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Green Industry

Energy and Resource Efficiency in the Vietnamese Steel Industry

Report prepared by UNIDO International Consultant

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UNIDO Vietnam Mission

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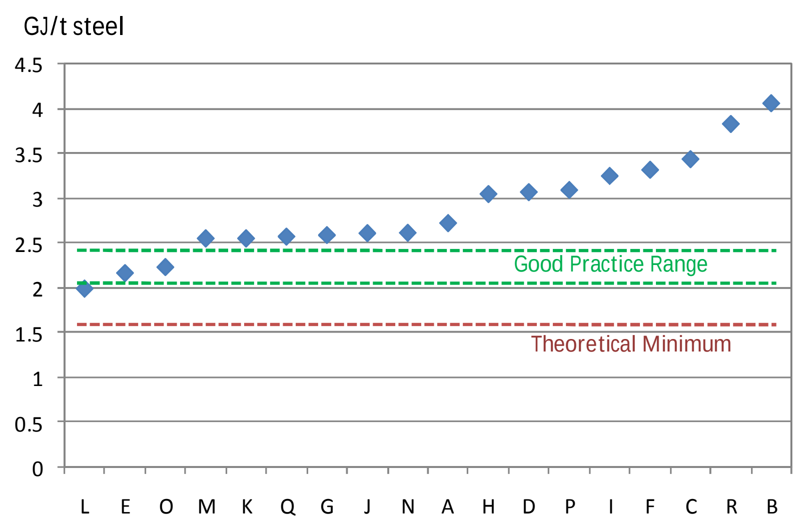
EXECUTIVE SUMMARY

This report summarises the results of a study on energy and resource efficiency in the Electric Arc Furnace (EAF) section of the Vietnamese steel industry, which was initiated by UNIDO with the support of the Vietnamese Steel Association. The mission was conducted in two Stages with one international and one national consultant. The first Stage included visits to six steel plants in early December 2010. The six plants, all based on EAF steelmaking, were chosen to provide a good cross-section of the industry with respect to geography, state and private ownership, age of facilities, scale of production and the level of technology. Preliminary findings were presented to a UNIDO-VSA Workshop in Ho Chi Minh City (10 December). In the second Stage, the analysis was extended to include the remaining EAF plants based on visits to twelve plants during April and May 2011.

Data on the main inputs and outputs of steelmaking, casting and rolling were collected in a systematic way to calculate the energy used in production and to analyse factors such as technology, productivity, process stability, resource efficiency and scrap quality. The analysis included a broader Life Cycle view of energy efficiency as well as calculations of greenhouse gas emissions. Insights were able to be drawn by comparing performance between the Vietnamese plants and also by reference to global good practice standards.

The results for production energy in EAF steelmaking, the most energy intensive step in the process, are summarised below. Whilst some of the Vietnamese plants are in line with global good practice, most are considerably less efficient.



The Vietnamese steel industry is growing rapidly. There is a need and an opportunity for a systematic approach to education and capability building, including best practice and knowledge sharing. New technology alone cannot ensure good practice or good efficiency. A priority needs to be placed on increasing the sector's capabilities for 'digesting' new technology and achieving systematic improvements in productivity and efficiency from existing equipment. Considerable opportunity exists to increase throughput across the sector, probably by some 300,000 tonnes per annum or more at the initial six plants. One aspect of the newly expanding industry is that the scrap supply system is still immature. Improving scrap quality will need to be an integral part of achieving world class process performance.

The initial analysis conducted for the first six plants was extended to eighteen of the steelmaking facilities in Vietnam using a simple spreadsheet model developed especially for UNIDO to make available to the Vietnamese steel industry as a self evaluation tool.

The Vietnamese steelmaking plants should consider setting some joint targets for improving energy efficiency relative to global benchmarks. Energy efficiency improvements should be driven by activities that improve the effectiveness of management systems as well as projects that expand facilities and introduce better technology. Improving energy efficiency should be seen as an integral part of continuously reducing costs per tonne and increasing total production.

The industry should consider collaborative ways to improve the performance and global competitiveness of the Vietnamese industry. The priority should initially be in EAF-based steel making, where there is the greatest room for improvement. UNIDO should give consideration to bringing in an international consultant in the area of high performance steelmaking from scrap supply to caster.

Effective collaboration across the Vietnamese steel industry to improve efficiency and productivity will need some basic organisational structure, some sort of forum to share ideas and coordinate activities. The industry should consider setting up a formal network, with representatives from all steelmaking plants, to take the UNIDO/VSA initiative forward from here.

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1. INTRODUCTION

Background

In Vietnam, UNIDO has provided advice towards the formulation of the recently issued *'Action Plan on Response to Climate Change of the Ministry of Industry and Trade (MOIT)'*. The steel sector is among those cited for application and transfer of low carbon, climate-friendly technologies in the MOIT Action Plan. In addition, the Law on Energy Efficiency and Conservation has just been promulgated by the Vietnamese government and brings with it requirements to improve energy efficiency in energy intensive sectors. UNIDO decided to include the steel sector in its technical cooperation activities on industrial energy efficiency. For UNIDO, this represents a pilot activity within its "Green Industry" initiative.

The Vietnam Steel Association (VSA) requested UNIDO to field a senior, international steel expert to advise the steel industry leaders on international experience in energy and resource efficiency in the sector and to facilitate discussion on possible concerted actions the sector stakeholders could take to improve energy and resource efficiency, so as to move on to a more sustainable growth trajectory. Recommendations would be based on a rapid assessment of the state of the industry through field visits and interviews with relevant government authorities and donors active in the field of energy and resource efficiency in the country. The mission has been conducted in two stages: a preliminary analysis was conducted based on a representative six Vietnamese steel plants and then a consolidated analysis was completed incorporating data from a further twelve plants. This report presents the results of both stages of the study covering eighteen plants in total.

The mission

Management for the mission came from Ms Nilgün F. Taş, UNIDO Vietnam Representative, and Ms. Le Thi Thanh Thao, UNIDO National Programme Officer. Dr Joe Herbertson was appointed as the international consultant and Mr Chu Duc Khai was appointed as the national consultant.

The first stage of the work was based on a visit to Vietnam by Dr Herbertson from 1-11 December 2010. VSA arranged for Dr Herbertson and Mr Khai to visit six steel plants across the country. In addition, interviews were conducted with VSA leaders, MOIT officials and donors with an interest in energy efficiency and climate change.

