MANGANESE
The Global Picture – A Socio Economic Assessment
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</tbody>
</table>
Executive Summary

Socio-economic assessment (SEA) is the term used to describe a set of analytical tools and approaches for analysing the net social and economic impacts associated with a specific product, process or activity. It is an important tool for assessing the total contribution of an activity or sector to the economy, its overall impacts on society as a whole and the trade-offs involved in any policy decision that affects the productive activities of a sector. There is a growing recognition that industry benefits from being more proactive in the development and use of SEA. Indeed, many industry sectors have prepared their own SEAs with the aim of providing additional evidence on the contribution and role of their activities to economies around the world.

This report presents the findings of the first global SEA on Manganese (Mn). The study is based on a top-down analysis of the key supply chains for Mn, starting from Mn ore production, through Mn alloy production and focussing on the major downstream sector (the steel industry), as well as selected uses of Mn and Mn-containing products. It outlines the economic importance of Mn ore and alloys in terms of their direct and indirect economic value, as well as their effects on employment (jobs and wages). In compiling this report, we have utilised production and economic data relating to Mn and its use sectors, as well as a range of modelling tools and methodologies to assess, in economic terms, the criticality of Mn to the steel industry, based on the unique physico-chemical properties of Mn and the specific qualities that it imparts to particular steel products. As well as financial and economic benefits, there are also social, environmental and human health benefits associated with the use of Mn in its downstream applications. These benefits have been identified and monetised where possible (taking into account data availability) and the socio-economic contribution of Mn at regional and national levels have been highlighted.

Key Findings

The mining of Mn ore and production of Mn ferroalloys make significant economic and social contributions to national and regional economies where these activities take place. In 2013, global production of Mn ore totalled ~58 million Mt and was worth an estimated US $10.2 - $11.1 billion to the global economy (this value is based on market prices and quantities of Mn ore produced). Key figures are as follows:

**Mn ore production in 2013**

- Total value: US$ 21 - 23 billion, taking into account supply chain multiplier effects.
- Direct employment: 44,000 - 78,000 people worldwide, plus 33,000 - 59,000 jobs created through indirect and induced employment effects.
- Total wages paid to direct employees: US $2.7 - 4.6 billion per year.

**Mn alloy production in 2013**

- Total value: US$ 146.1 billion, taking into account supply chain multiplier effects.
- Direct employment: 67,000 - 86,000 jobs worldwide plus 217,000 - 278,000 jobs created through indirect & induced employment effects.
- Total wages paid to direct employees: US $613 - 796 million per year.

Global Mn Ore Production: 57,799 Kt

Global Value (including supply chain multiplier effects): US$ 21,100 – 23,000 million

Global employment (direct, indirect & induced): 77,700 – 136,600 Jobs

Note: All Mn Ore producing countries have been highlighted (blue), but data are only given for the top eight.
Applications & Importance

Manganese is a critical raw material input and additive for the steel industry. Overall, it could be argued that, without Mn, the entire steel industry (based on the current physico-chemical properties of steel) would not exist and, as a result, the entire value of the steel industry – an estimated US$ 964 billion to US$ 1,446 billion in 2013 – is reliant on the continued supply of Mn. There is, however, some potential for product substitution for certain steel types. Examples of key downstream uses in steel and other applications are given below.

**MAIN USES OF MN ORE**

- **Manganese Ore**
- **Feedstock for Ferroalloys** 93% - 94%
  - **Ferroalloys** ~85%
    - SiMn: ~56%
    - HC FeMn: 35%
    - Ref FeMn: 9%
  - **Slag** ~15%
  - **Crude Steel** ~90%
  - **Other** ~10%
    - Foundry: 70%
    - Welding: 30%


**Advanced High Strength Steels (AHSS)** AHSS provide excellent ductility and strength when compared to conventional steels. This is important in automotive applications as it can lead to weight reduction, lower fuel consumption and associated emissions, and improved crashworthiness. The use of AHSS in motor vehicles could lead to global savings of between 8 and 28 million Mt of CO₂ per year and fuel savings in the region of 0.35-1.13 l/km per car (equating to an annual global fuel cost saving of US$ 435 - 1,400 billion).

**Engineering Steels** Engineering steels require critical and often stringent levels of elasticity, strength, ductility, toughness and fatigue resistance and, in some cases, may also require resistance to high or low temperatures, corrosive and other aggressive environments. Mn is an essential component in these steels and can also be used to adjust their mechanical properties.

**Stainless Steels** Mn is a key component of low-cost stainless steel formulations, notably S200-series stainless. The market for S200 steel is valued at around US $13 billion per year and could reach US$ 18.7 billion - 35.7 billion by 2020. This niche market would not exist without Mn.

**Agriculture** Mn is a trace mineral that is essential for the metabolism of all living organisms (plants and animals). Mn deficiency is common in the soils of many locations globally. For example, in northern Indiana, USA, it is estimated that it could lead to annual losses for soybean producers of between US $196 - 392 million, if Mn-containing fertiliser is not applied.

**Batteries** Development of the lithium manganese oxide (LMO) battery could offer the opportunity for the wide-scale introduction of battery electric vehicles (BEVs). Assuming that BEVs make up 15% of all new car sales by 2020 and that 50% of future electric vehicles contain the LMO battery, the total value of CO₂ emissions reductions could be between US$ 723 - 5,214 million for the European Union (EU). If 80% of future electric vehicles contain the LMO battery, reductions of between US$ 1,157 - 8,343 million could be expected in the EU. In addition, this would lead to reductions in PM10 emissions and hence pollution related health effects.

**SiMn Slag** Approximately 65% of the fuel used in cement production is used in the calcination phase. Because SiMn slag is precalcined, its use as an alternative to limestone can reduce CO₂ emissions. Furthermore, if SiMn slag is used, less fuel needs to be burned, which results in further emissions reductions. Recent research also points to Mn slag conveying enhanced physical and mechanical properties to cement.
1. Introduction

Manganese (Mn) plays a very important role in the global economy, even if the dependence of various industry sectors, products and/or applications on Mn is not always recognised.

In 2013, approximately 53 million metric tonnes (mt) of Mn ore (wet) was produced globally, making Mn the fourth most consumed metal after iron, copper and aluminium. The production and processing of Mn ore and Mn alloys, as well as the associated capital and operating expenditures, make significant economic and social contributions to local, national and regional economies where these activities take place, as measured by indicators such as gross domestic product (GDP), employment, tax revenues, etc.

Mn is also a critical raw material input and process additive for the steel industry and the continued growth of this industry relies on Mn. Indeed, demand for Mn ore and alloys depends directly on the needs of the steel industry and it can be observed that international consumption of Mn ore is closely associated with the emerging economies, with China accounting for over half of total global consumption.

Besides steel, Mn has a number of other important downstream uses which make significant contributions to national and global economies each year. For example, Mn is a critical element in the manufacture of Mn batteries (notably, those used in electric vehicles), the production of aluminium alloys (e.g. for beverage cans) and in consumer electronics (e.g. television circuit boards). Mn is also an essential micronutrient needed for plant growth and plays a vital role in agricultural production. It is also critical for maintaining the health and well-being of the human body and is used in food supplements and medicines.

This report provides the results of the first global study on the socio-economic importance of Mn. It is based on a top-down analysis of the key supply chains for Mn, starting from Mn ore production, through Mn alloy production and covering the major downstream user sector, the steel industry. It outlines the economic importance of Mn ore and alloys in terms of their direct and indirect economic value, as well as their effects on employment (jobs and wages). In compiling this report, we have utilised production and economic data relating to Mn and its use sectors, as well as a range of modelling tools and methodologies to assess, in economic terms, the criticality of Mn to the steel industry, based on the unique physico-chemical properties of Mn and the specific qualities that it imparts to particular steel products. As well as financial and economic benefits, there are also social, environmental and human health benefits associated with the use of Mn in its downstream applications. These benefits have been identified and monetised where possible (taking into account data availability) and the socio-economic contribution of Mn at regional and national levels have been highlighted.

Socio-economic analysis provides the tools and methods for estimating the social and economic benefits of an industry to a community, ranging from a single neighbourhood to the global community as a whole. It provides a well-established framework for calculating the social and economic importance of the products in which an element, such as Mn, is used. Ultimately, this report sets out how the production and use of Mn is helping to meet society’s needs in a sustainable way, with the aim of ensuring that some of the economic benefits that have so-far not been well understood are better recognised by governments and other key stakeholders.
2. Manganese Ore

Reserves

Manganese (Mn) is found as a free element in nature (often in combination with iron) and is the 12\textsuperscript{th} most abundant element in the earth’s crust. It is one of the most widely used and versatile chemical elements in the world and is the fourth most consumed metal (after iron, copper and aluminium).\textsuperscript{1} Currently, only 12 of the 300 minerals containing Mn are of mining significance.

Current estimates of world Mn ore reserves reach several billion tonnes.\textsuperscript{2} In terms of metal content, global Mn reserves are estimated to lie in the region of 570 million mt, with South Africa containing between 85\% and 92\% of the world’s high grade Mn ore. Although significant Mn ore deposits are widely distributed across China, there are no reserves of high grade Mn ore in the country.

Mn reserves, in the form of polymetallic nodules, have also been discovered on deep ocean floors and are seen as a potentially valuable source of Mn in the long-term future.

### ESTIMATED GLOBAL MN RESERVES (METAL CONTENT, KILOTONNES)

<table>
<thead>
<tr>
<th>Country</th>
<th>Estimated Reserves</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Africa</td>
<td>150,000</td>
</tr>
<tr>
<td>Ukraine</td>
<td>140,000</td>
</tr>
<tr>
<td>Australia</td>
<td>97,000</td>
</tr>
<tr>
<td>Brazil</td>
<td>54,000</td>
</tr>
<tr>
<td>India</td>
<td>49,000</td>
</tr>
<tr>
<td>China</td>
<td>44,000</td>
</tr>
<tr>
<td>Gabon</td>
<td>24,000</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>5,000</td>
</tr>
<tr>
<td>Mexico</td>
<td>5,000</td>
</tr>
<tr>
<td>Other countries</td>
<td>Small</td>
</tr>
<tr>
<td><strong>World total (rounded)</strong></td>
<td><strong>570,000</strong></td>
</tr>
</tbody>
</table>

Source: USGS (2014)
Production & Consumption

Production

In 2013, approximately 58 million mt of Mn ore (wet) was produced globally, with the five major producers being China, South Africa, Australia, Gabon and Brazil. All are major seaborne exporters, except for China, which imports approximately 50% of its requirements.

In 2013, production of high grade ores stood at 16 million mt (wet), with Australia, Gabon, South Africa and Brazil, supplying over 95% of the international market. Medium grade ores accounted for around 16 million mt (wet); Australia, South Africa and India were the three major producers. Low grade ores accounted for around 26 million mt (wet), with the market dominated by China. China accounts for around 40% of global Mn ore production and produces nearly 90% of the world’s low grade Mn ore.

Consumption

Demand for Mn depends directly on the needs of the steel industry and so international consumption of Mn ore is closely associated with the emerging economies.

In 2013, total global consumption of Mn ore stood at 17.4 million mt (metal content), up 4.2% on 2012 (16.7 million mt). China accounted for the majority of all Mn ore consumed (62%). India, Ukraine and South Korea accounted for a further 16% of global Mn ore consumption.

GLOBAL MN ORE PRODUCTION (2010-2013) (KILOTONNES)

GLOBAL MN ORE CONSUMPTION (KILOTONNES, CONTENT)
Contribution to the Global Economy

Mn ore production provides two main types of economic value: its direct economic value, where this equates to the market value of Mn ore, as determined by market prices and quantities produced (output); and its indirect economic value, where this refers to the value generated in the supply chain by the production of Mn ore (estimated using input-output multipliers).

The direct economic value of Mn ore production (globally) is estimated at US$ 10.2 – US$ 11.1 billion per year. Of this, high grade Mn ore accounts for around US$ 4.3 – US$ 4.6 billion per year, while medium grade and low grade Mn ores account for US$ 3.1 – US$ 3.4 billion/year and US$ 2.8 – US$ 3.1 billion/year respectively.

In terms of indirect economic value, Mn ore production generates products (e.g. Mn alloys) and economic output in other upstream and downstream sectors (e.g. energy, transport, construction, etc.). Using input-output multipliers, it has been estimated that the total indirect contribution of Mn ore to the global economy is in the range of US$ 11.0 – US$ 11.9 billion per year.

Overall, the total economic contribution of Mn ore production (globally) is estimated at US$ 21.1 – US$ 23.0 billion per year.

Contribution to National Economies

Over 80% of the total economic contribution of Mn ore can be attributed to the production of Mn ore in the top five producing countries (China, South Africa, Australia, Gabon and Brazil). That said, the GDP of many other countries is enhanced by the production of Mn ore (see table, right). While the contribution of Mn to the GDP of countries such as China and Brazil may appear relatively small, the economies of these countries are large and the data must be interpreted within this context. Also, note that when indirect impacts across the supply chain are taken into account, the actual contribution of Mn to national GDPs is much higher (for Gabon, this could be as high as 10%).

