CAS Outreach Workshop
Lausanne, October 25, 2014

From Waste to Gold:

Cradle to Cradle Material Recycling of Waste of Electrical and Electronic Equipment

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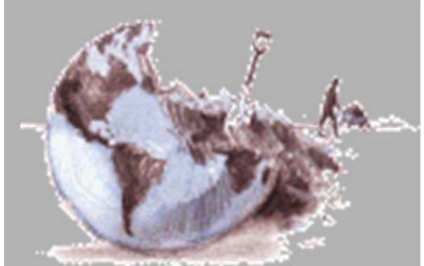

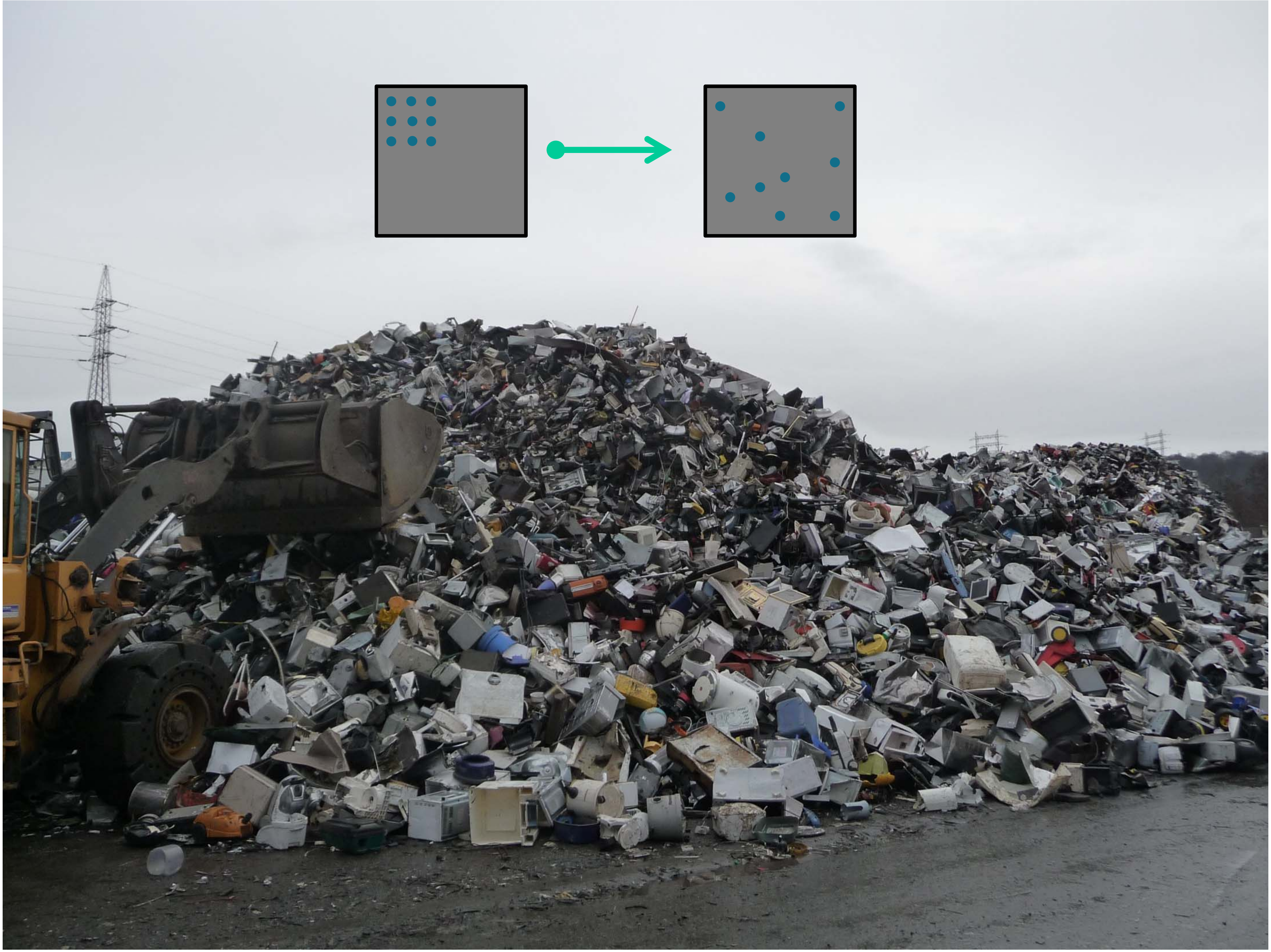

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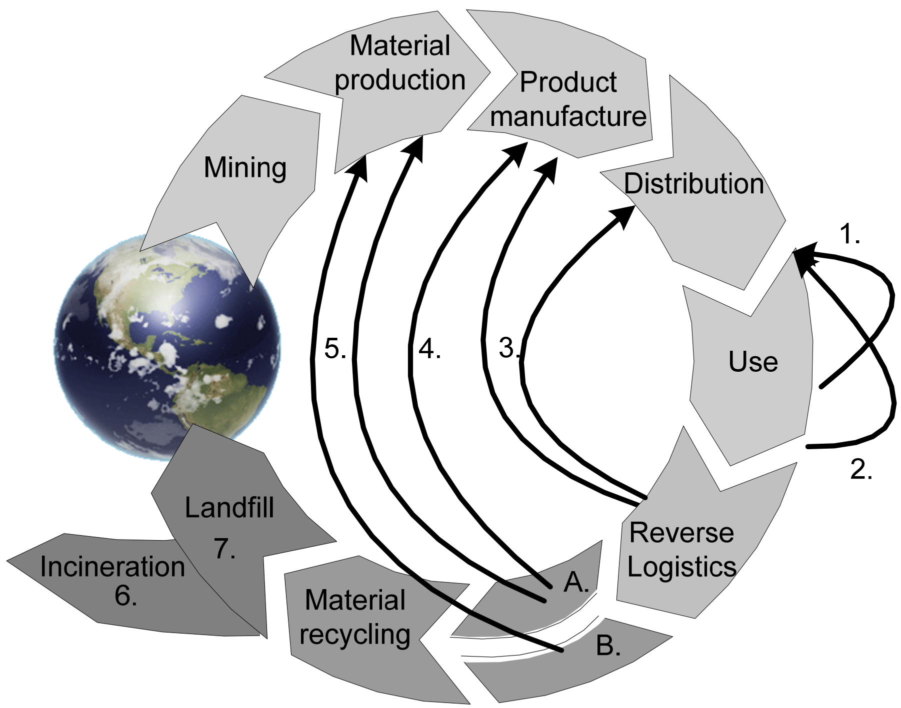
End-of-Life Treatment



EoL scenarios

1. Maintenance
2. Repair
3. Product Reuse
4. Upgrading
   Downgrading
   Remanufacturing
   Component reuse
5. Material recycling
6. Incineration
7. Landfill

EoL processes

A. Disassembly
B. Shredding

Other processes
- Sorting
- Cleaning
- Inspection

Prevention of waste

Reuse of products

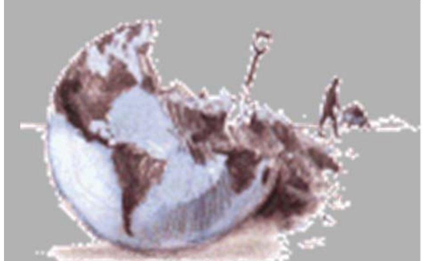
Reuse of components

Material recycling

Incineration with energy conversion

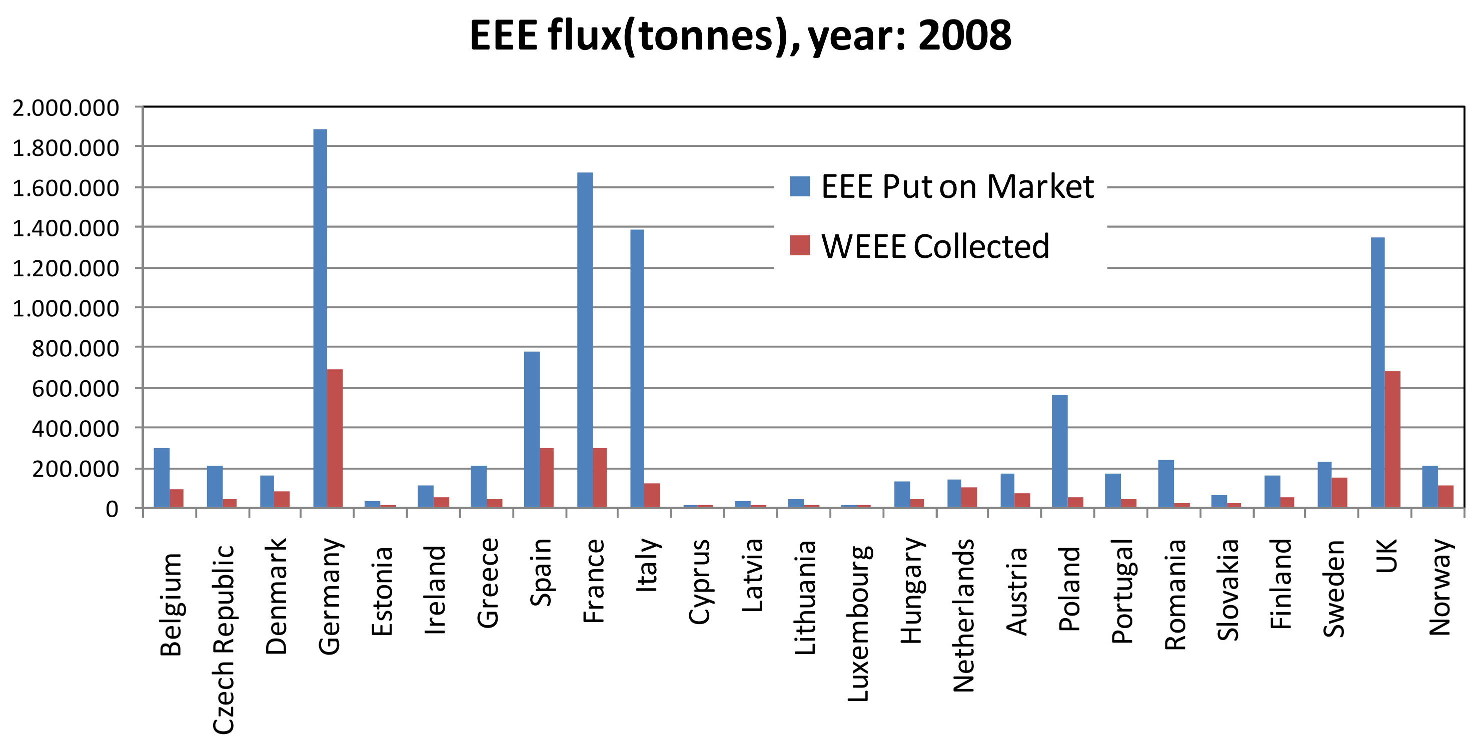
Incineration without energy conversion

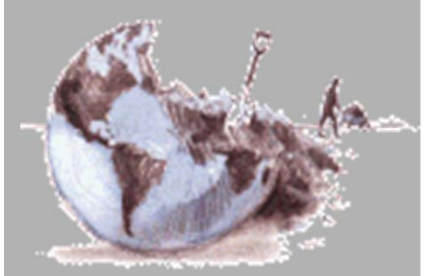
Landfill



End-of-Life Treatment

WEEE distribution and collection rate in Europe





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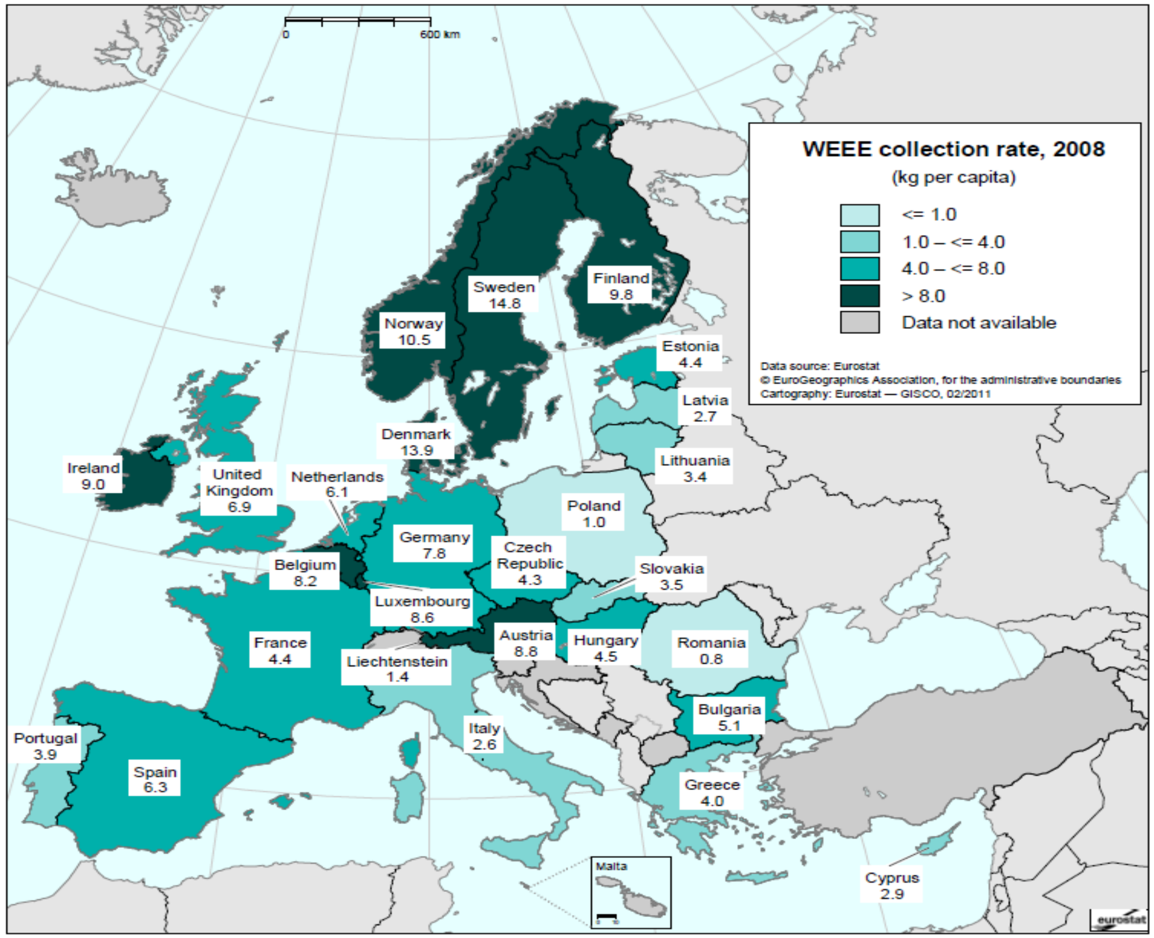
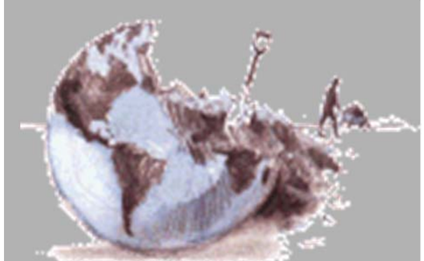
WEEE collection rate in Europe





The EU WEEE Directive currently sets a minimum collection target of 4 kg per annum per inhabitant.

