Società Chimica Italiana
Divisione di Didattica Chimica

Accademia Nazionale delle Scienze detta dei XL 1782

Piano Nazionale Lauree Scientifiche

VII SCUOLA NAZIONALE DI DIDATTICA DELLA CHIMICA "GIUSEPPE DEL RE"

La Chimica per uno sviluppo sostenibile e l'educazione civica

Bertinoro (FC), 6 - 9 ottobre 2022

Metalli Preziosi da Riciclo

Bertinoro, 7 ottobre 2022

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* Three pillars of the multifaceted sustainability concept

The triple bottom line for the circular economy: planet, people, profit

1. **Decoupling of production of chemicals, materials and fuels from fossil feedstock taking building block from renewable resources**
2. **Consumables are returned to the biosphere without negative effects after a sequence of bio-cascading steps in a climate and carbon neutral world**
3. **Renewable energy is used to fuel the processes**
4. **Zero waste approach (waste does not exist because atoms are not destroyed in chemical reactions): recycling and upcycling**
5. **Focus on non-renewable resources**

https://link.springer.com/book/10.1007/978-3-030-63436-0

European Commission

What is the European Green Deal?

December 2019
#EUGreenDeal

The European Green Deal is about **improving the well-being of people**. Making Europe climate-neutral and protecting our natural habitat will be good for people, planet and economy. No one will be left behind.

The EU will:

- Become climate-neutral by 2050
- Protect human life, animals and plants, by cutting pollution
- Help companies become world leaders in clean products and technologies
- Help ensure a just and inclusive transition

TRANSFORMING THE EU'S ECONOMY FOR A SUSTAINABLE FUTURE

https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf

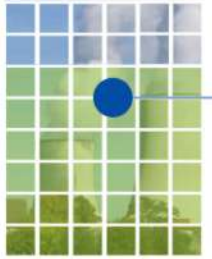
CLIMATE

The EU will be **climate neutral in 2050**.
The Commission will propose a European Climate Law turning the political commitment into a legal obligation and a trigger for investment.

Reaching this target will require action by all sectors of our economy:

ENERGY

Decarbonise the energy sector



The production and use of energy account for more than **75%** of the EU's greenhouse gas emissions

BUILDINGS

Renovate buildings, to help people cut their energy bills and energy use

40% of our energy consumption is by buildings

INDUSTRY

Support industry to innovate and to become global leaders in the green economy

European industry only uses **12%** recycled materials

MOBILITY

Roll out cleaner, cheaper and healthier forms of private and public transport

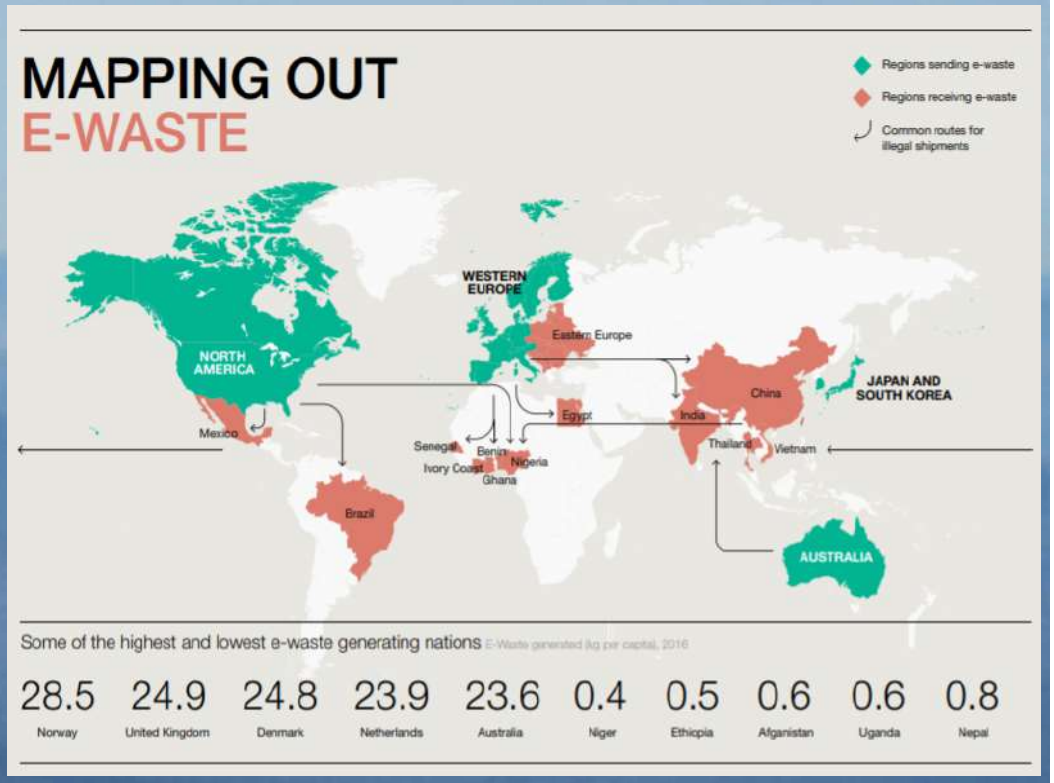
Transport represents **25%** of our emissions

