TOWARDS SUSTAINABLE GOLD EXTRACTION WITH CYANIDE-FREE LEACHING AND INNOVATIVE ELECTROCHEMISTRY

Ivan Korolev
Research Scientist, Circular Economy Solutions

Morecovery Workshop

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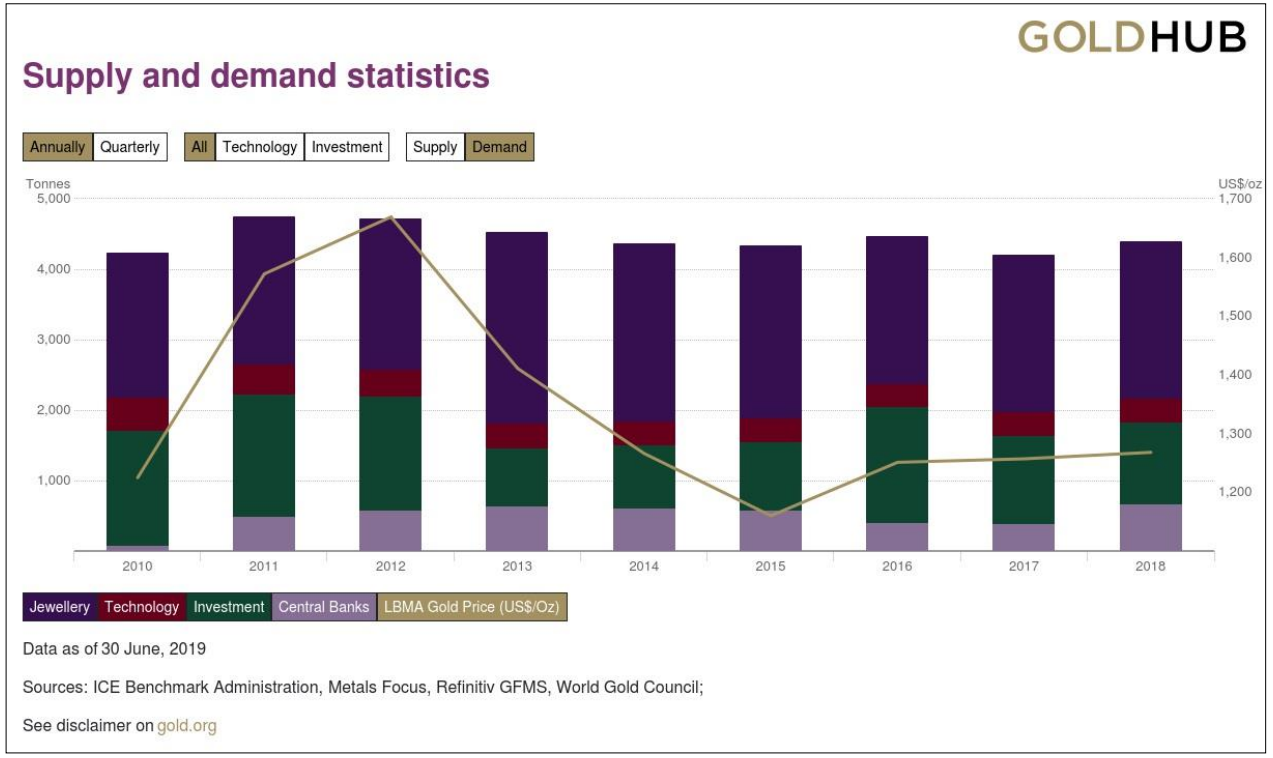
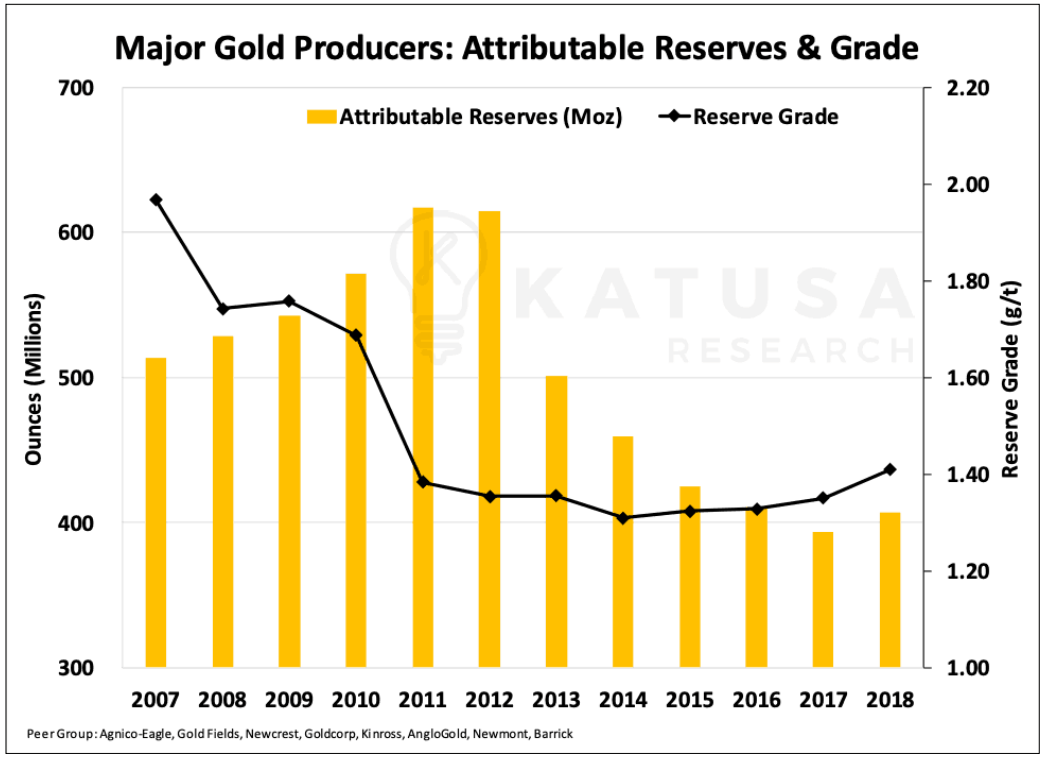
INTRODUCTION