<table>
<thead>
<tr>
<th>Country</th>
<th>Direct Value as % of GDP</th>
<th>GDP* (US$ million, 2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>0.03%</td>
<td>8,227,103</td>
</tr>
<tr>
<td>South Africa</td>
<td>0.62%</td>
<td>384,313</td>
</tr>
<tr>
<td>Australia</td>
<td>0.12%</td>
<td>1,532,408</td>
</tr>
<tr>
<td>Gabon</td>
<td>5.94%</td>
<td>18,377</td>
</tr>
<tr>
<td>Brazil</td>
<td>0.03%</td>
<td>2,252,664</td>
</tr>
<tr>
<td>India</td>
<td>0.02%</td>
<td>1,858,740</td>
</tr>
<tr>
<td>Malaysia</td>
<td>0.07%</td>
<td>305,033</td>
</tr>
<tr>
<td>Ghana</td>
<td>0.52%</td>
<td>40,711</td>
</tr>
</tbody>
</table>

*Based on data from the World Bank.
THE CONTRIBUTION OF MN ORE TO THE GLOBAL ECONOMY (2013)

**China**
- **Direct Contribution**: 2,530 - 2,760 (US$, million)
- **Indirect Contribution**: 4,086 - 4,457 (US$, million)
- **Total Contribution**: 6,616 - 7,217 (US$, million)

**South Africa**
- **Direct Contribution**: 2,375 - 2,590 (US$, million)
- **Indirect Contribution**: 2,289 - 2,497 (US$, million)
- **Total Contribution**: 4,664 - 5,088 (US$, million)

**Australia**
- **Direct Contribution**: 1,817 - 1,982 (US$, million)
- **Indirect Contribution**: 1,052 - 1,148 (US$, million)
- **Total Contribution**: 2,114 - 2,339 (US$, million)

**Gabon**
- **Direct Contribution**: 1,092 - 1,191 (US$, million)
- **Indirect Contribution**: 1,052 - 1,148 (US$, million)
- **Total Contribution**: 2,114 - 2,339 (US$, million)

**Brazil**
- **Direct Contribution**: 621 - 677 (US$, million)
- **Indirect Contribution**: 692 - 755 (US$, million)
- **Total Contribution**: 1,313 - 1,433 (US$, million)

**India**
- **Direct Contribution**: 390 - 425 (US$, million)
- **Indirect Contribution**: 203 - 221 (US$, million)
- **Total Contribution**: 593 - 645 (US$, million)

**Malaysia**
- **Direct Contribution**: 211 - 230 (US$, million)
- **Indirect Contribution**: 227 - 248 (US$, million)
- **Total Contribution**: 438 - 478 (US$, million)

**Ghana**
- **Direct Contribution**: 210 - 229 (US$, million)
- **Indirect Contribution**: 203 - 221 (US$, million)
- **Total Contribution**: 413 - 451 (US$, million)

**Ukraine**
- **Direct Contribution**: 260 - 284 (US$, million)
- **Indirect Contribution**: 148 - 161 (US$, million)
- **Total Contribution**: 408 - 445 (US$, million)

**Kazakhstan**
- **Direct Contribution**: 231 - 252 (US$, million)
- **Indirect Contribution**: 131 - 143 (US$, million)
- **Total Contribution**: 363 - 396 (US$, million)

**Others**
- **Direct Contribution**: 430 - 469 (US$, million)
- **Indirect Contribution**: 332 - 362 (US$, million)
- **Total Contribution**: 762 - 831 (US$, million)

**World**
- **Direct Contribution**: 10,167 - 11,091 (US$, million)
- **Indirect Contribution**: 10,954 - 11,949 (US$, million)
- **Total Contribution**: 21,121 - 23,041 (US$, million)
Industry Employment

Direct Employment

Between 44,000 and 78,000 people are directly employed in Mn ore production globally. Uncertainties in the exact figure are due to a lack of reliable data from China, which accounts for over 50% of all direct employment in Mn ore mining. South Africa is the second largest employer in Mn ore mining, followed by Australia (although this could change based on planned mine closures/openings). In total (globally), between US$ 2,700 million and US$ 4,600 million per annum is paid in wages to those employed directly in the production of Mn ore, with workers in China, Australia and South Africa accounting for the majority (~80%) of wages paid.

Indirect / Induced Employment

The production of Mn ore creates indirect employment (estimated at 22,000 to 39,000 people) in businesses that supply goods and services to the Mn ore mining sector (e.g. transport and logistics, machinery and repairs, etc.). It also creates induced employment estimated at a further 11,000 to 20,000 jobs as a result of income (wages) from direct and indirect employment being re-spent on final goods and services. In total, it is estimated that between 77,000 and 136,600 people are employed as a result of Mn ore production worldwide.

TOTAL EMPLOYMENT IN MN ORE PRODUCTION

<table>
<thead>
<tr>
<th>Country</th>
<th>Low Estimate</th>
<th>High Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>1,182</td>
<td>2,364</td>
</tr>
<tr>
<td>Australia</td>
<td>529</td>
<td>727</td>
</tr>
<tr>
<td>South Africa</td>
<td>462</td>
<td>673</td>
</tr>
<tr>
<td>Gabon</td>
<td>147</td>
<td>200</td>
</tr>
<tr>
<td>Brazil</td>
<td>99</td>
<td>139</td>
</tr>
<tr>
<td>Ghana</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>India</td>
<td>66</td>
<td>106</td>
</tr>
<tr>
<td>Ukraine</td>
<td>49</td>
<td>73</td>
</tr>
<tr>
<td>Malaysia</td>
<td>32</td>
<td>48</td>
</tr>
<tr>
<td>Mexico</td>
<td>22</td>
<td>33</td>
</tr>
<tr>
<td>Others</td>
<td>69</td>
<td>107</td>
</tr>
<tr>
<td>Total</td>
<td>2,731</td>
<td>4,620</td>
</tr>
</tbody>
</table>

ESTIMATE OF WAGES FOR MN ORE (US$ MILLION)

<table>
<thead>
<tr>
<th>Country</th>
<th>Low Estimate</th>
<th>High Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
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<tr>
<td>Others</td>
<td>69</td>
<td>107</td>
</tr>
<tr>
<td>Total</td>
<td>2,731</td>
<td>4,620</td>
</tr>
</tbody>
</table>
3. Manganese Alloy

Production & Consumption

Production

Globally, most of the Mn ore used by the steel industry is processed into suitable metallic alloy forms before being used in steel production. There are three main Mn-containing ferroalloys used for steelmaking:

- **Silicomanganese (SiMn)**, which accounts for around 70% of all Mn alloys produced;
- **High Carbon Ferromanganese (HC FeMn)**, which accounts for around 20% of all Mn alloys produced; and
- **Refined Ferromanganese (Ref FeMn)**, (medium-carbon (MC) and low-carbon (LC)) which account for around 10% of all Mn alloys produced.

In 2013, production of Mn alloys totalled 19 million mt, up 8% on 2012. Production of SiMn totalled 13.2 million mt, while production of HC FeMn and Ref FeMn accounted for 4.2 million mt and 1.7 million mt respectively.

Consumption

China is the world’s largest consumer of Mn alloy (all types), consuming 11.5 million mt in 2013.

Globally, the most consumed alloy type is SiMn, which is primarily used for the production of steel long products and critical elements in the construction industry. China (8.52 million mt), India (0.76 million mt), the United States (0.45 million mt) and Russia (0.37 million mt) are all important consumers of SiMn. Both HC FeMn and Ref FeMn are used to make flat and quality steel products and require the use of high grade ore. Important consumers of Ref FeMn include China (0.85 million mt), the Japan (0.14 million mt) and the United States (0.13 million mt). China (which consumed 2.09 million mt of HC FeMn in 2013), Japan (0.44 million mt) and India (0.41 million mt) are important consumers of HC FeMn.
Contribution to the Global Economy

In terms of direct economic value, the global production of Mn alloy is valued at around US$ 23 billion per year, based on global production of around 19 million mt and 2013 market prices. As indicated in the table below, China contributed approximately US$ 14.4 billion worth of Mn alloy to the global economy in 2013, which is approximately half of the total value of all Mn alloy produced. Large contributions to the global economy were also made by Mn alloy producers in India (US$ 2.5 billion), South Africa (US$ 0.9 billion) and Ukraine (US$ 0.8 billion).

Global production of SiMn is valued at US$ 15.8 billion per year, while HC FeMn and Ref FeMn account for US$ 5.1 billion and US$ 2.1 billion respectively. In total, the value of Mn alloy production worldwide, taking into account downstream multiplier effects in the supply chain, is estimated at around US$ 146 billion per year, of which China accounts for 74%. SiMn accounts for around 70% of the total economic contribution of Mn alloys and HC FeMn and Ref FeMn account for 20% and 10% respectively.

**TOTAL CONTRIBUTION OF Mn ALLOY TO THE GLOBAL ECONOMY (US$, BILLION)**

<table>
<thead>
<tr>
<th>Country</th>
<th>Direct Value</th>
<th>Indirect Value</th>
<th>Total Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>14.38</td>
<td>94.40</td>
<td>108.79</td>
</tr>
<tr>
<td>India</td>
<td>2.51</td>
<td>8.49</td>
<td>11.00</td>
</tr>
<tr>
<td>South Korea</td>
<td>0.63</td>
<td>4.28</td>
<td>4.91</td>
</tr>
<tr>
<td>Ukraine</td>
<td>0.83</td>
<td>2.51</td>
<td>3.34</td>
</tr>
<tr>
<td>South Africa</td>
<td>0.86</td>
<td>2.43</td>
<td>3.29</td>
</tr>
<tr>
<td>Japan</td>
<td>0.60</td>
<td>2.22</td>
<td>2.82</td>
</tr>
<tr>
<td>Norway</td>
<td>0.76</td>
<td>1.90</td>
<td>2.66</td>
</tr>
<tr>
<td>Russia</td>
<td>0.35</td>
<td>1.07</td>
<td>1.42</td>
</tr>
<tr>
<td>Spain</td>
<td>0.30</td>
<td>0.91</td>
<td>1.21</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>0.23</td>
<td>0.71</td>
<td>0.95</td>
</tr>
<tr>
<td>Others</td>
<td>1.66</td>
<td>4.04</td>
<td>5.70</td>
</tr>
<tr>
<td>World</td>
<td>23.11</td>
<td>122.96</td>
<td>146.07</td>
</tr>
</tbody>
</table>

**TOTAL (DIRECT & INDIRECT) CONTRIBUTION OF Mn ALLOY BY COUNTRY (2013)**

**ESTIMATED PRODUCTION VALUE (US$ BILLION, 2013)**


Industry Employment

Direct Employment

Between **67,000** and **86,000 people** are directly employed in the production of Mn alloys globally. As indicated in the figure (next page), approximately **87%** of direct employment in Mn alloy production can be found in China. This is to be expected, given that China accounts for nearly two thirds of all Mn alloy production. India is the next most important employer, followed by Brazil.

When broken down by type of Mn Alloy, as would be expected, SiMn is the main source of direct employment in Mn alloy production, accounting for between 50,000 and 64,000 direct jobs. HC FeMn accounts for between 12,000 and 16,000 direct jobs, while 5,000 to 7,000 people are directly employed in the production of Ref FeMn.

Indirect/Induced Employment

It is estimated that there are between **202,000** and **258,000 people** indirectly employed in the production of Mn alloys globally and a further **25,000 to 22,000 jobs** are created through induced employment effects. Overall, total employment (i.e. direct, indirect and induced) relating to the production of Mn alloy (all types) is estimated at between **284,000 and 366,000 people** globally. The vast majority of jobs created in the production of Mn alloy are located in China (around **87% of all jobs** - direct, indirect and induced). India, Brazil and Kazakhstan account for a further **6%** of all employment in Mn alloy production.

In total, between **US$ 621 million** and **$809 million per annum** is paid in wages to those employed directly in the production of Mn alloys (worldwide), with workers in China, Norway and Japan accounting for the majority of wages paid.

TOTAL (GLOBAL) EMPLOYMENT IN MN ALLOY PRODUCTION

<table>
<thead>
<tr>
<th></th>
<th>Low Estimate</th>
<th>High Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SiMn</strong></td>
<td><strong>75%</strong></td>
<td></td>
</tr>
<tr>
<td><strong>HC FeMn</strong></td>
<td><strong>18%</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Ref FeMn</strong></td>
<td><strong>7%</strong></td>
<td></td>
</tr>
<tr>
<td><strong>World</strong></td>
<td><strong>621.4</strong></td>
<td><strong>808.8</strong></td>
</tr>
</tbody>
</table>

ESTIMATE OF WAGES FOR MN ALLOYS (US$ MILLION)

<table>
<thead>
<tr>
<th>Country</th>
<th>Low Estimate</th>
<th>High Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>474.8</td>
<td>593.4</td>
</tr>
<tr>
<td>Norway</td>
<td>40.6</td>
<td>60.8</td>
</tr>
<tr>
<td>Japan</td>
<td>19.5</td>
<td>29.3</td>
</tr>
<tr>
<td>Spain</td>
<td>16.6</td>
<td>24.9</td>
</tr>
<tr>
<td>Brazil</td>
<td>13.8</td>
<td>17.2</td>
</tr>
<tr>
<td>South Korea</td>
<td>11.2</td>
<td>16.8</td>
</tr>
<tr>
<td>France</td>
<td>8.0</td>
<td>12.1</td>
</tr>
<tr>
<td>United States</td>
<td>7.8</td>
<td>11.7</td>
</tr>
<tr>
<td>Australia</td>
<td>7.6</td>
<td>11.4</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>4.3</td>
<td>5.4</td>
</tr>
<tr>
<td>Others</td>
<td>17.2</td>
<td>25.9</td>
</tr>
<tr>
<td>World</td>
<td><strong>621.4</strong></td>
<td><strong>808.8</strong></td>
</tr>
</tbody>
</table>
ESTIMATE OF TOTAL EMPLOYMENT IN MN ALLOY PRODUCTION (ALL ALLOY TYPES, LOW ESTIMATE)

<table>
<thead>
<tr>
<th>Country</th>
<th>Total</th>
<th>Induced</th>
<th>Indirect</th>
<th>Direct</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>249,210</td>
<td>13,370</td>
<td>176,880</td>
<td>58,960</td>
</tr>
<tr>
<td>India</td>
<td>7,240</td>
<td>350</td>
<td>5,160</td>
<td>1,720</td>
</tr>
<tr>
<td>Brazil</td>
<td>4,820</td>
<td>260</td>
<td>3,420</td>
<td>1,140</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>4,120</td>
<td>240</td>
<td>2,910</td>
<td>970</td>
</tr>
<tr>
<td>Zaire</td>
<td>2,480</td>
<td>70</td>
<td>1,800</td>
<td>600</td>
</tr>
<tr>
<td>Ukraine</td>
<td>2,400</td>
<td>130</td>
<td>1,700</td>
<td>570</td>
</tr>
<tr>
<td>Namibia</td>
<td>2,380</td>
<td>70</td>
<td>1,730</td>
<td>580</td>
</tr>
<tr>
<td>Norway</td>
<td>2,180</td>
<td>160</td>
<td>1,520</td>
<td>510</td>
</tr>
<tr>
<td>South Korea</td>
<td>1,780</td>
<td>90</td>
<td>1,270</td>
<td>420</td>
</tr>
<tr>
<td>Spain</td>
<td>1,700</td>
<td>80</td>
<td>1,210</td>
<td>400</td>
</tr>
<tr>
<td>Others</td>
<td>6,600</td>
<td>260</td>
<td>4,750</td>
<td>1,580</td>
</tr>
</tbody>
</table>
4. Manganese in Steel

Overview

By far, the most important use of Mn worldwide is as a process additive and alloying material in steelmaking. Mn is intentionally present and used as an alloying element in almost all types of steel and is a residual constituent of all others, making it the most prevalent alloying agent, after carbon.

