International Seminar on Impurities in Copper Raw Materials: Regulation and Social Receptivity about Impurities in Copper Raw Materials
Tokyo, Japan, October 2018

Impurities in Copper Raw Materials and Regulatory Advances in 2018: A Global Overview

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International Copper Study Group
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www.icsg.org
ICSG Membership: Japan one of our most valuable and active members in 2018

- Membership open to any country involved in copper production, use or trade.
- 25 member governments plus the European Union in 2018
- Countries joining recently: Iran, Mongolia, DR Congo and Brazil.
- Headquarters in Lisbon, Portugal.
- With International Lead and Zinc Study Group and International Nickel Study Group
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3. New Global and Regional Regulations on Transport, Treatment and Disposal

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5. Impurities in Trade of Copper Concentrates and Blending Plants

6. Processing More Complex Concentrates: Industry Responses


8. Conclusions
### Promote In Situ Separation

1. One strategy is to separate the concentrates with high and low impurities in situ, to avoid the transport and processing of materials with impurities.

2. This requires a specialized process to take charge of the concentrate with high impurities. Every day resources becoming more complex.

3. Roasting is a solution for some impurities, but handling and disposal of the impurities extracted must be included. In current operations, projects and expansions.

### Innovation in Regulations

1. Regulations seen as obstacle but is also a way to seek solutions and improve the quality of products.

2. 2017 regulatory systems common denominator: sustained increase of the regulations and extension of its scope.

### Optimize Copper Value Chain

1. Arsenic and other impurities accumulates throughout the mining-metallurgical process and solutions for its proper handling, requires further technological development.

2. Technology solutions should look to "optimize the system" and solve problems along the entire value chain and not transfer them to the next stage.

3. The process does not end with the recovery of value from copper, but with the final disposal of the process residues in a non-leachable, compact and stable way.

### Research Other Industries/ Avoid Old Mistakes

- Learn from experiences and technologies from other industries (uranium in situ leaching), trying to look outside conservative solutions as invest in smelters in remote locations.
ICSG tracks the global copper supply side of the value chain, with limited statistics on impurities on concentrates and scrap.

**Copper concentrates**

- SX-EW: <3.9 Mt in 2016, <3.8 Mt in 2017!

- Concentrate Smelted: >16 Mt-Cu in 2016
  - Concentrate Refined: <15.6 Mt-Cu in 2016

- Scrap Smelted: 2.88 Mt-Cu in 2016
  - Scrap Refined: 3.22 Mt-Cu in 2016

- Scrap directly melted by fabricators: 4.93 million tonnes copper in 2016

**Fabricators of copper and alloy products:**
- copper wire rod
- copper tubes
- copper sheet
- copper rod bars
- copper alloy tubes
- copper alloy sheet
- copper alloy rod
- foundry castings

ICSG Refined Copper Use + Scrap Direct Melt 2016 = 28.3 Mt-Cu
Copper Raw Materials Impurities: ICSG Selected Findings in 2017-2018

Impurities in Mine Supply Facing Increasing Regulatory Pressures
1. New mines and plants more complex, deeper and expensive on lower ore grades
2. More complex copper concentrates; opportunity to recover valuable by-products
3. Limited expansion in operational mines and new mine capacity constraint 2018-2024
4. Large amounts of mineral waste can pose threats to public health and safety.
5. Falling copper content in concentrates trade: more impurities adding to higher costs
6. More international agreements on a global regulation of mineral waste after Minamata?

More Impurities in Plants Processing Copper Raw Materials
1. In 2021 over 60% of smelting capacity will be in Asia: must deal with impurities in advance
2. More impurities as Hg, As and Bi increasing smelters flue dust and other hazardous wastes
3. More demand for smelter products, but they content more As, Pb, Bi and other metals
4. ~ 50% of fabrication capacity in China in 2018, raw material imports dependency to continue

Global Bottleneck in Recycled Copper Raw Materials in 2018
1. No more recycled copper waste to China. EU/US/others scrap /waste to be processed somewhere.
2. Worldwide fabricators demand high grade scrap , but only refined copper available at a price.

Impurity Solution Via Market Mechanisms? Only Blending Works
1. Falling prices in exchanges 2011-2016 but ICSG reports deficits of refined copper every year.
2. Still is profitable to blend dirty/clean concentrates, but the trend is to more complex supply.
2. Regulatory Drivers: Risks, Ore Grades, Impurities and Plants Location
More occupational deaths related to carcinogenics in post industrial economies in recent years.

Carcinogenics

Arsenic

Increasing occupational risks in industrializing economies for As, Pb and H2SO4.

H2SO4

Lead

http://ghdx.healthdata.org/
UN World Health Organization: Arsenic, Mercury and Lead between the 10 “chemicals of major public health concern” in 2018.


**World: Arsenic Related Occupational Deaths 1990-2015**


Minamata Treaty: Smelters Environmental Management

Management and disposal of mercury wastes

Blending feed stocks to control mercury emissions

Particulate matter control measures

Atmospheric mercury emissions control measures

Lower mercury content in smelter feed

Fugitive emissions from point sources capture

India Tamil Nadu Pollution Control Board approved 400 kt smelter expansion. Violent local reaction, incidents, plant permanently closed now.

India Sterlite smelter was a efficient energy and water user. “protests were around the expansion of the plant”.

