kg LiC_6 (The latter value is derived assuming a LiC_6 layer thickness of 0.5 mm and adopting a density of 2250 kg/m^3 (cf. Zabel et al. (1983))). The formation of the aluminium foil is inventoried by adopting the respective data set (cf.: Hans-Jörg Althaus et al. (2004)).

No direct emissions to air, soil and water associated with the assembly of the $LiMn_2O_4$ electrode are inventoried as no information is available with the exception of heat emission to air which is derived directly from the amount of electrical powere supplied during the electrode manufacturing process.

The relevant amount of infrastructure is determined adopting the information from the MAXELL (2003) environmental report in a similar manner like for the positive $LiMn_2O_4$ electrode. This calculation is performed as follows:

<- Single price of LiIo rechargable battery in CHF: 103.45 $ = 136.554 CHF
<- Conversion of consolidated net sales: 65'532'000'000 ¥ = 727'405'200 CHF
<- LiIo revenue fraction: 727'405'200 CHF * (1/3) * 0.6 = 145'481'040 CHF
<- Annual LiIo battery package production:
145'481'040 CHF / 136.554 CHF = 1'065'377 LiIo-battery packages/year
<- Annual $LiMn_2O_4$ electrode production:
1'065'377 LiC_6 electrode/year * 0.166 kg = 177'292 kg LiC_6 electrode/year
<- Infrastructure demand per kg $LiMn_2O_4$ electrode:
1 plant / (177'292 kg LiC_6 electrode * 50 years) = 1.12807e-7 plants /kg LiC_6 electrode

4.7.4 Dataset "Battery, LiIo, rechargable, prismatic, at plant"

Housing

The housing of the battery package as well as of the battery cells is assumed to be made primarily out of polyethylene. No explicit information could be found on the separator production process. Thus, the processing is modelled by adopting the ecoinvent data set "injection moulding" (Hischier (2007)). Assuming a thicknesses of the battery package housing of 0.8 mm (own measurements) and likewise of

the battery cell housing of 0.8 mm (adopted from Matsushita Battery Industrial Co. (2002)), adopting the earlier made specifications for the battery package and the battery cells and adopting a density of 970 kg/m^3, the mass fraction of polyethylene per kg LiIo rechargable battery is derived as follows:

<- Housing mass of LiIo rechargable battery:

Surface S = 2 * ((0.077 m * 0.128 m) + (0.077 m * 0.020 m) + (0.128 m * 0.020 m)) = 0.0279 m^2

S * 0.0008 m * 970 kg/m^3 = 0.022 kg PE-HD /LiIo battery package

<- Housing mass of the LiIo cells:

Surface S = 2 * ((0.034 m * 0.0498 m) + (0.034 m * 0.0103 m) + (0.0498 m * 0.0103 m)) = 0.00256 m^2

S * 0.0008m * 970 kg/m^3 * 4 cells = 0.016 kg PE-HD /LiIo battery cell

<- Total housing mass **per kg** LiIo rechargable battery (1 battery = 0.19 kg):

0.143 kg + 0.084 = 0.226 kg PE-HD /LiIo battery package

Housing, inner lining (battery jacket)

The jacket of the rechargable battery cells is assumed to be made of aluminium (cf.: KOKAM™ (2006), Matsushita Battery Industrial Co. (2002), Electronics-Lab (2006)). The thickness of the aluminium lining layer is assumed as 0.078 mm. Hence, the mass fraction of aluminium per kg LiIo rechargable battery package is performed as shown above, resulting in 0.124 kg aluminium per kg battery. No explicit information could be found on the lining production process but the processing of the jacket is modelled by adopting the process "Sheet rolling, aluminium, at plant" (Classen et al. (2007)). No other processes and related material and energy consumptions or emissions are inventoried.

Separator

"Tetrafluoroethylene" is used as proxy to represent polytetrafluoroethylene which the separator layers are actually made of (cf.: Noda et al. (2005), W.L. Gore & Associates Inc. (2003)). Details on the inventory of the manufacturing of this proxy material can be found in H.-J. Althaus et al. (2007). No explicit information could be found on the separator production process. Thus, the processing is modelled by adopting the ecoinvent data set "injection moulding" (Hischier (2007)).

To calculate the amount of separator per kg LiIo rechargable battery package the same dimension specifictions as for the electrodes is adopted. Accordingly, and adopting a density of 850 kg/m^3 (W.L. Gore & Associates Inc. (2003)) the mass of the separator per kg rechargable battery package is determined as 0.0629 kg separator per kg of LiIo rechargable battery package.

Terminals (positive, negative)

Copper is inventoried as the basic input material for the negative and positive terminals (Linden & Reddy (2002)). The number of contacts per battery package is estimated to be 12, the number of contacts per battery cell to be 2. Based on own measurements a size of (W x D x H): 2.0 mm x 0.01 mm x 1.0 mm (battery package contacts) resp. 4.0 mm x 0.01 mm x 1.0 mm (battery cell package contacts) for the contacts is determined. The density of copper is 8920 kg/m^3. No explicit information could be found on the terminals production process, hence the processing of the terminals is modelled by adopting the ecoinvent data set "Sheet rolling, copper, at plant" (Classen et al. (2007)). The calculation of the amount is performed as follows:

<- Mass of battery package copper contacts per kg LiIo rechargable battery:

0.002 m * 0.001 m * 0.00001 m *8920 kg/m^3 * 12 = 0.0000021408 kg Cu / LiIo battery package

= 0.0000021408 kg Cu / LiIo battery package *1 / 0.189659712 kg

= 1.129e-5 kg Cu/kg LiIo battery package

<- Mass of battery cell copper contacts per kg LiIo rechargable battery:

0.004 m * 0.001 m * 0.00001 m * 8920 kg/m^3 * 2 = 0.0000007136 kg Cu/LiIo battery cell

0.0000007136 kg Cu/LiIo battery cell * 4 Cells = 0.0000028544 kg Cu/LiIo battery package

0.0000028544 kg Cu/LiIo battery package * 1 / 0.189659712 kg
1.505e-5 kg Cu / kg LiIo battery package

< Total copper contact mass per kg LiIo rechargable battery:
1.129e-5 kg + 1.505e-5 kg = 2.634e-5 kg Cu/kg LiIo battery package

Contact plating

The terminals are assumed to be plated with tin (Winch et al. (2002)). It is assumed that the share of tin amounts to 1% of the terminal weight (made of copper) and is calculated to 2.634E-7 kg tin per kg LiIo rechargable battery package. The coating process including energy and auxiliary supply etc. is approximated by adopting the ecoinvent dataset "zinc coating, pieces" (Classen et al. (2007)).

Final Assembly of LiIo battery package

To run the battery assembly process four different auxiliary materials have been taken into account – thermal heat from natural gas, thermal heat from light fuel oil, electrical power and water. The amount of the four auxiliaries consumed during the battery assembly is calculated based on the information documented in MAXELL (2003).

For electrical power the following specifications (if not otherwise mentioned, from MAXELL (2003) is adopted and pre-assumptions made:

-> Total power consumption at HITACHI:	140'000'000 kWh
-> Total area of HTACHI plants:	721'000 m^2
-> Area of Kyoto work:	211'647 m^2
-> Total rechargable battery production capacity at Kyoto works:	1/3
-> Total LiIo battery package production capacity for Kyoto in 2003:	0.6
-> Total consolidated net sales of batteries in 2003:	65'532'000'000 ¥
-> Average price of a LiIo-battery package in 2003 [30]	103.45 $
-> Currency exchange rate ¥ <> CHF (exchange rate at Aug 25, 2006):	100 ¥ = 1.11
-> Currency course $ <> CHF (exchange rate at Sep 12, 2006):	$ = 1.32 CHF

The calculation is then performed as follows:

<- Production area share of Kyoto plant: 211'647 m2 * 100% / 720'168 m2 = 29.4%

<- LiIo production area share of Kyoto plant: 29.4%* (1/3)*0.6 = 5.88%

<- Total annual power consumption for LiIo production:
5.88%*140'000'000 kWh/100% = 8'228'360 kWh

<- Conversion of US-$ LiIo price into CHF: 103.45 $ = 136.554 CHF

<- Conversion of ¥-consolidated net sales into CHF: 65'532'000'000 ¥ = 727'405'200 CHF

<- Number of LiIo produced:
727'405'200 CHF * (1/3) * 0.6/ 136.554 CHF = 1'065'374 LiIo battery packages

<- Electrical power consumed per LiIo rechargable battery produced:
8'228'360 kWh / 1'065'374 LiIo battery package = 7.72 kWh / LiIo battery package

<- Electrical power consumed per kg LiIo rechargable battery produced:
7.72 kWh/ LiIo battery package * 1 kg / 0.19 kg = 41.31 kWh /kg LiIo battery package

[30] Fujitsu FPCBP64 batteries & accessories (http://www.atbatt.com/laptop-batteries/b/Fujitsu/m/FPCBP64.asp), accessed October 19, 2006.

Based on the above documented specifications and adopting the total annual thermal energy consumption at HITACHI of 1'349'000 L light fuel oil (MAXELL (2003)) the amount of thermal energy consumed per kg LiIo battery package is calculated as 15.95 MJ per kg batteries. Concerning the consumption of natural gas, a total consumption of 10'700'000 m^3 is reported in MAXELL (2003), resulting in 112.05 MJ of natural gas per kg LiIo battery packages.

Last but not least, the amount of water is calculated adopting again the above made specifications and is approximated taking the annual water consumption at HITACHI of 1'190'000 m^3. This results in a consumption of 346.1 m^3 water per kg of LiIo battery packages.

Infrastructure

The infrastructure, i.e. the share of battery plant consumed to finally assemble 1 kg of LiIo rechargable battery packages is calculated adopting the above made specifications and assuming a life time of the HITACHI Kyoto plant of 50 years. Hence an amount of 1.877e-8 plants per kg battery packages results from this calculation.

4.7.5 Data "Electrolyte, 4-Fluoro-1.3-dioxolan-2-one, at plant"

Due to a lack of respective information, the dataset "chemicals organic, at plant" is used as a proxy herefore. It covers the addition of the substance 4-Fluoro-1.3-dioxolan-2-one which has been determined as key component of modern LiIo rechargable battery electrolytes (C.-h. Chen et al. (2002), Miyazaki et al. (1991)) to the battery component.

To calculate the amount of electrolyte per kg LiIo rechargable battery package the same dimension specifictions as for the electrodes is adopted. Accordingly, and adopting a density of 1300 kg/m^3 (GFS Chemicals Inc. (2004)) the mass of the electrolyte per kg LiIo rechargable battery package is determined as 0.0962 kg electrolyte per kg of LiIo rechargable battery package.

4.7.6 Data uncertainty

The inventoried data set relies on the most recently available literature information reflecting LiIo rechargable battery technology for laptop applications as used in the past few years (2002-2006). Own measurments is used to approximate the dimension of the key battery components. However, the dataset is subject to several limitations:

- No comprehensive and complete information on industrial battery production technologies.
- No environmental data (i.e. emissions and waste generation) directly associated with the battery manufacturing.
- No information concerning the consumption of auxiliaries.

According to the identified limitations the corresponding uncertainty is documented.

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Loca-tion	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Electrode, positive, LiMn2O4, at plant	S	battery, Lilo, rechargeable, prismatic, at plant				component, estimated based on the physical dimensions of a NOKIA 3330 Lilo accu (outer size) and the specific density of LiMn2O4 (it was assumed that the total value is multiplied by 0.5 to take for the mismeasurment of the outer size into account)	electronics	module	No	GLO	Electrode, positive, LiMn2O4, at plant	3.26E-01	kg	Braun et al., 2001; Linden and Reddy, 2002	1	1.21	(3,4,1,2,1,4,3)
Electrode, negative, LiC6, at plant	S					component, estimated based on the physical dimensions of a NOKIA 3330 Lilo accu (outer size) and the specific density of LiC6 (it was assumed that the total value is multiplied by 0.5 to take for the mismeasurment of the outer size into account)	electronics	module	No	GLO	Electrode, negative, LiC6, at plant	1.66E-01	kg	Braun et al., 2001; Linden and Reddy, 2002; Gore, 2003; Tossici et al., 1997, Tossici et al., 1996; Isaev et al., 1997; Mitzutani et al., 1997	1	1.12	(3,4,1,2,1,4,3)
Electrolyte, 4-Fluoro-1.3-dioxolan-2-one, at plant	S					Electrolyte, estimated based on the specific density for 1.3-dioxolane-2-one and the physical dimensions of a NOKIA 3330 Lilo accu and assume that 40% of the accu volume are occupied by the electrolyte. "Chemicals organic, at plant" used as PROXY.	chemicals	organics	No	GLO	chemicals organic, at plant	9.62E-02	kg	EAA 2001; LBNL, 2005	1	1.07	(3,4,1,2,1,4,3)
Tetrafluoroethylene, at plant	S					proxy for PTFE separator (Gore®), estimated based on physical dimensions of a NOKIA 3330 Lilo accu and a 10 layer winding assumed and multuplied with the density of PTFE (0.85 g/cm3)	chemicals	inorganics	No	RER	tetrafluoroethylene, at plant	6.29E-02	kg	Gore, 2003; Daisuke et al., 2005	1	1.24	(3,4,1,2,1,4,3)
processing of tetrafluoroethylene	S						plastics	processing	No	RER	injection moulding	6.29E-02	kg	Gore, 2003; Daisuke et al., 2005	1	1.24	(5,4,1,2,1,4,3)
Tin, at regional storage	S					basic input material for terminal (negative) tin plated, estimated based on the mass of the Al-alloy and the terminal nickel (1% of the total mass was assumed to be the mass of the coating)	metals	extraction	No	RER	tin, at regional storage	2.63E-07	kg	Linden and Reddy, 2002	1	1.24	(5,4,1,2,1,4,4)
coating process	S			continued ▼		zinc coating process	metals	processing	No	RER	zinc coating, pieces	2.63E-07	m2	Linden and Reddy, 2002	1	1.24	(5,4,1,2,1,4,4)

Fig. 4.14 Unit process inventoy of the data set “Battery, Lilo, rechargable, prismatic, at plant”.

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Loca-tion	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
				▼													
copper, primary, at refinery	S	battery, Lilo, rechargeable, prismatic, at plant		continued		basic input material for terminal (positive & negative) tin plated	metals	extraction	No	RAS	copper, primary, at refinery	2.63E-05	kg	Linden and Reddy, 2002; Kokam, 2006	1	1.24	(5,4,1,2,1,4,4)
Polyethylene, HDPE, granulate, at plant	S					proxy for terminal (positive & negative) treatment	plastics	polymers	No	RER	polyethylene, HDPE, granulate, at plant	2.26E-01	kg	NOKIA, 2006	1	1.24	(5,4,1,2,1,4,3)
processing of polyethylene (HDPE)	S					basic material for tube insulating (non-moulded), calculated based on the physical dimensions of a NOKIA 3330 accu (BMC-3)	plastics	processing	No	RER	injection moulding	2.26E-01	kg	NOKIA, 2006	1	1.24	(5,4,1,2,1,4,3)
Aluminium, production mix, at plant	S						metals	extraction	No	RER	Aluminium, production mix, at plant	1.24E-01	kg	Kokam, 2006	1	1.24	(5,4,1,2,1,4,4)
processing of aluminium	S					basic material for the battery jacket	metals	processing	No	RER	Sheet rolling, aluminium, at plant	1.24E-01	kg	Kokam, 2006	1	1.24	(5,4,1,2,1,4,3)
Electricity, high voltage, production UCTE, at grid	S					formation of the battery gasket and jacket and the foil, estimated based on NOKIA 3330 accu	electricity	production mix	No	UCTE	Electricity, high voltage, production UCTE, at grid	4.13E+01	kWh	HitachiMaxell 2003	1	1.24	(2,3,1,2,1,1,2)
Heat, light fuel oil, at industrial furnace 1MW	S					power needed for form the tube insulating, to manufacture the Al-alloy, needed by the final accu manufacturer to run hi facitlities (see HitachiMaxel Env Report 2003), estimated based on the HITACHI Env Report 2003 + the exchange rate Y <-> CHF 2006-02-22	oil	heating systems	No	RER	Heat, light fuel oil, at industrila furnace 1MW	1.59E+01	MJ	HitachiMaxell 2003	1	1.24	(2,3,1,2,1,1,1)
Water, decarbonised, at plant	S					energy needed to manufacture the aluminium alloy tin plated, needed by the final accu manufacturer to run hi facitlities (see HitachiMaxel Env Report 2003), estimated based on the HITACHI Env Report 2003 + the exchange rate Y <-> CHF 2006-02-22	water supply	production	No	RER	water, decarbonised, at plant	3.80E+02	kg	HitachiMaxell 2003	1	1.24	(2,3,1,2,1,1,4)
Heat, natural gas, at industrial furnace low-NOx >100kW	S			continued ▼		water needed for cooling process water, estimated based on the HITACHI Env Report 2003 + the exchange rate Y <-> CHF 2006-02-22	natural gas	heating systems	No	RER	heat, natural gas, at industrial furnace low-NOx >100kW	1.23E+02	MJ	HitachiMaxell 2003	1	1.24	(2,3,1,2,1,1,2)

Fig. 4.14 Unit process inventoy of the data set “Battery, Lilo, rechargable, prismatic, at plant”. (Cont.)

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Loca-tion	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Battery Plant		battery, Lilo, rechargeable, prismatic, at plant		▼ continued		consumed by the final battery manufacturer (see Env Report HitachiMaxell 2003), estimated based on the HITACHI Env Report 2003 + the exchange rate Y <-> CHF 2006-02-22	electronics	Metals	Yes	SE	facilities precious metal refinery	1.88E-08	Unit	HitachiMaxell 2003	1	2.11	(4,4,3,2,3,3,9)
				Battery, Lilo, reachargable, prismatic, at plant		dataset "facilities precious metal refinery" used as proxy	electronics	module	No	GLO	battery, Lilo, rechargeable, prismatic, at plant	1.00E+00	kg		1	1.24	(3,3,1,2,1,4,3)
				Disposal, plastic, consumer electronics, 15.3% water, to municipal incineration		representative for a NOKIA 3330 Lilo accu	waste management	hazardous waste incineration	No	CH	Disposal, plastic, consumer electronics, 15.3% water, to municipal incineration	8.49E+00	kg	HitachiMaxell 2003	1	1.24	(2,3,1,2,1,1,6)
				Toluene, to air		estimated based on the HITACHI Env Report 2003 + the exchange rate Y <-> CHF 2006-02-22	air	high population density			Toluene	5.48E-02	kg	HitachiMaxell 2003	1	1.24	(2,3,1,2,1,1,21)
				Heat, waste, to air		see HitachiMaxel Env Report 2003, estimated based on the data given in the Hitachi Report - no data were found on the total exhaust air volume the data refer to	air	unspecified			Heat, waste	3.22E+01	MJ	HitachiMaxell 2003	1	2.11	(2,3,3,2,3,3,31)

Fig. 4.14 Unit process inventoy of the data set “Battery, Lilo, rechargable, prismatic, at plant”. (Cont.)

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Copper carbonate, at plant	G	Electrode, positive, LiMn2O4, at plant					chemicals	inorganics	No	RER	copper carbonate, at plant	3.28E-02	kg	Anonymous work, 2004; Braun et al., 2001	1	1.08	(2,2,2,2,1,1,4)
Manganese, concentrate, at beneficiation	G					proxy for Li2Co3, value estimated based on stöchiometric calculation (see LiMn2O4 stoechio.pdf, mass derived from ratio given in Lilo battery electrode manufacturing.pdf)	metals	extraction	No	GLO	manganese, concentrate, at beneficiation	8.22E-01	kg	Anonymous work, 2004; Braun et al., 2001	1	1.08	(2,2,2,2,1,1,4)
Acetylene, at regional storehouse	G					proxy for MnO2, value estimated based on stöchiometric calculation (see LiMn2O4 stoechio.pdf, mass derived from ratio given in Lilo battery electrode manufacturing.pdf)	chemicals	organics	No	CH	acetylene, at regional storehouse	2.22E-02	kg	Braun et al., 2001	1	1.06	(1,2,2,1,1,1,4)
Graphite, at plant	G					electrodes (precursors) immersed into this, value for mass estimated from ratio given in Lilo battery electrode manufacturing.pdf	chemicals	inorganics	No	RER	graphite, at plant	4.44E-02	kg	Braun et al., 2001	1	1.06	(1,2,2,1,1,1,4)
Polyvinylidenchloride, granulate, at plant	G					electrodes (precursors) immersed into this, value for mass estimated from ratio given in Lilo battery electrode manufacturing.pdf	plastics	polymers	No	RER	polyvinylidenchloride, granulate, at plant	4.44E-02	kg	Braun et al., 2001	1	1.06	(1,2,2,1,1,1,4)
Pyrrolidinone, -n-methyl-, (at plant)	G					electrodes (precursors) immersed into this, value for mass estimated from ratio given in Lilo battery electrode manufacturing.pdf	chemicals	organics	No	RER	N-methyl-2-pyrrolidone, at plant	2.84E-01	kg	Beijing Green Huayang, 2006	1	2.56	(5,5,5,5,5,5,4)
Lithuim, at plant	G					electrodes (precursors) immersed into this, non qualitative estimate, no figures for processing were available	chemicals	inorganics	No	GLO	phosphoric acid, fertiliser grade, 70% in H2O, at plant	1.45E-01	kg	W.L Gore, 2004; Linden and Reddy, 2002	1	1.36	(4,4,3,3,3,4,4)

continued ▼

Fig. 4.15 Unit process inventory of the data set ”Electrode, positive, LiMn2O4, at plant”.

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Loca-tion	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
				▼ continued													
Sheet rolling, aluminium	S	Electrode, positive, LiMn2O4, at plant				basic input material for the Li-foil to which the electrode is sandwiched, estimated based on LiMn2O4 and Li density	metals	processing	No	RER	sheet rolling, aluminium	1.45E-01	kg		1	1.36	(4,4,3,3,3,4,3)
Helium, liquid, at plant	S					proxy, formation of the Li-foil	chemicals	organics	No	GLO	helium, at plant	5.60E+00	kg	Braun et al., 2001	1	#ZAHL!	(4,4,4,4,3,4,4)
Electricity, high voltage, production UCTE, at grid	S					proxy for helium, estimated based on the density of argon (assumed that the manufacturing box is 1m3)	electricity	production mix	No	UCTE	electricity, production mix UCTE	3.56E+00	kWh	Tesic, 2006	1	1.21	(1,2,1,2,3,1,2)
Battery plant	S					for heating the induction furnace, calculated based on the technical data sheet (Induction oven.htm)	electronics	Metals	Yes	SE	facilities precious metal refinery	5.76E-08	Unit	Hitachi, 2003		3.12	(4,4,3,2,3,3,9)
			S	Electrode, positive, LiMn2O4, at plant		dataset "facilities precious metal refinery" used as proxy	electronics	module	No	GLO	Electrode, positive, LiMn2O4, at plant	1.00E+00	kg		1		
			S	Heat. Waste, emission to air			air	unspecified			Heat, waste	1.60E+00	MJ		1		

Fig. 4.15 Unit process inventory of the data set ”Electrode, positive, LiMn2O4, at plant”.

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Graphite, at plant	S	Electrode, negative, LiC6, at plant					chemicals	inorganics	No	RER	graphite, at plant	6.93E-01	kg	W.L. Gore 2006; Isaev et al., 1997; Mizuni et al., 1997	1	1.51	(4,5,4,2,3,5,4)
Sheet rolling, aluminium, at plant	S					part of the electrode material in ratio 1:2	metals	processing	No	RER	sheet rolling, aluminium	2.40E-01	kg	W.L. Gore 2006; Isaev et al., 1997; Mizuni et al., 1997	1	1.51	(4,5,4,2,3,5,4)
Aluminium, production mix, at plant	S					processing of the electrode bonding material	metals	extraction	No	RER	aluminium, production mix, at plant	2.40E-01	kg	W.L. Gore 2006; Isaev et al., 1997; Mizuni et al., 1997	1	1.51	(4,5,4,2,3,5,4)
Litium, at plant	S					basic input material for the supporter to which the LiC6 electrode mass is bonded to	chemicals	organics	No	GLO	lithium, at plant	6.68E-02	kg	W.L. Gore 2006; Isaev et al., 1997; Mizuni et al., 1997	1	1.51	(4,5,4,2,3,5,4)
Battery plant	S					part of the electrode material in ration 1:2	electronics	Metals	Yes	SE	facilities precious metal refinery	1.13E-07	Unit			3.12	(4,4,3,2,3,3,9)
			S	Electrode, negative, LiC6, at plant		dataset "facilities precious metal refinery" used as proxy	electronics	component	No	RER	Electrode, negative, LiC6, at plant	1.00E+00	kg	EPBA Europe, 2000	1		

Fig. 4.16 Unit process inventory of the data set ”Electrode, negative, LiC6, at plant”.

5 Toner

5.1 Introduction

Toner is a coloured powder used in laser printers and photocopiers which forms the text and images on the printed paper. The datasets described in this chapter relate to the use in printers described in the respective chapter "printer" within part III of this report here.

This chapter is mainly based on data from a Swedish environmental product declaration of a remanufactured toner cartridge (Perfect Print Sweden AB (2002)) a comparative LCA of a Hewlett Packard black toner cartridge (First Environment (2004)) and an LCI on pulverised toner (Ahmadi et al. (2003)).

Due to proprietary nature of the data, it is not possible to establish the composition neither of an average toner formulation nor of a generic cartridge. Remanufacturing has been considered.

5.2 Material Characterisation, Production & Market

Toner is used in the digital printing process also denoted as electrophotography or xerography. Since its start from the copying machine application it has evolved to handle digital signal information by using a laser beam source. Being able to deal with digital image signal, electrophotography became an important output device for workstations and personal computers. A more detailed description of the printing process is given in Ohta (2006) and Ahmadi et al. (2003).

In the laser printing technology the toner builds a unit with the cartridge. The cartridge contains a part of the technology used for the marking process and the toner needed. Because of the electrostatic nature of image transfer, toner powder must have the feature of chargeability or magnetism.

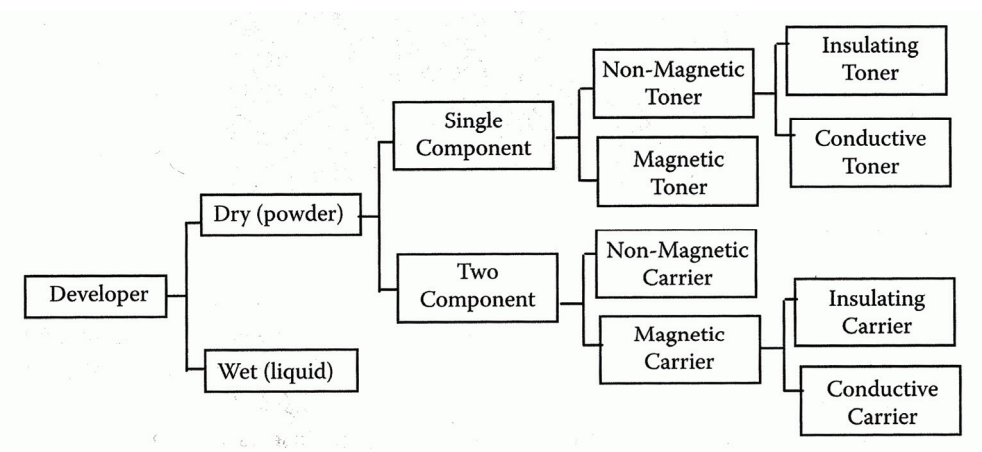


Fig. 5.1 Classification of developer for laser printers (Ohta (2006)) .

Generally toner systems can be divided according to number of components and electrostatic features into six classes (Fig. 5.1). The toner itself may be a part of the developer, where it cannot unify all features necessary and it has to be mixed with carrier. Dry toner can be manufactured mechanically by pulverisation (conventional process) or chemically by polymerisation (Chemically Processed Toner, CPT).

The market share of CPT is in the rise, although still small compared to the conventional Emulsion Aggregation (EA) toner. Galliford (2004) estimates the CPTs share on the global market with 1.6% (2'450 t – 1'900 t black, 550 t coloured) in 2001 to rise to 6.7% in 2006. By 2006 an estimated 45 % of colour toner and 10% of the black toner will be manufactured by chemically prepared methods.

Toner consists generally of following ingredients: Binder resin, carrier and colourant. The toner composition of most of the introduced colour lasers since 1994 have been monocomponent, non-magnetic design. A recent development has been the use of monocomponent, magnetic black toner in combination with monocomponent nonmagnetic cyan, yellow and magenta toners, first introduced in the HP4500 (Ohta (2006)).

Due to the multitude of toner cartridge supplier, it is not easy to tell, how the average toner is like. According to information of a responsible person at Hewlet-Packard following toner can be regarded actually as representative average: LaserJetC9700Black, LaserJetQ5949A-XPrint, LaserJetC9701ACyan, LaserJetC9702AYellow and LaserJetC9703AMangenta. Their composition is represented in Tab. 5.1 and Tab. 5.2 compared with other sources.