This first stage[1] culminated in a UNIDO-VSA workshop in Ho Chi Minh City on 10 December where the consultants presented their preliminary findings. The Workshop was attended by around 75 people, primarily from the steel industry, but also a good cross section of representatives from government, party and donor organisations. Several speakers at the HCMC Workshop provided the broad context for a focus on energy and resource efficiency in the Vietnamese steel industry[2]. VSA gave an introduction to the Workshop[3] and an overview of the state of the Vietnamese steel industry[4]. UNIDO outlined the objectives of this mission on steel sector energy and resource efficiency and provided the wider 'Green Industries' perspective[5]. MOIT provided an introduction to the Climate

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1 An interim report was issued after the first stage of the work (Herbertson, April 2011)

2 Delegates attending the Workshop were provided with copies of the presentations. For additional copies or other information regarding this initiative, please contact Ms. Thao at the Hanoi offices of UNIDO; +84-4 3942 4000; L.Thao@unido.org

3 Mr. Pham Chi Cuong, Chairman Vietnam Steel Association

4 Presentation by Mr Dinh Huy Tam, Secretary General, VSA

5 Presentation by Ms Thao, UNIDO Officer in Charge.

Change Action Plan[6] and also to the National Target Programme and Law on Energy Conservation and Efficiency[7].

Information gathering

Prior to his visit to Vietnam, the international consultant was provided with extensive reading material by UNIDO and VSA on the steel industry in Vietnam and the implications of the recently promulgated Law on Energy Efficiency and Conservation on the sector. This was used to prepare a questionnaire[8] to assess resource use, with an emphasis on energy, and plans to improve resource efficiency in the sector. This questionnaire was circulated to steel companies and government officials and used by the international and national consultants to collect detailed information initially from a representative group of six steel producers. The field visits gathered information on technologies employed, and data on energy and resource efficiency performance, as well as plans for improving efficiency and advancing sustainable development. The visits and meetings were used to assess the willingness to set targets for improvements at individual plants and within the sector and the affinity for sector wide collaboration.

It should be highlighted here that, without exception, people in the steel plants visited were open, cooperative, friendly and willing to provide data. This was very much appreciated by the consultants and is a positive sign for future stages in this initiative.

The approach

Since this mission will represent the first steps in what could be a long and constructive program for the Vietnamese steel industry and its stakeholders, it was considered important to start by understanding the current level of resource efficiency in the industry, before jumping to solutions. Without an analysis of current reality, it would be difficult to systematically improve performance at plant or sector level. The priority was therefore to collect reliable data that could be used to calculate the energy efficiency of individual plants, where the results from different operations could be compared to each other and also compared to good practice globally. Analysis of the energy and resources used in production could then be used to take a broader 'life cycle' view, where off site factors, such as the supply of electricity, energy and steelmaking inputs could be taken into account, and the overall Greenhouse Gas emissions estimated.

For the rapid first stage assessment, there was only time to visit six of the country's eighteen EAF based steelmaking plants. Primary steel production in Vietnam is predominantly by EAF-based steelmaking and billet casting. The six plants were selected to be as representative as possible of the industry as a whole in terms of location, ownership, production range and age

Data collected during the plant visits was analysed using complex models developed by The Crucible Group in Australia[9]. To help with the assessment, the Vietnamese data was compared to a reference plant from the Crucible's data bases, which had been chosen to represent good practice globally.

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6 Presentation by Mr. Hoang Van Tam, Officer, Industrial Safety Techniques and Environment (ISEA), Ministry of Industry and Trade (MOIT)

7 Presentation by Mr. Tran Viet Hoa, Officer, Office of National Program on Energy and Conservation

8 Energy and Resource Efficiency in the Vietnamese Steel Industry, Questions for Discussion and Plant Specific Data Collection Request; Joe Herbertson, UNIDO Consultant, November 2010

9 The Crucible Group Pty Ltd is the company of the international consultant; the company has extensive experience in Life Cycle Analysis, modelling material and energy flows in complex industrial systems (particularly in the steel industry), evaluating the greenhouse gas emissions of operations, and sustainable development (especially in the minerals and energy resource sector).

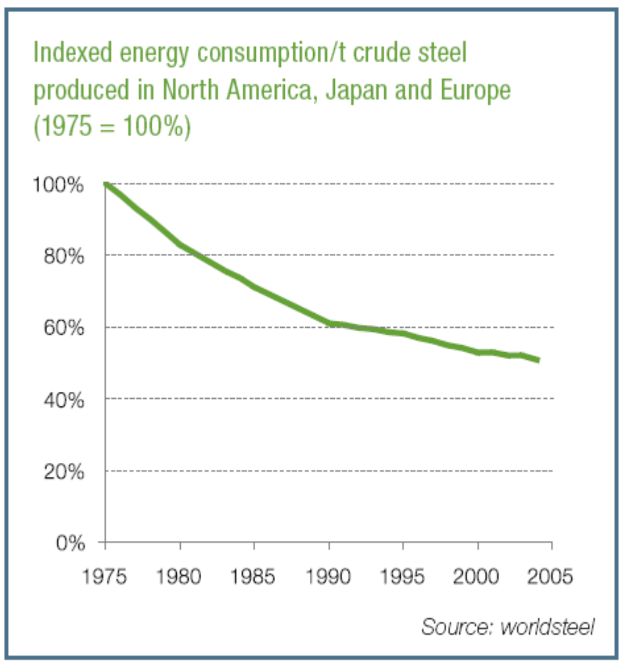
The second stage of the work was based on visits to the remaining EAF steelmaking plants in Vietnam by the National Consultant (Mr Chu Duc Khai) during April and May 2011. Analysis of data was conducted using an Evaluation Tool specially developed for the purpose by The Crucible Group Pty Ltd in Australia[10].

International perspectives

International perspectives on energy and resource efficiency in the steel industry are brought into this report as an integral part of the discussion of the Vietnamese results. However, some preliminary comments are made here to provide some context.

Globally the steel industry has a very impressive history of progressive improvement in energy efficiency. For example, the energy consumption per tonne of crude steel produced in the established steel industries of North America, Japan and Europe has been reduced by 50% since 1975, as shown in Figure 1 below from the World Steel Association.