Increasing social media awareness on operational and abandoned copper mine tailings ownership and risks.
Record growth in copper concentrate impurities in the last 5 years before 2017, related to record world production of concentrates.
Arsenic content in copper concentrates up 92% in 2010-2016 in copper mines with >0.2% Arsenic in concentrate output.

From 2010 to 2016, in this dataset:
Only three mines have decreased arsenic content in concentrate
14 mines have the same arsenic content in concentrate
19 mines have increased arsenic content in concentrate

Select Mines with Arsenic >0.2% in Concentrate

Global average copper ore grade 0.45% Cu in reserves reported and 0.65% Cu in 2015 mine production (ICSG-rmit.edu.au 2018)

### Global weighted average of copper concentrate output, around 25% Cu based on reported 2015 data (ICSG-RMIT 2018)

<table>
<thead>
<tr>
<th>Process Configuration</th>
<th>Cu Recovery</th>
<th>Cu Concentrates</th>
<th>Mo Concentrates</th>
<th>Tailings</th>
<th>Waste Rock</th>
<th>OC Strip</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>kt conc.</td>
<td>%Cu</td>
<td>kt Cu</td>
<td>%Mo</td>
<td>kt Mo</td>
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<tr>
<td>Flotation (&gt;40% value Cu)</td>
<td>83.3</td>
<td>13,161.9</td>
<td>26.04±7.08</td>
<td>15.96 (56)</td>
<td>3,427.9</td>
<td>16.9 (5)</td>
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<tr>
<td>Flotation (&lt;40% value Cu)</td>
<td>76.3</td>
<td>742.7</td>
<td>24.89±4.45</td>
<td>16.00 (28)</td>
<td>184.9</td>
<td>nr</td>
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<tr>
<td>Flotation + Heap Leach</td>
<td>82.4 / 67.1</td>
<td>2,609.7</td>
<td>26.55±2.93</td>
<td>20.69 (7)</td>
<td>692.8</td>
<td>14.2 (1)</td>
</tr>
<tr>
<td>Heap Leach</td>
<td>65.6</td>
<td>nr</td>
<td>nr</td>
<td>nr</td>
<td>nr</td>
<td>nr</td>
</tr>
<tr>
<td>Flotation + Hydrometallurgy</td>
<td>78.9</td>
<td>1,412.3</td>
<td>20.64±5.56</td>
<td>14.00 (5)</td>
<td>291.5</td>
<td>nr</td>
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<tr>
<td>Flotation + Smelter + Refinery</td>
<td>88.4</td>
<td>5,335.2</td>
<td>21.74±5.28</td>
<td>12.95 (9)</td>
<td>1,160.1</td>
<td>35.6 (3)</td>
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<tr>
<td>Hydrometallurgy-Cu</td>
<td>88.2</td>
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<td>nr</td>
<td>nr</td>
<td>nr</td>
<td>nr</td>
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<tr>
<td>Hydrometallurgy-Au</td>
<td>71.5</td>
<td>25.9</td>
<td>19.48</td>
<td>16.67 (2)</td>
<td>5.0</td>
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<tr>
<td><strong>GRAND TOTAL</strong></td>
<td><strong>83.9</strong></td>
<td><strong>23,287.7</strong></td>
<td><strong>24.74±6.18</strong></td>
<td><strong>15.85 (107)</strong></td>
<td><strong>5,762.1</strong></td>
<td><strong>66.7 (9)</strong></td>
</tr>
</tbody>
</table>

Notes: %OC – proportion of ore derived from open cut mining; Strip ratio – ratio of waste rock to ore from open cut-derived ore; nr – not reported. *Values are recovery for flotation / heap leach, respectively.
Main reason for copper ore grade averages down 1990-2017: most profitable low grade porphyry deposits became mined first.

Copper Mines Operational and Undeveloped by Deposit Classification

<table>
<thead>
<tr>
<th>Deposit Classification</th>
<th>%Cu 2017</th>
<th>Operational Mt-Cu</th>
<th>Undeveloped Mt-Cu</th>
<th>% Copper Mine Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epithermal</td>
<td>0.18%</td>
<td>5</td>
<td>0.3%</td>
<td></td>
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<tr>
<td>Magmatic Sulphides</td>
<td>0.29%</td>
<td>76</td>
<td>4.2%</td>
<td></td>
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<tr>
<td>Sedimentary Pb-Zn</td>
<td>0.39%</td>
<td>11</td>
<td>0.6%</td>
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<tr>
<td>Porphyry Deposits</td>
<td>0.45%</td>
<td>1317</td>
<td>73.5%</td>
<td></td>
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<tr>
<td>Others</td>
<td>0.59%</td>
<td>16</td>
<td>0.9%</td>
<td></td>
</tr>
<tr>
<td>Skarn</td>
<td>0.70%</td>
<td>34</td>
<td>1.9%</td>
<td></td>
</tr>
<tr>
<td>Iron Oxide Cu-Au</td>
<td>0.71%</td>
<td>135</td>
<td>7.5%</td>
<td></td>
</tr>
<tr>
<td>Volcanogenic Sulphides</td>
<td>0.78%</td>
<td>32</td>
<td>1.8%</td>
<td></td>
</tr>
<tr>
<td>Sedimentary Deposits</td>
<td>1.52%</td>
<td>165</td>
<td>9.2%</td>
<td></td>
</tr>
</tbody>
</table>

World Copper Grades

World Average Copper Ore Grades by Mine Type %Cu

World Copper Mine Production, Copper Ore Grades and Energy Use in Copper Mining: 2003-2013

Copper ore grades declined fast, and new challenges are emerging:
As, Hg complexity in processed ores, less oxides vs sulphides, ore process technologies, refractory ores.

