

## Methodology for Developing a Strategic Road Map for Reducing Energy Consumption and CO<sub>2</sub> Emissions for Iron and Steel Plants

Sunil Kumar<sup>1</sup> and Yakov Gordon<sup>1</sup>

<sup>1</sup>Hatch Ltd.  
2800 Speakman Drive, Mississauga, Ontario, Canada L5K 2R7  
Phone:(905)855-7600  
Email: sunil.kumar@hatch.com; iakov.gordon@hatch.com

### INTRODUCTION

To address climate-change, the steel industry is increasingly focusing on the reduction of energy consumption and CO<sub>2</sub> (Green-House Gas) emissions. A methodology that incorporates a sound technical element to the assessment of improvement opportunities, was developed to help steel companies create a strategic roadmap for reducing CO<sub>2</sub> emissions and energy consumption. The methodology is bottom-up and is applied in fair detail to the specific operations of the iron and steel industry. The methodology was adopted at several operating plants (integrated plants, mini mills and others) to generate Levelized CO<sub>2</sub> Abatement Cost Curves (LCC) and Levelized Energy Abatement Cost Curve (LECC) which formed the basis of the selection of improvement projects for strategic roadmap development. This paper describes the key points of the methodology as developed and implemented at several plant sites to identify and quantify energy savings and CO<sub>2</sub> emissions abatement within the iron and steel plants for the short term (1-5 years), the medium term (5-10 years) and the long term (>10 years).

### BACKGROUND

Climate change is expected to present new challenges and risks (and opportunities) to the iron and steel industry in terms of ensuring a sustainable business. The global iron and steel industry needs a robust techno-economic platform to prepare for formulating energy consumption / CO<sub>2</sub> emission reduction targets as part of the emerging climate change regulations.

To address this need for the steel industry, a novel methodology was developed to help focus on understanding and mitigating climate change risks, particularly those dealing with CO<sub>2</sub> emissions.

The methodology is based on a formalized approach adopted for identifying, quantifying, and ranking the CO<sub>2</sub> emissions (and energy consumption) reduction opportunities in a steel plant, so that a holistic understanding of the magnitude and costs associated with the various reduction scenarios can be achieved.

The methodology has been successfully applied to generate the Levelized CO<sub>2</sub> Abatement Cost Curve (LCC) and Levelized Energy Abatement Cost Curve (LECC) and develop the strategic roadmap for reducing energy consumption and CO<sub>2</sub> emissions for several operating plants with different process configurations: integrated steel plant (with BF / BOF), scrap based EAF mini mills, mini mills with charcoal-based mini blast furnaces, plantation and charcoal production, and iron ore mining operation.

An overview of the methodology is described in this paper with some sample results (outputs) related to quantifying and qualifying the energy savings and CO<sub>2</sub> emissions abatement within the steel industry.

#### Overview of Methodology

The methodology that incorporates a sound technical element to the assessment of energy and CO<sub>2</sub> emission reduction opportunities, was designed. In contrast to traditional economic modeling, the methodology is bottom-up, and is applied in much more detail to the specific operations of the iron and steel industry. The program to develop the roadmap for reducing energy consumption and CO<sub>2</sub> emission is composed of several steps which are covered in two phases.

##### Phase 1

- Establish baseline period (reference period) and collect data for this period

- For the baseline period, create inventory of all emission sources and sinks at site / business boundary level as well as disaggregation of inventory to operating unit level – for the baseline period
- Evaluate preliminary energy and mass balance for each process unit and for the entire steel plant
- Identify the key performance indicators (KPI's) for each process unit and conduct benchmarking:
  - Internal benchmarking – for each KPI, estimate figures for best month, average of best 3 months, and average of best 3 consecutive months
  - External benchmarking - identify best practice benchmarks and the best-in-similar-class benchmarks
  - Normalization of units to benchmark conditions and estimation of normalized benchmark figures
- Based on the outcome of the benchmarking exercise (external and internal), identify gaps (with respect to benchmark plant) and set improvement targets for the KPIs
- Identify improvement opportunities and actions (“improvement projects”) required to bridge the gap relative to the set targets (best practice performance levels) for the various KPIs
- Establish initial (preliminary) list of improvement projects for reducing energy consumption and CO<sub>2</sub> emissions – the projects could be operational improvements (with no or limited capital investment) or related to implementation of available technologies (with capital investment)