Directive 2008/98/EC, WASTE Hierarchy

Economia Lineare: depredo produco e getto con energia fossile
Economia Circolare: riciclo, riuso, restituisco con energie rinnovabili

* Electrical & Electronic Equipment (EEE)

The consumption of EEE is strongly linked to widespread global economic development and enhanced living standards and increases annually by 2.5 Mt
Electronics require gold.
Attractive technologies to address **climate change**, such as solar cells and electric car batteries, curb CO2 emissions but further increase the "e-waste" stream



V. Forti et al., *The Global E-waste Monitor (2020)*

EEE production is resource demanding

- high embodied energy
- Non renewable resources
- mounting shortage of raw materials
- Increase in e-waste

The fate of EEE matters!

* EEE usage results in a huge amount of E-waste

Since 2014
e-waste generation +9.2 Mt
e-waste recycling +1.8 Mt

Exported, wrongly discarded, landfilled, releases toxic substances (Hg, CFC, BFR) into the environment, creating persistent hazards.

- E-waste is an 'urban mine', containing precious and base metals
- The value of raw materials in the global e-waste generated in 2019 is ca. 57 billion USD
- A net saving of 15 Mt of CO_2 is due to the recycling of secondary raw materials substituted to virgin materials.

*Unrenewable resources

- E-waste comprise up to 60 different metals, plastics and refractory oxides (typically, 40%, 30% and 30%).
  - Base metals are Cu, Ni, Pb, Zn, Fe, Sn, Al
  - Precious metals are Au, Ag, Pd, Pt, Rh, Ir, Os, Ru
  - Specialty metals are In, Ga, Se, Sb, Te, Ta, rare earth elements
  - Other toxic metals are Hg, Cr, Cd
- PCBs contribute only to 6% of the weight of e-waste but they are the main source of valuable metals (Au, Ag, Pd, Pt, Cu, Ni, Co, Zn, and Al)

* Gold recycling

Why?

- Au in e-waste > 20 times than in natural gold ores
- Gold is the “paying metal”
- Gold is an“unsecure” endangered element

Where?

* PCBs, RAM boards
  * core of most electronics
  * 6% in weight of e-waste
  * concentrated source of precious and base metals (Au, Ag, Pd, Pt, Cu, Ni, Co, Zn, Al)

Charles et al 2017 doi: 10.1016/j.wasman.2016.11.018
Hagelüken et al 2010 doi: 10.1007/BF03214988
Sahajwalla et al 2020doi: 10.1016/j.mtsust.2020.100040

* Gold recycling: the state of the art

Dismantling

Metal separation

Gold recovery

Pyrometallurgy
scraps are burned in plasma arc or blast furnace

Floating slags, sinking sludges, oils from plastics, solid waste and toxic emissions are produced (at 1250 C lead vapors, dioxins, and furans are released)

