The environmental profile of manganese alloys
About Manganese
Manganese is a naturally-occurring element designated by the symbol Mn and the atomic number 25. It is a metal extensively used in everyday life, as well as an essential nutrient.

Oxides of manganese have been used since the Stone Age, initially as a pigment, then for various chemical usages, and eventually for steelmaking around the beginning of the 19th century. Today, about 90% of all manganese consumed goes into steel as an alloying element and it is highly valued for its hardening properties.

As with most valuable metals, the extraction and processing of manganese affect the environment. Earth is moved, water, fuel, electricity and many consumables are used, generating waste and emissions to air, land and water.

Manganese is used in many alloys, mainly steel, stainless steel, aluminum, and copper alloys, but also batteries and pigments. Its properties are used for water and wastewater treatment, agriculture (fertilizers, animal feed), fuel refining, and many other applications.

Manganese Industry Snapshot
Manganese is the 12th most abundant element in the earth’s crust. Most ore is mined in Asia, although the highest-grade ore comes from Africa, Australia and Brazil. The ore is transported to many countries to be smelted into manganese alloy. Ore mined in Mexico and China is primarily for domestic use.
The International Manganese Institute

The manganese industry is represented by the International Manganese Institute (IMnI), a not-for-profit industry association headquartered in Paris, France.

The goals of the IMnI are to inform its member companies of the best occupational safeguard measures to better protect their workers, and guide its members to follow environmental protection regulations and adopt responsible attitudes vis-à-vis local communities. IMnI’s Occupational Health, Environment and Safety (OHES) Committee is dedicated to achieving these goals.

Since 2008, the IMnI has embarked on the identification of the top ranking risks and opportunities for addressing the sustainability within the manganese industry. Over the past five years, IMnI invested some 4.3 million Euros to provide the Mn industry with guidance, tools and information that would allow it to anticipate occupational health, environment and safety demands whilst improving worker safety, sustainability and ensuring industry profitability.

The IMnI fosters sustainable industry practices through research, statistics and knowledge sharing events including the Annual International Manganese Conference, the only manganese-focused conference in the world.

The Manganese Life cycle Assessment (LCA)

Through active engagement with its stakeholders, the IMnI identified the need for accurate industry-wide environmental data to provide a performance baseline with which to drive industry improvements and communicate the environmental impacts of manganese production. A Lifecycle Assessment (LCA) was determined to be the best tool to simultaneously address these drivers, and the work was contracted to Hatch, a major consulting engineering firm that specializes in the mining and mineral processing sectors.

LCA, standardized under ISO 14040, is the most accepted scientific measure of environmental performance. This LCA was used to assess the potential environmental impacts associated with manganese production determined from an inventory of energy, material inputs and environmental releases and expressing these impacts relative to a kilogram of manganese alloy produced.

The Manganese Life cycle Assessment Project, started in 2012 and completed in 2014, was an unprecedented industry-led effort to build the most comprehensive global picture of the environmental impacts of manganese. Serving this purpose, 17 mines and smelters from China, India, Australia, South Africa, USA and France volunteered through the IMnI to contribute sensitive site data. Production in 2010 at each participating site was modeled according to ISO 14040 LCA standards, and peer-reviewed by an independent third party.

“The IMnI has a strong and enduring commitment to promoting good corporate citizenship.”

—Branislav Klocok, OHES Committee Chairman

“IMnI members focus on industry collaboration to drive sustainability performance.”

—Doreen McGough, IMnI OHES Manager
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The Manganese Production Process

The Manganese LCA Project focused on the three manganese alloys used in steelmaking:

- High-carbon ferro-manganese (HC FeMn)
- Refined ferro-manganese (Ref. FeMn)
- Silicon-manganese (SiMn).

Combined, these products comprise 90% to 95% of total manganese alloy production. The functional unit used throughout the study, one kilogram of manganese alloy (kg Mn-Alloy), is an aggregate measure of each alloy type.