As can be seen from the table below, large additions of Mn (about 12% to 13%) are used to make certain types of steel (e.g. Hadfield steel), however, the vast majority of steel production results in multi-purpose carbon steels containing around 0.5% Mn.

Production & Consumption

Global production of crude steel has increased significantly since the early part of the 20th century, from a few tens of million mt in 1900 to approximately 1,600 million mt in 2013. Today, there are over 3,500 different grades of steel, encompassing unique physical, chemical and environmental properties. In 2013, China produced around 48% of the world’s steel.

It is anticipated that production of crude steel will continue to increase over the next 20 years, reaching approximately 2,500 million mt by 2030.

Main Uses of Mn Ore

Sources: CPM Group (2010), Ideas First Research (2010), IMnI (2015, pers. comm.)

Steel Types Relevant to Mn

<table>
<thead>
<tr>
<th>Steel Types Relevant to Mn</th>
<th>% of Steel Produced</th>
<th>% of Mn Consumption</th>
<th>Mn Content per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Mn Content Steels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Mn Non-Magnetic Steel</td>
<td>1%</td>
<td>8%</td>
<td>11%</td>
</tr>
<tr>
<td>Hadfield Steel</td>
<td>1%</td>
<td>9%</td>
<td>13%</td>
</tr>
<tr>
<td>Stainless (200-Series)</td>
<td>0.4%</td>
<td>3%</td>
<td>12%</td>
</tr>
<tr>
<td>Low Mn Content Steels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Steel</td>
<td>87%</td>
<td>59%</td>
<td>0.5%</td>
</tr>
<tr>
<td>HSLA Steel</td>
<td>7%</td>
<td>13%</td>
<td>1.5%</td>
</tr>
<tr>
<td>Engineering/Construction Steel</td>
<td>3%</td>
<td>3%</td>
<td>1%</td>
</tr>
<tr>
<td>Stainless (excl. 200-Series)</td>
<td>2%</td>
<td>3%</td>
<td>1%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

Sources: CPM Group (2010), Ideas First Research (2010), IMnI (2015, pers. comm.)
In line with crude steel production, apparent global steel consumption has increased from just below 800 million mt in 2000 to just under 1,500 million mt in 2013. One of the key reasons for this growth has been a significant increase in steel demand from China (in 2000, China accounted for just 16% of total world apparent steel use; by 2013 this had risen to 47%). However, other developing regions have also seen an increase in their contribution to global steel use over this period.

As indicated in the pie-charts (right), over half of global steel production is used in the construction industry, with this proportion increasing to 57% when considering emerging economies alone (data for 2011). Other important sectors in which significant quantities of steel are used include mechanical machinery, metal products and the automotive industry, which account for 14%, 13% and 12% of global steel use respectively.

The Economic Value of Mn in Steel

The economic value of Mn in the context of steel making derives from two key aspects:

- Firstly, in its use as an alloying material, there are no known alternatives to Mn in the steel making process; and

- Secondly, Mn is basically the most cost-effective hardenability intensifier available and this is the reason it is used in all standard treatable steels. While Mn is not as powerful as nickel in its ability to stabilize austenite and more Mn is required to achieve the same effect, Mn has the advantage of being much less expensive and its effects can be reinforced by combining it with nitrogen, which is also an austenite-forming element.

Overall, it could be argued that, without Mn, the entire steel industry (based on the current physico-chemical properties of steel) would not exist and, as a result, the entire value of the steel industry – an estimated US$ 964 billion to US$ 1,446 billion in 2013 – is reliant on the continued production and use of Mn.

It is important to note that, at a more specific product level, there may be the potential for substitution of Mn in some uses. For example, in theory, there are technical substitutes to Mn in its use as a mild deoxidizer and desulphuriser; however, there are significant trade-offs (some of which are intended and acceptable) associated with adopting some of these substitutes. Likewise, it may also be possible to substitute Mn in some of the high Mn content steels (e.g. high Mn non-magnetic steels, Hadfield steel, stainless (200 series) steel) with other metals (e.g. Nickel, Boron, etc.) to produce alternative steels which confer alternative properties.
4.1 Manganese in Carbon Steel

Background

Steel is classified as carbon steel when no minimum content is specified or required for elements such as chromium, cobalt, nickel or titanium (among others); when the specified minimum for copper does not exceed 0.40%; or when the maximum content specified for manganese is less than 1.65%, silicon (<0.60%), copper (<0.60%). It is the most basic and versatile type of steel available and is produced in greater quantities than any other steel (accounts for over 80% of total steel produced).

Criticality of Mn in Carbon Steel

Mn is used as a process additive (deoxidizer and desulphuriser) in the production of most carbon steels. It reduces the tendency towards hot-shortness (i.e. cracking), resulting from the presence of sulphur, which enables the metal to be hot-worked. Although the use of Mn as a deoxidizer and desulphuriser has declined in recent years (e.g. with the advent of hot-metal desulphurization and ladle deoxidation), its use in steelmaking still relies on these properties to a large extent.

As an alloying element, Mn improves the physical qualities of steel by improving its strength, toughness, hardness and workability, making it less brittle, easier to form and more resistant to shock, abrasion and corrosion. The Mn content in carbon steels is often increased for the purpose of increasing depth of hardening and improving strength and toughness. By countering the brittleness caused by sulphur, Mn also has a beneficial effect on the surface finish of carbon steel. Carbon steels with Mn content (from 1% - 1.8%) are also known as carbon-manganese steels.

KEY USES OF CARBON STEEL

<table>
<thead>
<tr>
<th>Steel Type</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Carbon</td>
<td>Used to make flat-rolled sheets or steel strips for ships, wire products, car bodies, domestic appliances and tin plates. Also used for making bolts, bridges, buildings, forgings, gears, nails, pipes, rivets, screws and shafts.</td>
</tr>
<tr>
<td>Medium Carbon</td>
<td>Used to make auger bits, axles (including for cars), boilers, connecting rods, crank pins, crankshafts, drop forgings, forgings, gears, hammers, pipelines, rails and railway wheel assemblies, screwdrivers, shafting, sledges.</td>
</tr>
<tr>
<td>High Carbon</td>
<td>Used to make cutting tools, blades, springs and high-strength wires. Also used to make hammers, screwdrivers, saws, drills and other general tools.</td>
</tr>
<tr>
<td>Ultra-High Carbon</td>
<td>Used for specialist applications, e.g. (non-industrial-purpose) knives, axes or punches; blades and cutting, milling and precision tools; surgical cutlery; twist drills; pipe cutters; circular cutters; razors; engravers; saws for cutting steel; white drawing dies.</td>
</tr>
</tbody>
</table>

Source: The University of Toledo (no date)

Economic Importance of Mn

It has been estimated that 1.40 billion mt of carbon steel was produced in 2013, worth an estimated US$ 839 billion to US$ 1,259 billion. Since Mn is present in all carbon steels (either as a residual element, e.g. from its use as a process additive, or as an alloying element used to impart specific properties to the final steel), the entire value of the carbon steel market can be said to be dependent on the production and use of Mn.

Image courtesy of: Grand Steel Products Inc.
4.2 Manganese in Construction & Engineering Steel

Criticality & Economic Importance of Mn

Although the exact mechanical properties of construction/engineering steel can be altered by adjusting its carbon and Mn content and through the addition of various alloying elements (e.g. chromium, nickel, molybdenum, vanadium, titanium and bismuth), no direct substitute has been found for Mn in this application. It has been estimated that 48 million mt of construction/engineering steel was produced in 2013 (based on construction/engineering steel accounting for 3% of total global steel production). Since Mn is an essential component of these steels, the entire value of the construction/engineering steel market - an estimated US$ 29 billion to US$ 43 billion – is reliant on Mn.

Construction Steel

In construction, the most important property for steel to have is high strength and stress-bearing capacity. Not only does Mn improve the strength, hardness and toughness of construction steel, it is also the most economical hardenability intensifier (the most cost-effective way to increase the hardenability of carbon steel is to increase the Mn content from 0.6% to 1.4%). Mn is therefore critical to steel’s production and use in construction applications.

Steel frame construction offers significant advantages over more traditional materials, such as reinforced concrete. It has the highest strength-to-weight ratio of any building material (which increases safety), is cheap (around 5% to 8% less expensive than reinforced concrete), is flexible (can be produced into many shapes and forms), and can be prefabricated offsite, increasing the speed of construction onsite.

Steel also plays a vital role in the production of renewable energy and offers considerable advantages for the construction of wind turbine towers due to its strength and durability. Steel is 100% recyclable, which is of great importance when considering life cycle emissions. The environmental impacts of wind turbine construction would be significantly higher if an alternative, less recyclable, material were used. For example, lifecycle assessment studies indicate that a 6% increase in material recovery results in a 3% reduction in greenhouse gas emissions.

Engineering Steel

Engineering steel can be broadly defined as any steel that moves (rotates, twists or bends) rather than remaining still whilst in use. Engineering steels require critical and often stringent levels of elasticity, strength, ductility, toughness and fatigue resistance and, in some cases, may also require resistance to high or low temperatures, corrosive and other aggressive environments.

Engineering steels are used in a wide range of industrial applications including automotive, aerospace, railway, oil and gas extraction, mining, power generation, defence, agriculture, chemical construction and general engineering and manufacturing sectors. The automotive sector, including production of cars, buses, trucks and off-highway vehicles, accounts for over 50% of the market for engineering steels, with specific applications including crankshafts, gearbox gears, suspension arms, automotive springs and hydraulic components.

The composition of engineering steel is specifically tailored to create a product with the desired properties for its designated use. Engineering steels include carbon-manganese compositions, as well as compositions containing an array of other alloying elements. Nevertheless, Mn is present and a critical addition in the production of all engineering steels.

Image courtesy of: Engineering & Technology Magazine
4.3 Advanced High Strength Steels

Background

Advanced High Strength Steels (AHSS) (i.e. steels which typically have an ultimate tensile strength between 300 MPa and 1,500 MPa) offer a superior combination of ductility and strength compared to conventional high strength steels. They demonstrate a high fatigue endurance limit and generally have excellent formability. The high energy absorption capacity of AHSS allows them to be used in vehicles to help protect occupants during a collision and can also reduce vehicle weight. Hence, AHSS have undergone significant research and development in recent years, particularly in automotive applications.

Twinning Induced Plasticity (TWIP) steels (a type of AHSS) are a newly developed material characterised by a high rate of work hardening. High performance TWIP steels are fully austenitic and non-magnetic and demonstrate properties of both high ductility and strength. They can be stretched by up to 90% of their original length without breaking and resist tensile pressures up to 1,100 MPa.

Criticality & Economic Importance of Mn

Mn is the main alloying element in TWIP steels, comprising 18-30 wt.%. Mn is also the main alloying element in austenitic Mn steels more generally. In TWIP steels, Mn is crucial for preserving the austenitic structure of the steel and for controlling the material’s stacking fault energy (SFE). The key deformation process that gives TWIP steels their unique properties is the conversion of the material’s structure from austenite to martensite under stress. The high concentration of Mn within TWIP steels allows the material to be fully austenitic at room temperature, which is vitally important for enabling the material to be sufficiently ductile whilst resisting high stress levels without breaking (a key asset in materials used in automotive applications).

TWIP steels have the potential for use in various vehicle bodywork and structural components and offer considerable advantages compared to conventional steels, namely increased strength (twice as strong), increased energy absorption capability and reduced weight (5-6% less dense). The higher strength TWIP steels can also be used in thinner sheets, leading to further weight reductions (~10-20% with savings of up to 30% for certain components). Inclusion of TWIP steels within the FutureSteelVehicle design optimisation process (which demonstrates lightweight steel solutions to automakers) and the considerable research interest in TWIP steels suggests the use of this material will increase in future.

The principle advantage of AHSS (particularly TWIP steel) over conventional steel is the material’s combination of excellent ductility and strength, which allows for considerable weight savings. Although a relatively recent innovation, these steels have significant potential for use in future automotive applications, mainly because of their potential to increase the crashworthiness of vehicles (enhancing passenger safety) and reduce vehicle weight, leading to improvements in fuel consumption and emissions reductions. This is particularly important considering the recent rise in oil prices, increasing regulatory pressure to reduce the environmental impacts of vehicle emissions and the continuous increase in vehicle weight (by almost 90% in the EU between 1970 and 2010 - see graph overleaf).
It is estimated that for every 10% of weight eliminated from a vehicle’s total weight, fuel economy improves by 7%. Reducing a vehicle’s weight by 100kg, reduces fuel consumption by 0.25l/km and carbon emissions by approximately 7 gCO2/km. Although difficult to evaluate, it is estimated that the use of AHSS steels can result in a vehicle weight saving of around 10%-25%. Assuming an average car weighs 1,400 kg, CO2 emissions per car could be reduced by 9.8 to 31.5 g/km - equivalent to an estimated global saving of 8 million to 28 million tonnes of CO2 per year. The use of AHSS could reduce each car’s fuel consumption by an estimated 0.35-1.13 l/km. Applied to all cars globally, this equates to an estimated reduction in expenditure on fuel of US$ 435-1,400 billion per year. It is also worth noting the fact that average greenhouse gas emissions from primary production of steel are at least four to five times lower than alternative materials used in automotive applications.