Tab. 5.1 Composition of black toner. Compilation of values from some frequently used toners and literature.

Toner	Refill Toner	Black Toner	non-magnetic	magnetic	LaserJetC9700Black
Source	Perfect Print Sweden AB (2002)	Ahmadi et al. (2003)	Ohta (2006)	Ohta (2006)	Hewlett Packard (2006a)
Binder Resin Styrene Acrylate	48%	70 - 95%			75 - 85%
Carbon Black		0 - 5%	5 - 10%		1 - 8%
Magnetite		15 - 20%		20 - 80%	
Iron Oxide	45%				
Release agent Polypropylene/ Polyethylene / Wax	4%		0 - 5%		5 - 15%
Charge control agents		0.2 - 5%	1 - 5%		
External Charge / Flow Agents / Silica	3%	0 - 3%	0 - 5%		

Tab. 5.2 Composition of coloured toner. Compilation of of values from some frequently used toners and literature.

Toner	colour	LaserJetQ5949A-XPrint	LaserJetC9701ACyan	LaserJetC9702AYellow	LaserJetC9703AMangenta
Source	Ohta (2006)	Hewlett Packard (2006e)	Hewlett Packard (2006b)	Hewlett Packard (2006c)	Hewlett Packard (2006d)
Binder Resin Styrene Acrylate		45 - 55%	75 - 85%	75 - 85%	76 - 85%
Magnetite		40 - 50%			
Colourant	5 - 10%		1 - 5%	1 - 5%	2 - 5%
Release agent Polypropylene/ Polyethylene / Wax			5 - 10%	5 - 10%	6 - 10%
Charge control agents					
External Charge / Flow Agents / Silica		1 - 2%			

5.3 Use & Application

The laser printer is in a middle position regarding quality and productivity in the area of hard copy printing systems. Future development will show whether this technology will extend the application range on both ends or shrink due to the progress of alternative printing technologies, e.g. inkjet printer.

Most colour printers are inkjet based and only a small share of the yearly shipments are electrophotographic colour printers (Ohta (2006)).

The demand in universal copier/printers is expected to boom in the next years. This will cause overall toner demand to rise even though total copy volume may decline (InfoTrends (2005)). The printer market currently dominates the demand for toner, representing an 8% compound annual growth rate by 2008, reaching 412 million pounds used and nearly $12 billion in revenues (Fig. 5.2).

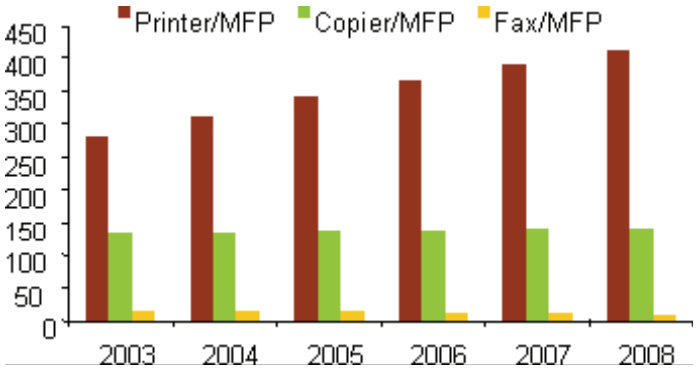


Fig. 5.2 World Toner Forecast by device in millions of pounds (InfoTrends (2005))

Colour is a key growth area. By 2008, InfoTrends (2005) expects full colour toner to account for 25% of all demand. One of the most important enablers for the colour market to grow is the continued use and improvement of toner. This is particularly the case for CPT, which is expected to offer better quality, lower usage costs, and higher machine reliability. Worldwide production of toner is strongly trending toward lower-cost areas, mainly China.

Lyra research, a provider of market and technology information, estimates that in 2004 more than 70 million OEM (original equipment manufacturers) and aftermarket colour and monochrome laser cartridges is shipped to Europe, the Middle East and Africa (EMEA), with Western Europe accounting for 76 %. For remanufactured laser cartridges a 27 % market share in 2004 is estimated with growing tendencies at the expense of OEM manufacturers (Mayhew (2006)).

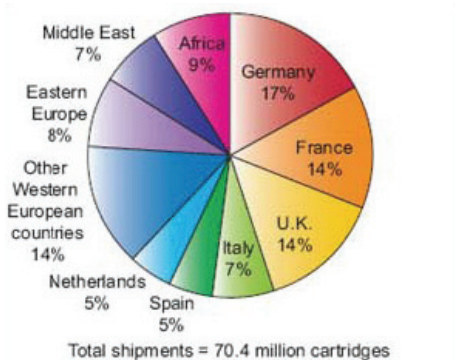


Fig. 5.3 Shares of destinations for laser cartridge shipments to Europe, the Middle East and Africa (EMEA) in 2004 (Mayhew (2006)).

5.4 System Characterisation

In this Chapter the datasets for black and coloured toner to be used in laserprinter are established. This is done with both an inventory for new toner cartridges and a dataset covering the whole life cycle of a toner cartridge with the functional unit of “mass of toner that is actually fixed on the printed paper” in kilograms. Following datasets are established:

A. Toner, black, powder, at plant [kg]

B. Toner, colour, powder, at plant [kg]

C. toner dataset, laser jet, b/w, at plant [unit]

D. toner dataset, laser jet, colour, at plant [unit]

E. Toner, black, used for printing [kg]

F. Toner, colour, used for printing [kg]

The first two datasets A & B (Toner, black / colour, powder, at plant) represent the pure pigment. They are used to build the datasets for production and use of the respective toner datasets (toner cartridge) C & D.

These second two datasets C & D (Toner dataset, laser jet, b/w / colour, at plant) describe the production of the toner, the cartridge, the packaging material, transport and disposal of the packaging material. They are needed on the one hand side in the devices (part III of this report) to complement the dataset for the printer manufacturing, on the other hand side they are used in datasets E & F.

The datasets E and F (Toner, black and colour, used for printing) correspond to the toner effectively printed including toner cartridge manufacturing, disposal and recycling, as well as losses of not fixed toner. They do not comprise the electricity used in the printing process. Their solely intended use is in the respective dataset in the use phase (see part IV of this report). There is no differentiation into original OEM cartridges and remanufactured cartridges. The datasets are modelled as Life Cycle of an individual cartridge, delivering a certain amount of toner on paper. The modelling thus is not dependent on image type, coverage and quality issues. Following industrial practice, refurbishment of the cartridge is assumed. Perfect Print Sweden AB (2002) indicates that cartridges can be used up to seven times, i. e. a cartridge may be refurbished six times until final disposal (Fig. 5.4).

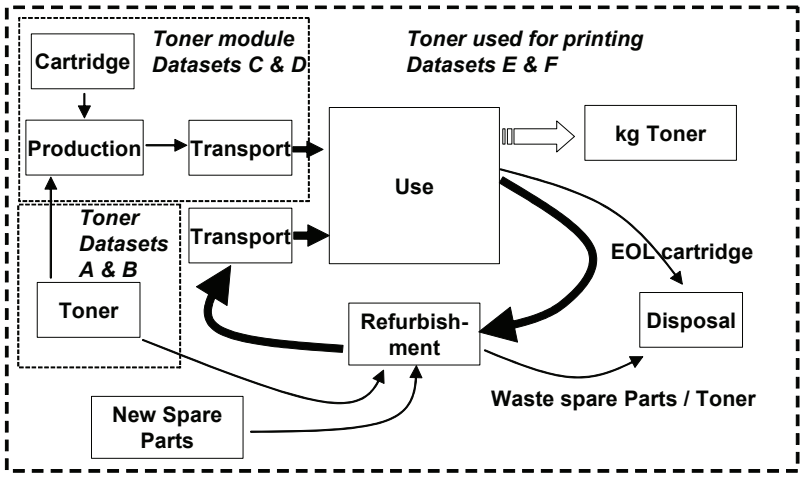


Fig. 5.4 The inventories for toner are modelled as life cycles with refurbishment. The functional unit refers to the printing of 1 kg toner.

5.5 Production of Toner Powder

The pulverised ink used in copiers and laser printers is denoted as toner. It basically consists of the colour together with a resin that forms a particle that is fixed on paper to represent a dot.

If two component development, the toner particles are transported by a oppositely charged carrier, whereas carrier and toner mixed together are called “developer”, thus it is a “two component devel-

oper". In the single development the system has no need for a carrier and thus is called a "one component developer".

The metadata of the two established inventories are given in (Tab. 5.6), their exchanges are shown in (Fig. 5.5).

Tab. 5.3 Ecoinvent meta information for the processes for the production of black and coloured toner powder.

Name	Toner, black, powder, at plant	Toner, colour, powder, at plant
Location	GLO	GLO
Infrastructure Process	0	0
Unit	kg	kg
Dataset Version	2.0	2.0
Included Processes	Includes the raw materials, their transportation and the energy use in the production. Infrastructure is included in the dataset of resin production. No process emissions considered.	Includes the raw materials, their transportation and the energy use in the production. Infrastructure is included in the dataset of resin production. No process emissions considered.
Amount	1	1
Local Name	Toner, schwarz, Pulver, ab Fabrik	Toner, farbig, Pulver, ab Fabrik
Synonyms	Pigment//Pigments	Pigment//Pigments
General Comment	The dataset represents the production of a black toner powder with the composition 5% Carbon Black, 18% Magnetite, 70% Binder Resin, the rest being organic and inorganic additives. It is designed for the use in black toner cartridges.	The dataset represents the production of a black toner powder with the composition 5% Colour, 83% Binder Resin, colour, the rest being organic and anorganic additives. It is designed for the use in colour toner cartridges of the colours Cyan, Magenta and Yellow.
Start Date	2002	2002
End Date	2005	2005
Data valid for entire period	1	1
Geography Text	European Electricity mix and material processing data for production site outside Europe	European Electricity mix and material processing data for production site outside Europe
Technology Text	Production by conventional pulverisation of styrene butadiene copolymer that is produced by emulsion polymerisation.	Production by conventional pulverisation of styrene butadiene copolymer that is produced by emulsion polymerisation.
Representativeness		
Production Volume	unknown	unknown
Sampling Procedure	Literature	Literature
Extrapolations	see Geography and Technology	see Geography and Technology
Uncertainty Adjustments	The chosen conventional technology might prove outdated and chemically produced toner less energy intensive. Due to proprietary nature and considerable bandwith of different formulations, high uncertainty assumed.	The chosen conventional technology might prove outdated and chemically produced toner less energy intensive. Due to proprietary nature and considerable bandwith of different formulations, high uncertainty assumed. Generic data for pigments underestimate actual impacts.

5.5.1 Processes of Toner Production

There are currently two general methods being used to make toners (powder ink):

- the conventional pulverised toner method and
- the chemically processed toner (CPT) method.

The conventional method uses a "pulverization technique" in which a large solid mass of toner is fractured and ground to a fine powder with a fairly tight particle size distribution.

The conventional production method cannot make the particles small enough for advanced printer technology. Digital technology today can print up to 1200 dots per square inch or dpi. Galliford (2004) states, that according to the Grunlach's Law there is an inverse relation between toner size and dot density in digital printing. In order to print up to 1200 dpi, toner particle size must be no greater than 3 μm. The limit of conventionally produced toner size is 8 μm. As soon the actual installed toner production capacities have become amortised the toner industry will invest in CPT technology.

In general, conventional toner is made using the same process, which involves compounding the raw materials (resin, magnetite, and pigment) followed by extruding the polymer melt into solid pellets. The pellets are then ground into micron-sized particles and classified (separated) to the desired size distribution. Particles from the classifier that are too big or too small are returned upstream for further processing (Fluharty (2005)).

The CPT process grows the toner particles 'bottom-up' from molecules using chemical synthesis and other physical properties. Currently, there are several technologies used to prepare CPT (Galliford (2004)):

- suspension polymerization
- emulsion polymerization / latex aggregation
- Polyester (Elongation) Polymerisation (PxP)
- Chemical milling (shear forces by mixing)

The particles usually are (micro)encapsulated to tune the properties such as tribo properties or melt rheology.

In both techniques colourants are added to the resin, being black or with different pigments. Where suspension polymerisation is quite susceptible to the choice of colourants and other non-polymerisable ingredients, the polymerisation and the pigmentation steps in the emulsion polymerisation do not interfere.

Pigments can be of different nature, Ohta (2006) states a non-benzene yellow pigment "C.I. Pigment Yellow 17", Quinacridone carmine 6B (Magenta) and Copper-phthalocyanine (Cyan) as pigments.

5.5.2 Life cycle inventory of "Toner, black, powder, at plant" in ecoinvent

Since data on toner formulation is proprietary and fast changing, no coherent study is available to establish this dataset. Two studies on toner manufacturing is available, one for conventional pulverised toner (Ahmadi et al. (2003)) and one on chemically produced toner (Fluharty (2005)). Whereas the former study describes a today probably outdated technology, the latter study does mainly rely on weak assumptions. Since the basic raw materials remained the same in the evolution of the toner-fabrication, a blend of different sources in Tab. 5.1 has been used to derive an average composition.

In this study the emulsion polymerisation process of the styrene-butadiene copolymer that constitutes the binder resin is chosen to reflect both the pulverisation toner process (polymerisation to form aggregates) and the emulsion polymerization / latex aggregation process as representative for the CPT. The production of binder resin may be well represented by the dataset "latex, at plant".

Tab. 5.4 shows the respective unit process inventory of one kg of toner. The energy requirement for conventional pulverised toner has been published in Ahmadi et al. (2003); it is modelled with the UCTE electricity production mix. Fluharty (2005) claims that the CPT process by emulsion polymerisation consumes only 65% of the conventional process without citing original literature. Therefore the

value for conventional toner production has been chosen in this study on the risk of overestimating the energy consumption but on the benefit of more reliable sources. The additives have been aggregated to be inventoried with a generic dataset for organic and inorganic chemicals respectively.

As for transport services relating to the raw material delivery the standard distances stated in the ecoinvent quality guidelines of 200 km by truck and 100 km by rail.

Infrastructure is supposed to be contained within the dataset "latex, at plant" chosen for the production of the emulsion polymerisation of styrene butadiene copolymer. No waste and disposal services are considered.

Tab. 5.4 Compilation of the most important constituents in 1 kg black toner powder according to Ahmadi et al. (2003) and Ohta (2006). Due to the broad range of formulations this list is not concluding. Therefore the min and max content indicated in the sources do not necessarily add up to 100% in any combination.

Production of Toner, Black	Unit	Mean	Min	Max
Carbon Black	kg	0.05	0	0.1
Magnetite	kg	0.175	0.15	0.20
Toner Additives Organic, total	kg	0.03	0.01	0.05
--- Polypropylene	kg	(0.01)		
--- Polyetyhlene	kg	(0.01)		
--- Carnuba wax	kg	(0.01)		
Toner Additives inorganic, total	kg	0.045	0.03	0.06
--- Charge control agent, Nigrosin	kg	(0.025)		
--- Silica	kg	(0.01)		
--- Zinc stearate	kg	(0.01)		
Binder Resin (Latex)	kg	0.7	0.5	0.95
Electricity	MJ	6.1		

5.5.3 Life cycle inventory of "Toner, colour, powder, at plant" in ecoinvent

The inventory for coloured toner differs only in its formulation from the black toner's inventory. All other exchanges are modelled equally like in the inventory of black toner.

As for black toner neither exact formulations, nor a representative range of components used in toner production are available for this study. Therefore the values are taken from various public sources (Ohta (2006)) and compiled to an inventory shown in Tab. 5.5. The energy requirements have been assumed to equal those in the production of black toner. Beside the higher content in binder resin, also the organic nature of the pigments differs from the black toner. Since no data on their formulation is available, they are approximated with the generic ecoinvent-dataset of organic chemicals.

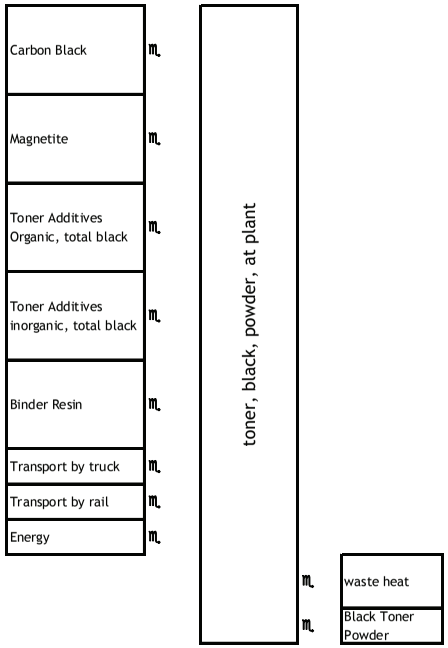
The additives have been aggregated to be inventoried with the generic dataset for organic and inorganic chemicals respectively. The energy consumption is assumed to be electricity and is modelled with the UCTE electricity production mix.

Tab. 5.5 Unit Process data of the Production of 1 kg colour toner.

Production of Toner, colour	Unit	Mean	Min	Max
Colour	kg	0.05	0.02	0.1
Toner Additives Organic, total	kg	0.08	0.05	0.1
--- Polypropylene	*kg*	(0.03)		
--- Polyetyhlene	*kg*	(0.03)		
--- Carnuba wax	*kg*	(0.02)		
Toner Additives inorganic, total	kg	0.045	0.03	0.06
--- Charge control agent, Nigrosin	*kg*	(0.025)		
--- Silica	*kg*	(0.01)		
--- Zinc stearate	*kg*	(0.01)		
Binder Resin	kg	0.825	0.7	0.95
Electricity	MJ	6.1		

5.5.4 Data quality and uncertainty adjustments

Due to differing formulations and toner types (magnetic, non-magnetic, resin content, etc) a quite large uncertainty range is assumed. This is indicated in the columns min and max in the respective tables. Within ecoinvent the uncertainty is reflected with a triangular distribution.



General Flow information							Representation in ecoinvent										Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent	Mean value	Mean value	Unit	Source	Type	StDv 95%	General Comment
Carbon Black		toner, black, powder, at plant				Black pigment	chemicals	inorganics	No	GLO	carbon black, at plant	5.00E-02		kg	Perfect Print Sweden AB (2002), Ahmadi (2003), Ohta (2006), Hewlett Packard (2006)	3		Triangular distribution [0.0E0, 5.0E-2, 1.0E-1] extends over 200%
Magnetite						For carrier / black pigment	electronics	module	No	GLO	magnetite, at plant	1.75E-01		kg	Perfect Print Sweden AB (2002), Ahmadi (2003), Ohta (2006), Hewlett Packard (2006)	3		Triangular distribution [1.5E-1, 1.8E-1, 2.0E-1] extends over 29%
Toner Additives Organic, total black						Release agent Polypro-pylene/ Polyethylene / Wax	chemicals	organics	No	GLO	chemicals organic, at plant	3.00E-02		kg	Perfect Print Sweden AB (2002), Ahmadi (2003), Ohta (2006), Hewlett Packard (2006)	3		Triangular distribution [1.0E-2, 3.0E-2, 5.0E-2] extends over 133%
Toner Additives inorganic, total black						External Charge / Flow Agents / Silica	chemicals	inorganics	No	GLO	chemicals inorganic, at plant	4.50E-02		kg	Perfect Print Sweden AB (2002), Ahmadi (2003), Ohta (2006), Hewlett Packard (2006)	3		Triangular distribution [3.0E-2, 4.5E-2, 6.0E-2] extends over 67%
Binder Resin						Copolymers of styrene and budadiene by • emulsion polymerization / latex aggregation	chemicals	organics	No	RER	latex, at plant	7.00E-01		kg	Perfect Print Sweden AB (2002), Ahmadi (2003), Ohta (2006), Hewlett Packard (2006)	3		Triangular distribution [5.0E-1, 7.0E-1, 9.5E-1] extends over 64%
Transport by truck						Rawmaterials over 100 km	transport systems	road	No	RER	transport, lorry >16t, fleet average	1.00E-01		tkm	calculated	1	2.09	(4,1,1,1,1,5,5)
Transport by rail						Rawmaterials over 200 km	transport systems	train	No	RER	transport, freight, rail	2.00E-01		tkm	calculated	1	2.09	(4,1,1,1,1,5,5)
Energy							electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	6.11E+00		kWh	Ahmadi A et al (2003), Tab. 1	1	1.22	(2,3,1,2,1,5,2)
				waste heat			air	high population density			Heat, waste	2.20E+01		MJ	from electricity use	1	1.22	
				Black Toner Powder			electronics	module	No	GLO	toner, black, powder, at plant	1.00E+00		kg				

Fig. 5.5 Unit process inventories of the datasets Toner, black, powder, at plant.

General Flow information							Representation in ecoinvent									Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent	Mean value	Mean value	Unit	Source	Type	StDv 95%	General Comment
Color		toner, colour, powder, at plant		waste heat		Pigments for Cyan, Magenta or Yellow	chemicals	organics	No	GLO	chemicals organic, at plant	5.00E-02		kg	Ohta (2006), Hewlett Packard (2006)	3		Triangular distribution [3.8E-2, 5.0E-2, 6.3E-2] extends over 50%
Toner Additives Organic, total colour				Coloured Toner Powder		Release agent Polypro-pylene/ Polyethylene / Wax	chemicals	organics	No	GLO	chemicals organic, at plant	8.00E-02		kg	Ohta (2006), Hewlett Packard (2006)	3		Triangular distribution [5.0E-2, 8.0E-2, 1.0E-1] extends over 63%
Toner Additives inorganic, total colour						External Charge / Flow Agents / Silica	chemicals	inorganics	No	GLO	chemicals inorganic, at plant	4.50E-02		kg	Ohta (2006), Hewlett Packard (2006)	3		Triangular distribution [3.0E-2, 4.5E-2, 6.0E-2] extends over 67%
Binder Resin, colour						Copolymers of styrene and budadiene by • emulsion polymerization / latex aggregation	chemicals	organics	No	RER	latex, at plant	8.25E-01		kg	Ohta (2006), Hewlett Packard (2006)	3		Triangular distribution [7.0E-1, 8.3E-1, 9.5E-1] extends over 30%
Transport by truck						Rawmaterials over 100 km	transport systems	road	No	RER	transport, lorry >16t, fleet average	1.00E-01		tkm	calculated	1	2.09	(4,1,1,1,1,5,5)
Transport by rail						Rawmaterials over 200 km	transport systems	train	No	RER	transport, freight, rail	2.00E-01		tkm	calculated	1	2.09	(4,1,1,1,1,5,5)
Energy, colour							electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	6.11E+00		kWh	Ahmadi A et al (2003)	1	1.22	(2,3,1,2,1,5,2)
							air	high population density			Heat, waste	2.20E+01		MJ	from electricity use	1	1.22	Calculation
							electronics	module	No	GLO	toner, colour, powder, at plant	1.00E+00		kg				

Fig. 5.5 Unit process inventories of the datasets Toner, colour, powder, at plant.

5.6 Production of Toner Cartridges

Although all produced toner cartridges work after a similar principle, there is a huge variety of different cartridge types, depending on application (high-end, low-end), producer (Fuji-Xerox, Hewlett Packard HP, Canon, Epson, etc.) and colour system (four colours, black).

The most frequently used cartridge size has a capacity of 5000 pages A4 printed with 5% coverage. There are other sizes that cover from 3'000 to 10'000 and more pages.

Colour lasers use the same fundamental electrophotographic steps like monochrome lasers. The primary difference between monochrome and colour is how to perform this process four times for a single sheet of paper, once for each of the four colours of cyan, magenta, yellow and black (CMYK) (Ohta (2006)). Hence the toner cartridge designs do not differ remarkably (Fig. 5.6).

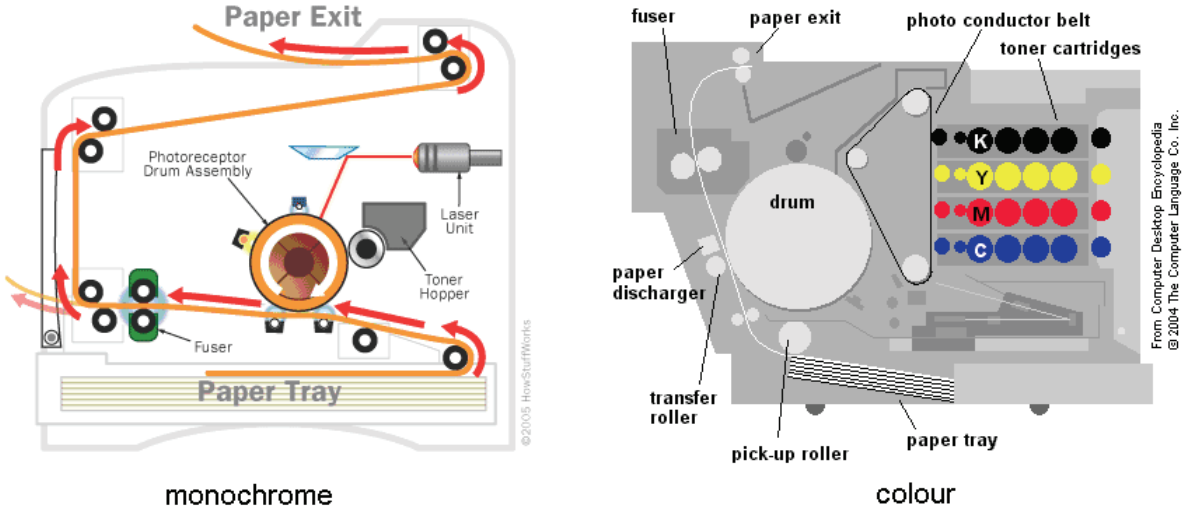


Fig. 5.6 The application of monochrome and colour toner cartridge for printing

The metadata of the two established inventories are given in Tab. 5.6, their exchanges are shown in Fig. 5.8.

5.6.1 Manufacturing process and components

The production process consists of forming the parts that are produced in-house and assembling the parts. After testing the cartridges they are packed and shipped. Most manufacturers are located in Japan and the U.S.

Tab. 5.6 Ecoinvent meta information for the processes for the production of cartridges for black and coloured toner.

Name	toner dataset, laser jet, b/w, at plant	toner dataset, laser jet, colour, at plant
Location	GLO	GLO
Infrastructure Process	0	0
Unit	unit	unit
Dataset Version	2.0	2.0
Included Processes	Includes the manufacturing of the semifinished parts, toner powder, the material transport to the site, the assembly, the packaging, No direct emissions are considered.	Includes the manufacturing of the semifinished parts, toner powder, the material transport to the site, the assembly, the packaging, No direct emissions are considered.
Amount	1	1
Local Name	Tonermodul, Laserdrucker s/w, ab Werk	Tonermodul, Laserdrucker farbig, ab Werk
Synonyms	toner cartridge//OEM cartridge	toner cartridge//OEM cartridge//CMYK
General Comment	This dataset refers to a standard black toner cartridge with a capacity of 5'000 prints A4 and coverage of 5%, specifically a HP C4096A for HP2100 printers. Original equipment manufacturer (OEM) manufacturing assumed, no re-manufacturing.	This dataset refers to a standard colour toner cartridge (cyan, yellow, magenta or black, CMYK) with a capacity of 5'000 prints A4 and coverage of 5%, specifically a HP C4096A for HP2100 printers. Original equipment manufacturer (OEM) manufacturing assumed, no re-manufacturing.
Start Date	2002	2002
End Date	2005	2005
Data valid for entire period	1	1
Geography Text	European Electricity mix and material processing data for production site outside Europe	European Electricity mix and material processing data for production site outside Europe
Technology Text	Assembly of the semifinished components by OEM to cartridges.	Assembly of the semifinished components by OEM to cartridges.
Representativeness		
Production Volume	unknown	unknown
Sampling Procedure	Literature	Literature
Extrapolations	see Geography and Technology	see Geography and Technology
Uncertainty Adjustments	Composition of cartridge is based on not so actual (2002) data that is adopted to 2004 situation. Some of the known components such as OPC are not reflected adequately.	Composition of cartridge is based on not so actual (2002) data of a cartridge for monochrome printer that is adopted to 2004 situation. Some of the known components such as OPC are not reflected adequately.

The toner cartridge fulfils two functions: first it is a container for the developer, i.e. toner and carrier. Second it carries the elements needed in the marking process. These elements are responsible for the composition of the toner cartridge (Fig. 5.7):

1. The primary charge roller (PCR) places a uniform negative charge on the surface of the organic photo-conducting (OPC) drum.
2. The laser passes through an aperture on top of the cartridge striking the OPC drum, which creates a temporary positive charge.
3. The developer roller circles through the toner hopper. Since the developer roller is magnetic, toner adheres to the surface of the roller.
4. The doctor blade smoothes the toner on the developer roller to a fine, consistent layer.
5. The developer roller and the OPC roll together but do not touch. Toner on the developer roller is attracted to the positively charged spots on the OPC and ‘jumps’ across the narrow gap to

fill in these spots. Unused toner on the developer roller rotates around again into the toner hopper.

