Process Systems Engineering and Mineral Processing

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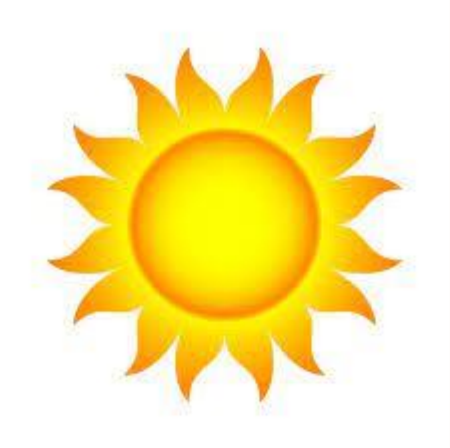
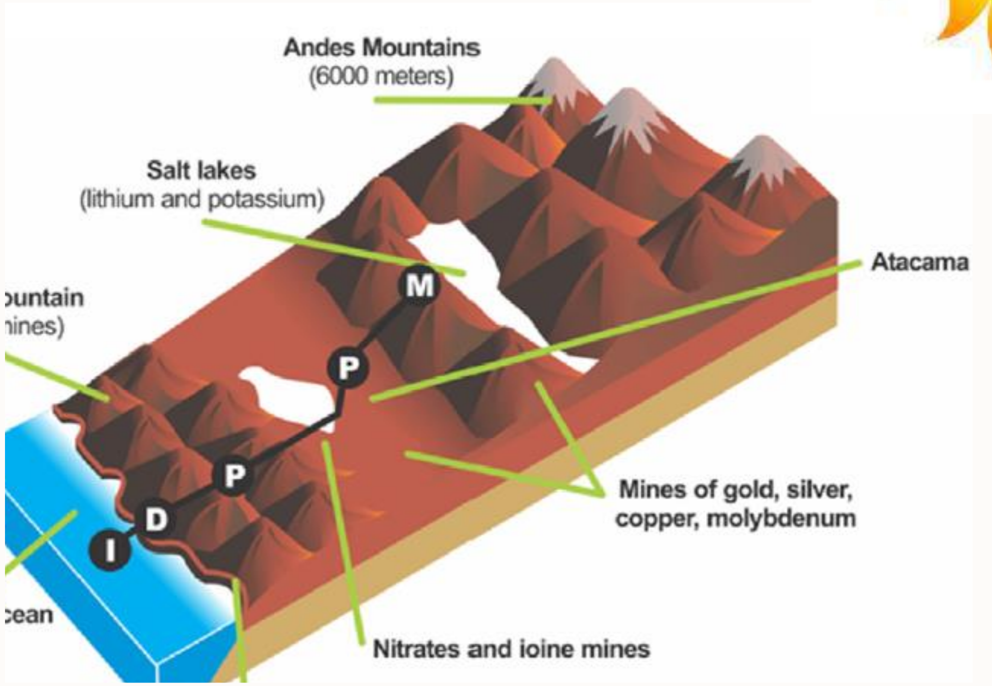
Seminar for the Energy Systems Initiative
Center for Advanced Process Decision-making
Carnegie Mellon University
June 10, 2022

Agenda

- Chile mining
- Mining industry situation
- PSE opportunities & examples

North of Chile



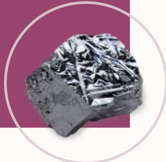


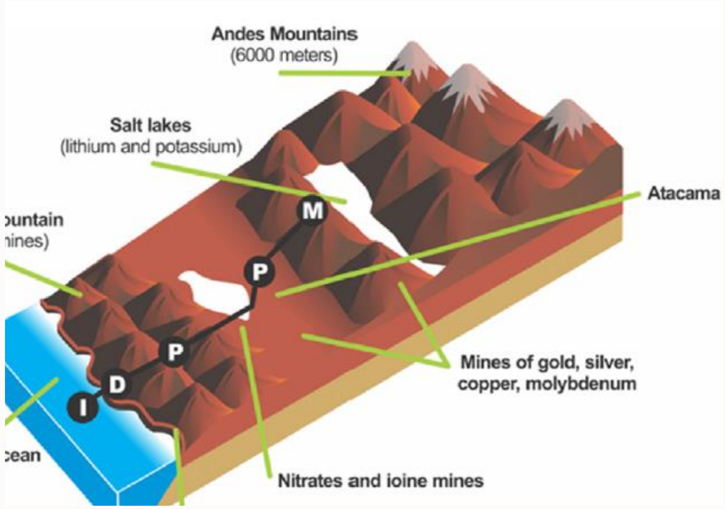
Atacama Desert (Cu,Li & Sun)

70% of world´s astronomical infraestructure

First world Cu, Iodine, Natural $NaNO_3$.

Second world Lithium (50% of world reserves), Molibdenum





Antofagasta City

The Atacama Desert is the driest nonpolar desert in the world.

Solar energy,

The highest incident solar radiation on the earth surface

Increased demand for metals by 2030

Coupled with rising urbanization rates, this will drive **higher demand** for industrial commodities such as **steel, zinc, and copper** to build high density housing, new manufacturing plants and connect cities with larger transport infrastructure networks.

As incomes rise, consumption of household electrical appliances, consumer electronics and packaged food in these economies will grow, supporting **increased aluminium demand**.

The transition to zero emissions energy will accelerate in the next decade. This too will rely on new metal-intensive electricity generation and transportation technologies such as renewable energy, nuclear power and electric vehicles that will create **higher demand for lithium, uranium, copper, and nickel.**

Ongoing innovation will see smaller, more powerful circuits and processors which rely on **rare earth elements, copper, and silver** to enhance their performance.

Commodity demand Outlook 2030
Mineral Council of Australia

Metals, including Critical Raw Materials, are an ideal candidate for a circular economy as they are eternally recyclable, and properly treated, secondary metals do not face downcycling or quality issues. However, in many cases, secondary resources are not sufficient to meet demand.

Electric vehicles contain around 60 kg of cooper compared to a conventional car which has around 8-22 kg. A battery-powered bus can contain up to 369 kg.

Ministerio de Min

"Copper is the new oil"