Ore is extracted from the ground using explosives, and hauled to a process plant to increase the ore grade through crushing, separation and beneficiation. Manganese ore is the main input to manganese furnaces, where heat, reducing agents and fluxes decompose the ore, driving off other elements as gas or slag and leaving just the metal behind. Reducing agents are typically coke and coal (carbon carriers). Many smelter sites chose to feed the furnace with material containing manganese, such as recycled dust and slags (low grade), or sinter (high grade). Sinter is made from heating ore and coke fines to form porous pieces of higher-grade manganese. Sinter plants can be located at both mine sites and smelter sites. Electric-arc furnaces (EAFs) produce SiMn and HC FeMn hot metal. Molten HC FeMn may be sent for further refining using an oxygen converter to remove some of the carbon present in the tapped metal. After tapping, the manganese alloys are cast, crushed and screened to produce lump manganese alloys. Manganese alloys produced in this way are subsequently used in the production of steel and stainless steel.

The Manganese LCA Project is a cradle-to-gate study with boundaries spanning all mining, smelting and associated upstream processes involved in the production of one kilogram of manganese alloy. Manganese production is an important component of the larger steel production lifecycle.
The Manganese Footprint

Manganese mining and smelting operations generate air emissions at several points along the process chain. At mine sites, emissions primarily occur from tailpipes and electricity generation. Many mines are too remote to access the power grid and operate using diesel generators. At smelter sites, most direct emissions originate from the furnaces, mitigated by a variety of pollution control techniques. Upstream processes delivering energy and consumables needed for manganese production contribute to total lifecycle emissions, especially those related to electricity used during manganese smelting.

Hatch collected air emissions data across the entire manganese lifecycle, including emissions of carbon dioxide (CO₂), methane (CH₄), nitrogen oxides (NOₓ), sulfur oxides (SOₓ), and particulate matter (PM), to determine the potential environmental impacts resulting from the production of one kilogram of manganese alloy.

**Global Warming Potential (GWP)** is a measure of the heat trapping effect of various greenhouse gases (GHG), expressed in units of carbon dioxide equivalent (CO₂e). GHGs contribute to adverse climate change effects including extreme weather events and sea level rise. Significant GHGs associated with manganese alloy production are related to power generation, fuel combustion, and use of carbon-containing chemical reducing agents during smelting.

**Photochemical Ozone Creation Potential (POCP)** is a measure of ground-level ozone formation, or smog, expressed in units equivalent to ethene emissions (C₂H₄e). Smog has adverse impacts on the environment and human health. The manganese supply chain contributes to smog-formation primarily through production of NOₓ and volatile organic compounds (VOCs) such as CH₄, which react in the presence of sunlight to produce ozone (O₃).

**Acidification Potential (AP)** is a measure of acid rain generating potential, expressed in units of sulfur dioxide equivalent (SO₂e). Acid rain can have an adverse impact on biodiversity in aquatic and terrestrial ecosystems. The most significant acidification effect comes from SOₓ and NOₓ emissions generated by mobile equipment, power generation, smelting, refining and sinter production.

**Particulate Matter (PM)** describes the total mass of suspended particles in air. Because of their adverse environmental and health effects when inhaled, particulates are a significant concern at manganese mines and smelters. Particulate matter is generated during material handling and transportation, sinter production, electricity generation, refining and smelting. A variety of PM controls are practiced in the manganese industry, including road dust suppression spray trucks, and bag houses and wet scrubbers to filter emissions from point sources.

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<table>
<thead>
<tr>
<th>Environmental Impacts (per kg Mn-Alloy)</th>
<th>Direct</th>
<th>Electricity</th>
<th>Off-Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWP</td>
<td>32%</td>
<td>59%</td>
<td>8%</td>
</tr>
<tr>
<td>POCP</td>
<td>26%</td>
<td>68%</td>
<td>6%</td>
</tr>
<tr>
<td>AP</td>
<td>14%</td>
<td>81%</td>
<td>4%</td>
</tr>
<tr>
<td>PM</td>
<td>34%</td>
<td>35%</td>
<td>31%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.0 kg CO₂e</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.0 g C₂H₄e</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>45.0 g SO₂e</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.6 g PM</td>
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</tr>
</tbody>
</table>
Water

Water used within the boundaries of manganese mines and smelters can fill two main purposes:

- Cooling water, which includes make-up water for non-contact cooling water circuits at the furnace and refining stages
- Process water, which includes water consumed by processes where the water comes in contact with contaminants and/or forms a necessary function within a given process stage.