Upward pressure on energy and water costs 2013-2018.
More water reuse from tailings. Urban waste waters treated by miners.
Top copper mines output down not just on strikes or export controls: falling copper grades in concentrate exported and lower head grades ahead.

Escondida head grades falling below 0.5% Cu in 2016-2018.

PT-FI expects to mine high-grade ore over the next several quarters prior to transitioning to the Grasberg Block Cave underground mine in early 2019."
After CAPEX fell >50% in 2012-2017, more utilization in mines operational expected and more projects delayed beyond 2023

COPPER MINE PROJECTS (cap ≥110Ktpy Cu)

Projects in this box planned for after 2023

World copper concentrate capacity to remain below 21 Mt to 2021

World copper concentrate capacity to remain below 21 Mt to 2021
World copper mine capacity growth 2017-2021: faster in Africa.
Chile SX-EW mine refined output to fall more on depleted oxides.
In Situ Recovery technology reduce waste/impurities, but face its own environmental challenges.

- **Lixiviant selection critical for ISR:**
- Sulphuric acid, nitric acid, sodium bicarbonate, or ammonium carbonate used in uranium and copper ISR operations to date with oxide minerals.
- Must be efficient at liberating the target metal, limited toxicity and neutralized or destroyed at the end of leaching operations.
- ISR recovery of metals from sulphide minerals
- require aggressive lixiviants, as acidic ferric iron.
- More aggressive solutions as nitric acid and others.
- Risks of underground water pollution remain high.

- **Florence copper mine in Arizona:**
- 99.5% water and 0.5% acid.
- No open pit, no tunnels, no blasting, no waste dumps, and no large equipment.

Source: ALTA 2018 Metallurgical Conference, Perth, Western Australia, May 2018
China copper smelter capacity: 3.8 Mt in 2010 to ~9.9 Mt in 2021 +2.7 Mt more copper smelter capacity expected 2018-2021.

More demand for clean concentrates and scrap in China ahead.
China investing to reduce gap between local smelting, refineries and fabricators, and investing in overseas copper mines.

Impurities treatment: critical for China miners to deliver clean raw material.
To reduce occupational and other deaths related to carcinogenic:
remove impurities close to mines and minimize transport of residuals.
Limited value of customs data for impurities analysis in trade: concentrate values declared in exports below import declarations.

Average Copper Concentrate Prices Reported by Exporters and Importers in 2007-2017 (USD/Tonne) Source: GTT data 2018
3. New Global and Regional Regulations on Transport, Treatment and Disposal
New UNEP mercury emission assessment to be published in 2018

UNEP draft 2018: Cu+Pb+Zn industry mercury emissions up by 10.8% or +21 t in 2010-2015.

UNEP world mercury emissions from primary non-ferrous industry: 302.5 tonnes in 2010 (Aluminium industry included)
European Commission: 60% of current atmospheric mercury deposition are from industrial areas of Europe now.

EU Best Available Technology Regulation BAT (2016)

mercury emission limit to air:
0.01 to 0.05 mg/m³

Best Available Technology BAT 11.

a: Use raw materials with a low mercury content, including by cooperating with providers in order to remove mercury from secondary materials.

% of atmospheric mercury depositions in the European Union
Published by the European Commission in November 2017


European Commission Mercury Regulation

• The EU firmly on track for becoming the first mercury-free economy.
• This includes an end to all uses of mercury in industrial processes
• and prohibiting any new use of mercury in products and industry.


The most strict mercury water emission limits for mercury to EU copper plants.

Average Mercury Content in World Copper Concentrate Production (in particles per million PPM)

<table>
<thead>
<tr>
<th>Year</th>
<th>2012</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

European Union BAT 2016 Regulation:
New Emission Limits to Water for Metal Industries (mg/l)
Under Minamata Convention, high mercury copper concentrates to be classified as “mercury waste”: Hg processing close to mines.

Minamata Convention Article 11 (2013)

“Mercury wastes” substances
(b) containing mercury or mercury compounds;
or (c) contaminated with mercury or mercury compounds,
in a quantity above thresholds
defined by the Conference of the Parties.

2018 Compliance Committee of the Convention Operational

2018: no enough public data on Hg in Cu concentrates to define the thresholds.
Non Mercury Regulatory Issues Related to Impurities and Emissions in Europe in 2017-2019

EU Emissions Trading System Regulation to Impact European Industry Using Copper

EU Eco-toxicity Risk Assessment for Cobalt, Lead and Granulated Copper


France, Italy and Luxembourg Joint Declaration for Transparent Assessment of Chemical Substances.
UNIMO marine pollution protocol (MARPOL) to enforce a 0.5% global sulphur emission cap, effective January 1st 2020.

- Current Global limit today is 3.5%.
- Liquified natural gas LNG provides the best long-term option, but is more expensive.
- Enforcement to increase shipping costs for copper concentrates, scrap and other commodities in 2020.
Chile Environmental Impact Assessment System changes proposed.
Chile copper smelters air emission limits: enforcement time has come.