Jeff Currie

Goldman Sachs

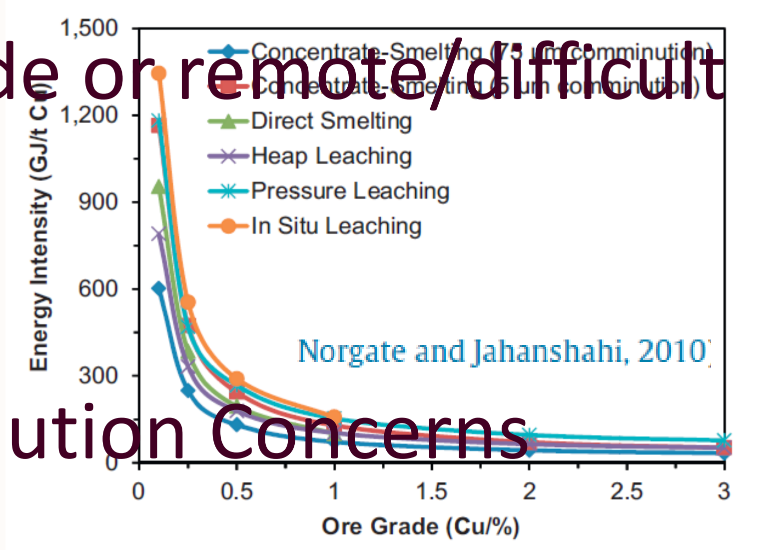
24 Mt

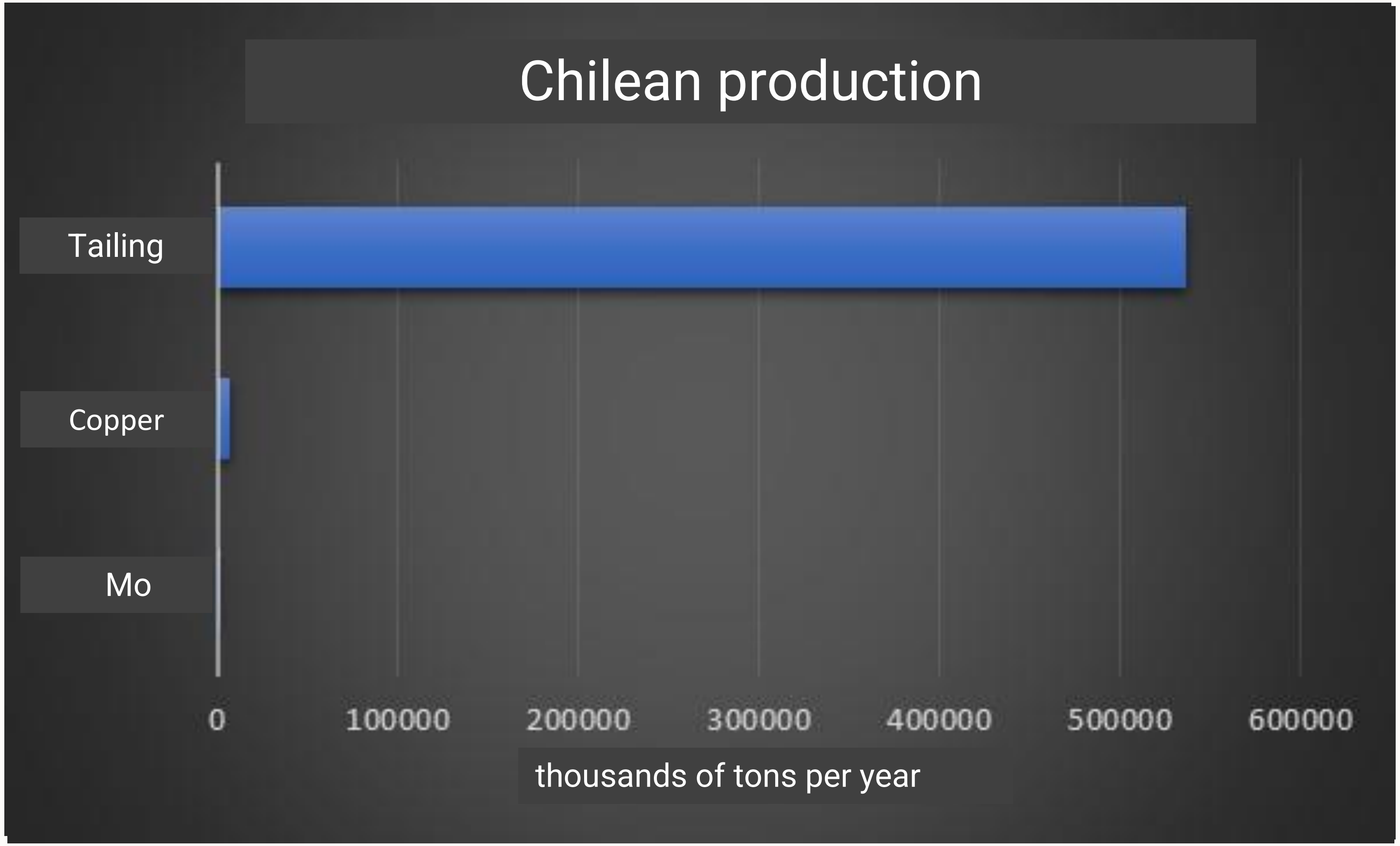
World Demand

World copper consumption doubles every 25-30 years.

Main Problems of Mining

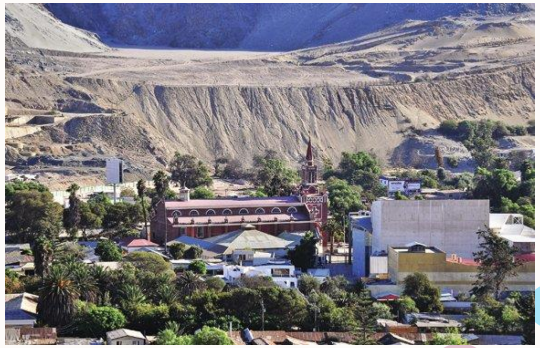
- Decrease in ore grades (e.g. Cu: 1940 ~ 7-2%; 2000~ 1%; 2019~0.6; 2100 ~ 0.2)
- More complex minerals and ore composition changes.
- High power consumption
- Keeping efficiency (cost/ton, energy/ton, water/ton)
- Declining productivity (ton) (low ore grade or remote/difficult regions)
- Mine safety
- Sustainability (e.g., water scarcity) & Pollution Concerns





- ✓ 718 tailings deposits
- ✓ 113 Active
- ✓ 433 Non-Active
- ✓ 139 Abandoned

(Sernageomin)



Typical Processes for metals

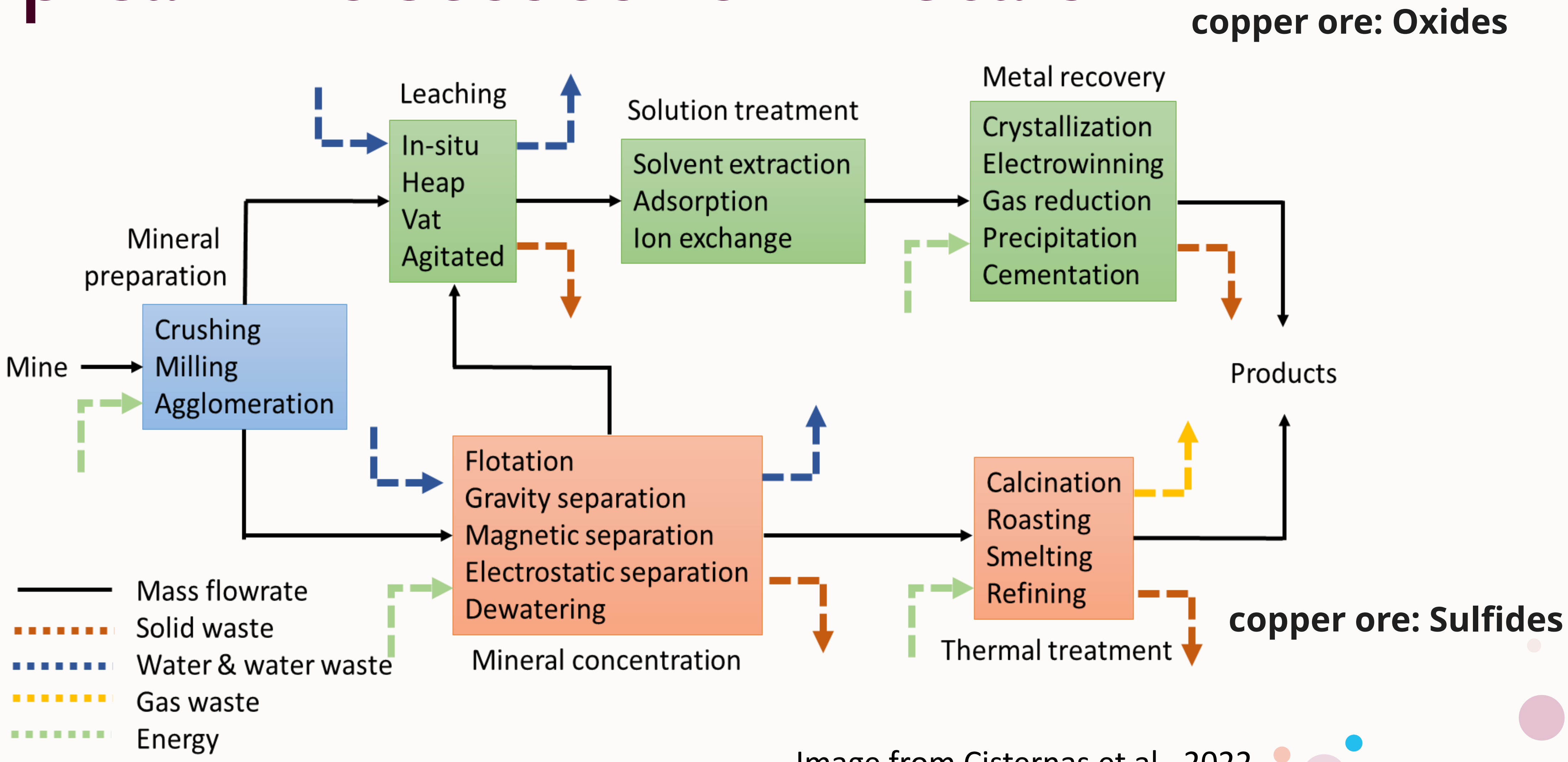


Image from Cisternas et al., 2022

Typical Process for metals from brines

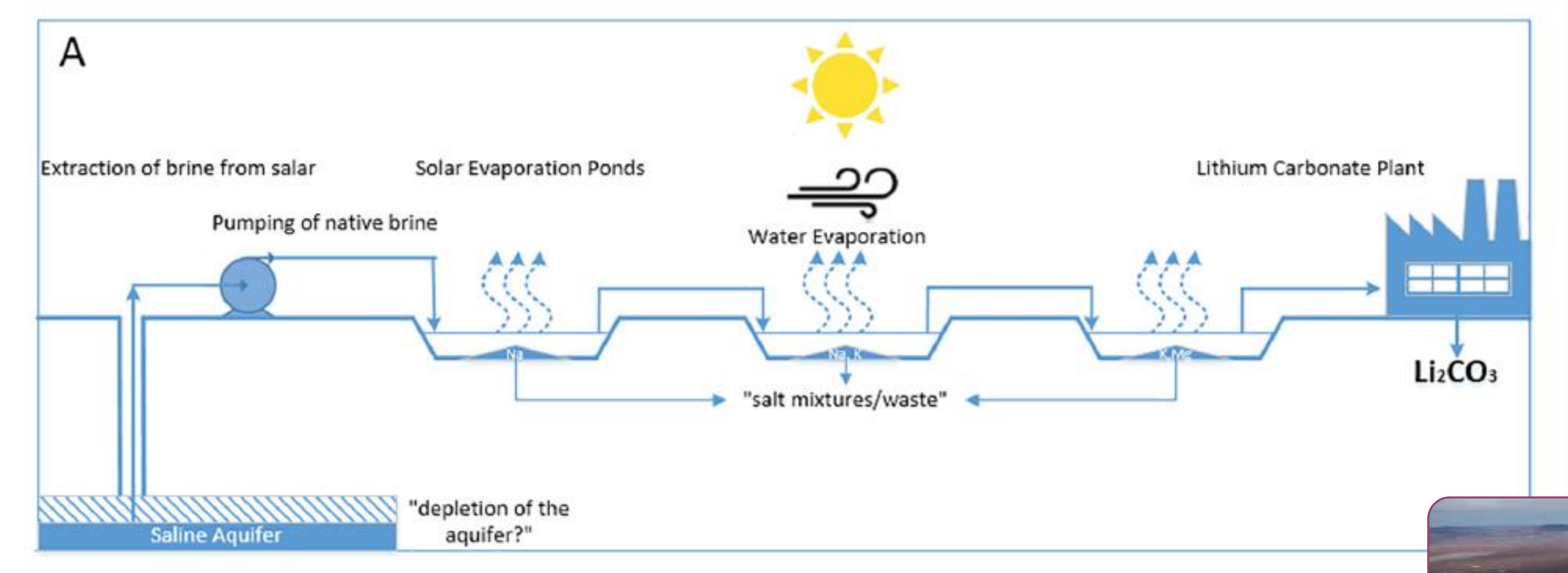


Image from Flexer et al., 2018

Main Problems:
Depletion of the aquifer (Atacama salt lake 0.15-0.19 % of Li)
Low efficiency (50% of Li recovery)
very slow process (months)