Figure 1



The average energy per tonne of steel produced in USA has reduced by four times over the last 50 years, as shown in Figure 2 below[11]. This is due to systematic and persistent productivity improvements, advances in continuous casting, and a relative shift to scrap based steelmaking in mini-mills (EAF)[12]. For an advanced industry such the USA, further improvements in energy efficiency can now only be incremental, as performance asymptotically approaches the theoretical minimum

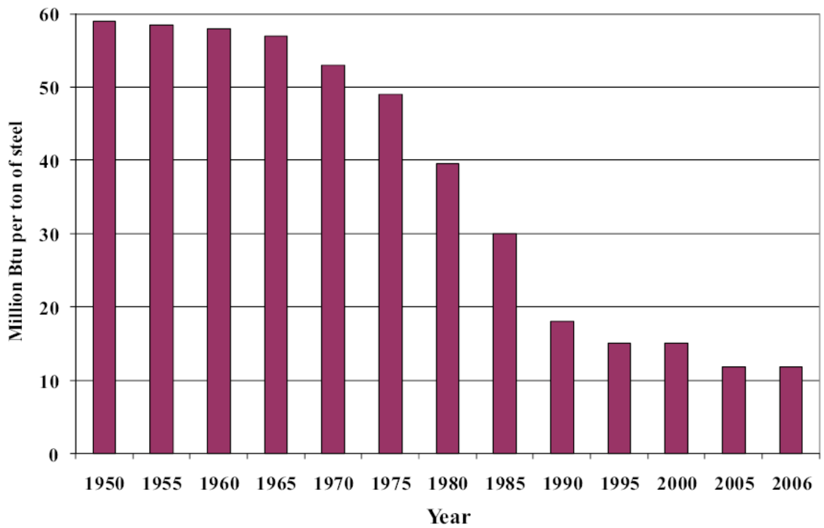
[10] The Evaluation Tool was designed by The Crucible as a simplified 'user friendly' spreadsheet model.

[11] Source: US Dept of Energy and the American Iron and Steel Institute (AISI)

[12] A good summary can be found in "Energy Use in the US Steel Industry: An Historical Perspective and Future Opportunities", September 2000, J. Stubbles, U.S. Department of Energy. See also "Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from the Iron and Steel Industry", U.S. Environmental Protection Agency

achievable for the processes and materials currently used in iron and steelmaking [13]. To achieve energy savings beyond this practical theoretical limit would require transformational change in steelmaking technologies[14].

Figure 2



A summary of energy efficiency progress in the American steel industry is given in Table 1 below. This is based on the total steel produced, in both integrated plants (BF-BOF) and mini-mills (EAF), and it includes the off-site energy associated with supply of electricity and input materials, as well as the energy used directly in production on-site at the steel plants.

Table 1

Average Energy for U.S. Steel Production	
1950	67 GJ per tonne
2006	14 GJ per tonne

13 "Theoretical Minimum Energies to Produce Steel for Selected Conditions", March 2000, R.J. Fruehan, O. Fortini, H.W. Paxton, R. Brindle, U.S. Department of Energy; international best practice is now around 30% above theoretical limits that could be considered practical or achievable with the main processes and materials used to make iron and steel today.

14 The potential for incremental and transformational change is discussed in "Saving One Barrel of Oil per Ton (SOBOT); A New Roadmap for Transformational of Steelmaking Processes", American Iron and Steel Institute, October 2005. See also "The State-of-the-Art Clean Technologies (SOACT) for Steelmaking Handbook", prepared by AISI for Asia Pacific Partnership for Clean Development and Climate, December 2007.

2. PRELIMINARY ANALYSIS OF SIX STEEL PLANTS IN VIETNAM

Of the six plants visited in Stage 1, all had EAF furnaces and billet casters; four had rolling mills, and all but one had ladle furnaces.

The questionnaire and data request sheets[15] were designed to collect data on the main inputs and outputs of production. This included energy inputs, such as electricity and fuels, as well as material inputs such as scrap, lime and water. Outputs were products, such as billets and rolled reinforcing bar, as well as residues such as slags and mill scale. The plant meetings were important to ensure that there was clarity around what was requested, so that data was as accurate as possible and on as consistent a basis as possible between the plants.

For the purposes of data collection, the operations were divided into three areas: steelmaking, casting (including ladle furnace) and rolling. When data covered more than one area, it was allocated back to these three areas, keeping the total constant[16].

On the steelmaking technology side, the plants fell into two broad groupings (three in each). One group had more advanced technology, namely larger batch sizes (60 tonne)[17], scrap preheating systems, water cooled EAF walls and bottom tapping. The other group were smaller batch sizes (15-20 tonnes), without the above features. Of the four plants with rolling mills (2 large, 2 small), three had provisions for hot/warm charging of billets to the rolling mill.

Production Energy

Production Energy is what is actually used in the operations directly on site. Sources of energy include:

- Electricity used directly in the main processes and also in support areas, such as dust treatment, water treatment, ancillary equipment such as cranes and lighting[18].
- The carbon content of the pig iron
- Electrodes
- Coal added to steelmaking for composition adjustments or injected for slag foaming[19]
- Fuel oil used in rolling mill reheat furnaces and for ladle preheating
- Natural gas used in rolling mills and preheating of ladles and scrap

The calculated results from the six plants visited are shown in Table 2 below, with all energy inputs being converted to the units of GJ per tonne of steel[20] at the three stages of steelmaking, casting and rolling. The results are listed in order of decreasing EAF Production Energy, i.e. the least energy efficient at the top, the most energy efficient at the bottom. Steelmaking is the most energy intensive step of production, with the greatest variation from the most to the least efficient

[15] Energy and Resource Efficiency in the Vietnamese Steel Industry, Questions for Discussion and Plant Specific Data Collection Request; Joe Herbertson, UNIDO Consultant, November 2010

[16] For example, electricity for support systems such as water treatment, cranes, offices was often measured and reported for steelmaking and casting together, in which case an estimate was made through discussion at the plant on the allocation between steelmaking and casting (including the ladle furnace)

[17] It should be highlighted that 60 tonne batch size is relatively small by international standards (100-140 tonne is more typical of good practice billet casting plants)

[18] An important part of the plant meetings was making sure that all direct and indirect electricity was accounted for.

[19] All coal used in the plants was anthracite

[20] The plants actually collect data for steelmaking, ladle furnace and casting on a "per tonne of billet" basis; in the table presented here, EAF steelmaking energies are however reported per tonne of liquid steel - as calculated from the data, not directly measured.

operations, as shown in Table 3 below. Improving energy efficiency in steelmaking should be the priority.

