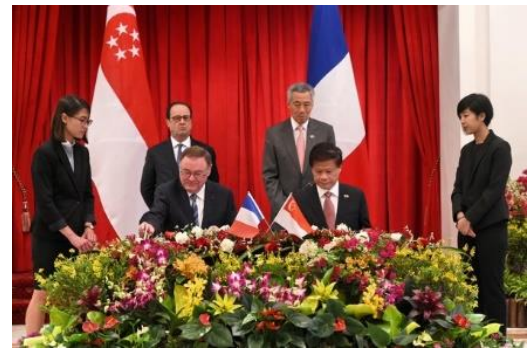Toward viable industrial solutions

URBAN MINING OF SPENT CRITICAL METALS FROM WEEE

Nicolas Charpentier,[1,2] Fabien Olivier,[1,2] Xia Dong,[2] Alex Yan Qingyu[2], **J.-C. P. Gabriel**,[1,2]

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[1] CEA
[2] NTU/SCARCE

WORLD MATERIALS FORUM

2013-2018

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

SCARCE

National Environment Agency
Safeguard · Nurture · Cherish

2018-2023-2028
Phase 1 | Phase 2
8 Mn€ | 12 Mn€

INVESTIR L'AVENIR

RECYCLAGE RECYCLABILITÉ RÉ-UTILISATION MATIÈRE PEPR

2023-2026

www.cea.fr

E-Wastes a Problem?

❑ 53.6 Mt (Million Metric Tonnes) in 2019 (74.7 Mt by 2030) – Worldwide, Asia (24.9 Mt), the Americas (13.1 Mt) and Europe (12Mt)[1]

❑ Only 17.4% collected & properly recycled; Many metals < 1%

Example of Metal recovery from PCBs. After:

≈ 5300 Eiffel towers

Facility	Location	Process Overview	Main metals recovered	Capacity (kt/year)
Aurubis smelter	Lünen, Germany	Black copper processing, electrorefining, and precious metal refining	Ag, Au, Cu, Pb, Sn, Zn	300 (only a fraction is e-waste)
Noranda smelter	Quebec, Canada	Feeding of e-waste to a copper smelter (14% of the total throughput). Upgrading in converter and anode furnaces. Electrorefining for metal recovery.	Ag, Au, Cu, Ni, Pd, Pt, Se, Te	100
Boliden Rönnskar smelter	Skelleftehamn, Sweden	Reactor smelting, copper refining and purification, and precious metal refining	Ag, Au, As, Bi, Cu, In, Ir, Ni, Pb, Pd, Pt, Rh, Ru, Sb, Se, Sn	120
Umicore smelter	Hoboken, Belgium	Smelting, copper leaching, electrowinning, and precious metal refining	Ag, As, Au, Bi, Cu, In, Ir, Ni, Pb, Pd, Pt, Rh, Ru, Sb, Se, Sn	350
DOWA Group smelter	Kosaka, Japan	Smelting, copper refining, and precious metal refining	Ag, Au, Bi, Cu, Ni, Pb, Sb, Sn, Te	150

Best is 16 metals out of 60+ in PCBs

[1] Global E-Waste Monitor 2020, UN
[2] Allied Market Research 2020

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❑ Ewaste Management Market estimated at $50 Bn in 2020 ($145 Bn in 2028)[2]

❑ Environmental concern and Global Warming Contributor

Including Fiberglass and Epoxy

≈ 5300 Eiffel towers

Taux de recyclage de 60 éléments à partir de produits en fin de vie.
(UNEP - 2011 - Recycling rates of metals - Graedel et al.)

> 50%
> 25–50%
> 10–25%
1–10%
< 1%

[1] Global E-Waste Monitor 2020, UN
[2] Allied Market Research 2020

E-Wastes a Problem?

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≈ 5300 Eiffel towers

European Critical Raw Materials Act
2030 benchmarks for strategic raw materials:

EU EXTRACTION
At least **10%** of the EU's annual consumption for extraction

EU PROCESSING
At least **40%** of the EU's annual consumption for processing

EU RECYCLING
At least **15%** of the EU's annual consumption for recycling

EXTERNAL SOURCES
Not more than **65%** of the EU's annual consumption of **each strategic raw material at any relevant stage of processing** from a single third country
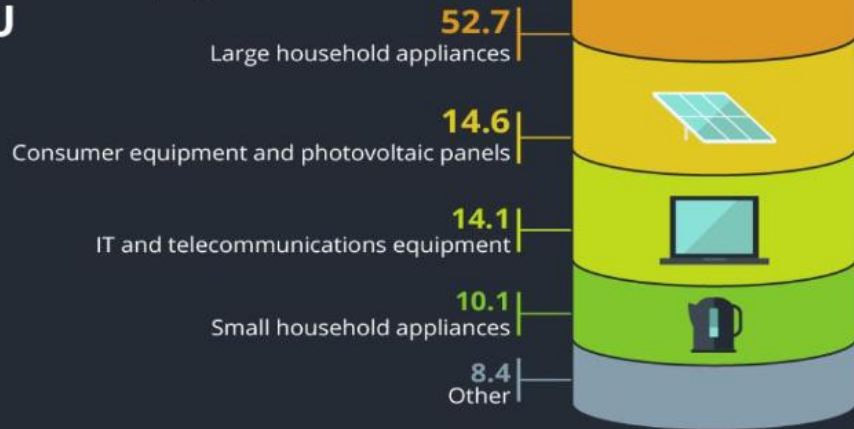
European Commission

[1] Global E-Waste Monitor 2020, UN
[2] Allied Market Research 2020

Where can what be found?

Infographic showing the percentage of e-waste per appliance type in the EU

ELECTRONIC AND ELECTRICAL WASTE IN THE EU

Total collected electronic and electrical equipment in the EU (%)

- 52.7 — Large household appliances
- 14.6 — Consumer equipment and photovoltaic panels
- 14.1 — IT and telecommunications equipment
- 10.1 — Small household appliances
- 8.4 — Other

Source: Eurostat (2020)

europarl.eu

Average material composition of large home appliances:

	Air conditioners	Dishwashers	Dryers
Acrylonitrile Butadiene Styrene	-	1,2%	4,7%
Aluminium	2,0%	0,25%	3,6%
Concrete	-	4,0%	-
Copper	21,9%	1,3%	3,8%
Copper + Aluminium	-	0,02%	0,01%
Electronics	2,4%	1,7%	2,8%
Glass	-	-	0,10%
Polystyrene	-	0,22%	0,68%
Polyamide	-	0,25%	0,15%
Polycarbonate	-	0,23%	0,13%
Polyethylene	-	0,36%	-
Polypropylene	-	10,2%	14,1%
Polyurethane Foam	-	0,35%	-
Polyvinyl Chloride	-	0,82%	0,17%
Stainless steel	-	17,3%	8,5%
Steel	45,1%	41,6%	52,0%
Other plastics	20,3%	5,8%	7,0%
Other	8,3%	14,4%	2,4%

34 Source: UNU-VIE SCYCLE calculations based on CECED members input, EuP studies and other sources.

5

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SCARCE

Where can what be found? Photovoltaic

Infographic showing the percentage of e-waste per appliance type in the EU
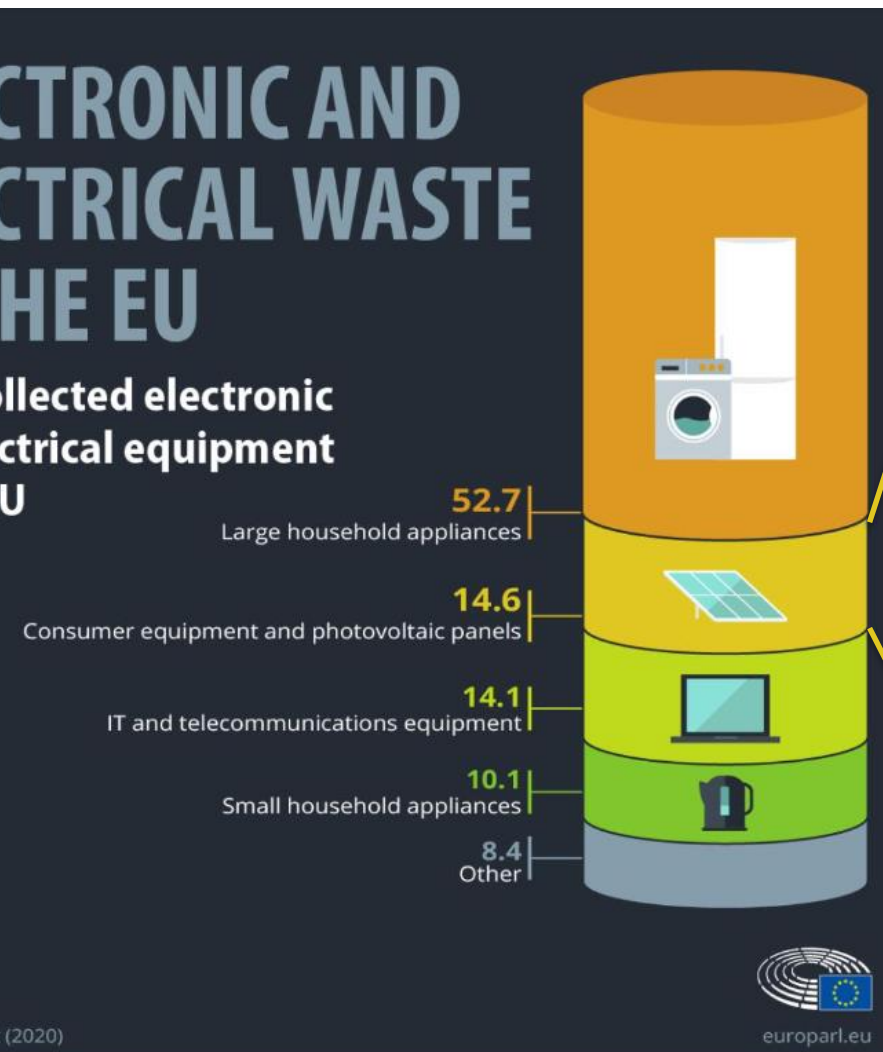
Material	Quantity	Unit	(wt/wt)
Glass, containing antimony (0.01-1 %/kg of glass)	700	kg	70 %
Aluminium frame	180	kg	18 %
Copper connector	10	kg	1 %
Polymer-based adhesive (EVA) encapsulation layer	51	kg	5.1 %
Back-sheet layer (based on polyvinyl fluoride)	15	kg	1.5 %
Silicon metal solar cell	36.5	kg	3.56 %
Silver	0.53	kg	0.053 %
Aluminium, internal conductor	5.3	kg	0.53 %
Copper, internal conductor	1.14	kg	1.14 %
Various metal (tin, lead)	0.53	kg	0.053 %
Total	**1 000**	**kg**	**100 %**

