Towards Sustainable Steelmaking – an LCA perspective

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Life Cycle Analysis studies have been undertaken for a range of steelmaking routes, including conventional and emerging technologies. It has been shown that the new iron and steelmaking technologies based on coal can match greenhouse gas emissions (GGE) from gas based reduction processes when credits for slag use in cement, and for electricity from offgas, are taken into account.

There is a range of improvement opportunities that offer the potential for major further reductions in GGE – a 50% reduction is a realistic target over time. From a GGE perspective, there are clearly benefits in integrating steel production with electricity generation and cement production; this is a good example of an industrial ecology opportunity.

To support the move towards sustainability, BHP Billiton has used its LCA capability to develop two software tools to enable architects/building industry and school students to develop an understanding of energy and GGE in building systems and lifestyle issues, respectively.

While GGE is now the major concern, it must also be recognised that other impacts of the steel production chain, eg those related to fresh water, will increasingly need to be taken into account.

KEY WORDS: sustainability; life cycle analysis; ironmaking; steelmaking; greenhouse gas emissions;

1. Background

While steel is considered to be an energy intensive material, with considerable greenhouse gas emissions (GGE) associated with its manufacture (worldwide in excess of 1.5 billion tonnes of CO\textsubscript{2}), it should be recognised that there have been steady improvements - change is a constant feature of the steel industry.

This is best illustrated by taking an historical perspective. In Fig. 1, the greenhouse gas emissions per tonne of steel are shown over the last two millennia. From the Middle Ages, major changes in technology and reductant/energy source occurred, with GGE dropping from around 1,000 down to just over 2 t CO\textsubscript{2}-e/t steel today.

Further reductions in GGE for iron and steelmaking can be achieved through new technology, use of by-products, process integration and renewable energy sources. The magnitude of these changes, together with the effect of alternative fossil fuels, can be defined by carrying out life cycle analyses. This has important implications for developing CO\textsubscript{2} reduction strategies, both for existing, and emerging, iron and steelmaking technologies.

The present paper gives a summary of results for LCA studies for a range of steelmaking routes, including conventional and emerging technologies. Although consideration of the whole value chain is essential for minimising the overall GGE for steel, the focus of the paper is on the processes from raw materials in the ground through to cast steel.

Prior to presenting the results, some brief comments are provided below on Life Cycle Analysis.

Fig. 1 GGE per tonne of steel

It should be also kept in mind that similar changes are occurring in support industries, particularly electricity generation which will underpin the growth of the EAF process step associated with many of the emerging iron and steelmaking technologies. The changes in GGE for coal-based electricity generation are shown in Fig. 2, from the commencement of commercial generation, through the present day, to emerging clean coal technologies.

Fig. 2 GGE per MWh of electricity
2. Life Cycle Analysis

Life cycle analysis (LCA) and life cycle assessment are internationally accepted techniques for measuring the environmental impacts over the life cycle of a defined system. Life cycle assessment is currently being standardised through a set of guidelines by the International Standards Organisation as part of the ISO 14000 series, and represents a specific application of the older, and more generic, type of systems modelling called life cycle analysis.

The methodology used in conducting this LCA is based on the 4-stage approach recommended in the ISO guidelines. It should be noted that, while the present study conforms to the ISO LCA guidelines in terms of methodology, transparency, etc, there are several technical differences due to the nature of the "product" life cycle being studied. ISO life cycle assessment is confined to "cradle-to-grave" analysis of the environmental impacts of a product for a specified function, e.g. the production, use and recycling/dumping to landfill of beverage containers. As steel is the focus of the present study, several aspects of the prescribed ISO definition of life cycle assessment do not apply – this is a "cradle-to-gate" analysis.

The basis for comparison in the present study is the system to produce 1 tonne of cast steel - the functional unit. Since the functional unit is 1 t of cast steel, the case studies included all processes from the extraction of resources through liquid steel production, treatment in a ladle metallurgy furnace, and finally casting in a slab caster. Except where noted, all hypothetical case studies were assumed to be located near Port Kembla (not meant to imply that these plants are proposed for Port Kembla).

For the production and use of fossil fuels, there are a range of environmental issues to be considered – however, this paper only reports greenhouse gas emissions.

