E-waste Recycling

NTU-Singapore CEA Alliance for Research in the Circular Economy (SCARCE)

Prof. Jean-Christophe P. Gabriel[1,2]
[1] *NIMBE, CEA, CNRS, Univ. Paris Saclay*
[2] *NTU SCARCE Lab*

Jean.gabriel@cea.fr

17 Juin 2022

Financial support from NEA & MND, award #USS-IF-2018-4

SCARCE?

26/03/2017

13/07/2018

13/03/2019

- Why CEA: 70 years expertise in complex wastes recycling
- Why Singapore: Need; speed in decision making/policies; market size, ASEAN showcase

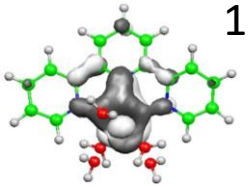
SCARCE?

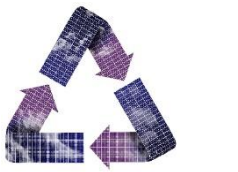
26/03/2017

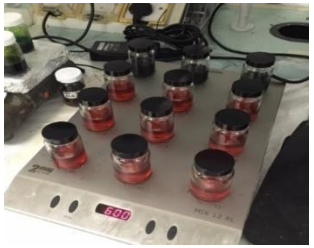
13/07/2018

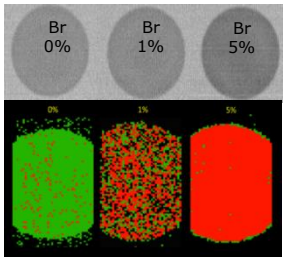
13/03/2019

- Develop Sorting, hydrometallurgy, separation, and materials reuse processes for management of e-waste from:
  - Recycling of advanced lithium ion Batteries
  - Recycling of Silicon Solar panels
  - Recycling and recovery of valuable metals from Printed circuit boards
  - Recycling and treatment of e-plastic part.
- Lab scale pilots (1-10 kg/h)



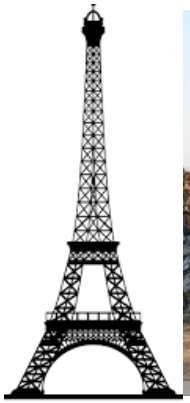






E-Wastes a Problem?

- 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%
- Ewaste Management Market estimated at $50 Bn in 2020 ($145 Bn in 2028)[2]
- Environmental concern and Global Warming Contributor



≈ 5300 Eiffel towers

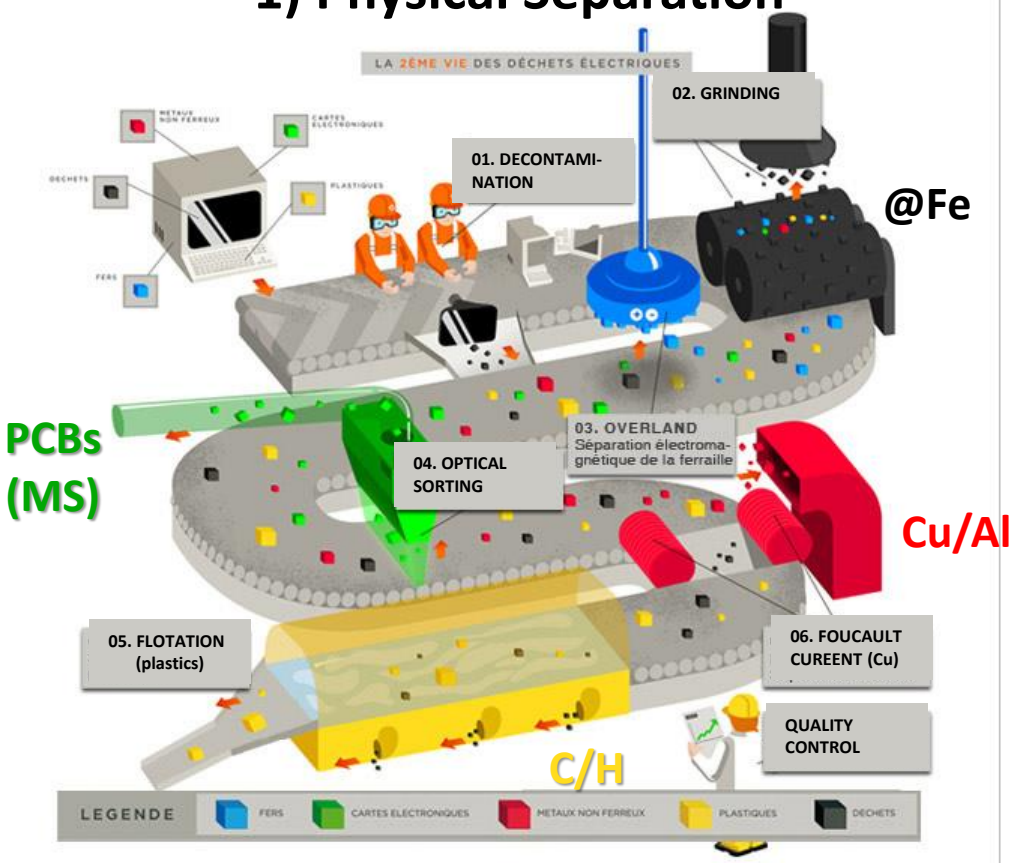
Taux de recyclage de 60 éléments à partir de produits en fin de vie.
(UNEP - 2011 - Recycling rates of metals - Graedel et al.)

[1] Global E-Waste Monitor 2020, UN

[2] Allied Market Research 2020

How are WEEEs Recycled?