Paiano, A., *Renewable and Sustainable Energy Reviews* **41**, 2015, 99.

To recover beyond Al / SiO_2: Delamination

6

Axel Briand, Lucas Liotaud , Antoine Leybros, Agnès Grandjean

PHOTORAMA

© Y. Caudic / CEA

Rapid Expansion ScCO$_2$
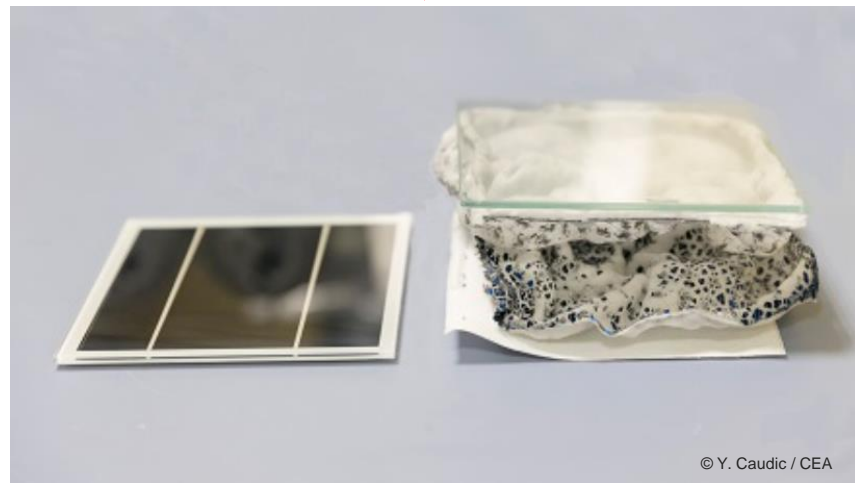
Glass
EVA
Si
Ag
PVF

© Y. Caudic / CEA

n's Horizon
reement No
958223.

cea

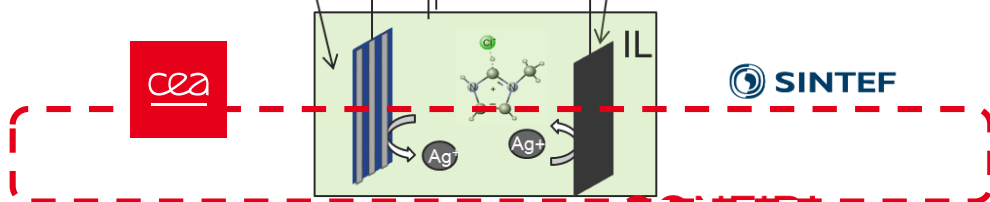# INNOVATIVE PROCESS? PHOTORAMA EU PROJECT