System boundaries included the provision of 3rd party goods and services, waste management and the production of by-products. Plant construction was excluded from the analysis, as the effect would be insignificant (i.e. less than 1% overall GGE).

While a broad range of current and future technologies was considered", only key summary information is provided in the following sections.

3. Displacement Credits

The defined system boundaries required consideration of by-products – especially interworks gas and slags. When a by-product from one process route is used to replace some other product, the environmental impacts for the main product can be credited for the overall saving in environmental impacts. LCA can identify and quantify these credits.

It is important to note that it is necessary that:

- the credits are allocated to the previous step in the manufacturing chain.

For this paper, the displacement credits of importance are:

- the use of slag to replace cement; the ironmaking step is then credited with the GGE normally attributed to cement production, and
- the use of offgases for electricity production, replacing electricity from the grid; the magnitude of the GGE credits is dependent on the GGE for grid electricity (and, in particular, the energy source and technology used for generation).

As an example, the GGE credit for slag as a cement replacement is discussed below, and shown schematically in Fig. 3.

For each 3.5 t of iron, 1 t of blast furnace slag is produced. This slag (if cooled by granulation) can be ground to replace 1 t of cement. This displaces the mining of 2 t of limestone and shale, calcination and clinker grinding, processes which normally emit around 1,020 kg CO2-e/t cement. The displacement credit is therefore 1,020 kg less 60 kg emitted from grinding the granulated blast furnace slag; i.e. approximately 1 t CO2-e/t of slag. For the purposes of this study, it is assumed that slag is functionally equivalent to Portland cement, at up to 50% substitution.

It should be noted that there is considerable variance in the reported GGE for Portland cement production due to technology, fuel type and the amount of other cementitious materials blended with the ground clinker. For this paper, data related to Australian average production for 1999 have been used.

The GGE credit for electricity produced from offgas has been calculated to be 950 kg CO2-e/MWh, using the coal based NSW grid as the base case.

The magnitudes of these credits for the various processes are shown graphically in the next section.

4. LCA results

LCA case studies were based on a range of process routes covering a conventional as well as emerging technologies, and the results are shown in Table 1 and Fig. 3.
Fig. 4. The sources of data, and assumptions made, are given in reference 1.

The basis for comparison is the conventional integrated route, which comprises coke ovens, sinter plant, blast furnace, BOS, slab caster and integrated electricity and oxygen production. The system boundaries for the other case studies, which include four emerging technologies (ie not commercialised) reflect a range of typical plant configurations, which include cogeneration (either steam or combined cycle gas turbines, depending on the properties of the offgases) of electricity using excess offgas.

Table 1 GGE (t CO2-e per tonne of cast steel)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Gross</th>
<th>Slag credit</th>
<th>Electricity credit</th>
<th>Net</th>
</tr>
</thead>
<tbody>
<tr>
<td>BF-BOS</td>
<td>2.74</td>
<td>0.26</td>
<td>0.32</td>
<td>2.16</td>
</tr>
<tr>
<td>COREX</td>
<td>4.14</td>
<td>0.44</td>
<td>1.98</td>
<td>1.72</td>
</tr>
<tr>
<td>O2 BF-BOS</td>
<td>2.94</td>
<td>0.24</td>
<td>0.97</td>
<td>1.73</td>
</tr>
<tr>
<td>Fastmelt</td>
<td>2.46</td>
<td>0.31</td>
<td>0.00</td>
<td>2.15</td>
</tr>
<tr>
<td>ITmk3</td>
<td>1.81</td>
<td>0.00</td>
<td>0.00</td>
<td>1.81</td>
</tr>
<tr>
<td>Hismelt</td>
<td>2.28</td>
<td>0.00</td>
<td>0.43</td>
<td>1.85</td>
</tr>
<tr>
<td>Tecnored</td>
<td>2.39</td>
<td>0.34</td>
<td>0.51</td>
<td>1.54</td>
</tr>
<tr>
<td>Midrex</td>
<td>1.96</td>
<td>0.00</td>
<td>0.00</td>
<td>1.96</td>
</tr>
<tr>
<td>Finmet-coal</td>
<td>1.95</td>
<td>0.00</td>
<td>0.00</td>
<td>1.95</td>
</tr>
<tr>
<td>Finmet-NG</td>
<td>1.42</td>
<td>0.00</td>
<td>0.00</td>
<td>1.42</td>
</tr>
</tbody>
</table>

Any excess electricity has been credited as displacing NSW grid electricity. This excess is small for most of the technologies, but can reduce the GGEs from COREX-BOS by up to 50%. Excess electricity is generated in most of the processes because the system boundaries omit the downstream consumers of electricity (reheat furnaces, mills, etc) present in most steelworks (ie the rest of the steelworks is not being considered). The advantages of integrating coal-based iron and electricity generation are significant, especially for GGE. In the present study, COREX-BOS compares favourably with the gas-based routes. This also applies to the (hypothetical) O2-BF route.