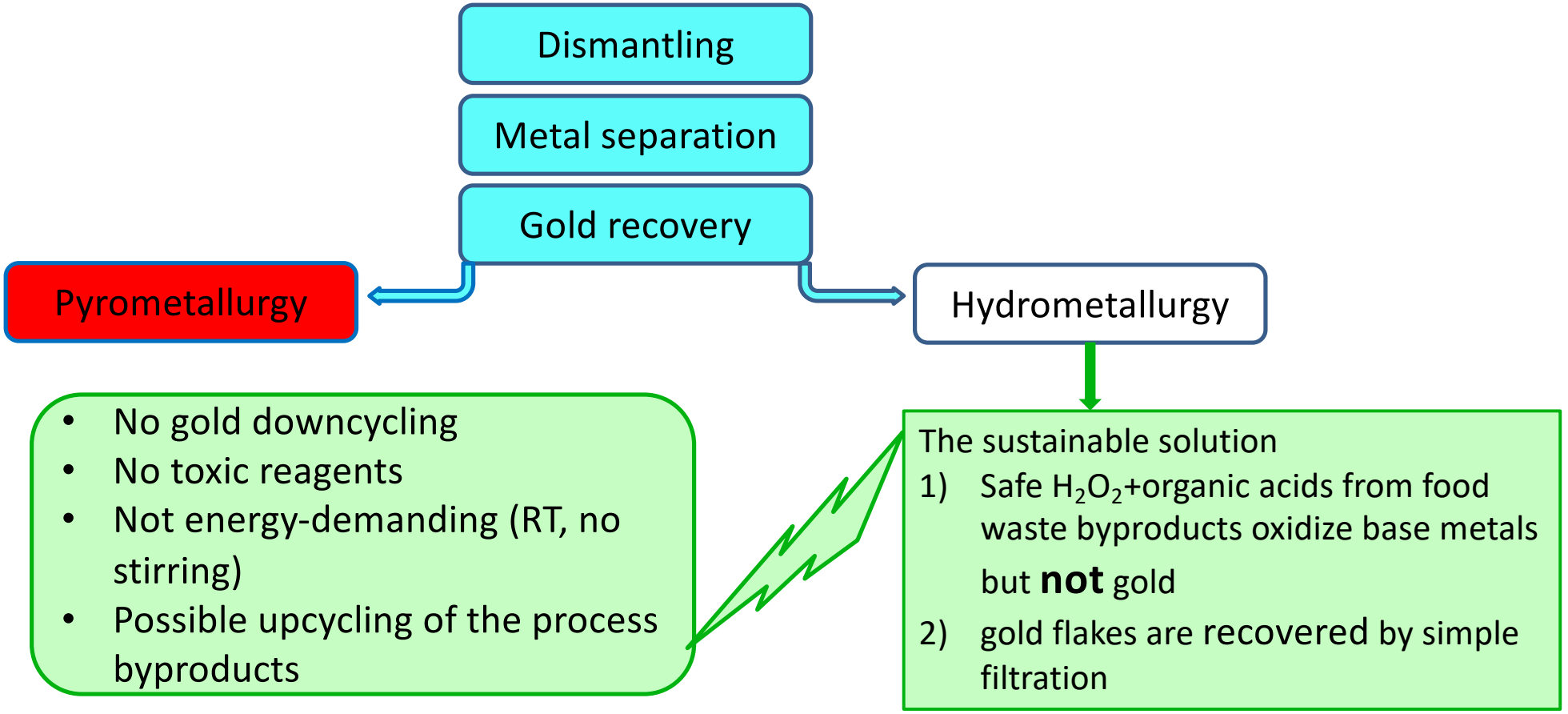
Hydrometallurgy

1. strong oxidizing agents + complexing leachants (cyanide, halides, thiourea and disubstituted thiourea, thiocyanate, thiosulfate) dissolve both base metals and gold (ex aqua regia, ozone in dilute chloride media, hypochlorite - chloride solutions)
2. gold ions are selectively reduced to gold metal

accidents at various gold recovery facilities resulted in severe contamination of natural water resources over the use of cyanide


12 Principles - Green Chemistry
Green Chemistry
Prevent Waste
Atom Economy
Avoid harmful synthetic method
Reduce product toxicity
Use safe or no solvents
Avoid high temperatures and pressures
Use renewable resources
Omit derivatization
Use catalysts
Design for degradation
In-process monitoring
Prevent accidents
https://royalsocietypublishing.org/doi/pdf/10.1098/rsos.191378

Gold recycling: how?
from alchemy to a sustainable solution



* SDG1. Profit: 78.0% of 53.6 Mt of e-waste in 2020 is uncollected with a wasted metal value of $57 billion: gold recovery could implement policies to end poverty (1.1, 1.2, 1.4, 1a, 1b)