6. The OPC Drum rotates around to meet the paper, transferring the toner to the page. The paper then continues on to the fuser.

7. The wiper blade removes any excess toner and media debris from the drum, cleaning it for the next cycle.

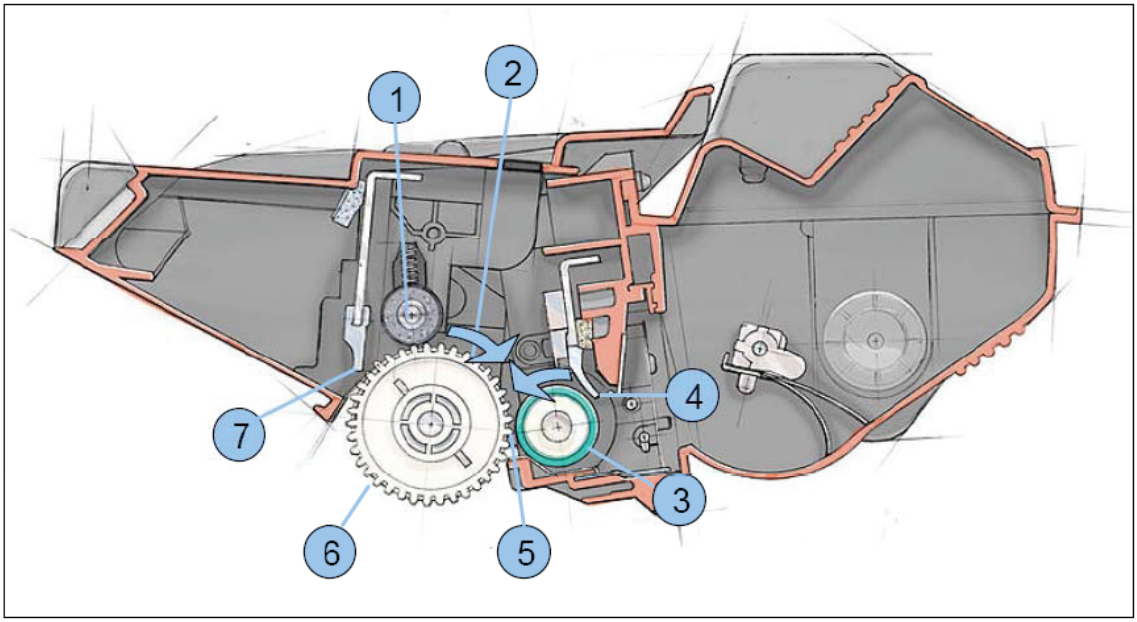


Fig. 5.7 **Components of a toner cartridge that provide the functions of the marking process. (1) primary charge roller, PCR, (2) Aperture for laser, (3) developer roller, (4) doctor blade, (5) Space between developer roller and OPC drum, (6) organic photo-conducting drum, OPC, (7) wiper blade. Description of the marking process in the text (First Environment (2004)).**

5.6.2 Life cycle inventory of monochrome and coloured toner cartridges.

This inventory corresponds to the original production (OEM) of an average toner cartridge, their filling with black or coloured toner, packaging, shipment to the customer and disposal of the packaging materials employed. As for the cartridge type HP C4096A for laser printer HP2100 has been modelled, since it is both, very often used and good documented by studies.

The inventory of black toner cartridge is also valid for its use in colour printer systems (three colours, one black).

The inventories for the production of both the black toner cartridge and the coloured toner cartridge are identical – except the type of toner powder contained, which is black toner powder and coloured toner powder, respectively. This assumption is based on the general similarity of the different cartridge types.

In this chapter following data sources is used: A study on a HP 96A cartridge vs. its remanufactured counterpart (First Environment (2004)), a detailed EPD for a remanufactured cartridge (Perfect Print Sweden AB (2002)) and a more recent overview on remanufactured HP cartridges (Perfect Print Sweden AB (2004)).

In First Environment (2004) a HP C4096A cartridge is analysed. On the official website it is stated to weight 3.63 lb (1.8 kg) including toner and package. Perfect Print Sweden AB (2004) says that they fill this kind of cartridge with 260g of new toner. Assuming the same amount of 260g of toner filling, and 454g packaging (First Environment (2004)) a 960g cartridge weight result. This value is in contrast to the indicated 880g (800 original parts, 80 new spare parts) in Perfect Print Sweden AB (2004) and differ from older more detailed publication, where 704 g for original and 462 g for new spare parts is indicated for a remanufactured cartridge with comparable page yield (Perfect Print Sweden AB (2002), Tab. 5.7).

Since no accurate values is available due to the proprietary nature of the cartridge producer, the values from the detailed remanufactured cartridge are chosen and scaled to the proportion of the more recent values of 880g in total. This approach assumes, that (a) the originally manufactured cartridge does not differ in materials deployed from the remanufactured counterpart, and (b) the materials and technologies did not change from the older but more detailed in 2002 study (1166g) and the newer document (880g) and a mere miniaturisation leads to a material reduction that is proportional to the older values.

Tab. 5.7 Detailed composition of a remanufactured toner cartridge as indicated in an EPD (Perfect Print Sweden AB (2002)) and a newer EPD, that states the values of the remanufactured C4096A cartridge. The values in the column "scaled total" are used in this study.

Cartridge	unit	Core parts	spare parts	total	Scaled core	Scaled spare	Scaled total
SmartToner EP-E (2002)							
Aluminium	g	28	162	190	21	122	143
ABS-plastic	g		148	148		112	112
GPP-plastic	g	254		254	192		192
Glassfibre	g	14		14	11		11
Ironpowder	g	49		49	37		37
LDP-plastic	g		5	5		4	4
Polyurethanerubber	g	49		49	37		37
Polyoxymethaneplastic	g	21	5	26	16	4	20
Polypropyleneplastic	g		18	18		14	14
Polyurethaneplastic	g	77		77	58		58
Steel	g	212	124	336	160	94	254
total	g	704	462	1166	531	349	880
HP C4096A (2004)	g	800	80	880			

The energy consumption has been estimated with the value for remanufacturing the OEM cartridge as stated in Perfect Print Sweden AB (2002) with 8 kWh of electricity per unit.

The materials employed in production are transported to the manufacturing site over 300 km by truck First Environment (2004). Total weight of the materials comprising of toner, cartridge, and packaging is 1596 g.

An example for cartridge packaging is given in First Environment (2004) and has been adopted for this dataset (Tab. 5.8). The internal packaging from metallised PET has roughly been approximated with LDPE foil manufactured by callendering PE granulates. No aluminum has been considered since the layer is thin and due to the small relevance no further investigations could be justified.

Tab. 5.8 Composition and mass of packaging material for one single specific cartridge (First Environment (2004)).

Material	Unit	Value
External Packaging. Paperboard, recycled cardboard	g	330
Internal Packaging. Composite from metallised PET and PE	g	50
End Caps, internal packaging, recycled paperboard	g	74
Total	g	454

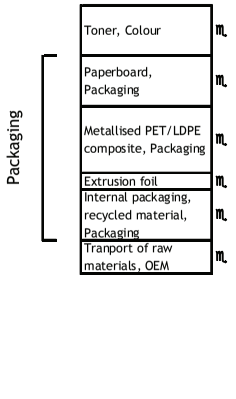
5.6.3 Data quality and uncertainty adjustments

Since no real data on cartridge composition and energy requirements are accessible, assumptions had to be made based on a related cartridge remanufacturing process. These assumptions impair the data quality. The uncertainties have been assessed with the pedigree matrix approach except for toner mass for which a normal distribution with 15% upper and lower confidence band has been assumed.

General Flow information							Representation in ecoinvent									Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent	Mean value	Mean value	Unit	Source	Type	StDv 95%	General Comment
Aluminium, original Cartridge	m	toner module, laser jet, b/w, at plant toner module, laser jet, colour, at plant				Tab 4	metals	extraction	No	RER	aluminium, primary, at plant	1.43E-01	1.43E-01	kg	Perfect Print (2002)	1	1.25	(2,4,1,2,3,3,3)
Aluminium processing	m						metals	processing	No	RER	section bar extrusion, aluminium	1.43E-01	1.43E-01	kg	Assumption	1	1.33	(4,4,1,2,3,3,3)
GPP-plastic	m					Tab 4. General Purpose Polystyrene	plastics	polymers	No	RER	polystyrene, general purpose, GPPS, at plant	1.92E-01	1.92E-01	kg	Perfect Print (2002)	1	1.25	(2,4,1,2,3,3,3)
Polyoxymethaneplastic	m					Tab 4. inventoried as GPPS	plastics	polymers	No	RER	polystyrene, general purpose, GPPS, at plant	1.96E-02	1.96E-02	kg	Perfect Print (2002)	1	1.25	(2,4,1,2,3,3,3)
Polyurethaneplastic	m					Tab 4. Inventoried as rigid PU foam	plastics	polymers	No	RER	polyurethane, rigid foam, at plant	5.81E-02	5.81E-02	kg	Perfect Print (2002)	1	1.25	(2,4,1,2,3,3,3)
Injectionmoulding	m					Processing of Plastics, sum.	plastics	processing	No	RER	injection moulding	2.69E-01	2.69E-01	kg	Assumption	1	1.33	(4,4,1,2,3,3,3)
Glassfibre	m					Tab 4.	glass	construction	No	RER	glass fibre, at plant	1.06E-02	1.06E-02	kg	Perfect Print (2002)	1	1.25	(2,4,1,2,3,3,3)
Ironpowder	m						electronics	module	No	GLO	magnetite, at plant	3.70E-02	3.70E-02	kg	Perfect Print (2004)	2	0.01	Normal distribution [3.1E-2, 3.7E-2, 4.3E-2] extends over 30%
Polyurethanerubber	m					Tab 4.	plastics	polymers	No	RER	polyurethane, flexible foam, at plant	3.70E-02	3.70E-02	kg	Perfect Print (2002)	1	1.25	(2,4,1,2,3,3,3)
extrusion PU-Rubber	m					Processing of rubber	plastics	processing	No	RER	extrusion, plastic film	3.70E-02	3.70E-02	kg	Perfect Print (2002)	1	1.25	(2,4,1,2,3,3,3)
Steel	m					Tab 4.	metals	extraction	No	RER	steel, electric, un- and low-alloyed, at plant	2.54E-01	2.54E-01	kg	Perfect Print (2002)	1	1.25	(2,4,1,2,3,3,3)
Steel processing	m					Processing of steel	metals	processing	No	RER	sheet rolling, steel	2.54E-01	2.54E-01	kg	Assumption	1	1.33	(4,4,1,2,3,3,3)
Electricity for Manufacturing	m					EPD indicates 23kWh per 2.9 Cartridges. Assumption: Remanufacturing = initial production.	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	7.93E+00	7.93E+00	kWh	Perfect Print (2002) & Assumption	1	1.58	(4,4,1,2,4,3,2)
Infrastructure Cartridge production	m					Zhuhai Gree Magneto-Electric Co Ltd: 800 employees 3'000'000 units per month in a 1750 m2 factory	construction processes	buildings	Yes	CH	building, hall	4.86E-06	4.86E-06	m2	internet & assumptions	1	3.11	(4,4,1,2,3,3,9)

continued ▼

Fig. 5.8 Unit process inventories of the datasets Toner datasets, black / colour, at plant.



General Flow information							Representation in ecoinvent									Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Loca-tion	Modul name in ecoinvent	Mean value	Mean value	Unit	Source	Type	StDv 95%	General Comment
Toner, Colour	m	toner module, laser jet, b/w, at plant	m	waste heat			electronics	module	No	GLO	toner, colour, powder, at plant	-	2.60E-01	kg	Perfect Print (2004)	2	0.04	Normal distribution [2.2E-1, 2.6E-1, 3.0E-1] extends over 30%
Paperboard, Packaging	m						paper & cardboard	cardboard & corrugated board	No	RER	corrugated board, recycling fibre, double wall, at plant	3.30E-01	3.30E-01	kg	First Environment (2004)	1	1.15	(1,4,1,2,1,4,3)
Metallised PET/LDPE composite, Packaging	m						plastics	polymers	No	RER	polyethylene, LDPE, granulate, at plant	5.00E-02	5.00E-02	kg	First Environment (2004)	1	1.15	(1,4,1,2,1,4,3)
Extrusion foil	m						plastics	processing	No	RER	extrusion, plastic film	5.00E-02	5.00E-02	kg	Assumption	1	1.15	(1,4,1,2,1,4,3)
Internal packaging, recycled material, Packaging	m						paper & cardboard	cardboard & corrugated board	No	RER	corrugated board, recycling fibre, double wall, at plant	7.40E-02	7.40E-02	kg	First Environment (2004)	1	1.15	(1,4,1,2,1,4,3)
Tranport of raw materials, OEM	m					300 km to manufacturing site, total weight 1.594 kg	transport systems	road	No	RER	transport, lorry >16t, fleet average	5.02E-01	5.02E-01	tkm	First Environment(2004)	1	2.07	(4,4,1,2,1,4,5)
							air	high population density			Heat, waste	2.86E+01	2.86E+01	MJ	from electricity use	1	1.58	
			m	Toner module, black			electronics	module	No	GLO	toner module, laser jet, b/w, at plant	1.00E+00	-	unit				
			m	Toner module, colour			electronics	module	No	GLO	toner module, laser jet, colour, at plant	-	1.00E+00	unit				

Fig. 5.8 Unit process inventories of the datasets Toner datasets, black / colour, at plant. (continued)

5.7 Toner, used for printing

After fulfilling the first use cycle toner cartridges are returned to remanufacturing sites, where they are refilled and refurbished. Some of the empty cartridges ("empties" or "core") are sorted out and disposed. While this can be perceived as average failure rate, the cartridge's life cycle also can be thought of as a number of subsequent refurbishment cycles (Fig. 5.9).

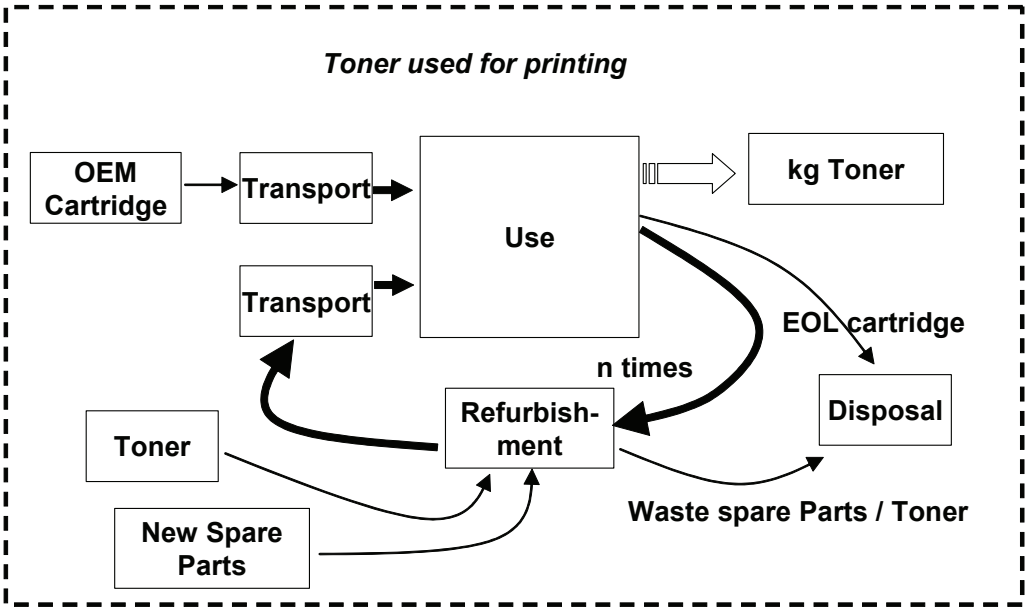


Fig. 5.9 Modelling of the datasets „Toner, black / colour, used for printing" as life cycle rather than a blend of OEM and refurbished cartridge. In this study an average of two use cycles is assumed.

Cartridges are remanufactured by specialised companies. They reuse the cores of original equipment manufacturers (OEMs) and refurbish it with replacement parts from different suppliers and refill it with toner.

The first step in any remanufacturing process is obtaining the empty cartridge ("core"). According to First Environment (2004) in 2000, at least 70 percent of first remanufacturing cycle cores is abandoned. Next, the remanufacturer must disassemble the cartridge. Disassembling a HP 96A is a multistep process that requires the removal of sensitive components such as the OPC drum (Fig. 5.7). After completing the desired degree of disassembly, components can be checked to determine their suitability for reuse. The component performance in a second (and additional) cycle is again impaired and the failure rate rises.

Not all of the toner powder is fixed on the paper, the rest is collected returned to remanufacturing together with the cartridge where it is prepared, sieved and reused. Ahmadi et al. (2003) assumes a fixation rate of 90% and a re-use rate of 66%.

The number of refurbishment cycles defines the skeleton of this unit process inventory. Tab. 5.9 gives an accounting scheme for two cycles and the assumptions above for a cartridge containing 260g toner.

The metadata of the two established inventories are given in (Tab. 5.9), their exchanges are shown in (Fig. 5.9).

Tab. 5.9 Quantification of Life Cycle stages covered in the dataset "Toner, black / colour, used for printing". Two use cycles (one initial, one refurbishment) assumed. Cartridge contains 260g toner.

Step	unit	Per Use Cycle	Per kg toner on paper
Production of Cartridge	unit	1	2.14
Production of Toner Black / CMY	kg	0.503	1.07
. Production of Toner, first use	kg	0.26	0.56
. Production of Toner, subsequent cycles	kg	0.2	0.52
--- Toner reused from Recycling	kg	0.017	
Recharge of Tonercartridge	unit	1	2.14
Disposal of Tonercartridge, incl Toner	unit	1	2.14
Toner on paper	kg	0.47	1
--- Toner to Recycling	kg	0.03	
--- Toner in last Cartridge	kg	0.03	
Toner reused	kg	0.017	
Waste toner to disposal	kg	0.009	0.019

Tab. 5.10 ecoinvent meta information for the processes for the use of toner.

Name	Toner, black, used for printing	Toner, colour, used for printing
Location	RER	RER
Infrastructure Process	0	0
Unit	kg	kg
Dataset Version	2.0	2.0
Included Processes	Includes the initial OEM cartridge, the transports to the customer, the remanufacturing and disposal of spare parts and spare toner and the final disposal of the cartridge. No emissions due to printing contained.	Includes the initial OEM cartridge, the transports to the customer, the remanufacturing and disposal of spare parts and spare toner and the final disposal of the cartridge. No emissions due to printing contained.
Amount	1	1
Local Name	Toner, schwarz, auf Papier gedruckt	Toner, farbig, auf Papier gedruckt
Synonyms	toner cartridge//OEM cartridge	toner cartridge//OEM cartridge//CMYK
General Comment	This dataset relates to the mass of black toner actually printed on paper. It assumes two use cycles, i.e. one as a OEM cartridge and a subsequent as remanufactured virgin core. It is to be used to reflect black toner use in both monochrome (b/w) and colour (black pigment) laser printer systems for cartridges with a capacity of 5000 sheets and a weight of env. 1 kg including toner.	This dataset relates to the mass of coloured toner printed actually printed on paper. It assumes two use cycles, i.e. one as a OEM cartridge and a subsequent as remanufactured virgin core. It is to be used to reflect coloured toner use in colour laser printer systems for cartridges with a capacity of 5000 sheets and a weight of env. 1 kg including toner.
Start Date	2002	2002
End Date	2005	2005
Data valid for entire period	1	1
Geography Text	European Electricity mix and material processing data for supplier outside Europe.	European Electricity mix and material processing data for supplier outside Europe.
Technology Text	Replacement of spare parts, assembly of semi-finished components.	Replacement of spare parts, assembly of semi-finished components.
Representativeness		
Production Volume	unknown	unknown
Sampling Procedure	Literature	Literature
Extrapolations	see Geography and Technology	see Geography and Technology
Uncertainty Adjustments	Composition of cartridge is based on 2002 data that is adapted to 2004 situation. Inventory may strongly be affected by user behaviour and number of remanufacturing cycles.	Composition of cartridge is based on 2002 data of a cartridge for monochrome printer that is adapted to 2004 situation. Inventory may strongly be affected by user behaviour and number of remanufacturing cycles.

5.7.1 Life Cycle inventory

There is a debate on how many remanufacturing cycles are applicable and the degree of quality decline of remanufactured toner cartridges. The original equipment manufacturers OEM like HP claim that the impairment of the print quality has such a degree, that no direct comparison of OEM cartridges and remanufactured cartridges possible. In First Environment (2004) a “sort and discard” rate of 20% to 36% (rejected “empties”) stated. Perfect Print Sweden AB (2002) indicates up to seven reuse cycles. These figures however are conditioned and true for remanufactured cartridges. They do not include the cartridges that are disposed of and do not enter the remanufacturing cycle. The value of roughly 25% market share of remanufactured cartridges however indicates a rather low recycling rate. A collection rate of 25% together with a “sort and discard” rate of 20% would give an overall recycling rate of 25%*(1-20%) = 20% that would support this 25% market share. Under this assumption 100 OEM cartridges would generate 20 first cycle cores and from these four second cycles and from

these one third cycle, resulting roughly in one quart of the OEM cartridges produced. This means that for an average lifecycle of a cartridge today merely one additional lifecycle or two use cycles respectively may be supported.

Tab. 5.11 Unit Process Inventory for 1 kg toner used for printing depending on the number of use cycles, whereas one use denotes the one-way situation without remanufacturing and seven uses the maximum indicated by Perfect Print Sweden AB (2002). In this inventory a two use cycles are assumed – one original and one as refurbished cartridge.

	Uses	1	2	3	5	7
Initial OEM cartridges	unit	4.27	**2.14**	1.42	0.85	0.61
Additional Toner for remanufacturing	kg	-	**0.52**	0.69	0.83	0.89
Remanufacturing cycles	unit	-	**2.14**	2.85	3.42	3.66
Disposal of remanufactured Cartridge	unit	4.27	**2.14**	1.42	0.85	0.61
Waste toner to disposal	kg	-	**0.019**	0.025	0.030	0.032

Initial OEM cartridges are modelled with the respective datasets for "toner datasets, black / colour, at plant" established in this chapter. Also the additional toner used for manufacturing refers to the respective datasets "Toner, black / colour, powder, at plant". The packed original cartridges are assumed to be shipped over an average distance of 300 km by truck and another 5'500 km by ship to the end user (First Environment (2004)). Since identical packaging of the OEM and remanufactured cartridge is assumed the respective exchanges for disposal correspond to the sum cartridge units (4.27 units).

Tab. 5.12 Assumed composition of a remanufactured toner cartridge as established for the dataset "toner datasets, black / colour, at plant". Only spare parts are changed in the remanufacturing step.

Cartridge	unit	core	spare	total
Aluminium	g	21	122	143
ABS-plastic	g		112	112
GPP-plastic	g	192		192
Glassfibre	g	11		11
Ironpowder	g	37		37
LDP-plastic	g		4	4
Polyurethanerubber	g	37		37
Polyoxymethaneplastic	g	16	4	20
Polypropyleneplastic	g		14	14
Polyurethaneplastic	g	58		58
Steel	g	160	94	254

The remanufacturing of the cartridges is based on the only detailed EPD for remanufactured cartridges in Perfect Print Sweden AB (2002) As explained in "5.6.2 Life cycle inventory of monochrome and coloured toner cartridges." the values are scaled to match the more recent cartridge design of HP C4096A. In the same turn the exchanged parts are disposed of to the municipal waste incinerator, except aluminium and steel that are assumed to be recycled (burdenfree, cut-off). Energy requirements are indicated in the EPD with 23 kWh per function unit, in this case per kg toner delivered by 2.9 remanufactured toner cartridges, hence 23 kWh / 2.9 equalling to 7.93 kWh/unit of electricity. In the used inventory model, 2.12 units per kg toner used for printing is required (Tab. 5.11).

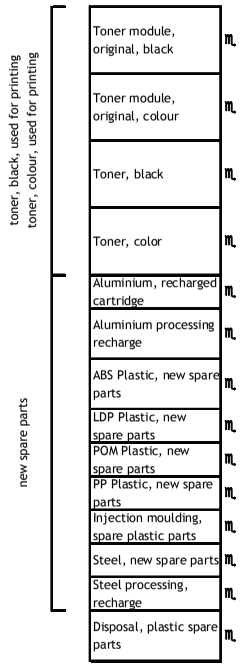
The infrastructure use per cartridge has been assumed with a value twice as big as for the OEM Cartridge because of the larger scale of the OEMs. Packaging and its disposal at the customer is assumed

to be identical like for the original OEM cartridge (see. *5.6.2 Life cycle inventory of monochrome and coloured toner cartridges.*).

A small amount of waste toner (10 %) is collected in the cartridge and is returned to the remanufacturing site, where a 66% of this waste toner can be reused to displace virgin toner powder (Ahmadi et al. (2003)). The disposal of toner is approximated with the one of Polystyrene, since most of its mass consists of styrene-butadiene-copolymer. No differentiation between monochrome and coloured toner is made. The final disposal of the cartridge is approximated with the dataset for Polystyrene disposal.

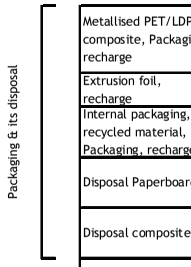
5.7.2 Data quality and uncertainty adjustments

The uncertainties of the exchanges of toner cartridges and also toner for refilling the cartridge have assumed to be lognormal with a lower interval that equals 85% of the average. This value is arbitrary but consistent with the assumption made for the toner contained in the cartridge. The uncertainties of all other exchanges have been assessed with the pedigree approach.



General Flow information							Representation in ecoinvent									Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent	Mean value	Mean value	Unit	Source	Type	StDv 95%	General Comment
Toner module, original, black	m					Numbers of uses assumed: 2	electronics	module	No	GLO	toner module, laser jet, b/w, at plant	2.14E+00	-	unit	Calculations, Ahmadi et al (2002)	1	1.18	LogNormal distribution [1.8, 2.1, 2.5] extends over 33%
Toner module, original, colour	m					Numbers of uses assumed: 2	electronics	module	No	GLO	toner module, laser jet, colour, at plant	-	2.14E+00	unit	survey	1	1.18	LogNormal distribution [1.8, 2.1, 2.5] extends over 33%
Toner, black	m						electronics	module	No	GLO	toner, black, powder, at plant	5.19E-01	-	kg	Perfect Print (2002)	1	1.18	LogNormal distribution [0.4, 0.5, 0.6] extends over 33%
Toner, color	m						electronics	module	No	GLO	toner, colour, powder, at plant	-	5.19E-01	kg	survey	1	1.18	LogNormal distribution [0.4, 0.5, 0.6] extends over 33%
Aluminium, recharged cartridge	m					2.1 remanufacturing cycles per kg toner	metals	extraction	No	RER	aluminium, primary, at plant	2.61E-01	2.61E-01	kg	Perfect Print (2002)	1	1.25	(2,4,1,2,3,3,3)
Aluminium processing recharge	m					Processing of the Aluminium parts	metals	processing	No	RER	section bar extrusion, aluminium	2.61E-01	2.61E-01	kg	Assumption	1	1.33	(4,4,1,2,3,3,3)
ABS Plastic, new spare parts	m						plastics	polymers	No	RER	acrylonitrile-butadiene-styrene copolymer, ABS, at plant	2.39E-01	2.39E-01	kg	Perfect Print (2002)	1	1.25	(2,4,1,2,3,3,3)
LDP Plastic, new spare parts	m						plastics	polymers	No	RER	polyethylene, LDPE, granulate, at plant	8.06E-03	8.06E-03	kg	Perfect Print (2002)	1	1.25	(2,4,1,2,3,3,3)
POM Plastic, new spare parts	m					Polyether, approximated with PE production	plastics	polymers	No	RER	polyethylene, LDPE, granulate, at plant	8.06E-03	8.06E-03	kg	Perfect Print (2002)	1	1.25	(2,4,1,2,3,3,3)
PP Plastic, new spare parts	m						plastics	polymers	No	RER	polypropylene, granulate, at plant	2.90E-02	2.90E-02	kg	Perfect Print (2002)	1	1.25	(2,4,1,2,3,3,3)
Injection moulding, spare plastic parts	m					Processing of the employed plastics ABS, LDP, POM, PP	plastics	processing	No	RER	injection moulding	2.84E-01	2.84E-01	kg	Assumption	1	1.33	(4,4,1,2,3,3,3)
Steel, new spare parts	m						metals	extraction	No	RER	steel, electric, un- and low-alloyed, at plant	2.00E-01	2.00E-01	kg	Perfect Print (2002)	1	1.25	(2,4,1,2,3,3,3)
Steel processing, recharge	m					Processing of the steel parts	metals	processing	No	RER	sheet rolling, steel	2.00E-01	2.00E-01	kg	Assumption	1	1.25	(2,4,1,2,3,3,3)
Disposal, plastic spare parts	m					Swiss Processes assumed	waste management	municipal incineration	No	CH	disposal, plastic, industr. electronics, 15.3% water, to municipal incineration	2.84E-01	2.84E-01	kg	Assumption	1	1.26	(4,4,1,2,1,4,6)

Fig. 5.10 Unit process inventories of the datasets “Toner, black / colour, used for printing” (continued).