New Process for metals from brines

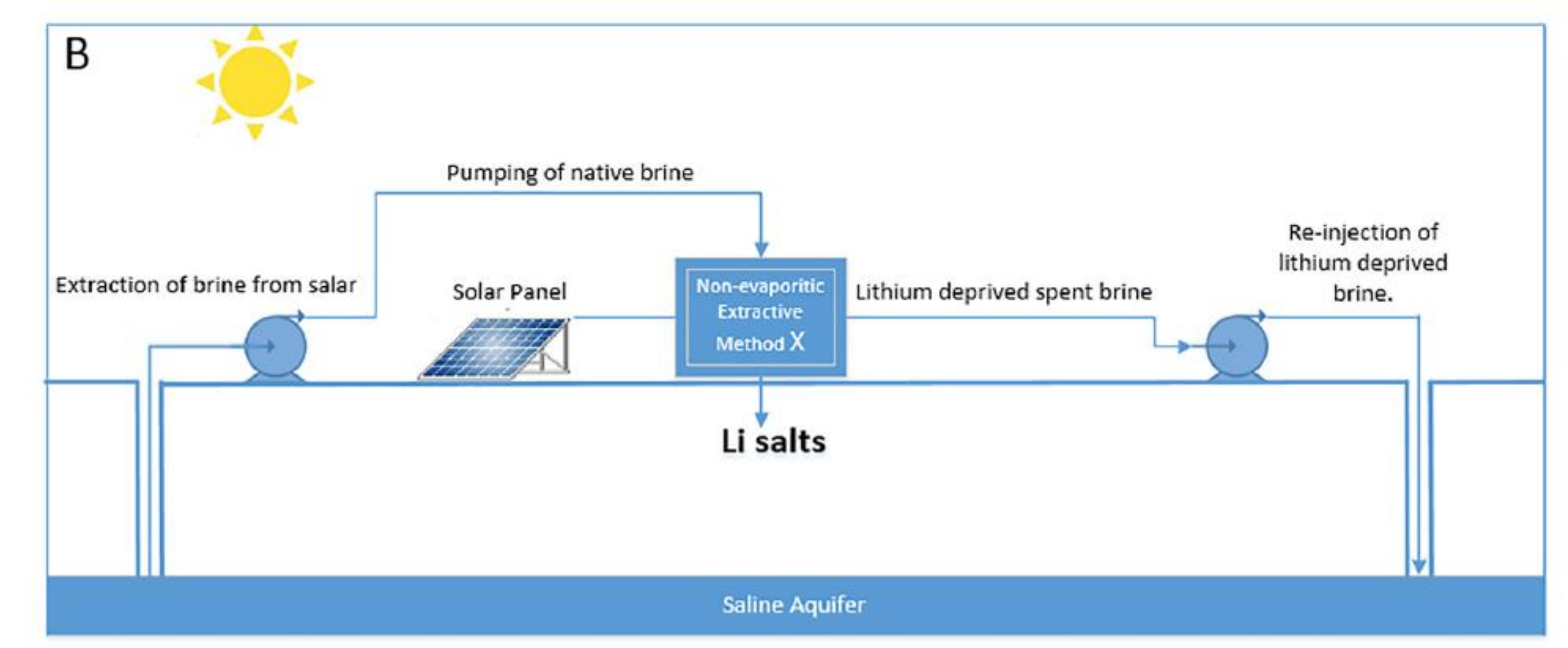


Image from Flexer et al., 2018

New Process for metals from brines

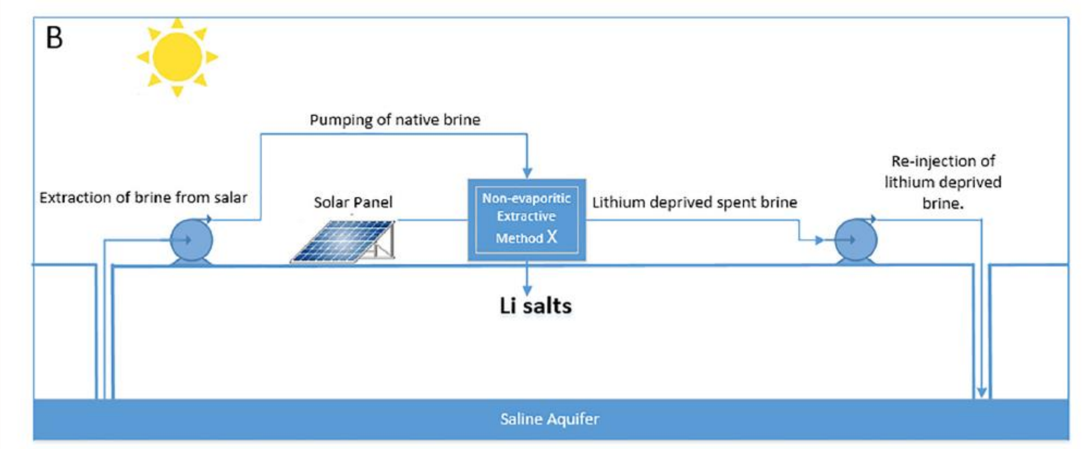
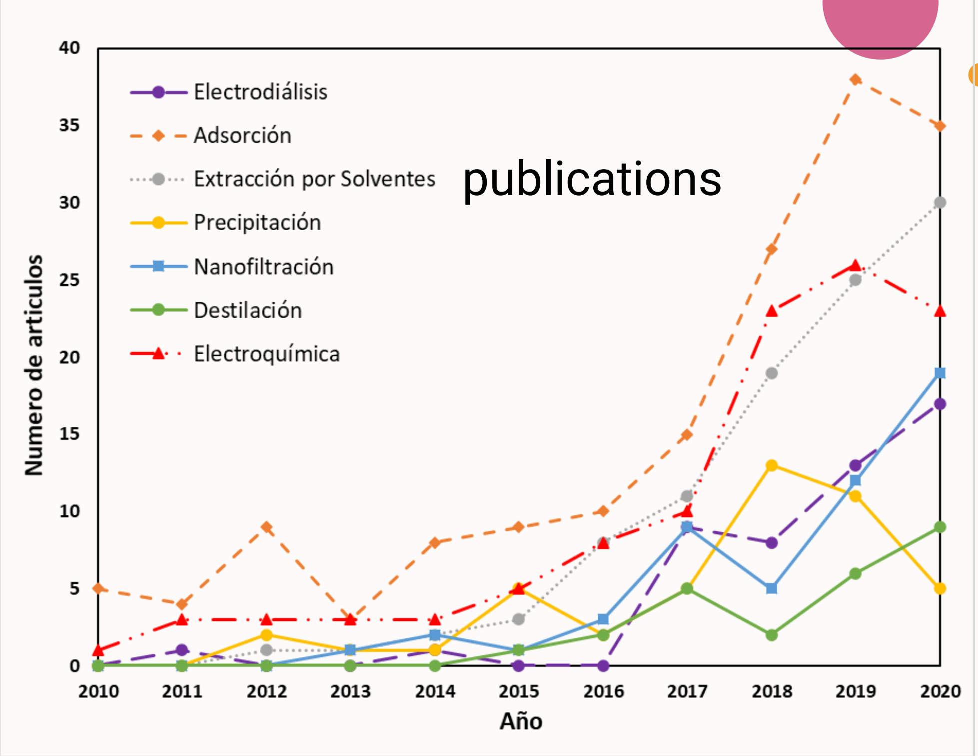