* SDG3. Safe gold recovery prevents marginalized populations exposition to health risks from (i) illegal and hazardous e-waste processing (ii) gold mining (3.9-3c)

* SDG4. Education, research-oriented didactic path, scientific edutainment online games and theater STE(A)M performances to improve awareness in children and adults and boost engagement via the aesthetics (gold/preciousness/classical masterpieces) in humanistic environments, impenetrable to science

* Women make up just 14.9% of gold miners but e-waste treatment in developing countries burdens them disproportionately (flexible hours permit them to care for children), with dangerous tasks without safety equipment and health insurance

* e-waste hazardous chemicals specifically affect women's morbidity/mortality, fertility.

* The proposed green gold recovery resolves barriers to fair labour independently of stereotypical gender roles, age, culture

* SDG 8. Decent job creation (8.3) without environmental degradation (8.4), avoiding modern slavery and child-labour in illegal e-waste treatment

* SDG9. The scale-up promotes sustainable industrialization (9.1) with resource-use efficiency and green technologies (9.4) enhancing scientific research(9.b) in developing countries

* SDG 11. Safe and sustainable urban waste management (11.6)

* SDG12. Prevents depredation of gold via its efficient use (12.2), with environmentally sound management of e-waste (12.4), especially in developing countries (12.1-12.a-12.c). The project inspires companies, policy-makers and people to adopt sustainable lifestyles (12.6-12.7-12.8) via recycling (12.5)

* SGD13. For every ton of e-waste recycled, 1.44 tons of CO2 are avoided (considering transporting and pretreatment): no virgin materials are produced, energy can be recovered from non-recyclables, and illegal flows are eradicated. The present strategy does not need recovery corrections because the regained gold is not downcycled

- SDG15. Avoiding dumping sites in developing countries reduces the degradation of natural habitats (15.5)

*SDG16. Avoiding dumping sites in developing countries is a just transiton

*SDG16. Avoiding dumping sites in developing countries needs strong partnership for the goal

Gold peeling:
systematic experiments with organic acids from food waste

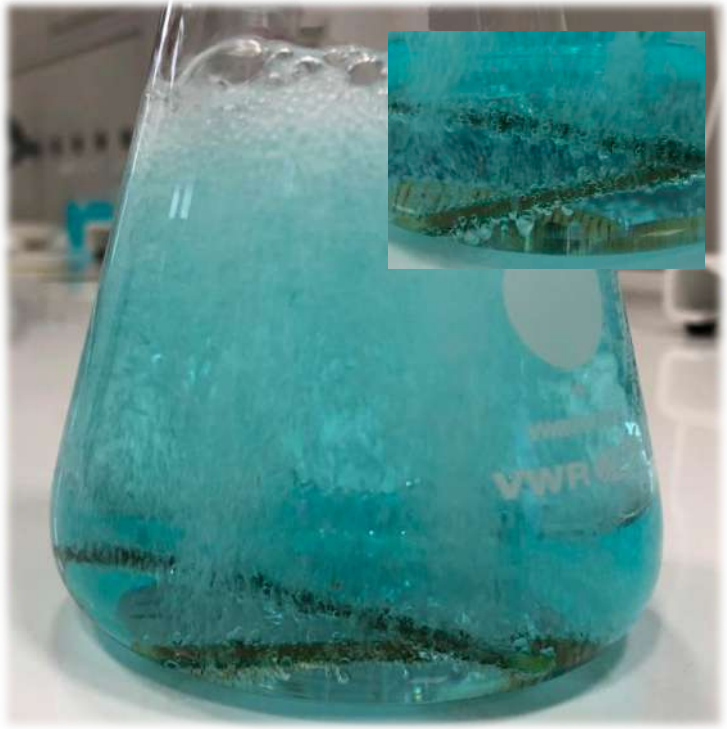
• volume of the reagents: 20 ml • RAM golden edges 5% of the reagent solution (w/v)	A	B	C	D
LA (M)	6.0	3.0	2.0	1.0
H_2O_2 (M)	6.0	3.0	2.0	1.0
complete peeling, 12 h	yes	yes	yes	No

Waste RAM boards: ELIXIR 512MB DDR-400MHz-CL3 PC3200U-30330 and S3+ PC3200/ DDR400 512MB