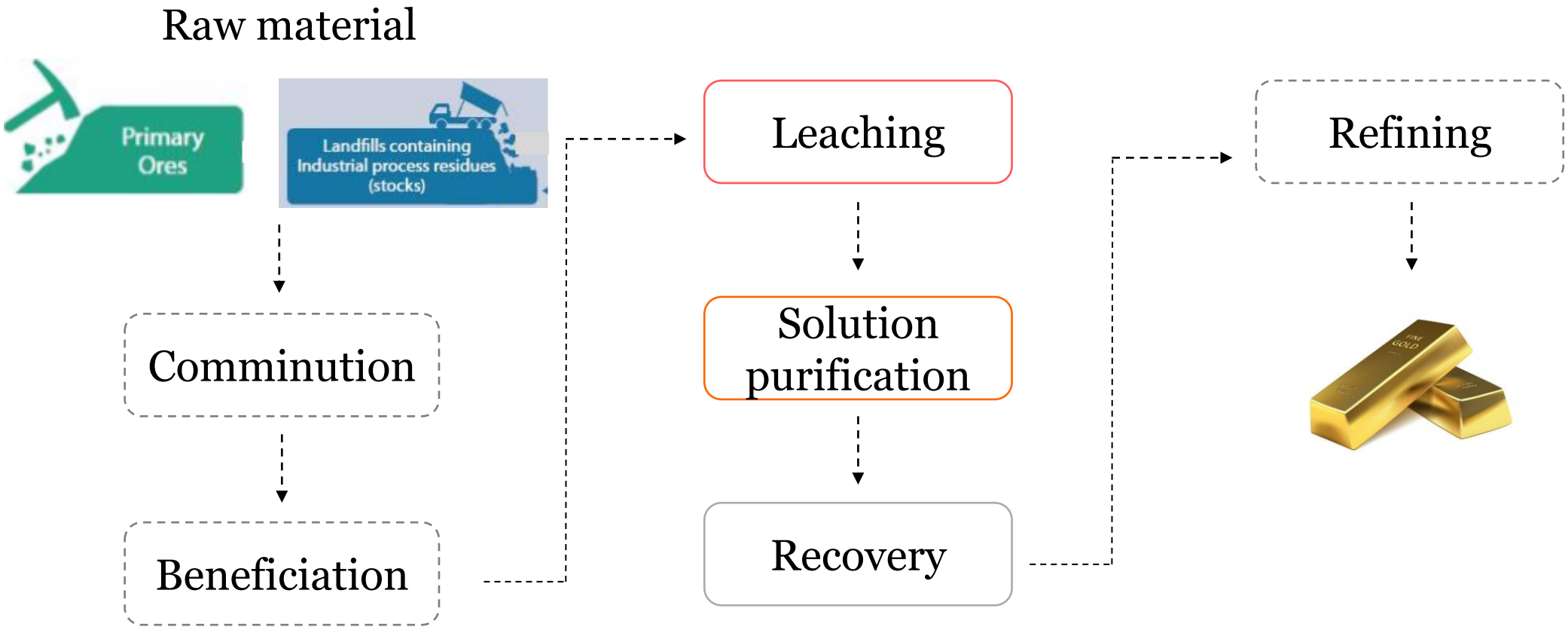
High demand for gold



Ore grades are on decline

Source: https://www.theinvestorspodcast.com/

GOLD PROCESSING TECHNOLOGY



CYANIDE LEACHING

Cyanide ion (CN^-), NaCN, KCN

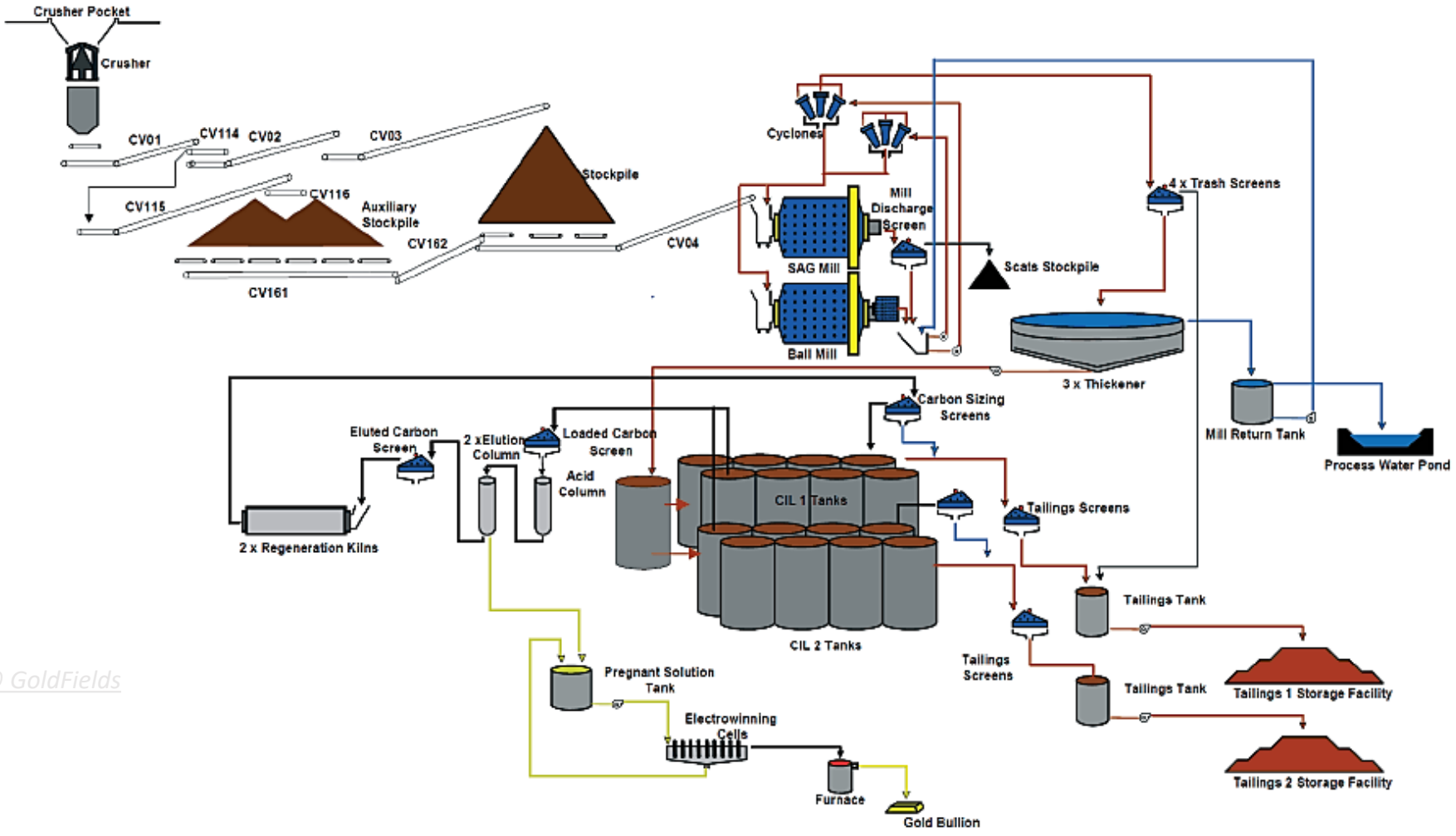
pH >10, room temperature, atmospheric pressure