Image from Flexer et al., 2018



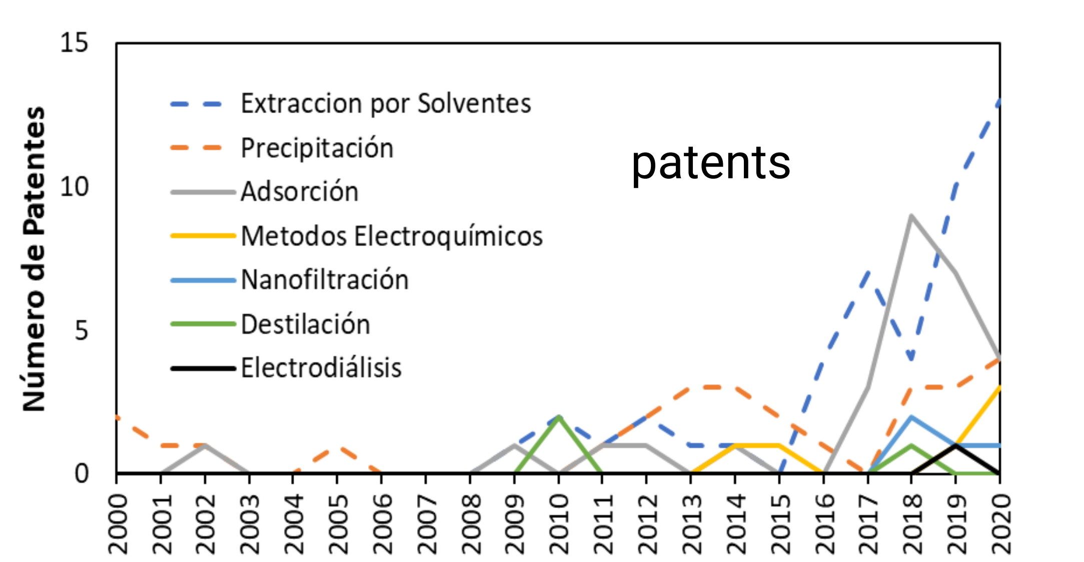


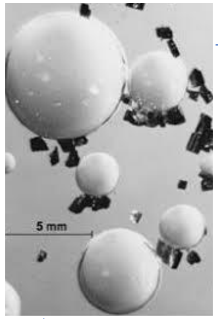
Image from Cisternas et al., 2021

Other characteristics of the mining industry

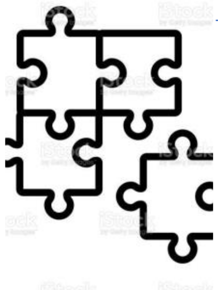
Still a strong focus on end of pipe technologies.

Few examples of cleaner production and industrial ecology.

Little attention to multiscale integration.



Greater focus on the micro scale research compared to other scales



Little attention to design and integration

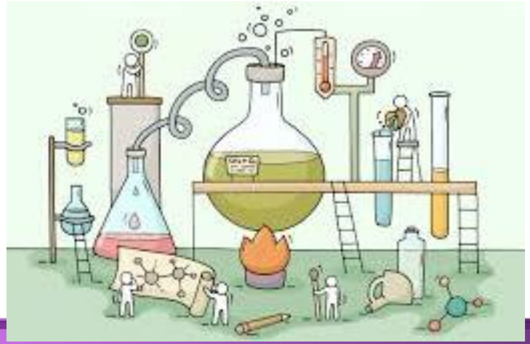
(1970-1990) Pollution treatment through end-of-pipe technology

2005

Arsenic Removal from Mine and Process Waters by Lime/Phosphate Precipitation: Pilot Scale Demonstration, 2005

1976

Laguitton, D., Arsenic Removal From Gold-Mine Waste Waters: Basic Chemistry of the Lime Addition Method. CIM Bull. 69, 105–109



Montana Tech of The University of Montana, USA

Canadian Inst Mining Metallurgy Petroleum

In mineral processing there is still a strong focus on pollution treatment through end-of-pipe technology

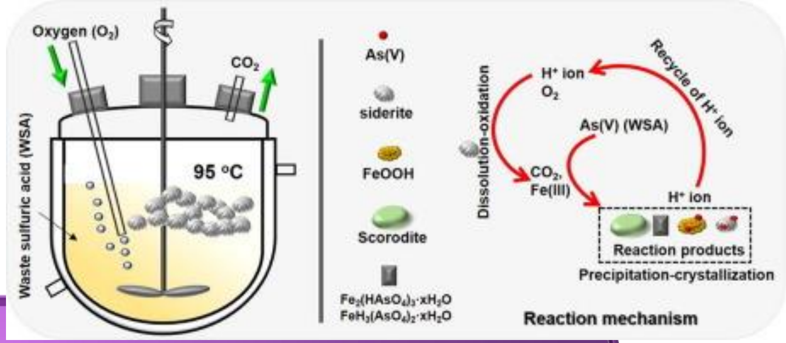
2005

Arsenic Removal from Mine and Process Waters by Lime/Phosphate Precipitation: Pilot Scale Demonstration, 2005

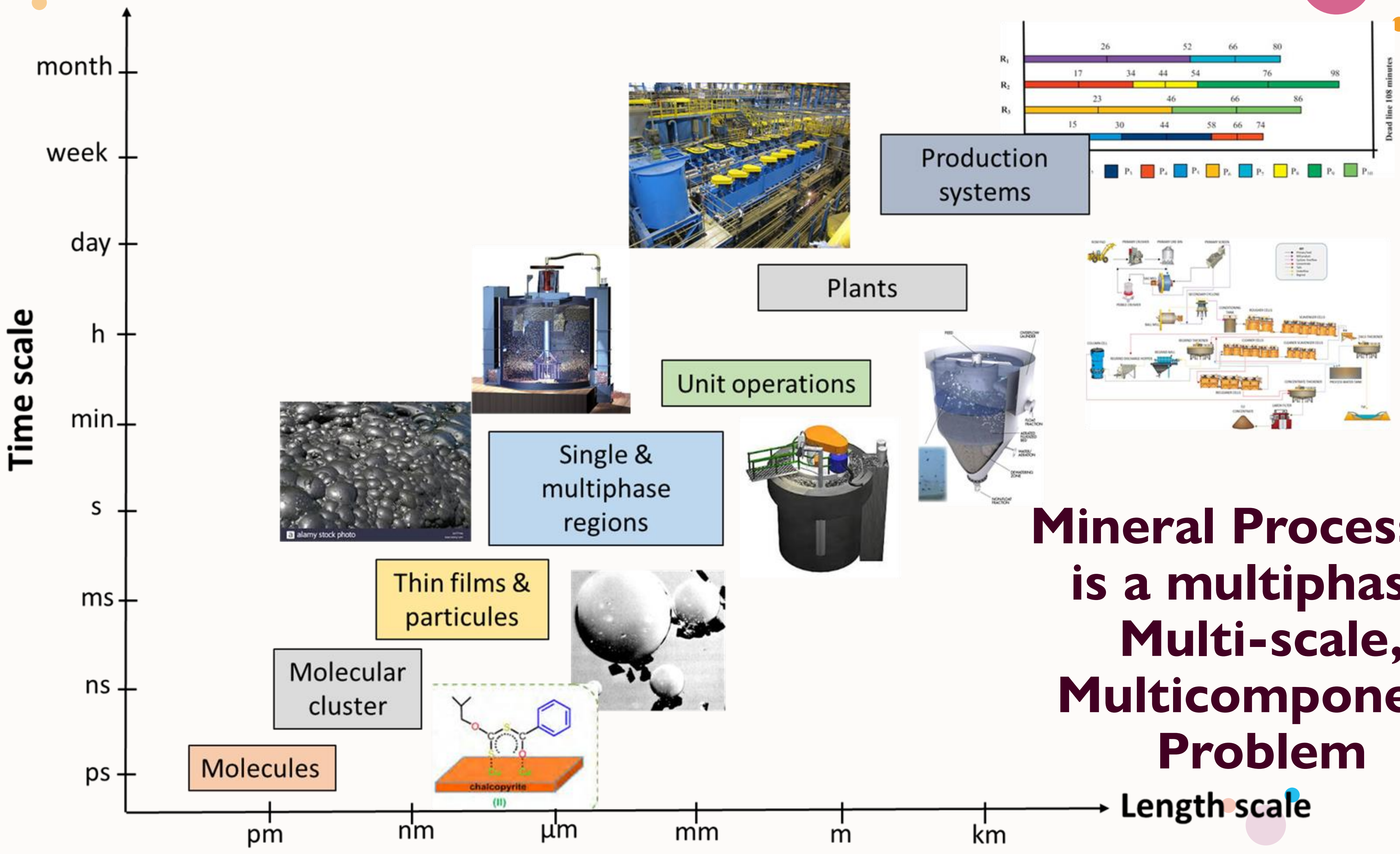
Montana Tech of The University of Montana, USA

2021

Arsenic removal from hydrometallurgical waste sulfuric acid via scorodite formation using siderite ($FeCO_3$) (also use hydrated lime), Chemical Engineering Journal, 2021



Key Laboratory of Industrial Ecology and Environmental Engineering. Dalian University of Technology, China