## Phase 2

- For each improvement project, estimate the magnitude of abatement of energy consumption and CO<sub>2</sub> emissions and evaluate the opportunities, eliminating any competing alternatives / suboptimal scenarios
- Apply “risk filter” to identify and eliminate any unacceptable (not feasible) opportunities -classification of projects under low-risk, medium risk, high risk (technology risks, implementation risks and other risks etc.)
- For the shortlisted projects, estimate operational cost (OPEX) impact, capital investment requirements (CAPEX) if any, and the time required for implementation of the opportunities (projects)
- Conduct financial analysis of each improvement project and on this basis, generate the LCC and LECC charts for evaluating the projects with regards to cost impact per ton of abatement of CO<sub>2</sub> emissions
- Select the feasible improvement projects for inclusion in the roadmap for reducing energy consumption and CO<sub>2</sub> emissions
- Define the sequence of implementation of the feasible improvement projects
- Develop roadmap for reducing energy consumption and CO<sub>2</sub> emissions, showing the short-term (1-5 years), medium-term (5-10 years) and long-term projects (>10 years); and estimate the extent of reduction of energy consumption and CO<sub>2</sub> emissions possible at each step of the roadmap.

## DATA QUALITY AND ACCURACY

An important point to note here is that data quality is a critical requirement for identifying improvement opportunities. As modern steelworks operate close to best practice or theoretical limits, practical brownfield improvements are expected to be marginal (depends on the efficiency level). In a previous review conducted for several iron and steel operations, the range of accuracy was identified as  $\pm 3\%$  to  $\pm 9\%$ , whereas  $\pm 5\%$  is essential to ensure that quality decisions can be made <sup>[1]</sup>.

The data capture, collection and reporting systems need to be frequently audited, in accordance with the prevailing standard.

The following areas need to be audited to ensure accuracy of the specific KPI's:

- Metering of fuels and electricity
- Weighing of solid fuels, reductants, and fluxes
- Weighing of products at each unit
- Systems for collecting the data from the field, transferring it to the reports and storing it.

Since comprehensive emissions management systems are relatively new for steel companies, it is usual to find a high degree of non-conformance in the data collection, analysis, storage, and reporting – clearly, this requires attention to implement system improvements.

Examples of typical non-conformances noted in steel plants that can have significant impact on the estimation of CO<sub>2</sub> emissions and energy consumption figures<sup>[1]</sup>:

- Weigh-bins used for metering coal / limestone are not calibrated, merely zeroed – in the integrated steel plant, these are the primary devices that the reporting relies upon for over approximately 80% of emissions.
- Coal weigh-feeder used for measuring coal delivered has poor reliability and in some cases, it was found to be not working; data was noted to be manually transcribed from it to the level 3 data system. In some plants, this device is used as a cross-check for the coal fed to the process
- Rail weighbridge has poor calibration history, and the data is manually captured. Not all trains are weighed, and the data is manually transcribed.

- Lack of controlled procedures across the plant for data capture and data entry, data checking and data review, data manipulation and storage as well as data recovery and reporting
- Missing (and/or incorrect) data in Level 1 and Level 2 systems due to sensor issues
- Lack of adequate sensors (meters) to measure the amount of fuel or electricity at the consumption points – in some shops, while there are several consumption points for electricity and natural gas, there is only a single meter for measuring the overall consumption at entry point
- No internal auditing of energy data or reports occurring, mainly due to lack of formal systems

In addition to addressing the non-conformances associated with the data collection and data accuracy, training of operators would also be necessary to make them aware of (and sensitive about) the importance of the accuracy of plant data collected for estimating the CO<sub>2</sub> emissions.