Gold peeling: heat is not necessary

At 60° Fenton chemistry triggered

$H_2O_2+e^- \rightarrow OH^-+OH\cdot$

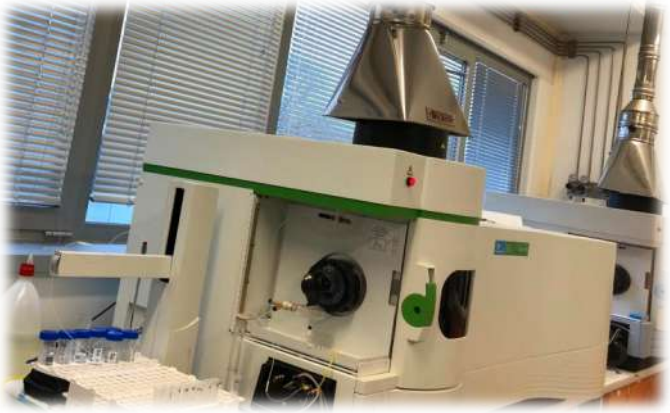


RT: energy saving and safe process

$H_2O_2+2H^++2e^- \rightarrow 2H_2O$

$Cu \rightarrow Cu^{++}+2e^-$

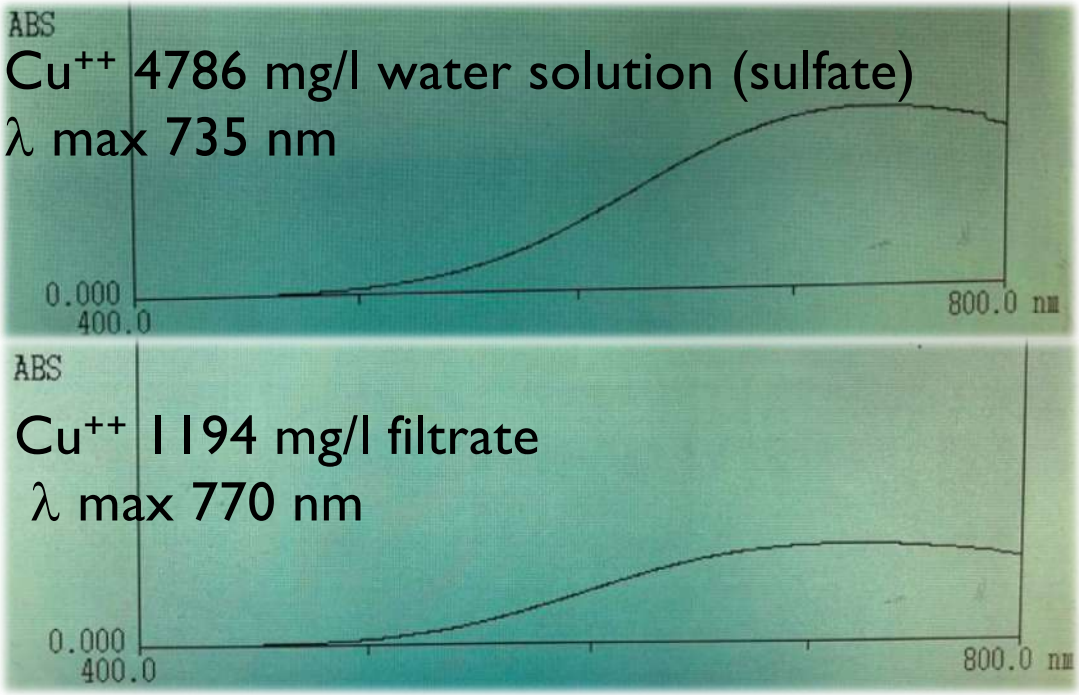
Ion Coupled Plasma-Optical Emission Spectroscopy of filtrates