Axel Briand, Lucas Liotaud , Antoine Leybros, Agnès Grandjean

PHOTORAMA
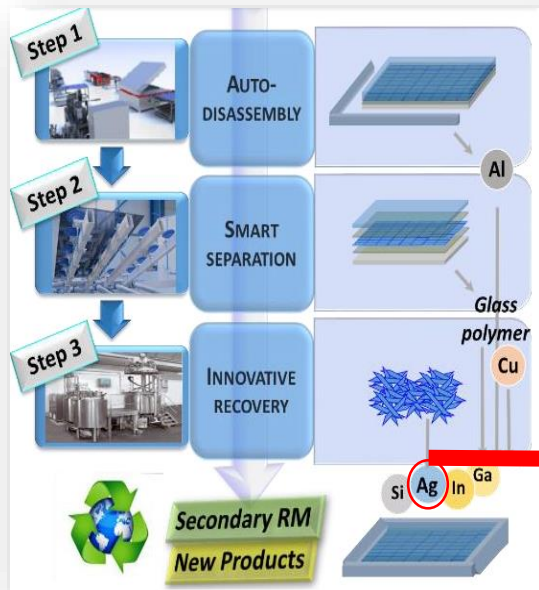
Innovative recovery of Ag in 1 step : electrolixiviation/electrodeposition