1) Physical Separation



© Ecologic, www.e-dechet.com/deee/recyclage-deee

2) Pyrometallurgy

- Metal Melting (requires smelter)

3) Hydrometallurgy

- Metal dissolution (Lixiviation)
- Purification (**liquid-liquid extraction**)
- Metal recovery (Electrolysis)

4) The additives problem

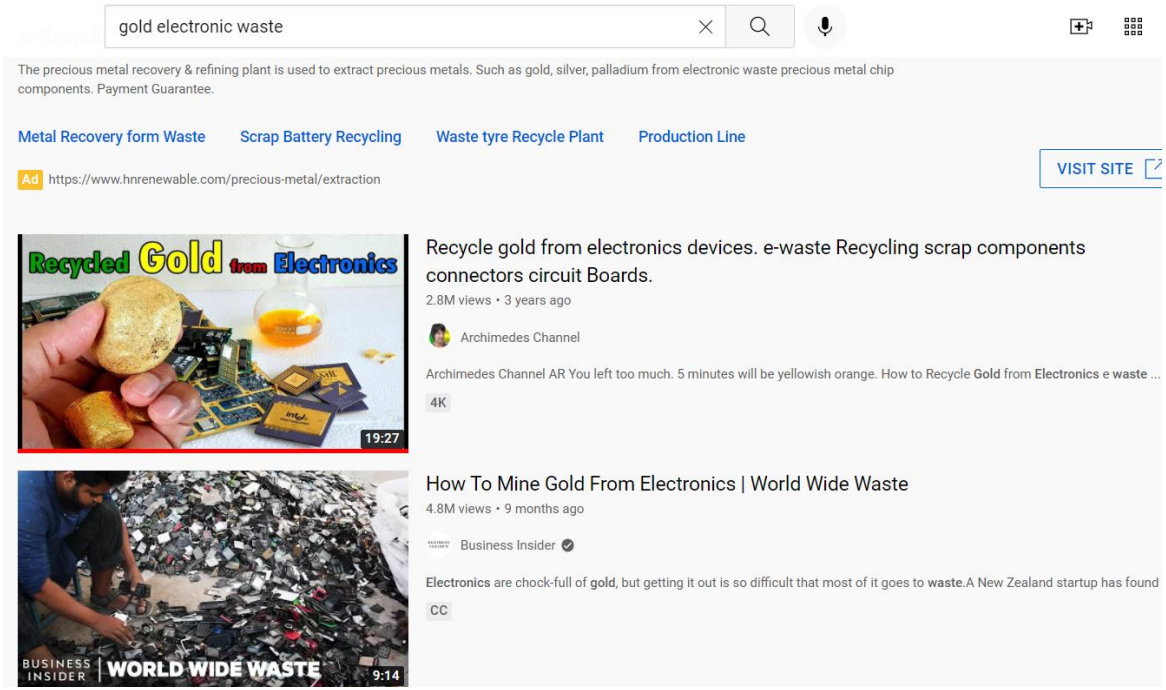
- Carbon black
- Flame retardants (Br, Sb)
- Toxic Metals (Sb, Cd; expl [Pb] = 2% in some household cables (Chun Miao *et al.*, 2022)

The Many Challenges in e-Waste Recycling

- WEEEs Collection
- Dismantling / disassembly
- Sorting
- Metals recovery
- Process development & costs
- Process waste management
- Business models
- …

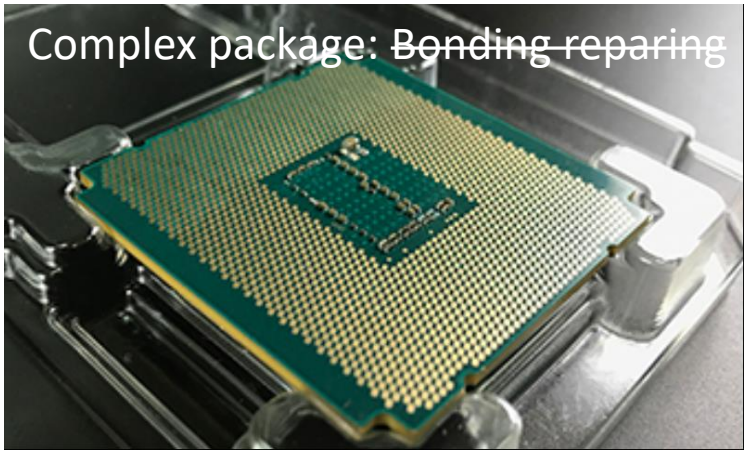
What Challenges In Collection?

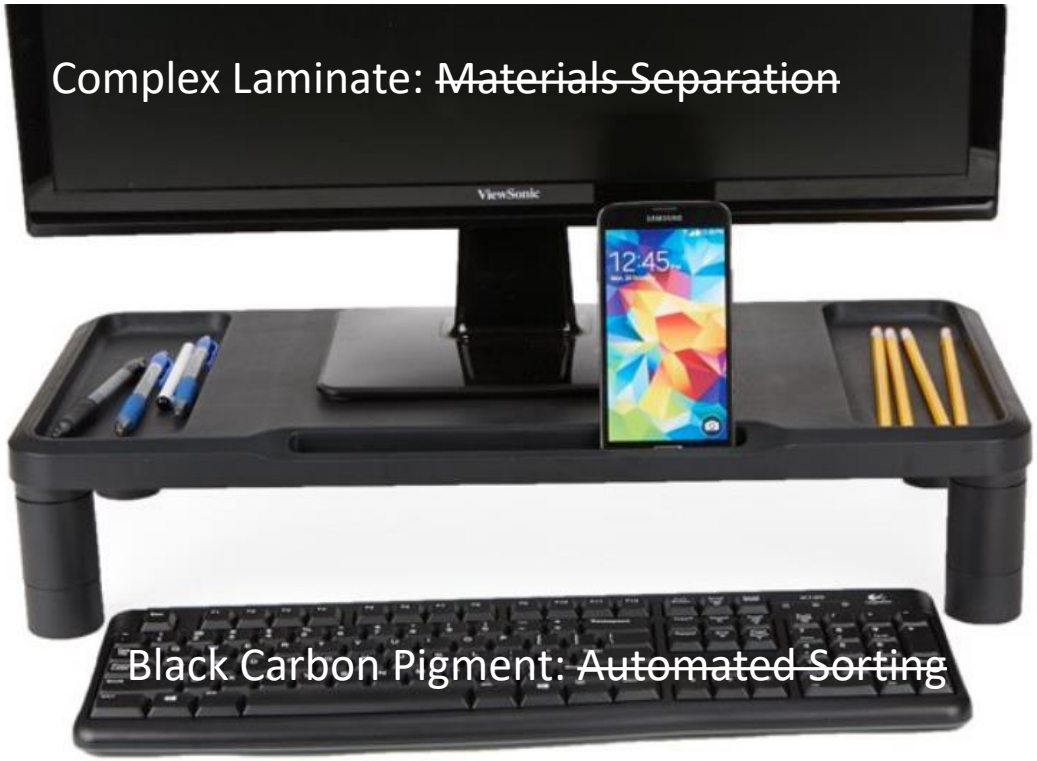
- High variability in collection rates from country to country
  (EU: 42.5%; Asia: 11.7% down to Africa: 0.9%).
- Large informal sector: capture value (intermediaries) and use unregulated processes: Au => big waste / environment
  (82.6% ewaste not recycled via official channels / 8% in trash => landfill or incinerated)
- Consolidation
  (20% exported)
- Safety (LiB)