The use of AHSS in vehicle design also has the potential to increase the crashworthiness of vehicles, thus enhancing passenger safety in the event of a collision. On average, there are 1.24 million fatal vehicle accidents and between 20 million and 50 million non-fatal injuries globally each year. These result in human costs (loss of life) and economic costs (e.g. loss of outputs, medical costs etc.). Assuming the use of AHSS in vehicles could reduce the number of incidents by 1% to 5%, savings in Europe are estimated at between US$ 81 million and US$ 407 million per year, taking into account both human and economic costs. It is estimated that 3% of India’s GDP (US$ 55.8 billion) is lost due to road traffic crashes each year and that around 15-5% of all road deaths in India involve the driver/passenger of a 4-wheeled vehicle. Assuming the use of AHSS could reduce such road deaths by 1% to 5%, total GDP savings are estimated at US$ 86 million to US$ 432 million per year.

What’s more, AHSS can be produced at a similar or even reduced cost compared to conventional steels (and significantly lower costs compared to alternative materials – see chart), which signifies the potential importance of these materials in the future.

It is estimated that, in 2009, 9.73 million tonnes of high Mn non-magnetic steel was produced resulting in the consumption of 1.07 million tonnes of Mn. This equates to approximately 1% of annual steel production and 8% of total Mn consumed in the production of steel. Forecasts suggest that, by 2015, production of high Mn non-magnetic steel (including TWIP steel) will reach 14.19 million tonnes, consuming 1.56 million tonnes of Mn.
4.4 Manganese in Austenitic Mn Steel

Background

Austenitic Mn steel, also known as mangalloy or Hadfield steel (after its 19th Century inventor, Sir Robert Hadfield), is a high Mn content steel that typically contains between 11% and 14% Mn. Austenitic Mn steel has unique properties which make it indispensable for applications in which great toughness and wear resistance are required. It is generally used in situations where assurance is required by the user against unexpected failure (e.g. in demanding applications where downtime cannot be accepted). Common uses for austenitic Mn steel include gears; spline shafts; axles; rifle barrels; earthmoving, mineral and mining equipment; grinding and crushing machinery; oil well drilling; power shovel buckets; railway points and crossover components; track work and rail road wheels; dredging; lumbering; steel-plants; cement plants; kiln and mill liners; stone crushers, jaw and gyratory crushers and ore processing equipment.

Criticality & Economic Importance of Mn

Austenitic Mn steel is a remarkable engineering alloy that, by definition, would not exist without Mn. Hence, it could be argued that the entire value of the austenitic Mn steel market is attributable to the availability and use of Mn. Importantly, the service life of austenitic Mn steel components is three to five times longer compared to carbon steel when exposed to slow abrasive wear. This can lead to a substantial reduction in costs associated with maintenance and replacement. Austenitic Mn steels perform most efficiently when external conditions cause extensive work hardening of the wear component’s surface. Under shock and impact, austenitic Mn steel almost triples its initial surface hardness, retains its interior toughness and acquires a high polish. The ability of Austenitic Mn steel to work harden up to its ultimate tensile strength is a key feature and, in this regard, this material has no equal. These features make this steel an ideal material for heavy impact and abrasive service applications. Austenitic Mn steel also exhibits high levels of ductility, toughness and slow crack propagation rates in comparison to other potentially competitive materials.

Railways

Railway switches and crossings are subjected to high and concentrated dynamic forces and must perform their duty with the highest levels of reliability and safety. On a plain track, a broken rail can still be passed by a train wheel due to built-in redundancy; however, failure of a switch/crossing component can lead to direct derailment of the first train that runs over it. Choice of engineering material is, therefore, critical.

Due to its unique properties (namely excellent work hardening ability, suitable strength and high toughness), austenitic Mn steel has been widely used to manufacture railway switches and crossings (frogs) for more than a century. Voestalpine (a global market leader in turnout technology for railways, metros and tramways) and Balfour Beatty Rail (the UK market leader for switches and crossings) both use austenitic Mn steel in the production of railway components (e.g. crossings and switches, as well as specialist embedded track-work for urban rail systems, ports and docks).
Austenitic Mn steel is used because it develops an exceptionally wear-resistant surface during operation and is, therefore, suitable for tracks experiencing very high axle loads. Its work hardening ability, together with its high wear-resistance and fracture toughness, increases the longevity of the component/track. For example, curved rails made of austenitic Mn steel have demonstrated life expectancies in excess of six times that of normal carbon steel rail. Replacing austenitic Mn steel with an alternative metal may reduce the anticipated lifespan of the component, thus leading to the need for more frequent maintenance and replacement and, hence, increased costs associated with materials, labour and lost profits due to downtime. Hence, the total direct benefits of austenitic Mn steel could be enormous given the thousands (if not millions) of turnouts that are used throughout the global rail system every year.

Indirect cost associated with delays (caused by increased maintenance) could also be significant if less durable materials are used and there could be a potentially greater risk of rail failures. In the UK alone it is estimated that train delays cost the economy over £1 billion (US$ 1.7 billion) per year, with turnout systems considered to be the main component of railway infrastructure that affects the ability of the system to operate to capacity.

Within the EU, the number of passengers and volume of cargo transported by rail is expected to double and triple respectively by 2020. This increase in demand cannot only be satisfied by building new railways; the efficiency of existing railways will also need to increase. In part, this can be achieved by increasing the capacity of the rail system, which directly relates to the frequency of repair and maintenance. Use of an alternative material, with lower strength and/or lower wear resistance, might lead to a reduction in train speeds as a means of reducing track wear (to prolong component life) and to increase safety. This could have a knock-on impact for journey times and, hence, passenger travel and freight deliveries. The use of durable materials (such as austenitic Mn steel) is therefore considered critical to the future development of the EU’s rail network and regional economic growth.

Over time, railway axle loads appear to be increasing, which is leading to an increase in the levels of stress and wear on railway components. This suggests that excellent toughness and wear resistance (properties associated with austenitic Mn steel) are likely to become increasingly important considerations in the manufacture of railway components in the future.

In terms of alternatives to austenitic Mn steel, bainitic steel, which has proven uses in switch and crossing applications as well as shallow radius track, could potentially be used in some applications. However, as with all steels, Mn is still a crucial alloying element in this type of steel (low-carbon bainite, for example, contains ~3.95% Mn). ArcelorMittal has developed a fully pearlitic micro-alloyed steel rail with mechanical properties considerably better than traditional C-Mn steel rails. The levels of C, Mn and Cr in this steel guarantee a very fine pearlitic microstructure, without the presence of brittle structures in the rail or its welds.
4.5 Manganese in Stainless Steel

Background

The term “stainless steel” is used to describe an extremely versatile family of engineering materials, which are selected primarily for their corrosion and heat resistant properties. They find use across a broad spectrum of applications and industries, as indicated in the diagram to the right. Mn is intentionally present and used, in various concentrations, in all types of stainless steel. Overall, it could therefore be argued that the entire stainless steel industry - valued at an estimated €80 billion (~US$ 106 billion) in 2010\(^6\) - is reliant on the continued production and use of Mn.

Economic Importance of Mn (200 series)

The addition of Mn to stainless steel promotes the stability of an austenitic crystalline structure. While nickel (Ni) is also an austenite forming element, Mn is able to achieve the same effect at a much lower cost. As such, Mn has become a key component of low-cost stainless steel formulations, notably 200-series stainless steel.

200-series stainless steel currently accounts for 3% of primary Mn consumption, and around 21% of all stainless steels; this creates a global market for 200-series stainless steel of around US$ 12.7 billion to US$ 25.4 billion per year (based on 2012 production). Assuming market growth of 5% per annum (currently 6.6%), 200-series stainless steel could reach around US$ 18.7 billion to US$ 35.7 billion in value by 2020 - a market which would not exist without Mn.

Criticality in Selected Applications

Bridges

Galling is a severe form of adhesive wear which occurs when two sliding surfaces fuse together as a result of cold welding. When Mn is added to stainless steel it forms Mn-rich sulphides, which act as solid lubricants in sliding contact and so stainless steels containing such sulphides exhibit strong resistance to galling. Indeed, grades such as Nitronic® 60 (which combine high Mn with high silicon contents) offer excellent galling resistance.

In bridge components (such as pins and bolting), galling can result in the need for expensive retrofitting, repair work and/or safety concerns. Lubricants are not the solution due to the long life-cycle of a bridge and lack of accessibility. Many lubricants are also hazardous to the environment. Thus, alloy selection is critical.

Perhaps the most significant development in the stainless steel market in recent years has been the emergence of the lean duplex grades. In some of the recently developed grades, Mn and N are used in combination to reduce the amount of expensive and volatile alloying elements to very low levels. This has a beneficial effect on cost and price stability, which is critical for construction projects with a long lead time (such as bridges).

One of the key advantages of duplex stainless steel is its excellent strength-to-weight ratio. With optimised design, the weight saving potential of using duplex stainless steel compared to austenitic grades or conventional mild steel is around 30% for bridge construction. This is important because it minimizes substructure costs and facilitates very shallow construction depths, which overcome problems with headroom and flood clearances, and minimizes the length of approach ramps. Minimum self-weight can also reduce the cost of transporting and handling components and is particularly beneficial in poor ground conditions.

LDX 2101®, for example, is alloyed with 5% Mn and has been used for bridges in Sienna (Italy) and Gaularfjell (Norway). Lean duplex rebar will also be used in Brisbane’s Gateway Upgrade Project, the first time LDX 2101 will be used as rebar.

Desalination Equipment

Besides structural applications, such as bridges, the high strength of duplex stainless steel is also useful for reducing the section thickness (and weight) of sheet and plate used in the walls of pressure vessels and storage tanks (as shown in the diagram below). For this reason, duplex stainless steels have quite a significant (and growing) market share in the water treatment sector. According to SMR (2009), duplex stainless steels make up a 13% share of all stainless steels used in the water treatment sector. Furthermore, the market for duplex desalination equipment is anticipated to grow by >10% per year in the forthcoming years.

POTENTIAL WALL THICKNESS REDUCTION IN STORAGE TANKS USING DUPLEX STAINLESS STEEL COMPARED WITH AUSTENITIC

Source: Outokumpu (no date)
4.6 Manganese in HSLA Steels

Background

High Strength Low Alloy (HSLA) steels, which account for around 7% of world steel production, are an important category of steels used primarily for their high strength. Although HSLA steels contain a range of alloying elements (including <2% Mn), they are not considered to be alloy steels in the normal sense, primarily because they are designed to meet specific mechanical properties, rather than a chemical composition. Indeed, HSLA steels are generally defined as steels having a yield strength >450 MPa.

In recent years, the production and use of HSLA steels has grown rapidly in a number of regions, especially China. Worldwide, production of HSLA steels has outpaced crude steel production by around 20% year-on-year since 2006.

Criticality of Mn in HSLA Steel

Mn is an important alloying constituent in HSLA steels, where it is used principally as a strengthening element. In these steels, relatively high Mn levels (1.0% to 1.8%) have a beneficial effect on the austenitic transformation temperature and its role in obtaining a very fine ferrite structure. Mn also improves low-temperature impact properties.

It is important to note that the key properties of HSLA steels are not provided solely (or arguably, mainly) by Mn. Other alloying elements can be added alone, or in combination, depending on the particular mechanical properties required. For example, niobium, vanadium and/or titanium may be added to increase strength, while zirconium and calcium improve formability. These micro-alloying additions help to refine the structure and strengthen the steel through the formation of carbide or nitride precipitates which are evenly distributed in the ferrite matrix. This is somewhat different from the role of Mn, which is critical to obtaining a very fine ferrite structure. In any case, Mn does have an effect on improving the precipitation strengthening of these micro alloying additions (e.g. in vanadium steel and also to a lesser extent niobium steels) and, as such, plays an important role in microstructural refinement.

There are no alternatives to Mn in HSLA steels. There are, however, alternative steels which can be used in the applications where HSLA steels are deployed but these steels do not offer the same benefits as HSLA steels. The principal advantages of HSLA steels compared with traditional carbon steels are: higher strength with good ductility; good formability at room temperature (which allows for greater part complexity and more manufacturing flexibility); good weldability with most conventional welding methods; and good corrosion resistance. As a result of these properties, HSLA steels have found application in automobiles, cranes, roller coasters and other structures that are designed to handle large amounts of stress and where a good strength-to-weight ratio is important. They can also be found in bridges, oil/gas pipelines, shipbuilding, suspension components, building structures, vehicles/transportation, tubular components, heavy equipment and off-shore/platforms.

MANGANESE IN THE CONSTRUCTION OF THE TRANS-ALASKA PIPELINE

HSLA steels were originally developed as flat-rolled products for the Trans-Alaska pipeline in the late 1960s. The good weldability of HSLA steel allowed reliable joining of pipe sections under difficult field conditions and the strength and fracture toughness of the steel permit the use of higher pumping pressures. To prevent hot oil from melting the permafrost underground, much of the pipe is suspended above the ground. Hence, the strength of HSLA steel was an important design parameter.

Sources: Russell & Lee (2005)
Criticality in Selected Applications

Overview

HSLA steels with the same strength are usually 20% to 30% lighter than carbon steel. This is important because increasing the yield strength of steel using Mn results in significant cost savings. Although the extent of potential savings varies across sectors and end-uses, the principle is the same. Some examples of specific applications are given below.

