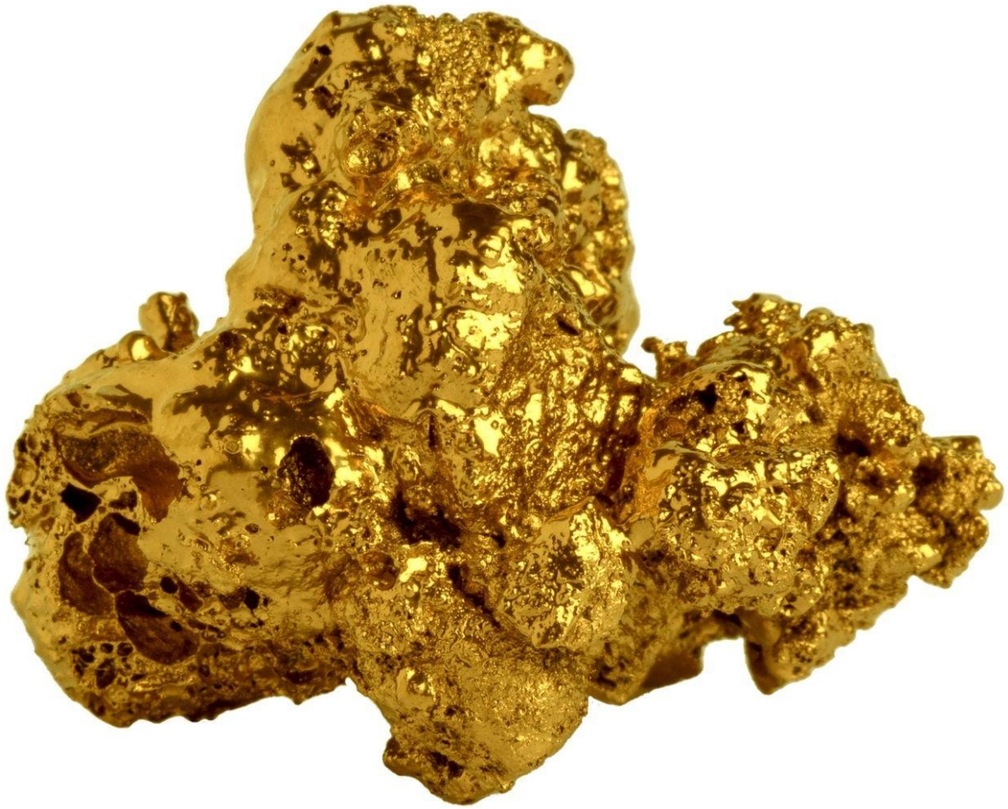
Global Gold Mining and Processing

Environmental and Social Impacts



Carrie Snyder, More Than Sustainability

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As good as gold: The Uses and Chemistry of Gold