Challenges in Dismantling / Decontamination

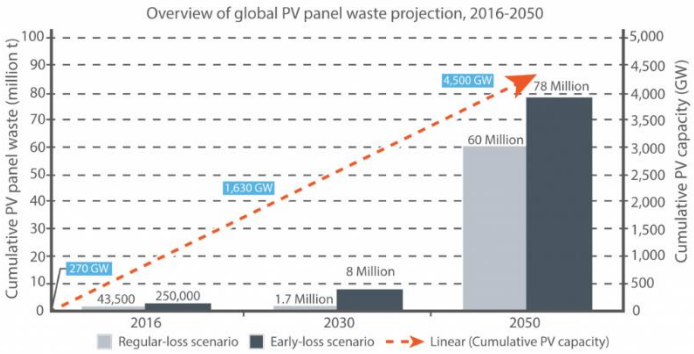
Lack of eco-conception: cannot be repaired/dismantled/sorted easily





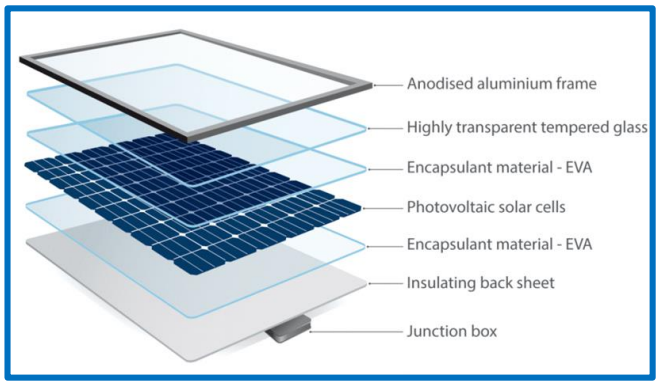
Dismantling Laminated Structures: Solar waste recycling

Principal Investigator:
Prof. Nripan Mathews (NTU)

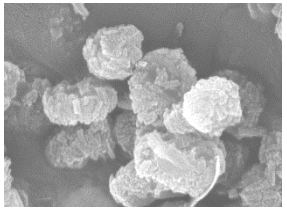


78 million tones of solar waste by 2050 → Raw material source for new panels.

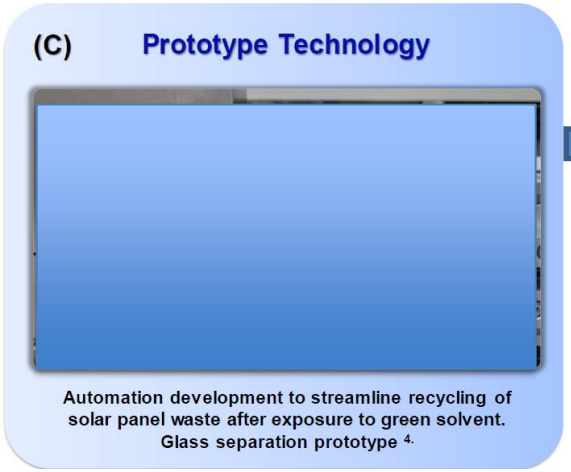
Presently recovered components: 85 wt%, Glass & Al frame