- Chile Environment Ministry to Modify Environmental Impact Assessment System (SEIA).
- Chile Environmental Assessment System SEA: Key Modifications Proposed.
- Chile Proposing Environmental Terms of Reference for Mining Projects
- Chile Administration Opens Dialogue on Copper Smelters Policy in 2018.
- Private Sector Perspective on Chile Policy on Copper Smelters and Refineries.
- Chilean Copper Smelters to Comply With Air Emission Limits by December 2018.
- Regulatory Compliance Challenges of Chilean Copper Smelters
- Chile Codelco Chuquicamata Comply with Decree on Air Emission Limits.
- Chile Environmental Court Stops Caserones Mine Tailings Pipeline on Spill.
- Fall in Mining Projects Asking Environmental Permits in Chile in H1 2018: -60%.
In Chile smelter technology reduced PM 2.5 improving air quality. But SO2, As and Hg concentrations remain a challenge in 2018.
In 2018 the US advance fast to develop domestic copper mine supply. Future copper concentrate impurities challenge in the United States.

- Two US National Monuments to be Downsized for Mining and Drilling.
- **US EPA**: Not To Require Miners Cleanup Costs Financial Capacity.
- **Alaska Pebble Copper Mine**: Project Legal Settlement on Permits Process.

- **US Army Corps of Engineers**: Scoping Pebble Copper Mine EIA
- **Pebble Limited Partnership’s Wetlands-fill Permit Approved**
- **US New Strategy to Secure Supplies of Critical Minerals**: Arsenic Included
- **US Department of Commerce**: Study on Steel/Aluminium Use in Critical Industries.
China 2013 “Special Emission Limits” on SO2, NOx, H2SO4, PM, Fe only in sensitive areas (47 cities) so no new copper smelters there.

Air Emission Limits for Chinese Copper Smelters in 2018
(non metal pollutants) in mg/m³

- Fluorides
- Particulate Material
- H2SO4 Mist
- Nitrogen Oxides
- Sulphur Dioxide

In 2018 few Chinese smelters comply with the special emission limits.

Sensitive areas expected to be expanded in late 2018
End of 2019: Chinese smelters must complete technical upgrades.
New minimum sulphur recovery rates for copper smelters in China: 1.2 Mt of small old smelters capacity to be replaced.

**Chinese Copper Smelters % Sulphur Capture Standard in 2018 - Reported by ENFI**

- Minimum Sulphur Collection in H2SO4 and Slag: 99%
- Minimum Sulphur Recovery in Off Gas: 97.50%

**Air Emission Limits for Metals in Chinese Copper Smelters in 2018.**

- Mercury: 0.012 mg/m³ (2013 Special Limit) vs. 0.012 mg/m³ (2010 Emission Limit)
- Arsenic: 0.4 mg/m³ vs. 0.4 mg/m³
- Lead: 0.7 mg/m³ vs. 0.7 mg/m³

*Source: MEP 2018*

**2010 Emission Standard of Pollutants for Copper, Nickel and Cobalt Industry.**

Air emission limits for Hg, Pb and As in China remains as in 2010.
China Ministry of Environment in 2018 actively inspect, cense, control and remediating copper smelters air, water and soil emissions.

Carbon Emission Trading System and CO2 Environmental Tax 2018

China Ministry of Environment Solid Waste Pollution Inspections in 2018

China Ministry of Environment Plan to Control Pollution by Heavy Metals

China Funds for Soil Contamination Recovery Target Copper Smelters

Soil Decontamination Regulations Implemented in 2018 in China.

Copper Smelters Emission Limits in China: Local Discharge Licences


China Second National Census on Stationary Sources of Pollution in 2018

China Total Pollutants Discharge Control Index Regime Implemented in 2018.

China Pollutants Discharge Permit System Management Guideline in 2018

China Emissions Permits 2018 Focus on Legal Liability and Disclosure
China State Council Blue Sky Protection Plan 2019-2021 to impact more than a few copper smelters operations

<table>
<thead>
<tr>
<th>Key regions</th>
<th>&quot;2+26&quot;</th>
<th>three year blue sky campaign</th>
</tr>
</thead>
<tbody>
<tr>
<td>BJ-TJ-HB and surrounding areas</td>
<td>Beijing</td>
<td>Beijing</td>
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<td></td>
<td>Tianjin</td>
<td>Tianjin</td>
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<tr>
<td>Hebei</td>
<td>Shijiazhuang</td>
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<td>Tangshan</td>
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<td>Xiong An New Area</td>
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<td>The Yangtze River Delta City</td>
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<td>Weinan</td>
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<td>Yanglin</td>
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</tbody>
</table>

Source: ICSG on Citigroup Research August 2018
A way for Chinese refineries to avoid smelter controls is to import smelter products: anode trade booming in 2017-2018.
4. Regulating Mineral Waste Flows and Copper Mine Tailings
Global copper concentrate output achieving new records 2018, so does the probability of copper mine tailings related incidents.