$$4Au + 8CN^- + O_2 + 2H_2O \rightarrow \mathbf{4Au(CN)_2^-} + 4OH^-$$

- Well-known and simple process
- High selectivity for gold and stability

- Highly toxic
- Risk for human health and environment
- Strict regulations
- Ban for the use of cyanide
- Low process efficiency in complex ores

GOLD CYANIDATION FLOWSHEET



ALTERNATIVE REAGENTS

Industrial scale:

- Thiosulfate ($S_2O_3^{2-}$)

(Barrick Gold at Nevada, USA)

Development Stage

- **Chloride (Cl^-)**
- **Glycine ($C_2H_5NO_2$)**
- Thiocyanate (SCN^-)
- Thiourea (CH_4N_2S)

CHLORIDE LEACHING

Chloride (Cl^-), NaCl

pH <3, elevated temperatures (65-95 °C), atmospheric pressure

$$Au + 4[Cl]^- + 3[CuCl]^+ \rightarrow [\boldsymbol{AuCl_2}]^- + [CuCl_3]^{2-}$$

$$Au + 2[FeCl_2]^+ \rightarrow [\boldsymbol{AuCl_2}]^- + Fe^{2+}$$

Less-toxic
Fast and efficient dissolution kinetics
Simultaneous dissolution of other metals

GLYCINE LEACHING

Glycine, NH_2CH_2COOH

pH >9, elevated temperatures (40-75° C), atmospheric pressure

$$4Au + 8NH_2CH_2COOH + 4OH^- + O_2 \rightarrow \mathbf{4Au(NH_2CH_2COO)_2^-} + 6H_2O$$

Non-toxic
Simple process
Stable over wide Eh-pH range
Easily recyclable and reusable
Strongly attract metal ions like Au

SOCRATES

Zero Waste

EU MSCA-ETN

WP 1: Metal extraction

Extraction of metals from industrial residues by:
- Solvometallurgy using organic solvents
- Ionometallurgy using Deep Eutectic Solvents (DESs)
- Hydrometallurgy using aqueous solutions
- Plasma metallurgy (Plasma-driven fuming process)

Main goals:
- Efficient extraction
- Selectivity
- Process scalability
- Economic feasibility

WP 2: Metal recovery

Synthesis of extractants, recovery of metals from both aqueous and ionic solutions by cementation, ion exchange and electrolytic techniques. In-silico approaches to describe solvent miscibility in solvent extraction processes and to design new extractants

Main goals:
- Recovery of solid metals
- High selectivity
- Process scalability
- Economic feasibility

Fe – rich sludge dissolved in DESs

Cementation of Fe out of DES on Zn substrate

SEM image of Cu flotation tailings

Cement mortars incorporating slags

WP 4: Advanced characterisation, mapping and integrated assessment of flowsheets

- Characterisation of SOCRATES residues:
  - Elemental composition
  - Mineralogical composition
  - Distribution of phases and elements
  - Porosity
  - Oxidation state of metal ions
- Sustainability assessment of flowsheets through simulation-based approach.

WP 3: Residual matrix valorisation

- Valorisation of residues from WP1 in applications such as cements, inorganic Polymers, catalysts

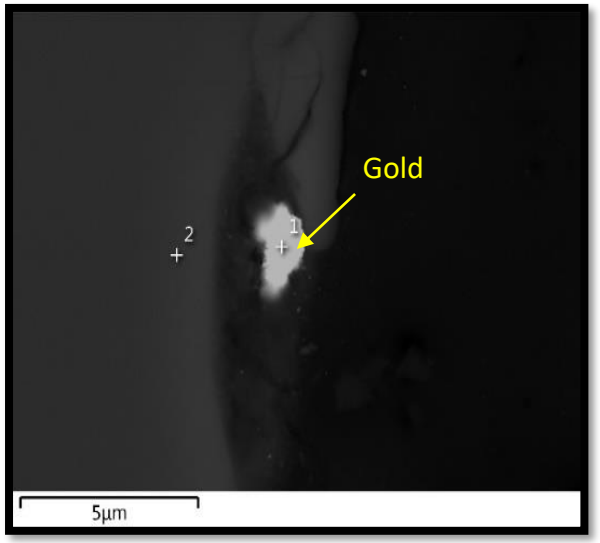
Main goals:
- Valorisation of the mineral fraction of the residues, composing 90-99% of the residues.