The new and emerging coal-based technologies can match or exceed the performance of gas based technologies – particularly ITmk3 and Tecnored. While these technologies are in an early stage of development and have small unit capacity, they should offer a practical approach to reducing GGE - incremental capacity and backwards integration of EAFs.

Despite the fundamental GGE advantage of using gas (both for reductant and electricity generation), the study has shown that advantages are diminished by the GGE from gas production and distribution, and the geographic difficulty in integrating DRI production with steelmaking.

For technologies that require a melter and/or an EAF (Fastmelt, ITmk3, Midrex, Finmet), further significant reductions in GGE can be achieved with changes in GGE from electricity generation. As the efficiency of fossil fuel conversion to electricity increases, the GGE associated with electricity use will decrease.

For coal based generation, the implementation of higher steam temperatures (up to 700°C) in the next 10-15 years will reduce the GGE by 0.15 t CO2-e/t cast steel, for those process routes that use coal-based electricity for steelmaking. It should also be noted that reductions in the GGE associated with electricity generation will also reduce the electricity credits shown in Table 1.

5. Renewables

While the use of renewable energy sources (such as photovoltaics, solar thermal, wind, biomass and hydro) can reduce the GGEs associated with electricity generation (and thereby reduce the GGEs for steel production when electric melters/EAFs are involved), there is also scope to use renewables directly in the production process, as charcoal from biomass.

Significant tonnages of iron have been produced in Brazil using eucalyptus wood, although the tonnage has been decreasing and the technology requires improvement.

This topic was the subject of a recent joint NSW State Forests - BHP Billiton project, which evaluated the suitability of a range of tree species for charcoal production. Plant scale trials were undertaken to assess the performance of charcoal in EAF steel production.
At present in Australia, it is only economic to use the charcoal for recarburisation (a 10-20,000 t market). In a carbon constrained world, with incentives for use of renewable energy, larger scale use in the steel industry may be feasible. In Australia, this would require at least a two-fold reduction in the cost of delivered green wood, development of larger scale carbonisation technology, and capturing credits for other environmental and social benefits (e.g. salinity amelioration, watershed protection, employment in regional areas).

While charcoal is weak compared to coke, it would be suitable as a blast furnace injectant, and could be used in many of the emerging ironmaking technologies where strength is not of prime concern.

To evaluate the effect of using charcoal as a blast furnace injectant at Port Kembla steelworks, an LCA was carried out, using charcoal to replace all injectant gas as well as 20% of the coke. The results are given in Table 2.

<table>
<thead>
<tr>
<th>Gross GGE</th>
<th>20% charcoal</th>
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<tbody>
<tr>
<td>Sequestration</td>
<td>2.16</td>
</tr>
<tr>
<td>By-products credit</td>
<td>-0.50</td>
</tr>
<tr>
<td>Net GGE</td>
<td>2.98</td>
</tr>
</tbody>
</table>

While the gross GGE is higher when charcoal is used (due to emissions from forestry and charcoal production), and the displacement credits are lower (less slag produced), the net GGE is substantially lower due to forest sequestration. This is equivalent to a saving of 3.0 Tg of CO₂-e at Port Kembla and would require an annual wood flow of around 4 million cubic metres.

6. Improvement opportunities

There are a number of opportunities to improve GGE for steel production, which can be adopted either individually or in combination. These are shown graphically in Fig. 5. It should be noted that the reduction levels indicated are not cumulative.

BF slag utilisation for cement varies widely around the world, with Japan, the Netherlands and Germany having high rates of utilisation; worldwide only ~25% of BF slag is used for cement with the majority being used for aggregate (negligible GGE credits). In the longer term, with additional R&D, there may be opportunities to use BOS slag in cement production.

