# *Global Stainless Steel Mining and Processing*

## *Environmental and Social Impacts*



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# What is Stainless Steel

- The word ‘steel’ means that **iron** (Fe) constitutes the bulk of the material, while the use of the adjective ‘stainless’ implies absence of staining, rusting or corroding. In order to impart ‘stainlessness’, **chromium** (Cr) must be added to at least ~11 wt%[1]
- There are more than 100 grades of stainless steel. Austenitic steels, which contain 16-26% Cr and up to 35% **nickel** (Ni), usually have the highest corrosion resistance
- **Manganese** (Mn) imparts the following three important properties to steel: sulfur fixing through desulphurizing, reducing oxygen level through deoxidizing, and enhancing mechanical properties, particularly strength and hardness[2]
- Although the amount of Mn consumed to make a ton of steel is small, ranging from 6 to 9 kilograms, it is an irreplaceable component[3]

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Alloying elements, important minerals and their respective effects on steel's properties (Modified from: Fenton, 2005; Hale, 2000).

| Alloying element | Main minerals | Effects of alloying elements on various steel properties |
|---|---|---|
| | | Improves and/or controls and/or imparts |
| Boron | Borax and Ulexite | Hardenability without loss of machinability and formability |
| Calcium | Calcite, Dolomite and Gypsum | Hardenability, strength, hardness and wear resistance. Reduces ductility, weldability, and toughness |
| Cerium/Zirconium/Magnesium | Monazite & Bastnasite/Zircon/Dolomite, Magnesite, Brucite, Talc, and Olivine | Shape of inclusions and toughness in high-strength low-alloy steels; deoxidizes steels. |
| Chromium | Chromite | Toughness, hardenability, wear and corrosion resistance, and high-temperature strength; increases depth of hardness penetration in heat treatment by promoting carburization |
| Cobalt/Tungsten | Cobaltite also Cu and Ni mining/ Wolframite and Scheelite. | Strength and hardness at elevated temperatures |
| Columbium/Tantalum | Pyrochlore and Columbite/Tantalite. | Fine-grain size, strength and impact toughness; lowers transition temperature; may decrease hardenability |
| Copper | Chalcopyrite, Bornite, Covellite, Chalcocite; Azurite, Malachite and the Cuprite. | Resistance to atmospheric corrosion and to a lesser extent strength with little loss in ductility; adversely affects hot-working characteristics and surface quality |
| Lead | Galena, Cerussite and Anglesite | Machinability; causes liquid metal embrittlement |
| Manganese | Pyrolusite, Braunite, Psilomelane, and to a lesser extent as Rhodochrosite | Hardenability, strength, abrasion resistance, and machinability; deoxidizes the molten steel and reduces hot shortness; decreases weldability |
| Molybdenum | Molybdeniteas, Wulfenite and Powellite. | Hardenability, wear resistance, toughness, elevated temperature strength, creep resistance, and hardness; minimizes temper embrittlement |
| Nickel | Limonite, Garnierite and Pentlandite | Strength, toughness, and corrosion resistance; improves hardenability |
| Phosphorous | Phosphate rocks | Strength, hardenability, corrosion resistance, and machinability; severely reduces ductility and toughness |
| Selenium | Selenide Selenate and Selenite. | Machinability |
| Silicon | Amethyst, Agate, Quartz, and in many Silicate minerals | Strength, hardness, corrosion resistance, and electrical conductivity; decreases magnetic hysteresis loss, machinability, and cold formability |
| Sulfur | Sulfide and Sulfate | Machinability when combined with manganese; lowers impact strenth and ductility; impairs surface quality and weldability |
| Tellurium | Telluride of gold | Machinability, forability, and toughness |
| Titanium | Rutile and Ilmenite | Hardenability; deoxidizes steels |
| Vanadium | Patronite, Vanadinite and Carnotite | Strength, toughness, abrasion resistance, and hardness at elevated temperatures; inhibits grain growth during heat treatment |



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# Substitutability

- There was one reference found regarding substitutability of stainless steel composition: “The missing amount of MnCrNi type of stainless steel can be replaced by a simpler chromium–manganese stainless steel alloy, enhanced with more molybdenum and niobium.”[5]
- Of course, then, the sustainability impacts of those additional elements would need to be considered (in addition to cost)
- Overall, elements like Ni are not seen to be readily substitutable

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# History of the Elements and Their Use in Steelmaking

- Fe has been used for over 4000 years in the making of weapons and tools[6] There is evidence that meteorites were used as a source of Fe before 3000 BC, but extraction of the metal from ores dates from about 2000 BC
- Manganese oxide (pyrolusite) has been used in glass making since the time of the pharaohs in Egypt[2] In particular, it has the ability to remove the green tint imparted by iron to glass.[7] At the beginning of the 19th century, both British and French metallurgists began considering the use of Mn in steelmaking[8]
- Cr is somewhat unique in that it came first in use in the leather tanning industry in the 1800's before it was used in metallurgy
- Ni wasn't much in human use separately until discovery of austenitic stainless steel in Germany in 1914, a development that stemmed from the 1913 discovery that Cr-bearing steels are resistant to chemical attack[9]