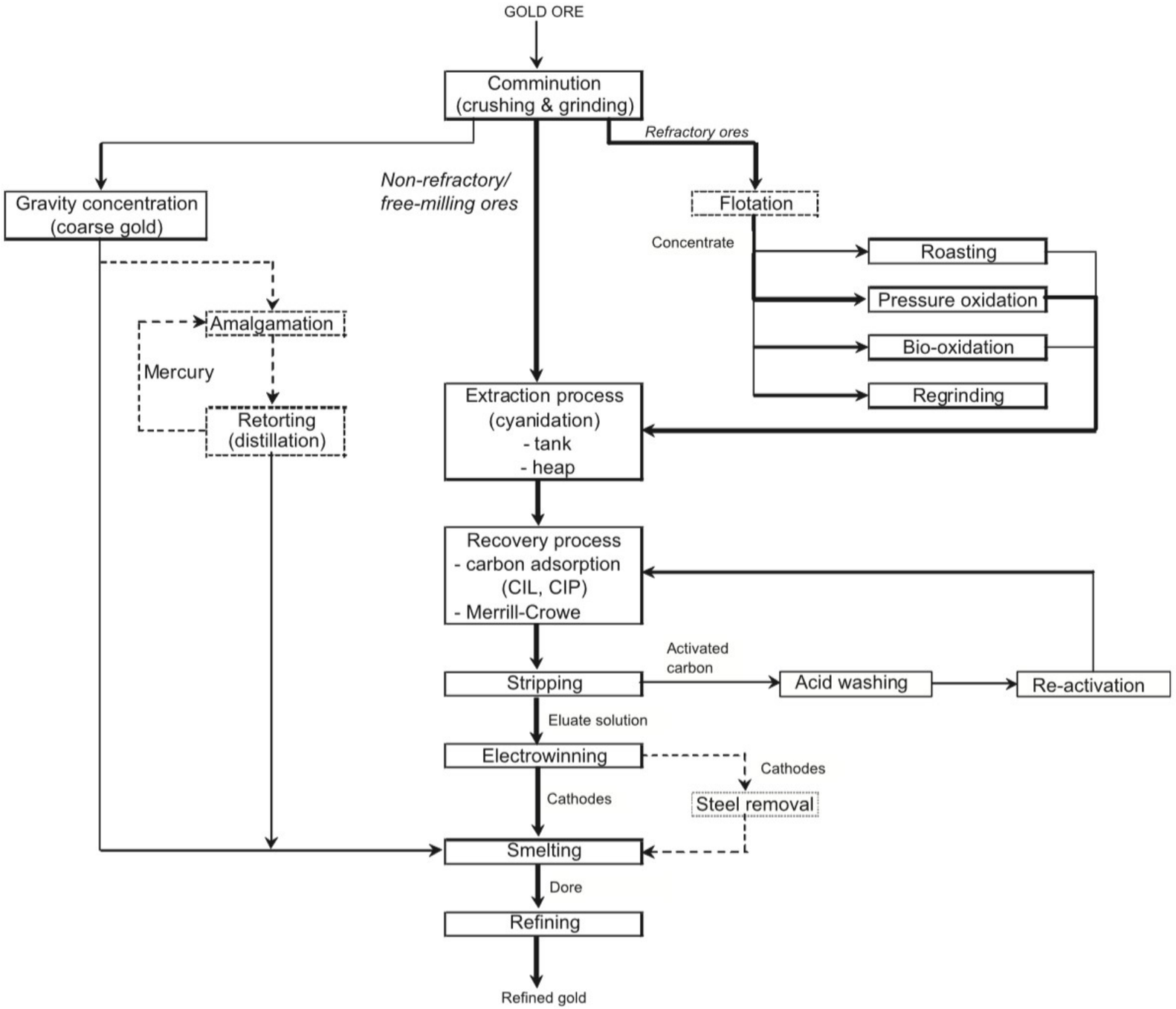
- Gold (chemical symbol Au) is one of the most highly valued metals by society—with mining and extraction at least 4000 years ago[1]—**due to its color and lustre, non-reactivity (i.e. does not tarnish), malleability, and rarity[2]. In electronics applications, gold is also valued for its conductivity and ease in creating layers and alloys**
- In 2019, almost half of global gold demand was for jewelry manufacturing, 7.5% for technology, and the remainder for investments and other financial purposes[3].
- **Gold is unique among metals in that most of what has been mined is recycled** (as opposed to dissipated or disposed of), as a result **98% of the gold that has been produced throughout history is still available or in-use**[4], although it would only fit in a cube that is 23 meters wide on each side[5]
- Ore contents in gold mines today range from 0.5 gram per ton (in small-scale mines) to several tens of grams per ton (in large industrial mines)[7]. This means that for **every one gram of gold produced, there are anywhere from tens of thousands up to almost two millions grams of waste materials generated, depending on the mine**. As with all metals, gold ore grades are generally decreasing over time[6]
- Gold mining is not particularly geographically concentrated, both due to geochemistry (ore deposit locations) and economic value (making gold mining profitable even for small, low-grade ores)
- In 2018 the top 10 gold-producing countries (in order) were China, Australia, Russia, the United States, Canada, Peru, Indonesia, Ghana, Mexico, and South Africa; accounting for about 63% of global production[4].
- However, **gold mining overall is in fact practiced in over 100 countries**[4], and is likely the most widespread and practiced mining type in the world[8]

