LIFE CYCLE ASSESSMENT
SUMMARY REPORT

The environmental profile of manganese alloys
Manganese is used in many alloys, but also batteries and pigments. Its properties are used for water and waste water treatment, agriculture (fertilizers, animal feed), fuel refining, and many other applications.

“The International Manganese Institute (IMnI) provides vision and guidance to the manganese industry by promoting economic, social and environmental responsibility and sustainability for all stakeholders.”

—Branislav Klocok, OHES Committee Chairman

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

—Doreen McGough, IMnI OHES Manager
Manganese - A Key Metal

Manganese is a metal used extensively in everyday life, as a critical component in a variety of engineering materials and advanced technologies, and as an essential nutrient for maintaining good health. Despite the importance of manganese as an essential alloying element in steel and stainless steel, the industry’s environmental profile was not well understood.

The Environmental Profile of Manganese Alloys summarizes the results of the Life Cycle Assessment (LCA) of Global Manganese Alloy Production, a landmark study commissioned to Hatch Ltd. by the International Manganese Institute (IMnI) to understand the environmental impacts of manganese production.

Manganese, designated by the symbol Mn and the atomic number 25, is a naturally-occurring element. Manganese is mined, then smelted in a furnace in the presence of iron or silica to form ferro-manganese and silicon-manganese alloys.

The production of manganese alloys involves many process steps that require resources to be extracted and energy and water to be used. These processes also generate emissions and waste.

Roughly 90% of manganese alloys are destined for the steel and stainless steel industry. Undesirable oxygen and sulphur in crude steel is minimized by manganese’s ability to combine with sulphur and its powerful deoxidation capacity. Manganese is also widely used as an alloying element of steel.

This LCA provides a better understanding of manganese production and forms an important pillar of IMnI’s Manganese Sustainability Programme which aims to continuously improve the environmental, social and economic performance of the manganese industry.
About the Project

The LCA of Global Manganese Alloy Production was a peer reviewed, ISO 14040 compliant study involving primary data from 17 mines and smelters worldwide. Combined, it is the most representative, current and comprehensive assessment of the environmental performance of the global manganese industry. The products considered in this study include:

- Silicon-manganese (SiMn), 65 - 68 wt.% Mn, < 2 wt.% C
- High-carbon ferro-manganese (HC FeMn), 74 - 82 wt.% Mn, < 7.5 wt.% C
- Medium to low-carbon / refined ferro-manganese (Ref. FeMn), 80 - 85 wt.% Mn, < 1.5 wt.% C

Goals And Scope

The goal of the LCA of Global Manganese Alloy Production, broadly speaking, was to generate for the first time comprehensive environmental data pertaining to manganese ore and alloy production which is accurate and representative of the global industry. The study was undertaken to serve simultaneously as:

- A tool for benchmarking individual site performance by process stage, giving each site a solid scientific basis to improve environmental performance; and
- A measure of the global industry for external stakeholders, providing, in particular, a connection to steel and stainless steel LCA data to improve the understanding and completeness of the environmental impacts of the steel supply chain.

The LCA of Global Manganese Alloy Production is a cradle-to-gate study with boundaries spanning all mining, sintering, smelting and associated upstream and downstream processes involved in the production of one kilogram of manganese alloy. It included an assessment of three main LCA impact categories: global warming potential (GWP), acidification potential (AP), and photochemical ozone creation potential (POCP). A number of key environmental indicators for air emissions, energy, water and waste were also examined.

About Manganese

More than 90% of the world’s mined manganese ends up in steel products.

Manganese has no satisfactory substitute in its major applications, which are related to metallurgical alloy use.

On average, 1 ton of steel contains about 7.5 kg of manganese.

The thin metal used in making aluminum beverage cans contains about 1% Mn to prevent metal corrosion.

The world’s second-largest market for manganese is dry-cell battery production. Without MnO\(_2\), the electrodes would become coated with waste, shortening battery life.