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# Abundance and Uses

- Fe is the 4th most abundant element and accounts for about 5% of the earth's crust[6]
- Mn is the 12th most abundant element in the Earth’s crust, with an average concentration of the order of 1,100 ppm[8]
- Cr is the 21st most abundant element[10]
- Ni is the 24th most abundant element in the Earth’s crust, comprising about 3% of the composition of the earth[11]
- **98% of the globally mined Fe ore is used for the production of steel[12] and 85%-90% Mn, 85% of Cr, and 70% of Ni produced is used for stainless steel[13]**

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# Iron Ores

- The types of ores primarily mined for Fe are various forms of iron oxides: hematite, goethite, and magnetite[14]
- Pure magnetite contains 72.4% Fe and hematite 69.9%, but, since these minerals never occur alone, the metal content of real ores is lower. Deposits with less than 30% Fe are commercially unattractive, and, although some ores contain as much as 66% Fe, there are many in the 50–60% range
- An ore's quality is also influenced by its other constituents, which are collectively known as gangue. Silica and phosphorus-bearing compounds are especially important because they affect the composition of the metal and pose extra problems in steelmaking
- The top 3 production countries in 2022 for Fe were Australia, Brazil, and China[15]

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# Manganese Ores (terrestrial)

- The most common Mn mineral is pyrolusite, which is mainly MnO2. Mn is also found in other minerals, such as pink rhodochrosite (MnCO3), rhodonite (MnSiO3), black manganite (MnO(OH)), and alabandite (MnS)[16]
- Mn ores (without impurities) contain a minimum of 15 percent manganese, but most ores are considerably higher grade, ranging up to about 50 percent manganese[3]
- The top 3 production countries in 2022 for Mn were: for Mn: South Africa, Gabon, Australia[18]

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# Manganese Ores (seabed)

- In 1868, minerals composed of concentric layers of Fe and Mn, called polymetallic nodules, were discovered in the bottom of the Arctic Ocean. A few years later it was discovered that these were present in most of the world's oceans[17]
- Polymetallic nodules, also called Mn nodules, contain various valuable metals such as Cu, Ni and Co, as well as traces of Mo, Ti, Pb, Li, Pt, Ti, Zr and Zn and light and heavy rare earth elements, which is why they are considered the most valuable oceanic mineral resource[17]
- It has been estimated Mn nodules cover about 10–30% of the deep Pacific floor[7]
- Rulings from the International Seabed Authority to determine whether modules in the Pacific can be mined are expected this year
- LCAs are unclear on the carbon impacts of deep sea mining (+ or - compared to terrestrial mining), and the biodiversity risks seem high

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# Nickel Ores

- While Ni's crustal abundance is greater than copper, zinc, and lead (Pb), unlike these elements, Ni suffers from a lack of deposits with significant concentration[19]
- Economically extractable reserves of Ni are in two groups: sulfide and laterite (oxide). While the minerals within these ores contain significant amounts of Ni, the actual Ni content in ores is typically <3% by weight[19]
- **The type of nickel produced for stainless steel is primarily obtained from laterites** (as opposed to sulfide ores)[20]
- Though there are more laterite than sufide deposits, **the processing of laterites is more energy intensive**. Overall, sulphide deposits are cheaper to process than laterites, although they require expensive underground mining techniques[21]
- The top 3 production countries in 2022 for Ni were: Indonesia, Philippines, and Russia[22]

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# Chromium Ores

- Most Cr ores consist of the mineral chromite, the ideal formula of which is FeCr2O4. It is widely dispersed in natural deposits, which are usually contaminated with O, Mg, Al, and silica; their chromium content (when pure) varies from 42 to 56%
- Chromite deposits are mined by both underground and surface techniques
- The top 3 production countries in 2022 for Cr were: South Africa, Turkey, and Kazakhstan[23]

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# Ore Grade Matters, and It's Decreasing