Table 2

PRODUCTION ENERGY		
Steelmaking GJ/tonne liquid steel	Casting GJ/tonne billet	Rolling GJ/tonne rolled product
3.8	0.4	No mill
3.6	0.2	No mill
3.3	0.3	1.7
3.1	0.3	1.6
2.6	0.5	1.5
2.1	0.2	1.2
Good Practice Reference Plant		
2.4	0.2	1.7

Table 3

Process Stage	Variation in Production Energy between Plants
Steelmaking	1.7 GJ/tonne liquid steel
Casting	0.3 GJ/tonne billet
Rolling	0.5 GJ/tonne rolled product

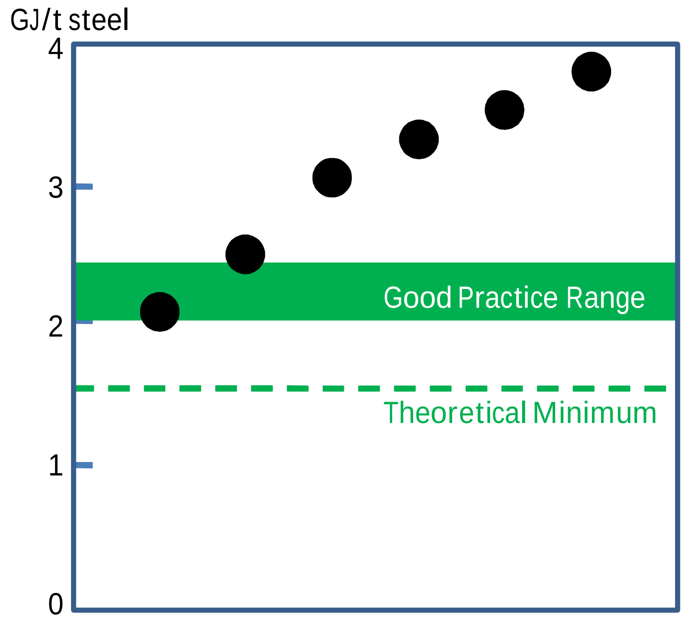
The benchmark range for EAF steelmaking for billet production is around 2.1 – 2.4 GJ/tonne of liquid steel[21]. This analysis therefore shows that at least one highly efficient Vietnamese operation is in line with global good practice, but most plants are considerably less efficient[22].

The range of EAF steelmaking production energies in the six Vietnamese plants and how they compare to global good practice and the practical theoretical limit[23] is shown in Figure 3 below, plotted in order of decreasing efficiency.

[21] Actual energy requirements for EAF steelmaking are given in "Theoretical Minimum Energies to Produce Steel for Selected Conditions", March 2000, R.J. Fruehan, O. Fortini, H.W. Paxton, R. Brindle, U.S. Department of Energy.

[22] The most efficient Vietnamese plant was slightly more efficient than the good practice reference plant. The rolling mill energy for the reference plant is relatively high in the range of Vietnamese plants, which reflects the more complex product range (eg .light structural sections)

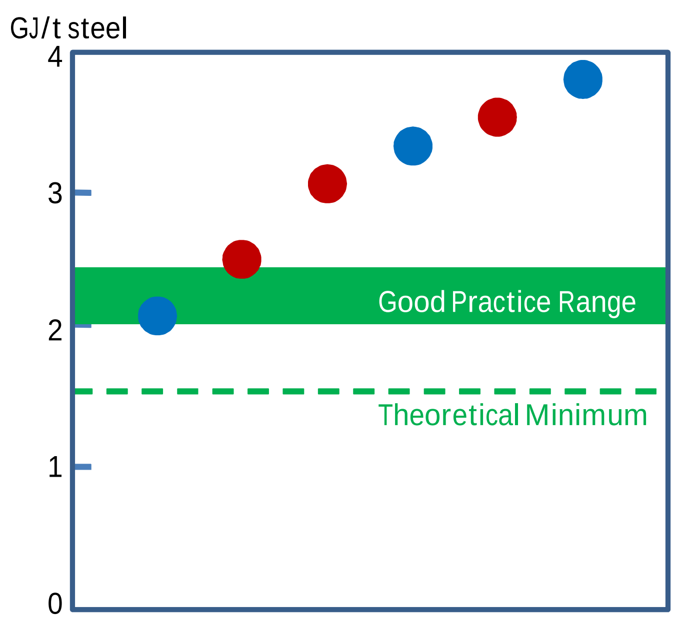
Figure 3



Technology

The figure is plotted again in Figure 4 below, but this time showing the difference between the two groups of plants with respect to steelmaking technology, namely the larger, more advanced plants (blue dots) and the smaller, less technologically advanced ones (red dots).

Figure 4



[23] Theoretical limit that is considered achievable with current processes and materials is 1.6 GJ/tonne of liquid steel produced in the EAF, see reference above.

This is an extremely interesting result. It shows that whilst the most efficient plant is one with larger batch size and advanced technology, so too is the least efficient. Better technology is important, but it is not enough. A key factor is therefore local capacity to get the most performance out of the equipment that they have. The world steel industry is very open and the latest technology can be purchased readily without constraints (other than money). But performance depends on competence in 'technology digestion', which boils down to the capacity to achieve process control and optimisation and systematic continuous improvement.

This result is also one that provides real encouragement that there is considerable scope to improve energy efficiency, for the bigger and the smaller plants.

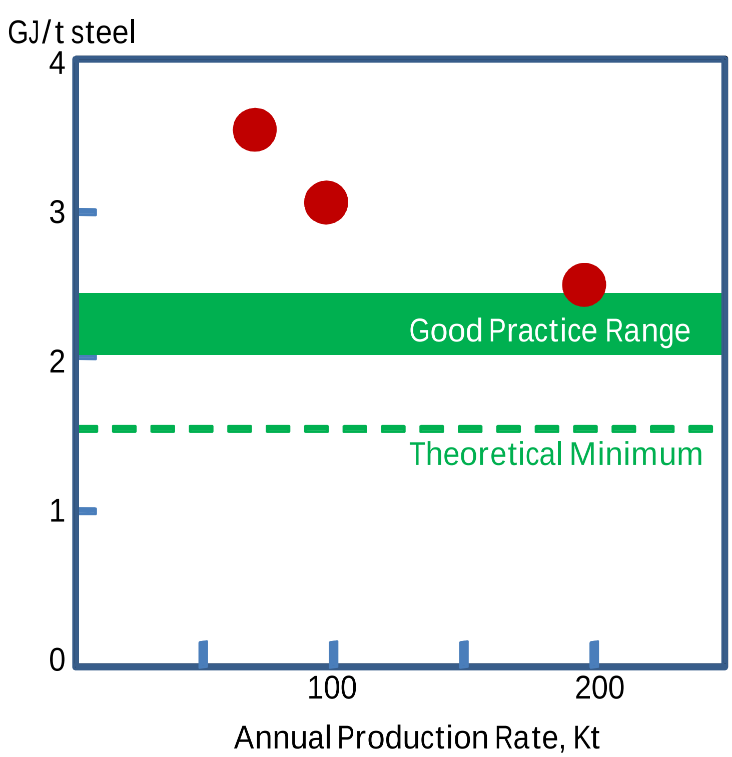
Productivity

The priority for any steel plant is to improve productivity, since this tends both to reduce the energy required and to increase the profitability per tonne produced.