MnO\(_2\) has been used for centuries in glassmaking. When mixed with molten silica, MnO\(_2\) causes iron impurities to oxidize from the ferrous to the ferric state, removing greenish tints from the melt.
The environmental profile of manganese alloys

All processes associated with the manganese supply chain were modeled, including:

- Mineral extraction and hauling;
- Ore processing and beneficiation;
- Sinter plant production;
- Manganese ore and sinter transportation;
- FeMn and SiMn furnace (smelting);
- Refining;
- Metal casting, crushing and screening;
- Slag processing;
- Mine site auxiliary processes; and
- Smelter site auxiliary processes.

Coverage

The regional distribution of participating facilities relative to the distribution of the supply and demand for manganese ore is shown below.

Figure 2: Global map of ore and alloy production

![Global map of ore and alloy production](image)

Figure 3: 2010 regional distribution of global ore production (left, 42.7 Mt) relative to participating mines (right, 7.9 Mt)

Figure 4: 2010 regional distribution of global alloy production (left, 14.6 Mt) relative to participating smelters (right, 1.2 Mt)

About the Industry

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 in the world to be smelted into manganese alloys. Ore mined in Mexico and China is primarily for domestic use.

Total reserves are very large. In South Africa only, deposits amounting roughly 15 billion tons had been identified in 2011.

High grade ore (>44%Mn) reserves are estimated to about 680 Mt.
The environmental profile of manganese alloys

The mineral extraction process involves surface and underground mining activities related to accessing the ore body and removing overburden, waste rock and run-of-mine (ROM) ore. The ROM ore is then hauled with conveyors or mobile equipment to the ore processing plant. The plant serves two primary functions: reducing the size of the ROM ore (crushing / screening) and separating the ore from accompanying waste rock (beneficiation), increasing the manganese content of the saleable ore. Mining and ore processing can produce large quantities of overburden, ore rejects and tailings (a waste rock / water slurry), depending on the nature of the ore body and plant configuration.

Sinter production is an optional process occurring after ore processing and prior to smelting. At the sinter plant, ore fines are agglomerated and partially reduced by heating in the presence of coal and coke fines, fusing smaller particles together to form larger agglomerates. The sinter produced is a manganese feedstock to the smelting process. Manganese ore and sinter transportation consists of delivery between the mine sites and smelters. Transportation is the only primary process that is not within the operational control of the participating mines or smelters.

Smelting involves the reduction of manganese ores and sinters in electric arc furnaces (EAFs) to produce molten metal and slag. The reduction of manganese oxides requires a reducing agent, typically coke and anthracite, and energy in the form of electricity supplied through carbon electrodes. Fluxes, typically lime and dolomite, are included to promote the separation of molten metal and slag phases. Molten metal and slag are tapped from the furnace and directed along sand runners to casting beds or allowed to solidify in large
pots. The solidified FeMn and SiMn metals are left to cool naturally, similarly to slags which may also be sprayed with water to accelerate the process before further handling. The metal and slag are then crushed and screened by hand or using electrical or portable, diesel-powered units into a lump product suitable for sale (metal and slag), recovery or waste disposal (slag). The high carbon ferro-manganese produced during smelting may be refined by blowing oxygen into the molten metal, reducing the carbon content of the metal.

Mine and smelter site auxiliary processes include consumables, activities and impacts serving the mining and smelting processes, such as materials handling, electricity generation, production of consumables, fuels, tires and lubricants, potable water treatment, and transport of material.
Methodology

The Environmental Profile for Manganese Alloys was peer-reviewed and followed the ISO14040 set of standards for life cycle Assessment (LCA). LCA measures the environmental impacts of a product, extending beyond the conventional operational boundaries of any one company or process stage.

The goal and scope determines the work plan for the LCA.

The inventory analysis models all material and energy flows into and out of each process, resulting in a life cycle inventory (LCI) containing all the data required to represent the system.