This project has received funding from the EU Framework Programme for Research and Innovation Horizon 2020 under Grant Agreement No. 721385

www.etn-socrates.eu

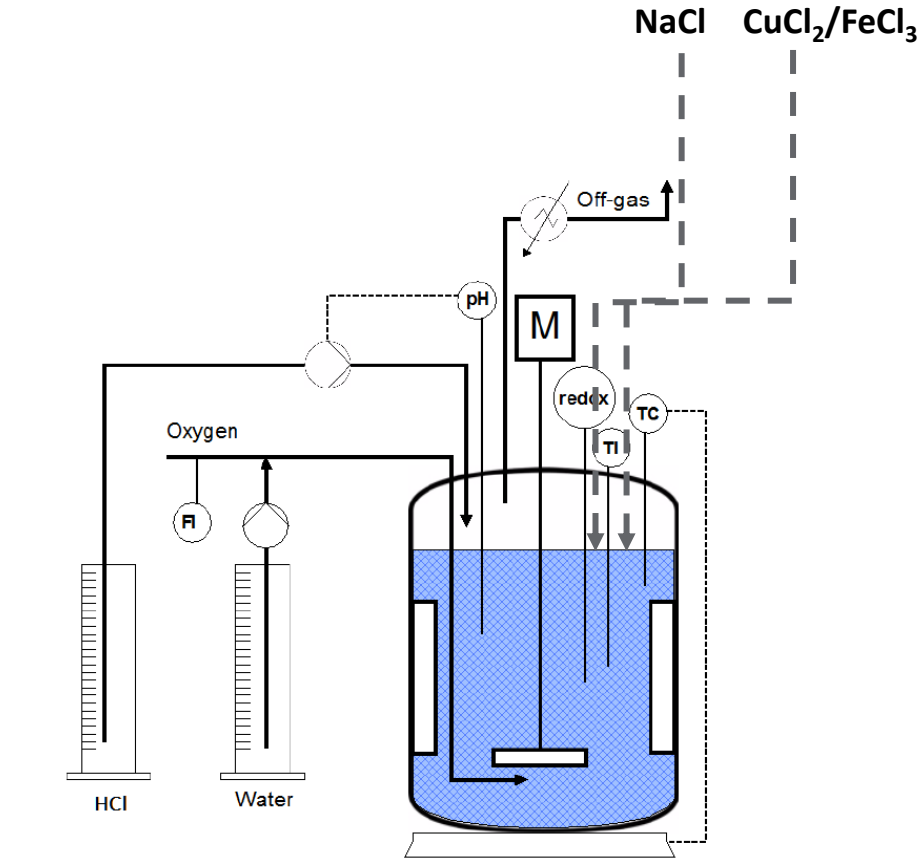
INITIAL MATERIAL

Element	Content	Mineral	Content
Au	0.21 ppm	Pyrite	1.8 %
Fe	3.56 %	Pyrrhotite	2.8 %
Cu	0.09 %	Chalcopyrite	0.2 %
Co	0.04 %	Sphalerite	0.07 %
Ni	0.03 %	Quartz	35 %
Zn	0.04 %	Dolomite	25 %
		Hornblende	22 %
		Others	13 %