## RESULTS AND DISCUSSIONS

The methodology developed by the authors was successfully applied to generate the LCC / LECC charts, which were considered in the selection of improvement projects for developing the strategic roadmaps for reducing energy consumption and CO<sub>2</sub> emissions at several operating plants with different process configurations. For developing robust baseline figures, data is collected for all process units for an extended period is considered (say, at least 3 operating years).

During this extended period, there are some months noted with abnormal production, and these months are not included in the baseline period. As presented in Figure 1, out of the 36 months (3 years period: January 2015 to December 2017) considered for establishing the baseline period, data for 6 months with abnormal production are excluded. The balance 30 months (with stable operation and normal production) are selected to develop the baseline figures.



Figure 1. Monthly liquid steel production considered for establishing the baseline period for the study showing 6 months with abnormally low production (<20 ktpm).

Once the baseline period is established, average baseline figures are estimated for the following parameters for each unit process:

- Production (for example, coke, sinter, pellet, hot metal, liquid steel, cast steel and rolled steel, etc., depending on steel plant configuration)
- Specific consumptions (input charge, electricity, fuels, fluxes, carbon, alloys etc., depending on the consumptions at the various units)
- Products / by-products (includes items such as cast / rolled products, pellets, sinter, by-products that are sold and/or shipped from the site).

Simplified mass and energy balance is conducted for the unit processes and for the overall plant site. Baseline energy consumption and CO<sub>2</sub> emission figures are estimated utilizing the average baseline figures estimated for each unit process.

Specific energy consumption and specific CO<sub>2</sub> emission figures were estimated for some reference plant configuration, and these are presented as examples.

Table 1. Specific Energy Consumption and CO<sub>2</sub> Emissions From Reference Plants

Steel Plant Configurations	Specific Energy Consumption	Specific CO <sub>2</sub> Emission
	GJ / t CS	t CO <sub>2</sub> / t CS
BF / BOF Integrated Plant	26.76	2.18
Scrap-Based EAF Mini Mill	9.75	0.38
Charcoal BF + EAF Mini Mill	15.01	0.78
Charcoal BF + Mini Mill	22.36	1.40
NG DRI + EAF Mini Mill	19.38	0.83

Although the values are presented per ton of crude steel, these figures include the energy consumption and CO<sub>2</sub> emissions associated with downstream rolling mills at these plants and the agglomeration unit operating at BF/BOF integrated plants. Another point to note here is that the plants operate with different hot metal / DRI to scrap ratios.

Table 2. Contributions to Overall CO<sub>2</sub> Emissions

Operating Parameters	BF / BOF Integrated Plant	Scrap-Based EAF Mini Mill	Charcoal BF + EAF Mini Mill	Charcoal BF + Mini Mill	Natural Gas DRI + EAF
	% of Total	% of Total	% of Total	% of Total	% of Total
Coal Blend for Coking	74.2	***	***	***	
PCI for Blast Furnace	14.7	***	***	***	
Charcoal for BF	***	***	72.9	90.2	***
Natural Gas	1.6	33.2	3.4	***	78.9
Electrical Power	3.6	41.3	18.3	5.2	19.6
Raw Fluxes	5.8	***	1.9	2.9	***
Purchased Pig Iron	***	11.5	***	***	***
Carbon-based Materials	0.1	8.5	2.1	1.6	0.2
Electrode	0.03	1.4	0.5	0.1	0.7
Others	0.03	4.1	1.0	***	0.7
	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>

As presented in Table 2, the main contributors of CO<sub>2</sub> emission are the main energy sources: metallurgical coal or charcoal, natural gas and electricity. The secondary contributors are purchased pig iron, carbon additions, raw (uncalcined) fluxes. It is evident that switching to “green electricity” and replacing natural gas with hydrogen gas, is expected to reduce the CO<sub>2</sub> emissions at all the plants but the DRI / EAF route is the biggest beneficiary. Reduction of >98% can be expected (in Scope 1 and 2 emissions); however, there is still some remaining CO<sub>2</sub> emissions from other materials used for steelmaking.