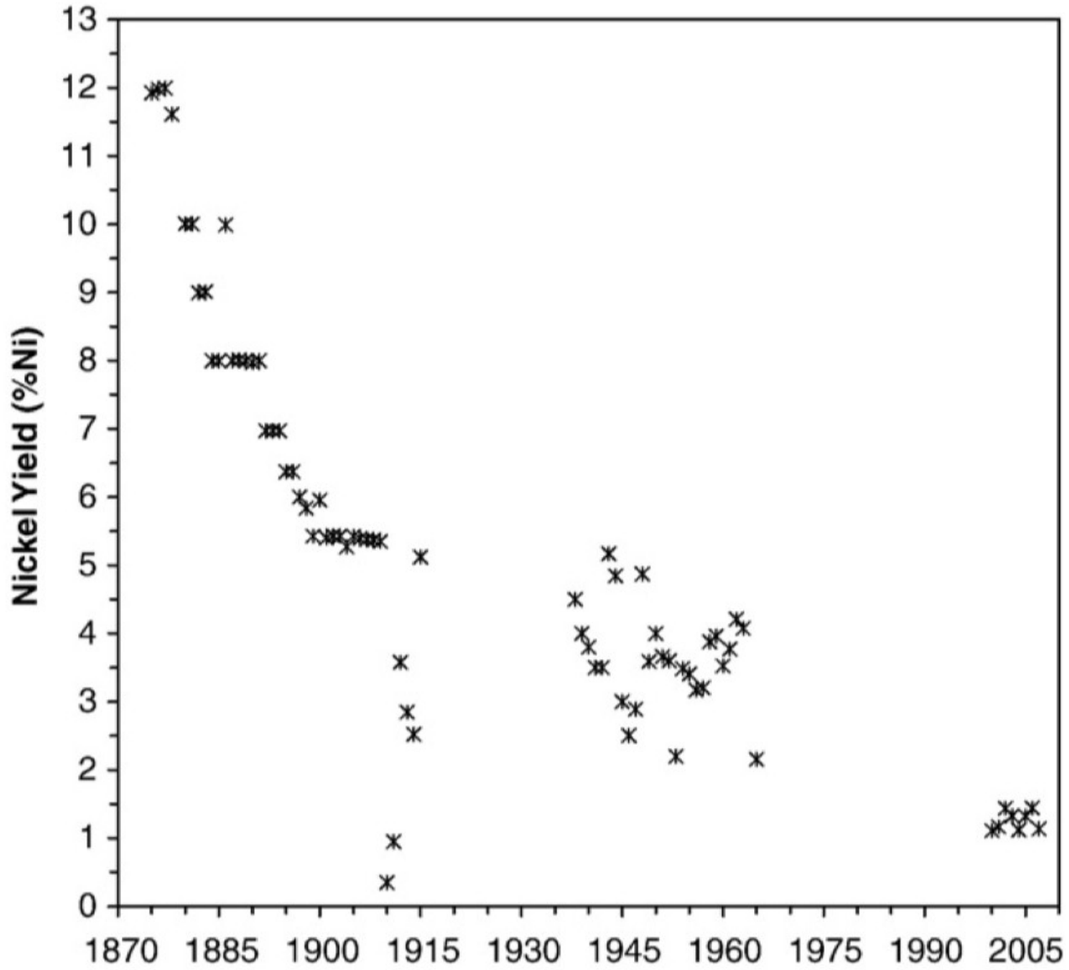



**Fig. 9.** Trends in New Caledonian ore yields over time.

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**Table 4: Energy inputs as a function of ore grade for Ni production from sulfide ores**

| Ore grade (%) | Energy inputs (mmBtu/ton) | |
|---|---|---|
| | Mining | Beneficiation |
| 0.50% | 48.837 | 45.589 |
| 1.00% | 23.883 | 22.295 |
| 1.50% | 15.716 | 14.671 |
| 2.00% | 11.679 | 10.903 |
| 2.05% (Default) | 10.152 | 9.477 |
| 2.50% | 9.277 | 8.660 |
| 3.00% | 7.686 | 7.175 |
| Break-up: For all ore grades | Diesel: 30.4%; Electricity: 69.6% | Electricity: 100% |

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# *Environmental Impacts – Mining*

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# Land Use and Biodiversity - Nickel Example

- **Overall, 40 percent of global nickel reserves are in protected areas or regions with high biodiversity, and 35% are in areas with high water stress.  Virtually all nickel laterite deposits are located in biodiverse and protected areas**[25]
- For example, New Caledonia is a south-west pacific territory composed by one main island, in a middle of a large lagoon, and three smaller islands, "Loyalty Islands". **The surrounding barrier reef was listed by UNESCO on the World Heritage List** under the name "The Lagoons of New Caledonia: Reef Diversity and Associated Ecosystems" in 2008[26]
- In New Calendonia, since nickel ore is located at 10–30 m depth under lateritic levels, extraction technique adopted is strip mining, resulting in large opencast areas[26]

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# Ground Displacement from Mining

- In an Fe mine in China, there has been **widespread evidence of regional horizontal displacement of the land surface, large distances away from the mining area**. The results also show that ground horizontal displacements are typically at least as great as the vertical component, that the maximum horizontal displacement occurs soon after undermining[27]
- Similarly, a **serious mine subsidence happened** in January 2007 at the Haolaigou Iron Ore Mine has caused a huge collapse pit on the surface[28]
- In a Ni mine in China, **underground backfill mining** is a complex and high-cost mining technique, which was designed to control ground pressure and prevent rock mass movement and ground deformation. Unfortunately, the high-level stresses strengthened the mechanical strength of the surrounding rock mass, **resulting in lower magnitude of vertical subsidence but greater expansion of horizontal deformation of the ground**[29]

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# Accidents: Fundão Iron Tailings Dam Collapse in Brazil - The Environment (1 of 2)

- In 2015, the Fundão dam collapsed and 43 million m3 of iron ore tailings were released, polluting 668 km of waterways from the Doce River to the Atlantic Ocean[30]
- **The collapse of Fundão was the biggest environmental disaster of the mining industry, both in terms of the volume of tailings dumped and the magnitude of the damage**[30]
- More than year after the tragedy, the mining company Samarco had still not carried out adequate removal, monitoring or disposal of the tailings, contrary to the premise of the total removal of tailings from affected rivers proposed by the country's regulatory agencies[30]

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# Accidents: Fundão Iron Tailings Dam Collapse in Brazil - The Environment (2 of 2)

- The tailings directly hit 135 identified semideciduous seasonal forest fragments, in a 298 ha of vegetation suppression, located on the banks of Gualaxo do Norte and Carmo Rivers and its tributaries. The tailings also directly hit 863.7 ha of Permanent Preservation Areas associated to watercourses, which were in protected areas, as defined by the federal forest code[30]
- Santarém Stream, Gualaxo do Norte River, and Carmo River were the main rivers and streams completely silted by the tailings. In addition, 294 small creeks were affected by the tailings[30]
- **Some days after the disaster, the sediments in suspension in the river water affected by the tailings contained iron (Fe) and manganese (Mn) at concentrations approximately 4 (Fe) and 1.5(Mn)-fold higher than the maximum Brazilian limit for water bodies quality assessment**[31]