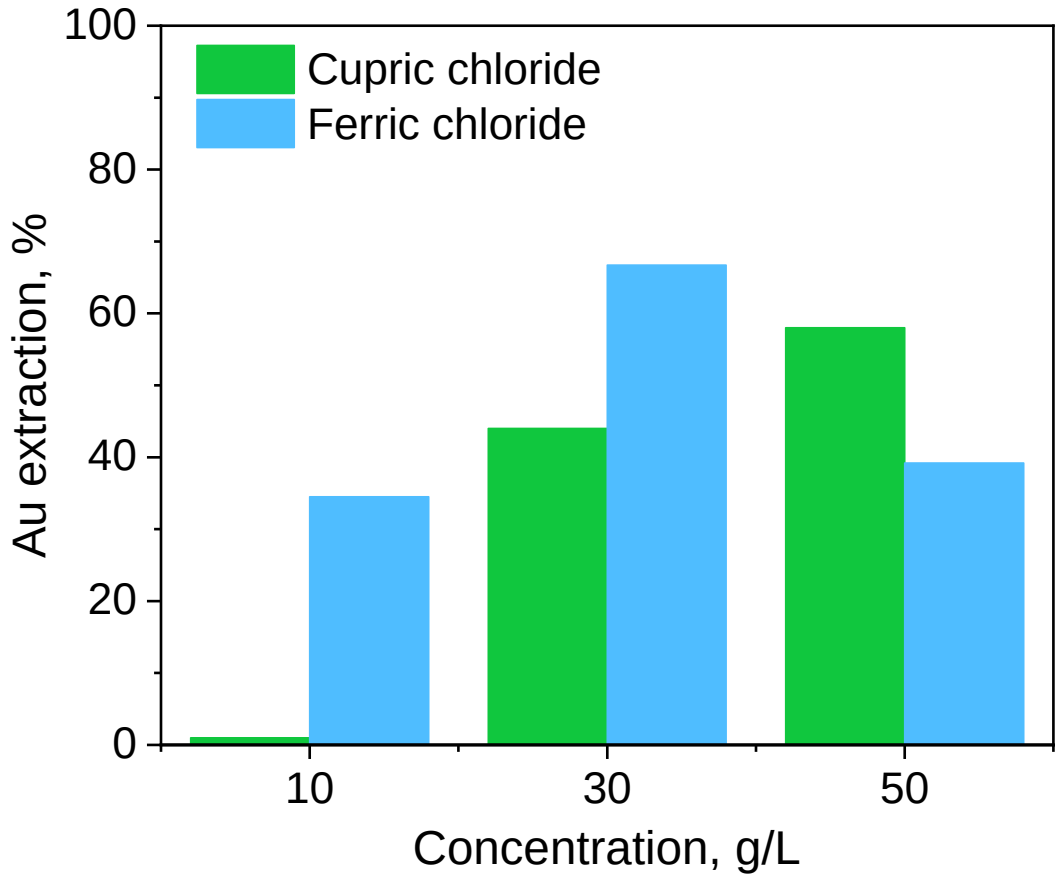


Gold at the rim of quartz grain

CHLORIDE LEACHING EXPERIMENTS



Titanium Reactor



NaCl	pH	T	Time
250 g/L	1-2	95 °C	24 h

Altinkaya et al., EMC 2019.

GOLD EXTRACTION

Flotation tailings

- Cyanide – 78%
- Ferric chloride – 67%
- Cupric chloride – 58%
- Glycine – 60%

Refractory ore

- Cyanide – 64%
- Ferric chloride – 93%
- Cupric chloride – 91%
- Glycine – 89%

ELECTROCHEMICAL METAL RECOVERY

METAL ELECTROWINNING

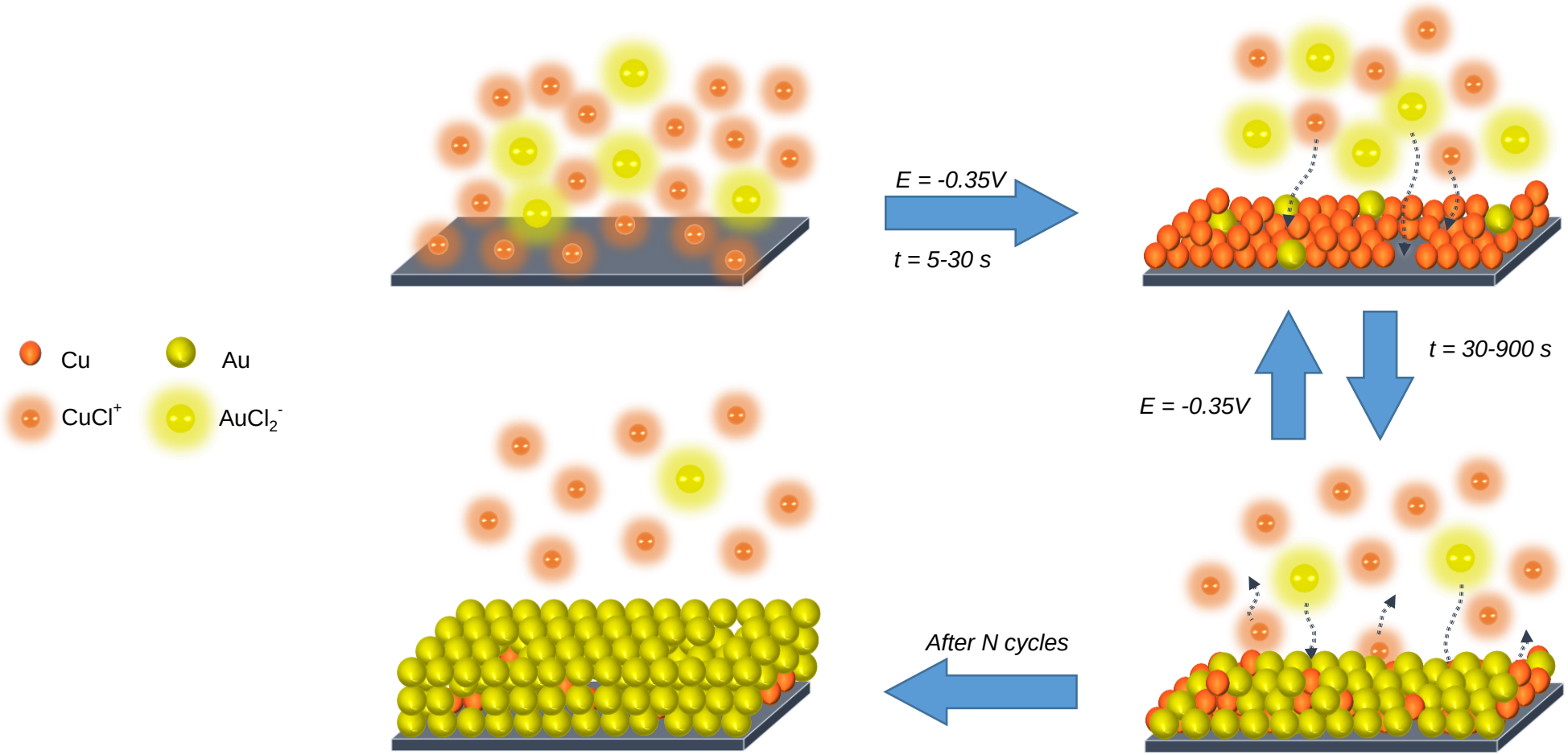
- Cathodic reaction:
  - $Me^{n+} + ne^- = Me^0$
- Anodic reactions:
  - $H_2O = ½O_2 + 2H^+ + 2e^-$
- Faraday's law:

$$\frac{m}{M} = \frac{I \cdot t}{z \cdot F}$$

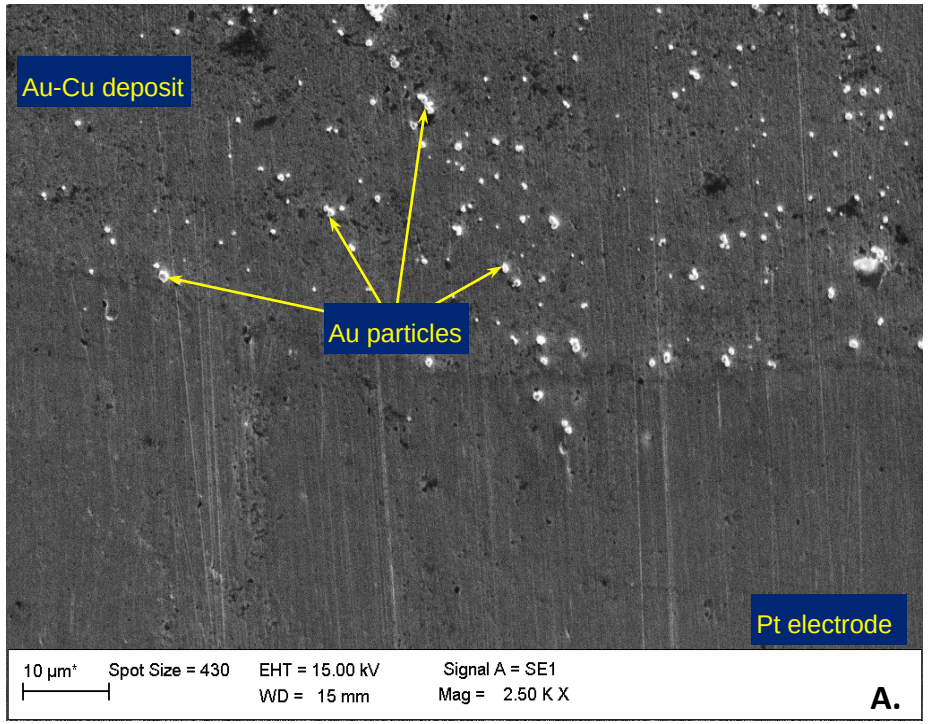
Gold electrowinning

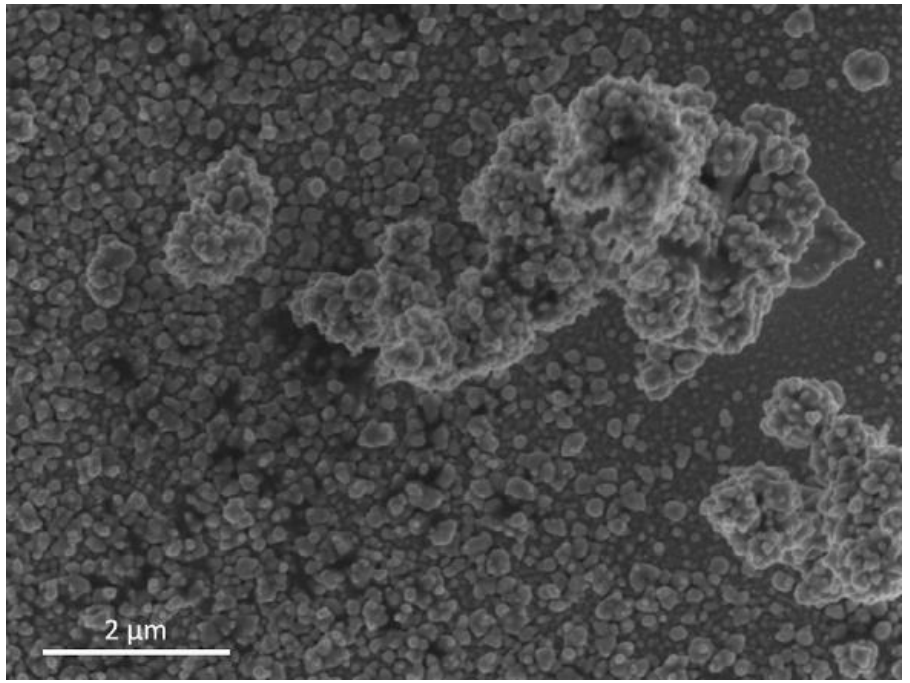
- **Mature technology (industrial scale)**
- Cyanide solutions
- Gold concentration: 20 - 100 mg/L
- Base metal impurities: < ppm level
- Overall recovery: 95 - 99%
- Current efficiency: 0.3 - 4.0%
- Energy consumption:
  1 - 100 kWh/kg Au

ELECTRODEPOSITION WITH REDOX REPLACEMENT (EDRR)