The benefits of increasing productivity are clearly illustrated in Figure 5 below (red dots), which shows the steelmaking production energies for the group of three small (15-20 tonne), less technologically advanced plants. Energy efficiency improves as a function of the production rates achieved.

All of these smaller plants have already achieved significant production rate increases over the past few years. One plant had increased the rolling mill capacity by 45% since original commissioning in 2002. Another had doubled steelmaking capacity since 2007, with plans to possibly double again. The third plant had increased steelmaking output by a factor of three since 1995, with another 20% increase to come in the next year.

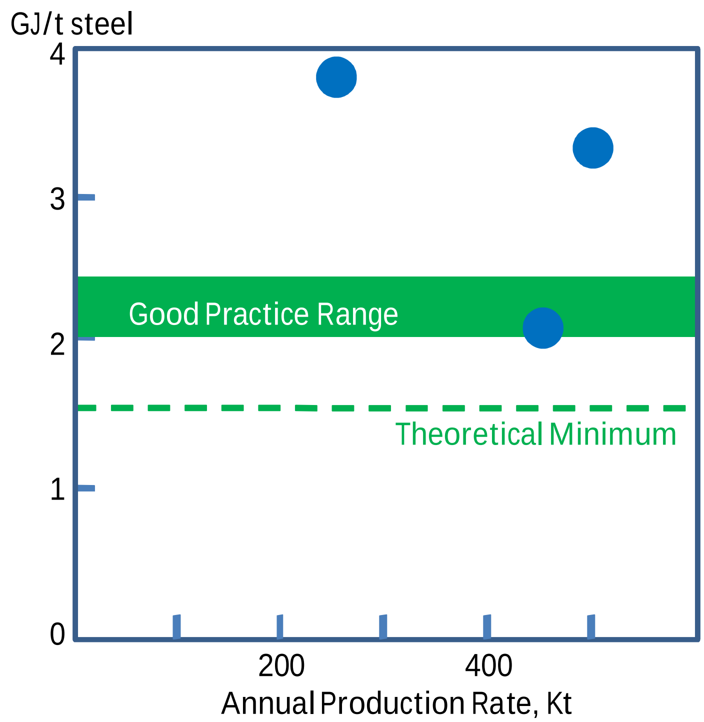
Figure 5



Increasing the output of the many smaller plants in Vietnam represents an important opportunity to achieve incremental industry restructuring and improve efficiency of the sector as a whole.

Energy efficiency as a function of productivity for the three larger, more technologically advanced plants, having the same batch size (60t), is shown in Figure 6 below (blue dots).

Figure 6



Of these larger plants, the one with the least efficiency and the lowest productivity is the newest one. It is reasonable to expect that significant improvements will be achieved over the coming years as the operators and management gain production experience. The key will be developing the capacity for process control, optimisation and systematic and persistent improvement. In principal, there is probably scope for doubling output at this plant, with corresponding improvements in efficiency.

Interestingly, the plant with the highest productivity (and shortest tap to tap times) is not the most efficient. It seems that the high productivity has been achieved with considerable fuel inputs to steelmaking and for scrap preheating (coal and natural gas). It is reasonable to assume that efficiencies could be improved significantly through a systematic process of combining energy accounting and optimisation of productivity.

The large plant with the best energy efficiency, in line with global best practice, showed all the hallmarks of a production system under process and management control. Of the six plants visited, it was also the one which appeared to have the best housekeeping, within and around the plant.

High productivity, good practice operations globally are generally characterised by short tap to tap times in steelmaking and long casting sequences, which are discussed below.

Tap to tap times

Typical good practice billet casting plants globally have EAF furnace sizes around 100 – 140 tonnes, with tap to tap times less than one hour. The situation for the six Vietnamese plants visited in Stage 1 is shown in Table 4 below, listed from the longest to the shortest tap to tap times (lowest to highest productivity). Only two of the plants have tap to tap times of one hour or less, indicating that considerable improvements are possible for most of the plants.

Table 4

Tap to Tap Time (minutes)
96
90
80
70
60
45

Sequence lengths

Typical good practice billet casting plants globally have extended sequence casting, around 24 hours without interruptions (say 24 ladles or more). This corresponds to total steel cast in the order of 3,000 tonnes, which underpins high productivity and is a reflection of good process stability. The situation for the six Vietnamese plants visited in Stage 1 is shown in Table 5 below.

Table 5

Sequence Casting Maximum No. of ladles	Typical Casting Volume Total tonnes
1	15
3	50
11	210
15	480
25	1,320
33	2,030

Two of the Vietnamese plants visited have achieved more than 24 ladles cast per sequence. In terms of total steel cast without interruption, the Vietnamese results tend to be well below global good practice due to a combination of short sequences and small batch sizes. The plant with single heat casting has no ladle furnace, but this will be changed in the near future[24].

Apparent metallic feed losses

Yields and energy efficiency are closely linked. For example, more metallic feed (scrap and pig iron) needs to be purchased than liquid steel is required to produce for casting, mainly to make up for slag losses. The higher these yield losses, the more lime will be needed for fluxing the slag and the more energy is required to produce a tonne of billet.

The situation for the six Vietnamese plants visited in Stage 1 is shown in Table 6 below, listed in order of decreasing apparent metallic feed losses[25] (in order of improving resource efficiency). As expected, the data shows that the higher these losses, the more lime is required for fluxing. The plant with the lowest apparent metallic feed loss (110 kg) and the lowest lime additions (65 kg) per tonne of billet is (not surprisingly) the one with the best steelmaking energy efficiency (2.1 GJ/tonne liquid steel).

Table 6

Apparent Metallic Feed Losses kg/tonne billet	Flux Additions kg lime/tonne billet
147	80
140	73
140	70
139	68
133	76
110	65
Good Practice Reference Plant	
64	40

The table also shows the results for a reference plant (global good practice), where apparent metallic feed losses and lime additions are substantially lower than for the Vietnamese plants, roughly half. Although poorly controlled slag metal chemistry could be a contributing factor[26], it is most likely that the main explanation for this difference is associated with scrap quality. 'Dirty' scrap means more slag, lower energy efficiency and higher apparent metallic feed losses. Inspection of the scrap yards at the plants suggested that there was a considerable amount of dirty scrap being processed.

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24 This small plant has plans for major increases in production throughput in a number of upgrading stages in steelmaking and casting and then the addition of a rolling mill.