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# Accidents: Fundão Iron Tailings Dam Collapse in Brazil - The People

- **Out of the 806 buildings directly hit by the tailings, at least 218 were completely destroyed**, distributed among 10 districts of five municipalities[30]
- Bento Rodrigues, just 6km from the Fundão dam, was the most damaged district with 84% of the affected buildings totally destroyed, followed by Paracatu de Baixo (40% of the buildings hit were destroyed). Roads, bridges/passages and a small hydroelectric plant were also damaged[30]
- **Areas of cultural heritage also suffered greatly, including at least two archeological sites, six places of historical and cultural interest, more than 2000 sacred pieces/material heritage, five caves**[30]
- **19 people died from the collapse**[30]

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# Environmental Impacts - Processing

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# Stainless Steel Processing

- Mixtures of Fe and the input metal are often produced as a precursor to steelmaking, instead of starting with a completely pure metal itself
- Each input metal has its own set of often complex processing steps before the stainless steel production process begins
- The steel making process in detail is complex, because different specific production chains exist based on their admixtures (Cr, Mo, etc.)[12]
- Overall, stainless steels are typically produced by a two-stage process:
  - First, raw materials (including scrap) are melted together in an electric arc furnace, with the composition of the molten metal used corresponding approximately to that of the desired steel product, apart from the carbon[32]
  - The, the molten metal is then transferred to a refining vessel (most commonly an argon-oxygen decarburization (AOD) vessel) which reduces the impurities (especially the carbon content) to the low levels required in the final product[32]

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# Waste

- It takes about 2.5 tons of chromite ore to make 1 ton of ferrochromium[33]
- Using high grade ores with 50% Mn content generates 1.2 tons of dumps for each ton of Mn production. However, the use of lean grade ore containing 20% Mn generates up to 7 tons of mining residues for each ton of Mn produced[34]
- During the production of stainless steel, massive solid wastes such as various dusts, pickling sludges, and mill scales are generated, accounting for more than 30% of the amount of steel produced[35]
- Much of this waste is classified as hazardous waste[36], and unfortunately, many slags still go to landfill[37]

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# Specific Pollutants

- Trace elements (TEs) are chemical elements found in very low concentrations. Although some elements are essential for human health and ecosystems, **they are all considered to be toxic at some threshold concentration**, including some being considered carcinogenic (As, Cd, Cr (VI), Ni)[38]
- TEs can behave in different ways when submitted to high- temperature processes. Some of them tend to remain in the solid-state (V, Cr, Mn, Co, Ni), others partially volatilize, and may recondense again before being emitted to the atmosphere (Zn, Pb, Cd, As), and some volatilize remaining in vapor phase until emitted to the atmosphere (Hg, F, Cl, Br). **The elements that volatilize can be emitted in the form of gas or fine particles able to travel great distances in the atmosphere before depositing, contaminating the soil and water and entering the food chain**[38]

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# Specific Pollutants (cont.)

- For example, **the iron and steel sector is the third-largest industrial complex in terms of environmental mercury pollution after gold and cement production**, with a share of 7.4% of the calculated global emissions[12]
- In addition, nitrogen oxides (NOx) are emitted in ore extraction by blasting activities and the vehicles used in the excavation process. Furthermore, NOx and SOx are also emitted during processing and recycling of iron ore[12]

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# Energy and Carbon Emissions

- **The steel industry is responsible for nearly 9% of anthropogenic energy and CO2 emissions**[39], and producing steel accounts for 25% of industrial carbon emissions[40], the world's largest industrial source of these emissions[41]
- Scenario analysis shows that global capacity for primary steel production is already near to a peak and that **if sectoral emissions are to be reduced by 50% by 2050, the last required blast furnace will be built by 2020**[39]
- Unfortunately, **iron and steel are also considered as one of hardest industries to decarbonize due to high heat requirements, using carbon as a process input, low profit margins, high capital intensity, long asset life, and trade challenges**[42]

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# Energy and Carbon Emissions (cont.)

- There are no easy ways to create large amounts of heat energy for many iron and steel processes without also releasing CO2 emissions, and coal is often used both as a source of heat and as part of the production processes[42]
- Similarly, the decades-long life cycles of iron and steel plants, the lack of clear financial incentives for decarbonization, and price volatility make it difficult to incorporate carbon reducing technologies[42]
- **The IEA estimates the additional cost of low-CO2 steel production to be between 10% and 50% compared to today, a cost increase significantly exceeding production margins**[43]

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# General Environmental Impacts - Nickel Example