General Flow information						Representation in ecoinvent									Uncertainty information		
Input		Process Name		Output	Remarks	Category	Sub-category	Infra-structure	Loca-tion	Modul name in ecoinvent	Mean value	Mean value	Unit	Source	Type	StDv 95%	General Comment
Metallised PET/LDPE composite, Packaging, recharge	▲	Toner, black and white / colour, used for printing, part II		▼ continued	Same as original	plastics	polymers	No	RER	polyethylene, LDPE, granulate, at plant	1.07E-01	1.07E-01	kg	First Environment (2004)	1	1.15	(1,4,1,2,1,4,3)
Extrusion foil, recharge	▲					plastics	processing	No	RER	extrusion, plastic film	1.07E-01	1.07E-01	kg	Assumption	1	1.15	(1,4,1,2,1,4,3)
Internal packaging, recycled material, Packaging, recharge	▲					paper & cardboard	cardboard & corrugated board	No	RER	corrugated board, recycling fibre, double wall, at plant	1.58E-01	1.58E-01	kg	First Environment (2004)	1	1.15	(1,4,1,2,1,4,3)
Disposal Paperboard	▲				including initial OEM Packaging	waste management	municipal incineration	No	CH	disposal, packaging cardboard, 19.6% water, to municipal incineration	1.73E+00	1.73E+00	kg	Assumption	1	1.26	(4,4,1,2,1,4,6)
Disposal composite	▲				including initial OEM Packaging	waste management	municipal incineration	No	CH	disposal, polyethylene, 0.4% water, to municipal incineration	2.14E-01	2.14E-01	kg	Assumption	1	1.26	(4,4,1,2,1,4,6)
Transport service recharge, Truck, total	▲				2 times 500 km for cartridge, 200 km for raw materials, 50 km for disposal services	transport systems	road	No	RER	transport, lorry >16t, fleet average	2.78E+00	2.78E+00	tkm	First Environment(2004)	1	2.07	(4,4,1,2,1,4,5)
Infrastructure recharge	▲				double of OEM	construction processes	buildings	Yes	CH	building, hall	2.08E-05	2.08E-05	m2	internet & assumptions	1	1.58	(4,4,1,2,4,3,2)
Electricity, recharge	▲					electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	1.69E+01	1.69E+01	kWh	Perfect Print (2002)	1	3.11	(4,4,1,2,3,3,9)
Disposal of spare toner	▲				approximated with Polystyrene disposal	waste management	municipal incineration	No	CH	disposal, polystyrene, 0.2% water, to municipal incineration	8.84E-03	8.84E-03	kg	Perfect Print (2002)	1	1.26	(4,4,1,2,1,4,6)
Disposal of toner cartridge incl spare toner	▲				approximated with Polyethylene disposal	waste management	municipal incineration	No	CH	disposal, polystyrene, 0.2% water, to municipal incineration	9.06E-01	9.06E-01	kg	Perfect Print (2002)	1	1.26	(4,4,1,2,1,4,6)
			▲	waste heat		air	high population density			Heat, waste	6.10E+01	6.10E+01	MJ	from electricity use	1	3.11	
			▲	Toner, used for printing		electronics	module	No	RER	toner, black, used for printing	1.00E+00	-	kg				
			▲	Toner, Colour, used for printing		electronics	module	No	RER	toner, colour, used for printing	-	1.00E+00	kg				

Fig. 5.10 (continued) Unit process inventories of the datasets “Toner, black / colour, used for printing”.

6 Drives

6.1 Introduction

This Chapter presents the datasets of the hard disk drives as well as the CD-ROM/DVD-ROM drives for both desktop and laptop computers.

Electronic computer components are produced and sold by internationally operating companies. Shape and function of the same brand and type do not vary in different parts of the world. Therefore, all the datasets described here are labelled with GLO, meaning that they are valid in the global context. The Chapter starts with general product information on the hard disk drives (Chapter 6.1.1) and CD/DVD-ROM drives (Chapter 6.1.2), continues with the system characterisation (Chapter 6.1.3), the use and application of the established datasets (Chapter 6.1.4) and concludes with the description of the specific datasets (Chapter 6.2 to 6.5).

6.1.1 Hard Disk Drive (HDD)

General Product Information & Market

Nearly every desktop computer and server in use today contains one or more hard-disk drives. One can even find VCR-type devices and camcorders that use hard disks instead of tapes. These billions of hard disks do one thing well – they store changing digital information in a relatively permanent form[31].

They is originally called “fixed disks” or “Winchesters” (a code name used for a popular IBM product). They later became known as “hard disks” to distinguish them from “floppy disks”[31]. For many years, hard disks is large, cumbersome devices, more suited to use in the protected environment of a data centre or large office than in a harsh industrial environment (due to their delicacy), or small office or home (due to their size and power consumption). Before the early 1980s, most hard disks had 8-inch (20 cm) or 14-inch (35 cm) platters, required an equipment rack or a large amount of floor space (especially the large removable-media disks, which is often referred to as "washing machines"), and in many cases needed high-current or even three-phase power hookups due to the large motors they used (Fig. 6.1). Because of this, hard disks is not commonly used with microcomputers until after 1980, when Seagate Technology introduced the ST-506, the first 5.25-inch hard disk, with a capacity of 5 megabytes[32].

Most microcomputer hard disks in the early 1980s is not sold under their manufacturer's names, but by OEMs as part of larger peripherals (such as the Corvus Disk System and the Apple ProFile). The IBM PC/XT had an internal hard disk, however, and this started a trend toward buying "bare" disks (often by mail order) and installing them directly into a system. Hard disk makers started marketing to end users as well as OEMs, and by the mid-1990s, hard disks had become available on retail store shelves[33].

[31] Marshall Brain: How Hard Disks Work (http://computer.howstuffworks.com/hard-disk.htm), accessed April 4, 2007.

[32] Wikipedia: Hard disk. (http://en.wikipedia.org/wiki/hard_disk), accessed April 4, 2007.

Fig. 6.1 IBM 62PC „Piccolo“ HDD, ca. 1979 – an early 8” disk (source: Hard disk, Wikipedia[33])

While internal disks became the system of choice on PCs, external hard disks remained popular for much longer on the Apple Macintosh and other platforms. The first Apple Macintosh built between 1984 and 1986 had a closed architecture that did not support an external or internal hard drive. In 1986, Apple added a SCSI port on the back, making external expansion easy. External SCSI drives are also popular with older microcomputers such as the Apple II series, and are also used extensively in servers, a usage which is still popular today. The appearance in the late 1990s of high-speed external interfaces such as USB and FireWire has made external disk systems popular among PC users once again, especially for users who move large amounts of data between two or more areas, and most hard disk makers now make their disks available in external cases[33].

Notebook drives are typically 2.5" in size and can range from 20 up to 200 GB in size. Most systems will have between 60 and 120 GB of data size that is more than enough for the standard notebook system. Some of the ultraportable systems use the newer 1.8" PC card style hard drives. These range in size from about 10 to 60 GB[34].

Main Hard disk components

A typical computer Hard disk is built with the following essential parts (see Fig. 6.2, Fig. 6.3 and Mohite 2005):

- Top and bottom cover (aluminium)
- Printed circuit board (different materials – metals and plastics)
- Platters (aluminium) with motor/coils (different materials)
- Read/write heads on a pointer (aluminium)
- Motor for the pointer arm, with ultra-strong magnet (different materials)

[33] Wikipedia: Hard disk. (http://en.wikipedia.org/wiki/hard_disk), accessed April 4, 2007.

[34] Kyrnin, M.: Understanding Notebook Drives (http://compreviews.about.com/od/storage/a/NoteDriveSpec.htm), accessed April 5, 2007.

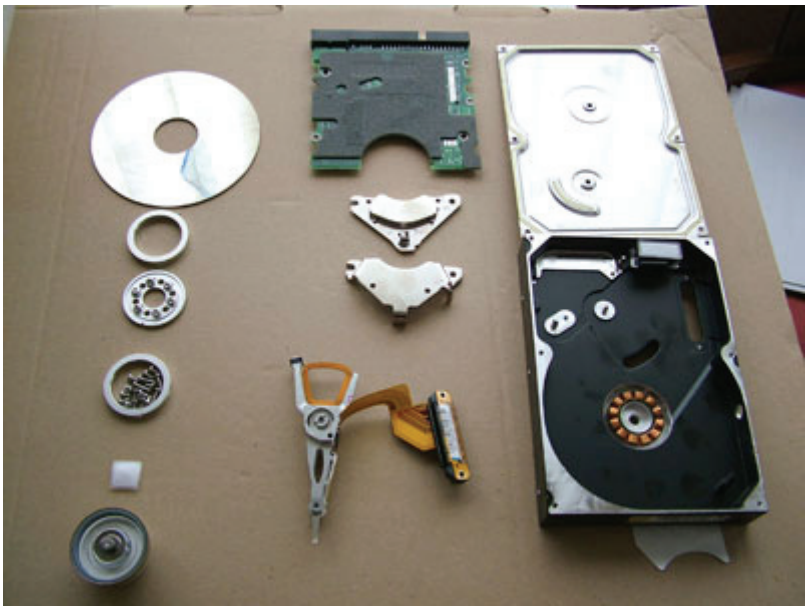


Fig. 6.2 Main parts of a computer Hard Disk Drive (source: PC Doctor Guide 2005[35])

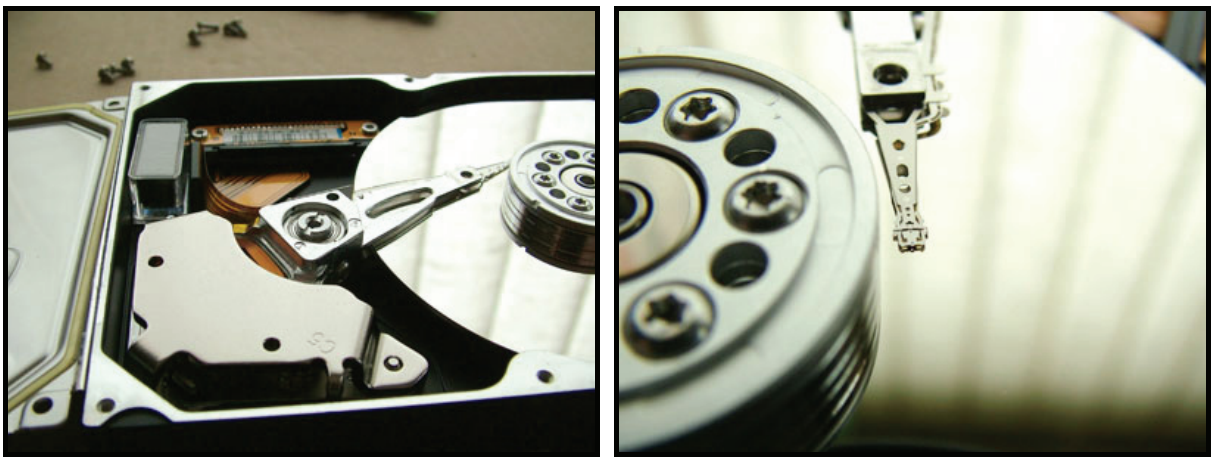


Fig. 6.3 Pointer with read/write head next to the platter of a desktop computer Hard disk drive (source: PC Doctor Guide 2005[35])

[35] PC Doctor Guide (http://www.pcdoctor-guide.com/wordpress/?p=595), accessed April 4, 2007.

Hard disk characteristics

A hard disk can be characterised according to its *capacity* and *physical* size and some other measures[36]:

- The capacity is usually quoted in gigabytes, older hard disks used to quote their smaller capacities in megabytes.
- The physical size on the other hand is quoted in inches. Almost all hard disks today are of either the 3.5" or 2.5" varieties, used in desktops and laptops, respectively. 2.5" disks are usually slower and have less capacity, but use less power and are more tolerant of movement. However, as of early 2007, manufacturers have started selling SATA and SAS 2.5" drives for use in servers and desktops (see paragraph further down for explanation of various disk families). The size designations are more nomenclature than descriptive: for example, a 3.5" drive is named for the size of the floppy disk whose drive bay size it is originally designed to occupy; the drive itself is actually wider
- Number of I/O operations per second: Modern disks can perform around 50 random access or 100 sequential access operations per second
- Power consumption (especially important in battery-powered laptops)
- Audible noise in dBA (although many still report it in bels, not decibels)
- G-shock rating (surprisingly high in modern disks)
- Transfer rate: Inner zone from 44.2 MB/s to 74.5 MB/s, outer zone from 74.0 MB/s to 111.4 MB/s
- Random access time: from 5 ms to 15 ms.

The disk *geometry* of different hard drives varies, but always follows the same layout, no matter what the size or storage capacity. In each hard drive, each platter has 2 sides, and both of these sides have the same structure in all platters[37]. Fig. 6.4 shows the layout of a Hard disk platter.

Tracks

Tracks are concentric circles of information on the disk. Unlike *CD*s, which have only one track that spirals out from the center, hard drives have many tracks. And unlike CDs, hard drive tracks start at the outer edges of the hard drive and work their way in. Tracks are read by placing the actuator arm and heads over the correct track, and the hard drive rotation will move the complete track under the head. There are many thousand tracks on each side of each platter in today's hard drives. Tracks are not referred to by themselves; instead they are part of cylinders, and broken down into sectors. The number of sectors in a track is dependent on which zone the track is part of [37].

Sectors

Sectors are the smallest geometry of a hard drive. Each sector is 512 bytes of user data, plus a few additional bytes are used for servo control, error detection and error correction. Sectors are sections of each track. Sectors are responsible for the storage of individual files[37].

[36] Wikipedia: Hard disk. (http://en.wikipedia.org/wiki/hard_disk), accessed April 4, 2007.

[37] IC Inside Computers: Think Quest 2007 (http://library.thinkquest.org/C006208/data/device-harddrives3.php), accessed April 4, 2007.

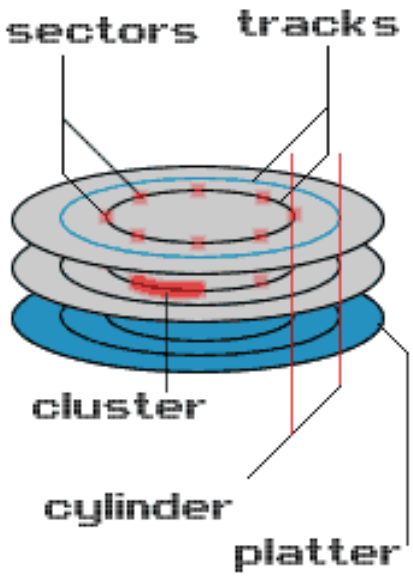


Fig. 6.4 Layout of a Hard disk platter to store information (source: IC Inside Computers, Think Quest 2007[38])

Cylinders

Cylinders are groupings of the corresponding tracks on all of the platters. Because each platter's actuator arm is connected to the other actuator arms, all of the different platter's heads will always be on the same tracks. It is logical that tracks are organized in cylinders. For example, track 3 on each platter composes the number 3 cylinder. This organization forms what can be visualized as an imaginary cylinder. Cylinders aren't needed for operation, but are used in all hard drives to make sector location easier[38].

Zones

Tracks are concentric circles on the platters, so the outer tracks will naturally have a larger circumference than the inner tracks. Because the outer tracks are bigger than the inner ones, they are able to store more data. To handle this, a feature called *zoned bit recording* (ZBR) is used. ZBR is often referred to as *multiple zone recording* or *zone recording*. Zoned bit recording is where outer tracks are grouped into different *zones*. These zones start on the outside tracks and are numbered in ascending order until it reaches the inner track[38].

Every track in a certain zone has the same number of sectors like every other track in that zone. Each zone can have a random number of tracks, and use a random number of sectors per track; it is up to the manufacturer to find the optimum numbers[38].

Partitions

In computer engineering, hard disk drive partitioning is the creation of logical divisions upon a hard disk that allows to apply operating system-specific logical formatting[39]. Each portion, or partition, has its own *boot record* and *FAT*. This allows a single hard drive to be partitioned to support different file structures [38].

[38] IC Inside Computers: Think Quest 2007 (http://library.thinkquest.org/C006208/data/device-harddrives3.php), accessed April 4, 2007.

[39] Wikipedia: Disk partitioning (http://en.wikipedia.org/wiki/Disk_partitioning), accessed June 25, 2007.

Disk families used in personal computers

Notable Hard disk families include Bit Serial Interfaces on the one hand and World Serial Interfaces on the other[40]:

- *Bit Serial Interfaces*: These families are connected to a hard disk controller with three cables, one for data, one for control and one for power. The hard disk controller provides significant functions such as serial to parallel conversion, data separation and track formatting, and required matching to the drive in order to assure reliability.
- *World Serial Interfaces*: These families connect to a host bus adapter (today typically integrated into the "North Bridge") with two cables, one for data/control and one for power. The earliest versions of these interfaces typically had a 16 bit parallel data transfer to/from the drive and there are 8 and 32 bit variants. Modern versions have serial data transfer. Examples for these kind of families are IDE, DMA, SCSI, SATA or SAS.
  - *Integrated Drive Electronics* (IDE) is later renamed to ATA, and then PATA. The name comes from the way early families had the hard disk controller external to the disk. Moving the hard disk controller from the interface card to the disk helped to standardize interfaces, including reducing the cost and complexity. In 2005/2006 parlance, the 40 pin IDE/ATA is called "PATA" or parallel ATA, which means that there are 16 bits of data transferred in parallel at a time on the data cable. The data cable is originally 40 conductor, but UDMA modes from the later disks requires using an 80 conductor cable (note that the 80 conductor cable still uses a 40 position connector.)
  - *Direct Memory Access* (DMA): EIDE is an unofficial update (by Western Digital) to the original IDE standard, with the key improvement being the use of DMA to transfer data between the disk and the computer, an improvement later adopted by the official ATA standards. DMA is used to transfer data without the CPU or program being responsible to transfer every word. That leaves the CPU/program/operating system to do other tasks while the data transfer occurs.
  - *Small Computer System Interface* is an early competitor with ESDI, originally named SASI for Shugart Associates. SCSI disks is standard on servers, workstations, and Apple Macintosh computers through the mid-90s, by which time most models had been transitioned to IDE (and later, SATA) family disks. Only in 2005 did the capacity of SCSI disks fall behind IDE disk technology, though the highest-performance disks are still available in SCSI and Fibre Channel only.
  - SATA (Serial ATA). The SATA data cable has one data pair for differential transmission of data to the device, and one pair for differential receiving from the device, just like EIA-422. Data must be transmitted serially. The same differential signaling system is used in RS485, LocalTalk, USB, Firewire, and differential SCSI.
  - SAS (Serial Attached SCSI). The SAS is a new generation serial communication protocol for devices designed to allow for much higher speed data transfers and is compatible with SATA. SAS uses serial communication instead of the parallel method found in traditional SCSI devices but still uses SCSI commands for interacting with SAS.

Manufacturers

As of 2007, more than 98% of the world's hard disks are manufactured by just a handful of large firms: Seagate, Western Digital, Samsung, and Hitachi which owns the former disk manufacturing division

[40] Wikipedia: Hard disk. (http://en.wikipedia.org/wiki/hard_disk), accessed April 4, 2007.

of IBM. Fujitsu continues to make mobile- and server-class disks but exited the desktop-class market in 2001. Toshiba is a major manufacturer of 2.5-inch and 1.8-inch notebook disks[41].

Dozens of former hard disk manufacturers have gone out of business, merged, or closed their hard disk divisions; as capacities and demand for products increased, profits became hard to realise, and there is shakeouts in the late 1980s and late 1990s. The first notable casualty of the business in the PC era is Computer Memories Inc. or CMI; after an incident with faulty 20 MB AT disks in 1985. CMI's reputation never recovered, and they exited the hard disk business in 1987. Many other smaller companies (like Kalok, Microscience, LaPine, Areal, Priam and PrairieTek) also did not survive the shakeout, and disappeared by 1993; Micropolis is able to hold on until 1997, and JTS, a relative latecomer to the scene, lasted only a few years and is gone by 1999, after attempting to manufacture hard disks in India using a second hand factory. Rodime is also an important manufacturer during the 1980s, but stopped making disks in the early 1990s amid the shakeout and now concentrates on technology licensing; they hold a number of patents related to 3.5-inch form factor hard disks[41].

6.1.2 CD-ROM Drive / DVD-ROM Drive

General Product Information & Market

Removable storage has been around almost as long as the computer itself. Early removable storage is based on magnetic tape like that used by an audio cassette. Before that, some computers even used paper punch cards to store information[42].

CDs and DVDs are everywhere these days. Whether they are used to hold music, data or computer software, they have become the standard medium for distributing large quantities of information in a reliable package. The CD-ROM and DVD-drive consists of three fundamental components[43]:

- A *drive motor* spins the disc. This drive motor is precisely controlled to rotate between 200 and 500 rpm depending on which track is being read.
- A *laser* and a *lens system* focus in and read the bumps.
- A *tracking mechanism* moves the laser assembly so that the laser's beam can follow the spiral track. The tracking system has to be able to move the laser at micron resolutions.

CD-ROM discs are read using CD-ROM drives (compare Fig. 6.5, Fig. 6.6 and Fig. 6.7), which are now almost universal on personal computers. A CD-ROM drive may be connected to the computer via an IDE (ATA), SCSI, S-ATA, Firewire, or USB interface or a proprietary interface, such as the Panasonic CD interface. Virtually all modern CD-ROM drives can also play audio CDs as well as Video CDs and other data standards when used in conjunction with the appropriate software.

There are two optical storage types with CD-ROMs. CD-R works by replacing the aluminium layer in a normal CD with an organic dye compound. This compound is normally reflective, but when the laser focuses on a spot and heats it to a certain temperature, it "burns" the dye, causing it to darken. In order to retrieve the data you wrote to the CD-R, the laser moves back over the disc and thinks that each

[41] Wikipedia: Hard disk (http://en.wikipedia.org/wiki/hard_disk), accessed April 4, 2007.

[42] Jeff Tyson: How Removable Storage Work (http://www.howstuffworks.com/removable-storage.htm), accessed April 4, 2007.

[43] Marshall Brain: How CDs Work (http://computer.howstuffworks.com/cd.htm), accessed April 04, 2007.

burnt spot is a bump. The problem with this approach is that you can only write data to a CD-R once. After the dye has been burned in a spot, it cannot be changed back[44].

CD-RW fixes this problem by using *phase change*, which relies on a very special mixture of antimony, indium, silver and tellurium. This particular compound has the following specific property: When heated to one temperature, it crystallizes as it cools and becomes very reflective; when heated to another, higher temperature, the compound does not crystallize when it cools and so becomes dull in appearance[44].

CD-RW drives have three laser settings to make use of this property:

- *Read* - The normal setting that reflects light to the optoelectronic sensor
- *Erase* - The laser set to the temperature needed to crystallize the compound
- *Write* - The laser set to the temperature needed to de-crystallize the compound

Other optical devices that deviate from the CD standard, such as *DVD*, employ approaches comparable to CD-R and CD-RW. An older, hybrid technology called *magneto-optical* (MO) is seldom used anymore. MO uses a laser to heat the surface of the media. Once the surface reaches a particular temperature, a magnetic head moves across the media, changing the polarity of the particles as needed[44].

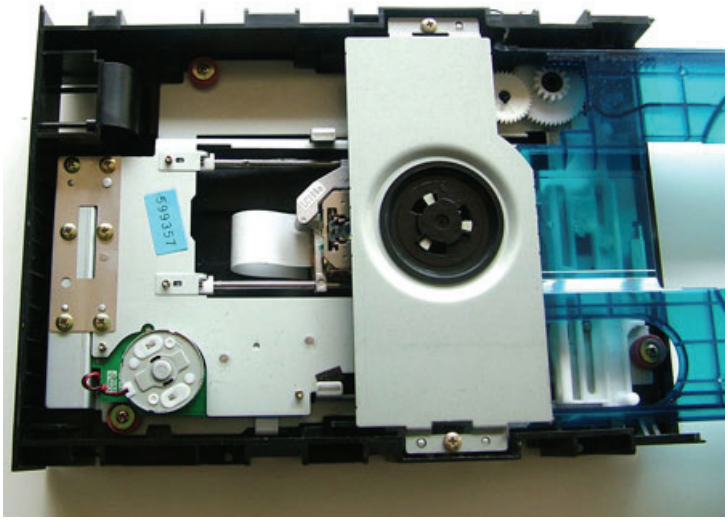


Fig. 6.5 The insides of a CD-ROM drive (source: PC Doctor Guide 2005, CD-RW drive, retrieved April 4, 2007, from http://www.pcdoctor-guide.com/wordpress/?p=1396)

A CD-ROM drive operates by using a laser to reflect light off the bottom of the disc. The reflected light is then read by a photo detector. The overall operation of a CD-ROM drive is as follows[45]:

1. The laser diode emits a low-energy infrared beam toward a reflecting mirror.

[44] Tyson, Jeff: How Removable Storage Works (http://www.howstuffworks.com/removable-storage12.htm), accessed April 04, 2007.

[45] McLean, Terry: How CD-ROM-Drive Works (http://www.e-articles.info/e/a/title/How-CD-ROM-drive-works/), accessed April 05, 2007.

2. The servo motor, on command from the microprocessor, positions the beam onto the correct track on the CD-ROM by moving the reflecting mirror.
3. When the beam hits the disc, its refracted light is gathered and focused through the first lens beneath the platter, bounced off the mirror, and sent toward the beam splitter.
4. The beam splitter directs the returning laser light toward another focusing lens.
5. The last lens directs the light beam to a photo detector that converts the light into electric impulses.
6. These incoming impulses are decoded by the microprocessor and sent along to the host computer as data.

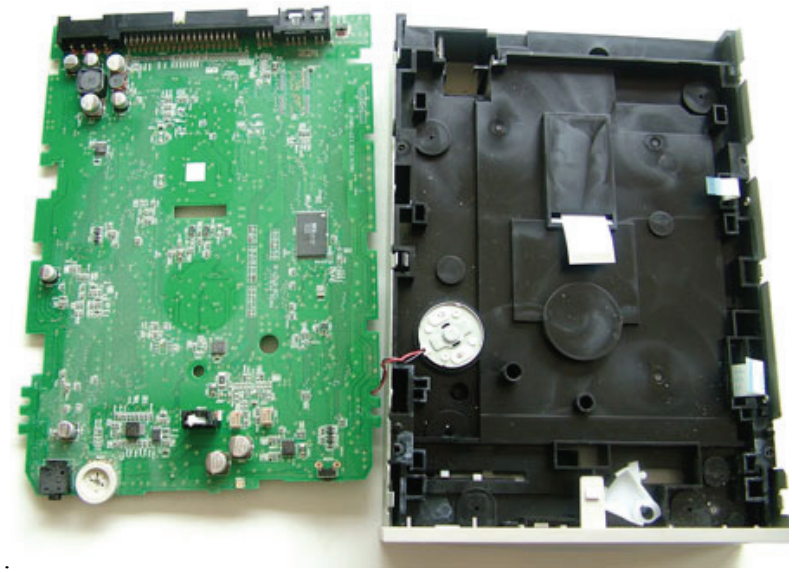


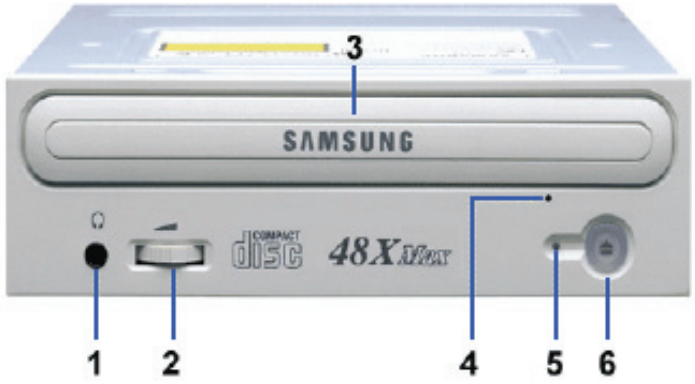
Fig. 6.6 The CD-ROM circuit board separated from the rest of the drive (source: PC Doctor Guide[46])

When first introduced, CD-ROM drives is too expensive for widespread use. In addition, drive manufacturers is slow in adopting standards, causing a time lag for the production of CD-ROM titles. Without a wide base of software to drive the industry, acceptance is slow.