Electrodissolution - Electrodeposition

(+) Electrodissolution of silver

(-) Electrodeposition of silver

© Y. Caudic / CEA

SINTEF

**Objective : Production of 1 kg/day of silver metal
Pilot line development** LuxChemtech

**Method based on Green Solvent & Recyclability:
Use of Deep Eutectic Solvent (DES)**

✓ *Low cost and environment impact, non-harmful and easy to make*
✓ *Stable mixture of components at their eutectic points*
✓ *Good conductivity and excellent solubility for silver chloride*
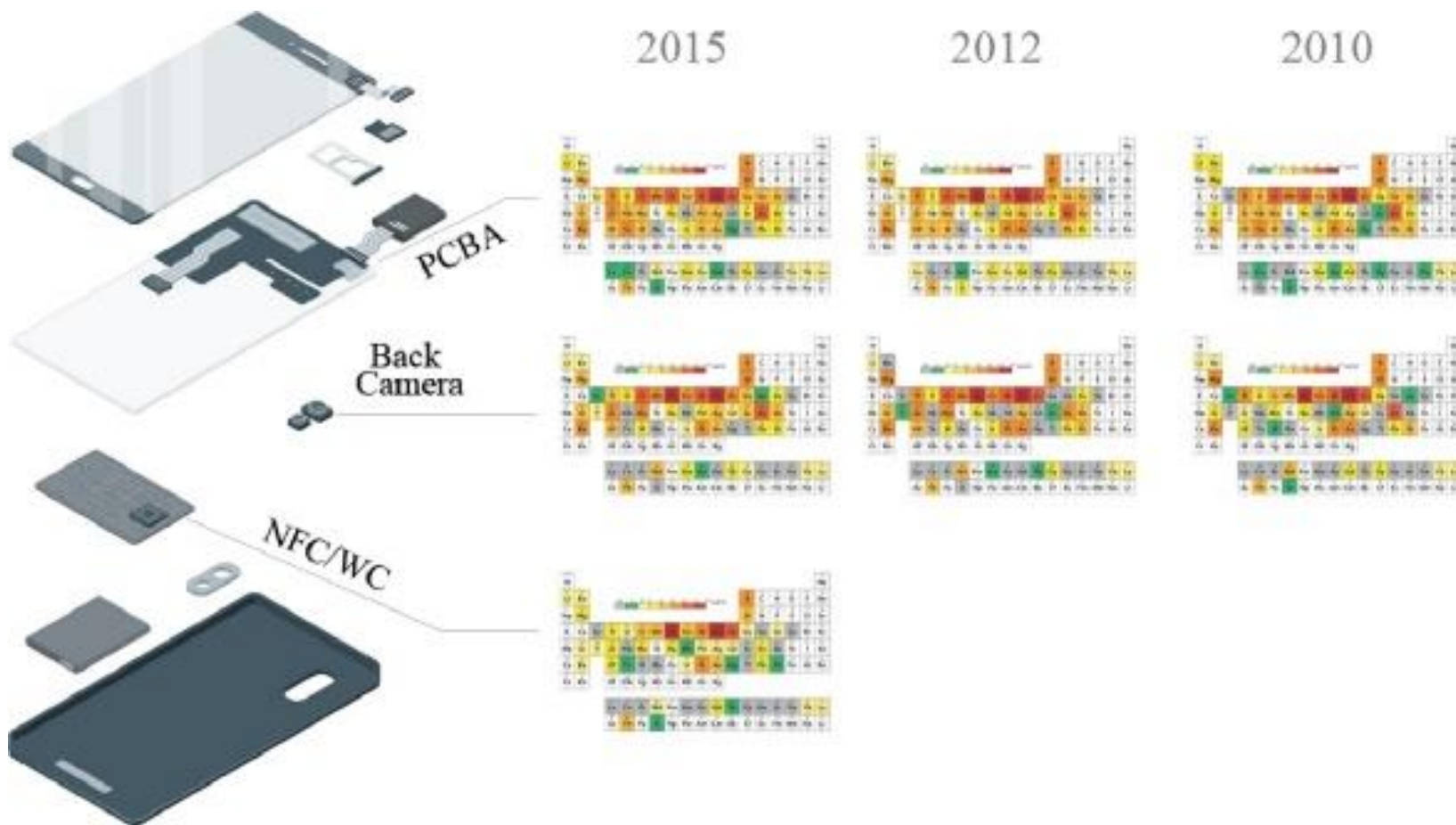
Where can what be found? IT & Telecom
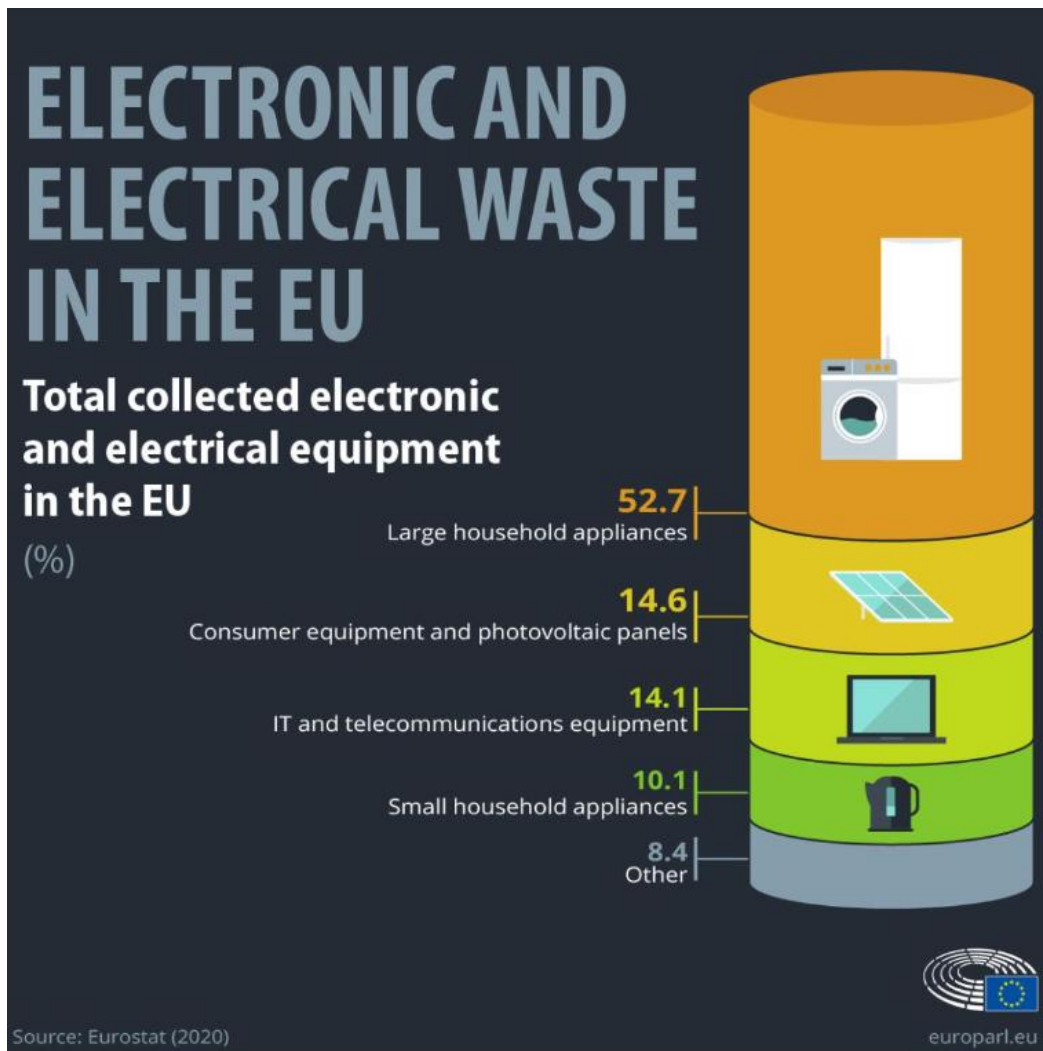
Infographic showing the percentage of e-waste per appliance type in the EU

Where can what be found? IT & Telecom

Example: Smart Phones

O. Tantawi, I. Hua, Resources, Conservation and Recycling, 175, 105886 (2021)

Where can what be found? IT & Telecom

- **PCBs = ~6-8 wt% of WEEEs**
- **High Variability: Space / Time / Value**
- **Little known detailed composition**
- **No standard protocols for analysis**
- **Empirical valuation**

=> Challenge = Valuation / Analysis / Sorting

Beyond manual: Can elemental sorting be done?