Mineral Processing is a multiphase, Multi-scale, Multicomponent Problem

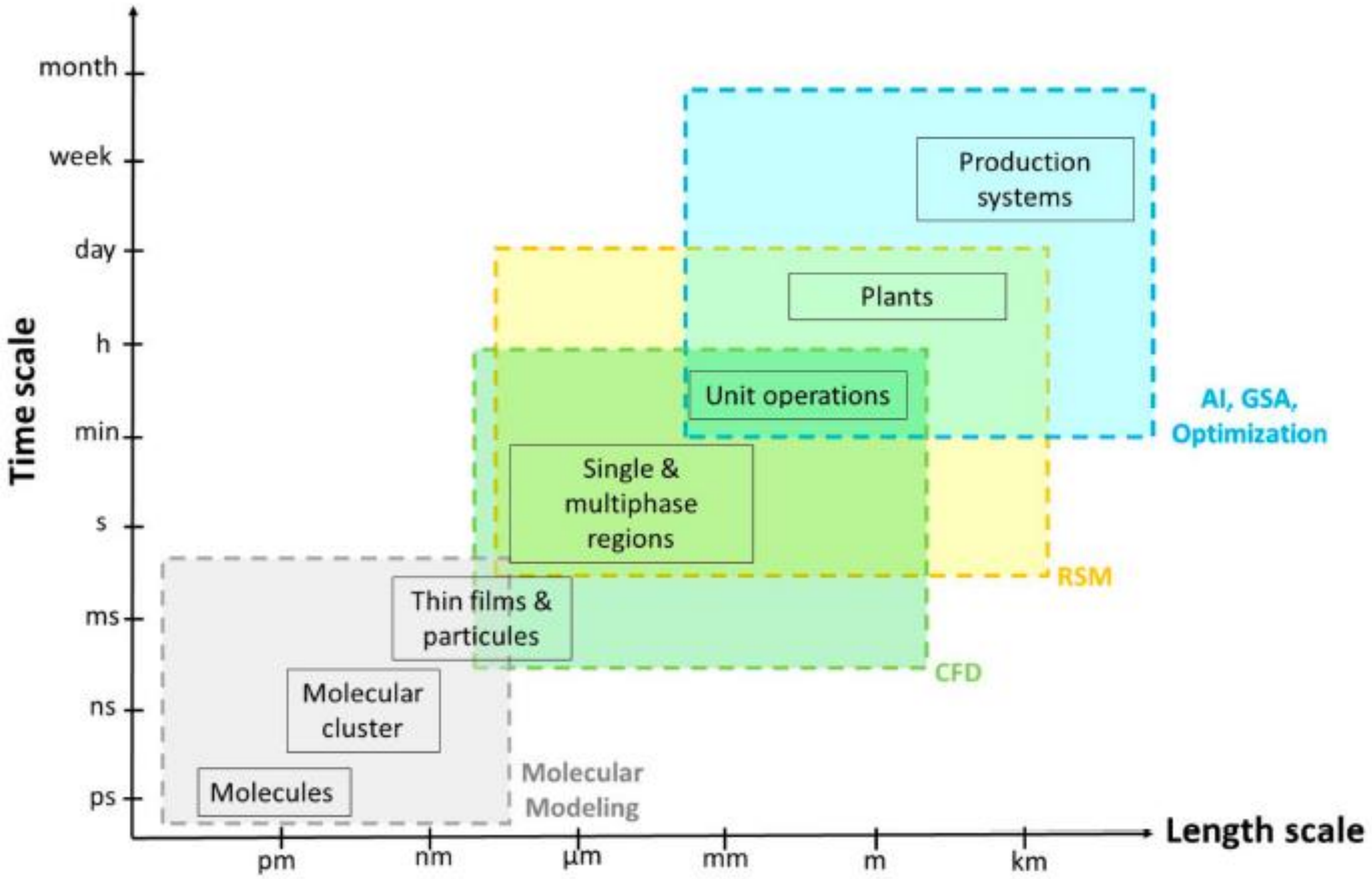
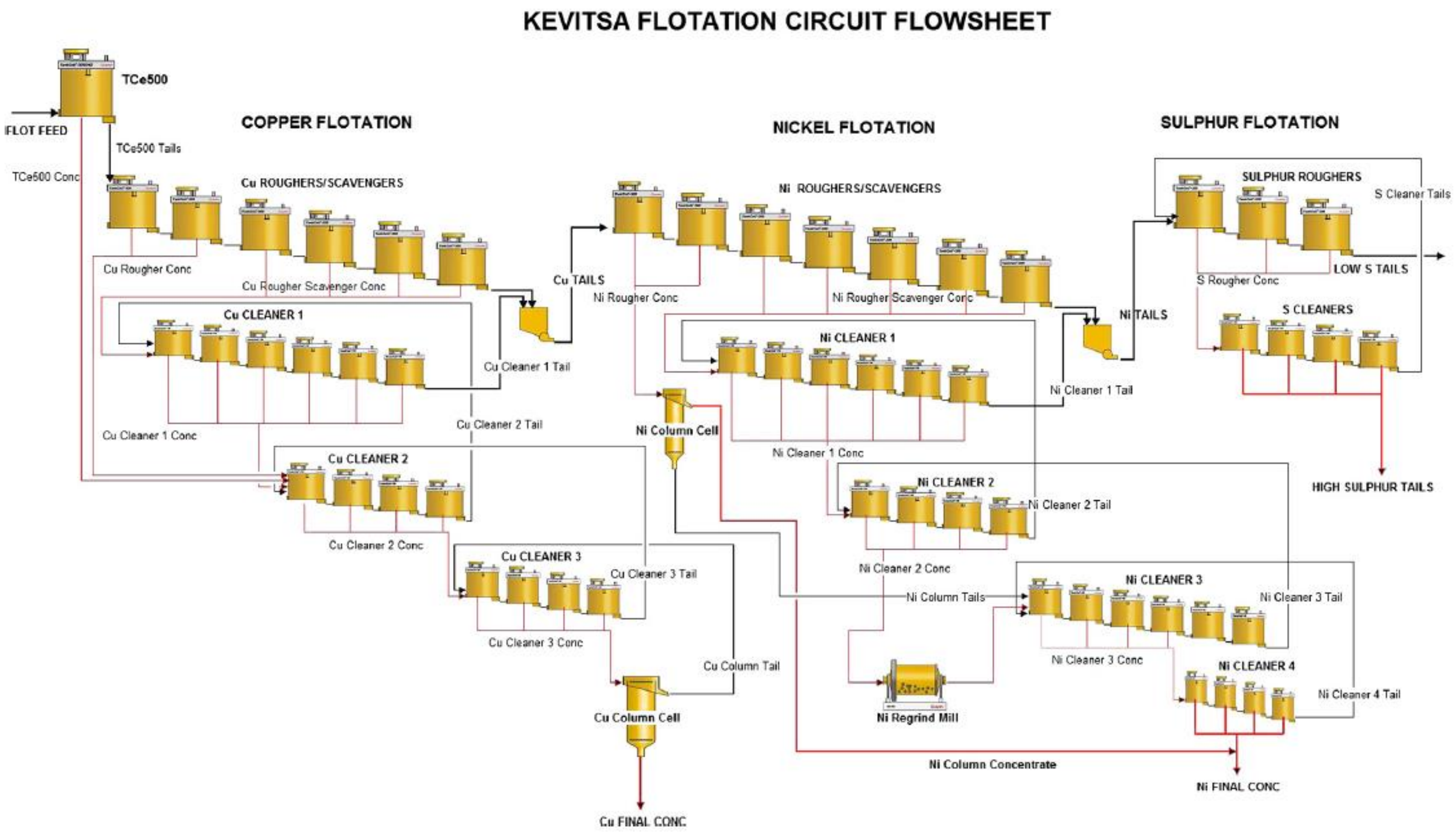


Figure 1. Levels of length and time alongside the modeling and optimization tools analyzed in this manuscript (CFD—computational fluid dynamics; RSM—response surface methodology; AI—artificial intelligence; GSA—global sensitivity analysis).

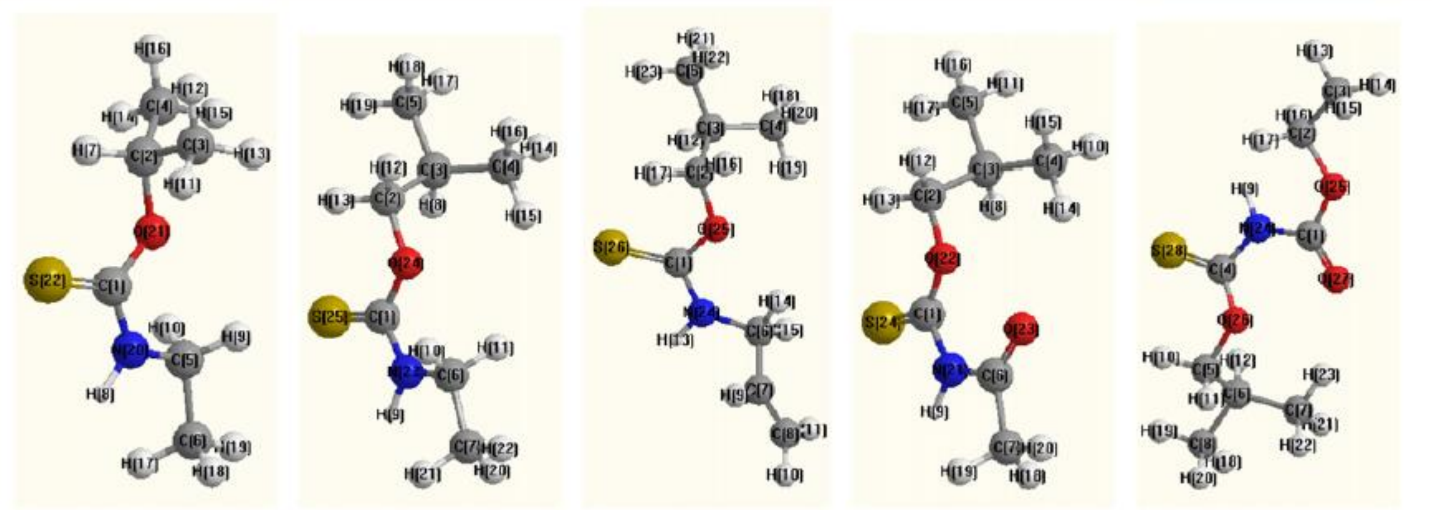
From **Trends in Modeling, Design, and Optimization of Multiphase Systems in Minerals Processing, Cisternas et al., 2020.**

51 % Nickel recovery, 78 % copper recovery, and 38% of the Sulfur feed finish in the tail (poor desulfurization) Kevitsa Flotation Circuit (Finland). Musuku et al. 2015



Inefficient process, opportunities for process intensification, process integration, control, design and analysis

Molecular Modeling for selective collectors



IPETC IBETC IBALTC IBACTC IBECTC

Identification of selective thionocarbamates collectors (CuFeS2 versus FeS2) based on Ab initio calculation methods, such as Hartree-Fock (HF) and density functional theory (DFT).