Methane emissions from coal mining (CBM/MVA) can be substantial, with significant variations geographically. It has been estimated that the total emissions worldwide are 30 Tg annually, of which only 5% are used¹⁶. From a life cycle perspective, the steel industry is impacted by emissions associated with coal used directly as a source of heat and reductant, as well as by coal used as an energy source in electricity generation.

The magnitude of the improvement opportunity shown in Figure 5 applies to the Port Kembla integrated steelworks. The value will be higher or lower in other locations, depending on the methane content of the particular coal, and measures taken to use the methane as an energy source, or to convert it to the lower greenhouse impact gas, CO₂. In Australia, two underground mines (Appin/Tower) utilise pre-drainage methane to generate 94 MW. The utilisation of methane in mine ventilation air (approximately 50% of the total coal seam methane) has been slower to develop. A 0.3 MW pilot scale non-catalytic oxidiser is under evaluation at Appin colliery, supported by the Australian Coal Association.

The ability to realise the biomass/charcoal opportunity will be dependent on geographic proximity of the biomass source to the steel plant, and the cost of alternative sources of energy and reductant. The forthcoming conference in Brazil (1st International Conference on Biomass for Metal Production and Electricity Generation) is an indication of the developing interest in the large scale use of biomass.

Scrap steel recovery and use is increasing, and a significant increase will require a higher level of interaction between the steel industry and its customers, to increase the ease of recovery of steel, post consumption, and its quality. In industry sectors using steel, there are many sustainability driven initiatives which will facilitate the transition.

As shown earlier, there is considerable scope for GGE reduction using new iron and steelmaking technologies, whether by more intensive blast furnace operation (oxygen rich blast), or by reduction of coal/ore pellets in rotary hearth or shaft furnaces.
7. Engaging the customer and consumer

The development of sustainable steel requires an entire value chain approach. As part of this, an important issue for the steel industry is engaging the customer and the consumer. BHP Billiton has taken two initiatives related to this, by developing:

- a user friendly LCA decision support tool for architects (LISA), and
- an LCA model which enables school students to estimate the environmental impacts of their home and family (CHAPPY).

LISA (LCA In Sustainable Architecture) was developed in response to requests by architects and the construction industry for a simplified LCA tool to assist the design and construction of more sustainable buildings. It contains interactive LCA case studies and is freeware available from www.lisa.au.com, or on CDROM from the Centre for Sustainable Technology at the University of Newcastle.

LISA is designed to support identification of key environmental issues in construction and understand materials choices in a whole-of-life context.

CHAPPY (Children Helping Achieve Planet Preservation with You) was developed as a community contribution, in conjunction with local schools. It enables the student to interactively estimate the effects of the many aspects of their family's home and lifestyle; including recycling of household waste, on issues such as energy consumption and GGE. It is available as freeware from www.chappy.au.com.

8. Conclusions

The use of cradle-to-gate life cycle analysis has enabled the GGE impacts of alternative process technologies, and fuel and reductant types, to be determined. It has been shown that the new iron and steelmaking technologies based on coal can match GGE from gas based reduction processes when credits are taken into account. For those processes using a melter and/or EAF, further reductions in GGE can be achieved through improvements in electricity generation.

There is a range of improvement opportunities which offer the potential for major further reductions in GGE – a 50% reduction is a realistic target over time. While some of these improvements can impose additional costs, others (eg BF slag use for cement) can be achieved with economic benefit to the steel producer.

From a greenhouse perspective, there are clearly benefits in integrating steel production with electricity generation and cement production; this is a good example of an industrial ecology opportunity.

As the steel industry moves towards sustainability it will be important to develop links with customers and consumers to educate, and to develop product stewardship practices. BHP Billiton has used its LCA capability to develop two software tools to enable architects/building industry and school students to develop an understanding of energy and GGE in building systems and lifestyle issues, respectively.

While GGE is now the major concern, it must also be recognised that other impacts of the steel production chain, eg those related to fresh water, will increasingly need to be taken into account.

REFERENCES

1) LCA of steel and electricity production in Australia, ACARP Report 9058 (2001); see www.ciss.com.au

2) Large scale use of forest biomass for iron and steelmaking, SERDF (2001). see www.sustainabletechnology.com.au