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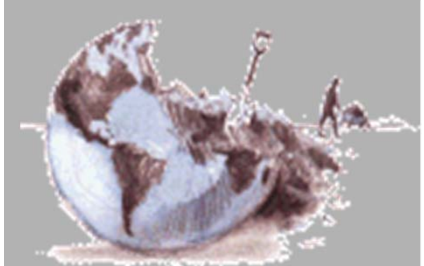
End-of-Life Treatment

Belgian organisations and companies involved in the EoL treatment

Recupel organizes the collection, sorting, treatment and recycling of Waste Electrical and Electronic Equipment (WEEE) in Belgium.

Van Gansewinkel Groep is market leader in collecting and processing waste into raw materials and energy.

Umicore is a global precious metals recycling group.



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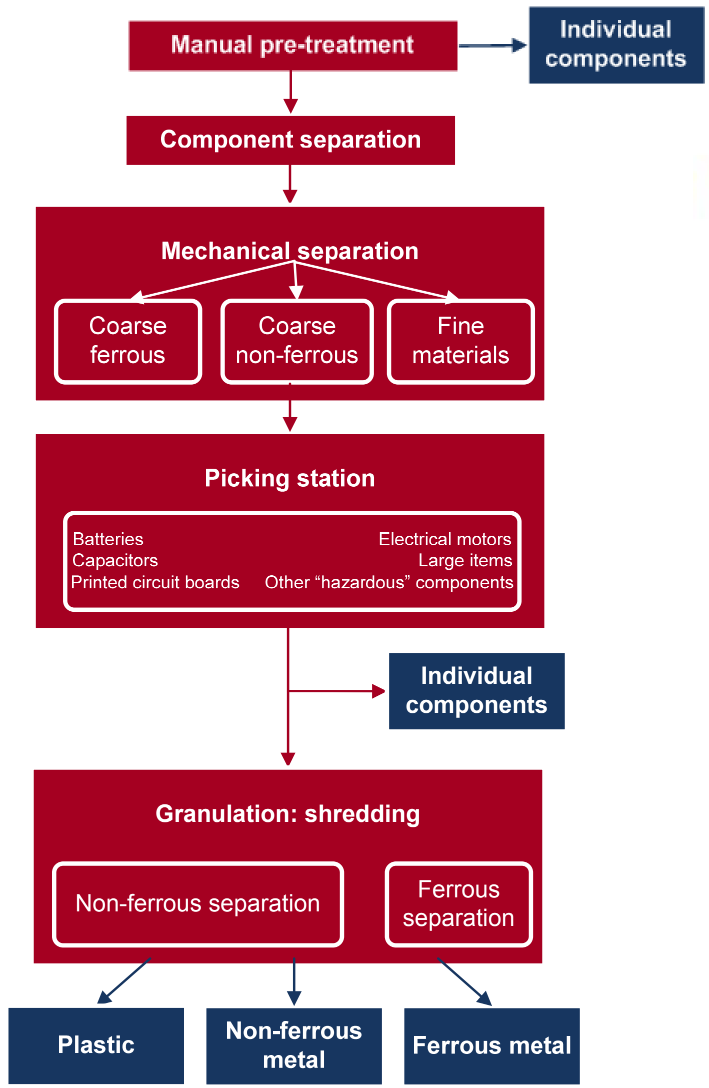
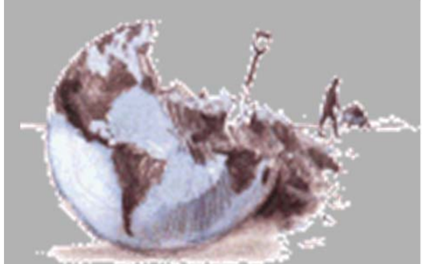
End-of-Life Treatment

Example of an EEE recycling line



Source: SIM Group UK Ltd



End-of-Life Treatment

Example of an EEE recycling line

Turning electronic waste into cash (3:16)

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End-of-Life Treatment

Example of EEE recycling: CRT processing line

Hand dismantling → Monitor body & electronics to WEEE line

Cathode ray tubes

Crushing & metal removal → Metals

Sieving / Cleaning → Waste and fine materials

Grinding → Waste and fine materials

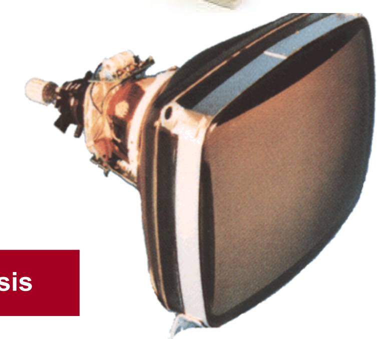
Magnet and metal detector → Metal recycling; → Waste and fine materials

Glass separation

Unleaded glass → Homogenising → Bulk, big bag & silo storage

Leaded glass → Homogenising → Bulk, big bag & silo storage

Homogenising → Sampling & analysis

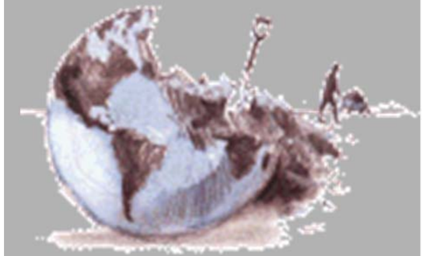


Source: SIM Group UK Ltd

End-of-Life Treatment

Example of a CRT recycling line

How to recycle a CRT Television (2:33)



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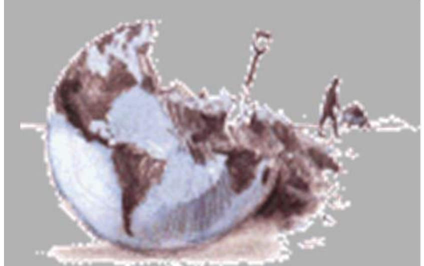
Material value of WEEE

Equipment type (origin of the printed circuit board)	*Silver (g/t)*	*Gold (g/t)*	*Palladium (g/t)*	*Platinum (g/t)*
Computer CRT Monitor	150	9	3	
Computer LCD Monitor	1300	490	99	
Printer	350	47	9	
Telephone	2244	50	241	
Mobile telephone	5540	980	285	7

In general, presently mined ores for the extraction of gold and palladium contain less than 10 g/t of precious metals (Hagelüken et al. 2005).

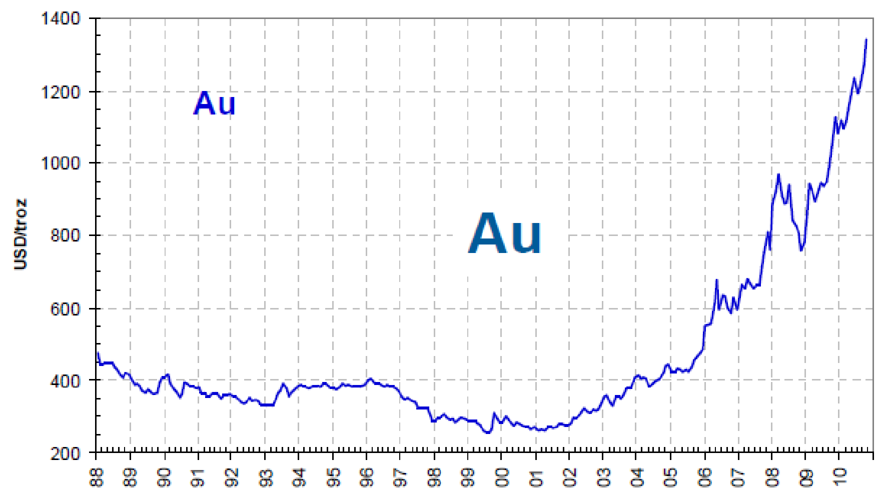
Concept of ‘**Urban Mining**’.

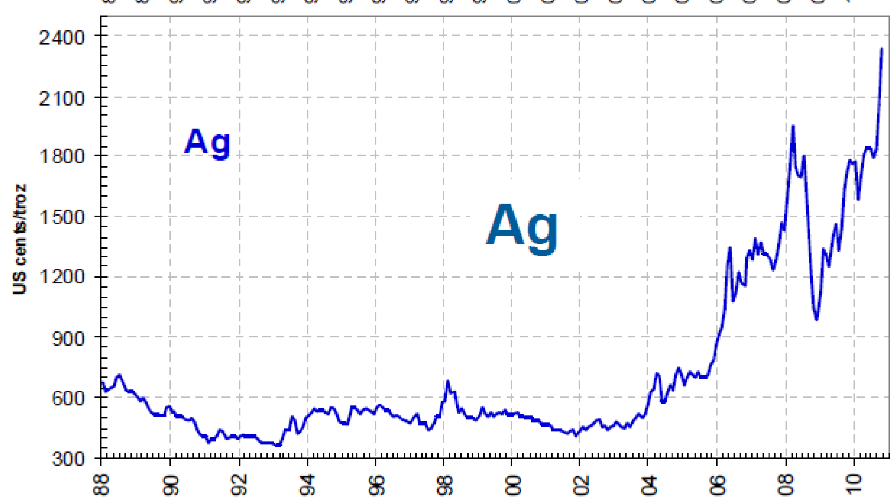


P. Chancerel, *et al.*, "Assessment of Precious Metal Flows During Preprocessing of Waste Electrical and Electronic Equipment," *Journal of Industrial Ecology*, vol. 13, pp. 791-810, 2009.

End-of-Life Treatment

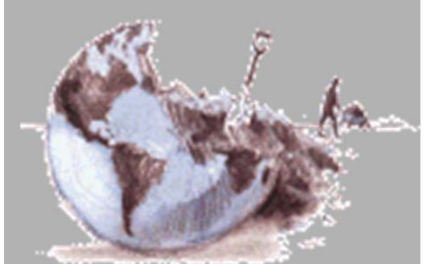
Increasing market value of precious metals





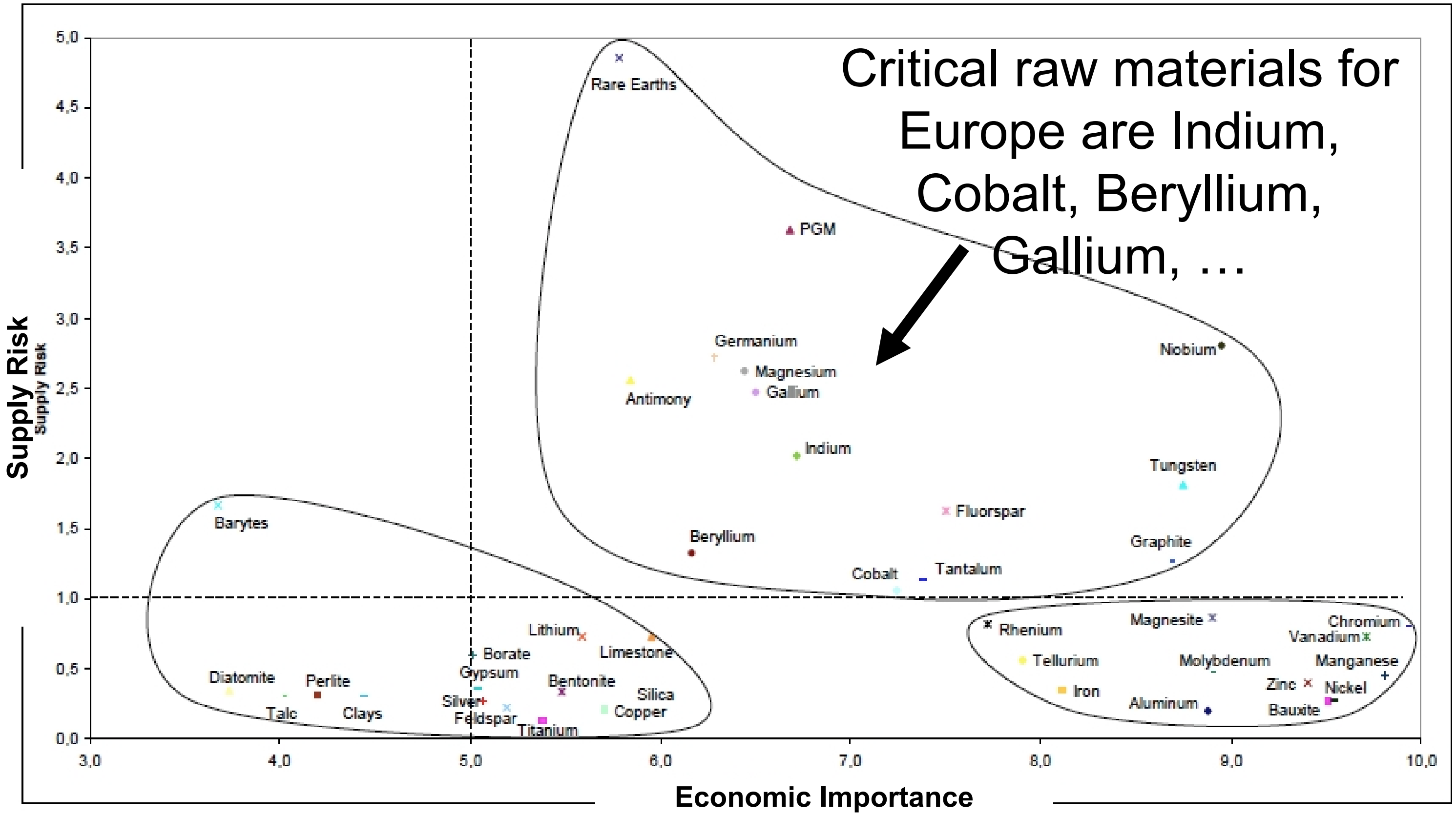
Rapidly increasing gold and silver prices from 1988 - 2010

Short and limited impact of economic crisis

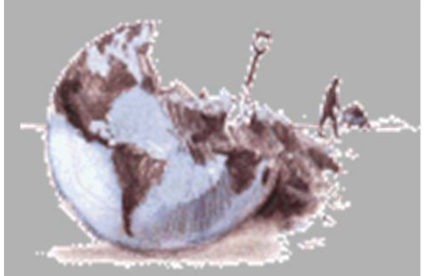


End-of-Life Treatment

Scarcity of certain precious metals in Europe



'Defining Critical Raw Materials for the EU', Report from the Raw Material Supply Group ad hoc working group defining critical raw materials, July 30, 2010