In a life cycle impact assessment (LCIA), the LCI is used to calculate the environmental impacts of production across multiple categories such as GWP, AP and POCP.

The interpretation is a critical review, organization and analysis of the results generated by the study, and is an iterative process leading to refinements in each stage of the project.

Data Sources

Primary processes are within the operational control of participating manganese mines and smelters. Their consumables, throughputs and impacts were determined from measured or calculated site data, production databases, invoices, metered/measured readouts, analysis and test reports, stack emissions tests, supplier data, design specifications, and other sources.

Secondary processes occur outside the primary manganese supply chain beyond the operational control of the participating sites. They were modeled using secondary data provided by previous LCA studies and government sources, including GaBi4®, Ecoinvent®, US-EPA and Environment Australia NPI data.

Validation Stages

Three distinct validation stages were employed during the study to validate the primary dataset and ensure the completeness of the study:

- A review to identify remaining data gaps and site data either inconsistent or conflicting with other site data sources;
- A review of the data by representatives of each site, providing an opportunity for amendments to the data, intended to validate the modeling and interpretation of site data;
- An anomaly analysis process comparing the consistency of various process and environmental indicators across the range of industry data collected to identify outliers.
Model Analysis & Benchmarking

The system was modeled using a linear combination of process modules, each representing primary and secondary processes involved in a given stage along the manganese supply chain. This model framework was devised to allow for the formation of the global model as well as site and process stage models built from various process module subsets to facilitate the industry benchmarking process.

Each of the 17 participating mines and smelters were modeled individually, with their respective upstream and downstream processes. The site models were then compiled into groups representing mines, sinter plants and smelters producing HC FeMn, Ref. FeMn and SiMn alloys.

Sites producing multiple alloys were divided by product type, proportioning the flows, processes and impacts pertaining to each product into their respective grouping. This system yielded separate process routes for each manganese alloy type considered in the study.

To satisfy the broad objectives of the study, the model was developed and assessed at multiple levels, including:

- Global-level (all mine sites and smelters);
- Site-level (comparing individual and groups of mines and smelters);
- Process-level (comparing individual process stages across all sites); and by
- Scope (upstream and downstream stages relative to the primary processes within the site or global supply chain boundaries).

Treatment of Manganese Byproducts

During the manganese alloy production process, a number of byproducts are produced which must be accounted for by the LCA model. Byproducts include:

- Slags, sold and used as aggregate for construction or as a feedstock for SiMn production; and
- Captured Mn-rich dusts, particularly during manganese refining, used for a variety of purposes.

With the exception of FeMn slag, all byproducts were considered either low value or not produced in significant enough quantities to share the environmental impacts of manganese alloy production. FeMn slag, an important manganese carrier for SiMn production, forms a moderate revenue source and cost for FeMn and SiMn producers, respectively. Using an economic allocation, FeMn slag used in SiMn production was considered to transfer 10% of the environmental impacts of FeMn alloy production to the SiMn process.
Impact Categories & Environmental Indicators (Results)

This study included an assessment of three main LCA impact categories as well as several key environmental indicators. The results are shown below and expressed in terms of 1 kg of average manganese alloy, a functional unit weighted based on the number of HC FeMn, Ref. FeMn and SiMn producers participating in the study.