Process water has a higher potential for contaminating water outflows than cooling water, which does not come into contact with any throughput materials. On average, 6.6 L of process water are required to produce 1 kg of manganese alloy. Process water is used at mine sites in the separation and beneficiation of ore and at smelter sites to cool slag and for wet slag granulation. A number of other areas contribute to water consumption, such as dust suppression on roadways and stockpiles at mines and smelters.

The management and recirculation of water at mines and smelters varies greatly across the manganese industry, influenced by a number of local and regional factors including water availability and government licenses.

Energy

Primary Energy Demand (PED) is a measure of the energy delivered to the primary manganese supply chain through intermediate energy carriers such as electricity, fuels, explosives and reducing agents. Comprehensive Energy Demand (CED) incorporates all energy losses upstream of the manganese supply chain associated with energy processing and delivery.

The results of the study show that electricity demand, particularly at the furnace, is the dominant operating parameter contributing to the environmental impacts of manganese alloy production, occurring at upstream power generation facilities. The high electricity demand at the furnace and the primarily coal-fired upstream power generation sources of participating manganese countries emphasize the importance of electricity demand on environmental performance.

Energy Extracted and Delivered (MJ/kg Mn-Alloy)

<table>
<thead>
<tr>
<th>Energy Delivered</th>
<th>Energy Delivered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>2.4 MJ</td>
</tr>
<tr>
<td>Electricity</td>
<td>13.5 MJ</td>
</tr>
<tr>
<td>Reductant</td>
<td>19.6 MJ</td>
</tr>
<tr>
<td>Total</td>
<td>35.5 MJ</td>
</tr>
</tbody>
</table>

The energy demanded by the manganese process requires upstream resources to be extracted, transformed, and transported to the gates of manganese mines and smelters. Roughly half of the energy contained in the resources at extraction is lost before entering the primary manganese supply chain.
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Waste

Waste and rejects are produced at various stages of manganese production. By mass, the largest sources of waste are associated with manganese mining. Mining wastes include overburden (top soil and rock above the ore body), ore rejects (below-grade ore) and tailings. Overburden is usually inert and is deposited in stockpiles on the mine site, changing the contour of the landscape but without contamination. Overburden can be used as backfill or covered with vegetation. Ore rejects can be processed if economically feasible, or integrated in the landscape at closure. Tailings storage facilities are monitored to measure any contamination of local water tables, although the manganese tailings from sites participating in this study do not contain acidifying or otherwise hazardous materials.

Smelters produce SiMn and HC FeMn slags, which contain the non-gaseous waste products from the smelting process. Slags may be directly recovered within manganese production for their manganese content, or used as a low-or no-cost material for local building and road construction. Only a small portion of slag is ultimately deposited as waste.

The Path Forward

The Manganese LCA Project provides the industry with a comprehensive understanding of the environmental performance of global manganese production, unlocking the potential to drive industry improvement. A series of process-specific environmental and operational benchmarks available through the LCA are now being utilized by individual manganese producers to identify improvement opportunities. Links between operating parameters and environmental impacts will support strategic decision-making and enhance economic and environmental performance within the industry.

The LCA will also help to provide an open dialogue between manganese producers and consumers built around a shared understanding of the environmental profile of the industry. By fostering collaborative efforts such as the Manganese LCA Project and through leveraging its results, the manganese industry will continue to reach new levels of environmental performance.
Hatch
Hatch is an employee-owned, multidisciplinary professional services firm that delivers a comprehensive array of technical and strategic services, including consulting, information technology, engineering, process development, and project and construction management to the Mining, Metallurgical, Energy, and Infrastructure sectors. Hatch’s Environmental Services Group (ESG) works seamlessly with project teams to minimize adverse environmental impacts, provide substantial benefits to local communities, and facilitate financial value for clients.

IMnI
The International Manganese Institute (IMnI) is a not-for-profit industry association that represents manganese ore and alloy producers, manufacturers of metallurgical products or chemical compounds, trading houses, industry service providers, companies involved in Mn business development, universities and research organizations around the world. Founded in 1975, with headquarters in Paris, France, IMnI’s mission is to provide vision and guidance to the Mn industry by promoting economic, social and environmental responsibility, and sustainability to all stakeholders.

For detailed results, please refer to the Manganese Alloy Global LCA Report available at www.manganese.org