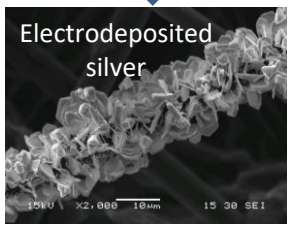
Lithium-Silicon Battery



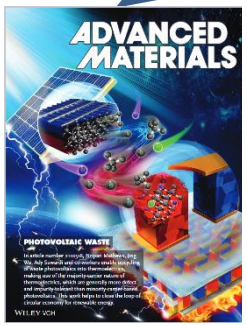
Metal Organic Framework



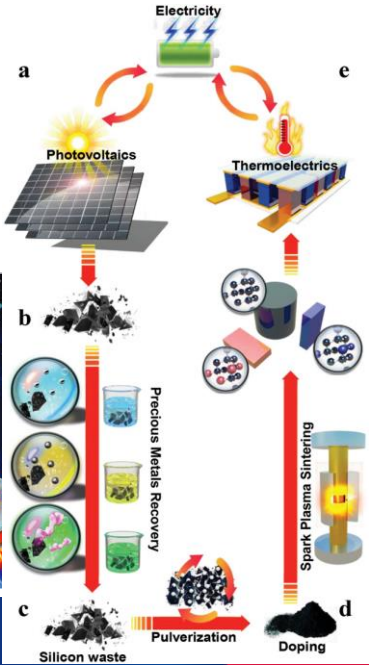
Hydrometallurgical treatments



Upcycled applications



Thermoelectric Materials

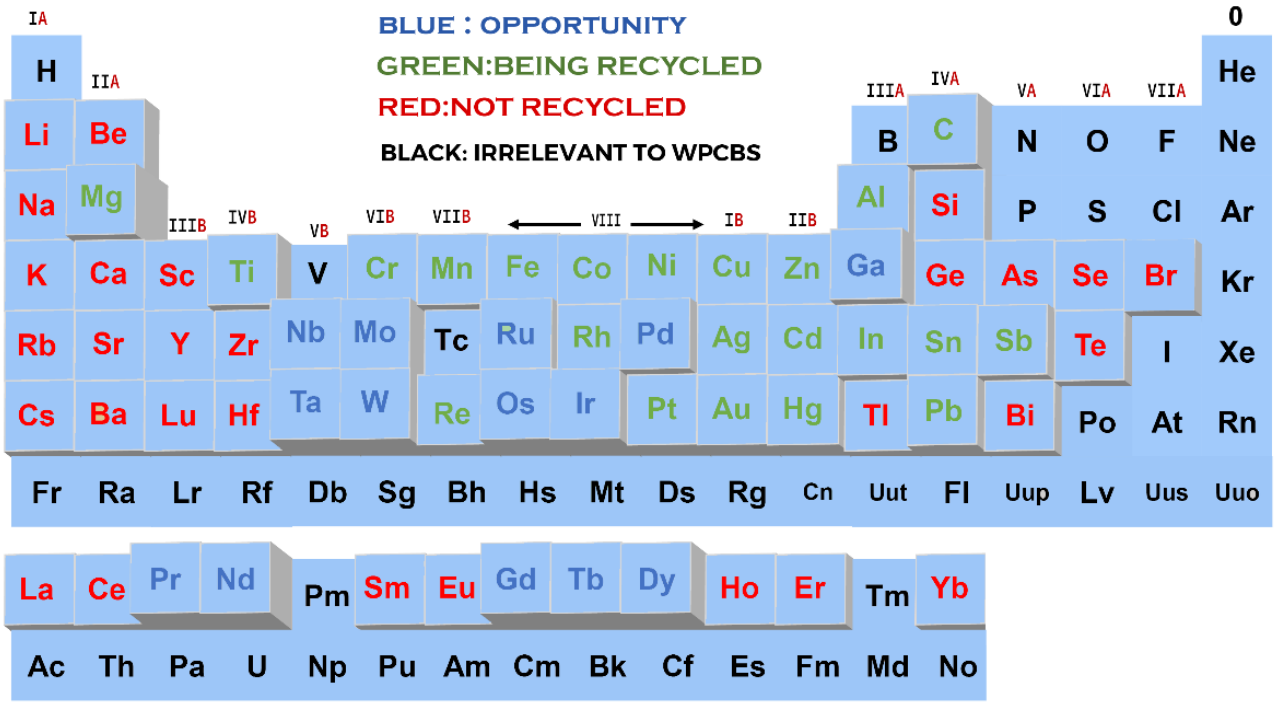


Jing Cao, et al. Adv. Mater. (2022) 2110518

Challenges in Sorting & Metal Recovery: Focus on Printed Circuit Boards (PCBs)

Current situation

- Concentrations too low
- Few elements recovered



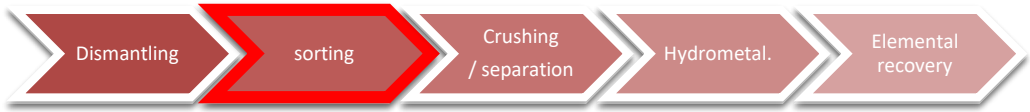
Challenges in Sorting & Metal Recovery: Focus on Printed Circuit Boards (PCBs)

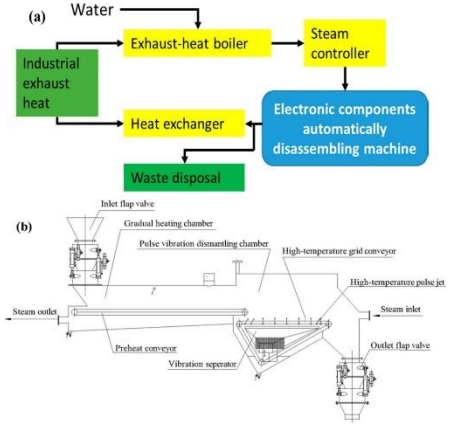
Current situation

- Concentrations too low
- Few elements recovered

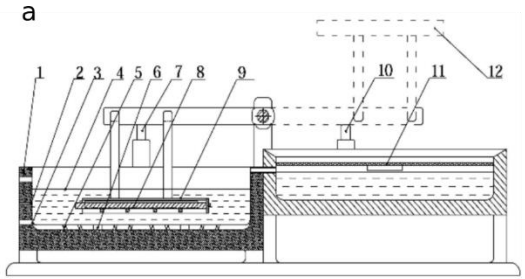
Our strategy: Enriching the stream: 1) **Need to dismantle PCBs (commercial)**

2) **Sorting e-components to Increase the concentration of elements (<u>No Commercial</u>)**

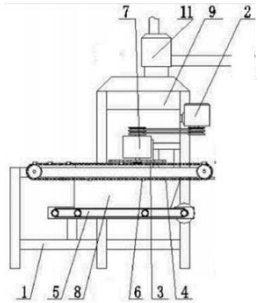




Chen et al., 2013



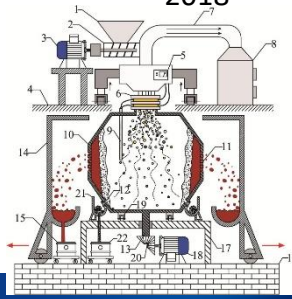
Huang et al., 2007



(Fang, Li et al. 2017)

(Li, Dong et al. 2018)

Meng et al. 2018



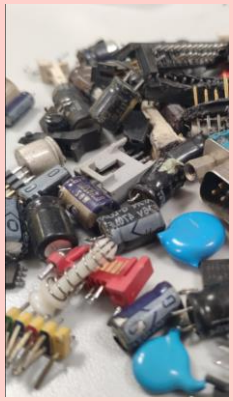
Change of paradigm: Disassemble instead of grinding

⇒ Simplified mixtures = new viable opportunities

(Au, Pt, Pd, M^x réfractaires: W, Mo, Nb, Ta; terres rares; Cr, Co, Ga, In, Mn, Ni, Sb, Sn, Zr etc.)