**World Copper Concentrates Output**
ICSNG July 2017

<table>
<thead>
<tr>
<th>Year</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>15,225</td>
</tr>
<tr>
<td>2016</td>
<td>16,474</td>
</tr>
<tr>
<td>2017</td>
<td>16,250</td>
</tr>
</tbody>
</table>

**World Copper Concentrates Output Growth**
2018 Vs 2017 - ICSG July 2017

<table>
<thead>
<tr>
<th>Period</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>January - April 2017</td>
<td>5,000</td>
</tr>
<tr>
<td>January - April 2018</td>
<td>5,200</td>
</tr>
</tbody>
</table>
Knowledge of mineral content in old and operational mine tailings: basic step for sound management and tailings re-mining.

### Chile Mine Tailings Average Content of Selected Minerals in 2018 g/tonne

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Average Content (g/tonne)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>0.04</td>
</tr>
<tr>
<td>Mercury</td>
<td>2.07</td>
</tr>
<tr>
<td>Cadmium</td>
<td>5.14</td>
</tr>
<tr>
<td>Silver</td>
<td>13.03</td>
</tr>
<tr>
<td>Cobalt</td>
<td>25.97</td>
</tr>
</tbody>
</table>

### Average Mineral Content in 1,324 Mine Tailings in Chile data in grams/tonne. Source: Sernageomin 2017

![Average Mineral Content Chart](chart.png)

- Cu g/ton
- As g/ton
- Zn g/ton
- Pb g/ton
- Bi g/ton
- Sn g/ton
- Al2O3 %
- Ag g/ton
- Fe2O3 %
- MgO %
- Yb g/ton
- S03 %
- Cr g/ton
- V g/ton
- SUMA
- Sb g/ton
- Rb g/ton
- Ni g/ton
- SiO2 %
- W g/ton
- Hf g/ton
- Gd g/ton
- REE %
- Er g/ton
- Lu g/ton
- Au g/ton
- Ta g/ton
- Th g/ton
- Ce g/ton
- Ho g/ton
- Nd g/ton
- Tb g/ton
- P2O5 %
- MnO %
- Mo g/ton
- Y g/ton
- Co g/ton
- K2O %
- Na2O %
- CaO %
- Cd g/ton
- Na %
- TiO2 %
Inadequate management of abandoned mine tailings keeping global industry related fatal accident rates high.

In February 2018 Zambia government’s mining investment arm gave a 10 percent stake in the Black Mountain mining waste site to small-scale miners.

Ten miners killed and another 10 injured in June 2018 after the dumping site for copper mining waste collapsed.

- Similar fatal incidents in the area, known for illegal mining around the dumpsites.
- Serious concerns remain about safety measures at the site which continues to suffer periodic collapses.
Inability of mining companies to reach a standard of construction and management that they acknowledge is possible. A standard that requires the commitment of dedicated personnel and funding.

UNEP, Canadian International Resources and Development Institute (CIRDI) and GRID-Arendal report "Taking Action to Reduce Pollution in the Extractive Sector" - December 2017.
UNEP: no cohesive international public enforcement regarding mineral waste: % of serious and very serious failures of all tailing failures is growing.

UNEP: ~3,500 mine tailing dams worldwide in 2018. Over 99 tonnes of tailings for one tonne of copper content. Major failures occurring at 2-5 of these dams a year, minor failures ~35 per year (UN). Expectations of more serious mine tailing failures ahead as copper concentrate output grows.

[Graphs showing mine tailing failures by decade and type of failure]
APEC Mine Closure Checklist for Governments 2018: implementation of closure measures will significantly reduce the liability.

If a “walk-away” condition can be achieved, then the post-closure liability would be zero.

Residual liability related to post-closure monitoring and maintenance: State?
Many mine tailing failures in Peru not reported by UNEP in 2018. Only one mine tailing not reported is operational. All others abandoned.

<table>
<thead>
<tr>
<th>Localización</th>
<th>Altura de la presa</th>
<th>Año</th>
<th>Causa</th>
<th>Consecuencias</th>
<th>Estado de la Presa</th>
<th>Sistema constructivo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casapalca</td>
<td>60 m</td>
<td>1952</td>
<td>Sismo</td>
<td>Varios muertes, contaminación del río Rimac.</td>
<td>Abandonado</td>
<td>Agua ambar</td>
</tr>
<tr>
<td>CENTROMIN</td>
<td></td>
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<tr>
<td>Casapalca</td>
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<td>Abandonado</td>
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<tr>
<td>CENTROMIN</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milpo</td>
<td>80 m</td>
<td>1956</td>
<td>Sismo</td>
<td>Varios muertes, interrupción de la carretera centro de Pasco-Huánuco, caídas atmosféricas</td>
<td>Reconstrucción</td>
<td>No ...</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Almirante</td>
<td>40 m</td>
<td>1962</td>
<td>Sismo</td>
<td>Ruptura en el cerro de la Presa, terremotos, caídas atmosféricas</td>
<td>Abandonada</td>
<td>No ...</td>
</tr>
<tr>
<td>Quinuichica</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yau Yacu</td>
<td>80 m</td>
<td>1989</td>
<td>Sismo</td>
<td>Interrupción de la carretera central y...</td>
<td>Abandonada</td>
<td>Agua ambar</td>
</tr>
<tr>
<td>Centomin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recuperada</td>
<td>60 m</td>
<td>1969</td>
<td>Desconocido</td>
<td>Contaminación del río Rimac.</td>
<td>Abandonada</td>
<td>No ...</td>
</tr>
<tr>
<td>Buenaventura</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Almirante</td>
<td>40 m</td>
<td>1970</td>
<td>Sismo</td>
<td>Contaminación del río San Felipe</td>
<td>Desconocido</td>
<td>No ...</td>
</tr>
<tr>
<td>Quinuichica</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Alacocha</td>
<td>20 m</td>
<td>1971</td>
<td>Falta en el drenaje</td>
<td>Intervención de la carretera central.</td>
<td>Abandonada</td>
<td>No ...</td>
</tr>
<tr>
<td>Tacampampa</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atezica</td>
<td>80 m</td>
<td>1971</td>
<td>Sismo</td>
<td>Desastres, daños, contaminación del río Rimac.</td>
<td>Abandonada</td>
<td>No ...</td>
</tr>
<tr>
<td>San Nicolás</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>90 m</td>
<td>1980</td>
<td>Construcción</td>
<td>Contaminación del río Uruco.</td>
<td>Abandonada</td>
<td>No ...</td>
</tr>
<tr>
<td>Amebilla</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corralillo</td>
<td>200 m</td>
<td>1996</td>
<td>Sismo</td>
<td>Contaminación, desastres del río Carapaz.</td>
<td>Abandonada</td>
<td>No ...</td>
</tr>
<tr>
<td>Cazano</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Financial Assurance Instruments for Copper Mine Waste/Tailings. Almost 100% of "fat tail" losses below standard for "insurable risk".