- **Highest Techno approach: Optical recognition + Laser disassembly + Robotic picking**

Florian Sauer et al.: Recovery of Tantalum from Printed Circuit Boards – An overview of the IRETA Project

Recovery of Tantalum from Printed Circuit Boards

An Overview of the IRETA Project

Florian Sauer, Bum-Ki Choi, Gesa Beck, Mathias Wickleder

- **Higly selective**
- **0,3 s / EC**
- **High CAPEX (Laser + Robotic arm)**
- **Partial solution**

- **Whole PCB disassembly**

Disassembly →

+ Bare boards (Cu, Au, Fiber glass & epoxy)

+ Solder (with or without lead)

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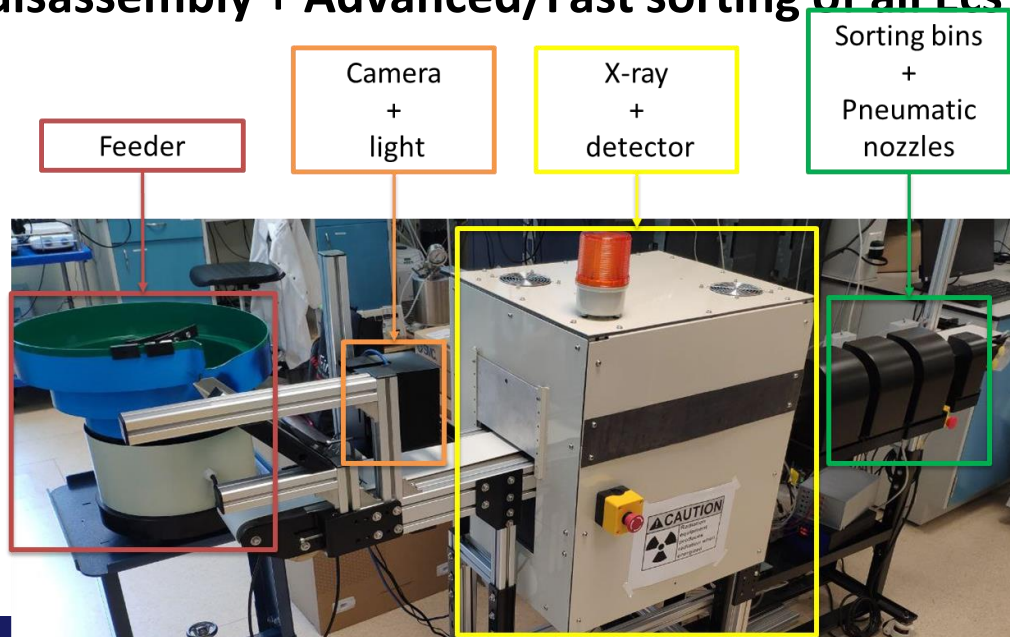
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10 kg/h
Single lane
Prototype

Feeder

Camera + light

X-ray + detector

Sorting bins + Pneumatic nozzles

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

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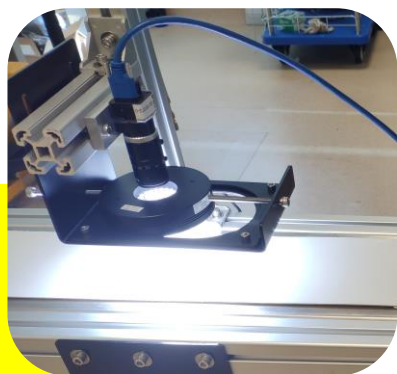
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Results obtained on 14 kg batch of wasted PCBs: Bare PCB (Cu+FG+Au)+Solder+ loose ECs)

- 10-5 mm ECs
  - Accuracy: 96.4 %

Al capacitors	IC/Connectors	Inductors	MLCC
Al, Ni, Sn	Ni, **Au**, Al, Cu, Sn, Si	Fe, Cu	**Ba, REEs**, Ti, Ni, Sn, Ag

- 5-1 mm ECs:
  - Accuracy: 97.8 %

MLCC	IC/Connectors	Resistor	MLCC
Ba, REEs, Ti, Ni, Sn, Ag	**Au**, Ni, Al, Cu, Sn, Si	Ni, Al, Cu, Sn, C	**Ba, REEs**, Ti, Ni, Sn, Ag

Optical Sorting: Can sort 90%

14

Beyond manual: Can elemental sorting be done?