**Table 1.** Overview of some of the core ecological impacts of nickel mining and processing

| Ecological Impacts | Sources |
|---|---|
| Air pollution | Sulphur dioxide release; mining processes generate large emissions of dust containing nickel, copper, cobalt and chromium; transportation of ores also loads dust into the atmosphere. |
| Contribution to global warming and climate crisis | Nickel has one of the highest global warming potential associated with its mining and processing compared to most metals. |
| Water catchment pollution and sea-water contamination | Incorrect disposal/accidents of slag; mine tailings, fuel spillage or other waste; acid leaching (used primarily in laterite production) can consume chemicals with significant effects on water quality (sulphuric acid and ammonia). Lateritic processing done in tropical areas and humid regions requires the removal of large amounts of water. |
| Soil or crop contamination | Incorrect disposal/accidents of slag, mine tailings, fuel spillage or other waste. |
| Groundwater contamination | Incorrect disposal/accidents of slag, mine tailings, fuel spillage or other waste. |
| Landscape fragmentation or loss | Acid drainage from nickel operations is linked to significant damages to crops and territories[12] |
| Biodiversity loss | Clearance of ecologies and deforestation.Coral reefs are particularly at risk from sea waste disposal. |
| Fishery depletion | Disposal of tailings into water bodies |
| Noise pollution | Extractive machinery and processing facilities |
| Landslides | Clearance of ecologies; erosion linked to deforestation |

Source: data compiled from the Environmental Justice Atlas.[40]



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# Reported Environmental Impacts and Conflicts - Nickel Example

**Table 2.** Reported socio-environmental impacts and conflicts related to nickel production around the world

| Mining Project Name | Country | Company | Ecosystem Type & Impacts | Documented Impacts |
|---|---|---|---|---|
| Various (projects across Taimyr peninsula, Amur region, Murmansk region, Kola peninsula and Krasnoyarsk krai) | Russia | Nornickel | Tundra/taiga | Biodiversity loss; landscape destruction; soil and air pollution; waste overflow; water pollution through oil spills; Indigenous rights violations |
| Cerro Matoso | Colombia | South32 | Semi-tropical/ arid grassland | Indigenous & Afro-Descendant rights violations; water and airborne pollution; |
| Various (Sorowako, Asera, Pomalaa) | Sulawesi, Indonesia | Vale, Solway Investment Group, Indonesia Asahan Aluminium | Tropical, marine | Water and airborne pollution; sea waste disposal; deforestation; dangerous tailings accumulation; Indigenous rights violations |
| Rönnbäckenn (proposed project) | Sweden | Nickel Mountain | Subarctic | Land rights; Indigenous rights violations; pollution |
| Various | Cuba | Sherritt International, Cubaniquel | Cloud forests; pine forests; coral reefs. | Waterborne, air and soil pollution |
| Various projects in Western Australia (including the Kalgoorlie Nickel Smelter) | Australia | BHP Billiton | Subtropical desert | Pollution, respiratory impacts, acid depositions on soils and plants, impairment of visibility, dispersion of sulphur dioxide |
| Selebi Philwe (nickel copper mine) | Botswana | BCL Limited | Savannah, tableland | Pollution of sulphur dioxide; widespread respiratory health concerns; significant contamination of air linked to smelting |
| Various (Raglan, Voisey's Bay, Sudbury Area) | Canada | Glencore, Vale, Jin Horoc Nonferrous Metal Group | Boreal forests; Tundra; subartic tundra | Landscape fragmentation; loss of woodland; fuel spillage; soil contamination; Indigenous treaty rights violations; Indigenous (Inuit and Innu) rights violations; impacts on fisheries; water pollution; waste overflow; impact on biodiversity |
| Various (Rio Tuba, Santa Cruz, Coral Bay, Mindoro) | Philippines | Nickel Asia Corporation, Intex Resources | Tropical rainforest; Evergreen forests; Malesian flora | Air and waterborne pollution; landscape destruction; loss of food security from lands rendered infertile; tailing spills; deforestation; loss of water quality; damage to reefs |
| Ramu NiCo | Papua New Guinea | Metallurgical Corporation of China (MCC) | Tropical rainforest | Wastewater pollution; sea tailings disposal; damage to fisheries and crops; poisoning of local species |
| Onca Puma | Pará, Brazil | Vale | Tropical | Violations of the community rights of Xikrin and Kayapó peoples; pollution; deforestation; water quality damage |
| Voisey's Bay | Labrador, Canada | Vale | Subarctic tundra | Indigenous (Inuit and Innu)rights violations; impacts on fisheries; water pollution; waste overflow; impact on biodiversity |
| Ambatovy | Madagascar | Sumitomo Corporation, Kores | Subtropical | Fishery depletion; water and air pollution; leaks of sulphur dioxide |
| Talvivaara | Finland | Terrafame | Boreal forest | Water pollution |

Source: own elaboration with data from the Environmental Justice Atlas. [40]



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# *Human Health Impacts*

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# Human Health (1 of 4): Fe (associated toxins)

- A study to evaluate metal concentrations in areas near selected iron and steelmaking industrial areas in China found **As** and **Pb** contamination presented the largest fraction of the impacts on human toxicity[45]
- Another study measured the concentrations of toxic elements in samples from agricultural soils in an iron ore mining area in China. The four heavy metals exceed their background values, especially in the case of **Hg**. Iron ore mining was the main cause of the increased concentrations of **As** and cadmium (**Cd)**[46]
- In Slovakia near an iron-ore mining–processing factory it was concluded that the content of **Hg, Cd, Cr, Cu, As, Fe, Mn,** and **Mg** is above the toxicity level. In particular **As, Fe, Mn,** and **Mg** are the most serious pollutants in the area under investigation, and their pronounced excess indicates contamination[44]