DISMANTLING

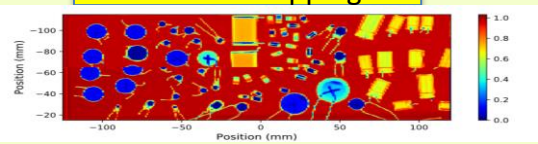
Waste-PCBs

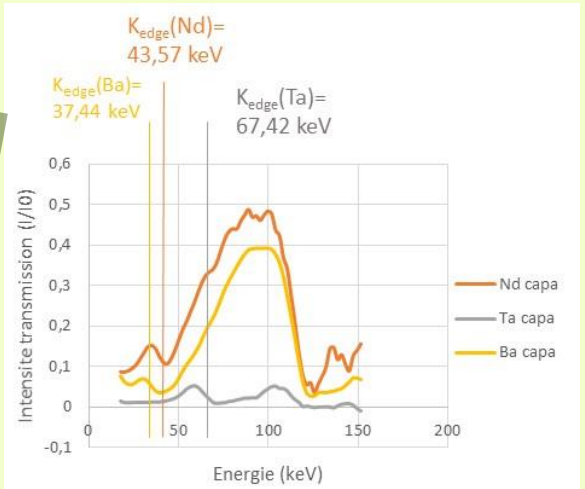


Electronic components mixture

JC Gabriel et al. Patents pending

ME- XRT mapping

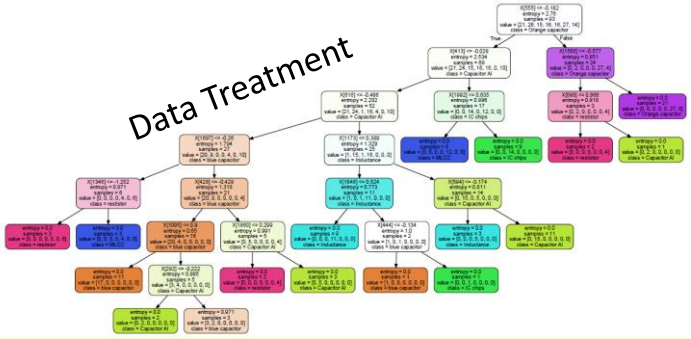




Sort / element

AA Maurice et al. *Sustainability* 2021

Data Treatment



Ta^0: 99+%

Nd_2O_3: 99+% ($~250k/t

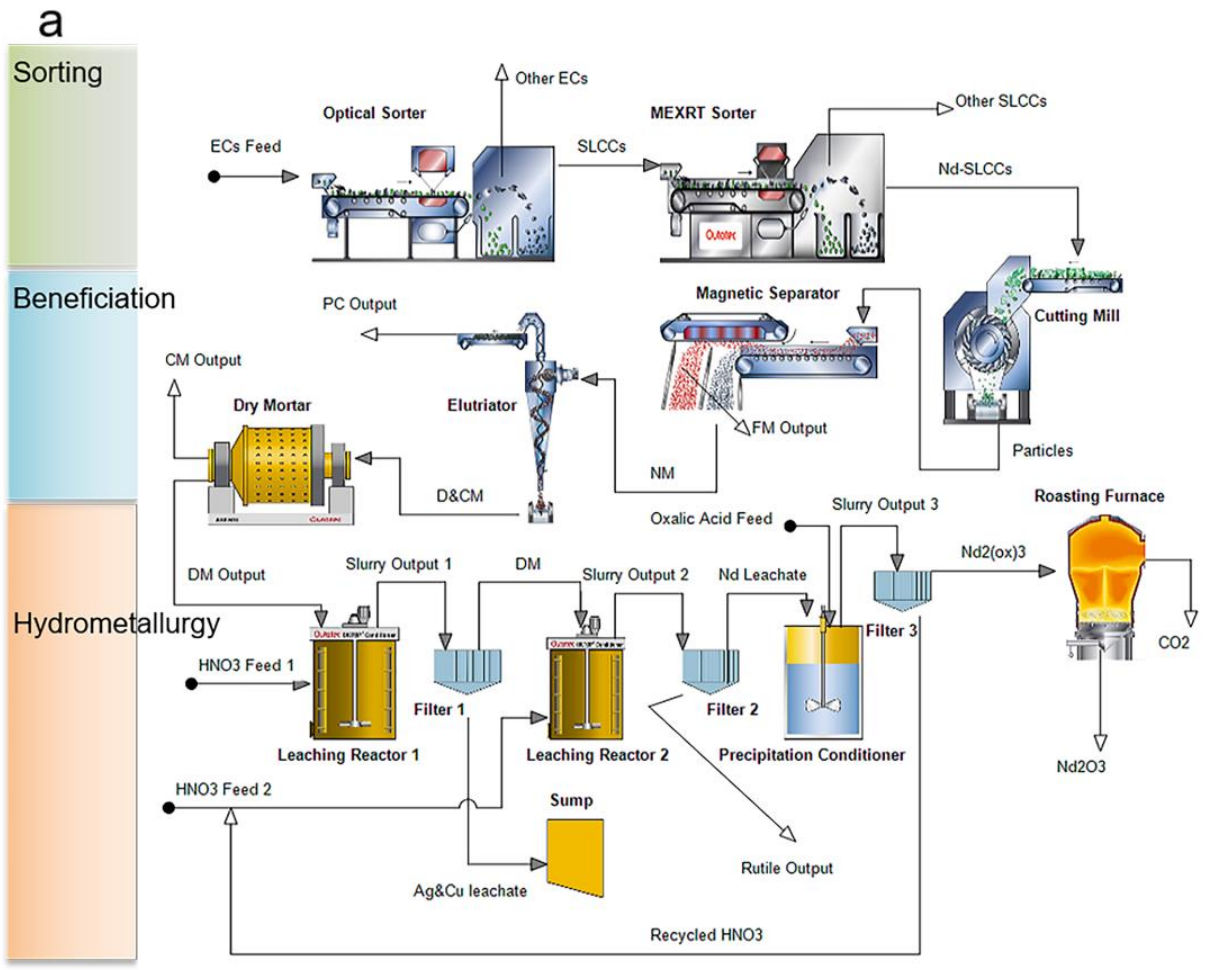
PURIF.