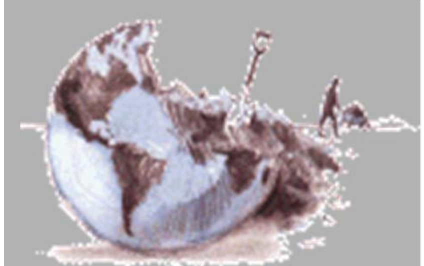


End-of-Life Treatment

Shortcomings of European EoL treatment

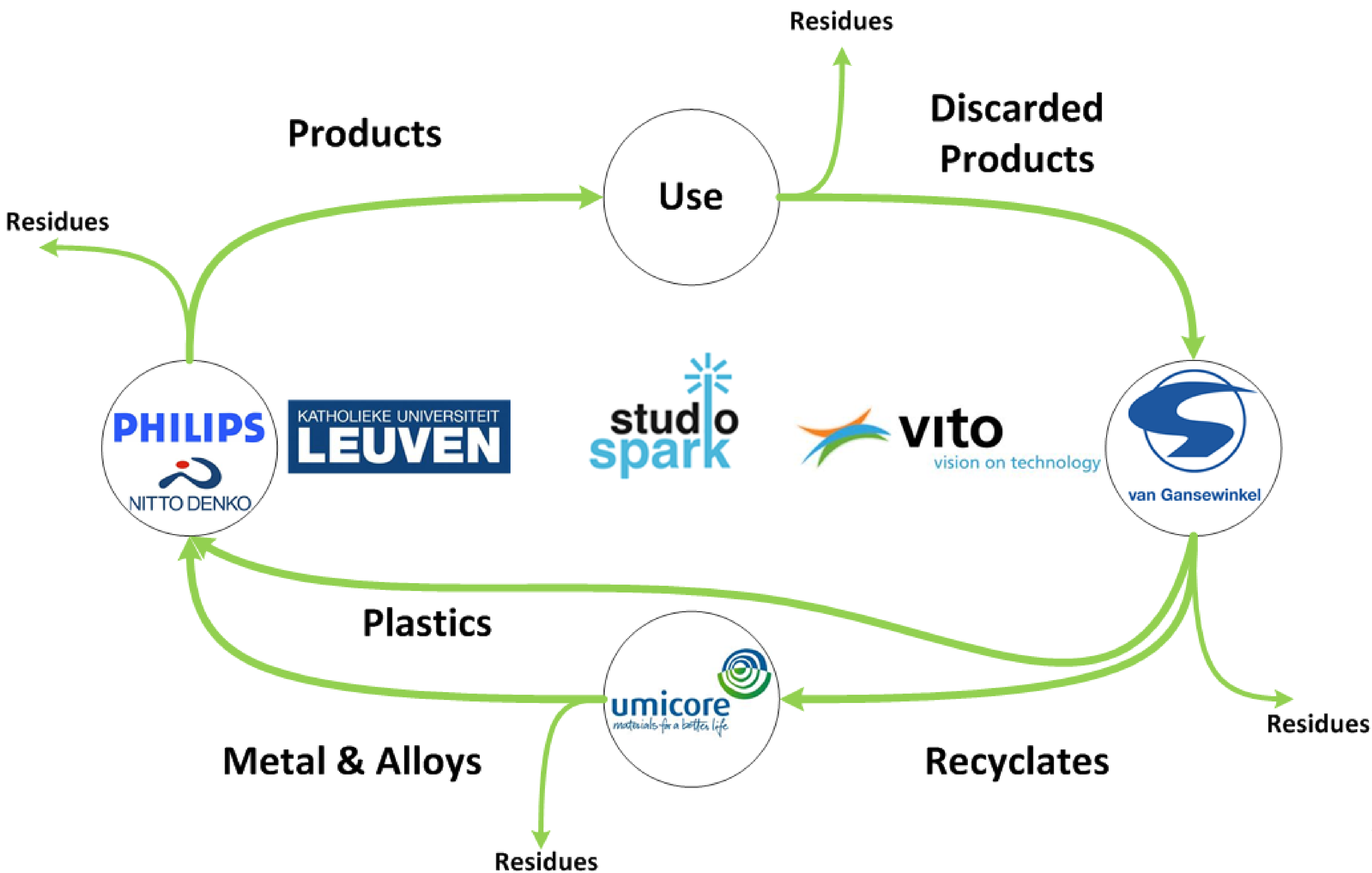
Illustrative figures with gold as example:

After C. Hagelüken, Umicore, Care Innovation, 2010




Case Study
PHILIPS

PRIME



Residues
Products
Discarded Products
Use
Residues
PHILIPS
NITTO DENKO
KATHOLIEKE UNIVERSITEIT LEUVEN
studio spark
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vision on technology
van Gansewinkel
Plastics
umicore
materials for a better life
Metal & Alloys
Recyclates
Residues
Residues

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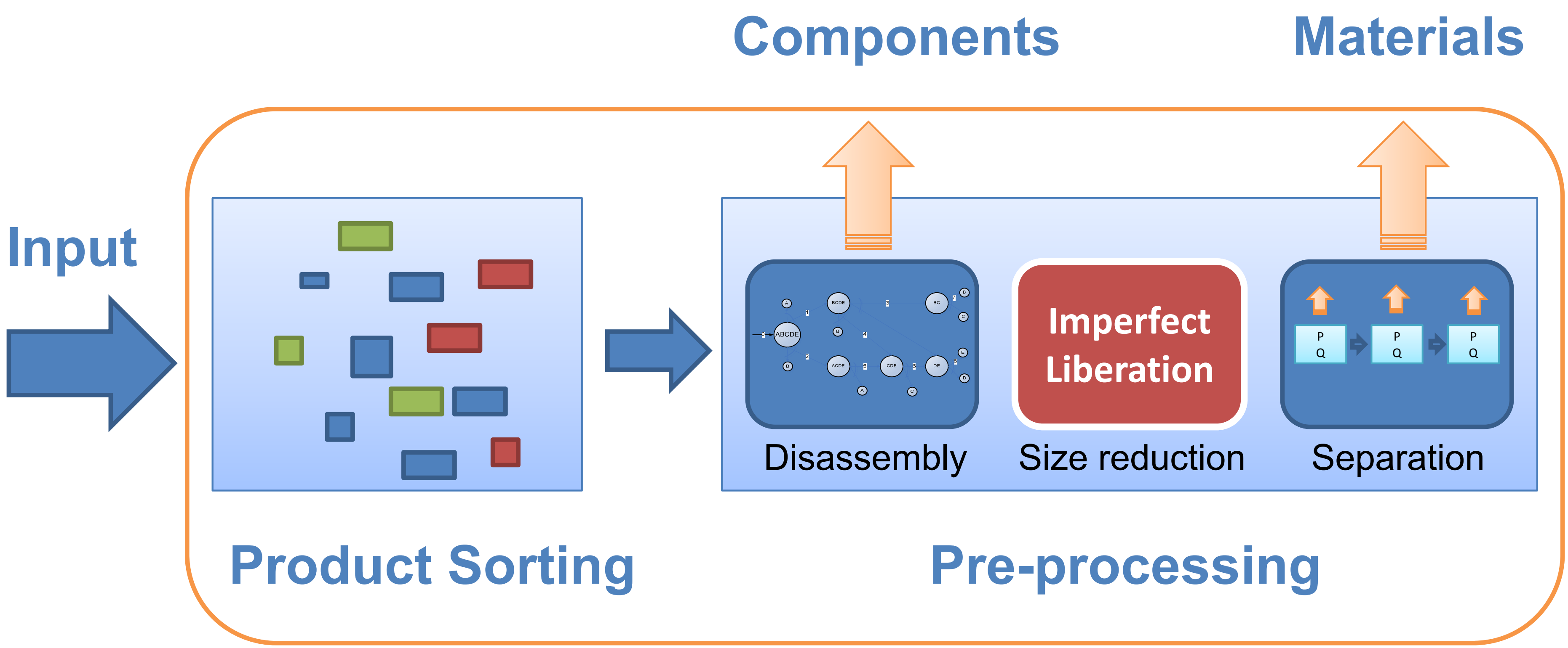
Maximize recovery of materials from discarded LCD TVs

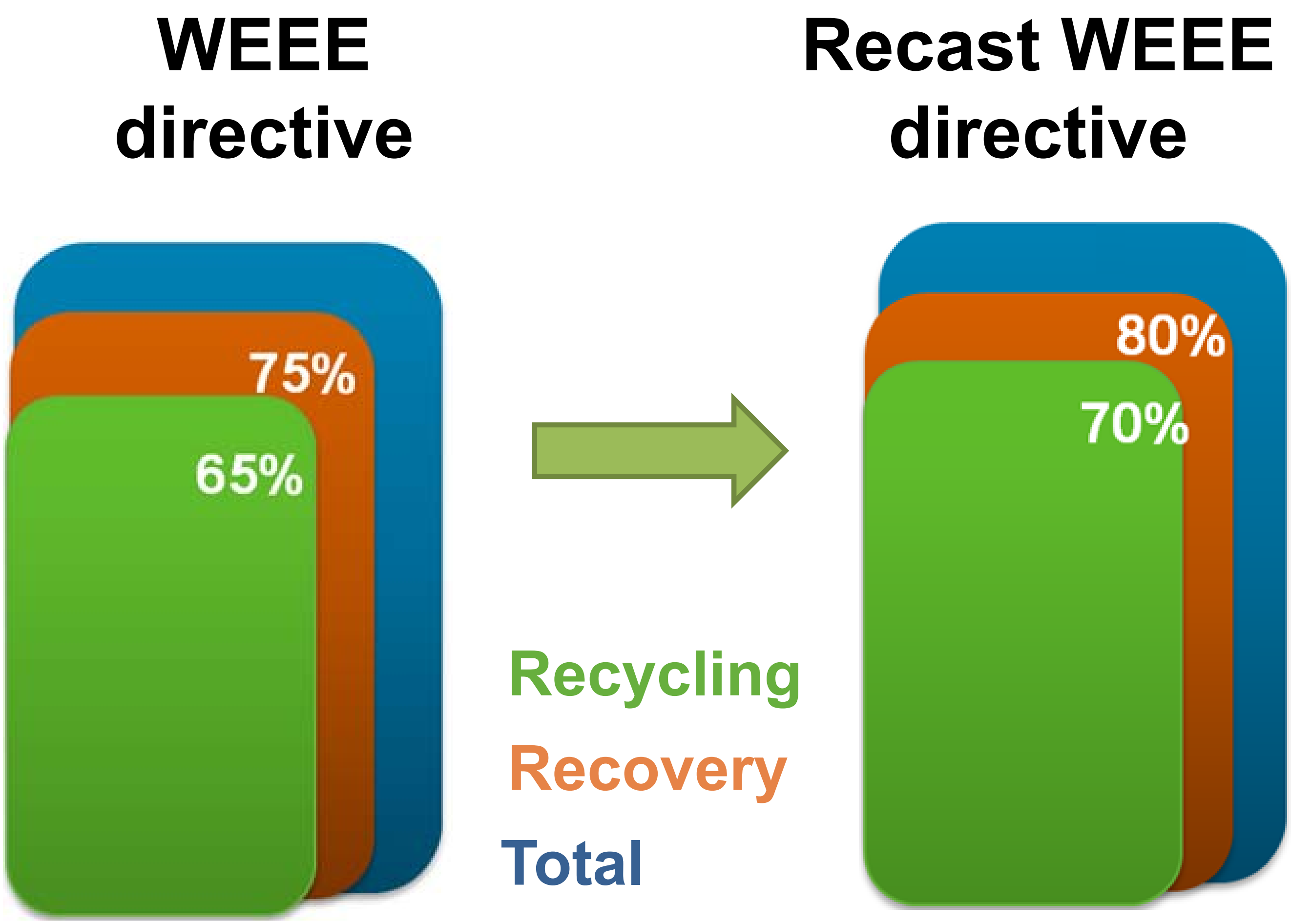
- Optimize recycling processes
- Business Model
- Design Guidelines

Recycling Process Optimization

Economic & Environmental



Legislation: Recycling Targets

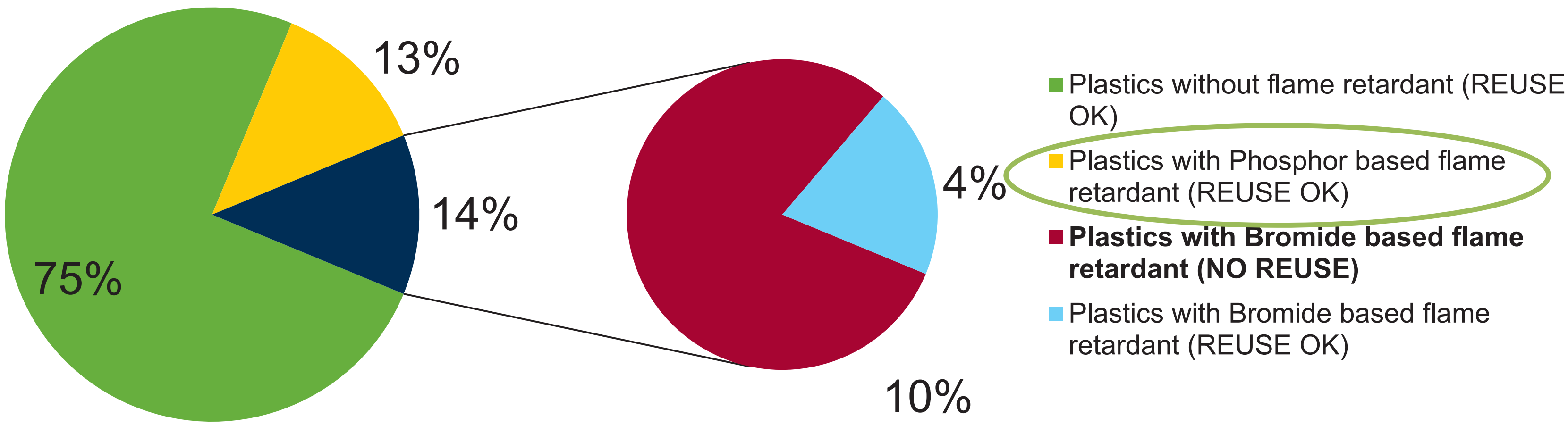


Plastic Separation: ?

Plastic Separation: ?

Flame retardants in WEEE [1]

Bromide flame retardants in housings from EoL TVs and monitors [2]



[1] (2011). *Waste Electrical and Electronic Equipment (WEEE)*. Available: http://scp.eionet.europa.eu/themes/waste
[2] M. Schlummer, "Recycling of styrene polymers from shredded screen housings containing brominated flame retardants," *Journal of applied polymer science,* vol. 102, p. 1262, 2006.

Back Covers Closed Loop Recycling

- Performed at Apparec
- Two batches:
  - 57 kg of PC/ABS FR 40 single blend
  - 150 kg of PC/ABS FR 40 mix blends
- Basic "cleaning" step
- Initial size reduction performed

Back Covers Closed Loop Recycling

INPUT	REGRINDING	OUTPUT
Batch 1 : PC/ABS FR 40 (150 kg) mix blends Batch 2 : PC/ABS FR 40 (57 kg) single blend Contaminations: tapes, foils, stickers No metal contaminations Colors: white, grey, black	Small lab regrind machine	Particles < 5 mm, possible to directly mould again

Evaluation of Closed Loop Recycling ?