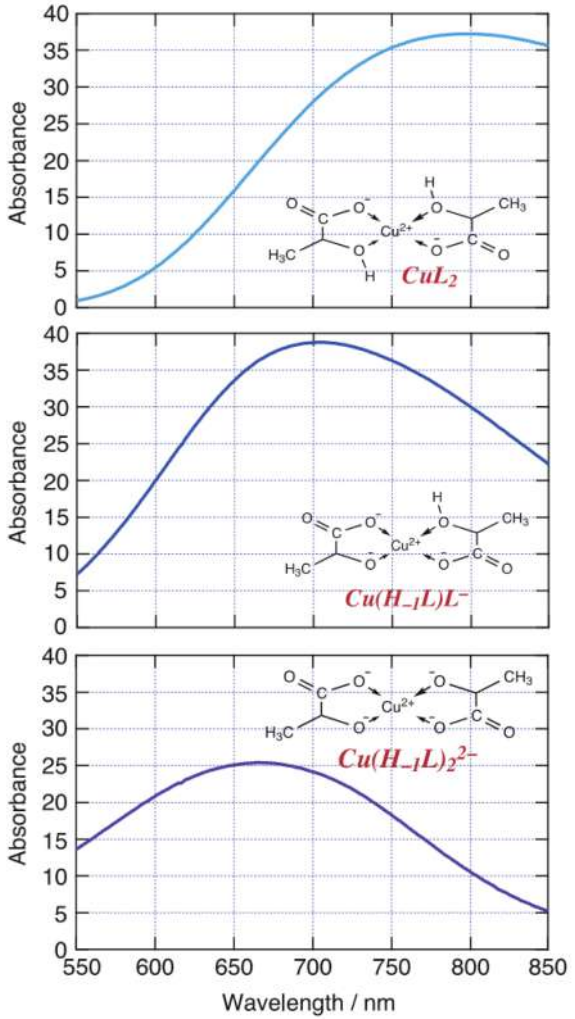
	A	B	C	D
Cu (mg/g RAM edges)	213.949	230.908	236.457	0.316
Ni (mg/g RAM edges)	16.405	17.268	17.112	1.251
Zn (mg/g RAM edges)	0.294	0.340	0.321	0.115
Pb (mg/g RAM edges)	0.050	0.063	0.072	0.003
Au (mg/g RAM edges)	0.002	0.002	0.002	0.001
Cu RSD (%)	0.9	1.6	1.4	1.2
Ni RSD (%)	1.5	1.2	1.1	0.9
Zn RSD (%)	1.3	1.5	1	0.9
Pb RSD (%)	1.2	1.6	1.7	0.9
Au RSD (%)	1.1	1.3	1.7	1.5

- Be, Cd, Li, Mn, Mo, Sn, Tl <LOQs
- Ag, Al, As, B, Ba, Co, Cr, Fe, Sb, Se, Ti < 0.05 mg/g RAM edges
- Gold has not been leached (these results and negative spot tests with $SnCl_2$)

A UV-Vis Spectrophotometric characterization of the filtrate



The presence of species in the filtrate depend on redox potentials and equilibrium constants



Chen T et al. 2019 doi:10.1149/2.1231914jes

From e-waste, using food waste.....

...to gold...

...and Cu Lactate

useful to obtain Cu_2O for the eco-design of circular electronics

A paradigm shift to circular electronics needs research outreach STE(A)M

https://www.youtube.com/watch?v=arU8aXsJBvs

https://www.youtube.com/embed/HtDVhNiVpjk	Saturno
https://www.youtube.com/embed/SIZtjTigd2Y	Giove
https://www.youtube.com/embed/bG-xAh40COY	Marte
https://www.youtube.com/embed/AC-tC9H_0Rk	Venere
https://www.youtube.com/embed/lGum5oH_1qU	Mercurio
https://www.youtube.com/embed/r9YO62gj2V0	Luna
https://www.youtube.com/embed/kfJRyfyPx6o	Sole

https://youtu.be/yz3AveKLiW8 https://youtu.be/pScf2RfP51M

https://iopscience.iop.org/article/10.1088/1361-6528/ac9ec6

Nanotechnology

ACCEPTED MANUSCRIPT • OPEN ACCESS

Recovery of gold from e-waste via food waste byproducts

Teresa Cecchi[1], Zhaojing Gao[2], Christophe Clément[2], Anthony Camus[2], Andrew Karim[2], Olivier Girard[2] and Clara Santato[2]

Accepted Manuscript online 31 October 2022 • © 2022 The Author(s). Published by IOP Publishing Ltd

What is an Accepted Manuscript?

DOI 10.1088/1361-6528/ac9ec6

Grazie per l'attenzione!

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