After the production costs of both drives and discs began to drop, CD-ROMs is rapidly assimilated into the PC world. This is particularly due to the ever-expanding size of PC applications. Virtually all software is now supplied on CD-ROM, even though only 10% of the potential disc capacity is normally used. In some cases, particularly large programs are now distributed on DVD as well as CD[47].

[46] PC Doctor Guide: CD-RW drive (http://www.pcdoctor-guide.com/wordpress/?p=1396), accessed April 4, 2007.

[47] McLean, Terry: How CD-ROM-Drive Works (http://www.e-articles.info/e/a/title/How-CD-ROM-drive-works/), accessed April 05, 2007.



1. **Headphone Connector**

   The sound output terminal enables you to plug stereo headphones into the drive. It requires a 3.6 mm stereo mini-jack.

2. **Headphone volume control**

   This headphone volume control adjusts the volume for your headphones. You can only use the headphone jack and volume control when you have installed the required software utilities. For example, the Microsoft Windows Media player can be used.

3. **Disc compartment**

   The compartment opens and closes automatically when you press the Eject button.

4. **Emergency eject hole**

   If the compartment does not open when you press the Eject button, power off the computer, insert a pin or unfolded paper clip in the hole and push firmlhy)

5. **LED**

6. **Eject Button**

1. **Digital output terminal**

   You can connect a sound card or MPEG card which support Digital output terminal to your drive using this two-pin terminal.

2. **Sound output terminal**

   You can connect a sound card to your drive using this four-pin terminal.
   This function is not covered in detail in this guide. Refer to the documentation supplied with your sound card.

3. **Master/slave select terminal**

   Usually, this is a pre-set configuration as illustrated below.
   Verify that the setting is as illustrated. If it is not, simply remove the jumper and place it in the correct position.

4. **Interface terminal**

   This input/output interface terminal is used to connect the 40-pin flat cable from the IDE interface to the CD-ROM drive.

5. **Power terminal**

   The power terminal is a four-conductor male plug.
   (A : +5V DC)
   (B : +12V DC)

Fig. 6.7 Front and rear design of a CD-ROM for a Desktop computer around 2003 (source: Samsung (2007))

On May 16, 2006 Toshiba released its first PC with a HD DVD-ROM drive, the Toshiba Qosmio 35. There are also a number of laptops and desktops from Hewlett Packard (HP), Acer, Samsung, LG Electronics (LGE), Fujitsu and others equipped with HD DVD drives. All desktop systems so far use the NEC HR-1100A HD DVD-ROM, which is for OEM (Original Equipment Manufacturer) usage only[48].

DVD recorders use a laser (usually 650 nm red) to read and write DVDs. The reading laser is usually not stronger than 5 mW, while the writing laser is considerably more powerful. The faster the writing speed is rated, the stronger the laser is. DVD burner lasers often peak at about 100 mW in CW (continuous wave; 225 mW pulsed)[49].

6.1.3 System Characterisation

Study object:

The datasets of this Chapter describe current hard disk drives and CD/DVD-ROM drives for desktop computers and laptops. The inventories include all input and output data of the production stage (materials, process energies, transport, emissions where known). Raw material extraction processes are linked to the metal and plastic datasets used as input to the electronics datasets.

Functional unit(s) and datasets:

The datasets for both the HDD and CD/DVD-ROM drives are expressed in units, e.g. in 1 unit of HDD for a desktop computer.

In the framework of new ecoinvent datasets in the field of electronics, the following HDDs and CD/DVD-ROM drives are inventoried:

Name of dataset	Unit	Region	Chapter
HDD, desktop computer, at plant	unit	GLO	6.2
HDD, laptop computer, at plant	unit	GLO	6.3
CD-ROM/DVD-ROM drive, desktop computer, at plant	unit	GLO	6.4
CD-ROM/DVD-ROM drive, laptop computer, at plant	unit	GLO	6.5

Sources and Representativeness:

Although there is a large variety of all kinds of HDD and CD/DVD-ROM drive models, the data availability for input materials and processing steps is rather poor. Nevertheless, the goal is to describe a typical drive per category (see list above), and to use representative data. Where possible, the data for the drive-datasets is taken from literature or product specifications by leading manufacturers. For the HDD and CD/DVD-ROM drives in a desktop computer, good-quality data is available, whereas for the laptop drives, the various material inputs had to be calculated on the basis of the information for desktop drives.

The ICT industry is a global business nowadays, and electronic devices are spread throughout all regions of the world. For this reason, the datasets for the HDD and CD/DVD-ROM drives are valid globally (GLO). However, as there are dozens of producer companies in the world, it is impossible to describe an “average” device with one single dataset. Yet, the authors try to picture desktop and laptop drives that are a) widely spread, b) world-wide available and c) not older than 4 years.

[48] Wikipedia: HD DVD (http://en.wikipedia.org/wiki/HD_DVD), accessed April 4, 2007.

[49] Wikipedia: DVD recorder (http://en.wikipedia.org/wiki/DVD_recorder), accessed April 13, 2007.

Configuration of datasets:

As mentioned above, the datasets for drives (HDD, CD/DVD-ROM) include materials (metals, plastics), required process energy (moulding, rolling or extruding of materials into shapes), electricity for the assembly, transport from regional storage to production site (on the basis of ecoinvent standard transport distances), the infrastructure (factory), and some emissions to air, water (industrial water) and soil. The disposal phase is not included in these datasets, as these components (drives) are built into either a desktop or a laptop computer, and therefore the disposal phase is attributed to those datasets.

The basic concept of the dataset structure of electronic components like e.g. HDDs is to build on unit processes. This concept is applied e.g. in case of the printed wiring board (PCB). However, the data found to establish the datasets are mainly based on material specifications. For that fact, according to the ecoinvent logic, material inputs (e.g. steel) are combined with a processing dataset (e.g. sheet rolling, steel).

Fig. 6.8 indicates the setup of the HDD dataset on the example of a desktop computer.

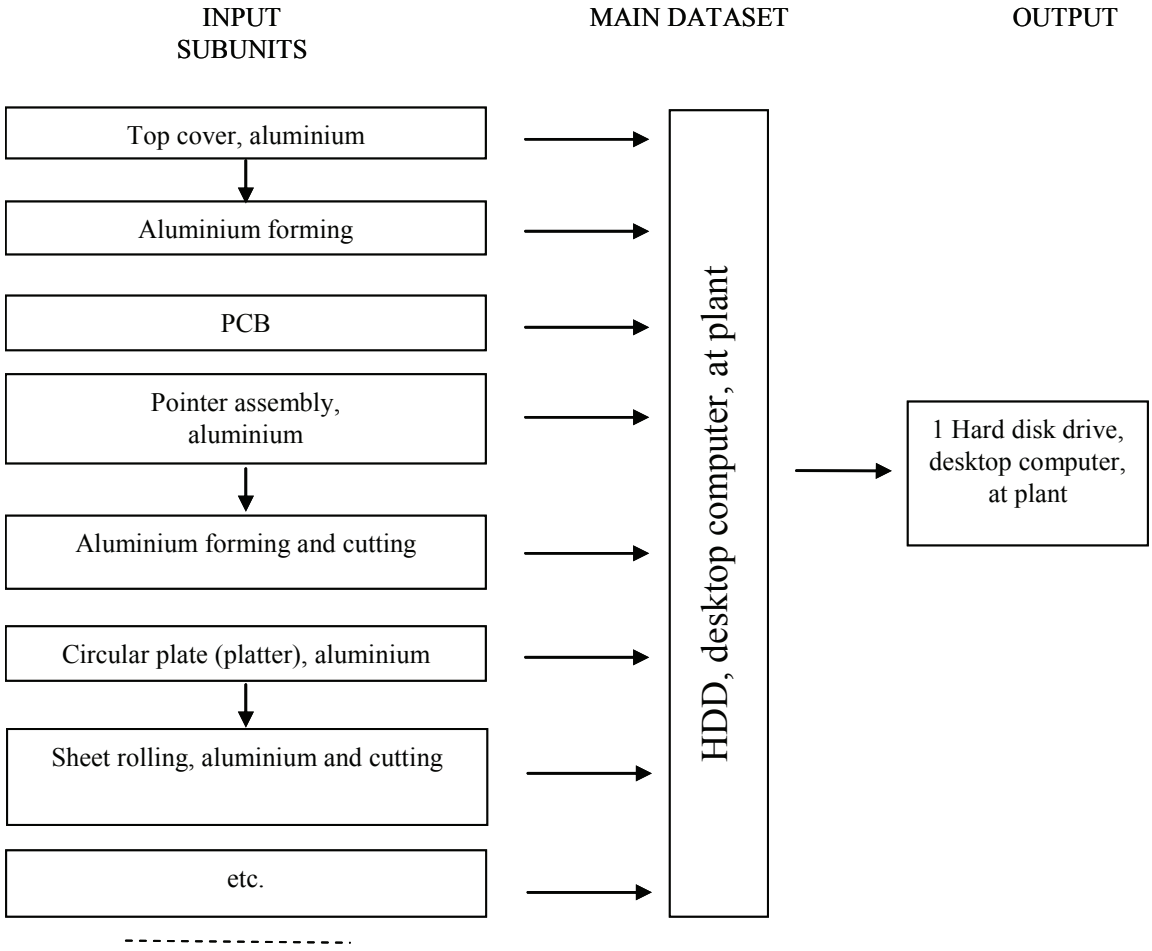


Fig. 6.8 Structure of main datasets of HDDs; here the example for the HDD of a desktop computer

Time period:

The data applied for the HDD and CD/DVD-ROM drive datasets originate mainly from the years before 2005. The main data source (Mohite 2005) unfortunately does not state the production year of the analysed desktop HDD or the CD-ROM drive. Still, the examined drives will most certainly originate from the period 2002-2005. The newer HDDs (up to 160 GB) have a much higher capacity than the analysed product (10 GB). All in all, it can be said that the data used to describe the HDD and CD/DVD drives is reasonably recent, and corresponds with the electronic devices (desktop and laptop computer) assessed in this ecoinvent report. It may not be latest available technology, but representative for the stock of devices being currently in use.

Sampling procedure:

First of all, a literature and Internet survey is carried out. Material specifications of HDDs or CD/DVD-ROM drives are hardly available, especially for laptops and notebooks. However, some product specification sheets by leading manufacturers (Toshiba, Fujitsu, Samsung etc.) allowed confirming the total weight and dimensions of the analysed products. For the laptop HDD and CD/DVD-ROM drive the material composition had to be calculated and assumed according to the reduced total weight compared to the desktop drives (see calculation setup in Chapter 6.3 and 6.5, Tab. 6.3 and Tab. 6.9).

6.1.4 Use & Application

The four datasets listed in Chapter 6.1.3 can be applied to describe the production of hard disk drives and CD/DVD-ROM drives of desktop and laptop computers. No distinction is made between office and home devices. The datasets are applicable for average HDDs and CD-ROM drives in the beginning of the century. For powerful computers, these datasets are not fully representative.

These computer drive datasets are applicable for any region in the world, as the electronic devices are produced in different continents by world-wide running companies. For this reason all the datasets provided for HDDs and CD/DVD-ROM drives are valid in the global context (GLO).

6.2 Dataset “HDD, desktop computer, at plant”

6.2.1 Dataset description and meta information

The dataset “HDD, desktop computer, at plant” illustrates the “gate-to-gate” phase of a hard disk drive for a desktop computer. The functional unit of this dataset is 1 unit of HDD. The HDD looked at has a storage capacity of 10 GB. The post consumer waste treatment is not included in this dataset, as a HDD is normally integrated into a computer and being disposed of therewith. General information on the hard disk drive of a desktop computer and its function can be found in Chapter 6.1.1 .

The main source for this hard disk drive dataset is the dissertation of Mohite (2005). Major weight contributions to the total HDD-weight of 0.575 kg (for desktop computer) resulted from the main frame and top cover (0.12 and 0.242 kg; both aluminium), the frame for the pointer assembly (0.076 kg, steel), the bottom circular plate/platter (0.052 kg, aluminium) and the printed wiring board (0.042 kg). More information on the weights of the different HDD components for a desktop computer can be retrieved from Tab. 6.1 or from the general flow information of this dataset in Fig. 6.9 to Fig. 6.11.

The energy input for the HDD assembly is assumed to be the same as for a laptop, and is based on the energy input for the computer mouse assembly by Stachura (2006). For the process steps "steel cutting" and "aluminium cutting", input data is assumed on the basis of information released by Mepsaws, a leading metal saw supplier in Italy[50]. For an automatic metal sawing machine, Mepsaws publishes a power supply of 1.5 to 2.2 kW. The running time of the sawing machine to cut a metal sheet into shape for the HDD depends on the material characteristics and the complexity of the shape. The cutting time for the HDD steel frame and for the pointer assembly (aluminium) is assumed to be 30 seconds, and 40 seconds for the platters/circular plates (also aluminium).

Tab. 6.1 Component material and weight of the hard disk drive (source: Mohite (2005))

No.	Part description	Quantity	Material	Weight	
				Grams	Ounce
1	Top Cover	1	Aluminum	120	4.2
2	PCB	1	PCB	42	1.5
3	Frame which holds the pointer assembly	1	Steel	76	2.7
4	Pointer Assembly	1	Aluminum	8	0.3
5	Circular plate which holds the hard disk CD	1	Aluminum	2	0.1
6	Circular plate beneath the plate which holds the hard disk CD	1	Aluminum	6	0.3
7	Bottom circular plate which is attached to the main frame	1	Aluminum	52	1.8
8	Plastic part	1	ABS	1	0.035
9	Main black frame	1	Aluminum	242	8.5
10	Hard Disk	1	Aluminum	22	0.8
11	Torxs	25	Steel	4	0.2

The facility heating energy, the packaging as well as the scrap materials are not inventoried for this dataset. For scrap materials it is assumed that all scrap (mainly metals) is being recycled and reused.

The infrastructure for the HDD production has been taken into account and has been calculated via the annual production volume (1.2 mill.) for a hard disk drive factory in China (Nikkei Business (2003)).

Tab. 6.2 includes all important and necessary (meta) information to use the data correctly.

[50] Mepsaws: Automatic Cobra Metal Saw (http://www.mepsaws.it/index.php), accessed April 25, 2007.

Tab. 6.2 ecoinvent meta information of the HDD of a desktop computer (GLO)

Name	**HDD, desktop computer, at plant**
Location	GLO
Infrastructure Process	0
Unit	unit
Dataset Version	2.0
Included Processes	Describes the production of a hard disk drive for a desktop computer. Calculated per 1 produced hard disk (1 unit). Included are the materials (mainly metals and plastics) with their respective manufacturing processes (e.g. sheet rolling or blow moulding). Further inventoried is the infrastructure (factory), the electricity for the assembly of the hard disk drive, the respective waste heat, and the required rail and road transport for input materials from the regional storage to the factory. Not included are emissions to air and water (negligible), the heating of the facility, scrap materials (recycled and reused), the packaging, as well as the disposal, which is attributed to the desktop computer as a whole.
Amount	1
Local Name	HDD Laufwerk, Desktop Computer, ab Werk
Synonyms	Hard disk//hard drive//Festplatte
General Comment	This dataset can be applied to describe the production of a common hard disk drive in the last 3 years before the reference year 2005 (Model "Western Digital", IDE hard drive, 10 GB, total weight 0.575 kg). The dataset includes material information for all the major hard disk drive components (covers, printed wiring board, circular plates (platters), pointer assembly, etc.). The information is mainly based on one dissertation work plus desktop-specific data provided by a leading HDD manufacturer.
Start Date	2002
End Date	2006
Data valid for entire period	1
Geography Text	A computer hard disk drive may be assembled anywhere in the world.
Technology Text	The production of a hard disk drive for a desktop computer includes the metal processing steps rolling, cutting, section bar extrusion and coating. Plastic parts are blow moulded or extruded into required shapes.
Representativeness	unknown
Production Volume	unknown
Sampling Procedure	Data is based on literature. Weighing of components happened at a Technical University after professional disassembly.
Extrapolations	see Geography and Technology
Uncertainty Adjustments	None

6.2.2 Life Cycle inventory and General Flow Information

The layout of the dataset "HDD, desktop computer, at plant GLO" with general flow information, remarks, sources, values and uncertainty information are shown in Fig. 6.9 to Fig. 6.11 below.

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Top cover Aluminium	→	HDD, desktop computer, at plant PART 1				Top cover made from aluminium	metals	extraction	No	RER	aluminium, production mix, at plant	0.12	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Aluminium forming	→					Aluminium forming into shape	metals	processing	No	RER	section bar extrusion, aluminium	0.12	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
PCB	→					Printed Circuit Board; unspecified printed wiring board taken as proxy	electronics	module	No	GLO	printed wiring board, mounted, unspecified, at plant	0.042	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Frame for pointer assembly	→					Steel frame holding the pointer assembly	metals	extraction	No	RER	steel, low-alloyed, at plant	0.076	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Steel forming	→					Steel forming into	metals	processing	No	RER	sheet rolling, steel	0.076	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Steel cutting	→					Energy for cutting the steel frame; 2000 W for 30 seconds	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	0.016667	kWh	Own assumptions based on Mepsaws (2007)	1	1.2366	(1,4,1,3,1,5,2)
Pointer assembly Aluminium	→					Pointer assembly (actuator) for HDD made from Aluminium	metals	extraction	No	RER	aluminium, production mix, at plant	0.008	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Aluminium forming	→					Forming of Aluminium into Pointer shape	metals	processing	No	RER	section bar extrusion, aluminium	0.008	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Aluminium cutting	→					Energy for cutting the aluminium plate into pointer shape; 1500 W for 30 seconds	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	0.0125	kWh	Own assumptions based on Mepsaws (2007)	1	1.2366	(1,4,1,3,1,5,2)
Circular Plate 1	→					Circular plate to hold the harddisk	metals	extraction	No	RER	aluminium, production mix, at plant	0.002	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Circular Plate 2	→					Reinforcing circular plate	metals	extraction	No	RER	aluminium, production mix, at plant	0.006	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)

Fig. 6.9 Flows for "HDD, desktop computer, at plant GLO" (part 1) and their representation in the ecoinvent database

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Sheet rolling	→	HDD, desktop computer, at plant PART 2				Rolling of aluminium into sheets	metals	processing	No	RER	sheet rolling, aluminium	0.008	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Aluminium cutting	→					Cutting of circular plates into shape; 1500 W for 40 seconds.	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	0.016667	kWh	Own assumptions based on Mepsaws (2007)	1	1.2366	(1,4,1,3,1,5,2)
Bottom circular plate Aluminium	→					Bottom circular plate attached to the main frame made from aluminium	metals	extraction	No	RER	aluminium, production mix, at plant	0.052	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Aluminium forming	→					Forming of aluminium into plate shape	metals	processing	No	RER	section bar extrusion, aluminium	0.052	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Plastic part	→					Plastic part related to pointer assembly; material ABS	plastics	polymers	No	RER	acrylonitrile-butadiene-styrene copolymer, ABS, at	0.001	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Blow moulding	→					Blow moulding of white ABS granulates into housing part	plastics	processing	No	RER	stretch blow moulding	0.001	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Main frame Aluminium	→					Main black frame; material Aluminium	metals	extraction	No	RER	aluminium, production mix, at plant	0.242	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Aluminium forming	→					Forming of aluminium into main frame shape	metals	processing	No	RER	section bar extrusion, aluminium	0.242	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Hard Disk	→					Hard disk; material aluminium	metals	extraction	No	RER	aluminium, production mix, at plant	0.022	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Aluminium forming	→					Forming of aluminium into hard disk shape	metals	processing	No	RER	section bar extrusion, aluminium	0.022	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)

Fig. 6.10 Flows for "HDD, desktop computer, at plant GLO" (part 2) and their representation in the ecoinvent database

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Coating of platters	→	HDD, desktop computer, at plant PART 3				Coating process; 4 sides of platters, diameter 88.9 mm; aluminium taken as proxy for ferrite	metals	processing	No	RER	powder coating, aluminium sheet	0.02	m2	Mohite (2005)	1	1.34403	(3,4,1,3,3,5,3)
Torx screws	→					25 torx screws made out of chromium steel	metals	extraction	No	RER	chromium steel 18/8, at plant	0.004	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Forming steel screws	→					Forming of 25 torx screws	metals	processing	No	RER	hot rolling, steel	0.004	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Electricity Assembly	→					Electricity for HDD assembly; assumed to be the same as for laptop	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	1.67	kWh	Assumption based on Stachura (2006)	1	1.34403	(3,4,1,3,3,5,2)
Infrastructure	→					Calculated per production site via the annual production volume (GS Magicstore in China: 1.2 mio) and the life-span of the factory (25 years); proxy electronic component factory	electronics	component	Yes	GLO	electronic component production plant	3.33E-08	unit	Own calculations based on assumptions made on information by Nikkei Electronics Asia (for 2003)	1	3.10715	(2,4,1,3,3,5,9)
Transport road	→					Transport from regional storage by 32 t lorry (RER) to factory for metals and plastics	transport systems	road	No	RER	transport, lorry 32t	0.0575	tkm	ecoinvent (2000) standard transport distances of materials	1	2.10173	(2,3,1,1,3,5,5)
Transport rail	→					Transport from regional storage by rail (RER) to factory for metals and plastics	transport systems	train	No	RER	transport, freight, rail	0.115	tkm	ecoinvent (2000) standard transport distances of materials	1	2.10173	(2,3,1,1,3,5,5)
			→	Waste heat		Waste heat from metal cutting processes and HDD assembly energy	air	low population density			Heat, waste	6.165	MJ	Derived from electricity input numbers	1	1.2366	(1,4,1,3,1,5,13)
			→	HDD for desktop computer		Production of hard disk drive for desktop computer; total weight ca. 0.58 kg	electronics	module	No	GLO	HDD, desktop computer, at plant	1	unit				

Fig. 6.11 Flows for "HDD, desktop computer, at plant GLO" (part 3) and their representation in the ecoinvent database

Data Uncertainty and Input Data for Database ecoinvent

The dataset represents a typical hard disk drive for a desktop computer. The data are mainly based on information provided in a dissertation work by Mohite (2005). The fact that this typical HDD does not represent the majority of world-wide available hard disks for desktop computers has been accounted for in the uncertainties of the dataset.

There is no direct natural resource input to the dataset "HDD, desktop computer, at plant". Neither direct air emissions nor any waste are balanced for this HDD dataset. Information on the release of industrial waste water is not available. Ecoinvent standard distances for rail and road transport are applied for the transfer of materials from regional storage centres to the production site (Frischknecht et al. (2007)).

6.3 Dataset "HDD, laptop computer, at plant"

6.3.1 Dataset description and meta information

The dataset "HDD, laptop computer, at plant" illustrates the "gate-to-gate" phase of a hard disk drive for a laptop computer. The functional unit of this dataset is 1 unit of HDD. The HDD looked at has a storage capacity of anything between 40 and 100 GB (compare e.g. Seagate (2007)). The post consumer waste treatment is not included to this dataset, as a HDD is nowadays integrated into a computer and being disposed of therewith. General information on the hard disk drive of a laptop computer and its function can be found in Chapter 6.1.1 . Fig. 6.12 shows a typical HDD of a laptop computer.

Fig. 6.12 40 GB-Hard disk drive of a HITACHI laptop computer (source: http://www.bidorbuy.co.za/jsp/item/Item.jsp?Trade_TradeId=2350916#)

Although there is a lot of information on the total weight and the dimensions of a laptop HDD, no direct weight data of the individual components of a laptop HDD is available. As a consequence, the weights of the laptop HDD components had to be calculated on the basis of the information available for the desktop HDD (Mohite (2005)), see Chapter 6.2. Tab. 6.3 shows the exact calculation setup to figure out the weight of the individual components for the laptop HDD. Wherever reasonable, the ratio of the total weight of the HDDs is applied to calculate the weight of the individual HDD-components

for laptops. Major weight contributions to the total laptop HDD-weight of 0.115 kg (referring to Seagate (2007)) resulted from the main frame and top cover (0.044 and 0.024 kg; both aluminium), the frame for the pointer assembly (0.015 kg, steel) and the bottom circular plate (0.01 kg). More information on the weights of the different HDD components for a laptop computer can be retrieved from Tab. 6.3 or from the general flow information of this dataset in Fig. 6.13 to Fig. 6.16.

The energy input for the HDD assembly is assumed to be the same as for a laptop, and is based on the energy input for the computer mouse assembly by Stachura (2006). For the process steps "steel cutting" and "aluminium cutting", input data is assumed on the basis of information released by Mepsaws, a leading metal saw supplier in Italy[51] (see Chapter 6.2.1.).

The facility heating energy, the packaging as well as the scrap materials are not inventoried for this dataset. For scrap materials it is assumed that all scrap (mainly metals) is being recycled and reused.

The infrastructure for the HDD laptop production has been taken into account and has been calculated via the annual production volume (1.2 mill.) of a hard disk drive factory in China (Nikkei Business (2003)).

Tab. 6.3 Calculation setup for laptop HDD component weights derived from desktop HDD component weights

Components/Material	HDD Desktop	Unit	HDD Laptop	Calculation setup
Top cover Aluminium	1.20E-01	kg	2.38E-02	Ratio Laptop HDD to PC HDD is 0.115/0.58=0.198 (=Ratio of total weights)
PCB	4.20E-02	kg	8.33E-03	Ratio Laptop HDD to PC HDD is 0.115/0.58=0.198
Frame for pointer assembly	7.60E-02	kg	1.51E-02	Ratio Laptop HDD to PC HDD is 0.115/0.58=0.198
Pointer assembly Aluminium	8.00E-03	kg	4.08E-03	Ratio platter surface Laptop HDD vs. PC HDD
Circular Plate 1	2.00E-03	kg	1.02E-03	Ratio platter surface Laptop HDD vs. PC HDD
Circular Plate 2	6.00E-03	kg	3.06E-03	Ratio platter surface Laptop HDD vs. PC HDD
Bottom circular plate Aluminium	5.20E-02	kg	1.03E-02	Ratio Laptop HDD to PC HDD is 0.115/0.58=0.198
Plastic part	1.00E-03	kg	5.10E-04	Ratio platter surface Laptop HDD vs. PC HDD
Main frame Aluminium	2.42E-01	kg	4.36E-02	Ratio Laptop HDD to PC HDD is assumed to be a bit less than 0.115/0.58=0.198, taken as 0.18
Hard Disk	2.20E-02	kg	5.61E-03	Ratio platter surface Laptop HDD and PC HDD (1 Platter only for Laptop HDD)
Coating Platters Ferrite	2.79E-06	kg	4.99E-07	Laptop HDD 63.5 mm platter diameter, desktop HDD 88.9 mm; 1 platter
Torx screws	4.00E-03	kg	2.40E-03	15 screws Laptop HDD instead of 25 for PC HDD
Total weight HDD for PC	5.75E-01	kg	1.18E-01	Total weight HDD for Laptop
			1.15E-01	Target weight for Laptop HDD

Tab. 6.4 includes all important and necessary (meta) information to use the data correctly.

[51] Mepsaws: Automatic Cobra Metal Saw (http://www.mepsaws.it/index.php), accessed April 25, 2007.

Tab. 6.4 ecoinvent meta information for the HDD of a laptop computer (GLO

Name	**HDD, laptop computer, at plant**
Location	GLO
Infrastructure Process	0
Unit	unit
Dataset Version	2.0
Included Processes	Describes the production of a hard disk drive for a laptop computer. Calculated per 1 produced hard disk (1 unit). Included are the materials (mainly metals and plastics) with their respective manufacturing processes (e.g. sheet rolling or blow moulding). Further inventoried is the infrastructure (factory), the electricity for the assembly of the hard disk drive, the respective waste heat, and the required rail and road transport for input materials from the regional storage to the factory. Not included are emissions to air and water (negligible), the heating of the facility, scrap materials (recycled and reused), the packaging, as well as the disposal, which is attributed to the desktop computer as a whole.
Amount	1
Local Name	HDD Laufwerk, Laptop Computer, ab Werk
Synonyms	Hard disk//hard drive//Festplatte
General Comment	This dataset can be applied to describe the production of a common hard disk drive in the last 3 years before the reference year 2005 (2.5 inch or 63.5 mm of radius, up to 80 or more GB, total weight 0.115 kg). The dataset includes material information for all the major hard disk drive components (covers, printed wiring board, circular plates (platters), pointer assembly, etc.). The information is mainly based on one dissertation work plus laptop-specific data provided by a leading HDD manufacturer. Data for the desktop HDD have been extrapolated to the lighter laptop HDD by specific calculation setups.
Start Date	2002
End Date	2006
Data valid for entire period	1
Geography Text	A laptop hard disk drive may be assembled anywhere in the world.
Technology Text	The production of a hard disk drive for a laptop computer includes the metal processing steps rolling, cutting, section bar extrusion and coating. Plastic parts are blow moulded or extruded into required shapes.
Representativeness	unknown
Production Volume	unknown
Sampling Procedure	Own estimations based on literature. Weighing of original components happened at a Technical University after professional disassembly.
Extrapolations	see Geography and Technology
Uncertainty Adjustments	None

6.3.2 Life Cycle inventory and General Flow Information

The layout of the dataset "HDD, laptop computer, at plant" with general flow information, remarks, sources, values and uncertainty information are shown in Fig. 6.13 to Fig. 6.16 below.