Computational fluid dynamics (CFD) modelling of flotation process (Fluidity)

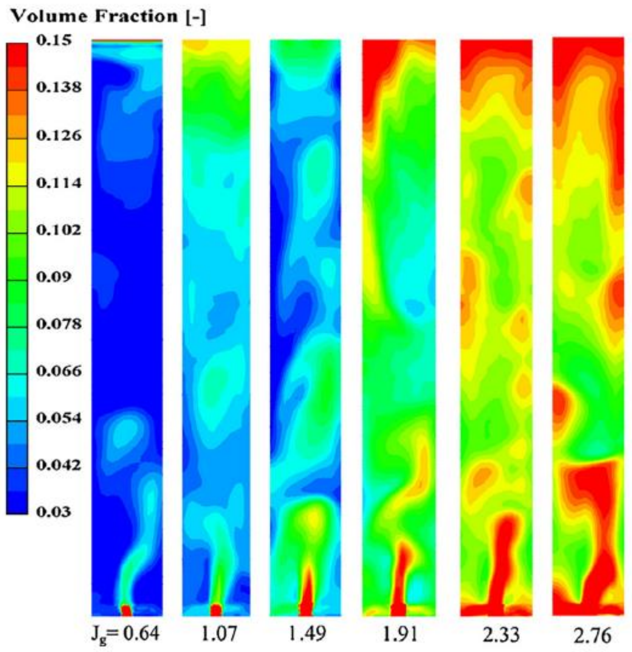


Fig. 9. Predicted gas volume fraction distribution for flotation column with 10% volume fraction of coal particles at superficial gas velocity of (a) 0.64, (b) 1.07, (c) 1.49, (d) 1.91, (e) 2.33, and (b) 2.76, cm s^{-1} (Sarhan et al., 2017a,b).

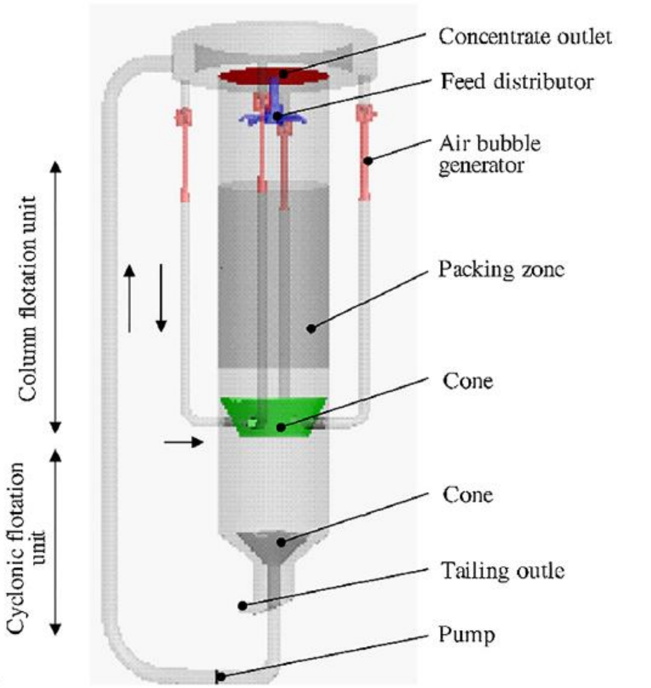
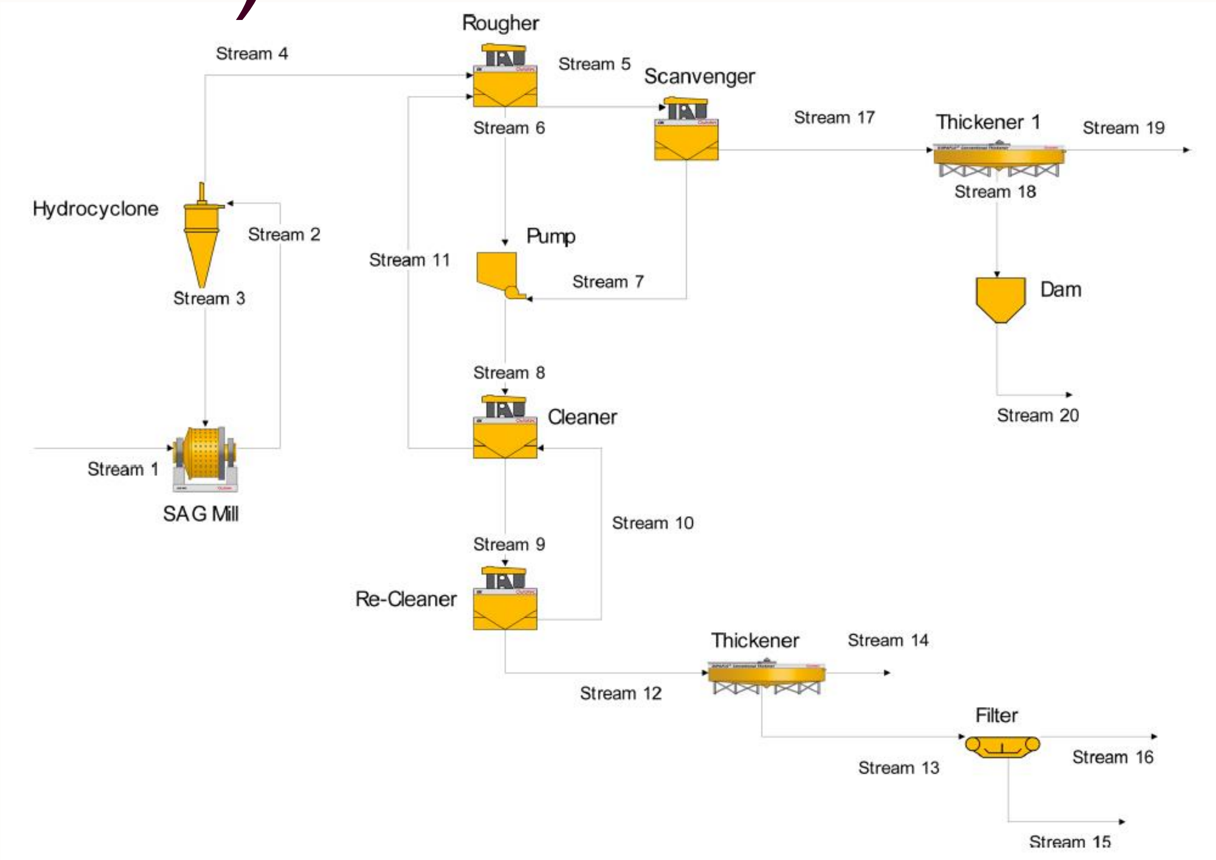
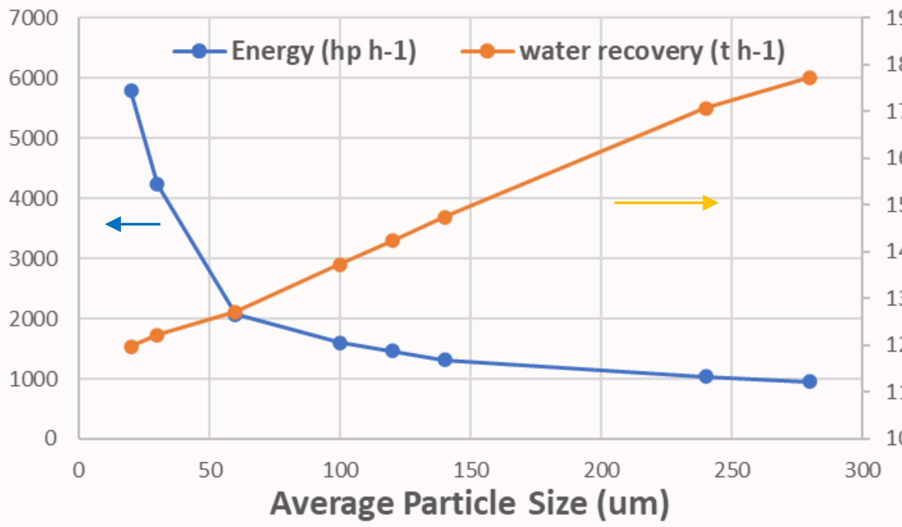