100% recycled material

Peeters J.R. et al. , Closed Loop Recycling of Plastic Housing for Flat Screen TVs

Problems with Current Mass Based Metrics

- Degree of **Cycle Closure** is not accounted

- **Materials**' importance is ignored

- **System** approach

Evaluation Method

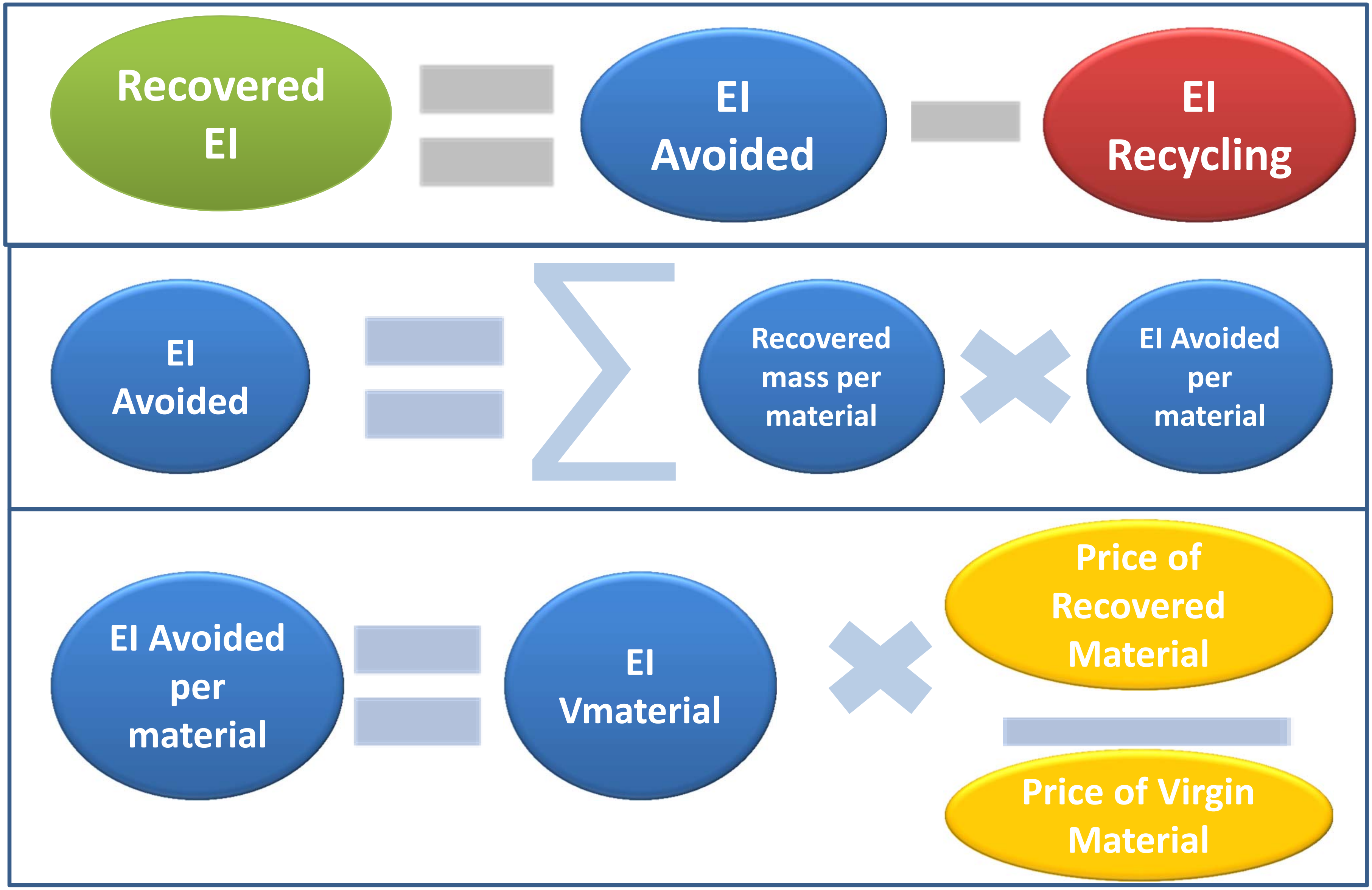
Recovered EI = EI Avoided − EI Recycling

Evaluation Method

Recovered EI = EI Avoided − EI Recycling

EI Avoided = ∑ Recovered mass per material × EI Avoided per material

Evaluation Method



Assumptions

Stable Market is already in place for secondary materials

Reduced price of downcycled materials is in relation to the ‘quality’ of materials

Reduced quality multiplied with the impact for producing the material equals the impact of producing the material it will replace

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Evaluation Method: Example

Closed loop:

Recovered EI (mPT) = (3 kg) * (632 mPT/kg * 78%) – 218 mPT

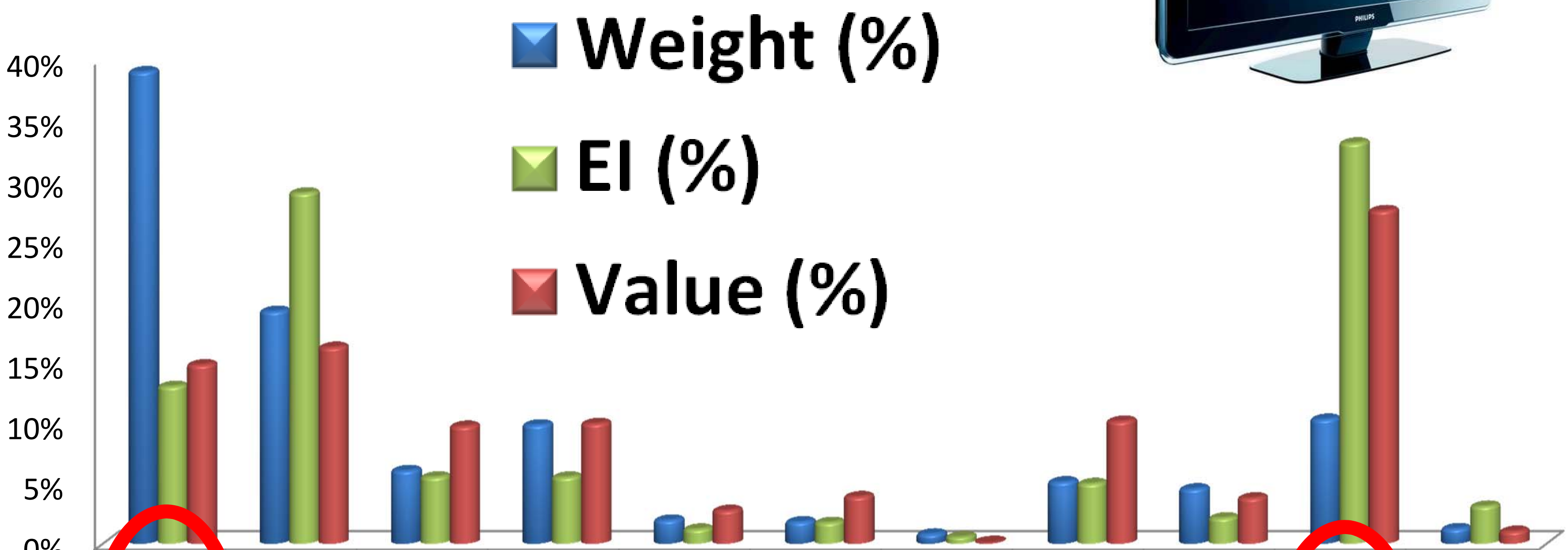
Recovered EI (mPT) = 1261

Downcycling:

Recovered EI (mPT) = (3 kg) * (632 mPT/kg * 13%) – 218 mPT

Recovered EI (mPT) = 29

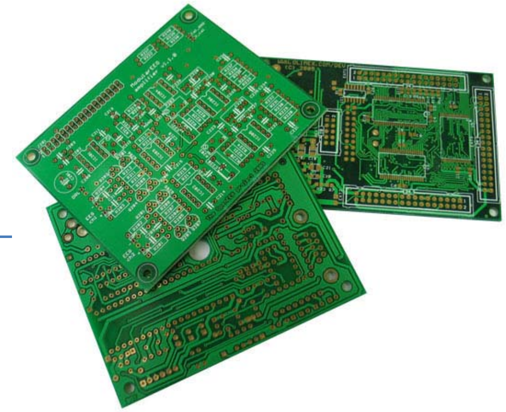
LCD TVs Analysis

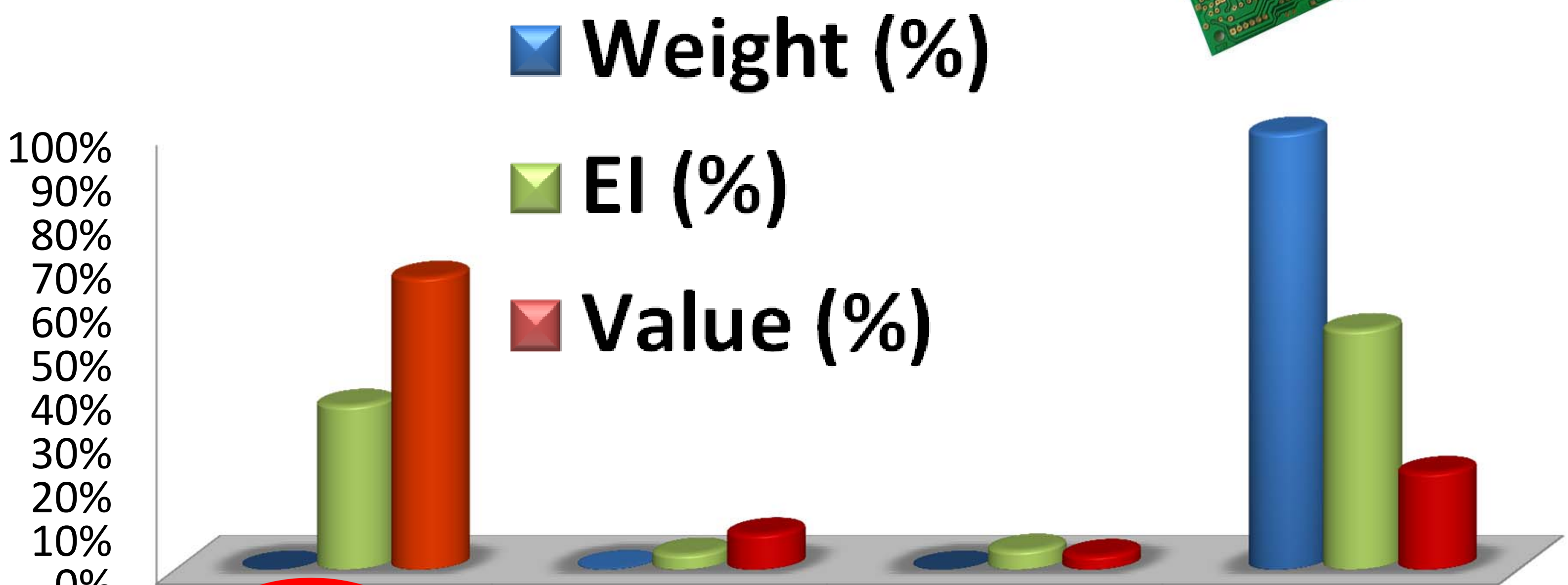


	Steel	Aluminum	PC/ABS	HIPS	ABS	PC + GF	Other Plastics	PMMA or PC	PET	PCBs	Wires
Weight (%)	39%	19%	6%	10%	2%	2%	1%	5%	5%	10%	1%
EI (%)	13%	29%	6%	6%	1%	2%	1%	5%	2%	33%	3%
Value (%)	15%	16%	10%	10%	3%	4%	0%	10%	4%	28%	1%

Based on the analysis of 105 EoL LCD TVs
EI Data Sources: Ecoinvent 2.2; Ecolizer 2.0
Virgin Material Value used
LCD panel not included

Valuable Metals in PCBs



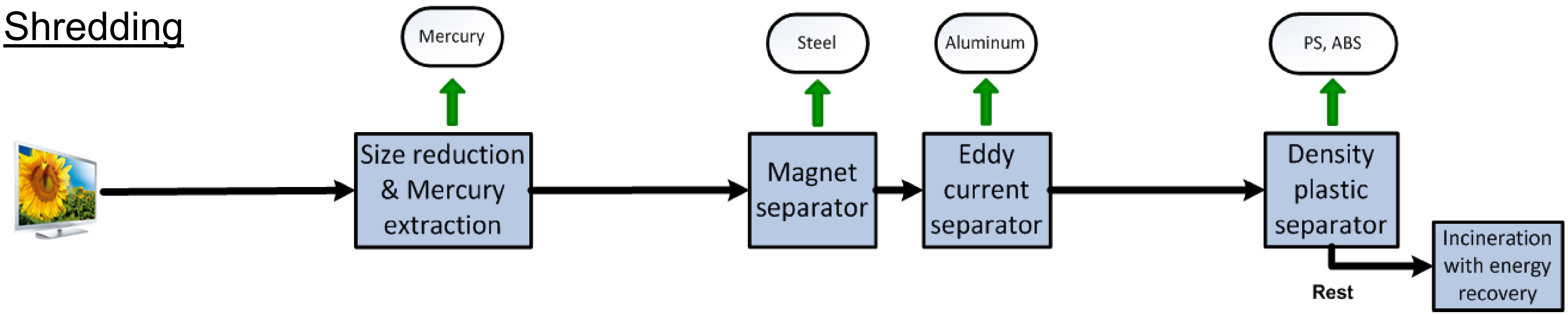


	Gold	Silver	Palladium	Copper
Weight (%)	0,05%	0,31%	0,01%	99,64%
EI (%)	37%	3%	4%	55%
Value (%)	67%	8%	3%	22%

Average of representative PCBs: SSB, TICON, Power Supply and other big PCBs
Only valuable metals included