EDRR RESULTS





t_{ED} = 5 s, t_{RR} = 20 s, E_{ED} = -320 mV vs SCE

Recovery: 9.3%

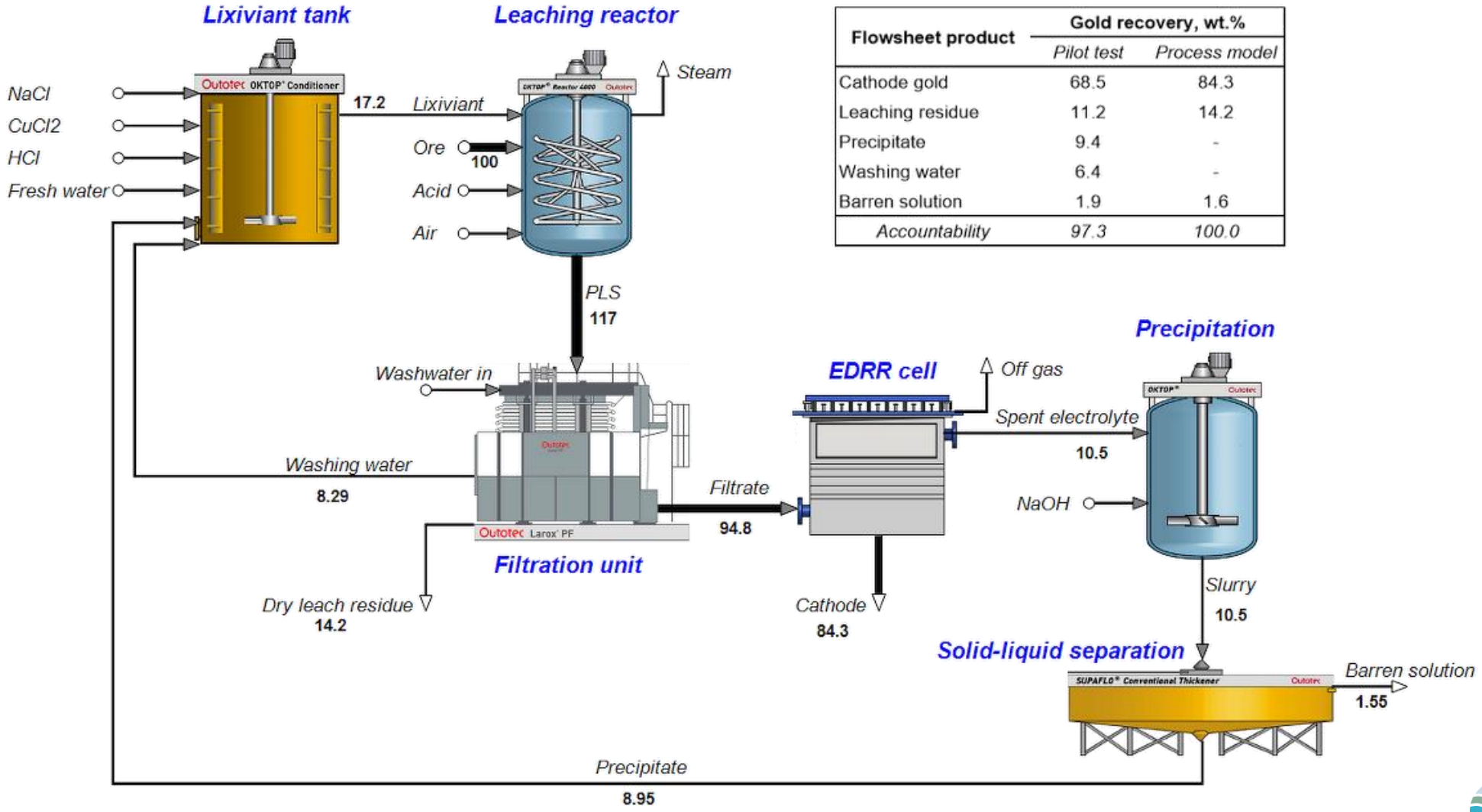
Purity: 52.3%

t_{ED} = 15 s, t_{RR} = 900 s, E_{ED} = -350 mV vs SCE

Recovery: 94.4%

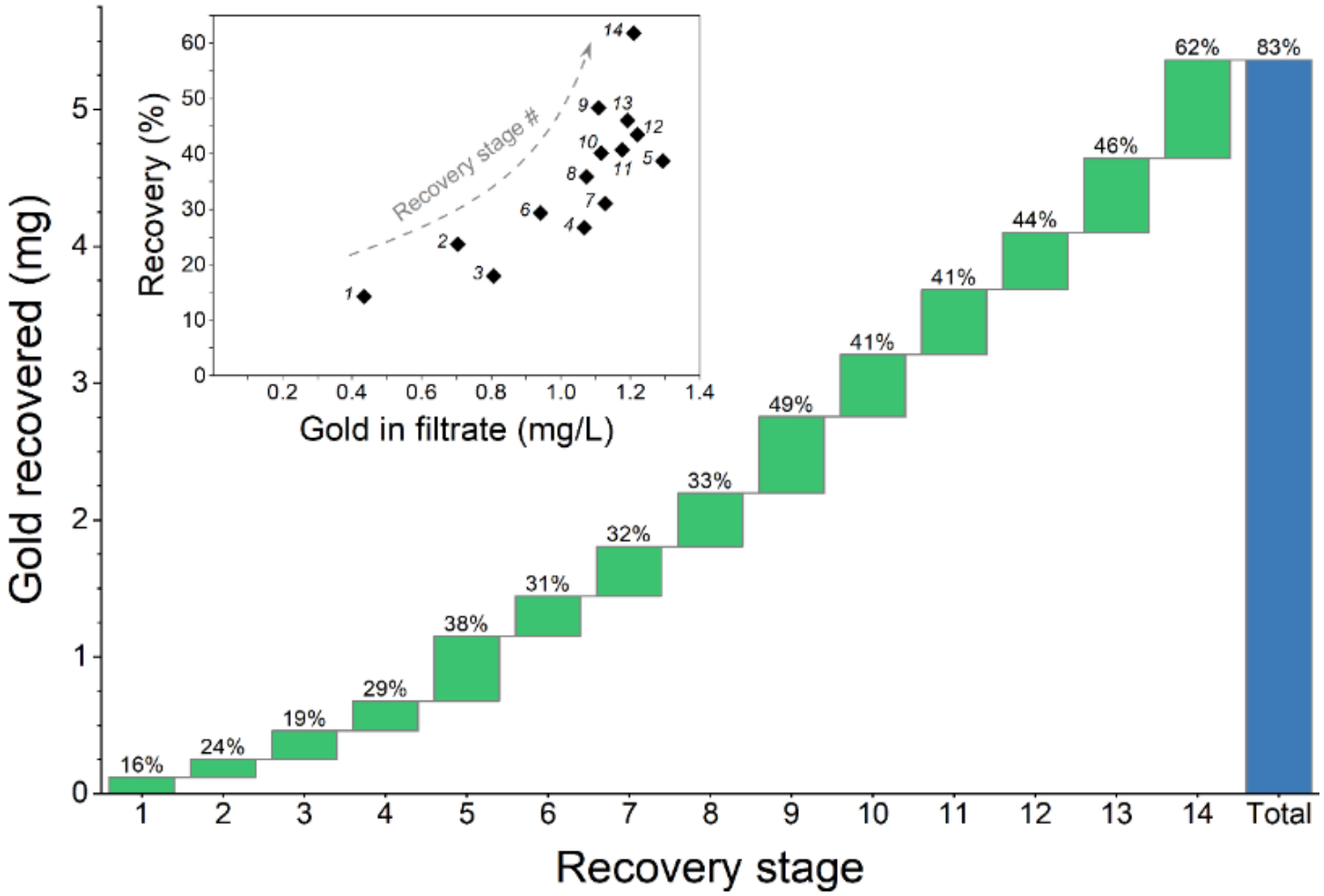
Purity: 93.7%

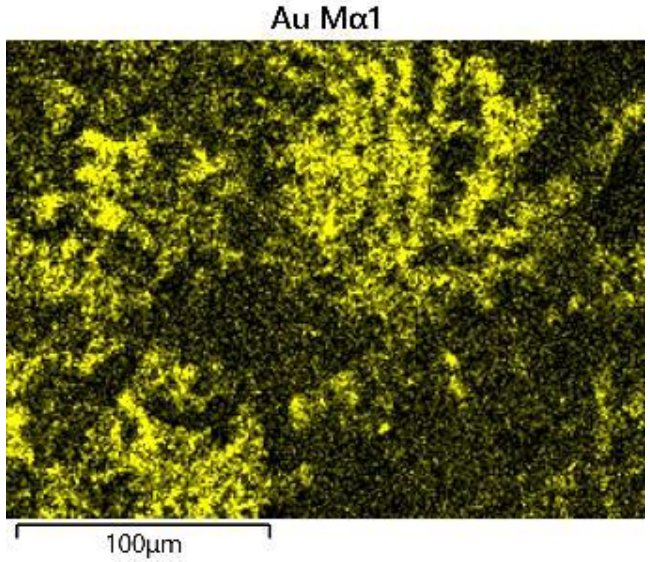
CONTINUOUS PROCESS FOR GOLD RECOVERY

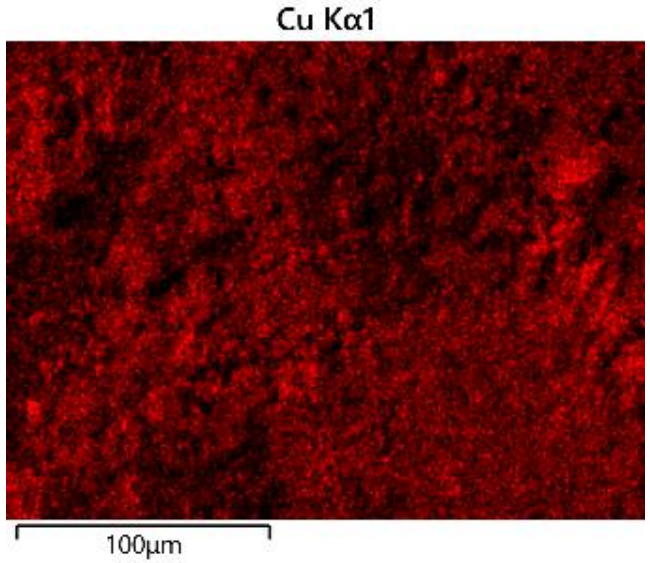


Flowsheet product	Gold recovery, wt.%	
	Pilot test	*Process model*
Cathode gold	68.5	84.3
Leaching residue	11.2	14.2
Precipitate	9.4	-
Washing water	6.4	-
Barren solution	1.9	1.6
Accountability	*97.3*	*100.0*

RESULTS OF EDRR MINI-PILOT







EDRR vs. ELECTROWINNING

Conventional electrowinning

- **Mature technology (industrial scale)**
- Cyanide solutions
- Au concentration: 20 - 100 mg/L
- Gold recovery: 95 - 99%
- Current efficiency: 0.3 - 4.0%

EDRR

- **Developing process (mini-pilot)**
- Chloride media
- Au concentration: 0.1 - 2 mg/L
- Gold recovery: > 80%
- Current efficiency*: 0.01 - 0.5%