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Sitting on a gold mine: Large-Scale Mining and Processing (LSM)

- An estimated **85% of the world's gold supply comes from large-scale mining**, managed by national and transnational corporations[9]. Both open-pit and underground mining methods are used, with open-pit favored more recently[2]
- **The primary method of refining—for ~80% of gold produced[2]—is 'cyanidation', in which the mined ore is soaked in a solution of sodium cyanide (NaCN) to leach out gold**[9]. (While there are alternatives to cyanide use[13], they have not been widely adopted mainly due to their high consumption and/or cost[2])
- "Milling and heap leaching for gold require cycling of millions of liters of alkaline water containing NaCN, free cyanide, and metal cyanide complexes that are available to the biosphere"[10]. Remnants of processed and leached deposits, called 'tailings', are transported to outdoor tailings storage facilities for long-term storage. "Tailings solids are often piled to construct 'tailings dams' which embank 'tailings ponds'—large lagoons of effluents and slurry waste from the mining process. In most modern large-scale gold mining operations, **over 99% of the originally mined ore eventually becomes tailings**."[9]
- It should be noted that some, but not all, cyanide can degrade into non-toxic components by microbiota[9], but at the same time, "under certain alkaline conditions, cyanide may persist for at least a century in groundwater, mine tailings, and abandoned leach heaps."[10] In addition, **mine tailings often, unavoidably, contain high levels of heavy metals such as iron, copper, zinc, arsenic, lead, cadmium, and mercury co-present in the ore and waste rock**[8]
- "Breaches and failures in these tailings dams can release high concentrations of cyanide and heavy metals into adjacent soils and waterways, which can be lethal to wildlife and people. Animals that come in contact with unnetted tailings ponds are also at risk of poisoning and death."[9] **Unfortunately, failures of mining tailings dams occur all over the world. It is important to note these collapses are not limited to less-regulated countries.** In 2014, for example, the tailings dam at Mount Polley mine in Canada collapsed[11]. Overall, tailings dams failures can occur due to poor engineering, but **many also are primarily attributed to natural events like earthquakes and flooding**[12] **which are difficult to avoid or control**

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All that glistens: Artisanal and Small-Scale Gold Mining (ASGM)

- **There are approximately 50 million people involved in ASGM in approximately 70 different countries**[14]. Artisanal miners extract underground ore manually, using rudimentary methods[15]
- **Many resasons including: the consistent high demand and price of gold, easy and accessibility of initial gold mining processes, limited economic development and alternative employment options in rural areas, and poor implementation of mining laws and frameworks in many countries, have contributed to the proliferation of artisanal and small-scale gold mining** (ASGM)[3,14]
- One of the most globally impactful problems with ASGM is the **common use of mercury to extract gold from ores**[14].
- A 20% gold is the level of purity required for the smelting process. To achieve this, artisinal miners often use a mercury amalgamation process. Mercury forms an alloy (amalgam) with gold, chemically separating it from other minerals[9].
- **Miners and traders then burn off the mercury, often in an open flame,** leaving just the gold[26]. Once the mercury is no longer effective at extracting gold, miners abandon open dumps of mercury-contaminated tailings[9].
- Overall, **mercury losses through gold amalgamation process can be as high as 80% of the initial input**[15]. As a result, **37% of global mercury emissions come from ASGM**[16]
- Over time, mercury vapor inhaled by miners results in impaired cognitive function, neurological damage, kidney damage and several other health problems[16]. **But the danger isn't just limited to the miners. "Elemental mercury emitted into the air can travel virtually worldwide,** eventually coming to rest on the soil or water. Once it lands —or if it is released directly into soil or water through industrial activity —it can be converted by microorganisms into methylmercury, which bioaccumulates in aquatic organisms and works its way up the ocean food chain."[17] "Elevated mercury concentrations have been found in humans hundreds of kilometers away from gold mining centers"[18]

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Fool's gold: Why Use Mercury?