Chile Law 20,551 regulates actions aimed at mitigating the effects of mining to ensure the physical and chemical stability of the facilities. In 2018 Chile Ministry of Mines drafting modifications to the regulations for the closure of mines and plants.
Mining companies want to avoid disasters and environmental damage, given costs to their reputation and profits lost. What to do?


Tailings facilities even in dry climates recurrently saturated above 80%.

- For existing mines, applying Best Available Technologies BATs
  - to conduct dry closure of tailings impoundments.
Mines should dewater tailings and pursue all alternatives to perpetual water covers.
Appointment of Independent Tailings Review Boards to provide third-party advice on all phases design, construction, operation and closure.
- For new mines, a shift to “BATs” in tailings storage, including
  - to eliminate surface water from the impoundment;
  - promote unsaturated conditions in the tailings with drainage provisions
  - and achieve good conditions throughout the tailings deposit by compaction.
The best way to avoid liquefaction of mine tailings during earthquakes is to keep tails in unsaturated state: < 80% liquefaction risk is minimal.
In South America the trend towards tailings filtration, economically attractive when the value of water reaches US$ 3-5/m³. However, this can lead to an accumulation of undesirable impurities. As water circuits are tightened, more impurities are retained which makes processes more complex.

Counter measures include treating the bleed stream by either reverse osmosis or, more recently by nano-filtration.

Emerging strategy: reduce water usage by pre-concentration of the feed ore:
- removing gangue using mineral processing:
  - screening, jigs,
  - reflux classification,
  - dense media cyclones.

Pre-concentration drastically reduces the ore mass that reports to intensive downstream processing.

Rejects can be useful for the structural improvement of the tailings dam.

Source: ALTA 2018 Metallurgical Conference, Perth, Western Australia, May 2018
5. Impurities in Copper Concentrates Trade and Blending Plants Boom.
More complex concentrate supply from countries with low or no smelter capacity: fast growth in % of impurities exported.
World copper concentrate market ~60 Mt per year. Half exported. Importers more dependent from Chile, Perú, Australia and Indonesia.
63% of all copper concentrates exported from Chile and Peru in 2017. 66% of all copper concentrates imported by China and Japan in 2017.
Impurities in copper concentrates exports from Chile and Perú are growing faster than the 30%-32% copper content estimated.

More and better data is available in ICSG 2018 research. For most countries, copper concentrates trade is reported only in gross weight.
Indonesia export permits delays reduced trade of copper concentrates and valuable impurities in 2017.

On more complex concentrates imported and blended, Spain exporting more than Indonesia, US, Canada or Brazil in 2017.
In 2018 blending plants are treating more volumes of increasingly complex copper concentrates in Spain, Peru and East Asia.

Copper, lead and zinc concentrates with high As, Hg, Cd, Bi and Fe blended in Spain, South Korea, Malaysia and Taiwan (China) in recent years.

2018 Taiwan (China) blending plant closed and reallocated to Korea, but low capacity utilization.

2016-2018 Trafigura blending plant operational @ FCX smelter area in Huelva Spain

2018 new Logismin. SA new blending plant in Callao, Peru.

Glencore Perubar warehouse and blender in Callao (2016)

Two more blending plants from Chinese smelters Daye Nonferrous and Jianxi Copper to start operations in Malaysia in the near future.

Blister from complex concentrates and dismantled scrap expected in Malaysia in the future.
Global average arsenic content in copper concentrates in 2016: ~50% of maximum limit accepted to import concentrates to China.

In 2017 China rejected proposals of the industry to reduce limits on imported copper concentrates impurities.
First blending plant for complex concentrate operating in Fujiang Ningde China. New Ningde smelter close to the port started operations in June 2018. 200 kt then expected expansion to 400 kt/y.