Figure 8: Impacts and indicators per kg of manganese alloy product

<table>
<thead>
<tr>
<th>Impact Category</th>
<th>SI Mn</th>
<th>HC FeMn</th>
<th>Ref. FeMn</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Global Warming Potential (GWP)</strong></td>
<td>6.9</td>
<td></td>
<td></td>
<td>6.0 kgCO₂e</td>
</tr>
<tr>
<td>Total measure (in kgCO₂e) of the atmospheric</td>
<td>5.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>heat trapping effect of air emissions</td>
<td>6.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>contributing to climate change over a 100-year</td>
<td>6.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>period.</td>
<td>5.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Acidification Potential (AP)</strong></td>
<td>52.5</td>
<td></td>
<td></td>
<td>45.0 gSO₂e</td>
</tr>
<tr>
<td>Total measure (in gSO₂e) of the contribution</td>
<td>35.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>of emissions to the formation of acid in the</td>
<td>49.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>atmosphere.</td>
<td>47.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Photochemical Ozone Creation Potential (POCP)</strong></td>
<td>3.3</td>
<td></td>
<td></td>
<td>3.0 gC₂H₄e</td>
</tr>
<tr>
<td>Total measure (in gC₂H₄e) of the contribution</td>
<td>2.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>of air emissions to the formation of ground-</td>
<td>3.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>level ozone (smog).</td>
<td>3.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Nitrogen Oxides (NOₓ)</strong></td>
<td>20.1</td>
<td></td>
<td></td>
<td>18.7 g</td>
</tr>
<tr>
<td>Total mass of mono-nitrogen oxides (NO, NO₂)</td>
<td>15.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>generated during combustion when nitrogen</td>
<td>22.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and oxygen are present in the combustion zone.</td>
<td>20.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sulphur Oxides (SOₓ)</strong></td>
<td>37.5</td>
<td></td>
<td></td>
<td>30.9 g</td>
</tr>
<tr>
<td>Total mass of sulfur and oxygen containing</td>
<td>23.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>compounds generated during combustion of</td>
<td>31.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sulphur-containing materials such as coal and</td>
<td>30.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>oil.</td>
<td>31.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Particulate Matter (PM)</strong></td>
<td>11.5</td>
<td></td>
<td></td>
<td>9.6 g</td>
</tr>
<tr>
<td>Total mass of suspended particles in air,</td>
<td>8.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>generated at various processes, primarily</td>
<td>8.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>during material handling and electricity</td>
<td>8.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>generation.</td>
<td>8.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Energy</strong></td>
<td>86.1</td>
<td></td>
<td></td>
<td>73.4 MJ</td>
</tr>
<tr>
<td>Comprehensive energy demand associated with</td>
<td>63.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>resource inputs (e.g. crude oil, coal, etc.)</td>
<td>68.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>into the system, including to upstream and</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>downstream sources.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Primary Energy</strong></td>
<td>39.6</td>
<td></td>
<td></td>
<td>35.6 MJ</td>
</tr>
<tr>
<td>Total primary energy delivered to the</td>
<td>31.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>manganese production processes (electricity,</td>
<td>34.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>diesel, coke, etc.), including off-site</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>electricity production.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Primary Water Consumption (Water)</strong></td>
<td>12.9</td>
<td></td>
<td></td>
<td>11.3 kg</td>
</tr>
<tr>
<td>Total make-up cooling and process water delivered</td>
<td>8.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>to manganese production processes, including</td>
<td>13.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rainfall and storm water collection if utilized</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>by the operation.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Primary Waste Generation (Waste)</strong></td>
<td>21.9</td>
<td></td>
<td></td>
<td>26.5 kg</td>
</tr>
<tr>
<td>Total waste generated by the primary manganese</td>
<td>29.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>supply chain, classified by hazardous and non-</td>
<td>30.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hazardous wastes, overburden, ore rejects,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tailings and slag.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Analysis by Scope

The life cycle assessment approach provides the full scope of environmental impacts. It is interesting to understand exactly where these impacts come from relative to the primary manganese supply chain.

The upstream generation of electricity plays a large role in the overall impact of manganese alloys. More than 50% of the total value of each indicator is associated with the generation of power consumed at manganese facilities, except for particulate matter and primary energy. The impacts of power generation are largest for acidification potential (AP) and associated SO\textsubscript{x} emissions, 81% and 89%, respectively.