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Top cover Aluminium	→	HDD, laptop computer, at plant PART 1				Top cover made from aluminium; weight ratio Laptop HDD vs. Desktop	metals	extraction	No	RER	aluminium, production mix, at plant	0.023793	kg	Calculated from information on Desktop HDD by	1	1.2366	(1,4,1,3,1,5,3)
Aluminium forming	→					Aluminium forming into shape	metals	processing	No	RER	section bar extrusion, aluminium	0.023793	kg	Calculated from information on Desktop HDD by Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
PCB	→					Printed Circuit Board; unspecified printed wiring board taken as proxy; weight	electronics	module	No	GLO	printed wiring board, mounted, unspecified, at plant	0.008328	kg	Calculated from information on Desktop HDD by	1	1.2366	(1,4,1,3,1,5,3)
Frame for pointer assembly	→					Steel frame holding the pointer assembly; weight ratio Laptop HDD vs. Desktop HDD is 0.115/0.58 (=ratio of total HDD weights)	metals	extraction	No	RER	steel, low-alloyed, at plant	0.015069	kg	Calculated from information on Desktop HDD by Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Steel forming	→					Steel forming into frame shape	metals	processing	No	RER	sheet rolling, steel	0.015069	kg	Calculated from information on Desktop HDD by Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Steel cutting	→					Energy for cutting the steel frame; 2000 W for 30 seconds (assumed to be the same as for Desktop HDD)	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	0.016667	kWh	Own assumptions based on Mepsaws (2007)	1	1.2366	(1,4,1,3,1,5,2)
Pointer assembly Aluminium	→					Pointer assembly for HDD made from aluminium; value taken as ratio of Laptop HDD vs. Desktop HDD for platter	metals	extraction	No	RER	aluminium, production mix, at plant	0.004082	kg	Calculated from information on Desktop HDD by Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Aluminium forming	→					Forming of Aluminium into Pointer shape	metals	processing	No	RER	section bar extrusion, aluminium	0.004082	kg	Calculated from information on Desktop HDD by	1	1.2366	(1,4,1,3,1,5,3)
Aluminium cutting	→					Energy for cutting the aluminium plate into pointer shape; 1500 W for 30 seconds	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	0.0125	kWh	Own assumptions based on Mepsaws (2007)	1	1.2366	(1,4,1,3,1,5,2)

Fig. 6.13 Flows for "HDD, laptop computer, at plant GLO" (part 1) and their representation in the ecoinvent database

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Circular Plate 1	→	HDD, laptop computer, at plant PART 2				Circular plate to hold the harddisk; material aluminium; value taken as ratio of Laptop HDD vs. Desktop HDD for platter surface (63.5^2/88.9^2)	metals	extraction	No	RER	aluminium, production mix, at plant	0.00102	kg	Calculated from information on Desktop HDD by Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Circular Plate 2	→					Reinforcing circular plate; aluminium; value taken as ratio of Laptop HDD vs.	metals	extraction	No	RER	aluminium, production mix, at plant	0.003061	kg	Calculated from information on Desktop HDD by	1	1.2366	(1,4,1,3,1,5,3)
Sheet rolling	→					Rolling of aluminium into sheets	metals	processing	No	RER	sheet rolling, aluminium	0.004082	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Aluminium cutting	→					Cutting of circular plates into shape; 1500 W for 40 seconds.	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	0.016667	kWh	Own assumptions based on information by Youcom (2007)	1	1.2366	(1,4,1,3,1,5,2)
Bottom circular plate Aluminium	→					Bottom circular plate attached to the main frame made from aluminium; weight	metals	extraction	No	RER	aluminium, production mix, at plant	0.01031	kg	Calculated from information on Desktop HDD by	1	1.2366	(1,4,1,3,1,5,3)
Aluminium forming	→					Forming of aluminium into plate shape	metals	processing	No	RER	section bar extrusion, aluminium	0.01031	kg	Calculated from information on Desktop HDD by Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Plastic part	→					Plastic part related to pointer assembly; material ABS; value taken as ratio of Laptop HDD vs. Desktop HDD for platter surface (63.5^2/88.9^2)	plastics	polymers	No	RER	acrylonitrile-butadiene-styrene copolymer, ABS, at plant	0.00051	kg	Calculated from information on Desktop HDD by Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Blow moulding	→					Blow moulding of white ABS granulates into housing part	plastics	processing	No	RER	stretch blow moulding	0.00051	kg	Calculated from information on Desktop HDD by Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Main frame Aluminium	→					Main black frame; material aluminium; ratio Laptop HDD to PC HDD is assumed to be a bit less than 0.115/0.58=0.198, taken as 0.18	metals	extraction	No	RER	aluminium, production mix, at plant	0.04356	kg	Calculated from information on Desktop HDD by Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Aluminium forming	→					Forming of aluminium into main frame shape	metals	processing	No	RER	section bar extrusion, aluminium	0.04356	kg	Calculated from information on Desktop HDD by Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)

Fig. 6.14 Flows for "HDD, laptop computer, at plant GLO" (part 2) and their representation in the ecoinvent database

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Hard Disk	→	HDD, laptop computer, at plant PART 3				Hard disk; material aluminium; value taken as ratio of Laptop HDD vs. Desktop HDD for platter surface (63.5^2/88.9^2)	metals	extraction	No	RER	aluminium, production mix, at plant	0.005612	kg	Calculated from information on Desktop HDD by Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Aluminium forming	→					Forming of aluminium into hard disk shape	metals	processing	No	RER	section bar extrusion, aluminium	0.005612	kg	Calculated from information on Desktop HDD by Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Coating Platters	→					Coating of platters with a fine ferrit compound; 63.5 mm platter diameter; 1 platter for Laptop HDD; aluminiun coating taken as proxy for ferrite	metals	processing	No	RER	powder coating, aluminium sheet	0.01	m2	Wikipedia (2007) and Maurer Magnetic AG (2007)	1	1.34403	(3,4,1,3,3,5,3)
Torx screws	→					15 torx screws made out of chromium steel	metals	extraction	No	RER	chromium steel 18/8, at plant	0.0024	kg	Calculated from information on Desktop HDD by Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Forming steel screws	→					Forming of 15 torx screws	metals	processing	No	RER	hot rolling, steel	0.0024	kg	Calculated from information on Desktop HDD by	1	1.2366	(1,4,1,3,1,5,3)
Electricity Assembly	→					Electricity for HDD assembly; assumed to be the same as for laptop assembly	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	1.67	kWh	Assumption based on Stachura (2006)	1	1.34403	(3,4,1,3,3,5,2)

Fig. 6.15 Flows for "HDD, laptop computer, at plant GLO" (part 3) and their representation in the ecoinvent database

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Infrastructure	→	HDD, laptop computer, at plant PART 4				Calculated per production site via the annual production volume (GS Magicstore in China: 1.2 mio) and the life-span of the factory (25 years); proxy electronic component factory	electronics	component	Yes	GLO	electronic component production plant	3.33E-08	unit	Own calculations based on assumptions made on information by Nikkei Electronics Asia (for 2003)	1	3.10715	(2,4,1,3,3,5,9)
Transport road	→					Transport from regional storage by 32 t lorry (RER) to factory for metals and plastics	transport systems	road	No	RER	transport, lorry 32t	0.012408	tkm	ecoinvent (2000) standard transport distances of materials	1	2.10173	(2,3,1,1,3,5,5)
Transport rail	→					Transport from regional storage by rail (RER) to factory for metals and plastics	transport systems	train	No	RER	transport, freight, rail	0.024816	tkm	ecoinvent (2000) standard transport distances of materials	1	2.10173	(2,3,1,1,3,5,5)
			→	Waste heat		Waste heat from metal cutting processes and HDD assembly energy	air	low population density			Heat, waste	6.165	MJ	Derived from electricity input numbers	1	1.2366	(1,4,1,3,1,5,13)
			→	HDD for laptop computer		Hard disk drive for laptop computer; total weight ca. 0.118 kg	electronics	module	No	GLO	HDD, laptop computer, at plant	1	unit				

Fig. 6.16 Flows for "HDD, laptop computer, at plant GLO" (part 4) and their representation in the ecoinvent database

Data Uncertainty and Input Data for Database ecoinvent

The dataset represents a typical hard disk drive for a laptop computer. The data are mainly based on information provided in a PhD work by Mohite (2005). The fact that this typical HDD does not represent the majority of world-wide available hard disks for laptop computers has been accounted for in the uncertainties of the dataset input and output flows.

There is no direct natural resource input to the dataset "HDD, laptop computer, at plant". Neither direct air emissions nor any waste are balanced for this HDD dataset. Information on the release of industrial waste water is not available. Ecoinvent standard distances for rail and road transport are applied for the transfer of materials from regional storage centres to the production site (Frischknecht et al. (2007)).

6.4 Dataset "CD-ROM/DVD-ROM drive, desktop computer, at plant"

6.4.1 Dataset description and meta information

The dataset "CD-ROM/DVD-ROM drive, desktop computer, at plant" illustrates the "gate-to-gate" phase of a CD/DVD-ROM drive for a desktop computer (see Fig. 6.17). The functional unit for this dataset is 1 unit of CD/DVD-ROM drive. The post consumer waste treatment is not included in this dataset, as a drive is nowadays primarily integrated into a computer and being disposed of therewith. General information on the CD/DVD-ROM drive of a desktop computer and its function can be found in Chapter 6.1.2.

Fig. 6.17 CD/DVD-ROM Drive for a desktop computer (source: Google-Bilder www.buslinkbuy.com)

The main source of information that describes this CD/DVD-ROM drive dataset is a dissertation by Mohite (2005). The total CD-ROM drive weighed by Mohite (2005) is 0.938 kg, which represents an average weight type compared to other models (Tab. 6.5).

Tab. 6.5 Total weight of different CD/DVD-ROM drives for desktop computers

Brand	Weight in kg	Source
NEC	0.938	Mohite (2005)
Panasonic	0.915	http://support.gateway.com
Samsung	0.740	www.samsungodd.com
Mandax	0.864	ecoinvent Chapter on devices
Plextor	1.100	www.plextor.com
Used in this study	0.938	Mohite (2005)

Major weight contributions to the total CD/DVD-ROM drive of 0.938 kg (for desktop computer) stem from the top and bottom cover (0.22 kg and 0.188 kg; both steel), the metal frame (0.096 kg; steel), the main plastic frame (0.086 kg; PE) and the printed wiring board (0.082 kg). More information on the weights of the different CD/DVD-ROM drive components for a desktop computer is shown in Tab. 6.6 and described in the general flow information of this dataset in Fig. 6.18 to Fig. 6.22.

The energy input for the CD/DVD-ROM drive assembly is assumed to be the same as for a laptop, and is based on the energy input for the computer mouse assembly by Stachura (2006). For the process steps “steel cutting”, the input data is assumed on the basis of information released by Mepsaws, a leading metal saw supplier in Italy[52]. For an automatic metal sawing machine, Mepsaws publishes a power supply of 1.5 to 2.2 kW. The running time of the sawing machine to cut a metal sheet into shape for the desktop CD/DVD-ROM drive depends on the material characteristics and the complexity of the shape. The cutting time for the CD-ROM drive’s top and bottom cover is assumed to be 40 seconds for both, at a power supply of 1500 W.

The facility heating energy, the packaging as well as the scrap materials are not inventoried for this dataset. For scrap materials it is assumed that all scrap (mainly metals) is being recycled and reused.

[52] Mepsaws: Automatic Cobra Metal Saw (http://www.mepsaws.it/index.php), accessed April 25, 2007.

Sr. No.	Part	Material	Quantity	Weight	
				Grams	Ounce
1	Bottom Cover	Steel	1	188	6.7
2	Main PCB	PCB	1	82	3
3	Main Plastic frame	PPE + PE	1	86	3.1
4	Plastic Subframe	PPE + PE - G	1	38	1.3
5	Metal frame	Steel	1	96	3.4
6	Optical Drive Motor with PCB	Iron	1	20	0.7
7	CD Insert Cover	ABS	1	24	1
8	CD Tray	PC/ABS	1	34	1.2
9	CD Motor Base Plate	Steel	1	40	1.5
10	Optical Reader assembly	ABS	1	18	0.6
11	Top Cover	Steel	1	220	7.8
12	Motor for CD Tray	Iron	1	18	0.6
13	CD Rotator Motor with PCB	Iron	1	40	1.5
14	Plastic gears	ABS	5	10	0.4
15	Optical reader Motion Rod	Steel	2	6	0.3
16	Screws	Steel	31	8	0.3
18	Miscelleneous Plastic Parts	ABS	5	10	0.4

Tab. 6.6 Materials and weights of different components of a typical CD-ROM drive (Mohite (2005))

The infrastructure for the CD/DVD-ROM drive production has been taken into account and has been calculated via the annual production volume (1.2 mill.) for a hard disk drive factory in China (Nikkei Business (2003)).

Tab. 6.7 includes all important and necessary (meta) information to use the dataset correctly.

Tab. 6.7 ecoinvent meta information for the CD/DVD-ROM drive of a desktop computer (GLO)

Name	**CD-ROM/DVD-ROM drive, desktop computer, at plant**
Location	GLO
Infrastructure Process	0
Unit	unit
Dataset Version	2.0
Included Processes	Describes the production of a CD-ROM/DVD-ROM drive for a desktop computer. Calculated per 1 produced CD/DVD-ROM drive (1 unit). Included are the materials (mainly metals and plastics) with their respective manufacturing processes (e.g. sheet rolling or blow moulding). Further inventoried is the infrastructure (factory), the electricity for the assembly of the CD/DVD-ROM drive, the respective waste heat, and the required rail and road transport for input materials from the regional storage to the factory. Not included are emissions to air and water (negligible), the heating of the facility, scrap materials (recycled and reused), the packaging, as well as the post consumer disposal, which is attributed to the desktop computer as a whole.
Amount	1
Local Name	CD-ROM/DVD-ROM Laufwerk, Desktop Computer, ab Werk
Synonyms	
General Comment	This dataset can be applied to describe the production of a common CD/DVD-ROM drive in the last 3 years before the reference year 2005 (Model "NEC", IDE drive, total weight 0.938 kg). The dataset includes material information for all the major CD/DVD-ROM drive components (covers, printed wiring board, optical reader, motor(s), tray, etc.). The information is mainly based on one dissertation work plus CD/DVD-ROM drive specific data provided by leading optical drive manufacturers (Samsung, Plextor, Panasonic).
Start Date	2002
End Date	2006
Data valid for entire period	1
Geography Text	A CD/DVD-ROM drive may be assembled anywhere in the world.
Technology Text	The production of a CD/DVD-ROM drive for a desktop computer includes the metal processing steps rolling, cutting and section bar extrusion. Plastic parts are blow moulded or extruded into required shapes.
Representativeness	unknown
Production Volume	unknown
Sampling Procedure	Data is based on literature. Weighting of CD/DVD-ROM drive components happened at a Technical University after professional disassembly.
Extrapolations	see Geography and Technology
Uncertainty Adjustments	None

6.4.2 Life Cycle inventory and General Flow Information

The layout of the dataset "CD-ROM/DVD-ROM drive, desktop computer, at plant GLO" with general flow information, remarks, sources, values and uncertainty information are shown in Fig. 6.18 and Fig. 6.22 below.

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Bottom cover Steel	→	CD-ROM/DVD-ROM drive, desktop computer, at plant PART 1				Bottom cover of CD-ROM; material steel	metals	extraction	No	RER	steel, low-alloyed, at plant	0.188	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Steel forming	→					Forming of steel; steel sheet rolling	metals	processing	No	RER	sheet rolling, steel	0.188	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Steel cutting	→					Energy for cutting the steel frame; 1500 W for 40 seconds	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	0.016667	kWh	Own assumptions based on Mepsaws (2007)	1	1.24346	(2,4,1,3,1,5,2)
Main PCB	→					PCB; main printed wiring board of CD-ROM	electronics	module	No	GLO	printed wiring board, mounted, unspecified, at plant	0.082	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Main plastic frame	→					Main plastic frame; material PE	plastics	polymers	No	RER	polyethylene, HDPE, granulate, at plant	0.086	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Plastic subframe	→					Plastic subframe	plastics	polymers	No	RER	polyethylene, HDPE, granulate, at plant	0.038	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Extrusion of plastic	→					Plastic extrusion for mainframe and subframe	plastics	processing	No	RER	injection moulding	0.124	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Metal frame	→					Metal frame for CD-ROM; steel	metals	extraction	No	RER	steel, low-alloyed, at plant	0.096	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Optical drive motor PE share	→					Motor for optical drive; 90% of weight of optical drive motor with PCB; PE share 20%	plastics	polymers	No	RER	polyethylene, HDPE, granulate, at plant	0.0036	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)

Fig. 6.18 Flows for "CD-ROM/DVD-ROM drive, desktop computer, at plant GLO" (part 1) and their representation in the ecoinvent database

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Blow moulding PE	→	CD-ROM/DVD-ROM drive, desktop computer, at plant PART 2				Blow moulding of PE motor parts	plastics	processing	No	RER	stretch blow moulding	0.0036	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Optical drive motor Copper share	→					Motor for optical drive; 90% of weight of optical drive motor with PCB; Copper share 50%	metals	extraction	No	RER	copper, at regional storage	0.009	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Wire drawing copper	→					Wire drawing of copper	metals	processing	No	RER	wire drawing, copper	0.009	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Optical drive motor Steel share	→					Motor for optical drive; 90% of weight of optical drive motor with PCB; Steel share 30%	metals	extraction	No	RER	steel, low-alloyed, at plant	0.0054	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Sheet rolling steel	→					Sheet rolling of steel part	metals	processing	No	RER	sheet rolling, steel	0.0054	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
PCB for optical drive motor	→					PCB; 10%of weight for optical drive motor with PCB	electronics	module	No	GLO	printed wiring board, mounted, unspecified, at plant	0.002	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
CD insert cover ABS	→					CD insert cover made from ABS	plastics	polymers	No	RER	acrylonitrile-butadiene-styrene copolymer, ABS, at plant	0.024	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Injection moulding	→					Injection moulding of ABS granulate	plastics	processing	No	RER	injection moulding	0.024	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
CD Tray Polycarbonate	→					CD tray made out of PC	plastics	polymers	No	RER	polycarbonate, at plant	0.034	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Injection moulding	→					Injection moulding of PC granulate	plastics	processing	No	RER	injection moulding	0.034	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
CD motor base plate	→					CD motor base plate; steel	metals	extraction	No	RER	steel, low-alloyed, at plant	0.04	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)

Fig. 6.19 Flows for "CD-ROM/DVD-ROM drive, desktop computer, at plant GLO" (part 2) and their representation in the ecoinvent database

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Sheet rolling steel	→	CD-ROM/DVD-ROM drive, desktop computer, at plant PART 3				Sheet rolling of steel into plate	metals	processing	No	RER	sheet rolling, steel	0.04	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Optical Reader assembly	→					Optical reader assembly; assumed to be ABS material	plastics	polymers	No	RER	acrylonitrile-butadiene-styrene copolymer, ABS, at plant	0.018	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Injection moulding	→					Injection moulding of ABS granulate	plastics	processing	No	RER	injection moulding	0.018	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Top cover Steel	→					Top cover made from steel	metals	extraction	No	RER	steel, low-alloyed, at plant	0.22	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Sheet rolling steel	→					Sheet rolling of steel	metals	processing	No	RER	sheet rolling, steel	0.22	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Steel cutting	→					Cutting of top cover into shape; 1500 W for 40 seconds.	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	0.016667	kWh	Own assumptions based on Mepsaws (2007)	1	1.2366	(1,4,1,3,1,5,2)
Motor for CD tray PE share	→					Motor for CD tray; 90%of weight of CD Tray motor with PCB; PE share 20%	plastics	polymers	No	RER	polyethylene, HDPE, granulate, at plant	0.00324	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Blow moulding PE	→					Blow moulding of PE motor parts	plastics	processing	No	RER	stretch blow moulding	0.00324	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Motor for CD tray Copper share	→					Motor for CD tray; 90%of weight of CD Tray motor with PCB; Copper share 50%	metals	extraction	No	RER	copper, at regional storage	0.0081	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Wire drawing copper	→					Wire drawing of copper	metals	processing	No	RER	wire drawing, copper	0.0081	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Motor for CD tray Steel share	→					Motor for CD tray; 90%of weight of CD Tray motor with PCB; Steel share 30%	metals	extraction	No	RER	steel, low-alloyed, at plant	0.00486	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Sheet rolling steel	→					Sheet rolling of steel part	metals	processing	No	RER	sheet rolling, steel	0.00486	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)

Fig. 6.20 Flows for "CD-ROM/DVD-ROM drive, desktop computer, at plant GLO" (part 3) and their representation in the ecoinvent database

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
CD Rotator motor PE share	→	CD-ROM/DVD-ROM drive, desktop computer, at plant PART 4				CD Rotator motor; 90%of weight of CD Rotator motor with PCB; PE share 20%	plastics	polymers	No	RER	polyethylene, HDPE, granulate, at plant	0.0072	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Blow moulding PE	→					Blow moulding of PE motor parts	plastics	processing	No	RER	stretch blow moulding	0.0072	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
CD Rotator motor Copper share	→					CD Rotator motor; 90%of weight of CD Rotator motor with PCB; Copper share 50%	metals	extraction	No	RER	copper, at regional storage	0.018	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Wire drawing copper	→					Wire drawing of copper	metals	processing	No	RER	wire drawing, copper	0.018	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
CD Rotator motor Steel share	→					CD Rotator motor; 90%of weight of CD Rotator motor with PCB; Steel share 30%	metals	extraction	No	RER	steel, low-alloyed, at plant	0.0108	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Sheet rolling steel	→					Sheet rolling of steel part	metals	processing	No	RER	sheet rolling, steel	0.0108	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
PCB for CD rotator motor	→					PCB; 10%of weight for CD Rotator motor with PCB	electronics	module	No	GLO	printed wiring board, mounted, unspecified, at plant	0.004	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Plastic gears	→					5 plastic gears made from ABS plastic	plastics	polymers	No	RER	acrylonitrile-butadiene-styrene copolymer, ABS, at plant	0.01	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Injection moulding	→					Moulding of ABS granulates into gear shapes	plastics	processing	No	RER	injection moulding	0.01	kg	Assumption based on Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Optical reader motion rod Steel	→					Optical reader motion rod made out of steel	metals	extraction	No	RER	steel, low-alloyed, at plant	0.006	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Forming of rod	→					Production of steel rod	metals	processing	No	RER	section bar rolling, steel	0.006	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Screws	→					31 screws chromium steel	metals	extraction	No	RER	chromium steel 18/8, at plant	0.008	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)

Fig. 6.21 Flows for "CD-ROM/DVD-ROM drive, desktop computer, at plant GLO" (part 4) and their representation in the ecoinvent database

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Forming steel screws	→	CD-ROM/DVD-ROM drive, desktop computer, at plant PART 5				Forming of steel screws	metals	processing	No	RER	hot rolling, steel	0.008	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Miscelleneous plastic parts	→					Different miscelleneous plastic parts; taken as ABS	plastics	polymers	No	RER	acrylonitrile-butadiene-styrene copolymer, ABS, at plant	0.01	kg	Mohite (2005)	1	1.2366	(1,4,1,3,1,5,3)
Forming of plastic parts	→					Injection moulding	plastics	processing	No	RER	injection moulding	0.0108	kg	Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Energy	→					Electricity for CD-ROM assembly; assumed to be the same as for laptop assembly	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	1.67	kWh	Assumption based on Stachura (2006)	1	1.34403	(3,4,1,3,3,5,2)
Infrastructure	→					Calculated per production site via the annual production volume (GS Magicstore in China: 1.2 mio) for DVD/CD drives and the life-span of the factory (25 years); proxy printed wiring board mounting plant	electronics	module	Yes	GLO	printed wiring board mounting plant	3.33E-08	unit	Own calculations based on assumptions made on information by Nikkei Electronics Asia (for 2003)	1	3.10715	(2,4,1,3,3,5,9)
Transport road	→					Transport from regional storage by 32 t lorry (RER) to factory for metals and plastics	transport systems	road	No	RER	transport, lorry >16t, fleet average	0.09362	tkm	ecoinvent (2000) standard transport distances of materials	1	2.10173	(2,3,1,1,3,5,5)
Transport rail	→					Transport from regional storage by rail (RER) to factory for metals and plastics	transport systems	train	No	RER	transport, freight, rail	0.18724	tkm	ecoinvent (2000) standard transport distances of materials	1	2.10173	(2,3,1,1,3,5,5)
			→	Waste heat		Waste heat from metal cutting processes and CD/DVD-ROM drive assembly energy	air	low population density			Heat, waste	6.06	MJ	Derived from electricity input numbers	1	1.2366	(1,4,1,3,1,5,13)
			→	1 CD-ROM/DVD-ROM drive for desktop computer		Production of hard disk drive for desktop computer	electronics	component	No	GLO	CD-ROM/DVD-ROM drive, desktop computer, at plant	1	unit				

Fig. 6.22 Flows for "CD-ROM/DVD-ROM drive, desktop computer, at plant GLO" (part 5) and their representation in the ecoinvent database

Data Uncertainty and Input Data for Database ecoinvent

The dataset represents a typical CD-ROM/DVD-ROM drive for a desktop computer. The data are mainly based on information collected for an impact assessment of computer disk drives by Mohite (2005). The fact that this typical CD/DVD-ROM drive does not represent the majority of world-wide available CD/DVD-ROM drives for desktop computers has been accounted for in the uncertainties of the dataset.

There is no direct natural resource input to the dataset "CD-ROM/DVD-ROM drive, desktop computer, at plant". Neither direct air emissions nor any waste are balanced for this CD/DVD-ROM drive dataset. Information on the release of industrial waste water is not available. Ecoinvent standard distances for rail and road transport are applied for the transfer of materials from regional storage centres to the production site (Frischknecht et al. (2007)).

6.5 Dataset "CD-ROM/DVD-ROM drive, laptop computer, at plant"

6.5.1 Dataset description and meta information

The dataset "CD-ROM/DVD-ROM drive, laptop computer, at plant" illustrates the "gate-to-gate" phase of a CD/DVD-ROM drive for a laptop computer (see Fig. 6.23). The functional unit for this dataset is 1 unit of CD/DVD-ROM drive. The post consumer waste treatment is not included in this dataset, as a drive is nowadays primarily integrated into a computer and being disposed of therewith. General information on the CD/DVD-ROM drive of a laptop computer and its function can be found in Chapter 6.1.2.

Fig. 6.23 CD/DVD-ROM Drive of a laptop computer (source: Google-Bilder http://techreport.com)

Although there is a lot of information on the total weight and the dimensions of a laptop CD/DVD-ROM drive, no direct weight data for the individual components of a laptop CD/DVD-ROM drive is available. As a consequence, the weights for the laptop CD/DVD-ROM drive components had to be calculated on the basis of the information available for the desktop CD-ROM drive (Mohite (2005)), see Chapter 6.4. Tab. 6.9 shows the exact calculation setup to estimate the weight of the individual components for the laptop CD/DVD-ROM drive. Wherever reasonable, the ratio of the total weight of the CD/DVD-ROM drives is applied to calculate the weight of the individual CD-ROM drive compo-

nents for laptops. The total CD-ROM drive weighs 0.249 kg, which represents a type that is slightly heavier compared to other models (Tab. 6.8). However, this type has been chosen under the following criteria: it represents better the models built-in in laptops being currently in use (e.g. the laptop CD-ROM drive described in part III of this report has a similar weight with 0.231 kg (von Geibler et al. (2003)).

Tab. 6.8 Total weight of different CD/DVD-ROM drives for laptop computers

Brand	Weight in kg	Source
HP Omnibook	0.231	vonGeibler 2003
Teac I	0.163	http://support.gateway.com
Teac II	0.195	www.samsungodd.com
Toshiba	0.249	http://sdd.toshiba.com
Used in this study	0.249	

Major contributions to the total CD/DVD-ROM drive weight of 0.249 kg (for laptop computer) results from the top and bottom cover (0.044 kg and 0.038 kg; both steel), the metal frame (0.022 kg; steel), the main plastic frame (0.021 kg; PE) and the printed wiring board (0.020 kg). More information on the weights of the different CD/DVD-ROM drive components for a laptop computer is shown in Tab. 6.9 and in the general flow information of this dataset in Fig. 6.24 to Fig. 6.28.