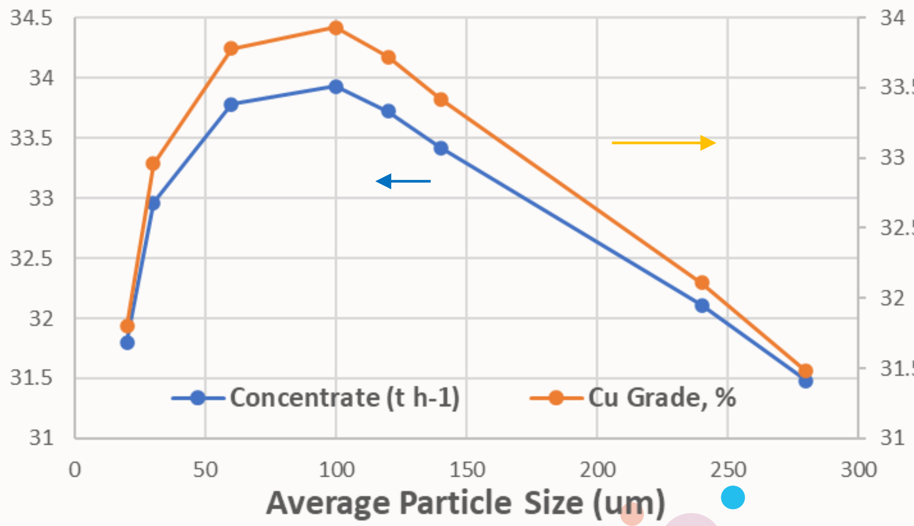
Fig. 10. A schematic view of cyclonic-static micro-bubble flotation column (Yan et al., 2012).

Although, in practice, design of flotation cells has largely been based on the practical experience and empirical design approach, it is expected that use of physics-based modelling involving mechanisms of flotation kinetics and multiphase hydrodynamics will provide better insight into the rigorous design of the equipment, removing the need to design equipment with an extra safety margin, which can often lead to larger equipment than needed (Wang et al., 2018).

Use of mineral processing simulators: (HSC Sim)







Particle Size Effect on the Efficient use of Water and Energy (Donoso et al 2013)

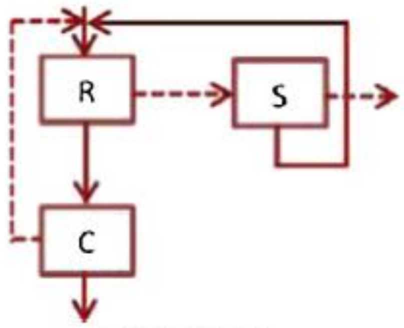
Optimization-based design (GAMS)

What is the effect of the epistemic uncertainties of stage recoveries in the design of flotation circuits?

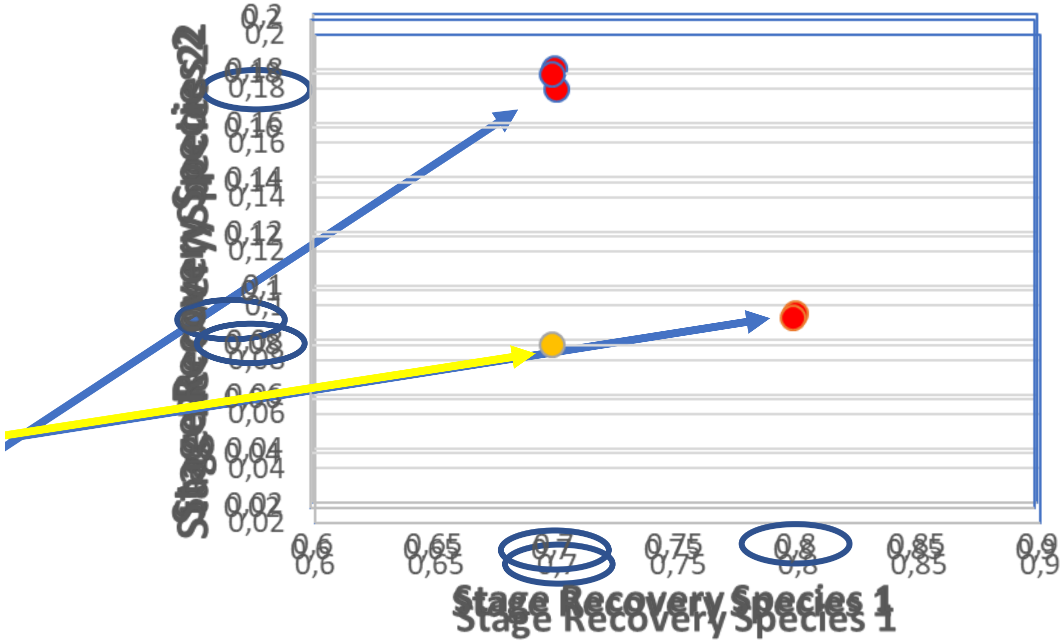
Represent Stage Recovery by Uniform Distribution

Species 1 $P_1 \sim U(0.6, 0.9)$

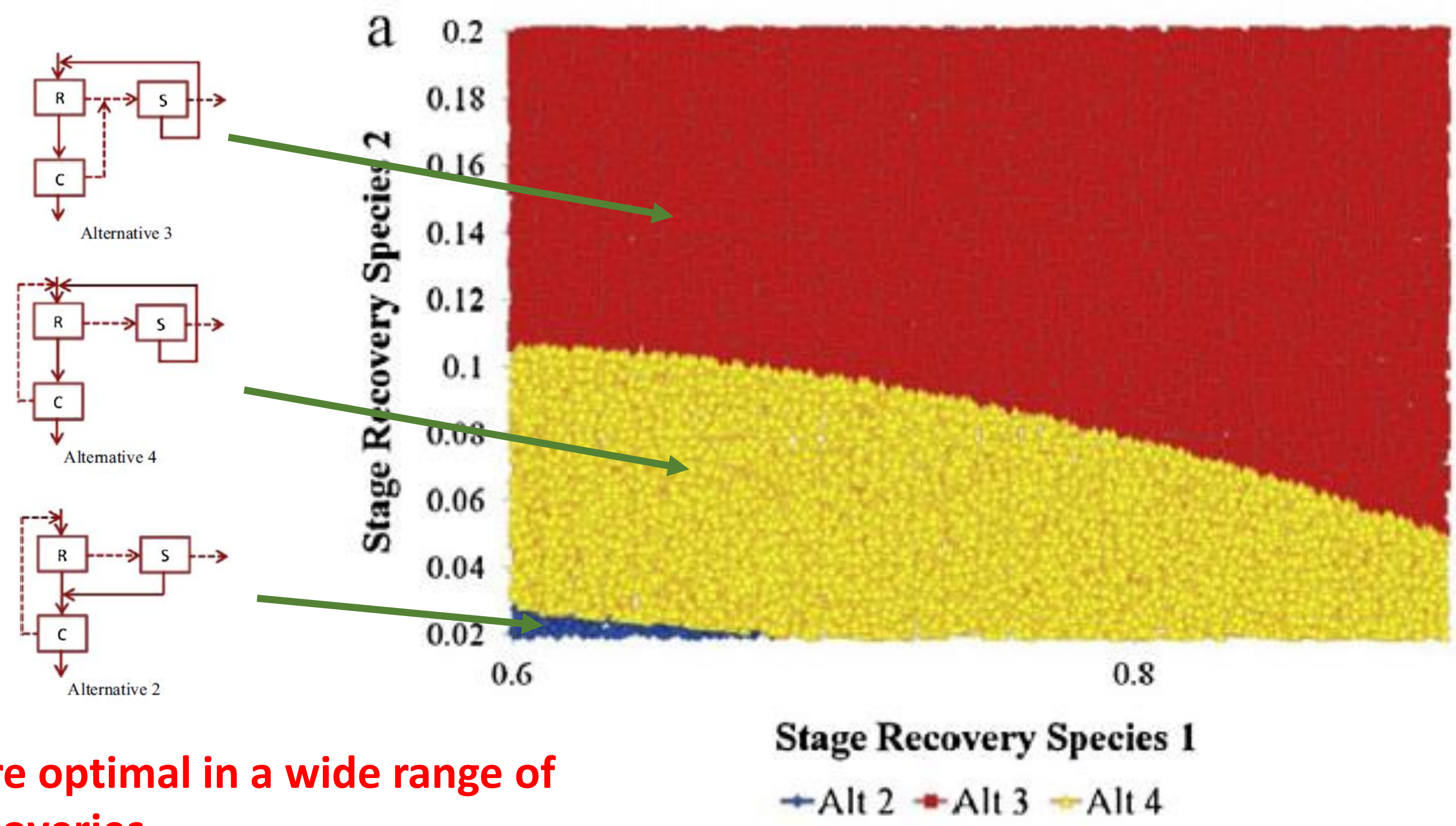
Species 2 $P_2 \sim U(0.02, 0.2)$



Alternative 4

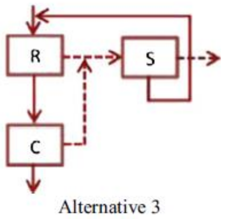


Optimal configurations for 30,000 cases of recovery for species 1 and 2 (Cisternas et al., 2015)