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# Human Health (2 of 4): Ni

- Nickel contact can cause a variety of side effects on human health, such as allergy, cardiovascular and kidney diseases, lung fibrosis, lung and nasal cancer. Recently, researchers, trying to characterize the capability of nickel to induce cancer, have found out that epigenetic alterations induced by nickel exposure can perturb the genome[47]

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# Human Health (3 of 4): Mn

- Inhaled Mn can lead to a permanent neurological disorder called manganism, which causes such symptoms as tremors, difficulty walking, and facial muscle spasms. Exposure to Mn dust can lead to lung inflammation and impaired lung function[3]. Manganism occurs in many places, including South Africa[48]
- In the Ukraine, increased amounts of skeletal deformities were found in children living near Mn mines[49]
- In central Mexico, Ecuador, and the US, studies found that airborne Mn environmental exposure is inversely associated with intellectual function in young school-age children[50]
- Manganese madness, a psychiatric syndrome characterized by compulsive behavior, emotional lability, and hallucinations from Mn overexposure. Mn overexposure causes irreversible damage and degeneration of neurons[51]

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# Human Health (4 of 4): Cr

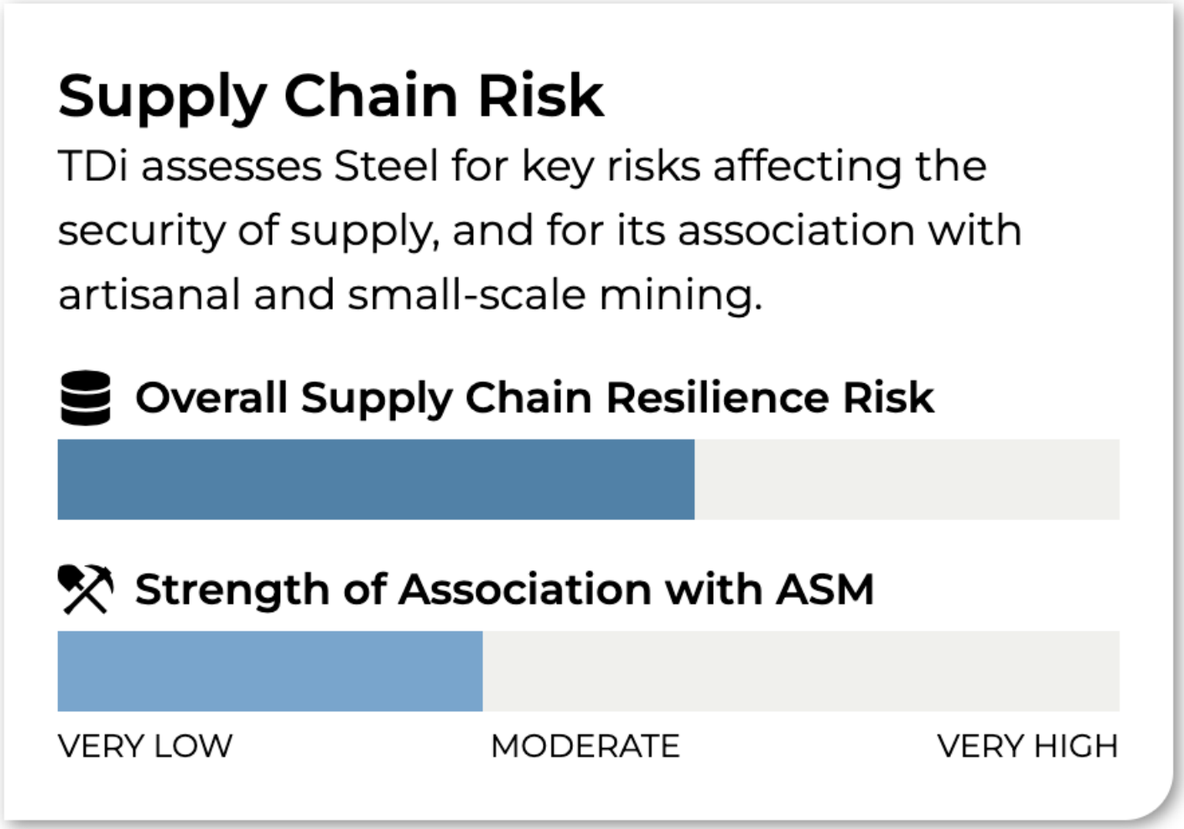
- **Cr(III) (trivalent chromium) is considered to be a trace element essential for the proper functioning of living organisms, whereas Cr(VI) (hexavalent chromium) exerts toxic effects on biological systems**[52]
- Exposure to Cr can occur through the three major routes such as absorption through the skin, direct ingestion and inhalation of Cr containing particles[53]
- **Bioaccumulation of Cr(VI), can lead to teratogenesis and mutagenesis**. Occupational and environmental exposure to Cr(VI) can cause multiple organ toxicity, as well as irritation and ulcers in the stomach and small intestine, anemia, damage of the male reproductive system[54]
- **Cr(VI) toxicity results in the inhibition of plant growth and metabolism**[55]
- As such, **Cr(VI) is considered to be one of the most detrimental heavy metals released to the environment**[53]

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# *Social Sustainability Impacts*

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# Steel and Sustainability









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# Artisanal Small-Scale Mining