25 Apparent Metallic Feed Loss is defined here as the amount of scrap and pig iron purchased minus the amount of liquid steel produced for casting. For example, if 1.15 tonnes of scrap and pig iron is needed to produce one tonne of billet and there is 1% more liquid steel than billet, then Apparent Metallic Feed Losses is 1,150 kg (metallic feed) minus 1,010 kg (liquid steel) = 140 kg.

26 In the Vietnamese plants visited, slag volumes are generally not measured and slag chemical analysis are rarely conducted. There will be opportunities to improve performance with better EAF and ladle slag measurement and control.

In addition to the cleanness and chemical factors, scrap density is also very important[27]; more uniform and higher scrap density leads to greater process stability, increased productivity and improved efficiency.

The Vietnamese steel producing sector is rapidly growing. Liquid steelmaking production had been at around 300kt/a since National Unity (1975), but has grown to close to 3Mt/a over the past decades, ie. by a factor of ten. One feature if this rapid growth is that there is not yet an established 'scrap service industry' in the country. Improving scrap quality (both cleanness and density) would assist the steelmaking industry generally.

Electrode consumption

Electrode consumption rates per tonne or production are a reflection of how stable the operations are being conducted. The results for the Vietnamese plants visited are shown in Table 7 below, listed in order of decreasing electrode consumption (increasing stability).

The three small, less technologically advanced plants had the highest EAF electrode consumptions rates (3.1 - 4.1 kg/tonne billet); the three larger, more advanced plants had lower EAF electrode consumption rates (1.35 – 2.7 kg/tonne billet).

Table 7

EAF kg/tonne billet	LF kg/tonne billet
4.1	-
3.4	1.0
3.1	0.9
2.7	0.7
1.45	0.5
1.35	0.55

The global good practice reference plant has EAF electrode consumption of 0.45 kg per tonne of billets, well below the Vietnamese plants studied, indicating the potential for improvements in process stability.

Rolling mill performance

Four plants visited in Stage 1 had rolling mills. In these plants, energy usage was in the range 1.2-1.7 GJ/t product (see Table 2). Energy efficiency is a function of rolling schedules (order sizes) and the dimensions and quality of products. The variation from most to least efficient is 0.5 GJ/t product, compared to the much larger variation in steelmaking and casting of almost 2 GJ/t billet between the most and least efficient plant (see Table 3).

[27] One plant reported that scrap density could vary from 200kg to 1 tonne per cubic metre. Such variability has a very negative impact on scrap feeding and EAF melting performance

Energy improvements are certainly possible, but in the rolling mills efficiencies are more in line with global good practices than is the case in steelmaking.

Yield losses (tonnes billets rolled minus tonnes billets sold) for the four plants were in the range 2.9 to 5.9%. This represents 1.9 to 4.9% steel returned as scrap to the EAF, since mill scale losses in all plants were reported as 1%.

From a theoretical perspective, the energy in hot rolling is primarily determined by reheating requirements[28]. The theoretical energy for deformation is only 0.02 GJ/t, compared to 0.83 GJ/t for heating billets when cold charged[29]. With hot charging of billets at an average of 800^oC, the theoretical heating energy drops by around 65% to 0.29 GJ/t. This highlights the energy efficiency benefits of direct charging of hot billets to rolling mills.

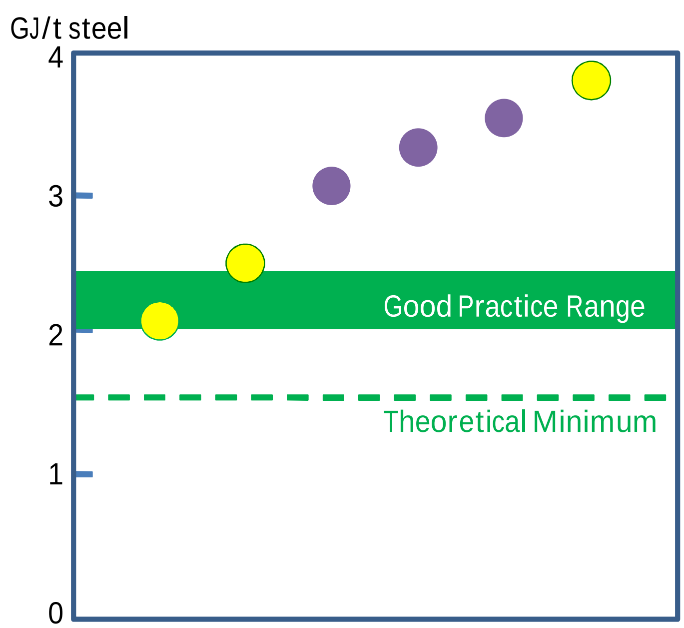
Public and private ownership

The Vietnamese steel industry is being progressively privatised, through the building of private companies and joint private-state equity in the Vietnam Steel Corporation group of companies. The six plants visited in this study were half private and half partly or wholly state owned.

The results for steelmaking production energies are replotted here in Figure 7 below, but this time providing some perspective on the ownership, namely between the privately owned plants (yellow dots) and the full or part state owned plants (purple dots).

The two most efficient plants are privately owned. The least efficient is also privately owned, but it is a new operation with substantial improvements in throughput and efficiency possible over the coming years.

Figure 7



[28] "Theoretical Minimum Energies to Produce Steel for Selected Conditions", March 2000, R.J. Fruehan, O. Fortini, H.W. Paxton, R. Brindle, U.S. Department of Energy.

[29] Assuming a reheat furnace temperature of 1200^oC.

Resource efficiency

From the six plant visits, it appears that the industry is operating essentially on a 'no waste' basis.

Water: all sites have recirculating water systems for cooling in EAF, LF and caster operations, with fresh water used only to make up for evaporation losses.

Slags: all sites send slag for processing, including Fe recovery to the EAF plant, and use of materials in construction.

Dust: all sites visited send their EAF dusts for processing and zinc recovery

Mill scale: all sites send their mill scale to processors, especially pig iron producers

Reject steel: reject steel is sold for lower quality applications or returned to the EAF; all scrap is used or recycled

Broader life cycle perspectives

The data and results presented above were only associated with the direct use of energy and material resources for production on site. This is what can be directly controlled at plant level and therefore should be the main focus for efficiency improvements in operations. However, from a higher level company perspective, and certainly for the steel sector as a whole and its stakeholders (especially government policy makers), it is important to understand all of the energy and resources being used. This means taking a "Life Cycle" view and understanding the off-site as well as the on-site factors.