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  - accuracy: 98.8 %

| Al capacitors	IC/ Connectors	Inductors	Other SLCC	Nd SLCC	Ta capacitor
Al, Ni, Sn	**Au**, Ni, Al, Cu, Sn, Si	Fe, Cu	**Ba, REEs**, Ti, Ni, Sn, Ag	**Ba, Nd**, Ti, Ni, Sn, Ag	**Ta**, Ni, Mn, Ag, Co, Fe

- 5-1 mm ECs:
  - accuracy: 94.2 %

Resistor	IC/ Connectors	Other SLCC	Nd SLCC	Ta capacitor	Ba MLCC	Non Ba MLCC
Ni, Al, Cu, Sn, C	**Au**, Ni, Al, Cu, Sn, Si	**Ba, REEs**, Ti Ni, Sn, Ag	**Ba, Nd**, Ti, Ni, Sn, Ag	**Ta**, Ni, Mn, Ag, Co, Fe	**Ba, REEs**, Ti, Ni, Sn, Ag	Ca, Mn, Ni, Sn, Ag

ME-XRT Sorting

New Business opportunities: Neodymium

NB: Nd ased Capacitor = 10% of Nb demand
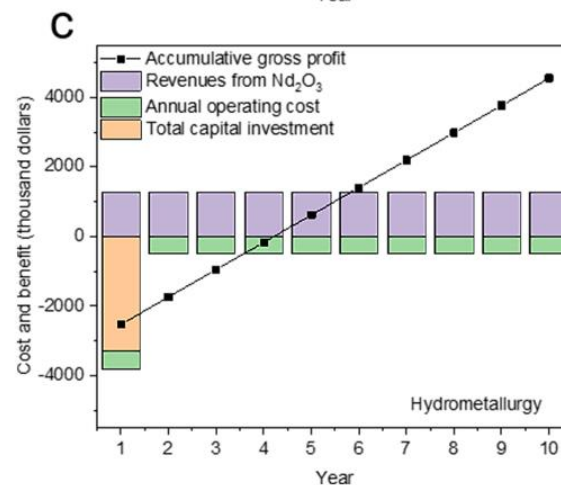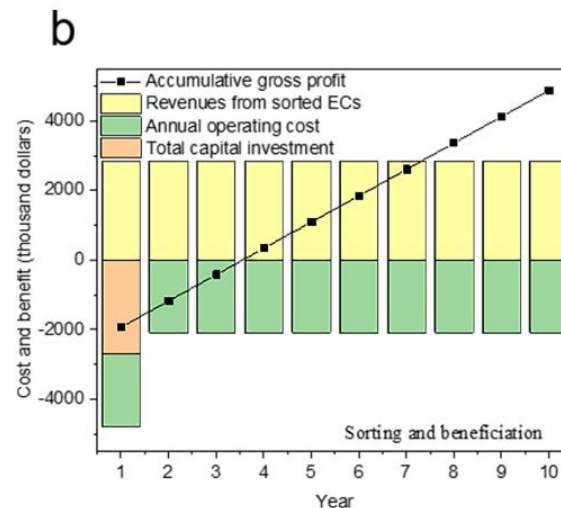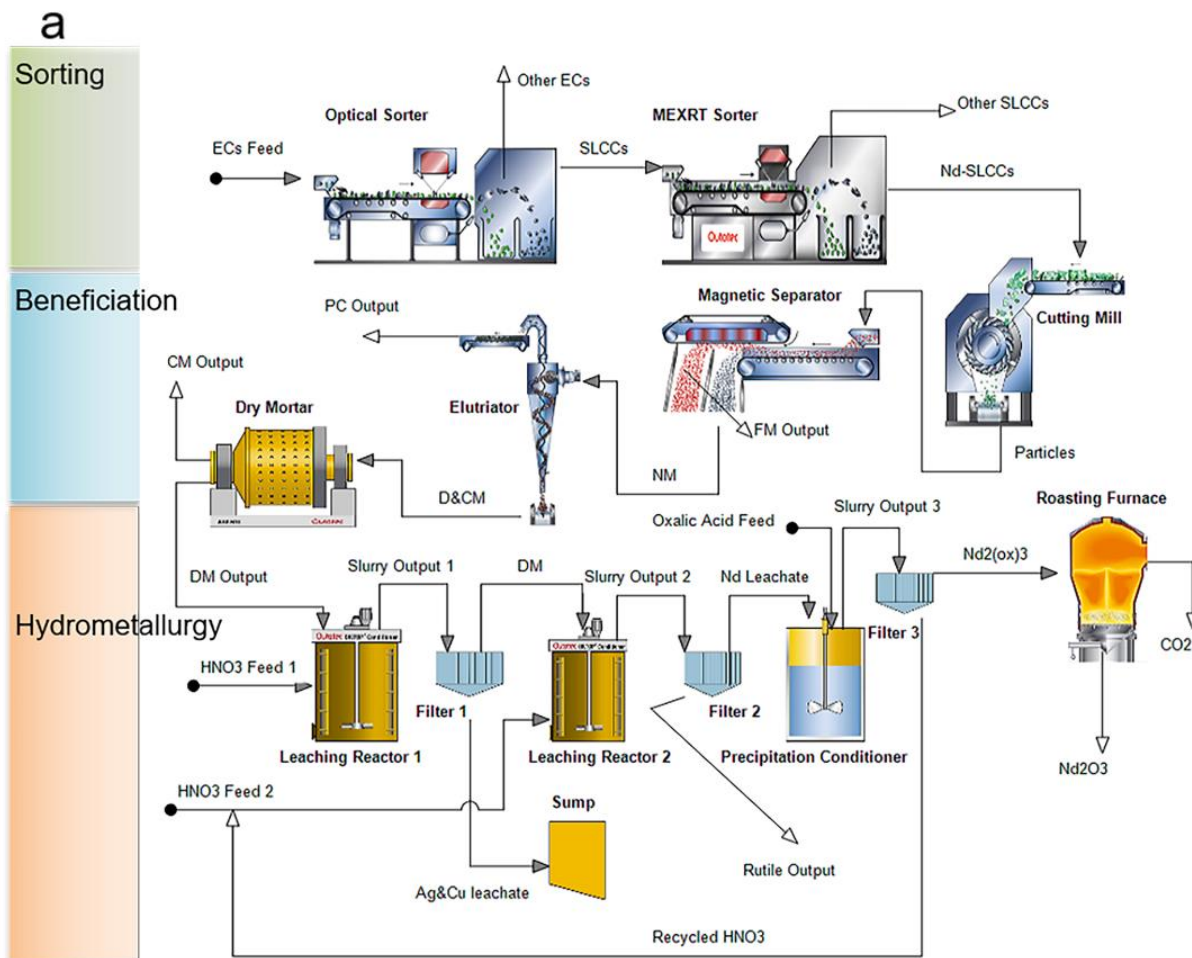
Flowsheet & economic assessment: payback in 3-5 years
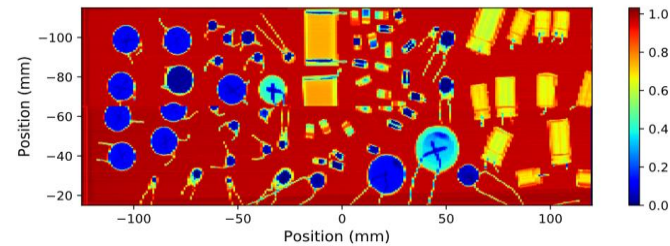
Next Step and Overall Impact on Value Chain

* **Scale up (Partners?) + other metals: Nb, W, Mo, Ga, Ge, Te, Sb, In, Os, Re…/ (B, FG?)**

* **Electronic component / Composition Database** (millions of large entries)

High Throughput Automated Composition
Measurement at Synchrotron Radiation sources
10^6 ECs/day measured

=> trade at the right price! $f([all\ metals]_{accurate})$

© P. GINTER/ESRF

Optical + ME- XRT mapping & Recognition of all Ecs
=> Detailed Valuation of PCBs' composition & metal value

* **Value Chain: Industrial Recyclers**

Disassembly/Sorting

Containerisation

BLUE : OPPORTUNITY
GREEN:BEING RECYCLED
RED:NOT RECYCLED
BLACK: IRRELEVANT TO WPCBS

© MTB

Call for Action!

17 => 35% of recycling rate + CRMA goals are achievable with:

a) **Smart design (eco-design) => enable easy disassembly / Recognition**

b) **Stronger Recycler – Technology developers links**

c) **Recycling of currently wasted spent metals (beyond B2B)**

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Will require:

a) Rapid scale up & Adoption of promising technologies

b) Economically viable recycling process adapted to new inputs

c) Customers in the EU for recycled metals.

Thanks for your attention!

Funding Acknowledgement:

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