- So given these dangers, why is mercury used for AGSM[19]?
  - **It is easy to use, and it works quickly**
  - **It can be used by one person independently**
  - **It effectively extracts gold in most field conditions**
  - **It is cheaper than most alternative techniques**
  - **It permits custom processing of small individual ore batches**
- But despite these advantages, **mercury amalgamation is in fact highly inefficient at extracting gold, yielding only 30-40% of the recoverable gold from ore**, whereas alternatives involving gravitational separation techniques can yield 2-3 times as much gold[17].
- However, these alternatives require investment and training, which most miners cannot afford and do not have access to. "These are people looking to survive today. **"If you are a poor farmer relying on that two grams of gold at the end of the day to buy food or put your kid in school, you are not likely to experiment with a shaker table or new gravitational technique"**[17]
- There has been a **significant effort on the part of global organizations and governments to eliminate mercury use in AGSM**, including the ratification of the Minamata Convention by over one hundred countries starting in 2017[16], and millions of dollars have been spent on policies, regulations and interventions[14].
- **Unfortunately, these efforts have been largely unsuccessful**[20]. There have been many reasons suspected for this, but one worth noting is the **inability of these programs to address the most pressing difficulties (and thus the priorities) of the miners themselves**

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For example, a survey of ASG miners in Peru[21] found:

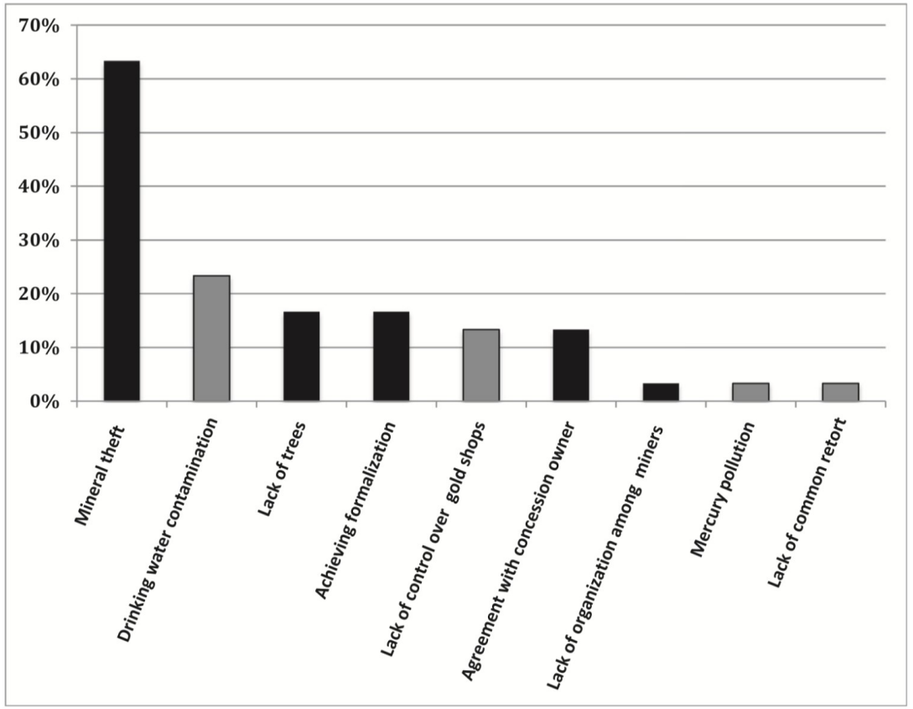


Fig. 1. The most significant ASGM-related challenges. Challenges implicating mercury are shown in grey. The percentages represent the total number of times each challenge appeared in the responses (n = 30).