This broader perspective is also necessary to calculate the greenhouse gas intensity of the plant, company or sector. After all, the biggest GHG emissions for billet production are associated with off-site electricity generation.

Embodied Energy

Considerable energy is used off site to generate electricity, produce pig iron, make lime and so forth. The 'embodied energy' is a Life Cycle basis for measuring energy used in production, when the energy used in supplying the inputs is also included. Taking one of the Vietnamese plants as an example, as shown in Table 8 below, the energy contained in or used to manufacture steelmaking inputs is considerably more than used directly on site. The full embodied energy in this case is $3^1/_2$ times greater than the direct production energy for steelmaking. This means for every GJ directly required at the steel plant itself, the total demand on the energy resources of society and the economy is $3^1/_2$ GJ.

Table 8

Production Energy (On Site Only) GJ/t steel	Embodied Energy (On and Off Site) GJ/t steel
2.5	8.7

For the above example (Table 8), the embodied energy breakdown is shown in Table 9 below. From a total energy perspective, on and off site, it is clear that electricity is the major factor, followed by pig iron production.

Table 9

Energy Form at Plant	Contribution to Total Embodied Energy %
Electricity	64
Pig Iron	16
Coal	10
Lime	7
Electrodes	2
Other	1

Greenhouse Gas Emissions

Vietnam has significant renewable energy in its electricity supply system (eg. around a third hydro-electric power). Therefore billet production in Vietnam has significant GHG advantages compared to countries more dependent on coal for electricity generation. Based on the breakdown of electricity supply provided by Energy Institute[30], we have calculated GHG emissions per MWh in Vietnam to be around 514 kg CO_2equivalent, compared to around 1,000 kg for black coal power and around 1,350 kg for brown coal.

Using The Crucible Group's models, the full Embodied Energy and the Greenhouse Gas Emissions of billet production[31] at the six Vietnamese plants have been estimated, as shown in Table 10 below.

[30] Vietnam energy supply breakdown for the period of 2006-2009 is hydro 32-36%; natural gas & diesel 44-46%; anthracite, oil & imported from China 19 - 21%

[31] Combining steelmaking, ladle furnace and casting

If Vietnam is like most countries, it is quite likely that hydro electricity will not be able to be expanded at the rate required for industrial growth, such as in the steel industry. If the gap is made up by coal fired power stations, then of course the current greenhouse gas advantages for the country will be steadily eroded. At a sector level, the steel industry has a stake in national policy debates on how future energy requirements will be met to satisfy industry and climate change pressures.

Table 10 also includes estimations for the global good practice reference plant, which is operating in a region where electricity is primarily generated from black coal.

Table 10

Production Energy GJ/tonne billet	Embodied Energy GJ/tonne billet	Greenhouse Gas Emissions kg CO_2e/t billet
4.2	12.6	1,237
3.7	10.0	966
3.6	9.1	890
3.4	8.9	783
3.1	8.7	793
2.3	6.9	630
Good Practice Reference Plant		
2.6	9.3	926

Efficiency at the process, life cycle and total system levels

To put energy efficiency into some broader, fundamental system perspectives, the author proposes the concepts of 'Process Efficiency', 'Life Cycle Efficiency' and 'Total System Efficiency'.

- Process Efficiency compares the actual use of energy in production (E_{ACT})[32] to the minimum energy theoretically required (E_{MIN})[33]. Process Efficiency, defined here as E_{MIN}/E_{ACT}, is increased by using less energy on site, which is the direct responsibility of the plant people
- Life Cycle Efficiency compares the actual use of energy in production with the full embodied energy (E_{EMB}), which includes off-site factors. Life Cycle Efficiency, defined here as E_{ACT}/E_{EMB}, is improved by using less energy on site more efficient energy supply systems and higher proportions of renewable energy. This is a shared responsibility between the steel company (eg. through process efficiency and energy/fuel selection), the energy sector (eg through efficient technology and distribution systems) and the government (eg. through energy policy, particularly in relation to electricity generation).

[32] E_{ACT} is the same as Production Energy, shown in Table 2 and Figure 3 etc.

[33] E_{MIN} for EAF steelmaking is taken to be 1.6 GJ/tonne, the 'theoretical minimum'

- Total System Efficiency compares the theoretical minimum energy required in production (E_{TH}) with the full embodied energy (E_{EMB}). Total System Efficiency, defined here as E_{MIN}/ E_{EMB}, is Process Efficiency multiplied by Life Cycle Efficiency[34].

The process, life cycle and total system efficiency definitions and the results of calculations are shown in Table 11 below, for the case of EAF steelmaking, the most energy intensive step in the production sequence. The table lists the six Vietnamese plants in order of increasing on-site energy efficiency (deceasing Production Energy). These plants all use electricity from the Vietnamese grid, so the main factor effecting Life Cycle Efficiency for the different plants is the amount of pig iron used in each plant[35].

Table 11. Efficiency Perspectives for EAF Steelmaking

Process Efficiency (1)	Life Cycle Efficiency (2)	Total System Efficiency (1x2)
Theoretical Minimum Energy (E_{MIN}) divided by Actual Production Energy (E_{ACT})	Actual Production Energy (E_{ACT}) divided by the total Embodied Energy (E_{EMB})	Theoretical Minimum Energy (E_{MIN}) divided by the total Embodied Energy (E_{EMB})
42%	33%	14%
44%	38%	17%
48%	40%	19%
52%	38%	20%
62%	36%	22%
76%	30%	23%
Good Practice Reference Plant		
67%	26%	17%

The results of similar calculations for the global good practice reference plant are also included in Table 11. It is interesting that at a Life Cycle level, it is actually less efficient than many of the Vietnamese plants; this is because the embodied energy of the global reference plant is higher than the Vietneamese plants due to its dependence on black coal power and its higher use of pig iron. The Vietnamese plants benefit from the higher proportion of renewable energy (especially hydro) in electricity generation.

The Total System Efficiency is quite low (in the range 14 – 23%), which highlights that the theoretical minimum energy required to make steel is a small fraction of the total demand made on the energy resources of society and the economy.

34 (E_{MIN}/E_{ACT}) x (E_{ACT}/E_{EMB}) = E_{MIN}/E_{EMB}

35 On an equal weight basis, the embodied energy of carbon contained in pig iron is considerably higher than the embodied energy of carbon contained in coal. Both of these include the energy associated with mining, coal washing and transport, but the embodied energy of the carbon in pig iron includes the additional energy associated with cokemaking and ironmaking.

In a sustainable future, steel plants in Vietnam and globally would have very high production energy efficiencies and would rely predominantly on renewable energy resources. That is the combination that fundamentally underpins high performance steelmaking and low greenhouse gas emissions.