The energy input for the CD/DVD-ROM drive assembly is assumed to be the same as for a laptop, and is based on the energy input for the computer mouse assembly by Stachura (2006). For the process steps “steel cutting”, the input data is assumed on the basis of information released by Mepsaws, a leading metal saw supplier in Italy[53]. For an automatic metal sawing machine, Mepsaws publishes a power supply of 1.5 to 2.2 kW. The running time of the sawing machine to cut a metal sheet into shape for the laptop CD/DVD-ROM drive depends on the material characteristics and the complexity of the shape. The cutting time for the CD-ROM drive’s top and bottom cover is assumed to be 40 seconds for both, at a power supply of 1500 W.

The facility heating energy, the packaging as well as the scrap materials are not inventoried for this dataset. For scrap materials it is assumed that all scrap (mainly metals) is being recycled and reused.

The infrastructure for the CD/DVD-ROM drive production has been taken into account and has been calculated via the annual production volume (1.2 mill.) for a hard disk drive factory in China (Nikkei Business (2003)).

[53] Mepsaws: Automatic Cobra Metal Saw (http://www.mepsaws.it/index.php), accessed April 25, 2007.

Tab. 6.9 Calculation setup for laptop CD/DVD-ROM drive components derived from desktop CD/DVD-ROM drive

Components/Material	CD/DVD ROM Drive Desktop	Unit	CD/DVD ROM Drive Laptop	Calculation setup
Bottom cover Steel	1.88E-01	kg	3.76E-02	Ratio Laptop CD/DVD drive to PC CD/DVD drive is a bit less than 0.231/0.938=0.246; taken as 0.2
Main PCB	8.20E-02	kg	2.02E-02	Ratio Laptop CD/DVD drive to PC CD/DVD drive is 0.231/0.938=0.246 (ratio of total weights)
Main plastic frame	8.60E-02	kg	2.12E-02	Ratio Laptop CD/DVD drive to PC CD/DVD drive is 0.231/0.938=0.246
Plastic subframe	3.80E-02	kg	9.36E-03	Ratio Laptop CD/DVD drive to PC CD/DVD drive is 0.231/0.938=0.246
Metal frame	9.60E-02	kg	2.17E-02	Ratio Laptop CD/DVD drive to PC CD/DVD drive for metal frame is 49.02/216.72=0.226
Optical drive motor PE share	3.60E-03	kg	8.87E-04	Ratio Laptop CD/DVD drive to PC CD/DVD drive is 0.231/0.938=0.246
Optical drive motor Copper share	9.00E-03	kg	2.22E-03	Ratio Laptop CD/DVD drive to PC CD/DVD drive is 0.231/0.938=0.246
Optical drive motor Steel share	5.40E-03	kg	5.40E-03	Ratio Laptop CD/DVD drive to PC CD/DVD drive is 0.231/0.938=0.246
PCB for optical drive motor	2.00E-03	kg	4.93E-04	Ratio Laptop CD/DVD drive to PC CD/DVD drive is 0.231/0.938=0.246
CD insert cover ABS	2.40E-02	kg	5.91E-03	Ratio Laptop CD/DVD drive to PC CD/DVD drive is 0.231/0.938=0.246
CD Tray Polycarbonate	3.40E-02	kg	8.37E-03	Ratio Laptop CD/DVD drive to PC CD/DVD drive is 0.231/0.938=0.246
CD motor base plate	4.00E-02	kg	2.00E-02	Laptop CD/DVD drive is half the size of PC CD/DVD drive
Optical Reader assembly	1.80E-02	kg	4.43E-03	Ratio Laptop CD/DVD drive to PC CD/DVD drive is 0.231/0.938=0.246
Top cover Steel	2.20E-01	kg	4.40E-02	Ratio Laptop CD/DVD drive to PC CD/DVD drive is a bit less than 0.231/0.938=0.246; taken as 0.2
Motor for CD tray PE share	3.24E-03	kg	7.98E-04	Ratio Laptop CD/DVD drive to PC CD/DVD drive is 0.231/0.938=0.246
Motor for CD tray Copper share	8.10E-03	kg	8.10E-03	The same for laptop as for PC
Motor for CD tray Steel share	4.86E-03	kg	4.86E-03	The same for laptop as for PC
CD Rotator motor PE share	7.20E-03	kg	7.20E-03	The same for laptop as for PC
CD Rotator motor Copper share	1.80E-02	kg	4.43E-03	Ratio Laptop CD/DVD drive to PC CD/DVD drive is 0.231/0.938=0.246
CD Rotator motor Steel share	1.08E-02	kg	2.66E-03	Ratio Laptop CD/DVD drive to PC CD/DVD drive is 0.231/0.938=0.246
PCB for CD rotator motor	4.00E-03	kg	9.85E-04	Ratio Laptop CD/DVD drive to PC CD/DVD drive is 0.231/0.938=0.246
Plastic gears	1.00E-02	kg	2.46E-03	Ratio Laptop CD/DVD drive to PC CD/DVD drive is 0.231/0.938=0.246

Tab. 6.9 (Cont.) Calculation setup for laptop CD/DVD-ROM drive components derived from desktop CD/DVD-ROM drive

Components/Material	CD/DVD ROM Drive Desktop	Unit	CD/DVD ROM Drive Laptop	Calculation setup
Optical reader motion rod Steel	6.00E-03	kg	6.00E-03	Ratio Laptop CD/DVD drive to PC CD/DVD drive is 0.231/0.938=0.246
Screws	8.00E-03	kg	5.16E-03	20 screws Laptop CD/DVD drive instead of 31 for PC CD/DVD drive
Miscellaneous plastic parts	1.00E-02	kg	2.46E-03	Ratio Laptop CD/DVD drive to PC CD/DVD drive is 0.231/0.938=0.246
Total weight CD/DVD for PC	9.36E-01	kg	2.47E-01	Total weight CD/DVD for Laptop
Target	9.38E-01	kg	2.49E-01	Target (Toshiba CD-ROM Drive)

Tab. 6.10 includes all important and necessary (meta) information to use the data correctly.

Tab. 6.10 ecoinvent meta information for the CD/DVD-ROM drive of a laptop computer (GLO)

Name	**CD-ROM/DVD-ROM drive, laptop computer, at plant**
Location	GLO
Infrastructure Process	0
Unit	unit
Dataset Version	2.0
Included Processes	Describes the production of a CD-ROM/DVD-ROM drive for a laptop computer. Calculated per 1 produced CD/DVD-ROM drive (1 unit). Included are the materials (mainly metals and plastics) with their respective manufacturing processes (e.g. sheet rolling or blow moulding). Further inventoried is the infrastructure (factory), the electricity for the assembly of the CD/DVD-ROM drive, the respective waste heat, and the required rail and road transport for input materials from the regional storage to the factory. Not included are emissions to air and water (negligible), the heating of the facility, scrap materials (recycled and reused), the packaging, as well as the post consumer disposal, which is attributed to the laptop computer as a whole.
Amount	1
Local Name	CD-ROM/DVD-ROM Laufwerk, Laptop Computer, ab Werk
Synonyms	
General Comment	This dataset can be applied to describe the production of a common CD/DVD-ROM drive in the last 3 years before the reference year 2005 (IDE drive, total weight 0.249 kg). The dataset includes material information for all the major CD/DVD-ROM drive components (covers, printed wiring board, optical reader, motor(s), tray, etc.). The information is mainly based on one dissertation work plus CD/DVD-ROM drive specific data provided by leading optical drive manufacturers (Toshiba, Teac, HP). Data for the desktop CD/DVD-ROM drive have been extrapolated to the lighter laptop CD/DVD-ROM drive by specific calculation setups.
Start Date	2002
End Date	2006
Data valid for entire period	1
Geography Text	A CD/DVD-ROM drive may be assembled anywhere in the world.
Technology Text	The production of a CD/DVD-ROM drive for a laptop computer includes the metal processing steps rolling, cutting and section bar extrusion. Plastic parts are blow moulded or extruded into required shapes.
Representativeness	unknown
Production Volume	unknown
Sampling Procedure	Own estimations based on literature. Weighing of original components happened at a Technical University after professional disassembly.
Extrapolations	see Geography and Technology
Uncertainty Adjustments	None

6.5.2 Life Cycle inventory and General Flow Information

The layout of the dataset "CD-ROM/DVD-ROM drive, laptop computer, at plant GLO" with general flow information, remarks, sources, values and uncertainty information are shown in Fig. 6.24 to Fig. 6.28 below.

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Bottom cover Steel	→	CD-ROM/DVD-ROM drive, laptop computer, at plant PART 1				Bottom cover of CD-ROM; material steel	metals	extraction	No	RER	steel, low-alloyed, at plant	0.0376	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Steel forming	→					Forming of steel; steel sheet rolling	metals	processing	No	RER	sheet rolling, steel	0.0376	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Steel cutting	→					Energy for cutting the steel frame; 1500 W for 40	electricity	production mix	No	UCTE	electricity, medium voltage, production	0.016667	kWh	Own assumptions based on	1	1.32299	(1,4,1,3,3,5,2)
Main PCB	→					PCB; main printed wiring board of CD-ROM	electronics	module	No	GLO	printed wiring board, mounted, unspecified, at plant	0.020194	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Main plastic frame	→					Main plastic frame; material PE	plastics	polymers	No	RER	polyethylene, HDPE, granulate, at plant	0.021179	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Plastic subframe	→					Plastic subframe	plastics	polymers	No	RER	polyethylene, HDPE, granulate, at plant	0.009358	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Extrusion of plastic	→					Plastic extrusion for mainframe and subframe	plastics	processing	No	RER	injection moulding	0.030537	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Metal frame	→					Metal frame for CD-ROM; steel	metals	extraction	No	RER	steel, low-alloyed, at plant	0.021714	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Optical drive motor PE share	→					Motor for optical drive; 90% of weight of optical drive motor with PCB; PE share 20%	plastics	polymers	No	RER	polyethylene, HDPE, granulate, at plant	0.000887	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Blow moulding PE	→					Blow moulding of PE motor parts	plastics	processing	No	RER	stretch blow moulding	0.000887	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Optical drive motor Copper share	→					Motor for optical drive; 90% of weight of optical drive motor with PCB; Copper share 50%	metals	extraction	No	RER	copper, at regional storage	0.002216	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)

Fig. 6.24 Flows for "CD-ROM/DVD-ROM drive, laptop computer, at plant GLO" (part 1) and their representation in the ecoinvent database

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Wire drawing copper	→	CD-ROM/DVD-ROM drive, laptop computer, at plant PART 2				Wire drawing of copper	metals	processing	No	RER	wire drawing, copper	0.002216	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Optical drive motor Steel share	→					Motor for optical drive; 90% of weight of optical drive motor with PCB; Steel share 30%	metals	extraction	No	RER	steel, low-alloyed, at plant	0.0054	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Sheet rolling steel	→					Sheet rolling of steel part	metals	processing	No	RER	sheet rolling, steel	0.0054	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
PCB for optical drive motor	→					PCB; 10% of weight for optical drive motor with PCB	electronics	module	No	GLO	printed wiring board, mounted, unspecified, at plant	0.000493	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
CD insert cover ABS	→					CD insert cover made from ABS	plastics	polymers	No	RER	acrylonitrile-butadiene-styrene copolymer, ABS, at plant	0.00591	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Injection moulding	→					Injection moulding of ABS granulate	plastics	processing	No	RER	injection moulding	0.00591	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
CD Tray Polycarbonate	→					CD tray made out of PC	plastics	polymers	No	RER	polycarbonate, at plant	0.008373	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Injection moulding	→					Injection moulding of PC granulate	plastics	processing	No	RER	injection moulding	0.008373	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
CD motor base plate	→					CD motor base plate; steel	metals	extraction	No	RER	steel, low-alloyed, at plant	0.02	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Sheet rolling steel	→					Sheet rolling of steel into plate	metals	processing	No	RER	sheet rolling, steel	0.02	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)

Fig. 6.25 Flows for "CD-ROM/DVD-ROM drive, laptop computer, at plant GLO" (part 2) and their representation in the ecoinvent database

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Optical Reader assembly	→	CD-ROM/DVD-ROM drive, laptop computer, at plant PART 3				Optical reader assembly; assumed to be ABS material	plastics	polymers	No	RER	acrylonitrile-butadiene-styrene copolymer, ABS, at plant	0.004433	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Injection moulding	→					Injection moulding of ABS granulate	plastics	processing	No	RER	injection moulding	0.004433	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Top cover Steel	→					Top cover made from steel	metals	extraction	No	RER	steel, low-alloyed, at plant	0.044	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Sheet rolling steel	→					Sheet rolling of steel	metals	processing	No	RER	sheet rolling, steel	0.044	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Steel cutting	→					Cutting of top cover into shape; 1500 W for 40 seconds.	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	0.016667	kWh	Own assumptions based on Mepsaws (2007)	1	1.2366	(1,4,1,3,1,5,2)
Motor for CD tray PE share	→					Motor for CD tray; 90%of weight of CD Tray motor with PCB; PE share 20%	plastics	polymers	No	RER	polyethylene, HDPE, granulate, at plant	0.000798	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Blow moulding PE	→					Blow moulding of PE motor parts	plastics	processing	No	RER	stretch blow moulding	0.000798	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Motor for CD tray Copper share	→					Motor for CD tray; 90%of weight of CD Tray motor with PCB; Copper share 50%	metals	extraction	No	RER	copper, at regional storage	0.0081	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Wire drawing copper	→					Wire drawing of copper	metals	processing	No	RER	wire drawing, copper	0.0081	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Motor for CD tray Steel share	→					Motor for CD tray; 90%of weight of CD Tray motor with PCB; Steel share 30%	metals	extraction	No	RER	steel, low-alloyed, at plant	0.00486	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Sheet rolling steel	→					Sheet rolling of steel part	metals	processing	No	RER	sheet rolling, steel	0.00486	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
CD Rotator motor PE share	→					CD Rotator motor; 90%of weight of CD Rotator motor with PCB; PE share 20%	plastics	polymers	No	RER	polyethylene, HDPE, granulate, at plant	0.0072	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Blow moulding PE	→					Blow moulding of PE motor parts	plastics	processing	No	RER	stretch blow moulding	0.0072	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
CD Rotator motor Copper share	→					CD Rotator motor; 90%of weight of CD Rotator motor with PCB; Copper share 50%	metals	extraction	No	RER	copper, at regional storage	0.004433	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)

Fig. 6.26 Flows for "CD-ROM/DVD-ROM drive, laptop computer, at plant GLO" (part 3) and their representation in the ecoinvent database

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Wire drawing copper	→	CD-ROM/DVD-ROM drive, laptop computer, at plant PART 4				Wire drawing of copper	metals	processing	No	RER	wire drawing, copper	0.004433	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
CD Rotator motor Steel share	→					CD Rotator motor; 90% of weight of CD Rotator motor with PCB; Steel share 30%	metals	extraction	No	RER	steel, low-alloyed, at plant	0.00266	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Sheet rolling steel	→					Sheet rolling of steel part	metals	processing	No	RER	sheet rolling, steel	0.00266	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
PCB for CD rotator motor	→					PCB; 10% of weight for CD Rotator motor with PCB	electronics	module	No	GLO	printed wiring board, mounted, unspecified, at plant	0.000985	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Plastic gears	→					5 plastic gears made from ABS plastic	plastics	polymers	No	RER	acrylonitrile-butadiene-styrene copolymer, ABS, at plant	0.002463	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Injection moulding	→					Moulding of ABS granulates into gear shapes	plastics	processing	No	RER	injection moulding	0.002463	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Optical reader motion rod Steel	→					Optical reader motion rod made out of steel	metals	extraction	No	RER	steel, low-alloyed, at plant	0.006	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Forming of rod	→					Production of steel rod	metals	processing	No	RER	section bar rolling, steel	0.006	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Screws	→					31 screws chromium steel	metals	extraction	No	RER	chromium steel 18/8, at plant	0.005161	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Forming steel screws	→					Forming of steel screws	metals	processing	No	RER	hot rolling, steel	0.005161	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Miscelleneous plastic parts	→					Different miscelleneous plastic parts; taken as ABS	plastics	polymers	No	RER	acrylonitrile-butadiene-styrene copolymer, ABS, at plant	0.002463	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)

Fig. 6.27 Flows for "CD-ROM/DVD-ROM drive, laptop computer, at plant GLO" (part 4) and their representation in the ecoinvent database

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
Forming of plastic parts	→	CD-ROM/DVD-ROM drive, laptop computer, at plant PART 5				Injection moulding	plastics	processing	No	RER	injection moulding	0.002463	kg	Own calculations based on Mohite (2005)	1	1.32299	(1,4,1,3,3,5,3)
Energy	→					Electricity for CD-ROM drive assembly; assumed to be the same as for laptop assembly	electricity	production mix	No	UCTE	electricity, medium voltage, production UCTE, at grid	1.67	kWh	Assumption based on Stachura (2006)	1	1.34403	(3,4,1,3,3,5,2)
Infrastructure	→					Calculated per production site via the annual production volume (GS Magicstore in China: 1.2 mio) for HDDs and the life-span of the factory (25 years); proxy electronic component factory	electronics	component	Yes	GLO	electronic component production plant	3.33E-08	unit	Own calculations based on assumptions made on information by Nikkei Electronics Asia (for 2003)	1	3.10715	(2,4,1,3,3,5,9)
Transport road	→					Transport from regional storage by 32 t lorry (RER) to factory for metals and plastics	transport systems	road	No	RER	transport, lorry >16t, fleet average	0.024688	tkm	ecoinvent (2000) standard transport distances of materials	1	2.10173	(2,3,1,1,3,5,5)
Transport rail	→					Transport from regional storage by rail (RER) to factory for metals and plastics	transport systems	train	No	RER	transport, freight, rail	0.049376	tkm	ecoinvent (2000) standard transport distances of materials	1	2.10173	(2,3,1,1,3,5,5)
			→	Waste heat		Waste heat from metal cutting processes and CD/DVD-ROM drive assembly energy	air	low population density			Heat, waste	6.12	MJ	Derived from electricity input numbers	1	1.2366	(1,4,1,3,1,5,13)
			→	1 CD-ROM/DVD-ROM drive for laptop computer		Production of color laser jet printer	electronics	component	No	GLO	CD-ROM/DVD-ROM drive, laptop computer, at plant	1	unit				

Fig. 6.28 Flows for "CD-ROM/DVD-ROM drive, laptop computer, at plant GLO" (part 5) and their representation in the ecoinvent database

Data Uncertainty and Input Data for Database ecoinvent

The dataset represents a typical CD-ROM/DVD-ROM drive used in a laptop computer. The data are mainly based on information collected for an impact assessment of computer disk drives by Mohite (2005) for a desktop computer, and projected down to a CD/DVD-ROM drive of a laptop computer. The fact that this typical CD/DVD-ROM drive does not represent the majority of world-wide available CD/DVD-ROM drives for laptop computers has been accounted for in the uncertainties of the dataset.

There is no direct natural resource input to the dataset “CD-ROM/DVD-ROM drive, laptop computer, at plant”. Neither direct air emissions nor any waste are balanced for this CD/DVD-ROM drive data-set. Information on the release of industrial waste water is not available. Ecoinvent standard distances for rail and road transport are applied for the transfer of materials from regional storage centres to the production site (Frischknecht et al. (2007)).

7 Power Supply Unit (PSU)

7.1 Introduction

This chapter describes the assembly of the power supply unit (PSU) of a typical Desktop PC. The lay-out of the examined product system is shown in Fig. 7.1.

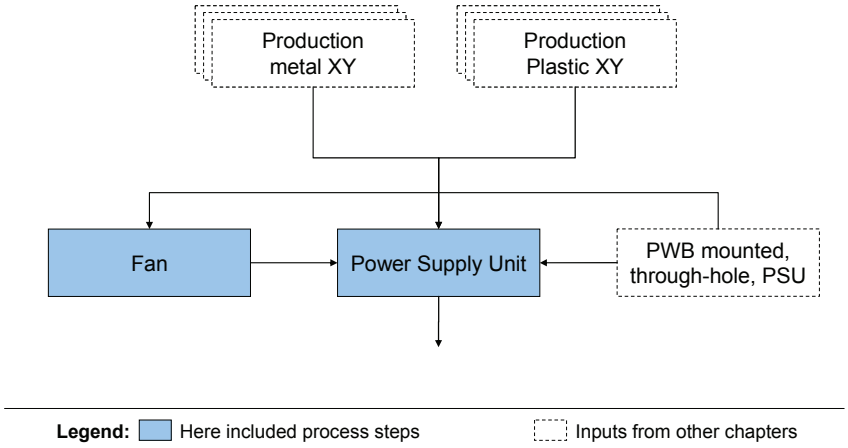


Fig. 7.1 The system for the power supply unit – comprising two new datasets as well as the links to datasets from other chapters (within this report here / within other ecoinvent reports)

7.2 System characterisation

Each Desktop PC has a power supply unit that transforms the 220V electricity from the plug to the adequate voltage used within such a device. The main components of such a PSU are (i) the housing, (ii) a fan for cooling, (iii) the printed wiring board with all its components and a whole bunch of various cables. The dataset distinguishes between these various parts.

Fig. 7.2 Photographies of a Power Supply unit – (from left to right) PWB and the various components (photo: Empa), the overall picture (photo from www.maincomp.com), housing and PWB and cables (photo: Empa)

The information about the composition and the weight are from dismantling activities of a PSU at Empa. The meta information of the two datasets of the PSU can be found in Tab. 7.1.

Tab. 7.1 Ecoinvent meta information for the datasets of the power supply unit for Desktop PC within the database.

Name	power supply unit, at plant	fan, at plant
Location	CN	GLO
Infrastructure Process	1	1
Unit	Unit	kg
Dataset Version	2.0	2.0
Included Processes	This dataset contains the material inputs that build up all together a power supply unit for a desktop PC. Requirements and emissions of the assembly process (energy, emissions, waste) are not included.	This dataset contains the material inputs that build up all together a fan, used in a power supply unit of a Desktop PC. Requirements and emissions of the assembly process (energy, emissions, waste) are not included.
Amount	1	1
Local Name	Netzteil, ab Werk	Ventilator, ab Werk
Synonyms		
General Comment	This dataset is a rough estimation of the material composition of the PSU in a desktop PC due to own measurements.	This dataset is a rough estimation of the material composition of a fan used in a PSU that can be found in a desktop PC.
Start Date	2005	2005
End Date	2005	2005
Data valid for entire period	1	1
Geography Text	Data of a Chinese product; commonly used in current desktop PC.	Data used has no specific geographical origin (see Sampling Procedure).
Technology Text	The dataset represents the material composition of a PSU, model ST-235ATX, from a Chinese producer.	The dataset represents the material composition of a fan, as used in PSU.
Representativeness	-	-
Production Volume	-	-
Sampling Procedure	Own dismantling & estimation	own dismantling & estimation
Extrapolations	See Geography and Technology	see Geography and Technology
Uncertainty Adjustments	None	None

7.3 Life Cycle Inventories

7.3.1 Dataset “power supply unit, at plant”

System characterisation

The dataset comprises material information about the various parts (housing, plugs, PWB, etc.) of such a PSU device. No requirements and emissions of the assembly efforts are included due to lack of respective information. The dataset represents the Switching Power Supply unit, model ST-235ATX, from the Chinese producer PC Winner.

Life Cycle inventory

As mentioned above, the dataset includes only direct inputs of materials and components. Details about the like this determined composition and the various parts, together with the used ecoinvent datasets, are summarized in Tab. 7.2.

Tab. 7.2 Material specification of the dismantled power supply unit (data sources: see text)

		PSU	Used ecoinvent dataset
Total weight	kg	**1.470**	
Housing	g	**571.9**	steel, low-alloyed, at plant / sheet rolling
Plugs & Buttons	g	**27.1**	plugs, inlet and outlet, for computer cable, at plant
Fan	g	**74.2**	fan, at plant
PWB, mounted	g	**603.4**	printed wiring board, power supply unit desktop PC, solder mix, at plant
cables, internal	g	**193.5**	cable, ribbon cable, 20-pin, with plugs, at plant

Data Uncertainty and Data

The uncertainty scores established according to the method used in the ecoinvent project (see Frischknecht et al. (2007)) include reliability, completeness, temporal correlation, geographical correlation, further technological correlation and sample size. The datasets represent a typical PSU of a desktop PC, based on own dismantling activities. Hence, the uncertainty values are estimated accordingly.

The resulting unit process raw data of 1 unit of a desktop PC PSU is shown in Tab. 7.4 (on page 260).

7.3.2 Dataset “fan, at plant”

System characterisation

The dataset comprises material information about the various parts (housing, plugs, PWB, etc.) of a fan, as used in current PSU devices. No requirements and emissions of the assembly efforts is included due to lack of respective information. The dataset represents a brushless rotary DC fan (12V, 0.15A).

Life Cycle inventory

As mentioned above, the dataset includes as only direct input the materials. Details about the composition and the various parts, together with the used ecoinvent datasets, are summarized in Tab. 7.3.

Tab. 7.3 Material specification of the dismantled 12V DC rotary fan (data sources: see text)

		fan	Used ecoinvent dataset
Total weight	g	**74.2**	
Housing	g	**32.6**	HDPE granulate / injection moulding
Rotator	g	**30.0**	80% HDPE granulate / injection moulding; 20% brass, at plant / casting, brass
PWB, mounted	g	**11.6**	printed wiring board, through-hole mounted, unspec., solder mix, at plant

Data Uncertainty and Data

The uncertainty scores established according to the method used in the ecoinvent project (see Frischknecht et al. (2007)) include reliability, completeness, temporal correlation, geographical corre-

lation, further technological correlation and sample size. The datasets represent a typical fan like it is used in the PSU of a desktop PC, based on own dismantling activities. Hence, the uncertainty values are estimated accordingly.

The resulting unit process raw data for 1 kg of a fan, as used in a desktop PC PSU, are shown in Tab. 7.5 (on page 261).

Tab. 7.4 Dataset “power supply unit, at plant (CN)”

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-struc-ture	Loca-tion	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
housing, material	⇧	power supply unit, at plant				assuming low allyed steel	metals	extraction	No	RER	steel, low-alloyed, at plant	5.72E-01	kg		1	2.10	own dismantling acitivites
housing, processing	⇧						metals	processing	No	RER	sheet rolling, steel	5.72E-01	kg		1	2.10	own dismantling acitivites
Fan	⇧						electronics	module	No	GLO	fan, at plant	7.42E-02	kg		1	2.10	own dismantling acitivites
plugs & buttons	⇧						electronics	component	No	GLO	plugs, inlet and outlet, for computer cable, at plant	1.00E+00	unit		1	2.10	own dismantling acitivites
internal cables	⇧						electronics	component	No	GLO	cable, ribbon cable, 20-pin, with plugs, at plant	1.94E-01	kg		1	2.10	own dismantling acitivites
PWB, mounted	⇧						electronics	module	No	GLO	printed wiring board, power supply unit desktop PC, solder mix, at plant	6.04E-01	kg		1	2.10	own dismantling acitivites
			⇧	PSU			electronics	module	No	CN	power supply unit, at plant	1.00E+00	unit		1		

Tab. 7.5 Dataset “fan, at plant (GLO)”

General Flow information							Representation in ecoinvent								Uncertainty information		
Input		Process Name		Output		Remarks	Category	Sub-category	Infra-structure	Location	Modul name in ecoinvent	Mean value	Unit	Source	Type	StDv 95%	General Comment
housing, material	⇩	fan, at plant				Assuming HDPE	plastics	polymers	No	RER	polyethylene, HDPE, granulate, at plant	4.39E-01	kg	own dismantling activities	1	2.10	own dismantling activites
housing, processing	⇩						plastics	processing	No	RER	injection moulding	4.39E-01	kg	estimation	1	2.10	own dismantling activites
rotor, material	⇩					Assuming 80%HDPE	plastics	polymers	No	RER	polyethylene, HDPE, granulate, at plant	3.23E-01	kg	own dismantling activities	1	2.10	own dismantling activites
rotor, material (II)	⇩					assuming 20%brass	metals	extraction	No	CH	brass, at plant	8.09E-02	kg	own dismantling activities	1	2.10	own dismantling activites
rotor, processing	⇩						plastics	processing	No	RER	injection moulding	3.23E-01	kg	estimation	1	2.10	own dismantling activites
rotor, processing (II)	⇩						metals	processing	No	CH	casting, brass	8.09E-02	kg	estimation	1	2.10	own dismantling activites
PWB, mounted	⇩					through-hole PWB, unspecified	electronics	module	No	GLO	printed wiring board, through-hole mounted, unspec., solder mix, at plant	1.56E-01	kg	own dismantling activities	1	2.10	own dismantling activites
			⇩	fan			electronics	module	No	GLO	fan, at plant	1.00E+00	kg		1		

8 References

Ahmadi et al. (2003) Ahmadi A., Williamson B. H., Theis T. L. and Powers S. E. (2003) Life-cycle inventory of toner produced for xerographic processes. *In: Journal of Cleaner Production*, **11**(5), pp. 573-582, Online-Version under: http://dx.doi.org/10.1016/S0959-6526(02)00090-2.