Offshore Installations

Over the last 10 to 15 years, there has been growing interest in the use of higher strength steels for offshore installations. The main application for these steels has been in the fabrication of production jack-ups – an end use with technically demanding requirements. HSLA steels have also been used in tethering attachments for floating structures in tension leg platforms (TLP’s) and for mooring lines with semi-submersible module offshore drilling units (MODUs).

HSLA steels offer a number of advantages over conventional steels, particularly where weight is important - in particular, they result in savings in the cost of materials while maintaining strength. The table below provides an illustration of the potential cost savings which could apply by using HSLA steel to build an offshore platform, compared with using a typical structural steel.48

The example (based on 1,000 tonnes of steel) indicates that the use of HSLA steel produces an overall cost reduction of around US$ 300,000 (~14%). The largest cost savings are realised at the fabrication stage, with cost savings of around US$ 225,000 (20%). It also shows that the use of HSLA steel creates a 30% reduction in the amount of material used (700 tonnes rather than 1,000 tonnes), as well as a reduction in transport and shipping costs.

Automotive Applications

Although HSLA steel is more expensive than carbon steel, it has proven popular within the automotive industry and accounts for up to 40% of the body mass of some modern passenger cars.49

Because HSLA alloys are stronger than carbon steels, they can be used in thinner sections, making them particularly attractive for transportation-equipment components where weight reduction is important. Using lighter weight steel reduces the overall weight of the vehicle which, in turn, lowers fuel consumption and CO2 emissions, offsetting the higher cost of the steel. This delivers benefits to steelmakers, helps ensure motor vehicle manufacturers can meet emissions targets and reduces vehicle owners’ costs. According to one source50, steelmakers can expect to earn $100 per ton of HSLA steel compared to $50 for carbon steel, while users can expect to save $39 (per ton of steel) when carbon steel is replaced with HSLA steel.

Furthermore, a recent study51 discovered that the use of HSLA steel with vanadium (HSLA-V steel) in trailer chassis results in a weight reduction of 680 kg which, assuming an annual transportation distance of 100,000 km, results in a saving of 312 litres of diesel.

Depending on design, the higher strength of HSLA steels can also translate into better fatigue and crash performance, while maintaining or even reducing section thickness.

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**ALTERNATIVE COSTS OF A WELDED CONSTRUCTION USING STEEL WITH HIGHER YIELD STRENGTH (US$)**

<table>
<thead>
<tr>
<th>Steel tonnage</th>
<th>S355 Carbon Steel</th>
<th>S460 HSLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Costs</td>
<td>660,000</td>
<td>610,000</td>
</tr>
<tr>
<td>Fabrication</td>
<td>1,200,000</td>
<td>875,000</td>
</tr>
<tr>
<td>Corrosion Protection</td>
<td>260,000</td>
<td>260,000</td>
</tr>
<tr>
<td>Engineering</td>
<td>175,000</td>
<td>175,000</td>
</tr>
<tr>
<td>Total Cost</td>
<td>2,200,000</td>
<td>1,900,000</td>
</tr>
</tbody>
</table>

*Source: Hulka (no date)*
5. Manganese - Impacts on Industry & Society

Introduction

While most Mn ore is used as direct feedstock for ferroalloys or steel production, around 2% to 6% of Mn ore is used in the production of specialist metallurgical and chemical products. These find application in a wide range of uses, including agricultural feed and fertilizer, food supplements and medicines, water treatment, batteries (importantly, those used in electric vehicles) and electronics. Mn is also the main alloying element in the 3XXX series aluminium alloys, which are widely used to make aluminium beverage cans. Although some Mn ore (around 13% to 15%) is lost to slag in the process of Mn alloy production, recent research suggests that this “waste” could be a valuable addition in the production of low carbon concrete.

The value of Mn in some of its key applications is explored further in the following sections.

**Some unique uses of manganese**

**Manganese in ships**

In 2006, German company MMG produced the world’s largest ship propeller for the Emma Maersk. The ship’s six-blade, single-piece propeller is 9.6 meters in diameter and is cast from an alloy consisting of copper, aluminium, nickel, iron and manganese.

Source: Bell (2012). Image courtesy of: Mecklenburger Metallguss GmbH (no date)

**Manganese in “big bang” simulation**

A Mn-containing non-magnetizable austenitic stainless steel was used to make the quadrupole magnets in the world’s largest “big bang” simulator (the Large Hadron Collider, based in Switzerland). The quadrupole magnets, consisting of four magnetic poles, act as magnetic lenses, focusing the particle beam alternately in horizontal and vertical direction and keeping it on a predetermined “flight path”.

5.1 Agriculture

Background

Mn is one of nine essential micronutrients for plant growth. It satisfies a number of biological processes, including ensuring optimal plant enzyme synthesis, nitrogen metabolism and lignin manufacture. Mn deficiency in plants reduces the chlorophyll content and ability of the plant to photosynthesize and also lowers resistance to root pathogens.

Criticality Mn in Agriculture

In certain regions of the world, soils are significantly deficient in Mn and this is likely to impair the production of arable crops (particularly crops with a high Mn requirement such as soybeans, peas, wheat, barley and oats). Crop losses as a result of Mn deficiency can have a significant social and economic impact on farmers as well as actors in the wider agricultural sector, the retail sector (food prices) and society (e.g. availability of bread and breakfast cereals). Impacts may also extend to animals grazing on these soils that may experience symptoms of Mn deficiency (e.g. impaired growth). In Mn-deficient areas, Mn is usually added to the soil as a fertiliser (e.g. as Mn sulphate) and animals may be fed Mn in the form of supplements.

Economic Importance

European Cereal Production

The economic importance of Mn in agriculture will vary by region, by soil conditions (e.g. temperature, moisture, pH), by the presence (or absence) of other nutrients (e.g. Mn deficiency can co-exist with iron deficiency) and the specific crop being planted (i.e. whether the crop has a high or low Mn requirement).

Using Europe as an example, Mn deficiency in agricultural soils occurs across large areas of Poland, North Western Spain, Scandinavia and the UK. In the UK specifically, it is the most common micronutrient deficiency seen in crops; sugar beet, cereals and peas are considered to be particularly susceptible.52 In the UK and Ireland, it is estimated that up to 20% of the area under arable crops is treated for Mn deficiency each year and that severe Mn deficiency can result in yield losses of up to 65% in winter cereals.53 Assuming that 15% to 20% of the total area under winter wheat and barley production in the UK and Ireland is treated for Mn deficiency each year and that yield losses for non-treatment lie in the region of 40% to 60%, the total benefit of treatment for Mn deficiency would be around US$ 370 million to US$ 667 million each year.

United States Soybean Production

Similarly, in Northern Indiana (United Stated) where soils are high in organic matter, soybean yields can increase by around 15 bushels per acre when Mn is added to deficient crops.54 Assuming 70 million bushels of soybeans are produced on Mn deficient soils and that yield losses from Mn deficiency lie in the region of 20% to 40%, the total value of additional yield (with the addition of Mn fertiliser) is estimated to be worth US$ 196 million to US$ 392 million in Northern Indiana alone. These figures do not take into account further impacts up the supply chain.

MANGANESE DEFICIENT SOYBEAN CROP

Image courtesy of: Sturgul (2009)
5.2 Batteries

Background

The global market for electric vehicles (EV) is forecast to reach over 6 million units by the year 2020, with the US currently accounting for ~38% of the world's electric vehicle stock. Although future growth in the EV market is expected to emanate mainly from the Asia-Pacific region, with countries such as China and Japan setting aggressive production and sales goals, the US is forecast to remain an important market for EV adoption through to 2020.

In the US, EVs currently emit about 84g CO2/km, which is significantly less than the amount of CO2 emitted on average by conventional vehicles with an internal combustion engine. Due to differences in the electricity mix, EVs in Europe perform slightly better, only emitting 70g CO2/km. In addition to reducing CO2 emissions, replacing conventional vehicles with EVs could also help reduce human exposure to other urban pollutants (e.g. PM10) which are associated with direct impacts on health, significantly reduce traffic noise in cities and significantly reduce oil dependency.

Criticality of Mn in Batteries

Many types of batteries have been investigated for use in EVs with extensive research having been conducted on lead acid, nickel-cadmium, nickel-metal hybrid, sodium-nickel chloride and lithium polymer batteries. A number of other batteries, such as the sodium-sulphur battery, are also in development but have not yet found significant practical application.

Although lithium-Mn oxide spinel (LMO) is a relatively new material, the ongoing expansion of the EV market may rely on its continued use in rechargeable batteries. LMO batteries are associated with good structural stability, low-cost and good electronic and lithium-ion conductivity. With growing concern over the safety and viability of other cathode designs (e.g. LCO), spinels based on LiMn2O4 are growing in popularity as cathode materials. The use of LMO battery technology is also particularly attractive as it offers a real opportunity for reducing reliance on lead, nickel and cadmium power sources in this important area, thereby offering potential environmental and health gains.

LMO batteries have already found application in commercially available EVs, including the Chevy Volt and the Nissan Leaf. However, research and development of this technology is still in the early stages and further technological advances are expected. Indeed, development of the LMO battery may potentially offer the opportunity for the wide-scale introduction of battery EVs.

AFTER STEEL, THE BATTERY SECTOR IS CURRENTLY THE SECOND LARGEST CONSUMER OF MANGANESE

<table>
<thead>
<tr>
<th>ENERGY DENSITY OF COMMON BATTERY TECHNOLOGIES</th>
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<tbody>
<tr>
<td>LCO</td>
</tr>
<tr>
<td>NMC</td>
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<tr>
<td>LMO</td>
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<tr>
<td>LFP</td>
</tr>
<tr>
<td>NiMH</td>
</tr>
<tr>
<td>NiCd</td>
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<tr>
<td>Lead acid</td>
</tr>
</tbody>
</table>

Source: RPA (2011)
Economic Importance

According to one recent report, the rapidly growing global market for EVs will create an overall market for lithium-ion batteries worth over US$ 24 billion by 2023, up from US$ 3.2 billion in 2013.61

Europe

Using a case study approach, the benefits associated with CO2 savings and reduced emissions of PM10s have been estimated across the EU for the period 2011 to 2020. Assuming that EVs make up 35% of all new car sales by 2020 and that 50% of future EVs contain the LMO battery, the total economic value of social benefits associated with CO2 emissions reductions has been estimated at between US$ 723 million and US$ 5,214 million. Assuming that 80% of future EVs contain the LMO battery, the economic value of the reductions is between US$ 1,157 million and US$ 8,343 million.

Assuming that a reduction of 15 µg/m³ PM10s leads to a gain of 140 life days, it is estimated that between 413,000 and 662,000 life years, or around half a life day per person by 2020, will be gained across the EU population by the year 2020 with a move to EVs. This is associated with total present value benefits of US$ 22 billion (50% uptake) and US$ 36 billion (80% uptake).

USA

Assuming that 2.6 to 6.0 million EVs are sold in the US over the period 2011 to 2020 and that 50% of these contain the LMO battery, the total value of social benefits associated with CO2 emissions reductions has been estimated at US$ 38 million to US$ 857 million. Assuming that 80% of future EVs in the US contain the LMO battery, the economic value of reductions is estimated at US$ 61 million to US$ 1,371 million. Note that, unlike the European example above, these values do not take into account any future improvements in the carbon intensity of the US electricity mix. The values given here therefore represent the minimum benefits that are likely to accrue (i.e. they are an underestimate).

5.3 Healthcare

Background

Although estimations of human requirements for Mn vary considerably, there is general agreement amongst health professionals that some Mn is essential for maintaining the health and wellbeing of the human body. Mn is associated with bone development and with amino acid, lipid and carbohydrate metabolism. Trace amounts of Mn are also needed for normal sexual functioning and may help lower the risk of osteoporosis in post-menopausal women. Mn deficiency has been demonstrated in animals and has been noted in humans in association with vitamin K deficiency. The main manifestations in all species studied are impaired growth, skeletal abnormalities, disturbed or depressed reproductive functions, lack of muscular coordination among newborns and defects in lipid and carbohydrate metabolisms.

In order to prevent the detrimental effects of Mn deficiency, various Mn chemicals (including MnSO₄, MnO and MnCl₂) have been used as food additives and dietary supplements for humans (and other animals). Manganese sulphate is also used in medicine to treat Mn deficiency (typically in animals) and manganese carbonate is used as a hematinic (this increases haemoglobin content of the blood and is used to treat anaemia). Mn may also help treat the symptoms of premenstrual syndrome (PMS) in women.

Some Mn chemicals have also been developed for use in specialised healthcare applications to assist in the diagnosis and treatment of numerous health issues. For instance, various Mn chemicals are known to be effective contrast agents for enhancement of Magnetic Resonance Imaging (MRI) at tissue, cellular and even molecular levels. MRI is a medical imaging technique that is widely used in hospitals for medical diagnosis. Research suggests that Mn doped superparamagnetic iron oxide nanoparticles can be used to form ultrasensitive contrast agents for liver imaging. This sensitive contrast agent may find application in the identification of small liver lesions and assist in the identification and evaluation of severity of liver diseases. Mn-based agents continue to be developed and new nanotechnologies have great promise for achieving high MR contrast. To date, gadolinium (Gd) has been the predominant paramagnetic used for MR paramagnetic contrast. However, the recent discovery and association of the use of this substance and nephrogenic systematic fibrosis (NSF) in some patients with severe renal disease or following a liver transplant has caused concern. Therefore, the pursuit of alternative methods to achieve personalised molecular imaging has renewed attention in

MN AS AN MRI CONTRAST AGENT

Image courtesy of: Wisegeek (no date)

Image A shows an MRI image of the left cochlea of a guinea pig before MnCl₂ administration. Image B shows the same cochlea after 12 h of MnCl₂ administration.
Mn and may increase the potential use of Mn based agents in the future. It is important to note that there are potential alternatives to gadolinium and Mn for use in MRI, including iron and copper.\textsuperscript{69}

The use of Mn-containing stainless steel implants began in the 1920’s and, due to the detrimental effects of metal corrosion on the human body, research and development in this field has focused on finding increasingly corrosion-resistant materials. Today, the most widely used metallic biomaterials include stainless steels, titanium and its alloys, cobalt-chromium based alloys, as well as tantalum, niobium and gold. Stainless steels are conventionally used in orthopaedics, with the main advantages being low cost, good mechanical properties and ease of processing.\textsuperscript{70} However, stainless steels have traditionally contained nickel, which is known to cause contact allergies. Nickel is the most common metal to cause contact dermatitis in orthodontics, with more cases of allergic reactions than for all other metals combined.\textsuperscript{75} It is estimated that 8.6% of the global population suffers from an allergy to nickel; 65 million people in Europe alone.\textsuperscript{71} Most cardiovascular and peripheral vascular stents are made from 316L stainless steel which contains strongly sensitising metals such as nickel and chromium.\textsuperscript{75} As a result, Mn-containing high-nitrogen nickel-free austenitic stainless steels are increasingly being used as replacements for nickel-containing steels in medical applications\textsuperscript{72}.