Direct impacts are generated within the operational control of participating sites, through fuel combustion, stack emissions, etc. Primary water demand and waste generation are, by definition, indicative of 100% primary processes. The most significant air emissions produced from primary processes are global warming potential (GWP), photochemical ozone creation potential (POCP), NO\textsubscript{x} emissions, and particulate matter (PM), contributing between 25% and 35% of total life cycle emissions. The primary energy occurring on-site (>60%) corresponds to the demand in coal and coke as reducing agents in the furnaces, and in fuel for mobile equipment. The primary energy associated with the production of electricity corresponds to the demand at the furnace and auxiliary processes.

The impacts that are not generated from primary, on-site processes or from electricity generation (secondary) come from other secondary processes such as the upstream manufacturing and transport of materials and consumables, and the downstream treatment of wastes. Their impact is minor, in comparison, with the exception of particulate matter generation and total energy, associated with the energy content of coal and crude oil extracted for reductants and fuels, respectively.

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**Figure 9: Environmental impacts and indicators, showing relative contribution from primary and secondary processes (Avg. Mn-alloy basis)**

<table>
<thead>
<tr>
<th>Impact / Indicator</th>
<th>Contribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWP</td>
<td>59%</td>
</tr>
<tr>
<td>AP</td>
<td>81%</td>
</tr>
<tr>
<td>POCP</td>
<td>68%</td>
</tr>
<tr>
<td>NO\textsubscript{x}</td>
<td>66%</td>
</tr>
<tr>
<td>SO\textsubscript{x}</td>
<td>89%</td>
</tr>
<tr>
<td>PM</td>
<td>35%</td>
</tr>
<tr>
<td>Total Energy</td>
<td>66%</td>
</tr>
<tr>
<td>Primary Energy</td>
<td>38%</td>
</tr>
</tbody>
</table>

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* By definition, primary water, waste and energy flows occur within the operational boundaries of manganese facilities. Total energy considers the value of energy carriers at their point of extraction.
Analysis by Process Stage

The manganese alloy supply chain starts with mining but ultimately centers on the smelting process occurring within electric arc furnaces. Among other materials, the smelting process requires ore, electricity, and coal-derived reductants, forming a critical junction between the three supply chains. As a result, the furnace and related power and consumables are responsible for over 70% of air emissions associated with manganese alloys.

The contribution of each major process is shown below:

Mining & Sintering
There are many similar process stages between mines and smelters, both involving material handling, crushing and screening, and the associated fuel and electricity consumption. The operation of mobile equipment at the mines and smelters contribute to elevated POCP and NOx emissions, while materials transport and handling as well as crushing and screening are significant sources of total fugitive PM emissions. Waste generation occurs primarily at mineral extraction where large quantities of overburden and waste rock are displaced.

Ore & Sinter Transport
The transport of ore and sinter to smelter sites is responsible for no more than 7% of each impact and indicator. Similarly to mining, fuel combustion for the operation of mobile equipment (trucks, rail, and ships) contribute to elevated POCP and NOx emissions.

Power Generation
The furnace process stage comprises 34% of primary energy demand but is the majority contributor to total energy and all air emissions categories except particulate matter.
Furnace (Direct)

Direct air emissions other than GWP and PM at the furnace are relatively minor, contributing between 5% and 8% of the total measures for AP, POCP, NO\textsubscript{x}, and SO\textsubscript{x}. Direct air emissions for these categories are proportionally low due to difference in emissions from the consumption of coal and coke in reduction reactions within the furnace compared to emissions from combustion boilers at coal-fired power stations.

Refineries

The refining process contributes additional impacts to the Ref. FeMn supply chain. The carbon contained in the molten HC FeMn charge is oxidized to reduce the carbon content of the output product, contributing to GWP. The addition of oxygen as well as nitrogen may promote the formation of NO\textsubscript{x} emissions, explaining the relatively high primary NO\textsubscript{x} emissions occurring during the refining process. PM emissions at the refinery are related to volatiles condensing in the off-gas stream as well as particles given off at the converter and during casting.