In 2016 Chinese smelters proposed blending in special administrative areas in China to reduce high buying costs.
Relative % of concentrates with challenging levels of impurities is growing. Relative % of high quality concentrates available for diluting is shrinking.

Options: expansion of current smelters that process complex concentrates?
More roasters in mine sites + hidromet plants processing smelter residuals?
New high oxygen blow smelters to mining regions replacing polluting technology?
6. Processing More Complex Copper Concentrates: Industry Responses
With limited SX-EW and scrap supply, more copper concentrates with low copper contents and more impurities processed worldwide.

2017 Global Copper Smelter Supply and Mine Refined SX-EW

Minerals in Copper Concentrate Stocks in August 2018
Source: Open Minerals ~200 kt gross weight (%)

Copper Content 21.50%
Lead Content 1.25%
Arsenic Content 0.39%
Mercury Content 0.008%
Copper Smelters Industry: Emerging Trends

1. Restrictions to process concentrates/scrap with high % of impurities
2. Both for reasons of environmental control and product quality.
3. Greater restrictions on the transport of concentrate
4. Focused mainly on replacing its handling in bulk by containers.
5. To ensure a consumer market for H2SO4
6. Tendency to valorize iron-silica slag, as a commercial product.

Improved hydrometallurgy technology of copper sulphides
but no large concentrate leaching plants yet.
Chile mineral supply complexity increased: so local smelters are processing more volumes of arsenic and other impurities.

Average Mineral Composition of Complex Copper Concentrates Processed in Selected Copper Smelters in South America (*)

<table>
<thead>
<tr>
<th>Mineral</th>
<th>2005-2014 %</th>
<th>2012-2014 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chalcosite Cu2S</td>
<td>30.73</td>
<td>0.31</td>
</tr>
<tr>
<td>Enargyte Cu3AsS4</td>
<td>23.81</td>
<td>0.56</td>
</tr>
<tr>
<td>Pyrites FeS2</td>
<td>22.12</td>
<td>18.31</td>
</tr>
<tr>
<td>Coveline CuS</td>
<td>3.88</td>
<td>3.78</td>
</tr>
<tr>
<td>Chalcopyrite CuFeS2</td>
<td>3.46</td>
<td>51.32</td>
</tr>
<tr>
<td>Bornite Cu5FeS4</td>
<td>2.81</td>
<td>6.49</td>
</tr>
<tr>
<td>Wurtzite ZnS</td>
<td>1.99</td>
<td>0.14</td>
</tr>
<tr>
<td>Tetrahedrite (Cu,Fe)12Sb4S13</td>
<td>0.52</td>
<td>0.85</td>
</tr>
<tr>
<td>Galene PbS</td>
<td>0.18</td>
<td>0.05</td>
</tr>
<tr>
<td>Cuprite Cu2O</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td>Molybdenite MoS2</td>
<td>0.06</td>
<td>0.14</td>
</tr>
<tr>
<td>Digenite Cu9S5</td>
<td>1.38</td>
<td>1.38</td>
</tr>
<tr>
<td>Gange</td>
<td>10.10</td>
<td>14.59</td>
</tr>
<tr>
<td>Other Minerals</td>
<td>0.25</td>
<td>2.01</td>
</tr>
</tbody>
</table>

(*) Alto Norte smelter, specialized in high As concentrates not included
Data: Technology Research Institute - University of Concepcion - Chile 2018
Chile refined copper supply keep falling, North America and Africa refined output is volatile: refined copper output growing only in China.
Refined copper output stagnated in EU-28, in Russia and Central Asia, in South Asia and Australia, in Japan and in the Korean Republic.
Many Flash smelters still re-circulate arsenic rich solid waste to the furnace to recover copper, increasing As emissions.

In bottom or side blown copper smelters over 80% of Arsenic is in gas
No dust re-circulated: most collected and treated to eliminate arsenic and recover valuable metals.
New smelters 2018-2021: larger scales, cleaner side/bottom oxygen blowing technology but Flash is the industry standard.
Smelter/refinery complexes are more competitive at large scales. But new hydromet technology competitive for complex concentrates. When oxides are available, SX-EW has the best economy of scale.

Copper Smelting and Hydrometallurgy for Copper Sulphide Ores and Concentrates
Drs. Parra, Mackey & Salas - ICSG Research Project 2018
In 2017 smelters in China treated ~30 Mt of copper concentrates and produced ~6 Mt of copper blister and anodes from concentrate.

China Copper Smelters Output and Impurities Flow in 2017 in tonne. Estimate based on ICSG and BGRIMM data.

Arsenic inflows ~50 kt per year, only ~10 kt of As outflows pre 2017.

Average Cu and As in concentrates treated in Chinese smelters:
18% to 20% copper / 0.20% to 0.25% arsenic

Source: BGRIMM- Proceedings of EMC Conference 2017
In the 1990s Chinese smelters used Japanese copper sulphate process to recover As residues: long process with high costs and 45% of As re-melted.

China smelters to process all waste together in side blowing furnaces: Arsenic sulphide pressure leaching operating in China Guixi smelter from 2008 to 2018.

- Arsenic leaching ratio: 95%
- Copper leaching ratio: 95%
- Rhenium leaching ratio: >98%
Tongling Group double side blowing smelter treat together pressure leaching residues, smelter flue dust and black copper mud residues, recovering Au, Ag, Sb, Pb and Bi.