**Economic Importance**

The global market for biomedical metals reached US$ 13.3 billion in 2012 with this expected to increase by 7.5% annually over the coming years. By 2016, the market is expected to approach US$ 17.8 billion in value and by 2020 is expected to reach US$ 23.7 billion.\textsuperscript{73} It should be noted that there are other metals used in biomedical applications, including titanium alloys and cobalt-based alloys with the use of titanium alloys considered to have the most promising growth prospects for the future. However, stainless steels are considered to be the largest product group of biomedical metals, accounting for more than half of the total biomedical metal market\textsuperscript{80} (an estimated US$ 6.7 billion in 2012). Mn is a critical component of these steels, which would not exist without its inclusion. The development of new nickel-free stainless steels and the relatively low cost of these materials (compared to alternatives) is likely to ensure the continued use of Mn-containing biomedical metal products in the future.

GLOBAL MARKET FOR BIOMEDICAL METALS, 2012 - 2020, US$ BILLION

Source: Acmite Market Intelligence (2013)
5.4 Aluminium

Background

Aluminium is the second most popular metal after steel. It finds widespread use in applications where weight is a decisive factor. While the construction and automotive industries are the largest consumers of aluminium globally (accounting for >50% of total global consumption), it is the packaging industry which is expected to display the highest growth rate over the next few years. The aluminium beverage can is the lightest form of beverage packaging on the market and provides a bright, decorative substrate. Aluminium cans are very robust and provide excellent protection during transport and distribution with minimum need for secondary packaging. They are also easily recycled. Other beneficial properties of aluminium for packaging include good formability, high corrosion resistance and UV-light resistance, all of which are vital when it comes to food packaging and storage. Use of aluminium packaging is not restricted to the food sector though; it also plays an important role in the packaging of consumer goods and pharmaceutical products, such as toothpaste.

Criticality of Mn in Aluminium Beverage Cans

The specific choice of material used for aluminium beverage cans has for years now been consolidated. Al-Mn alloy (3XXX series) is used for the body of the can (due to its specific mechanical properties and excellent workability), while Al-Mg alloy (5XXX series) is used for the lid (end) and tab. To some degree, Mn is present in almost all aluminium alloys, albeit as an impurity. Mn is, however, the main alloying element in the 3XXX series aluminium alloys, where it is used in concentrations of 1% to 2% wt. In general, the addition of Mn to aluminium alloy makes treatment and forming easier and increases ductility and strength. Mn helps aluminium to resist corrosion and, in combination with iron, improves the alloy’s castability and reduces shrinkage during metal solidification.

In 2011, ~254 billion beverage cans were manufactured globally, around 90% of which were made from aluminium (an estimated 229 billion units). Assuming a market value of US$ 0.01 to US$ 0.05 per unit, the total value of the aluminium beverage can market is estimated at US$ 2.5 billion to US$ 12.7 billion. The global market for metal cans is expected to reach US$ 51.6 billion in 2019, growing at a CAGR of 2.4% from 2013 to 2019. Given a market growth rate of 2.4%, the global market for aluminium beverage cans could be worth US$ 11 billion to US$ 22 billion by 2020.

The benefits of using Mn in aluminium can manufacture are experienced more strongly in some regions than in others. As outlined in the case study overleaf, the USA is the largest market for aluminium cans. However, Europe, Japan, China and Brazil are also major consumers. While beverage can consumption has experienced significant growth in the Middle East in recent years, the market for beverage cans in sub-Saharan Africa and India has been slow to develop. Nevertheless, can demand in these regions is expected to increase in the coming years in line with rising incomes, better retail infrastructure and changing consumer tastes. Hence the benefits of Mn are likely to increase in these regions in the future.
USA

The USA is the largest single market for beverage cans, accounting for around 43% of the global market (~109 billion cans in 2011).

Companies in the USA that manufacture metal cans employ as many as 28,400 people and generate an additional 155,800 jobs in supplier and ancillary industries.\(^8\) Assuming that 75% of people employed in the production of metal cans work in the production of aluminium beverage cans, around 138,150 people were employed as a result of US aluminium beverage can manufacture in 2011.

Workers employed directly in the manufacture of metal cans took home (in total) more than US$ 2 billion in wages and benefits in 2011, bringing total wages from direct, indirect and induced employment in the US industry to over US$ 10.5 billion.\(^9\) Again, assuming 75% of wages paid to employees in the manufacture of metal cans relate to jobs in the manufacture of aluminium beverage cans, total wages (direct, indirect and induced) resulting from aluminium beverage can production in the US equate to an estimated US$ 7.9 billion in 2011.

Not only does the manufacture of cans create jobs in the USA, the metal can industry also contributes to the economy as a whole. In 2011, the metal can industry was responsible for as much as $46.97 billion in total economic activity throughout the USA.\(^9\) In 2010, metal cans generated US$ 9.0 billion in sales in the USA, with aluminium cans accounting for approximately 35% (US$ 3.3 billion).\(^8\) Assuming that 35% of all economic activity in the metal can production sector in the USA is attributable to the production of aluminium beverage cans, it is estimated that the aluminium beverage can industry was responsible for as much as US$ 16.4 billion in total economic activity throughout the US economy in 2011. Total tax revenues in the USA related to aluminium beverage can production are estimated at US$ 1.5 billion.

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**CONTRIBUTION OF THE USA ALUMINIUM BEVERAGE CAN INDUSTRY**

<table>
<thead>
<tr>
<th>Economic Contribution</th>
<th>US$ 16.4 billion</th>
</tr>
</thead>
<tbody>
<tr>
<td>US$ 6.1 billion</td>
<td></td>
</tr>
<tr>
<td>US$ 6.2 billion</td>
<td></td>
</tr>
<tr>
<td>US$ 4.1 billion</td>
<td></td>
</tr>
</tbody>
</table>

**Employment**

- 138,150 Jobs
- 61,800 Jobs
- 55,100 Jobs
- 21,300 Jobs

**Wages**

- US$ 1.5 billion
- US$ 3.5 billion
- US$ 2.8 billion
- US$ 7.9 billion

**ESTIMATED TAXES GENERATED IN THE USA FROM ALUMINIUM BEVERAGE CAN PRODUCTION (US$ BILLION)**

- Federal Taxes: US$ 0.93
- State Taxes: US$ 0.53
- Total Taxes: US$ 1.46

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5.5 Slags and Cement

**Background**

Like steel, cement plays a vital role in meeting society’s needs for housing and infrastructure. The production of cement, however, is very energy-intensive and accounts for around 5% of global anthropogenic CO₂ emissions.\(^8^4\) As a means of improving the environmental performance of cement, research has been carried out to assess the feasibility of using Mn ferroalloy slag in its production.\(^8^5\) The results of this research point to a new and sustainable use for this by-product of the Mn production process - in cement production.

**Criticality of Mn in Slag**

There are several options for producing low carbon concrete, however, many of these options pose challenges today due to restrictions on use (e.g. fuel ash), declines in supply (e.g. blast furnace slag), cost/technical issues, etc. The use of Mn slag has been shown to have potential for use in its own right in blended cement production. It can also be combined with other approaches (e.g. use of lean mix concrete, carbon capture) to deliver even greater benefits. Recent research shows that Mn slag can be used to partly substitute cement concrete as a means of lowering the economic costs, as well as achieving enhanced physical and mechanical properties.\(^8^6\) In this supplementary role, concrete made with Mn slag exhibits very low strength and weight loss in synthetic seawater corrosion and freezing-thawing cycle tests.\(^8^7\)

**Economic Importance**

Around 65% of the fuel used in cement production is used in the calcination phase.\(^8^8\) Because SiMn slag is precalcined, its use in cement production means that less fuel needs to be burned which results in CO₂ emissions reductions. The table (right) gives an indication of potential CO₂ savings calculated from laboratory work. **Over the period 2011 to 2020, the value of these savings is estimated at US$ 1.55 million to US$ 7.83 million.**

Assuming just 1% of clinker produced worldwide in 2012 was made using SiMn slag, the **total (global) value of CO₂ reductions would be in the region of US$ 5.94 million to US$ 29.16 million.** Although fuel savings are more difficult to quantify (as they will vary depending on the fuel type used), it is likely that the savings would be substantial.

<table>
<thead>
<tr>
<th>POTENTIAL CO₂ SAVINGS FOR A KILN PRODUCING 850,000 TONNES OF CLINKER PER YEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
</tr>
<tr>
<td>CO₂ Production from 1st calcination ('000 tpa)</td>
</tr>
<tr>
<td>Process CO₂ savings against control ('000 tpa)</td>
</tr>
<tr>
<td>Theoretical heat of reaction (Zur Strassen) Kcal/kg</td>
</tr>
<tr>
<td>Combustion CO₂ due to the Qth assuming 93kg CO₂/GK emission</td>
</tr>
<tr>
<td>Combustion CO₂ saving against control ('000 tonnes)</td>
</tr>
<tr>
<td>Total CO₂ saving against the baseline ('000 tpa)</td>
</tr>
<tr>
<td>Total value of CO₂ savings (US$, million)</td>
</tr>
</tbody>
</table>

*Source: Carbon Enterprises (no date); Value of CO₂ savings (own estimate)*
5.6 Electronics

Background

Manganese ferrite (MnFe$_2$O$_4$) is a non-conductive ceramic compound and magnetic material with a cubic spinel structure which is used extensively in the manufacture of electronics and in various technological applications. It belongs to the wider family of so-called ‘soft ferrites’ with the chemical formula - XXFe$_2$O$_4$ – where XX could represent any of the divalent transition metals (e.g. Zn, Ni, Co, Cu, Mg, etc.). Of these, the most widely used soft ferrites are Manganese-Zinc (MnZn) and Nickel-Zinc (NiZn) ferrites, with MnZn accounting for around 70% of the global market for soft ferrites.\footnote{89}

Criticality of Mn in Electronics

The specific properties of Mn ferrite depend heavily on the composition, morphology and size of the Mn ore, as well as the preparation conditions. Through careful manipulation of their chemical composition and processing procedures, soft ferrites are tailor made to meet specific characteristics in electronic components. Indeed, many different material grades of MnZn ferrite can be manufactured depending on their desired end-use application. For example, MnZn ferrite cores are used for compact transformers and digital communication pulse transformers (signal transformers) where they provide a number of specific advantages including: high resistivity, wide range of operating frequencies, high permeability, time and temperature stability, large material selection, versatility of core shapes, low cost and light weight.\footnote{90} They can also be found in radio aerials and antenna rods (where high sensitivity and high magnetic permeability at radio frequencies are important pre-requisites), telecommunications equipment, computer memory cores and tape recorders (where ferrite particles are embedded in terylene tapes).\footnote{91} Large quantities of MnZn ferrite are also consumed in the manufacture of television circuit boards. Overall, MnZn ferrites are technologically important materials because of their high magnetic permeability and low core losses.\footnote{91} Indeed, the principle advantage of MnZn ferrite over its most important counterpart, NiZn ferrite, is its higher permeability and saturation induction levels, which makes MnZn ferrite highly suited to low frequency (<2 MHz) applications.\footnote{93}

Economic Importance

Magnetic materials can be divided into soft magnetic materials (comprising soft ferrites and electrical steel) and permanent magnet materials (comprising hard ferrites and NdFeB magnets). The global market for magnetic materials is forecast to reach \textbf{US$ 33 billion} by the year 2018, buoyed by strong demand from Asia, particularly China.\footnote{94} Soft magnetic materials (including MnZn ferrite) represents the largest product segment in this market. It is important to note that China currently accounts for over 50% of the world’s output of soft ferrite and that, between 2000 and 2007, China’s soft ferrite output effectively tripled. It is projected that soft ferrites will experience significant growth in the near future mainly driven by the resurgence of the global economy, rapid technological advancements and continued strong demand from existing applications in the electronics and IT sectors.\footnote{105}

At the turn of the century, the value of the global market for MnZn was estimated at \textbf{US$ 0.7 billion to US$ 1.4 billion} per year (based on soft ferrite accounting for 80% of the global market for powder magnetic products and MnZn accounting for 70% of the market for soft ferrite). Assuming this market has continued to grow at rate of 15% year-on-year, the global market for MnZn ferrites would be worth around \textbf{US$ 4 billion to US$ 9 billion} today. This may be an underestimate given that global output of soft magnetic materials reportedly grew at a CAGR of more than 16% between 2004 (230,000 tonnes) and 2010 (580,000 tonnes).\footnote{95}
5.7 Water

Background

Mn plays an important role in the provision and treatment/purification of water supply. Mn containing steels are used in a wide variety of water-related applications ranging from collection and storage to distribution and purification. These include pumps, pipes, well-drilling equipment and tanks for waste water treatment and desalination plants. Various forms of Mn (including Electrolytic Mn Metal (EMM) and potassium permanganate) are also used in water treatment and aquaculture applications and offer key advantages to other alternative substances.