CONCLUSIONS

- Works in cyanide-free media
- One-step process, applied directly after chloride leaching
- High purity (>90% Au) of final product is possible
- Further optimization is required to increase process efficiency
- Suitable for recovery of other (precious) metals present in aqueous solutions even in minor concentrations

OTHER APPLICATIONS OF EDRR METHOD

ELMERY
PRECIOUS METALS PRECISION

SELECTIVE PRECIOUS METAL EXTRACTION

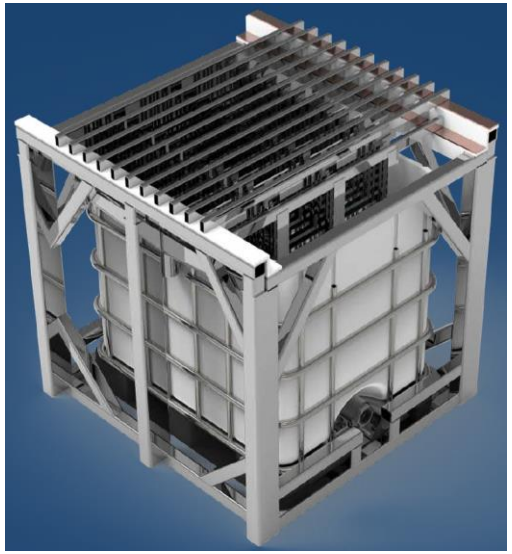
Based on years of experience and specific lab tests of your solution, you can choose a metal to be extracted, for example platinum or palladium.

COLLECTIVE PGM EXTRACTION AND MONETIZATION

Our team analyzes the options and helps you decide which group of extracted metals provide the best value.

IMPURITY REMOVAL

Removing impurities such as tellurium or selenium decreases the overall waste amount and increase the efficiency of the main process.



www.elmery.fi

GTK

THANK YOU!

ivan.korolev@gtk.fi