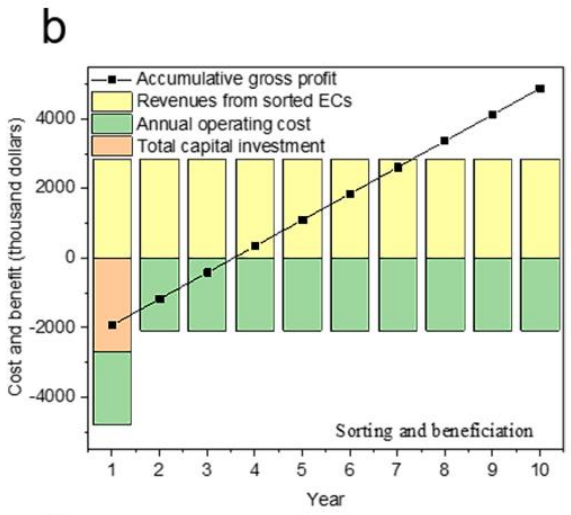
Phys/Hydro

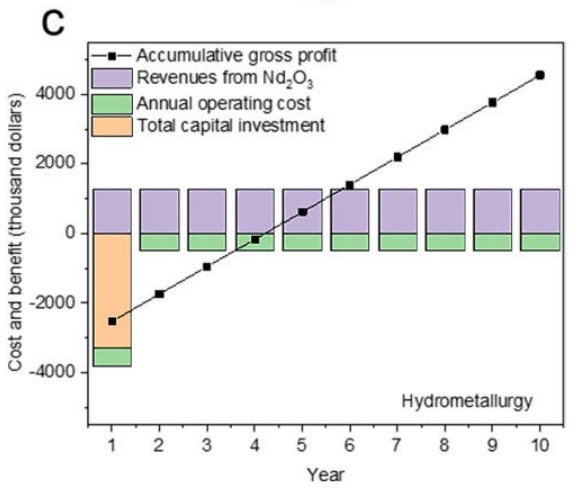
X. Dong et al. CEJ 2022

X. Dong; TH Nguyen Patents pending

Electronic Component Sorting Economic Viability?





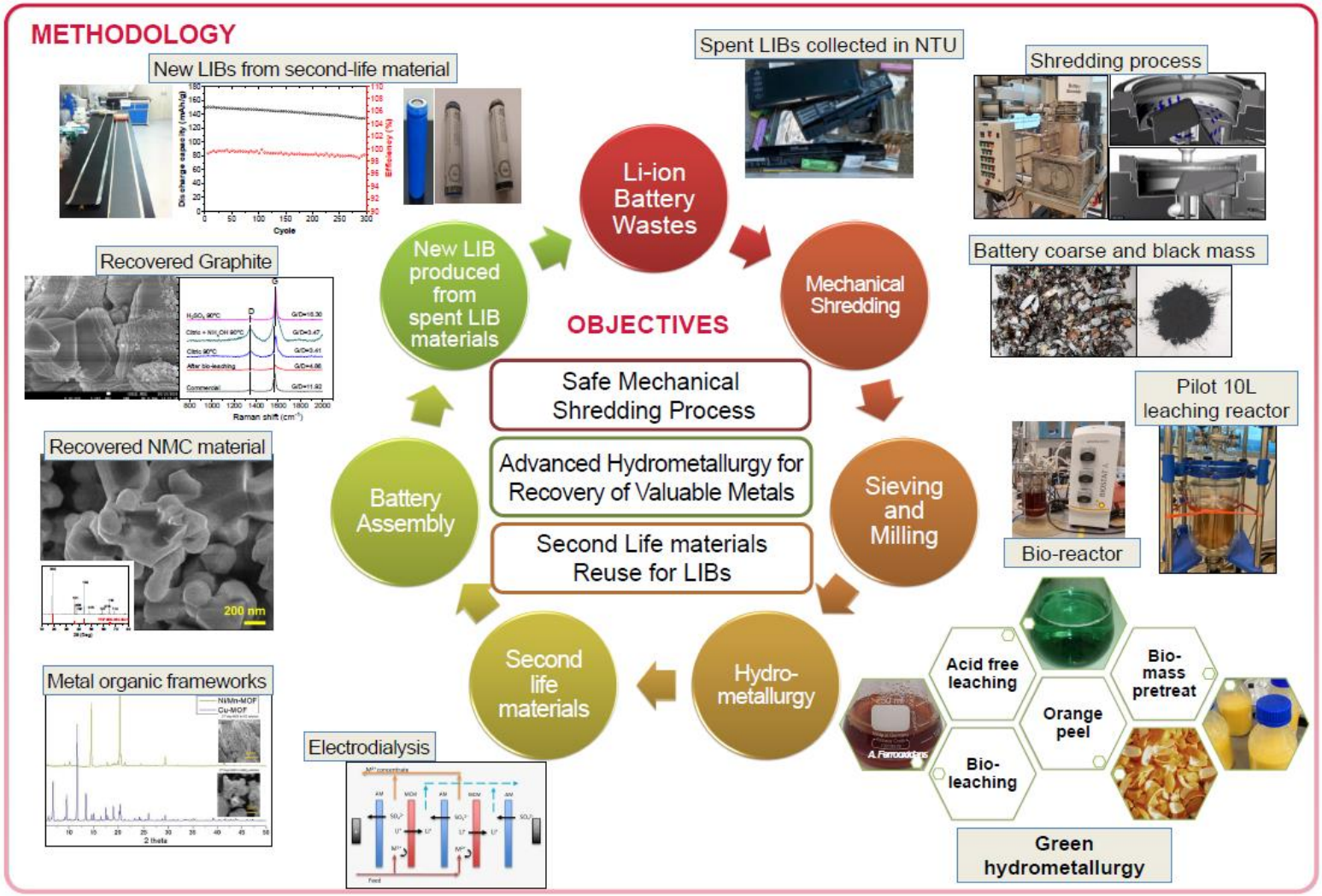


First assesment => profitable within 4 to 5 years

X. Dong et al. Chem. Engineering J. 441 (2022) 135886 / Patent Pending

Prof. Madhavi Srinivasan
Dr. Daniel Meyer
Assoc Prof. Dalton Tay
Prof. Cao Bin
Dr. Joseph Jegan Roy
Dr. Do Minh Phuong
Dr. Xing Zeng
Lim Hong Kit