Criticality of Mn in Water Related Activities

Although electrolytic manganese metal (EMM) is mainly used as an alloying element in the steel sector, EMM also finds use in a wide variety of other applications including anti-bacterial and anti-fungal agents, which are used to purify drinking water, treat waste water and in odour control. Electrolytic Mn dioxide crystals can be used to remove iron in solution from water. Both iron and manganese are unaesthetic parameters that are often present in groundwater. Mn dioxide is one of the most commonly used substances for the removal of iron, manganese hydrogen sulphide, arsenic and radium from water, particularly in the western U.S. Although there are numerous alternative iron and manganese removal technologies (e.g. sequestering, cation exchange, aeration and filtration etc.), the use of Mn dioxide oxidation/filtration media offers certain key advantages, including higher filtration rates, smaller treatment vessels (that occupy a smaller footprint), excellent co-contaminant removal of iron and Mn as well as sulphides and arsenic and the ability to reliably remove target substances at efficiencies of 90-99%.

Potassium permanganate is a powerful oxidising agent with bactericidal and algicidal properties. It is extensively used in drinking water purification and waste water treatment. It is also used for odour control, including deodorisation of discharges (e.g. from paint factories and fish processing plants) and to treat common fish pathogens such as gill parasites and external bacterial and fungal infections. There are alternative substances with bactericidal and algicidal properties (e.g. formalin, chelated copper or copper sulphate), however, copper toxicity increases in soft water areas and formalin should not be used in temperatures below 40°F. Therefore, the key advantages of potassium permanganate include its ability to be used in soft water areas and in cold environments (indeed, it is considered to be the only effective parasite treatment in cold water conditions). It is also used by fishery biologists and aquaculturists to inactivate piscicides actinomycin-A and rotenone (both of which are toxic to fish) in ponds and flowing waters.
Economic Importance

As indicated above, the use of potassium permanganate is considered to be particularly critical as a means for treating common fish pathogens and fungal infections in soft- and/or cold-water areas. One such region, where low average water temperatures and soft water conditions are combined, is Scotland.

Scotland is the third largest producer of farmed salmon in the world, with the industry worth an estimated £584.7 million (US$ 980 million) in 2011. Assuming the cessation of potassium permanganate use results in a yield losses equivalent to 1% of the value of the Scottish salmon farming industry, total losses from the cessation of potassium permanganate use in this application would equate to losses in the region of £5.8 million (US$ 9.1 million) per year. The total annual wage bill for the Scottish salmon farming industry is estimated at £36 million (US$ 56 million) per year, which translates to an annual input of almost £166 million (US$ 260 million) to the Scottish economy (mostly in the Highlands and Islands). This serves to highlight the importance of the salmon farming industry to the Scottish economy (and, in particular, remote regional economies) and the need to maintain healthy stocks.

It is also important to note the potential reliance and, hence, socio-economic importance of using potassium permanganate as a treatment for fish diseases in developing countries. Evidence suggests that potassium permanganate may be widely used to treat diseases in fisheries in the developing world, with a survey of 257 farmers undertaken in Bangladesh indicating that potassium permanganate was the most popular treatment. Fish is the second most valuable agricultural crop in Bangladesh and its production contributes to the livelihoods and employment of millions of people. It is estimated that approximately 1.3 million tonnes of fish (excluding shrimp and prawn) are produced each year from numerous inland aquaculture systems (including small homestead ponds and larger intensive enterprises). Again, assuming that the cessation of potassium permanganate use results in a 1% reduction in fish yield, direct losses to the Bangladeshi economy are estimated to lie in the region of US$ 8.8 million to US$ 12.5 million per year. Potential socio-economic impacts associated with reduced fish production yields could be significant given that fish provides more than 60% of animal source food in the Bangladeshi diet.

SCOTTISH SALMON FARMING

![Image of salmon farming](Image courtesy of: Sainsbury's (no date))

<table>
<thead>
<tr>
<th>Year</th>
<th>Projected Total Food Fish Consumption (000 Tonnes, Global)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>111,697</td>
</tr>
<tr>
<td>2010</td>
<td>119,480</td>
</tr>
<tr>
<td>2020</td>
<td>138,124</td>
</tr>
<tr>
<td>2030</td>
<td>151,771</td>
</tr>
</tbody>
</table>

6. Manganese - Regional Impacts

Africa

In 2013, the African region accounted for ~30% of global Mn ore production, with the two largest producing countries being South Africa (11 million mt) and Gabon (4.3 million mt). Ghana, Ivory Coast, Namibia and Egypt also produced small amounts of Mn ore. In total, US$ 3.8 billion to US$ 4.1 billion worth of Mn ore was produced in the African region in 2013, with the total economic value (direct and indirect) of production valued at US$ 7.5 billion to US$ 8.1 billion in this year.

South Africa is considered to hold around 80% of world Mn reserves, with around 92% of the world’s high grade Mn ore located in the Kalahari Basin. This is significant given that high quality steel products (such as flats and longs) use HC FeMn and Ref FeMn, which can only be made using high grade Mn ore. Hence, South Africa is likely to be a very important player in the future production of high quality steel; indeed, future production of Mn ore in South Africa is forecast to grow by an average of 11.7% between 2012 and 2020, depending on the future development of the country’s rail and port capacity.

In 2013, Africa accounted for just 2% of total global Mn ore consumption (i.e. 356,400 mt). Only Egypt and South Africa consumed significant quantities of Mn ore (accounting for 8% and 92% of total regional consumption respectively).

It is estimated that 11,200 to 17,100 people are currently employed in the production of Mn ore in Africa - a quarter of global employment related to Mn ore production. A further 8,400 to 12,800 people are thought to be employed as a result of indirect and induced employment effects. It is worth noting that the social multiplier effect of mining is believed to be very high in Africa - in South Africa, there is a dependency ratio of about 10 to 1 which suggests that Mn mining generates significant positive impacts in the communities where it takes place.

Also of note is that the fatality and injury rates associated with Mn ore production in 2012 were generally lower than most other mined commodities in South Africa (see graphs on the next page).

In 2013, Africa produced 17% of the world’s HC FeMn, 9% of its Ref FeMn and 1% of its SiMn. South Africa was by far the greatest contributor, with Egypt producing a small quantity of HC FeMn (accounting for 6% of African production).

In total, production of Mn alloy in Africa is valued at US$ 892 million per year, bringing the total economic value (direct and indirect) of Mn alloy production in Africa to an estimated US$ 3.4 billion per year.

It is estimated that approximately 5,000 to 7,700 people are currently employed in the production of Mn alloy in Africa (taking into account direct, indirect and induced employment effects); 50% in Zaire and 48% in Namibia.
FATALITY RATES PER MILLION HOURS WORKED PER COMMODITY MINED – SOUTH AFRICA (2012)

INJURY RATES PER MILLION HOURS WORKED PER COMMODITY MINED – SOUTH AFRICA (2012)

Source: Ramontja (2013)
CASE STUDY: SOUTH AFRICA (ASSMANG LTD)

Assmang Ltd is an important producer of Mn ore and alloy in South Africa and provides a significant socio-economic contribution to local (and regional) communities. A key priority of the Organisation is to ensure the health and safety of its employees. During 2011/12, the Mn ore production facilities at the Black Rock complex achieved 1.7 million fatality-free shifts and received an award for the safest and most improved underground mine. Mn alloy production at Cato Ridge Works also achieved 1.2 million fatality-free shifts during 2011/12.

Assmang also contributes to community outreach programmes that include extending HIV/Aids testing and disease management into local communities, the development of a community health care facility and a sight restoration project. Assmang Ltd contributes to social development with measures designed to educate and train local populations. The management demographic of the Black Rock Mn complex currently consists of 57% Historically Disadvantaged South African’s (HDSA), thus exceeding the 2014 target of 40%. In 2011/12, Assmang Ltd spent 9.3% of payroll on staff training, which is almost double the Mining Charter 2014 target of 5% and the number of learnerships and bursaries awarded has also increased over recent years, with these focussing on artisanal skills (such as electricians, boilermakers etc.). In addition to the above CSR initiatives, the company invests in ‘TEACH South Africa’, which aims to improve educational opportunities for children attending the most disadvantaged schools.

Assmang promotes employee home ownership by providing housing subsidies, discounted interest rates for housing loans as well as developing affordable housing (using, where possible, local suppliers and thus significantly contributing to the local economy). Assmang Ltd’s CSR spend in 2011/12 was approx. US$ 8.3 million (an increase of 60% compared to the previous year) and included infrastructure (road) upgrades and supply of a water reticulation system to the Madibeng Community.

Source: (Assmang, 2012)

CASE STUDY: GABON (ERAMET - COMILOG)

Manganese production is now the second-largest economic activity in Gabon. Eramet’s subsidiary Comilog (which operates an ore and sinter production business in Gabon) employs around 3,000 workers in this field. In Moanda, Comilog contributes to both economic and social development - the Company has policies to educate and train local populations and also contributes to the provision and operation of health (hospitals, maternity services, etc.), education and housing facilities. In 2011, 25% of Comilog’s payroll/wage bill was used for social purposes.

Comilog provides 33 hospital beds and 19 rooms dedicated to maternity care within the Marcel-Abéké hospital in Moanda. The hospital has treated more than 40,000 workers and performs more than 680 operations per year (61% of which are not on employees of Comilog). Furthermore, the hospital has one of the best equipped surgical wards in Gabon. In 2011, a new pharmacy was opened as well as 20 new fully functioning rooms. In partnership with public authorities and the health authority of Gabon, Comilog leads the ‘Gamma’ program; an AIDS prevention campaign.

Comilog also contributes to the provision of housing and infrastructure in Moanda and has approximately 1,000 houses within the town. In 2012, Comilog began to build 100 new homes for its staff. In 2011, the company renovated 3 km of national road to serve the industrial zone and also installed two 5,000 litre water tanks to provide drinking water to the area around the railway station. The company also supports education and training by providing materials to the professional training centre, by welcoming 200 trainees (on average) per year and by providing finance to the Henri Sylvoz School in Moanda. Comilog is developing a new metallurgical complex in Moanda, including a mining and metallurgical school, creating 400 jobs. Since 2005, Eramet (Setrag) has managed the Transgabon railway used to transport Mn ore, wood and other goods as well as passengers across Gabon.

Sources: Comilog (2011a); Comilog (2011b); Eramet (2006); Eramet (2012)
Asia

In the Asian region, India and China are important countries, accounting for around 16% of global Mn ore reserves (in 4th and 5th position globally). In terms of Mn ore production, China accounts for over a third of wet Mn ore produced (all grades) and ~90% of global production of low grade ores. Despite these abundant resources, production in the Asian region has not been able to keep pace with present demand. Today, China and India are the two largest importers of Mn ore in the world, with China importing approximately 50% of its Mn ore requirements. South Korea is also a major importer, importing more than one million tonnes of Mn ore each year, mainly from South Africa, Australia and Gabon. Japan is also an important trading country in the Asian region.

The Asian region is also an important player in the production of value added products. In 2011, India was the largest exporter of SiMn in the world. SiMn is preferred in many mini steel mills because it contains the right proportion of Mn (50-74%) and silicon (14-28%) as well as low carbon content (1-2.5%). India is also the fourth largest producer of crude steel in the world and is forecast to become the second largest producer of crude steel in the world by 2015. In the coming years, India’s steel usage is projected to grow by between 7% and 10% per year on the back of urbanisation and surging infrastructure investment.

The 200 series stainless steels have also made an important contribution to society in Asia. In India, 200 series stainless steels, which have a high Mn content, have been used extensively since the 1980s; these stainless steels are not only cheaper than 300 series stainless steels (due to their lower nickel content) but they are also available domestically. The market for 200 series stainless steel has experienced dramatic growth in China (and South East Asia more generally) over the last few years. In 2012, China produced approximately 5 million tonnes of 200 series stainless steel, making it the world’s leading producer of the metal.414 India is the world’s second largest producer of 200 series stainless steel. Although the majority of 200 series stainless steel produced in India is consumed domestically, a significant proportion is also exported to China.415

200 series stainless steel is particularly well suited to the rapidly growing consumer and manufacturing sectors in Asia. The development of 200 series stainless steel in Asia permitted the production of cost effective stainless steel products which has helped to meet increasing demand created by the expanding Chinese and Indian economies and the desire to improve living standards. 200 series stainless steel is most often used in the production of tableware and cookware, as well as in electrical products. 200 series stainless steel has also helped to fuel growth in the use of stainless steel in India (now the tenth largest producer of stainless steel in the world) although per capita consumption of stainless steel in India is still lower than the global average (1.2 kg compared to 9.4 kg).416 This highlights the continued potential for growth in the stainless steel industry in India. With the development of rural markets, consumption and application of 200 series stainless steel is expected to increase in the future.1

Mn is also a major source of employment in the Asian region. Over 50% of all workers employed in the production of Mn ore and alloys are based in China. Most of these workers are employed in small mines producing Mn ore. It has been reported that there are over 500 producers of 200-series stainless steel in China, the majority of which are small, private enterprises. In India, MOIL is a major employer in certain regions, accounting for over 6,500 workers overall.
America (North and South)

In 2013, the Americas produced 5% of the world’s Mn ore with Brazil and Mexico contributing 4% and 1% to global production respectively.

The total economic value (direct and indirect) of Mn ore production in the Americas is estimated at US$ 1.5 billion to US$ 1.6 billion per year, which equates to 7% of the global total. Trade data indicate that around 60% of the Mn ore exported from Brazil is imported by China, with significant quantities of Brazilian Mn ore also exported to France and Norway. The majority of Mn ore mined in Mexico is consumed within the country, however, some exports to Europe (notably Spain), the United States and China are recorded.