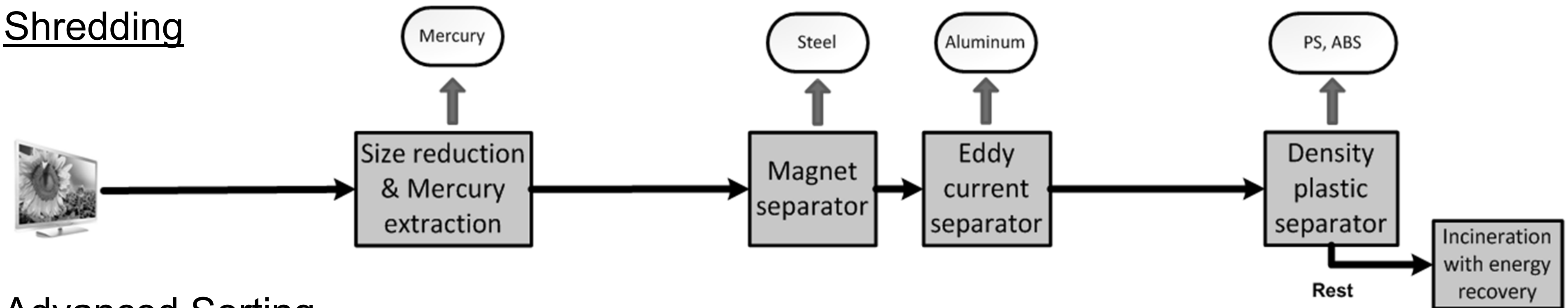
Scenarios

Shredding

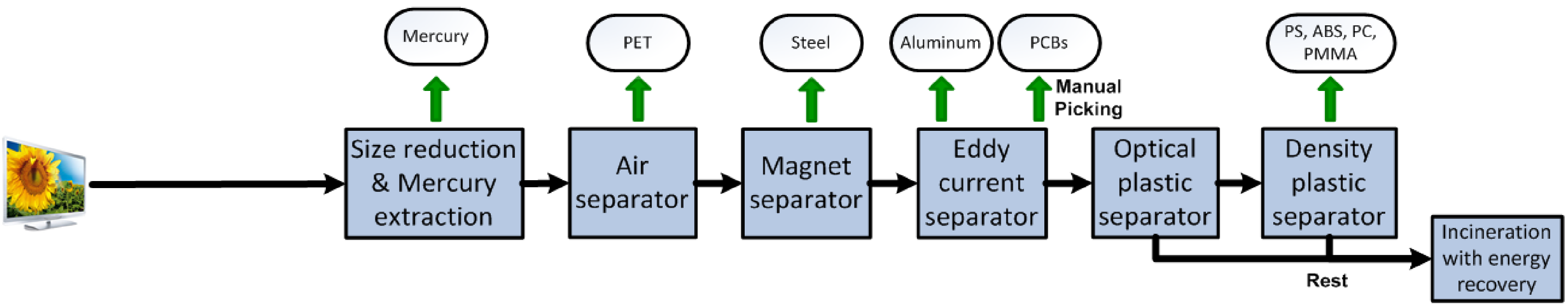


Scenarios

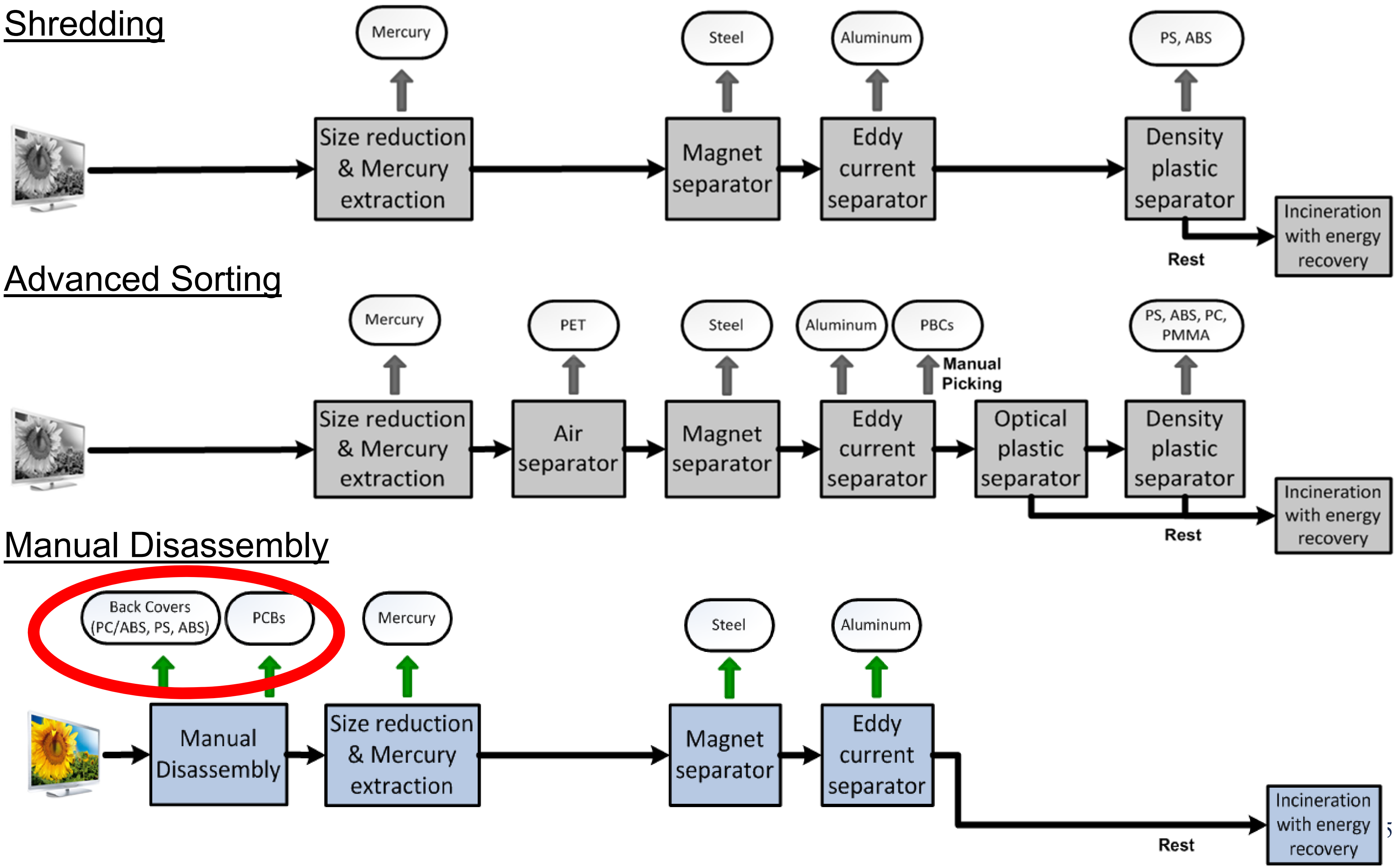
Shredding



Advanced Sorting

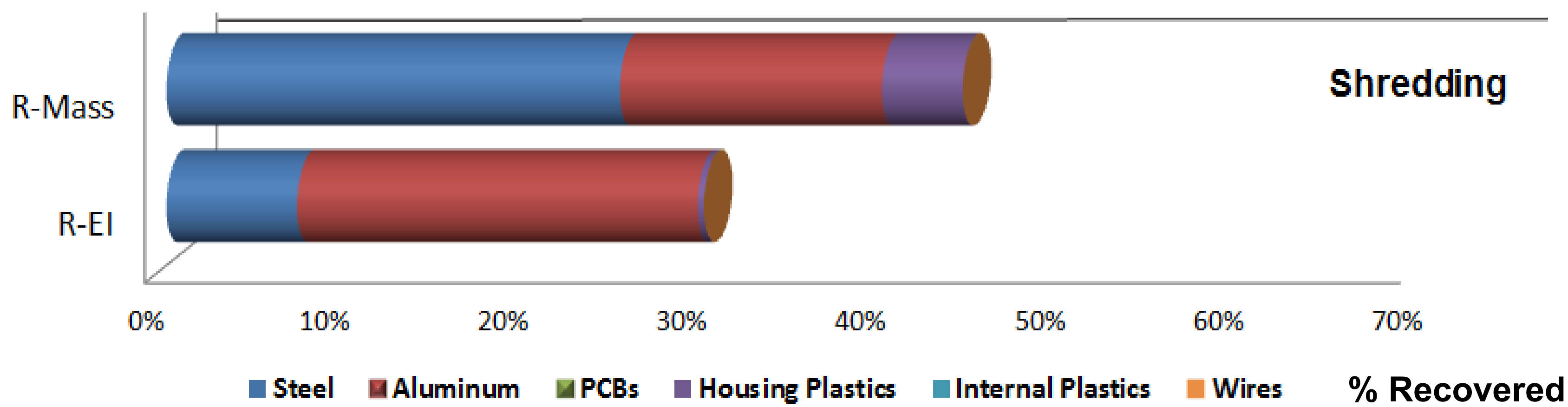


Scenarios



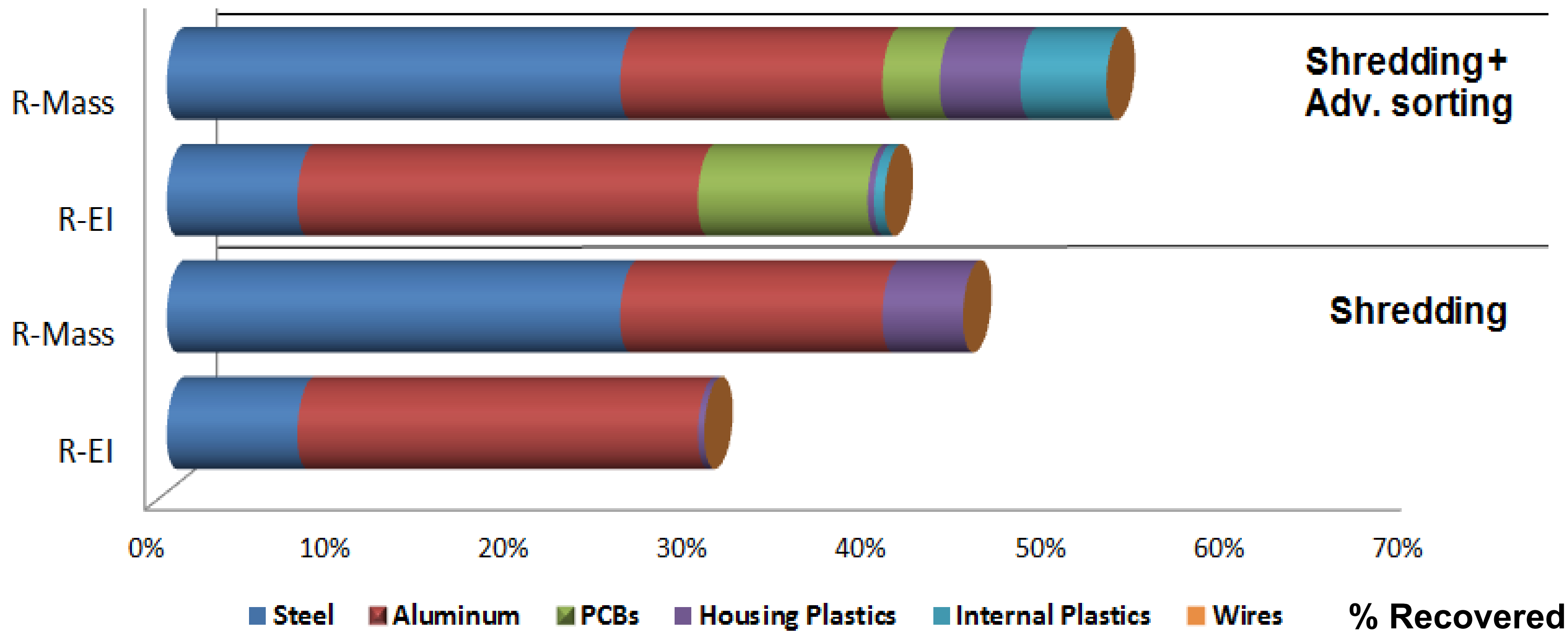
Shredding
Mercury
Steel
Aluminum
PS, ABS
Size reduction & Mercury extraction
Magnet separator
Eddy current separator
Density plastic separator
Incineration with energy recovery
Rest
Advanced Sorting
Mercury
PET
Steel
Aluminum
PBCs
PS, ABS, PC, PMMA
Manual Picking
Size reduction & Mercury extraction
Air separator
Magnet separator
Eddy current separator
Optical plastic separator
Density plastic separator
Incineration with energy recovery
Rest
Manual Disassembly
Back Covers (PC/ABS, PS, ABS)
PCBs
Mercury
Steel
Aluminum
Manual Disassembly
Size reduction & Mercury extraction
Magnet separator
Eddy current separator
Incineration with energy recovery
Rest

Scenario Analysis: Mass vs. EI



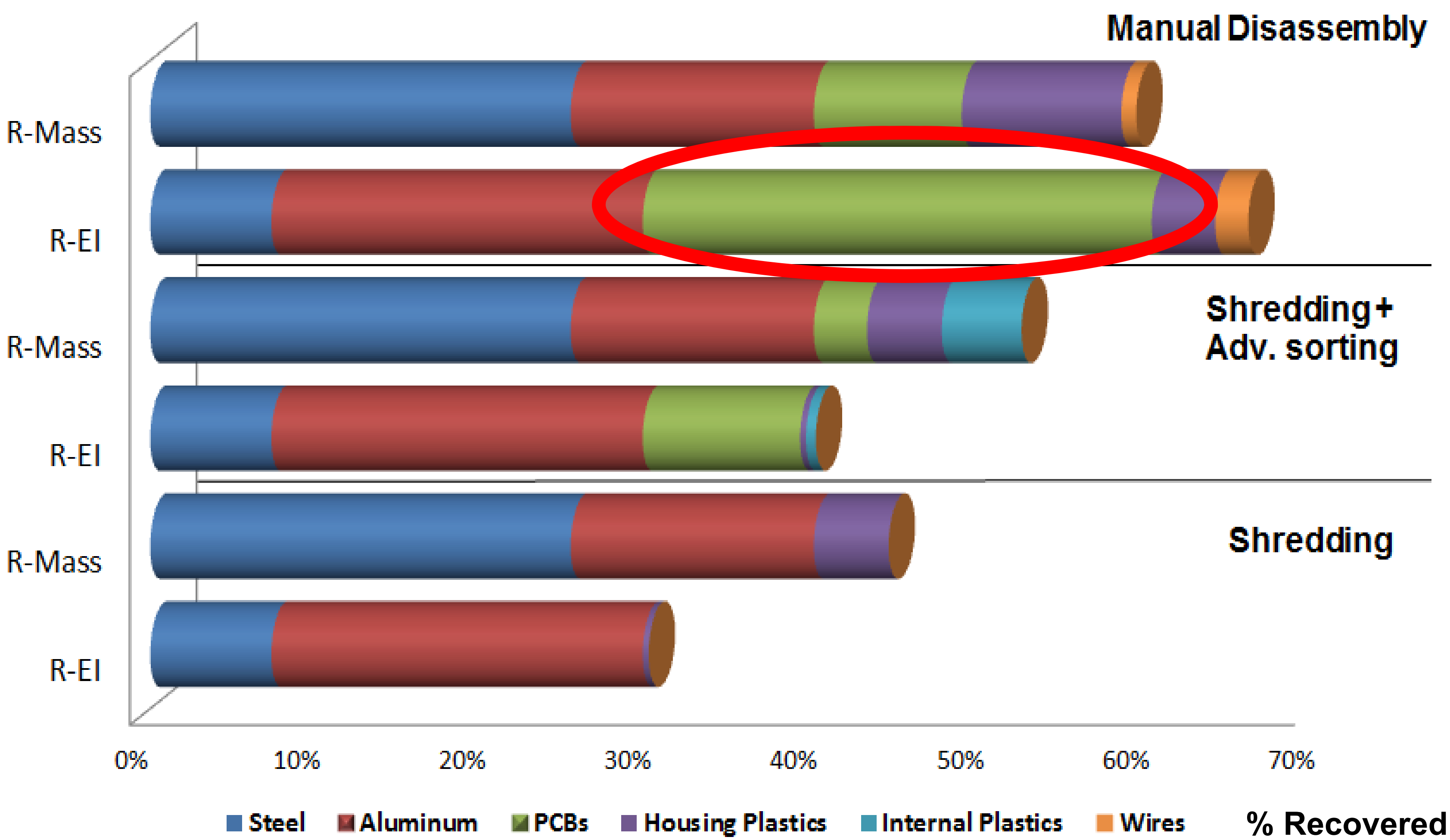
R-Mass: Recovered Mass
R-EI: Recovered Environmental Impact

Scenario Analysis: Mass vs. EI



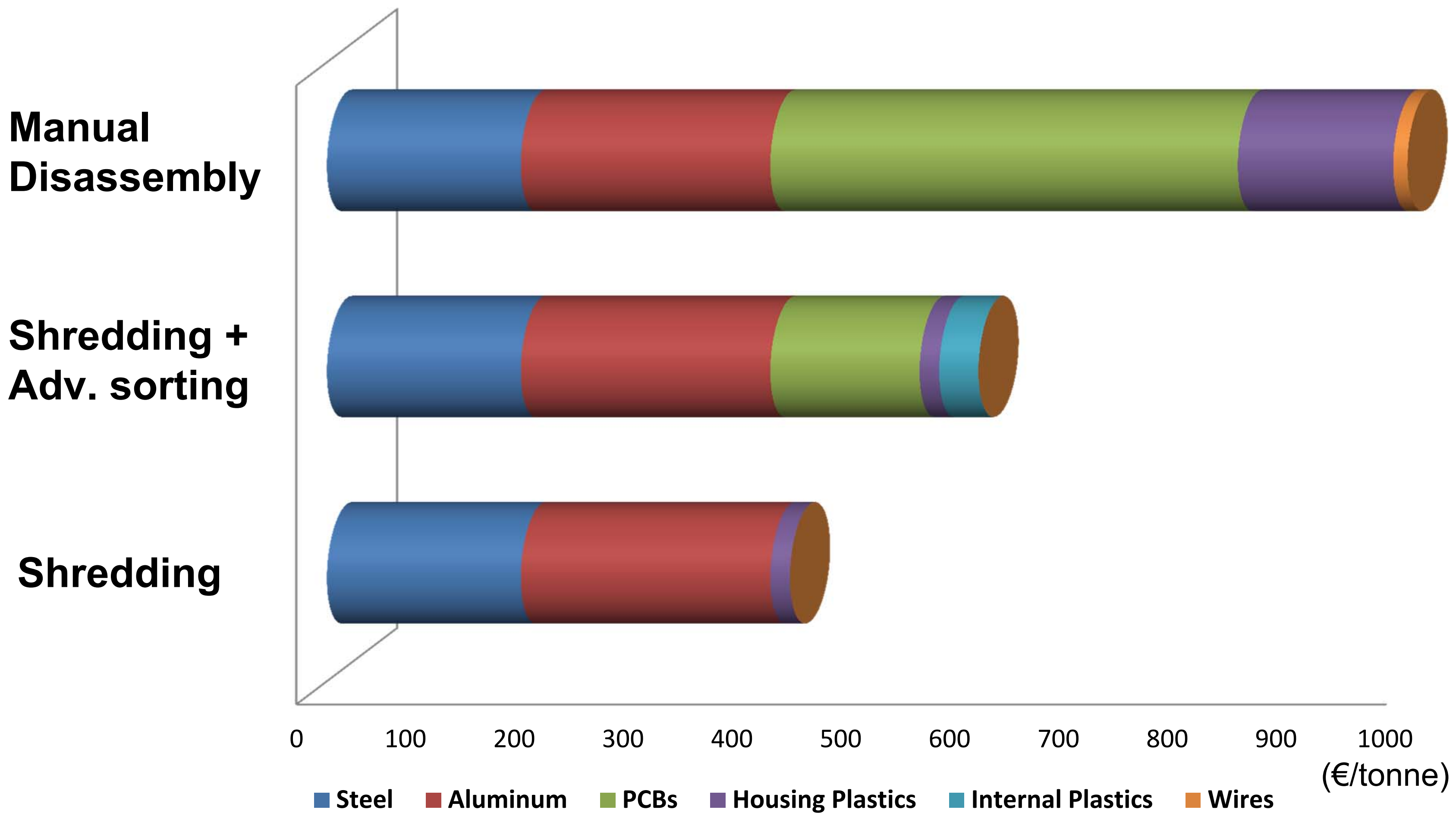
R-Mass: Recovered Mass
R-EI: Recovered Environmental Impact

Scenario Analysis: Mass vs. EI



R-Mass: Recovered Mass
R-EI: Recovered Environmental Impact

Scenario Analysis: Value recovery



Recycling costs not included

Findings

Mass based metrics are not a good indicator for environmental or economic performance.