- The literature doesn't focus a lot on the presence of ASM in the steel supply chain
- One article mentions Ni mining ASM in Indonesia and the Philippines and the conflicts with the large Chinese-owned mining companies[56]
- Another study was done about in West Timor, Indonesia, where an artisanal Mn mining boom began around 2007–2008. It found ASM to be a significant rural livelihood activity with an estimated 325,000 people actively engaged in mining over a wide area during the peak period from 2009-2011[57]

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# Indigenous Populations

## Canada

- Large chromite reserves have recently been discovered in the so-called Ring of Fire, Canada. However, it is located in an area that forms part of **the largest peatland in the world, as well as the traditional territories of several First Nations**, which highlights the sensitive nature of the intended developments[59]

## New Caledonia

- In the emblematic case of Kanaky, New Caledonia, which is home to approximately a fourth of global nickel deposits, **major long-standing conflicts with indigenous Kanaky communities** have occured ever since colonial nickel mining began in 1876[25]

## Russia

- The Aborigen Forum, a coalition of communities across the Russian Far East, North and Siberia have organised a **campaign against nickel mining**. In 2020, the forum called on companies to boycott purchases of nickel from the company Nornickel[25]

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# Indigenous Evictions - Guatemala Example

- Skye Resources in Canada bought the Guatemalan Nickel Company (CGN). In 2017, vehicles and state forces headed for the Q'eqchi' Mayan community of Lote 8, set high on a remote ridge. As they had done during the war when the military came, the men hid in the mountains for fear of being injured or abducted. Entering a settlement with only women and children did not deter the CGN security personnel, police officers, and soldiers from **destroying homes, burning crops, and killing animals**[60]
- Three years after surviving the trauma and receiving counseling, 11 Q'eqchi' Mayan women from Lote 8 **came forward with accusations of gang rape by the security personnel** during the violent eviction. Sexual violence was implemented in the same manner as it was during the war, to terrorize[60]
- **The women are suing HudBay (which later bought the CGN from Skye) in Canada for negligence causing physical and psychological harm**[60]

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# Mining Workers - Nickel Example

- **Poor employment conditions, violations of labour rights and unsafe work environments have been a recurrent concern across nickel mines**[25]
- Nickel mine workers are particularly at risk of developing co-morbidities, and have an increased risk of pulmonary diseases, nasal and lung cancer, and dermatological conditions. Sulfidic and oxidic nickel compounds have also all been found to be carcinogenic[25]
- **Research by the Transition Minerals Tracker shows that less than half of companies mining nickel (among other transition minerals) do not even have a human rights policy in place,** and many companies have multiple allegations of human rights abuses. Even when policies are in place, this does not necessarily imply adherence to them[25]

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# *Recycling and steel*

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# Steel Production from Scrap Today

- The primary blast furnace–basic oxygen furnace (BF–BOF) route is currently the world's most used production route for steel. **Yet the primary route is not completely primary, since, within the refining process of converting hot metal to crude steel, scrap is used as a cooling material**[61]
- About 26% of the steel is produced via the scrap-based (electric arc furnace) EAF route[61]
- **Most stainless steel produced in the Western world is based on scrap melted in an EAF, but because the amount of stainless steel scrap not is enough, also ordinary steel scrap has to be used**[62]
- **Overall, 32% of steel is produced from scrap input via the secondary route and partially via the primary route**[61]

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# Recycling Supply Challenges: In-stock Lifetimes and Demand Growth

- The good news is that **steel is the world's most recycled material, with end-of-life recovery rate estimates as high as 90%**[63]
- **One challenge is the in-use stock of steel**, which can span decades[62]
- For example, China did not produce any significant stainless steel end-of-life flows in 2000 or 2005 because its products-in-use were still too new[64]
- Stainless steel, too, can have long lifetimes.  In one model, it is estimated to be used for 19–100 years in average over its entire life cycle[65]
- The carbon steel emissions increase every 10 years due to maintenance needed to suppress corrosion, unlike stainless steel and aluminium[66]
- **The world's demand for metallic alloys exceeds the available amount of scrap by about one-third, estimated to continue until at least up to 2050**[67]

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# Types of Metal Recycling Loops (not including reuse within foundries and mills)

**Table 1** Metal recycling loop type examples

| Type 1<br>Closed metal loop | Type 2<br>Alloy loop | Type 3<br>Transfer to another metal pool | Type 4<br>Metallurgical re-separation |
|---|---|---|---|
| Steel scrap is recycled by a minimill where it is remelted and formed into semi-products. | Stainless steel alloys are retained in a distinct metal pool. Constituents include iron, chromium, nickel and other elements. | Nickel in low-alloy steel is recycled into the steel loop, where it is retained in dilute fractions in the steel pool. | Gold and platinum group metals are retained in copper-rich metallic fractions during electronic equipment recycling. At the copper smelter, these other metals are separated and refined. |
| Steel scrap is recycled by an integrated mill where the recycled metal is blended with primary metal coming from the blast furnace into the basic oxygen furnace | Aluminum–magnesium alloy used for beverage cans is recycled as a distinct pool. The purity and properties of the alloy are managed and preserved. | Chromium coating on steel is recycled into the steel loop, where it is retained in dilute fractions in the steel pool. | Zinc used for galvanizing follows the steel onto which it is coated. During steel recycling, zinc is separated to electric arc furnace dust, which is treated to remove cadmium. Zinc is then recovered in an Imperial Smelting Furnace. |
| Copper in applications where it is nearly pure is recycled back to semi-fabricators, where it is remelted and reformed into semi-products | Brass is a copper-zinc alloy that is collected and recycled to retain alloy properties. | Due to inefficiencies in physical separation, Copper particles are entrained with the steel recycling flow. Once melted, copper cannot be removed economically from the steel. | |