At this stage, it is important to also understand and keep in mind that the sources linked to Scope 3 CO<sub>2</sub> emissions considering purchased raw materials, calcined fluxes, refractory, diesel oil used for external transportation of raw materials and finished products. In the case of integrated BF/BOF plants where coal is the main fuel and reductant, the reduction of CO<sub>2</sub> emissions due to elimination of emissions from natural gas and electricity is not as significant (only ~5%) while in the case of scrap based EAF mini mills, the reduction is >70% for plants using 10-30% purchased pig iron and high percentage of chemical energy input.

For the key performance indicators (KPIs), the baseline figures are compared to the benchmark figures (both internal and external benchmarks) to establish the “potential gap” between current and best practice performance levels. The “potential gap” in performance is indicative of the improvement opportunity that exists with regards to improving the KPIs and reducing energy consumption, CO<sub>2</sub> emissions and reducing operating cost.

Improvement projects are identified to bridge the gaps and thus, enhance the current performance level of the plant to achieve best practice level in the short term. In addition, some “futuristic” projects are also defined to reduce the CO<sub>2</sub> emissions further in the medium-term and long-term.

Technical and financial analysis of the improvement projects was carried out with focus on the following points to develop the LCC (and LECC) chart:

- Assessment of impact on energy consumption, CO<sub>2</sub> emissions
- Estimation of impact on operating cost (OPEX) and CAPEX requirement
- Evaluation of financial feasibility of improvement projects.

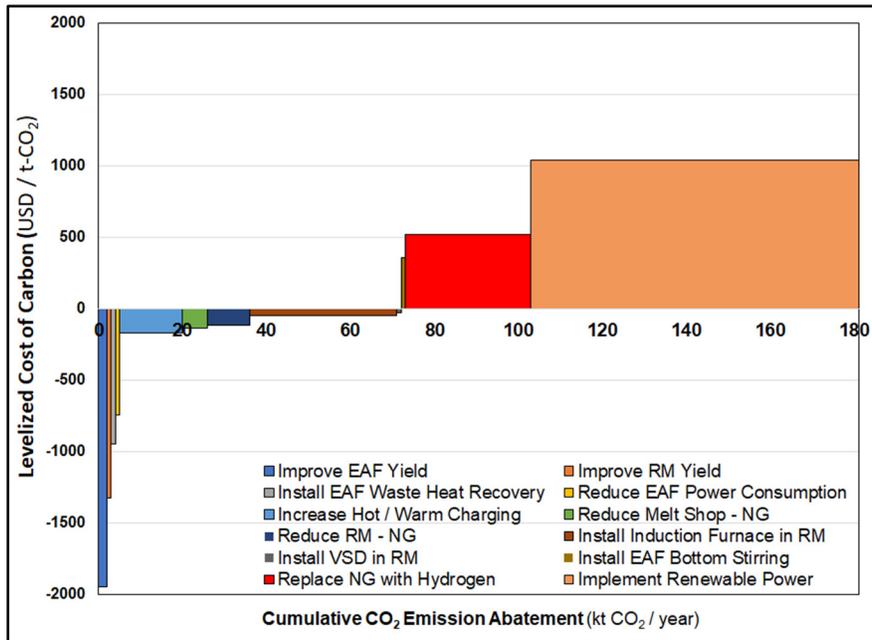


Figure 2. LCC chart developed for a scrap based EAF plant to evaluate the improvement projects.

In the LCC chart presented in Figure 2, improvement projects associated with CO<sub>2</sub> emissions reduction that have negative net cost values are associated with potential financial savings (even after the costs of implementing them, say through a CAPEX investment, have been included).

These projects typically include operational improvement initiatives with no / low capital cost (CAPEX). These initiatives are the so-called “low-hanging fruits” that should be implemented in the short term for improving the business bottom-line.