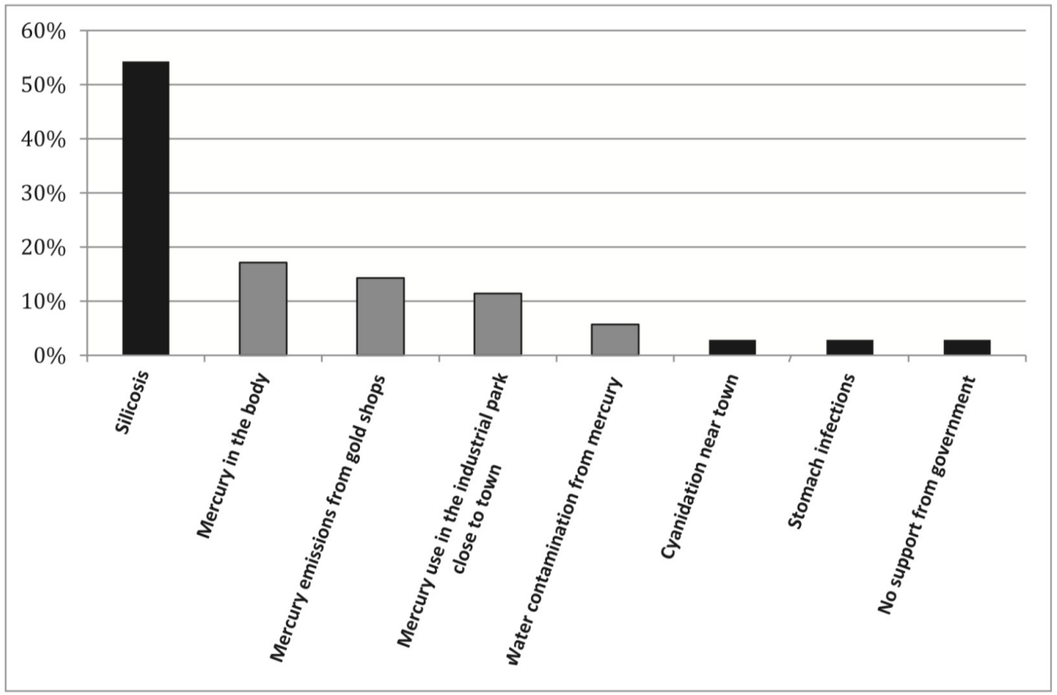


Fig. 2. The most significant ASGM-related public health concerns. Mercury-related public health concerns are shown in grey. The percentages represent the total number of times each challenge appeared in the responses (n = 35).