Current shredding based processes impede high recovery of precious metals and plastics resulting in high loss of EI and value.

The proposed method is a practical approach for assessing the recovered EI of recycled materials for operational optimization.

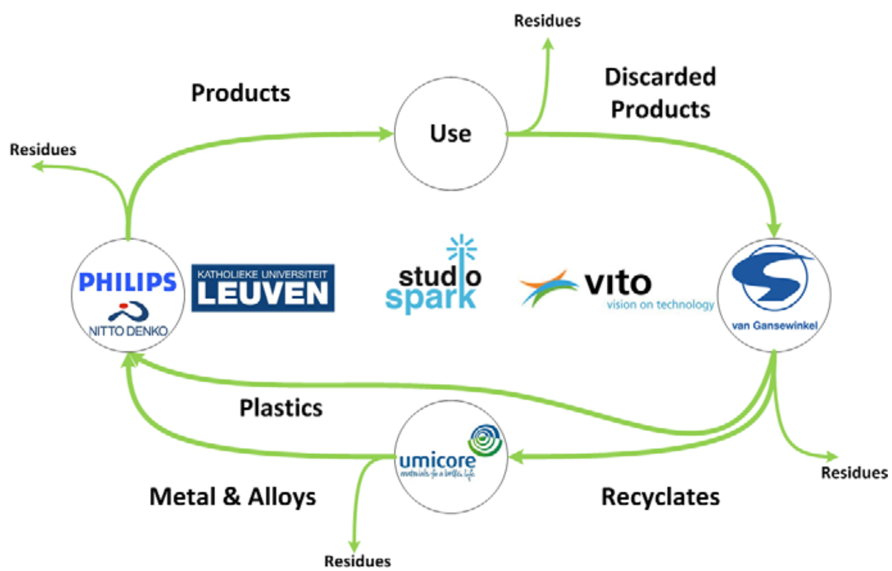
PRIME

Project summary:

http://www.mipvlaanderen.be/nl/webpage/97/prime.aspx

3 minute movie on youtube:

http://www.youtube.com/watch?v=COyVkyhT2Bw&sns=em



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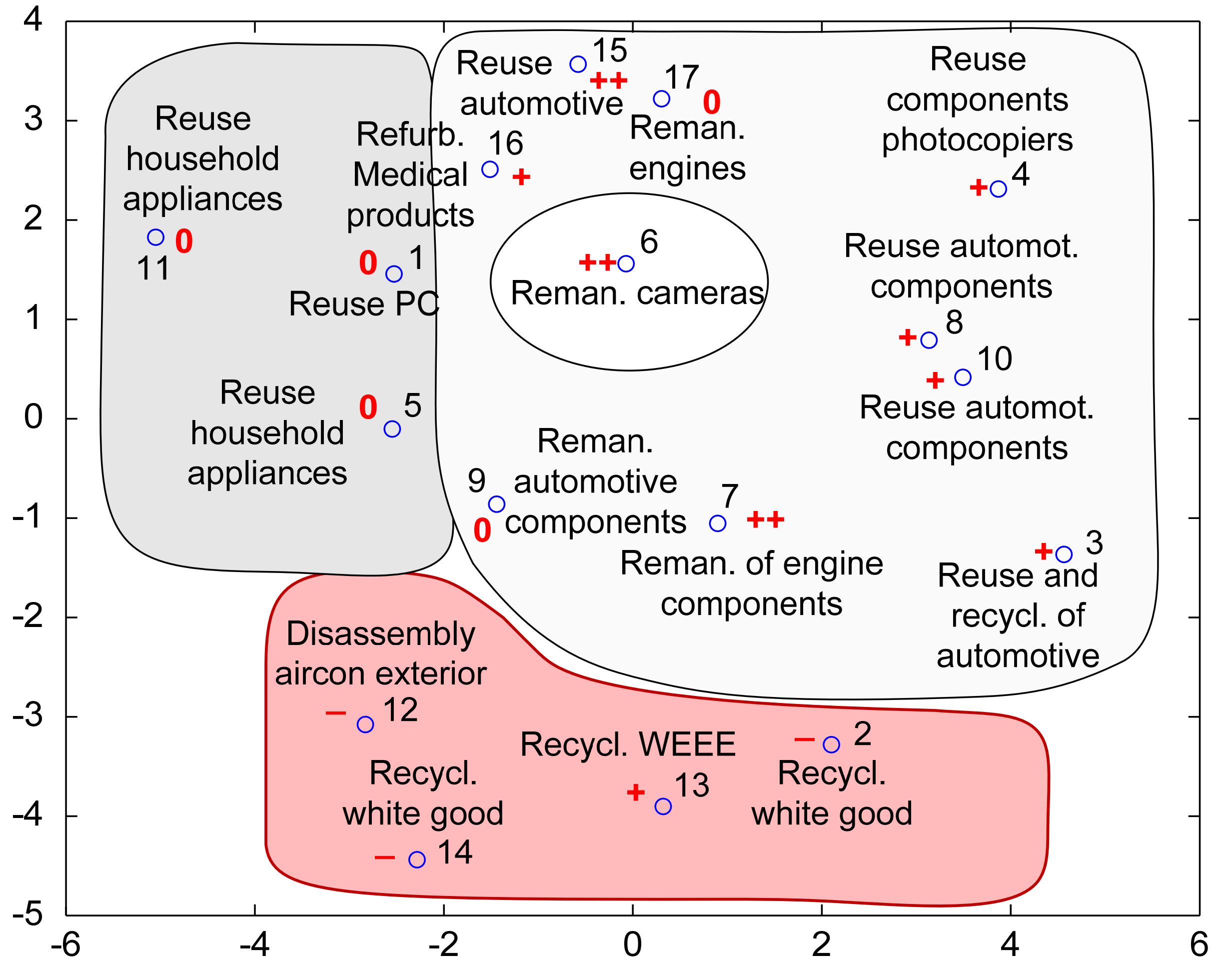
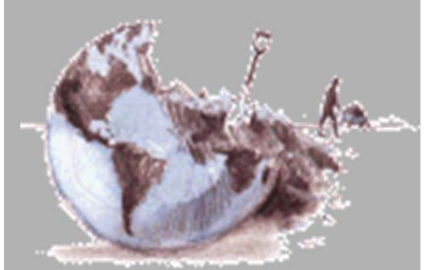
Feasibility of Disassembly

Economic Feasibility According to Product Type

"Efficiency and Feasibility of Product Disassembly: A Case Based Study", Duflou J.R., et al. CIRP Annals Manufacturing Technology Vol. 57/2/2008





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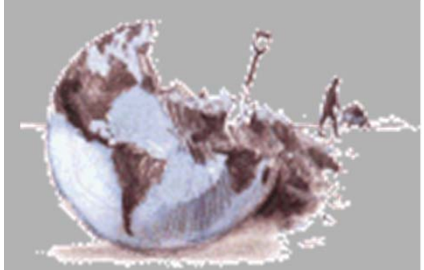
Feasibility of Disassembly

Disassembly or shredding ?

WEEE Examples as per the European Community directive 2002/96/EC



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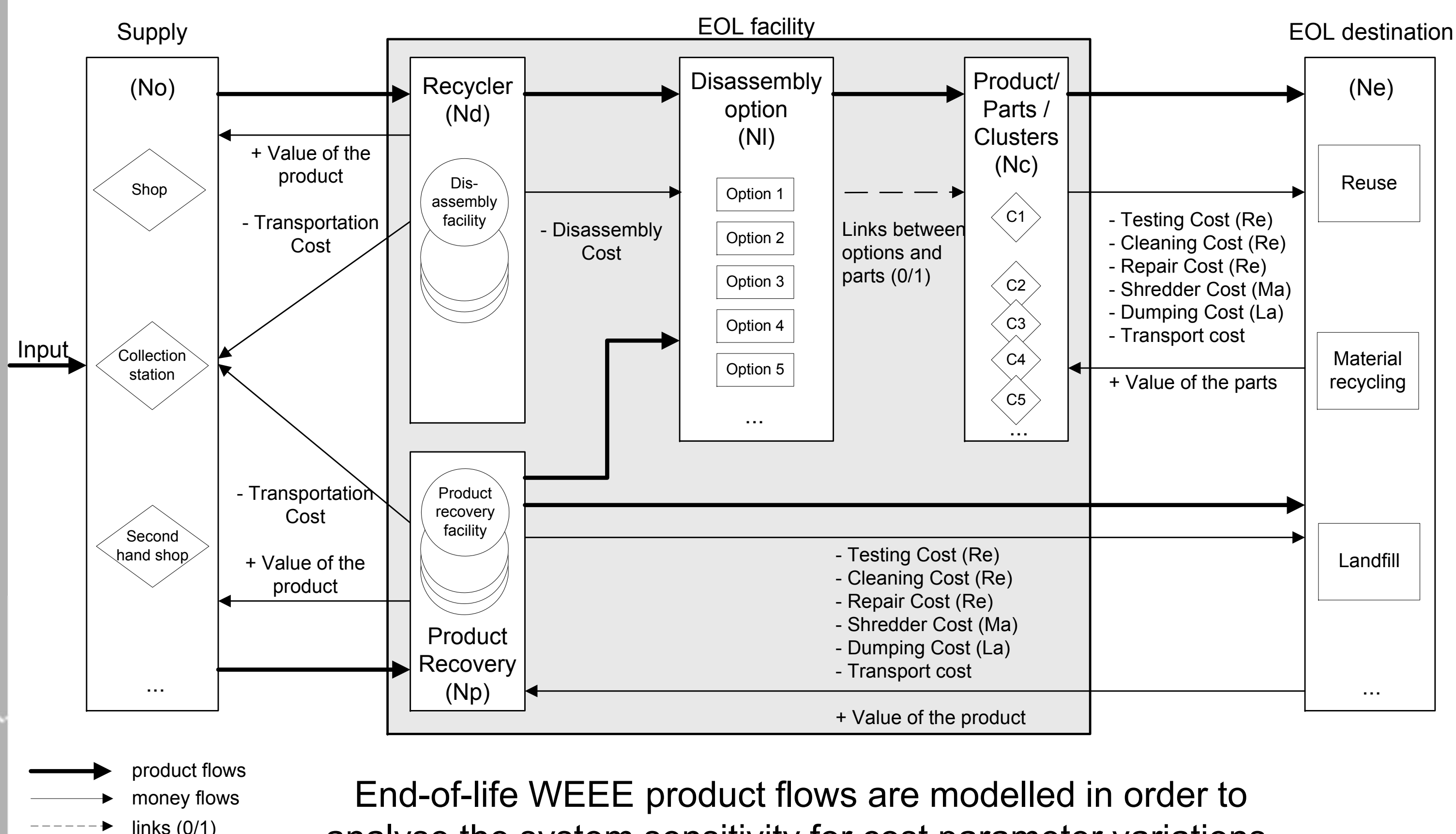
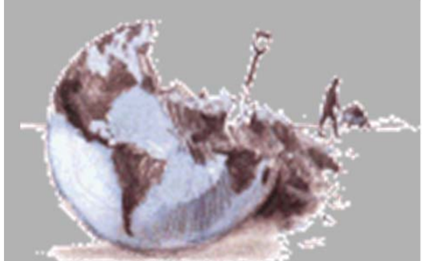
Feasibility of Disassembly

Disassembly or shredding ?
Feasibility determining factors:

LP-based EoL treatment modelling for WEEE





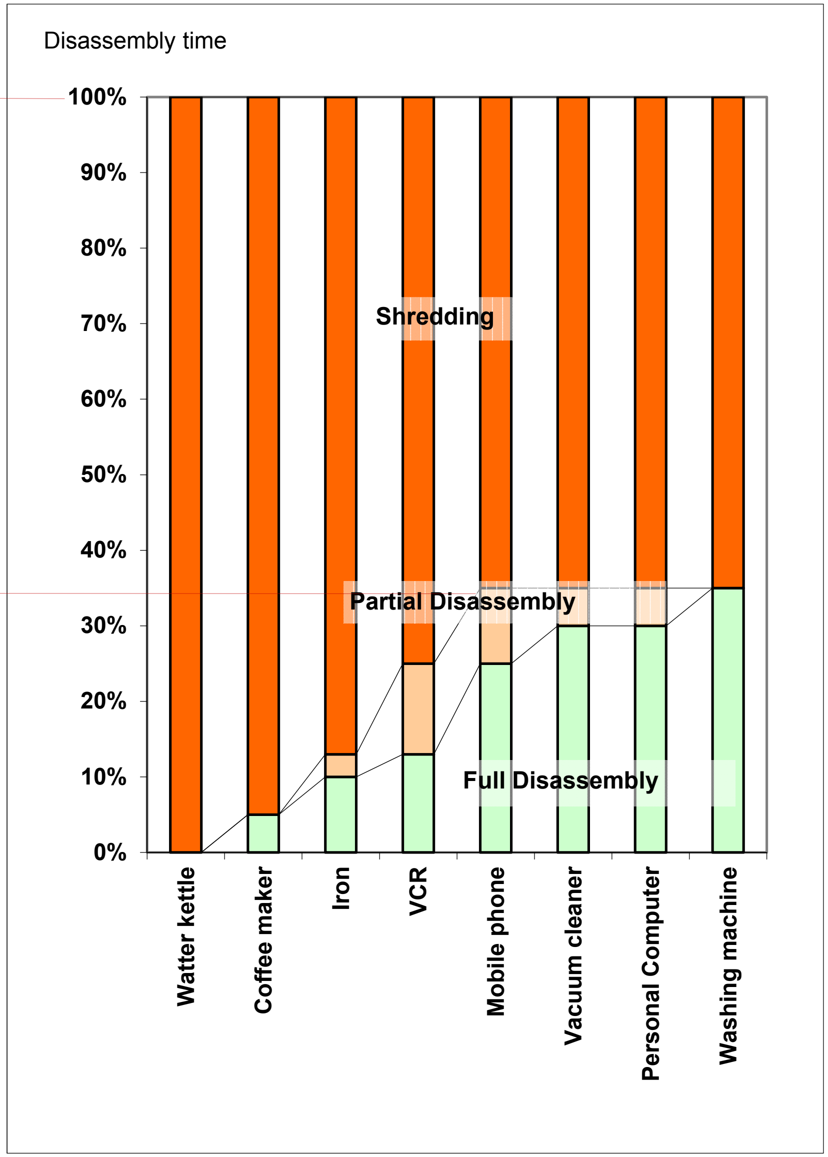
End-of-life WEEE product flows are modelled in order to analyse the system sensitivity for cost parameter variations.