Aighton (2003) Aighton P. (2003) Battery reycling campaign - take charge of the future. South West of Englang Regional Development Agency, Bristol

Althaus et al. (2007) Althaus H.-J., Chudacoff M., Hischier R., Jungbluth N., Osses M. and Primas A. (2007) Life Cycle Inventories of Chemicals. Final report ecoinvent data v2.0 No. 8. Swiss Centre for Life Cycle Inventories, Empa - TSL, Dübendorf, CH, Online-Version under: www.ecoinvent.ch.

Althaus et al. (2004) Althaus H.-J., Classen M., Blaser S. and Jungbluth N. (2004) Ecoinvent - Life Cycle Inventories for Metals. Swiss Centre for Life Cycle Inventories, Dübendorf

Alvarado Ascencio & Madsen (2005) Alvarado Ascencio C. and Madsen J. (2005) LCA comparison of alternative soldering techniques. PRé Consultant bv, Amersfoort (the Netherlands)

Arakawa (2005) Arakawa M. (2005) NTT prototype micro PEM for cell phones. In: *Fuel Cells Bulletin*, Vol. 2005.

AT&S AG (2006) AT&S AG (2006) Environmental Report 2006. Austria Technologie & Systemtechnik Aktiengesellschaft (AT&S AG), Fehring, Leoben (Austria), Online-Version under: www.ats.net.

BAJ (2006) BAJ (2006) Secondary battery sales statistics by volume. Download of 2006-08-31 from http://www.baj.or.jp/e/statistics/index07.html.

Behrendt et al. (1998) Behrendt S., Kreibich R., Lundie S., Pfitzner R. and Scharp M. (1998) Ökobilanzierung komplexer Elektronikprodukte. Innovationen und Umweltentlastungspotentiale durch Lebenszyklusanalyse. Springer, Berlin, Heidelberg (Germany)

Boulanger (2001) Boulanger R. (2001) Assembly Processes. In: *Printed Circuit Handbook* (ed. Coombs C. F.). McGraw-Hill Publishing, New York (NY, USA)

Braun et al. (2001) Braun A., Bergmann U., Wang H., Glatzel P., Funk T., Tucker M. C., Cramer S. P. and Cairns E. J. (2001) Oxidation state changes of Mn in lithium battery electrodes during electrode preparation. Lawrence Berkeley National Laboratories, Berkeley

Brown & Gabor (2006) Brown J. and Gabor L. (2006) THE RECHARGEABLE BATTERY RECYCLING CORPORATION REPORTS INCREASE IN COLLECTION NUMBERS. Rechargeable Battery Recycling Corporation, Atlanta

Buchmann (2004) Buchmann I. (2004) Battery Statistics. Download of 2006-08-31 from http://www.batteryuniversity.com/parttwo-55.htm.

Buchmann (2005) Buchmann I. (2005) Battery University. Download of 2006-08-24 from http://www.batteryuniversity.com/index.htm.

Calábek et al. (2006) Calábek M., Micka K., Krivák P. and Baca P. (2006) Significance of carbon additive in negative lead-acid battery electrodes. *In: Journal of Power Sources*, **158**, pp. 864-867.

Chen et al. (2002) Chen C.-h., Hyung Y. E., Vissers D. R. and Amine K. (2002) Lithium ion battery with improved safety, Vol. 7,026,074 (ed. U.S. Patent & Trademark Office). The University of Chicago, U.S.

Chen et al. (2005) Chen G., Zhuang G. V., Richardson T. J., Gao L. and Jr. P. N. R. (2005) Anodic polymerization of vinyl ethylene carbonate in Li-Ion battery electrolyte. Lawrence Berkeley National Laboratory, Berkeley

Classen et al. (2007) Classen M., Althaus H.-J., Tuchschmid M., Blaser S. and Jungbluth N. (2007) Life Cycle Inventories of Metals. Final report ecoinvent data v2.0 No. 10. EMPA Dübendorf, Swiss Centre for Life Cycle Inventories, Dübendorf, CH, Online-Version under: www.ecoinvent.ch.

Coombs (2001) Coombs C. F. (ed.) (2001) Printed Circuits Handbook. McGraw-Hill Companies, Inc., New York, Chicago, San Francisco

Custer (2000) Custer W. (2000) World PCB market - size, scope & electronics equipment end markets. *In proceedings from: China Printed Circuit Association*, Shanghai (China), March 19, 2000, Online-Version under: http://www.custerconsulting.com/PDF/cpca300.pdf.

Custer (2006) Custer W. (2006) Business Outlook - Global Electronics Industry. *In proceedings from: IPC/APEX 2006*, Online-Version under: http://www.custerconsulting.com/Pages/publications/CCA/200602-used_Expo-APEX_keynote/custer-IPC_Expo-APEX2006-Keynote.pdf.

Daetwyler (2006) Daetwyler (2006) Unilan Handbuch. Download of 8.2.2007 from http://daetwyler.de/d/produkte/unilan/service/handbuch/index.htm.

Delpho (2005) Delpho H. (2005) Mobilkommunikation 2009. Prognos AG, Basel, Online-Version under: http://www.mediareports.de/offen/index.php?mb2009.

Dixit et al. (1996) Dixit M., Kamath P. V., Kumar V. G., Munichandraiah N. and Shukla A. K. (1996) An electrochemically impregnated sintered-nickel electrode. *In: Journal of Power Sources*, **63**, pp. 167-171.

Draka (2004) Draka (2004) Environmental Report - Draka Norsk Kabel AS and Draka Comteq Norway AS. Environmental report from http://www.draka.no/drakanorway/PDF/Environmental_Report_2004.pdf .

Ehrlich (2002) Ehrlich G. M. (2002) Lihium-Ion Batteries. In: *Handbook of Batteries* (ed. Linden D. and Reddy T. B.), 3rd Edition Edition. McGraw-Hill Companies, Inc., New York, Chicago, San Francisco, Lisbon, London, Madrid, Mexico City, Milan, New Delhi, San Juan, Seoul, Singapore, Sydney, Toronto

Electronics-Lab (2006) Electronics-Lab (2006) How to rebuild a Li-Ion battery pack. Download of 2006-10-19 from http://www.electronics-lab.com/articles/Li_Ion_reconstruct/photos/image_21_f.jpg.

EPBA (2006) EPBA (2006) EU Portable Battery Market. Download of 2006-08-31 from http://www.epbaeurope.net/batterymarket.html.

European Portable Battery Association (2000) European Portable Battery Association (2000) Sales (Units) European Portable Battery Market - 2000. Download of 2006-08-29 from http://www.epbaeurope.net/statistics.html.

Fetcenko (2002) Fetcenko M. (2002) Propulsion and industrial Nickel-Metal hydride batteries. In: *Handbook of Batteries* (ed. Linden D. and Reddy T. B.), 3rd Edition Edition. McGraw-Hill Companies, Inc., New York, Chicago, San

	Francisco, Lisbon, London, Madrid, Mexico City, Milan, New Delhi, San Juan, Seoul, Singapore, Sydney, Toronto
First Environment (2004)	First Environment (2004) LaserJet Cartridge Environmental Comparison: A Life Cycle Study of the HP 96A Print Cartridge vs. its Remanufactured Counterpart in Germany. Project No. HPCKA002, Boonton, NJ as pdf-File under: mailto:LaserJetLCA@hp.com
Fluharty (2005)	Fluharty A. (2005) A Comparison of Conventional Toner to Chemically Produced Toner using Life Cycle Assessment. Institute for Environmental Science and Policy, Prosser Career Academy, Chicago Public Schools, Chicago, Illinois
Freitas (2001)	Freitas M. B. J. G. (2001) Nickel hydroxide powder for $NiO*OH/Ni(OH)_2$ electrodes of the alkaline batteries. *In: Journal of Power Sources*, **93**, pp. 163-173.
Frischknecht et al. (2007)	Frischknecht R., Jungbluth N., Althaus H.-J., Doka G., Dones R., Heck T., Hellweg S., Hischier R., Nemecek T., Rebitzer G., Spielmann M. and Wernet G. (2007) Overview and Methodology. Final report ecoinvent data v2.0 No. 1. Swiss Centre for Life Cycle Inventories, Dübendorf, CH, Online-Version under: www.ecoinvent.ch.
Frischknecht et al. (2004)	Frischknecht R., Jungbluth N., Althaus H.-J., Doka G., Dones R., Hischier R., Hellweg S., Nemecek T., Rebitzer G. and Spielmann M. (2004) Overview and Methodology. Final report ecoinvent 2000 No. 1. Swiss Centre for Life Cycle Inventories, Dübendorf, CH, Online-Version under: www.ecoinvent.ch.
Fujitsu-Siemens (2005)	Fujitsu-Siemens (2005) LIFEBOOK S7020 Your best friend on the move. Fujitsu Siemens Computers, Munich, Online-Version under: http://www.fujitsu-siemens.ch/products/mobile/notebooks/lifebook_s.html.
Galgoci et al. (2005)	Galgoci E. C., Chan S. Y. and Yacoub K. (2005) Innovative Molecular Defoamer Technology. Air Products and Chemicals Inc., Allentown, PA, Online-Version under: http://www.airproducts.com/.../74166723-C173-4CED-A6CF-C6F29BB89D84/0/InnovativeMolecularDefoamerTechnology.pdf.
Galliford (2004)	Galliford G. (2004) Exploring Chemically Prepared Toner. In: *Recharger online*.
Geibig & Socolof (2005)	Geibig J. R. and Socolof M. L. (2005) Solders in Electronics: A Life-Cycle Assessment. US EPA, Cincinnati (OH, USA)
GFS Chemicals Inc. (2004)	GFS Chemicals Inc. (2004) Material Safety Data Sheet: Ethylene Carbonate. GFS Chemicals, Inc., Powell
Goldman (1997)	Goldman P. J. R. (1997) The Desmear/Etchback Processes. In: *Printed Circuit Board Materials Handbook* (ed. Jawitz M. J.). pp. 21.1-21.22. McGraw Hill, New York, San Francisco, Washington, D.C., Auckland, Bogotá, Caracas, Lisbon, London, Madrid, Mexico City, Milan, Montreal, New Dehli, San Juan, Singapore, Sydney, Tokyo, Toronto
Goodell (1997)	Goodell S. (1997) Hot Air Leveling. In: *Printed Circuit Board Materials Handbook* (ed. Jawitz M. J.). pp. 30.1-30.31. McGraw Hill, New York, San Francisco, Washington, D.C., Auckland, Bogotá, Caracas, Lisbon, London, Madrid, Mexico City, Milan, Montreal, New Dehli, San Juan, Singapore, Sydney, Tokyo, Toronto

GSMAssociation (2006) GSMAssociation (2006) GSMA statistics Q2/06. Download of 2006-08-24 from http://www.gsmworld.com/news/statistics/pdf/gsma_stats_q2_06.pdf.

Hayes (1997) Hayes E. (1997) Primary Imaging Resist. In: *Printed Circuit Board Materials Handbook* (ed. Jawitz M. J.). McGraw Hill, New York, San Francisco, Washington, D.C., Auckland, Bogotá, Caracas, Lisbon, London, Madrid, Mexico City, Milan, Montreal, New Dehli, San Juan, Singapore, Sydney, Tokyo, Toronto

Hewlett Packard (2006a) Hewlett Packard (2006a) Material Data Safety Sheet for HP Color LaserJetC9700ABlack Print Cartridge for LaserJet 2500/1500.

Hewlett Packard (2006b) Hewlett Packard (2006b) Material Data Safety Sheet for HP Color LaserJetC9701ACyan Print Cartridge for LaserJet 2500/1500.

Hewlett Packard (2006c) Hewlett Packard (2006c) Material Data Safety Sheet for HP Color LaserJetC9702AYellow Print Cartridge for LaserJet 2500/1500.

Hewlett Packard (2006d) Hewlett Packard (2006d) Material Data Safety Sheet for HP Color LaserJetC9703AMagenta Print Cartridge for LaserJet 2500/1500.

Hewlett Packard (2006e) Hewlett Packard (2006e) Material Data Safety Sheet for HP Color LaserJetQ5949A-XPrint Cartridge for LaserJet1160/1320/3390.

Hinton (1997) Hinton P. (1997) Fabrication of Rigid Printed Wiring Boards. In: *Printed Circuit Board Materials Handbook* (ed. Jawitz M. J.). McGraw Hill, New York, San Francisco, Washington, D.C., Auckland, Bogotá, Caracas, Lisbon, London, Madrid, Mexico City, Milan, Montreal, New Dehli, San Juan, Singapore, Sydney, Tokyo, Toronto

Hischier (2007) Hischier R. (2007) Life Cycle Inventories of Packaging and Graphical Paper. Final report ecoinvent data v2.0 No. 11. Swiss Centre for Life Cycle Inventories, Empa - TSL, Dübendorf, CH, Online-Version under: www.ecoinvent.ch.

hmp (2006) hmp (2006) Umweltbericht 2005. Heidenhain-Microprint GmbH (hmp), Berlin (Germany), Online-Version under: www.hmp-heidenhain.de.

Indium Coorperation (2004) Indium Coorperation (2004) Indium Hi Grade Wave Solder Flux #1085 - Material Data Safety Sheet. The Indium Cooperation of America, Utica (NY, USA)

InfoTrends (2005) InfoTrends (2005) CAP Ventures Report Indicates World Toner Market Growing Steadily. Download of 01. Sept 2006 from http://www.capv.com/home/Press/2005/5.11.05.html.

Isaev et al. (1997) Isaev Y. V., Lenenko N. D., Gumileva L. V., Buyanovskaya A. G., Novikov Y. N. and Stumpp E. (1997) A NOVEL TYPE OF REACTION IN THE CHEMISTRY OF GRAPHITE INTERCALATION COMPOUNDS. THE PREPARATION OF ALKALI METAL GRAPHITE INTERCALATION COMPOUNDS BY ION EXCHANGE REACTIONS. *In: Carbon*, **35**(4), pp. 563-566.

Jawitz (1997) Jawitz M. W. (1997) Printed Circuit Board Materials Handbook. McGraw Hill, New York, San Francisco, Washington, D.C., Auckland, Bogotá, Caracas, Lisbon, London, Madrid, Mexico City, Milan, Montreal, New Dehli, San Juan, Singapore, Sydney, Tokyo, Toronto

Jayashree & Kamath (2001) Jayashree R. S. and Kamath P. V. (2001) Nickel hydroxide electrodeposition from nickel nitrate solutions: mechanistic studies. *In: Journal of Power Sources*, **93**, pp. 273-278.

Joubert et al. (2002) Joubert J.-M., Cerný R., Latroche M., Leroy E., Guénée L., Percheron-Guégan A. and Yvon K. (2002) A Structural Study of the Homogeneity Domain of $LaNi_5$. *In: Journal of Solid State Chemistry*, **166**, pp. 1-6.

Keating (1999) Keating J. (1999) Transition of MCM-C applications to MCM-L using rigid flex substrates. *In: Microelectronics Reliability*, **39**, pp. 1399-1406.

Kellenberger et al. (2007) Kellenberger D., Althaus H.-J., Jungbluth N. and Künniger T. (2007) Life Cycle Inventories of Building Products. Final report ecoinvent data v2.0 No. 7. Swiss Centre for Life Cycle Inventories, Empa - TSL, Dübendorf, CH, Online-Version under: www.ecoinvent.ch.

Kemna et al. (2005) Kemna R., van Elburg M., Li W. and van Holsteijn R. (2005) Methodology Study Eco-design of Energy-using Products. MEEUP - Product Cases Report. VHK - Van Holsteijn en Kemna BV, Delft (the Netherlands)

Klingenstein et al. (2004) Klingenstein W., Peichel R., Huber J., Paul C., Lenz M. and Geffcken W. (ed.) (2004) Halbleiter - Technische Erläuterungen, Technologien und Kenndaten. 3. Auflage Edition. Infineon Technologies A.G., München

KOKAM™ (2006) KOKAM™ (2006) Battery Division: Technical Information. Download of 2006-01-25 from http://www.kokam.com/english/biz/techinfo.html.

Leunig (2007) Leunig (2007) High-End Parallel Printer Cables Download of 16.2.2007 from http://www.leunig.de/_en/_pro/computer-cables/printer-cable_high_techdat.htm.

Li et al. (2004) Li Q., Lin Q., Jiang L. and Chou K.-C. (2004) On the characterization of $La_{1.5}Mg_{17}Ni_{0.5}$ composite materials prepared by hydriding combustion synthesis. *In: Journal of Alloys and Compounds*, **368**, pp. 101-105.

Linden (2002) Linden D. (2002) Basic concepts. In: *Handbook of Batteries* (ed. Linden D. and Reddy T. B.), 3rd Edition Edition. McGraw-Hill Companies, Inc., New York, Chicago, San Francisco, Lisbon, London, Madrid, Mexico City, Milan, New Delhi, San Juan, Seoul, Singapore, Sydney, Toronto

Linden & Magnusen (2002) Linden D. and Magnusen D. (2002) Protable sealed Nickel-Metal hydride batteries. In: *Handbook of Batteries* (ed. Linden D. and Reddy T. B.), 3rd Edition Edition. McGraw-Hill Companies, Inc., New York, Chicago, San Francisco, Lisbon, London, Madrid, Mexico City, Milan, New Delhi, San Juan, Seoul, Singapore, Sydney, Toronto

Linden & Reddy (2002) Linden D. and Reddy T. B. (ed.) (2002) Handbook of Batteries. 3rd Edition Edition. McGraw-Hill Companies, Inc., New York, Chicago, San Francisco, Lisbon, London, Madrid, Mexico City, Milan, New Delhi, San Juan, Seoul, Singapore, Sydney, Toronto

Locascio (2000) Locascio A. (2000) Manufacturing Cost Modeling for Product Design. *In: The International Journal of Flexible Manufacturing Systems*, **12**, pp. 207-217.

MacCallum & Edgar (2006) MacCallum M. and Edgar A. (2006) Concepts of Printed Circuit Design - online postgraduate courses for the electronics industry. Download of 2006-11-06 from http://www.ami.ac.uk/courses/ami4809_pcd/unit_01/.

Matsushita Battery Industrial Co. (2002) Matsushita Battery Industrial Co. L. (2002) Lithium Ion Batteries (Individual Data Sheets) Model: CGP345010. Panasonic, Osaka, Online-Version under: http://www.electronics-lab.com/articles/Li_Ion_reconstruct/CGP345010.pdf.

MAXELL (2003) MAXELL (2003) Environmental Report. Hitachi Maxell, Ltd., Tokyo

Mayhew (2006) Mayhew P. (2006) Aftermarket Strong in Western Europe With Opportunities to the East. In: *Recharger online*.

McKeeby & Phillips (1997) McKeeby D. and Phillips L. (1997) Lamination of Flex and Rigid-Flex Printed Wiring Boards. In: *Printed Circuit Board Materials Handbook* (ed. Jawitz M. J.). McGraw Hill, New York, San Francisco, Washington, D.C., Auckland, Bogotá, Caracas, Lisbon, London, Madrid, Mexico City, Milan, Montreal, New Dehli, San Juan, Singapore, Sydney, Tokyo, Toronto

MIGA (2004) MIGA (2004) Environmental Guidelines for Electronics Manufacturing. Multilateral Investment Guarantees Agency, Washington, D.C., Online-Version under: http://www.miga.org/index.cfm?aid=50.

Miyazaki et al. (1991) Miyazaki T., Ogino T., Masuda Y., Wada H. and Kawagoe T. (1991) Nonaqueous electrolyte secondary cell, Vol. 4,013,620 (ed. U.S. Patent & Trademark Office). Bridgestone Corporation, U.S.

Mizutani et al. (1997) Mizutani Y., Abe T., Ikeda K., Ihara E., Asano M., Harada T., Inaba M. and Ogumi Z. (1997) GRAPHITE INTERCALATION COMPOUNDS PREPARED IN SOLUTIONS OF ALKALI METALS IN 2-METHYLTETRAHYDROFURAN AND 2,5_DIMETHYLTETRAHYDROFURAN. *In: Carbon*, **35**(1), pp. 61-65.

Mohite (2005) Mohite (2005) Disassembly Analysis, Material Composition Analysis and Environmental Impact Assessment of Computer Disk Drives. *In:* (PhD at Texas Tech University), pp. 135 p.

Nichigoh (2006) Nichigoh (2006) Environmental Product Declaration for Wire and Cable World Wide Standard Cable ECO-FLEX Series from http://www.jia-page.or.jp/jia/epd/directory/nichigoh/nichigoh_e.pdf.

Nikkei Business (2003) Nikkei Business (2003) Chinese HDD Makers Shake-Up Industry. In: *Nikkei Electronics Asia December 2003 Issue*.

Noda et al. (2005) Noda D., Oonuki M. and Shima K. (2005) Nonaqueous electrolyte solution and nonaqueous electrolyte solution secondary battery employing the same (ed. US patent & Trademark office). Mitsubishi Chemical Corporation, US.

Ohta (2006) Ohta N. (2006) Color desktop printer technology. CRC Taylor & Francis, Boca Raton

partsdata (2007) partsdata (2007) Cable Competence Online - Druckerkabel. Download of 15.2.2007 from http://www.partsdata.de/PC-Kab._Drucker_5m_HQ_CD-05.html.

Perfect Print Sweden AB (2002) Perfect Print Sweden AB (2002) Envionmental Product Declaration of *SmartToner* EP-E. Pre-certified environmental product declaration Reg.nr: S-EP-00009 as pdf-File under: http://www.environdec.com/

Perfect Print Sweden AB (2004) Perfect Print Sweden AB (2004) Envionmental Product Declaration of Perfect Print Toner Cartridges. Pre-certified environmental product declaration Reg.nr: S-EP-00065 as pdf-File under: http://www.environdec.com/

Reddy & Hossain (2002) Reddy T. B. and Hossain S. (2002) Rechargeable lithium batteries (ambient temperature). In: *Handbook of Batteries* (ed. Linden D. and Reddy T. B.), 3rd Edition Edition. McGraw-Hill Companies, Inc., New York, Chicago, San Francisco, Lisbon, London, Madrid, Mexico City, Milan, New Delhi, San Juan, Seoul, Singapore, Sydney, Toronto

Sakai et al. (1992) Sakai T., Yoshinaga H., Miyamura H., Kuriyama N. and Ishikawa H. (1992) Rechargeable hydrogen batteries using rare-earth-based hydrogen storage alloys. *In: Journal of Alloys and Compounds*, **180**, pp. 37-54.

Samsung (2007) Samsung (2007) Optical Disk Drive - DVD Writer. Download of 5.4.2007.

Schullitz (2001) Schullitz M. (2001) Key success factors for M-commerce. Arthur D. Little Int. GmbH, Vienna.

SEAG (2006) SEAG (2006) Umweltbericht 2006 - Zusammenfassung. Schweizer Electronic AG (SEAG), Schramberg (Germany), Online-Version under: www.schweizerelectronic.ag.

Seagate (2007) Seagate (2007) Momentus 7200.1. *In*, pp., Online-Version under: http://www.seagate.com/docs/pdf/de-DE/datasheet/disc/ds_momentus7200.pdf.

Shenzen BAK Battery Co. (2006) Shenzen BAK Battery Co. (2006) Introduction to Shenzen BAK Battery Co. Download of 2006-07-01 from http://www.bak.com.cn/qiye-jianjie.asp.

Spielmann et al. (2007) Spielmann M., Dones R. and Bauer C. (2007) Life Cycle Inventories of Transport Services. Final report ecoinvent data v2.0 No. 14. Swiss Centre for Life Cycle Inventories, PSI, Dübendorf, CH, Online-Version under: www.ecoinvent.ch.

Stachura (2006) Stachura (2006) Umweltgerechte Produktentwicklung - Fallbeispiel: Computermaus. In: *Nachhaltigkeit in der Elektro(nik)industrie*, Vol. Reihe 16 Technik und Wirtschaft (ed. Herrmann C., Leitner T. and Paulesich R.). VDI Verlag, Braunschweig

Striebel et al. (2001) Striebel K. A., Sakai E. and Cairns E. J. (2001) Impedance studies of the thin film LiMn2O4/electrolyte interface. Lawrence Berkeley National Laboratory, Berkeley

Subbaiah et al. (2002) Subbaiah T., Mallick S. C., Mishra K. G., Sanjay K. and Das R. P. (2002) Electrochemical precipitation of nickel hydroxide. *In: Journal of Power Sources*, **112**, pp. 562-569.

Theriault & Rahn (2002) Theriault M. and Rahn A. (2002) New Avenues for Wave Soldering and Lead-Free Conversion. *In: Circuits Assembly*, pp. 34-36.

Tossici et al. (1996) Tossici R., Berrettoni M., Nalimova V., Marassi R. and Scrosati B. (1996) A high-rate carbon electrode for rechargeable lithium-ion batteries. *In: Journal of Electrchemical Society*, **143**(3), pp. L64-L67.

Tossici et al. (1997) Tossici R., Berrettoni M., Rosolen M., Marassi R. and Scrosati B. (1997) Electrochemistry of KC_8 in lithium-containing electrolytes and its use in lithium-ion cells. *In: Journal of Electrchemical Society*, **144**(1), pp. 186-192.

US EPA (1995) US EPA (1995) Profile of the Electronics and Computer Industry. EPA/310-R-95-002. U.S. Environmental Protection Agency, Washington D.C. (USA), Online-Version under: http://www.epa.gov/compliance/resources/publications/assistance/sectors/notebooks/electronics.html.

US EPA (2000) US EPA (2000) Implementing Cleaner Printed Wiring Board Technologies: Surface Finishing. EPA 744-R-00-002. United States Environmental Protection Agency (US EPA), Washington D.C. (USA)

USEPA (1995) USEPA (1995) Profile of the Electronics and Computer Industry. U.S. Environmental Protection Agency, Washington, Online-Version under: http://www.epa.gov/compliance/resources/publications/assistance/sectors/notebooks/electronics.html.

Virginia Plastics (2004a) Virginia Plastics (2004a) Conductor Insulation and Jacket Materials Key Properties. Download of 8.2.2007 from http://www.vaplastics.com/elec/reference/Insulation_JacketMaterials.html.

Virginia Plastics (2004b) Virginia Plastics (2004b) Engineered Cable - Available Configurations, Online-Version under: http://www.vaplastics.com/elec/cable/ec_config.html.

Virginia Plastics (2007) Virginia Plastics (2007) Definitions and Explanations on Cables from http://www.vaplastics.com/elec/reference/definitions.html.

von Geibler et al. (2003) von Geibler J., Ritthoff M. and Kuhndt M. (2003) The environmental impacts of mobile computing. A case study with HP. Wuppertal Institute, Wuppertal

W.L. Gore & Associates Inc. (2003) W.L. Gore & Associates Inc. (2003) Gore™ Excellerator®. W.L. Gore & Associates, Inc., Elkton.

W.L. Gore & Associates Inc. (2006) W.L. Gore & Associates Inc. (2006) Electrodes and Electrode Assemblies. Download of 2006-10-16 from http://www.gore.com/en_xx/products/electronic/battery/electrodes_and_electrode_assemblies.html.

Wadden et al. (1995) Wadden R. A., Scheff P. A., Frank J. E. and Conroy L. M. (1995) Emission Factor Development for Intermittent Workplace Sources. National Insitute of Occupational Safety and Health.

Wallenberger et al. (2004) Wallenberger F. T., Hicks R. J. and Bierhals A. T. (2004) Design of environmentally friendly fiberglass compositions: ternary eutectic SiO_2-Al_2O_3-CaO compositions, structures and properties. *In: Journal of Non-Crystalline Solids*, **349**, pp. 377-387.

Williams (1998a) Williams M. E. (1998a) Encycolpaedia of Occupational Health and Safety, Vol. 4th Edition (ed. Williams M. E.). International Labour Organisation.

Williams (1998b) Williams M. E. (1998b) Printed Circuit Board and Computer Assembly. In: *Encycolpaedia of Occupational Health and Safety*

Vol. 4th Edition. International Labour Organisation, Online-Version under: http://www.ilo.org/encyclopaedia/.

Winch et al. (2002) Winch C., Edevold C. and Mears G. (2002) Battery Terminal Jumper Clip (ed. US patent & Trademark office). Powerware Corporation,.

Zabel et al. (1983) Zabel H., Magerl A. and Rush J. J. (1983) Phonons in LiC_6. *In: Physical Review B*, **27**(6), pp. 3930-3933.

Zuckerbrod et al. (2002) Zuckerbrod D., Sassa R., Szabo M. and Mizenko M. (2002) Performance of Carbon-PTFE Electrodes and PTFE Separators in Electrochemical Double Layer Capacitors (EDLCs). W.L. Gore Associates, Inc., Online-Version under: http://www.gore.com/MungoBlobs/article_ptfe_electrodes_edlc_.pdf.

ZVEI (2006) ZVEI (2006) Umbrella Specs. Download of December 21 from http://www.zvei.org/index.php?id=1158.