Leached residues are dried

Add limestone, iron, silica, anthracite

Oxygen injected to furnace

Slag discharged

Anthracite and flux added

Pb, Bi, Au, Ag alloy

Lead flows out of furnace

Slag above, lead below

Sb to off gas and dust collection
Sweden Rönnskär copper smelter 2020 plan: deep repository and leaching plant to recover lead and zinc and reduce waste for disposal.
Many copper smelters with reverberatory furnaces still processing low grade copper scrap in China. 
Source: China ENFI Engineering Corporation . EMC 2017 Proceedings

Copper and Alloy Waste and Scrap Exports to China
Reported as HS Code 7404 - kt in Gross Weight

China Secondary Smelter Production
ICSG Statistics March 2017 kt

Recycled Copper Smelted and Refined in China
2017-2018 Trend kt-Cu

Dioxin is generated when smelting chlorine from plastics, rubber and waste in copper scrap and copper alloy scrap.

China still reporting more scrap refined than smelted in 2018.
China ongoing reform to reduce impurities in scrap/waste imports is affecting copper raw materials trade flows worldwide.

State Council Institutional Reform on Solid Waste Imports in China

Measures to Reduce the Volume of Imported Solid Wastes in China

Ongoing Reform to Foreign Scrap and Waste Import System

China Implements Plan to Reduce Imported Solid Waste in 2018

Impacts of Imported Waste Ban on Trade and Copper Specific Restrictions

China to Ban Low Grade Copper and Aluminium Scrap Imports by December 2018

Imported Waste Regulation: Expected Shortage of Copper Scrap in China
Exporters declarations 2017: China was still the main destination of scrap and waste with copper content.

2017 Destination of Cu, Alloy and Waste Scrap Exports in Gross Weight kt

- to All Other Countries: 2,309 kt, 45%
- to the European Union: 410 kt, 8%
- to China: 2,400 kt, 47%

2017 Exports of Copper Scrap, Alloy Scrap and Copper Waste in Gross Weight kt

- From All Other Countries: 3,132 kt, 61%
- European Union: 980 kt, 19%
- United States: 1007 kt, 20%
China March 2018: no more than 1% impurities in imported scrap.
April 2018: China to ban all imports of scrap with low metal content in 2019.

In early 2018 Chinese imports of low grade copper contracted.
But copper content in China “copper waste” imports increased to >50% Cu.
In early 2018, the US exported more high grade scrap in response to the Chinese ban on solid waste imports.

But in May 2018 China stopped accepting US scrap export applications, so US scrap exports to China fell to historic lows.
In 2017 close to 2.4 Mt of waste containing copper crossed a border in the European Union. Mainly as “copper alloy scrap”.

Most of the scrap and waste that left the EU in 2017 had low copper content. Over 500 kt of scrap exports not properly classified by EU exporters.
Close to 1 million tonnes in low copper scrap/waste exported from the European Union in 2017

Where the EU-28 will send or process low copper content scrap and copper waste now that China is not accepting it?
Only if rejected scrap and concentrates are melted outside China expect more blister, anodes, refined supply and exports.
In the short term more global copper concentrate output, and much more impurities exported to China and to the ROW.

Assuming 28% copper content 2015-2018!
Conclusions

More Impurities Increasing Copper Mine Costs and Mineral Waste Risks
1. Copper miners energy, water and waste disposal costs increase linked to falling copper ore grades.
2. More UN environmental guidelines on mining waste, concentrate transport to tailings (Minamata, UNEP, IMO, ISA, APEC).
3. As copper concentrates output breaks global records, mine tailings and other mineral waste risks jumping.
4. Copper mine tailing risks looking for regulatory approaches: legacy waste and wet tailings, key but expensive

Copper Concentrates Blending Was The Response to Concentrate Import Limits
1. Blending plants responded to import controls in China. Future blending plants to face shortage of clean concentrate.
2. New concentrate blending plant in Free Trade Zone in China linked to new copper smelting capacity.
3. Regulatory pressure on mercury emissions coincident with more blending of complex concentrates in Europe.

Promoting Investments in Clean Smelter Technologies Still Far from Mines
1. Trend to process concentrates close to manufacturers with large plants /more risks instead mining districts.
2. Global impurities challenges driven by copper concentrates boom on record new smelter capacity located in China.
3. China now regulating copper plants via emission controls, environmental taxes and “polluter pays” principles.
4. Stricter sulphur and PM emission rules in China in 2017. As, Hg and Pb emission limits to smelters unchanged ....yet.
5. New copper smelting technologies developed in China to capture and process most of concentrates impurities.
6. Smelters re designing to poly-metallic treatment and to capture and process impurities, but not in mining countries.
7. China solid waste import ban hit copper waste recycling in industrial economies. Concentrates waste ban ahead?

Regulate To Replace Old Smelting Technology and Reduce Carcinogenic Risks
1. High occupational risks related to carcinogensics in industrialized economies keep driving regulatory pressure.
2. But evidence that As, Pb and H2SO4 and other industry related risks growing fast in developing economies.
3. Copper smelters emissions face social license and governments licence decisions in India, China, Chile, and EU.
4. Green tape de-regulation ongoing ex-China: will protected sectors of the economy keep delaying smelters modernization?
Thank You.

For more information and data updates please visit www.icsg.org