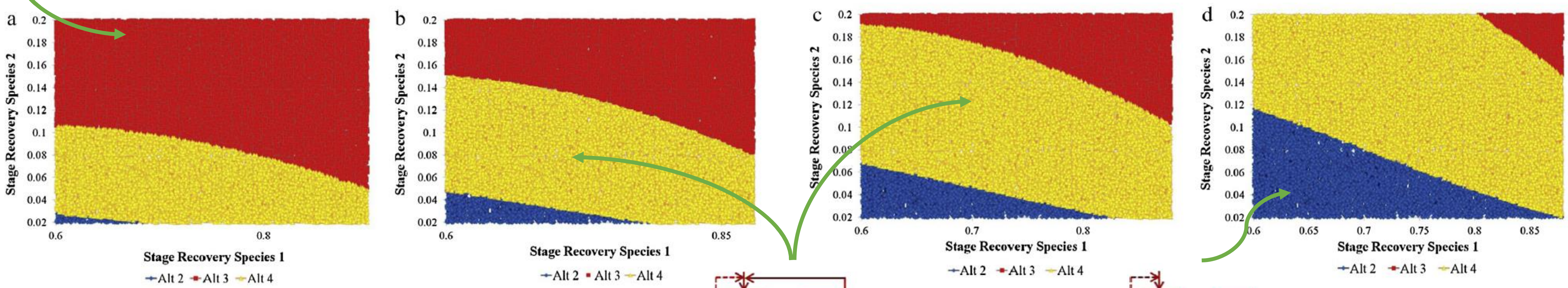


There are few structures that are optimal in a wide range of species recoveries

And the stochastic uncertainty? Price & Feed grade?

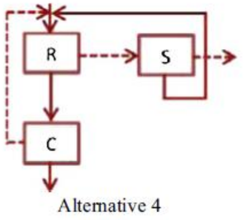


Optimal structure is more sensitive to the price of the metal and the feed grade.

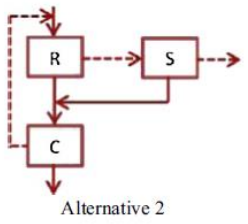


low price
low feed grade

low price
high feed grade

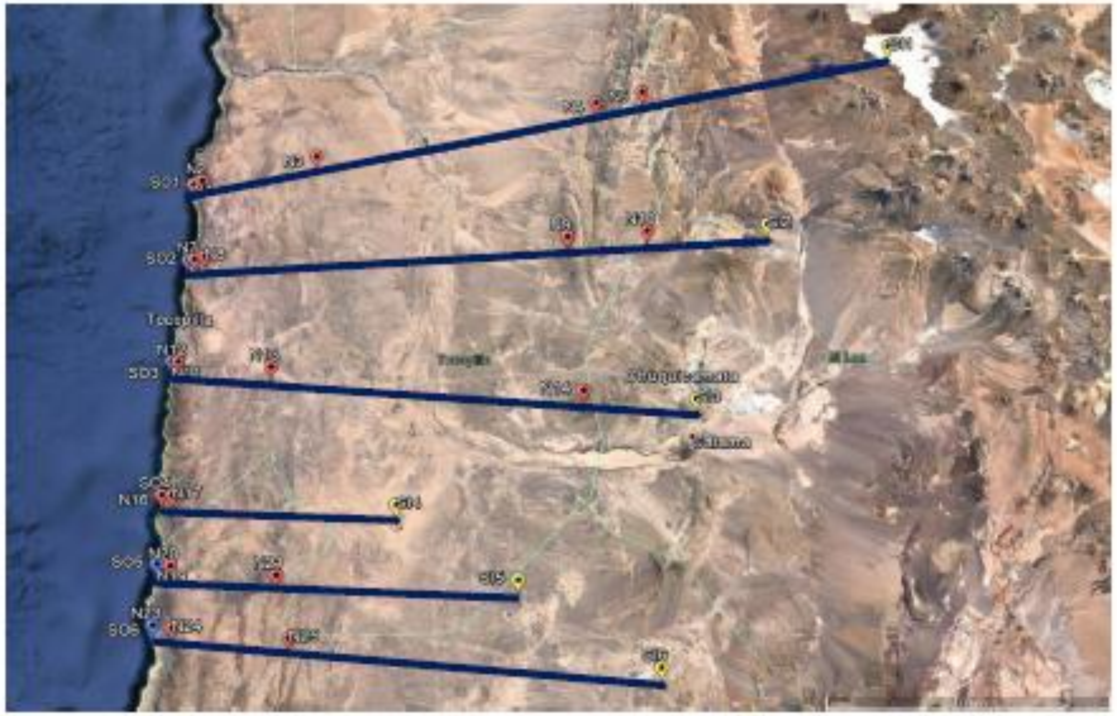


high price
low feed grade

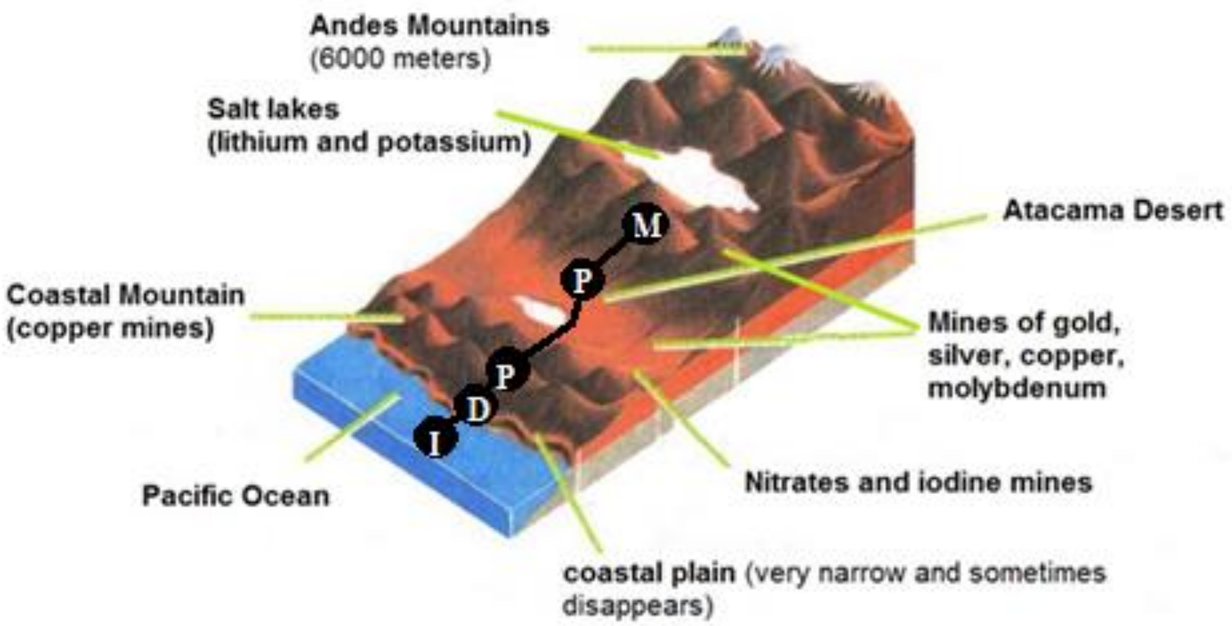


high price
high feed grade

Planning and flexible circuits design can be more important than adjusting stage recoveries



Each plant generates and transports its own water resources



Example. Use of seawater in mining

Plant Integration (initial conditions)

Herrera-Leon et al., 2019

Plant Integration (Integrate system)

Herrera-Leon et al., 2019

Examples of PSE Tools in MP

- Molecular modeling: standard software, e.g. Gaussian
- Optimization: standard software, e.g. GAMS
- General-purpose mineral processing and extractive metallurgy simulators: METSIM- HSC Chemistry for windows.
- Specific simulators: JKSimFloat (Flotation circuits), JKSimMet (comminution circuits).
- gProms is utilized for brine processing
- EDEM (DEM Solutions) is used for granular material simulation (Discrete Element Modeling)
- CFD simulation, Fluidity, ANSYS Fluents, Qfinsoft

Conferences

7th International Computational Modelling Symposium (Computational Modelling '19) was organised by Minerals Engineering International (MEI).

The specific areas included:
•Model development and computational techniques
•Modelling of minerals processing and materials handling unit operations
•Optimisation of plant and circuit operation and design
•Experimental validation including novel experimental techniques

Discrete Element Modelling (DEM), Computational Fluid Dynamics (CFD) and Finite Element Methods (FEM)

Conferences

This exciting new conference will cover:

- Optimisation and integration across different unit operations
- The integration of new equipment into existing flowsheets
- Circuit layout design; modelling and optimisation
- Equipment selection methods

Final comment

- The mining industry, and mineral processing in particular, must face several challenges. PSE can help meet these challenges by applying planning, process control, process design, modeling, process integration, process intensification, process optimization, among others.

Process Systems Engineering and Mineral Processing

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