Feasibility of Disassembly

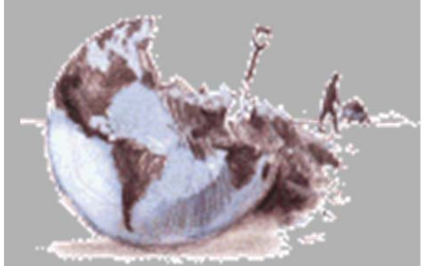
Feasibility determining factors:

Required productivity improvements for WEEE processing

> 65%



"Can Large-Scale Disassembly Be Profitable? A Linear Programming Approach to Quantifying theTurning Point to Make Disassembly Economically Viable", Willems B., Dewulf W., Duflou J., International Journal of Production Research, Volume 44, no 6 (2006)



Feasibility of Disassembly

Assembly:
Entropy reduction

Disassembly:
Entropy increase

Building: 22.6 min.

Controlled disassembly: 3.5 min.

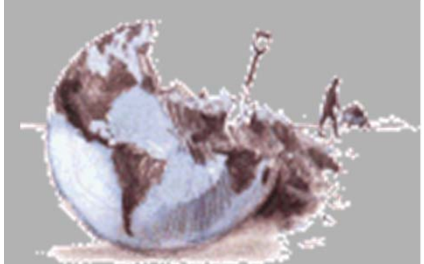
Feasibility of Disassembly

Active Disassembly Concept

One-to-one disassembly ⇔ One-to-many disassembly

- Disassembly as inverse assembly
- Connections reversed individually
- Limited automation potential
- Products treated sequentially

- Single action causing reversal of multiple connections
- Uniform trigger signal
- High automation potential
- Multiple products can be treated in parallel



EXTRACT :

Externally Triggered Active Disassembly

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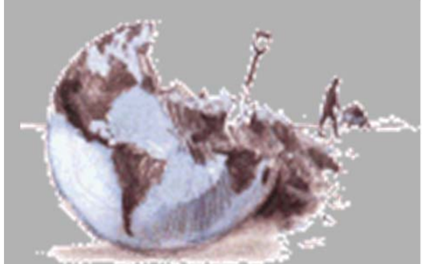
Feasibility of Disassembly

Active Disassembly Concept: EXTRACT

One-to-many fastening techniques

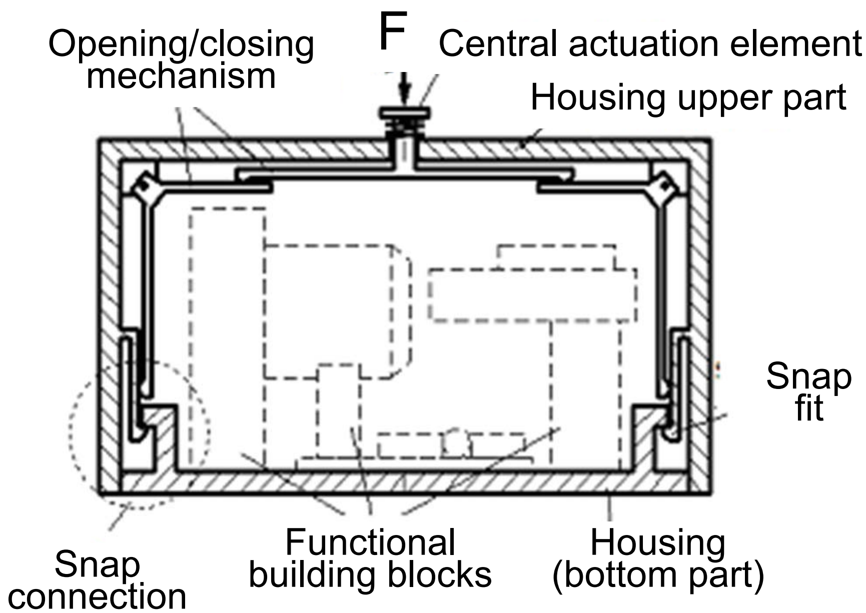
Disassembly embedded design	Active disassembly
• Product specific • Physical contact • Linking of fasteners	• Generic • NO physical contact • External trigger for *n* fasteners • ~ self-disassembly

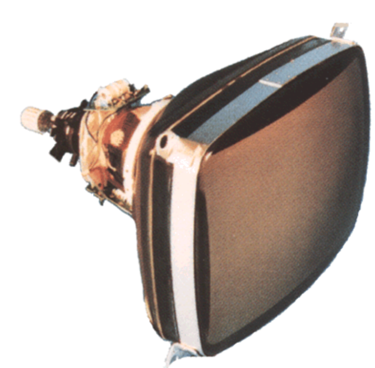


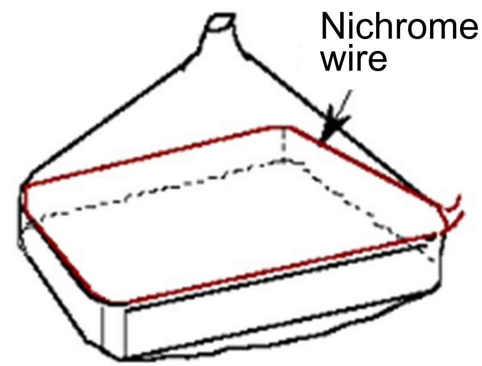
Feasibility of Disassembly

Disassembly Embedded Design

Examples:

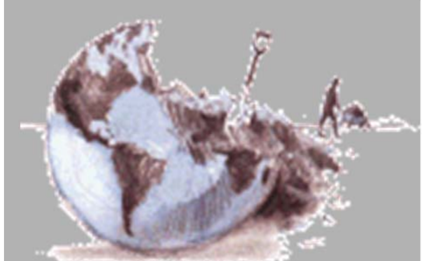






Source: Braunschweig, 2003

Source: Masui, 1999

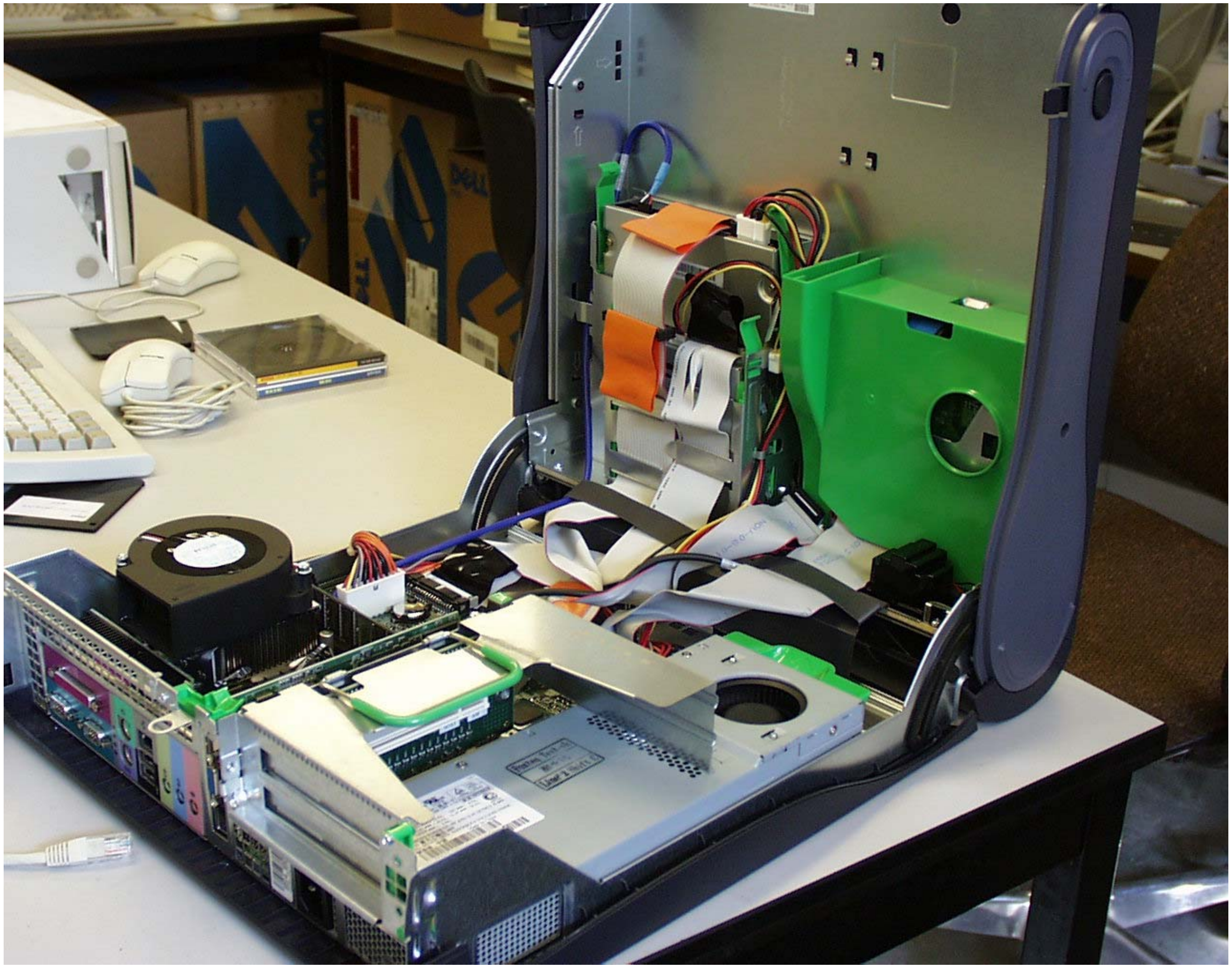


Feasibility of Disassembly

Disassembly Embedded Design

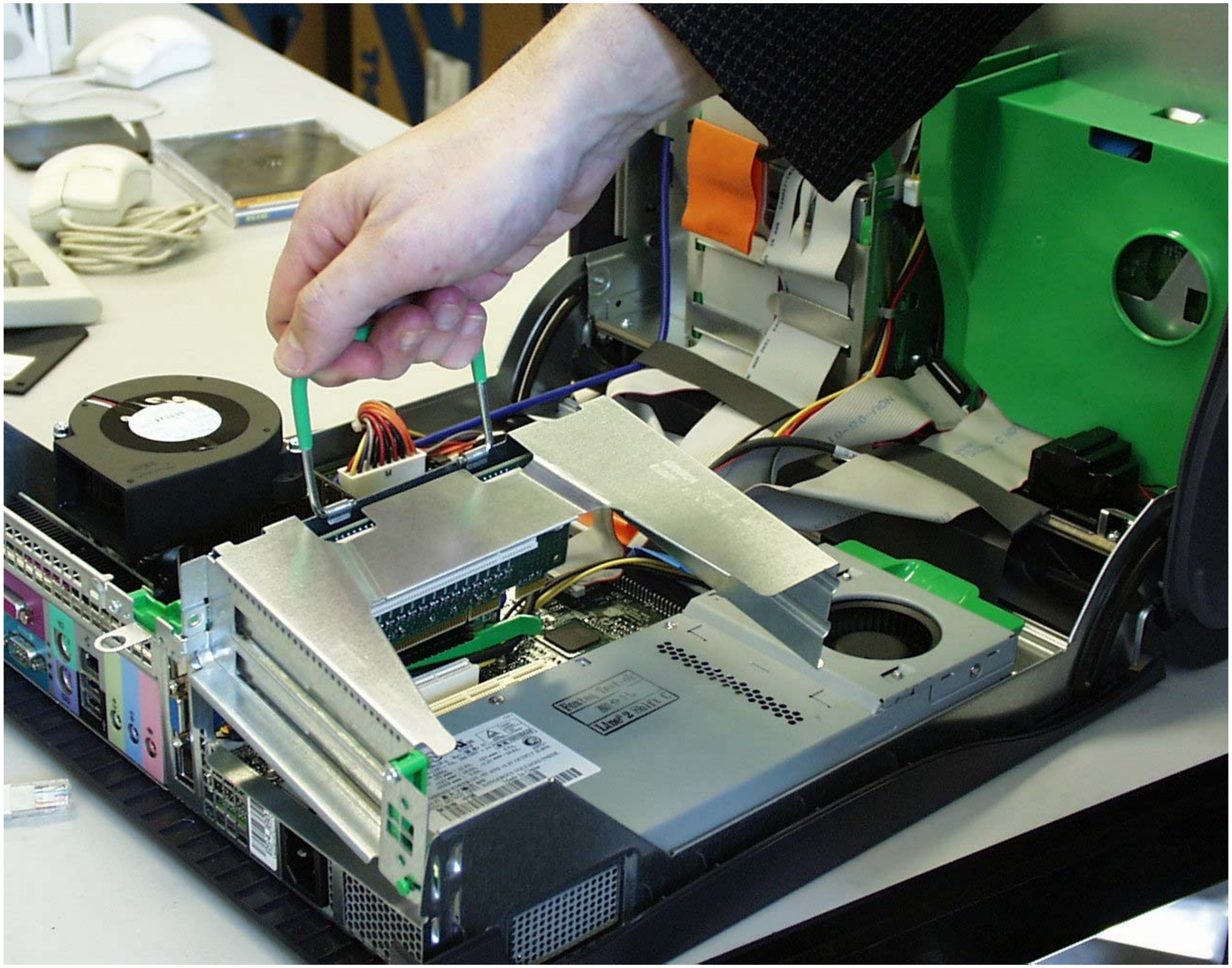
Feasibility of Disassembly

Disassembly Embedded Design



Feasibility of Disassembly

Disassembly Embedded Design



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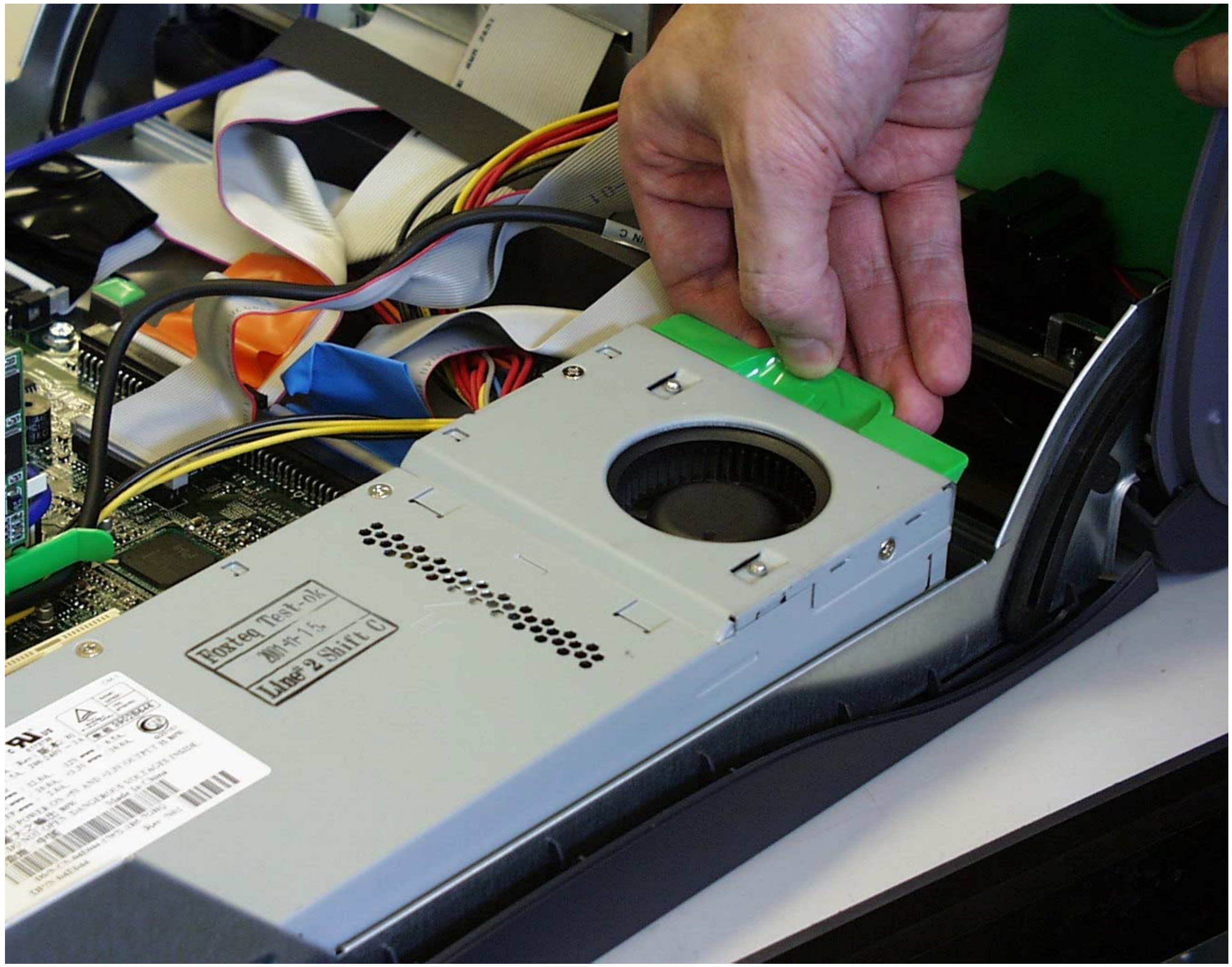
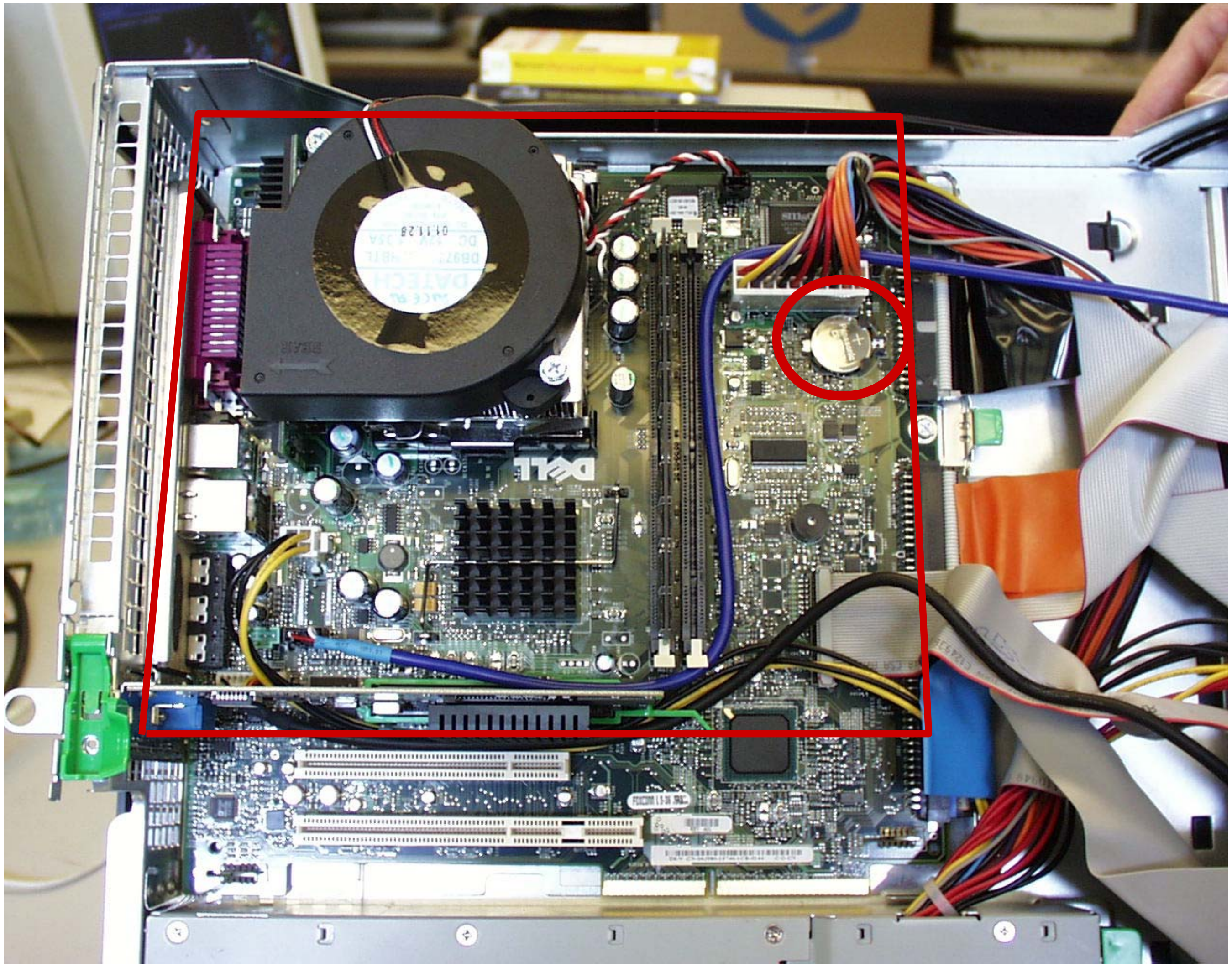
Feasibility of Disassembly

Disassembly Embedded Design



Feasibility of Disassembly

Disassembly Embedded Design



Feasibility of Disassembly

Available technologies determining the productivity of disassembly :

Disassembly oriented fasteners

Trigger principle	Disassembly embedded design	Active disassembly
Mechanical	Mechanical force (Braunschweig, 2003) Pneumatic force (Braunschweig 2003)	Pneumo-elements (Neubert, 2000) Pneumatic force (Willems 2007)
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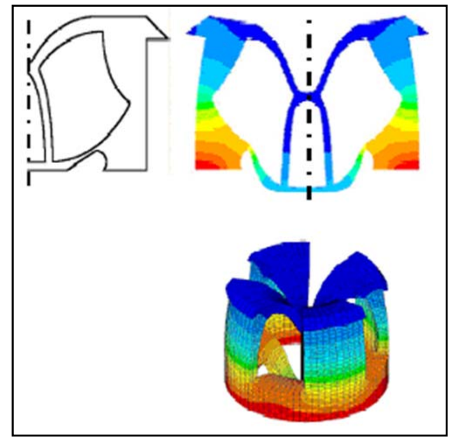
Thermal trigger principle



(Nishiwaki, 2000)
(Li, 2003)

Classification of innovative fasteners for self-disassembling products

KU LEUVEN

Feasibility of Disassembly

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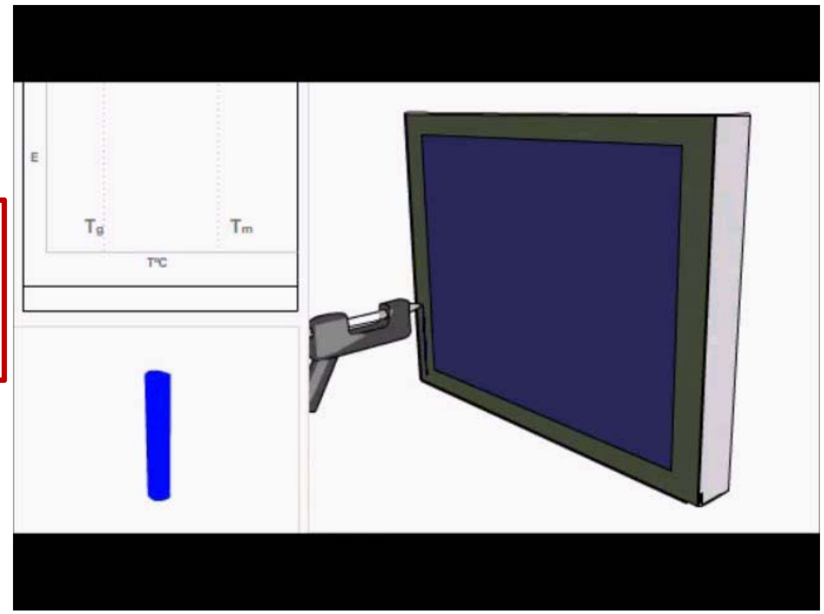
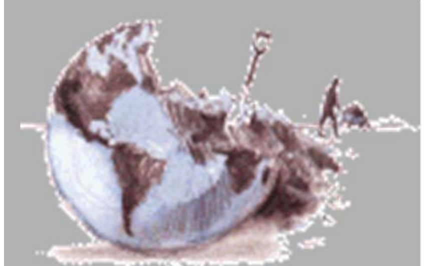


J.Chiodo, Active Disassembly Research Ltd

Classification of innovative fasteners for self-disassembling products



Feasibility of Disassembly

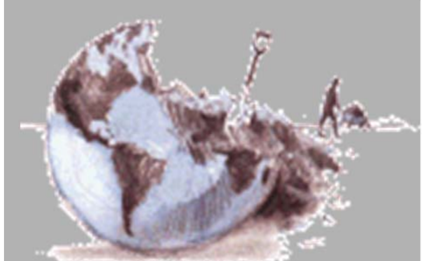
Available technologies determining the productivity of disassembly :

Disassembly oriented fasteners

NITTO DENKO

Debond-on-Command tape

Easy disassembly of parts
for repair or recycling



Feasibility of Disassembly

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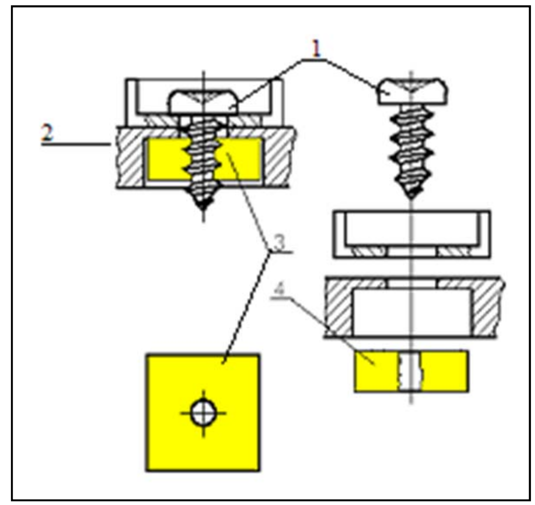
Classification of innovative fasteners for self-disassembling products

Chemical trigger principle



(Neubert, 2000)

Feasibility of Disassembly

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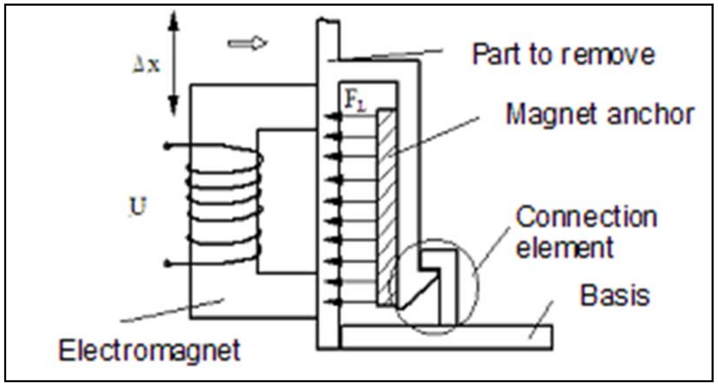
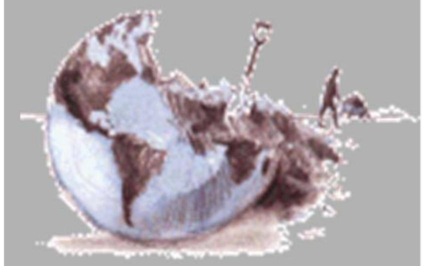
Electro magnetic trigger

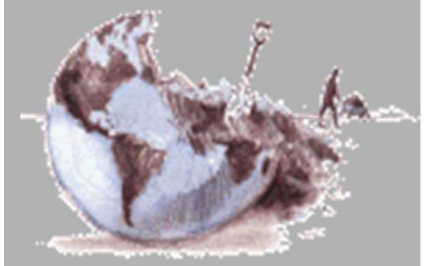


(Braunschweig, 2003)

Classification of innovative fasteners for self-disassembling products



Feasibility of Disassembly



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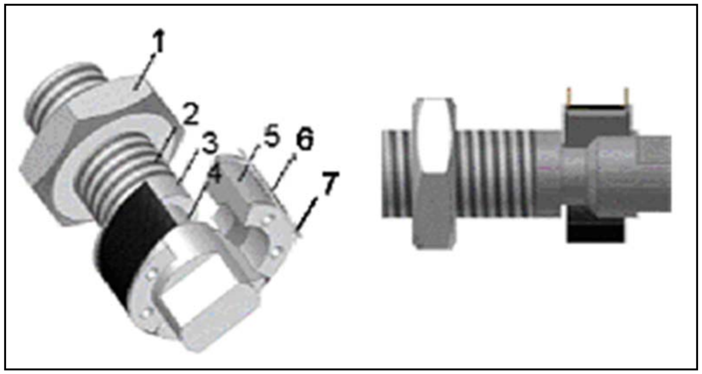
Electrical trigger principle



(Klett, 2003)

Classification of innovative fasteners for self-disassembling products

Feasibility of Disassembly

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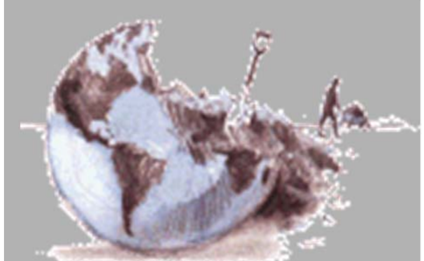
Mechanical trigger principle

Active disassembly with pressure triggered generic fasteners



Feasibility of Disassembly

Feasibility of Disassembly

Pressure Sensitive Fasteners for Active Disassembly

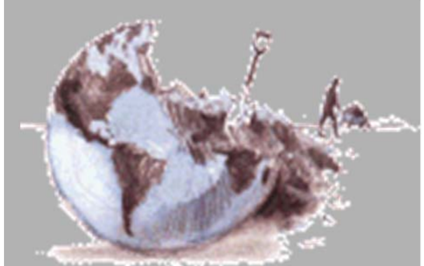
Jef Peeters
Wannes Van den Bossche
Prof. Joost Duflou
Prof. Wim Dewulf

Tom Devoldere
Eric Moons

René Slinckx

Extract Direct Project
Active Disassembly Research
2011 - 2014

research funded by



Feasibility of Disassembly

Available technologies determining the productivity of disassembly :

Disassembly oriented fasteners

Externally triggered self-disassembling generic fasteners: an ongoing development

Coverage of different product types functional requirements and product architectures