In contrast, those improvement projects with positive net cost values are associated with a net-cost increase per annum. Typically, these involve medium or high CAPEX investments. Although CAPEX investment is needed, these opportunities are often associated with significant reductions in energy consumption and CO<sub>2</sub> emissions. As discussed earlier, these projects are not feasible at a CO<sub>2</sub> price of 0 US\$/t-CO<sub>2</sub> (business as usual); however, these projects may become attractive in alternate pricing scenarios.

Based on the outcome of the evaluation of improvement projects using LCC (and LECC), the projects were finally selected for developing the strategic roadmap. The risks associated with the implementation of the improvement projects were assessed and the projects were finally selected for developing the strategic roadmap (Figure 3).

It is evident that it would be possible to reduce the CO<sub>2</sub> emissions by ~15% in the short term by implementing improvement projects that require no / very low capex; by about 13% in the medium term with the help of capex projects; and by ~34% in the long term with the help of 2 “futuristic” projects (replacement of natural gas with hydrogen and implementation of 100% renewable power) that are associated with high CAPEX / high OPEX and currently not viable.

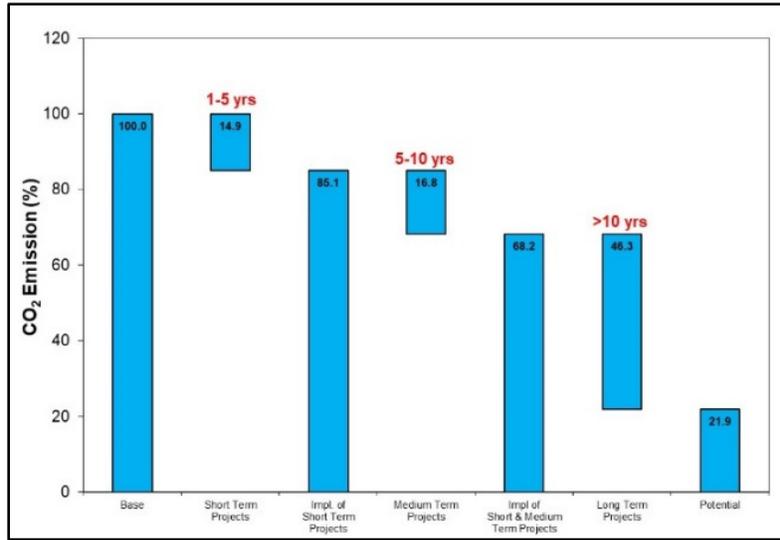


Figure 3. Strategic roadmap for reducing CO<sub>2</sub> emissions for a reference scrap-based EAF mini mill.

### SUMMARY AND CONCLUSIONS

The methodology presented in this paper provides a rigorous, robust, and defensible way to develop strategic roadmap for reducing energy consumption and CO<sub>2</sub> emissions in iron and steel plants.

The following guidelines apply to the successful application of the key elements of the methodology and its effective utilization:

- Energy and CO<sub>2</sub> emissions inventory need to be determined accurately
- Energy envelope for each process unit must be determined accurately
- Energy and mass balances must be modelled on a detailed KPI level
- Proper benchmarking through normalization must be completed to enable accurate target setting
- Cost of abatement curves enable target setting through the analysis of the economic evaluation of improvement opportunities

The iron and steel industry needs a robust techno-economic platform to prepare for the CO<sub>2</sub> emissions reduction targets as part of the emerging climate change regulations and risks.

The methodology presented by the authors meets this need by providing an objective, quantifiable model to guide the industry's capital spending in pursuit of addressing climate change business risks and opportunities.

### REFERENCES

1. S Kumar; M. Freislich; D. Mysko; L.A. Westfall; S. Bachenheimer: Addressing Climate Change - A Novel Greenhouse Gas Carbon Abatement Process for the Iron and Steel Industry; AISTech 2010 Proceedings, Volume 1, pp. 227-248.