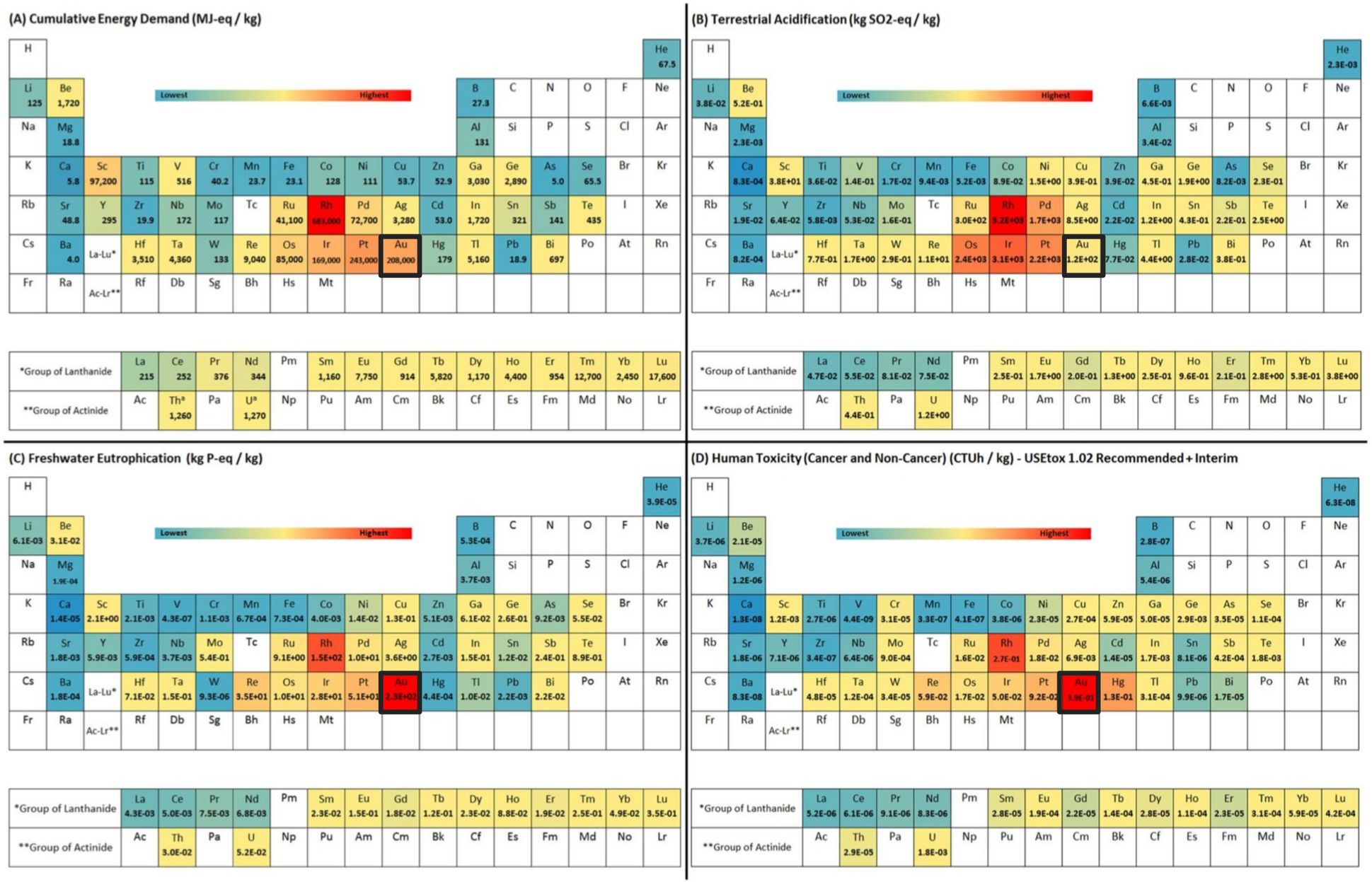
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A (not-so) gold standard: Sustainability Impacts

- From a social sustainability standpoint, a search on the Human Rights Watch site generates 539 results relating to gold[27]
- This is not surprising given **gold's status as a conflict mineral**. "Gold mining has been identified as a potential source of funding for armed groups involved in civil unrest in several countries, including the Democratic Republic of the Congo", and gold has been subject to the Dodd-Frank act in the US since 2010[4]
- But **gold's relationship with conflict isn't limited to the DRC**; for example "recent evidence suggests that gold mining in Colombia has been permeated by illegal organizations linked to the drug trade, driving armed conflict and criminality"[23]
- In addition, there are currently 3873 cases logged in the Environmental Justice Atlas; 8% of them have some association with gold[22]
- "**The major environmental and socio-economic problems caused by gold mining in the developing world include deforestation and erosion damage; acid mine drainage; disposal of tailings into rivers; noise, dust, air and water pollution from arsenic, cyanide and mercury**"[2]
- It is not surprising, then, that a study by Earthworks.org found that **the production of one gold wedding ring produces approximately 20 tons of toxic waste**"[7]