Mining is an important contributor to many Latin American economies and its value, as a proportion of GDP, has grown significantly over the course of the last decade. In 2001, mining accounted for 1.3% and 6.1% of GDP for Brazil and Mexico respectively. However, by 2011 mining accounted for 3.5% of Brazil’s GDP and 9.9% of Mexico’s GDP. Local economic and social benefits of mining can be even more significant. For example, between 1990 and 2006 in the southeast of the state of Pará (Brazil), the share of GDP attributable to seven municipalities that were directly impacted by Vale’s mining operations rose from 8.4% to 15.2% of Pará State GDP.

It is estimated that approximately 2,300 to 3,200 people are currently employed in the production of Mn ore in Brazil and 700 to 1,000 people in Mexico (considering direct, indirect and induced employment). Thus, the production of Mn ore creates 2,900 to 4,200 jobs in the Americas as a whole (difference due to rounding) and accounts for 4% of global employment related to Mn ore production.

It is apparent that the wages paid to workers employed in the production of Mn ore in the Americas, particularly in Brazil, are relatively high compared to wages paid in some other countries and regions. In 2013, an estimated US$ 99 million to US$ 139 million was paid in wages to those directly involved in Mn ore production in Brazil.

Brazil is therefore ranked fifth in terms of total wages paid (behind China, Australia, South Africa and Gabon). This is particularly significant given that Brazil is ranked seventh in terms of countries with the largest Mn ore workforce (considering direct employment only), which serves to highlight the importance of Mn ore production to the Brazilian economy and to those people, businesses and wider communities that are reliant on the income generated from employment within this sector.

MN ORE IN BRAZIL

Brazil is considered to hold 9.5% of the world’s Mn ore reserves and 15% of the world’s economically demonstrated resources of Mn ore. Estimates suggest that Brazil’s Mn ore production could increase by 15% by 2016 compared to 2011.

Sources: USGS (2014); Geoscience Australia (2012); IBRAM (2013)

In 2013, the Americas as a whole produced 7% of the world’s Ref FeMn, 3% of its SiMn and 2% of its HC FeMn. Brazil produced the greatest quantities of all Mn alloy types, accounting for 36% of total regional Mn alloy production. The total economic value (direct and indirect) of Mn alloy production in the Americas is estimated at US$ 2.5 billion per year (equivalent to 2% of the global economic value gained from production in 2013). It is estimated that approximately 6,300 to 8,200 people are employed in the production of Mn alloys in the Americas (taking account of direct, indirect and induced employment). The vast majority of these jobs (4,800 to 6,100) are located in Brazil, with a smaller number in Mexico, the United States, Venezuela and Argentina. In total, US$ 23 million to US$ 32 million was paid in wages to those employed directly in the production of Mn alloy in the Americas in 2013.
Europe

The European region (which includes Europe and the CIS) is an important hub for Mn alloy production and trade; approximately 13% of the world’s total Mn alloy is produced in this region.

The total economic value (direct and indirect) of Mn-related activities in the European region is estimated at approximately US$ 12 billion per year. In terms of Gross Value Added, the production of Mn alloy generates an estimated US$ 86 million each year in the EU-27 alone.

It is estimated that between 5,100 to 7,500 people are directly employed in this sector in Europe, with a further 11,300 to 16,400 people employed through indirect and induced employment effects.

Employees involved in the production of Mn alloy in Europe receive relatively high wages compared to their counterparts in other regions. In total, US$ 161 million to US$ 244 million was paid in wages to those employed directly in the production of Mn ore and alloys in 2013.

While the production of Mn alloys is not resource intensive, it is a highly specialized and technical process. As a consequence, the Mn industry has contributed to the creation of high-value economic clusters across the European region, as illustrated in the three case studies below.

CASE STUDY: FRANCE (GLENCORE MANGANESE FRANCE)

Dunkerque is an industrial port city, located in the Nord-Pas-de-Calais (northern France), that benefits greatly from the Mn value chain. Glencore’s Manganese France plant, located in Dunkerque, produces a combination of HC FeMn, FeMn slag and Mn sinter, with annual production totalling 610,000 tonnes (2010). As well as directly employing around 90 workers, Glencore’s Mn operations also benefit other businesses in the north east of France including, for example, IT and legal service providers located in Lille. The main materials used in the production of Mn alloys (Mn ore and coke) are imported from abroad (approximately 700,000 tonnes/year) and this generates jobs at Dunkerque port and in the maintenance of the nearby road and rail network. Other materials that are key to the production process, such as fluxes (limestone), aggregates (sand), sulphuric acid and industrial gas (nitrogen, oxygen, propane etc.), are obtained from local suppliers. Not only does this create local jobs, it also enables the plant to increase reactivity in response to material demand. In total, the Company spends €11 million per year (US$ 14.6 million) on goods and services from local suppliers.

A significant proportion of Glencore’s product is sold to the big European steel producers, with this including ArcelorMittal’s steel plant in Dunkerque (which employs around 3,500 staff). ArcelorMittal own several steel production sites near to Dunkerque, including sites at Florange, Desvres, Mardyck, Montataire and Mouzon. Although business decisions between alloy suppliers and steel producers are generally undertaken at group or regional level (rather than locally), there are likely to be some benefits of co-location for these organisations (e.g. reduced transportation costs, increased reactivity and having access to a specialized labour pool).

As a result of these activities, as well as the strategic location of Dunkerque, the production sites of many steel processors are located in the region. Examples include: Ascometal (supplier of special steels), GTS Industries (world leader in steel plates and sheets), Europipe (supplier of tubular foundations) and CMP (tank and pressure vessel maker). Many companies in downstream industrial sectors (including the automotive sector, construction sector, electronics and mechanical and electrical engineering sectors) are also located within close geographical proximity of the Nord-Pas-de-Calais. These activities have also benefited the city of Dunkerque, through job creation and economic prosperity. Actors within the Mn value chain have quick and easy access to each other and to customers in their national markets, as well as those in the neighbouring countries and the rest of Europe.
CASE STUDY: SLOVAKIA (OFZ)

OFZ a. s., located in Slovakia, is the largest central European manufacturer of ferroalloys, offering its customers a range of Mn-based products (including HC FeMn and FeSiMn). The Company is one of the most important suppliers of ferroalloy in the Central European region and is located centrally in relation to the traditional metallurgical centres of Slovakia, Poland, Czech Republic, Hungary and Austria, where the vast majority of its production is sold. The company supplies Mn alloys to two local steelworks (U.S. Steel Kosice s.r.o in Slovakia and Trinec Iron and Steelworks (Třinecké Železárny) in the Czech Republic) located approximately 200km east and 100km northwest of the OFZ a.s. facilities respectively. Třinecké Železárny produces approximately 2.5 million tonnes of steel annually and employs approximately 6,000 people. Around half the steel products produced by Třinecké Železárny are sold domestically with the remaining 50% shipped to more than 50 countries around the world (although the largest volumes of products are exported to neighbouring countries). The steelworks operated by U.S. Steel Kosice s.r.o., is the largest private employer in eastern Slovakia with a workforce of more than 13,000 people. The supply of Mn alloys from OFZ a.s. is critical to the operations undertaken at these plants.

OFZ’s plant in Istebné (Slovakia) is an important employer in the region; in 2013, the Company employed 200 people to manufacture its Mn-based products and made employee contributions (for Mn) totalling approximately €830,000 (US$ 1.1 million). A key priority of the organization is to ensure the health and safety of its employees. To this end the company has introduced a number of measures to effectively monitor employee health, including the presence of healthcare workers at hazardous workplaces. OFZ a. s. also provides employer health reinsurance, as required under the Slovakian healthcare system and works in cooperation with the local hospital to undertake health projects/training for staff.

Sources: OFZ a. s. (no date); OFZ a. s. (2011); OFZ a. s. (2014)
Oceania

Australia is the only country within the Oceania region to produce Mn ore. It is considered to hold 17% of the world’s Mn ore reserves, ranked third behind South Africa (26%) and Ukraine (25%). In 2013, Australia produced 13% of the world’s Mn ore (7.3 million mt) and was the world’s largest producer of high grade Mn ore (accounting for 36% of global production). This is important given that high quality steels can only be made using high grade ore.

Mining is one of the most important sectors of the Australian economy and typically accounts for around 5% of the country’s GDP. The mining sector’s share of GDP is forecast to increase to 7.6% by 2017. However, this figure would increase significantly if downstream mining related activities in industries such as manufacturing, construction, transport and storage, property and business services and electricity and gas were included.

Taking into account direct and indirect effects, it is estimated that the production of Mn ore contributes around US$ 3.4 billion to US$ 3.7 billion to the region’s economy each year, which is equivalent to around 16% of the global economic value gained from Mn ore production.

It is estimated that 6,800 to 9,300 people are currently employed in the production of Mn ore in Australia (considered direct, indirect and induced employment) – approximately 7% to 9% of global Mn ore employment.

It is widely reported that the wages paid to mine workers in Australia are high compared to those in other nations and sectors (as indicated in the table). This is important given that these workers are likely to have a higher level of disposable income, which can support jobs and economic growth in other sectors of the Australian economy. In 2013, an estimated US$ 529 million to US$ 727 million was paid in wages to those employed directly in the production of Mn ore in Australia.

As is the case with Mn ore production, Australia is the only country within Oceania to produce significant quantities of Mn alloy. In 2013, Australia produced ~3% of the world’s HC FeMn. SiMn and Ref FeMn are not produced in the region.

It is estimated that the production of Mn alloy contributes some US$ 572 million to the region’s economy each year (direct and indirect economic value), equivalent to 0.4% of the global economic value gained from Mn alloy production.

It is estimated that 100 to 200 people are directly employed in the production of Mn alloy in Australia, with a further 400 to 600 jobs generated in the supply chain. Total employment relating to the production of Mn alloys in Australia is estimated at 500 to 800 people in 2013, with around US$ 7.6 million to US$ 11.4 million paid in wages to employees (direct employment only).

In a global context, Oceania is a relatively small consumer of Mn alloys accounting for less than 1% of global apparent consumption in 2013.
7. Conclusion

Manganese plays a very important role in the global economy and various industry sectors, products and/or applications are heavily dependent on its production and use.

In countries such as Australia, China, Gabon, South Africa and Brazil, the production of Mn ore (and associated capital and operating expenditures) makes a significant contribution to the national economy (e.g. in terms of GDP). Overall, the total economic contribution of Mn ore production (globally) is estimated at US$ 21 billion to US$ 23 billion per year. There are also important social benefits from such operations reflected in employment figures. Between US$ 2,700 million and $ 4,600 million per annum is paid in wages to those employed directly in the production of Mn ore, with workers in China, Australia and South Africa accounting for the majority (~80%) of wages paid.

The global economy also benefits from Mn alloy production and processing, with global production of Mn alloy valued at around US$ 23 billion per year (of which, China contributes approximately US$ 14.4 billion). Large contributions to the global economy are also made by Mn alloy producers in India (US$ 2.5 billion), South Africa (US$ 0.9 billion) and Ukraine (US$ 0.8 billion). Taking into account downstream effects along the supply chain, the value of Mn alloy production worldwide is estimated at around US$ 146 billion per year.

Mn is a critical raw material input and process additive for the steel industry and the continued growth of this industry relies on Mn. Of particular importance are carbon steels (worth an estimated US$ 839 billion to US$ 1,259 billion in 2013) and construction/engineering steels (worth an estimated US$ 29 billion to US$ 43 billion). Recent innovations in the steel sector, such as in TWIP steels, have significant potential for use in future automotive applications, mainly due to their potential to increase the crashworthiness of vehicles (enhancing passenger safety) and reduce vehicle weight (reducing fuel consumption and emissions). Mn is also critical in the production of low-cost 200-series stainless steels; a market which could grow to reach around US$ 18 billion to US$ 35 billion in value by 2020.

Besides steel, Mn has a number of other downstream uses of social and economic significance. For example, Mn is a critical element in the manufacture of batteries (e.g. the lithium manganese spinel battery) that could offer the opportunity for the wide-scale introduction of battery electric vehicles. In the EU alone, this could lead to total CO2 emissions reductions worth an estimated US$ 723 million to US$ 8,343 million by 2020. An estimated 423,000 to 662,000 life years could be gained across the EU population by 2020 due to the associated reduction in PM10 emissions. Mn is also the main alloying element in the production of 3XXX series aluminium alloys used in beverage cans; a market estimated to grow to over US$ 11 billion by 2020.

Socio-economic analysis provides the tools and methods for estimating the social and economic benefits of an industry to a community, ranging from a single neighbourhood to the global community as a whole. While some of these benefits have been quantified in this first report, there are other benefits which are equally important but which have not been fully quantified at this stage. For instance, in Europe, the Mn industry has contributed to the creation of high-value economic clusters across the region. Mn is also an essential micronutrient needed for plant growth and plays a vital role in agricultural production. It is also critical for maintaining the health and well-being of the human body and is used in food supplements and medicines. It is hoped that this report will assist in ensuring that some of the economic benefits that have so-far not been well understood are better recognised by governments and other key stakeholders. It will also increase the appreciation of how the production and use of Mn is helping to meet society’s needs in a sustainable way.
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MANGANESE

The Global Picture - A Socio Economic Assessment

Manganese (Mn) plays a very important role in the global economy, even if the dependence of various industry sectors, products and/or applications on Mn is not always recognised. Mn is a critical raw material input for the steel industry but also has a number of other important downstream uses which make a significant economic and social contribution to national and regional economies where these activities take place.

This report presents the results of the first global study on the socio-economic importance of Mn, undertaken by Risk & Policy Analysts Ltd (UK) for the IMnI.

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.

Risk & Policy Analysts Limited (RPA) is an independent consultancy providing expert advice to both public and private sector clients around the world. Established in 1990, RPA’s team of multi-disciplinary experts offer a broad range of high quality services including policy and project appraisal, regulatory and business impact assessment, environmental policy and management, flood risk assessment and management, cost and risk-benefit analysis, environmental economics, socio-economic analysis and hazard and risk studies.

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