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# Steel Grades Adds Complexity and Results in Downcycling

- An important consequence that has received little attention thus far is that this trend of **substituting for some of the nickel in austenitic grades has the potential to negatively affect the recyclability of stainless steel if different grades are not recycled separately**[69]
- Narrow specifications only allow for limited amounts of manganese (typically less than 1%) and copper (typically less than 0.5%), creating a challenge for recyclers who cannot use magnetism to distinguish among the different austenitic grades[69]
- In cases where the low- and high-nickel grades are recycled together it will require additions of energy-intensive primary nickel in order to dilute the manganese and copper to acceptable levels[69]

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# Steel Grades Adds Complexity and Results in Downcycling (cont.)

- A study on stainless steel in 2015 concluded that on average, **85% of stainless steels are recycled once they reach their end of life, either to become new stainless steels (56%) or an iron source for carbon steels (29%) (essentially, downcycled)**[70]
- The study also considered the recycled content of stainless steels (the amount of scrap used in the production of new stainless steels). Globally, the average recycled content of stainless steel was 44% (32% stainless steel scrap and 12% carbon steel scrap)[70]
- **Scrap compatibility in secondary production can be better realized when avoiding compositionally over-designed alloys and instead using materials from only a limited composition spectrum**[67]
- Would recyclers be able to easily see what grade of steel your products contain?

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# Contamination Challenges, too

- **Concentrations of Cu over 0.1 wt % cause hot shortness**, a phenomenon leading to surface cracking in hot rolling and forming. **Sn exacerbates hot shortness, even at concentrations as low as 0.04 wt** %[63]
- Cu is pervasive in end-of-life scrap, originating mostly from wires and motors machinery that attach to steel during shredding. Sn contamination originates from packaging tinplate, which makes up a much smaller (<1%) portion of the scrap stream, and can be isolated and treated more readily prior to melting[63]
- **Closing the steel cycle requires more attention to the development of smart and low-carbon sorting, separation and refinery production, etc. as well as measures for improving source separation of steel scrap to improve the overall quality of secondary steel production**[71]

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# We're Not Recycling Metals Indefinitely Like We Could

- **In principle, metal atoms can stay in use indefinitely, due to their infinite recyclability**[72]
- However, **the theory is not consistent with analyses of recycling practices**. For instance, analyses have estimated that copper is used 1.9 times on a global scale and steel is used 2.67 times within the Japanese economy before ultimate disposal in a landfill or loss to the environment[72]
- **If we want our overall material supply to last a long time without having to expend massive amounts of energy for recovery and reuse, then recycling rates truly matter**

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# Losses Add Up

- For example, a modeling study assumed we are unable to find substitutes for Ni but increased primary production efficiency by 10%. **If the available resources are at least 2 Gt (much more than we produce annually today), we would still need an end-of-life recycling rate of 85% to meet our needs for 1000 years.** If less is available, the recycling rate would need to be even higher[73]
- **When losses are extremely difficult to recover (e.g. through contamination or dissipation), the situation becomes quite serious.** A unrecoverable loss of material like 15% compounds quickly over time. If you start with 1000 lbs, then in year 2 you have 850, in year 3 you have 723, in year 4 you have 614, in year 5 you have 522, and **in year 6 you already have less than half of what you started with**.
- Apart from recycling, a main tool for improving material efficiency is to increase product lifetimes[73]

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# Recycling Benefits

- **While the specifics for a particular grade of steel would need to be calculated (unfortunately there don't appear to be LCAs with that amount of specificity)**, some general ideas of the benefits of recycling steel include:
- Recycling 1 ton of steel conserves 1.1 tons of iron ore, 0.6 ton of coking coal, and 0.05 ton of limestone[74]
- Energy savings otherwise achieved by using scrap in current stainless steel operations: **29% for austenitic grades** and 16% for ferritic grades[69]
- In electric arc furnaces (EAFs), different grades of steel scrap are combined. A large industrial data set indicates scrap grades matters greatly; **electricity is up to 45% higher for low-quality scrap than for high-quality scrap**[75]
- Compared to primary processing procedures, no novel emissions are generated by recycling[12]

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# Summary

- Stainless steel is composed primarily of iron, chromium, nickel, and manganese, and most of the mining and production of these elements today goes towards steelmaking
- Like most other metals, the mining and processing of these materials generates large quantities of waste, often toxic.  In the case of nickel, and especially manganese and chromium, the elements themselves are toxic
- An iron tailings dam collapse in Brazil in 2015 is considered to be the largest environmental disaster of the mining industry, releasing pollutants into hundreds of waterways and killing 19 people
- It's hard to avoid impact from mining. For example, 40% of global nickel reserves are in protected areas or regions with high biodiversity, and 35% are in areas with high water stress.  Virtually all nickel laterite deposits (the primary source of nickel for stainless steel) are located in biodiverse and protected areas
- Stainless steel recycling can bring about benefits from an energy (and other sustainability factors) standpoint, but it is complicated by the various grades of steel and the presence of contaminants

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# *Thank you*

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