Smelter Consumables & Auxiliaries

The furnaces require the input of large quantities of reductants and fluxes such as coal, quartz, dolomite and limestone. The extraction and further processing of these reductants and fluxes contribute 10 to 14% of impacts. PM emissions are especially high as a result of upstream quarrying and mining of the furnace consumables. The total energy shown below principally accounts for the energy content of the coal and coke products fed to the furnace. The primary energy of smelter consumables and auxiliaries is associated with energy delivered to the furnace in the form of reductants and with the consumption of fuels on site.

* By definition, primary water, waste and energy flows occur within the operational boundaries of manganese facilities. Total energy considers the value of energy carriers at their point of extraction.

† The primary energy delivered to the furnace is reported in Power Generation and Smelter Consumables.
Influence of Electricity Generation

As highlighted in the previous sections, electricity generation is the single most significant process for most environmental impacts and indicators presented in this study. The contribution of primary (on-site) and secondary (upstream) electricity generation to each environmental impact and indicator shows that electricity generation contributes over 50% to all environmental air emissions and impact categories except PM, and over 80% for AP and SO\textsubscript{x}.

The environmental significance of electricity generation is due to the high electricity demand at the furnace and the high proportion of fossil fuel generation present in the upstream electricity grid in most manganese producing countries.

Upstream electricity generation has a large influence on the total environmental impacts and indicators of the manganese supply chain. The figure below represents the range of environmental performance for the industry average manganese supply chain for the least and most emissions-intensive regional power grids of the countries included in the study. The wide range of the results illustrates the impact of improving the environmental performance of the power generation grid on the environmental performance of the manganese industry.

Figure 10: Contribution of electricity generation on total environmental impacts and indicators (Avg. Mn-alloy basis)

Figure 11: Percentage change in total environmental impact and indicator results for a range of regional electricity grid performance, for the same primary energy delivered to site (Avg. Mn-alloy basis)
Energy Conversion

The energy carriers consumed by primary manganese processes (primary energy) are derived from raw energy resources (total energy), extracted, processed and transported to the primary manganese supply chain. Manganese mining and smelting relies on coal and coke (55%), electricity (38%) and fuels (7%) to deliver energy to the manganese process. Each energy carrier is derived from a variety of upstream energy resources, including coal, oil and gas, uranium and renewable energy. Depending on the efficiency of the energy conversion process, some energy carriers, such as electricity, require additional energy resources to make up for energy losses occurring upstream. Roughly half of the energy contained in the resources at extraction is lost before entering the primary manganese supply chain, with the most significant losses associated with power generation. For example, a 72% loss occurs during the processing of coal to electricity.

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. De-carbonization of electricity generation and improvements in furnace efficiency, including power generation from furnace off-gases would have a significant positive impact on the environmental impacts of manganese alloy production.

Figure 12: Energy extracted and delivered (MJ/kg Mn-Alloy)
Water Usage

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; and
- 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, 4.6 L of cooling water and 6.7 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.

![Figure 13: Process water consumption by process stage (Avg. Mn-alloy basis)](image13)

![Figure 14: Cooling water usage by process stage (Avg. Mn-alloy basis)](image14)
Waste & Byproducts Generation

Waste and byproducts 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 FeMn slags, which contain the non-gaseous waste products from the smelting process.

Both SiMn and FeMn slags may be directly recovered within manganese production for their manganese content, or used as a low-cost material for local building and road construction. Only 15% of slag is ultimately deposited as waste.
The Path Forward

The LCA of Global Manganese Alloy Production 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.

Best practices such as off-gas recovery for electricity generation and utilization of slag and dust as byproducts are already in place and should be encouraged. 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 LCA of Global Manganese Alloy Production and through leveraging its results, manganese producers are able to work collectively towards improving the environmental performance of the industry.
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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 based on sound data and science.

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

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