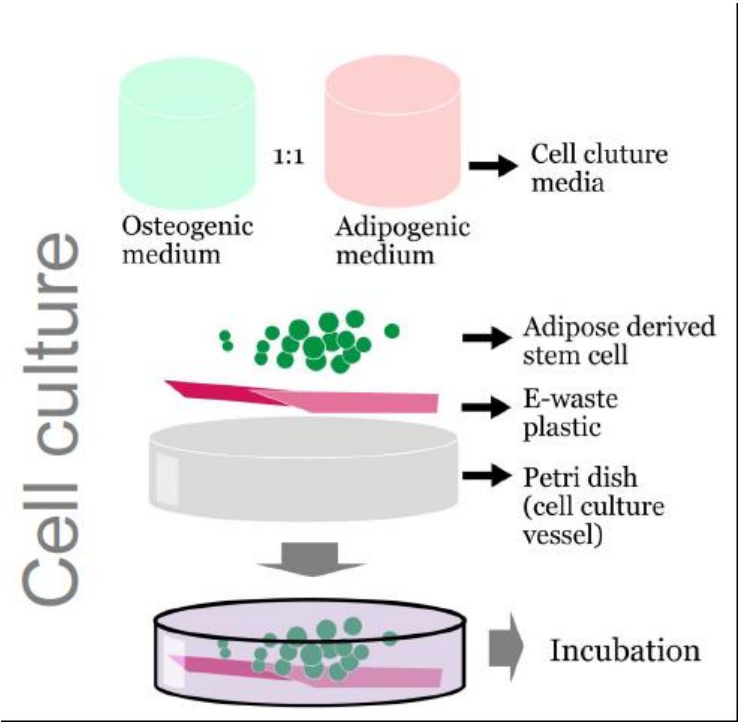
Lithium Batteries Recycling

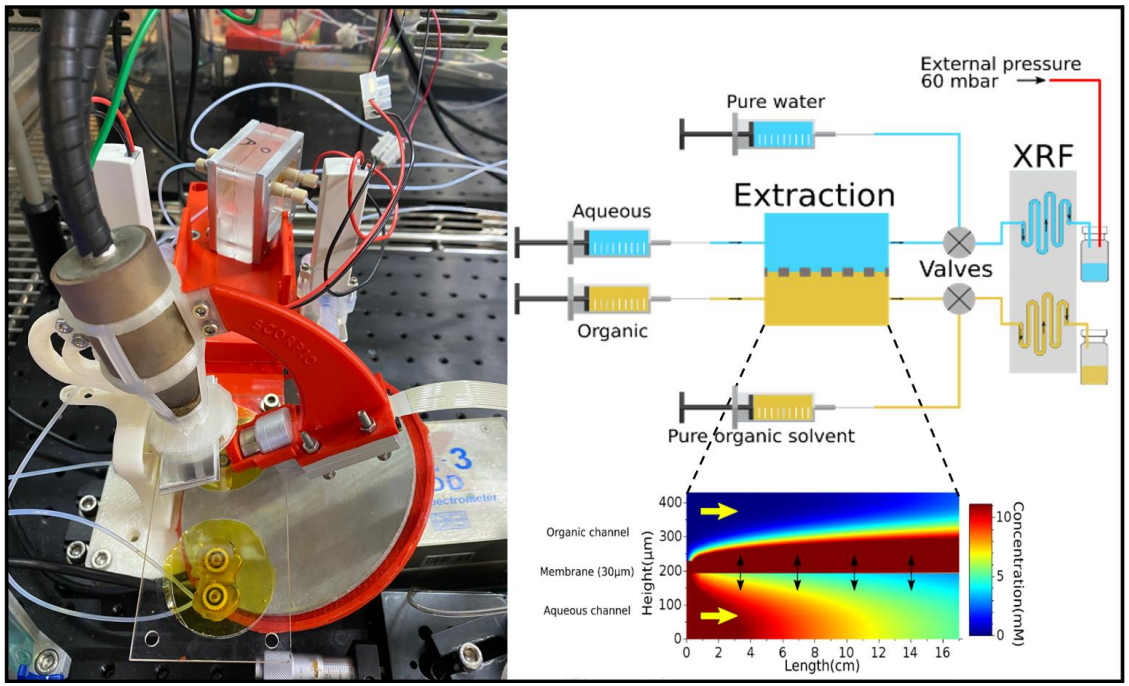


- Recovery >80 w% Spent LiB using green hydrometallurgy (**2 Licences**)
- Extraction rate (Co, Ni, Li, Fe, Mn) with purities > 90
- Demonstration of close loop: making of new LiB%