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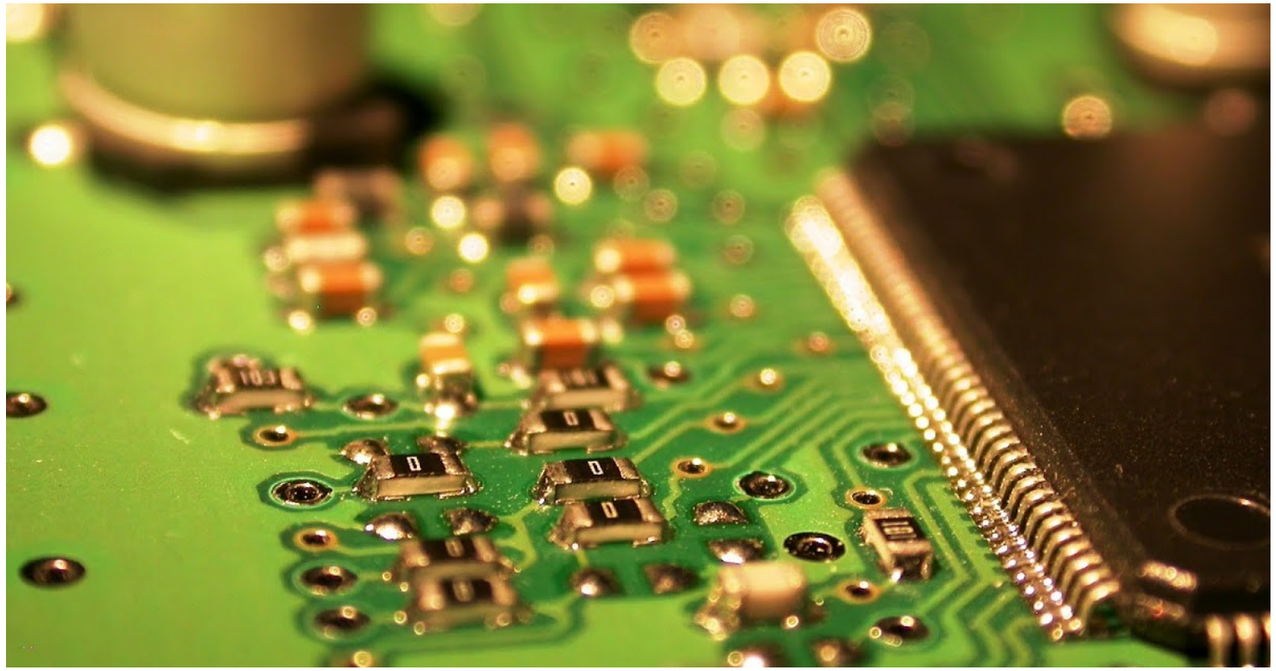
While the LCA data for metals isn't complete, and a precise study would need to be made to apply these results to a particular product, in a comparative analysis of LCAs **gold was found to have some of the worst environmental impacts of all metals in several categories**[24]:



The energy results are mainly attributable to the low grade of ores used for gold production compared to ores used in the production of most other metals[2]

Globa

A golden opportunity: Recycling



Creative Commons: https://www.quantumday.com/2012/07/320-tons-of-gold-worth-us21b-used.html

- **A significant portion of the embodied energy (and associated greenhouse gas emissions) of gold production is in the mining and mineral processing stage, unlike most other metals"**[2]
- **This makes the benefits of recycling gold even higher, as recycling avoids those stages of mined gold production**
- While gold is already highly recycled today, **recycling e-waste is an additional opportunity, providing "high grade ore" with gold concentrations in waste PCBs, for example, having 40-800 times higher gold concentrations than that of mined ore**[25]

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Summary

- Gold has high value in human society, as it has for thousands of years
- However, gold's natural chemistry and geology results in gold ore being widely distributed in small quantities throughout the world
- The two primary processes for extracting gold, cyanidation (for large-scale mines), and mercury amalgamation (for small-scale mines), are highly toxic to the environment
- Gold ranks as one of the worst metals in terms of environmental impact
- While (uneconomic) better alternatives exist for these chemicals, the co-presence of other toxic heavy metals with gold ore means that tailings ponds unavoidably pose environmental risk
- Even in the most regulated countries, tailings dam failures occur (often due to natural events like earthquakes and flooding)
- In addition, gold is associated with armed conflict in various parts of the world, resulting in its regulated as a conflict mineral in the US and elsewhere
- Because many of the environmental impacts (including energy) of gold are during the initial stages of mining and processing, recycling—which avoids these stages—can be highly beneficial
- Gold is already highly recycled today, but with the increasing volumes of unrecycled electronics, e-waste can become an important source of recycled gold, with PCB "ore grades" 40-800 times higher than that of mined gold ore

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Thank you

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