Conclusions: SCARCE Output Highlights Available for Licencing

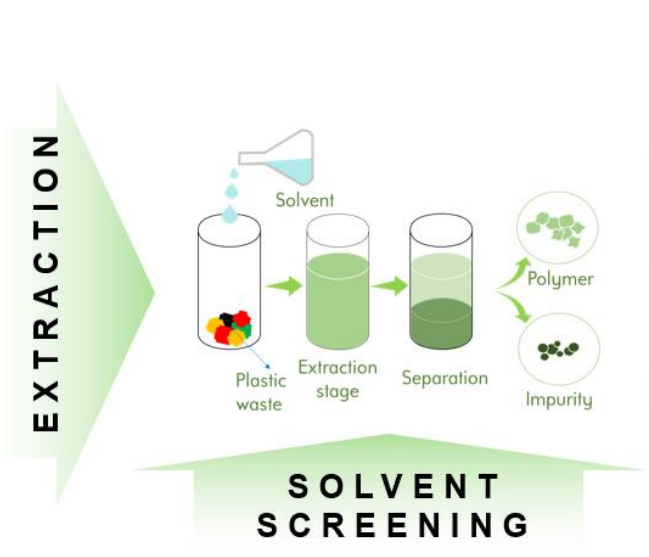
- **Re-use e-plastics for Cells Growth**
- **Fast Process development using 1st Xray Integrated Microfluidics**
- **Si recycling from PV pannels**
- **Elemental Sorting: Visible, ME-XRT (Ecs) and LIBS (Plastics)**
- **Nd & Ta Recycling from PCBs economically viable & green solvents**
- **Green closed loop recycling: LiB + Food waste – From LiB to LiB**

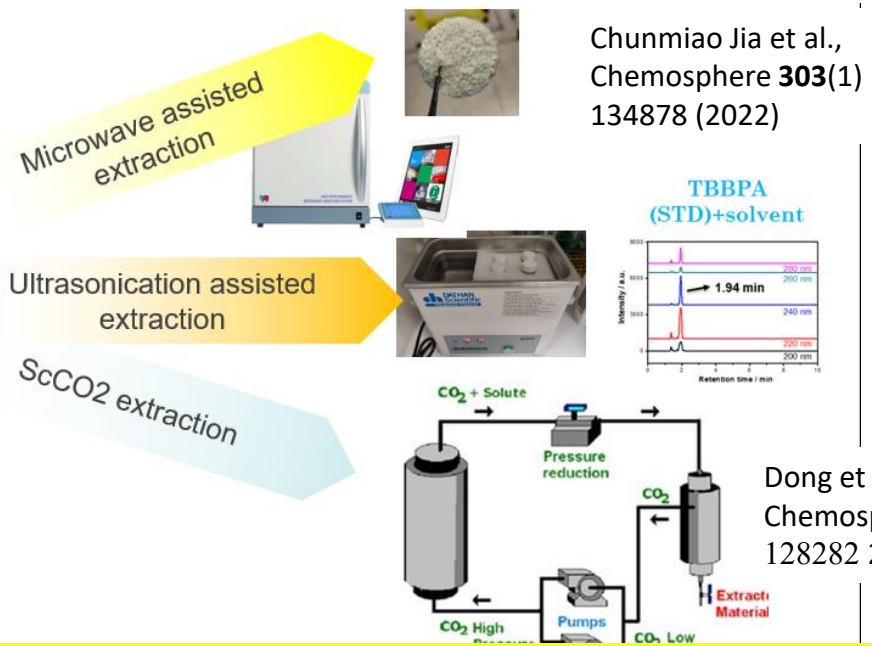




Conclusions: SCARCE Output Highlights Available for Licencing

- **Re-use e-plastics for Cells Growth**
- **Fast Process development using 1st Xray Integrated Microfluidics**
- **Si recycling from PV pannels**
- **Elemental Sorting: Visible, ME-XRT (Ecs) and LIBS (Plastics)**
- **Nd & Ta Recycling from PCBs economically viable & green solvents**
- **Green closed loop recycling: LiB + Food waste – From LiB to LiB**





Chunmiao Jia et al., Chemosphere **303**(1) 134878 (2022)

Dong et al. Chemosphere **263**, 128282 2021

=> SCARCE phase 2 under negociation (12/2022-12/2027): TRL 5 to 8 (+indus.)

Thanks for your attention!

CEA: jean-christophe.gabriel@cea.fr
T. +33 676 043 559

Nanyang Technological University:
jgabriel@ntu.edu.sg

Full publication list at: https://www.ntu.edu.sg/scarce

Thanks to ENSIC Nancy (Process) for two great Alumni:

Fabien Olivier
CEA/NTU joint PhD

Sarah Chevrier
VIA + PhD Student

Funding sources

National Environment Agency
Safeguard · Nurture · Cherish

SCARCE : *Financial support from NEA & MND #USS-IF-2018-4*

Industrial support from EPR ECOLOGIC SAS

EcoLogic
La 2e vie des équipements électriques

Acknowlegment and thanks to SCARCE's Team

NTU

Madhavi Srinivasan
Nripan Mathews
Prof. Cao Bin
Prof. Alex Yan Qingyu
Prof. Yu Jing
Lee Jong-Min (Assoc Prof) Dalton Tay Chor Yong

CEA

Dr. Andrea Brambilla
Dr. Anges Grandjean
Dr. Michael Carboni
Dr. Pierre Chagvardieff
Dr. Stephane Pellet Dr. Rostaing
Dr. Jean Duhamet
Dr. Jean Philippe Renault
Dr. Marlene Chapuis
Dr. Pierre Feydi
Dr. Emmanuel Billy
Dr. Jean Baptiste Sirven

SCARCE

Dr. Chan Jun Jie
Dr. Dja La Yang
Dr. Joseph Jeganroy
Dr. Wu Zhouran Kenny
Dr. Yuan Du
Dr. Do Minh Phuong
Dr. Saptak Rarotra
Dr. Vida Krikstolaityte
Dr. Sim Ying
Dr. Muhammad Iszaki
Dr. Tay Yeow Boon
Dr. Ines Beaugelin
Dr. Pham Huu Khue
Dr. Raihana Begum
Dr. Fang Wei
Dr. Liu Daobin
Dr. Xu Junhua
Dr. Xia Dong
Dr. Ange Maurice
Dr. Varun Rai
Dr. Dinh Ngoc Khang, Roy
Lina Cherni
Sarah Chevrier
Fabien Olivier
Nicolas Charpentier
Dr. Shi Pu Jiang
Dr. Wan Yan
Dr. Jia Chun Miao
Dr. Pallab Das
Dr. Zeng Qiang
Dr. Wang Hao