Conclusions from Stage 1

The Vietnamese steel industry is growing rapidly[36] and it has the hallmarks of a new industry taking shape in a developing economy. With such a rapidly growing industry, there is a need and an opportunity for a systematic approach to education and capability building, including best practice and knowledge sharing. At least one plant in this preliminary study is world class from an energy efficiency perspective, but most are considerably less efficient. Batch sizes are small by global standards and most of the people employed in the plants have only a few years experience in the industry.

Opportunities for improvement

Existing and new plants are able to access best available technology (BAT) from global equipment suppliers, but technology alone cannot ensure good practice or good efficiency. A priority needs to be placed on increasing the sector's capabilities for acquiring/digesting new technology, managing and achieving systematic improvement in productivity and efficiency, getting the best performance from existing equipment and being able to introduce new technology efficiently and effectively.

Since some of the larger, more modern plants visited in Stage 1 are actually inefficient by global standards, there is an opportunity for improvement through optimisation of productivity and efficiency. Some of the small plants have demonstrated the capacity to increase production significantly, and this is presumably an opportunity for other small plants to grow. This study suggests that there is considerable opportunity to increase throughput across the sector. In the view of the author, it is reasonable to expect that total production at the six plants could be increased by 300,000 tonnes per annum or more. This would come primarily from progressive upgrading of two of the smaller plants and by gaining experience and building capability at the newest of the larger plants.

Priority should be given to the EAF steelmaking area, which is the most energy intensive step in the making of steel products and also where there is the greatest room for improvement (see Table 3). One aspect of the newly expanding industry is that the scrap supply system is still immature. Improving scrap quality will need to be an integral part of achieving world class process performance.

The approach should be to focus primarily on increasing productivity, lowering costs and improving efficiency with the existing equipment at a plant. This will help to increase throughput and sales, raise revenues and build management and operator competence. That will prepare the plant for the next step in upgrading the facilities through capital investment in improved technology and expansion projects. The improvement cycle can then continue with further increases in productivity and efficiency, and so on.

Growth in the sector means that new plants will be built and these can be with bigger batch sizes and best available technology (BAT). This is an opportunity for technology transfer via the global equipment suppliers.

[36] Steelmaking production has increased by about a factor of ten in less than a last decade.

Efficiency Evaluation Tool

The Stage 1 analysis presented above was conducted using complex models by The Crucible Group in Australia. Subsequently a more simple to operate, spreadsheet based version has been developed by the company especially for UNIDO to make available to the Vietnamese steel industry.

The tool provides the framework to record basic plant information about the main process units and production levels at a plant[37]. Process inputs and outputs for steelmaking , casting and rolling (on a per tonne of billet or product basis) are then entered into the spreadsheet[38] and the model calculates the equivalent annual use of these inputs and the liquid steel production rate. The model then calculates the production energy, embodied energy and greenhouse gas emissions of the plant, with a breakdown of on-site and off-site site energy and greenhouse gas emissions for the different process inputs and sub-totals for steelmaking, casting and rolling stages of production.

The model generates graphs of the relative contribution of the different process inputs to the total production energy, on-site and off-site greenhouse gas emissions of the plant. It is envisaged that the model could be transferred to the plants as a self evaluation tool[39].

Individual plants can be shown the analysis for their own plant, check the data and learn how to use the Efficiency Evaluation Tool.

The tool has been used in the first instance by the National Consultant, Mr Chu Duc Khai, to extend the analysis to the remaining steel plants[40], as presented in the next section of this report (Stage 2).

37 Plant descriptions and data such as the age and size of the main process units and production rates of billets and rolled product

38 Steelmaking inputs and outputs to the model are the amounts of scrap, pig iron, electricity, coal, natural gas, fuel oil, diesel, lime, oxygen, argon, water, electrodes and slag. Casting and ladle furnace inputs and outs are electricity, electrodes, argon and water and returned steel. Rolling mill inputs and outputs are billets, electricity, natural gas, fuel oil, diesel, water, returned steel and millscale.

39 Technical staff could use the tool to monitor energy efficiency as conditions change at the plant, and also to predict the energy efficiency gains that could be expected from improvement projects.

40 Six plants were included in this first stage, from the total of 18 steelmaking plants in Vietnam.

3. CONSOLIDATED ANALYSIS OF EIGHTEEN STEEL PLANTS IN VIETNAM

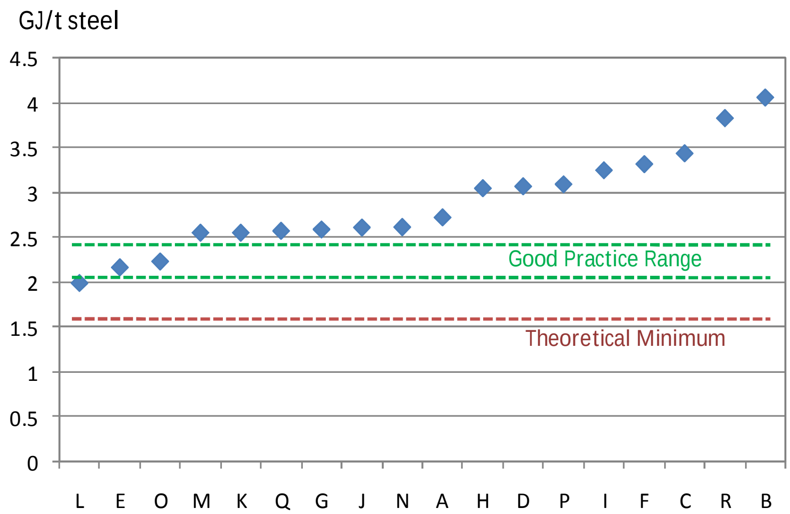
The preliminary analysis presented above for the six plants has been extended to all eighteen of the steelmaking facilities in Vietnam. The visits to the plants were undertaken by the National Consultant, Mr Chu Duc Khai, in contact with technical staff at the remaining twelve plants. Data was collected and analysed using the Efficiency Evaluation Tool. The consolidated results for the eighteen plants are presented in this section. Energy and efficiency results are concentrated on the EAF steelmaking area as this is the most energy intensive part of operations with the greatest opportunity for improvements.

The eighteen plants have been labelled from A to R to maintain anonymity; plant data has been provided on a confidential basis for this study and the details of each plant analysis are provided only to that specific plant.

Production energy

Production energy results in EAF steelmaking are shown in Figure 8 below in order of decreasing efficiency (increasing production energy intensities). For the eighteen Vietnamese plants, one can see that three are within the global good practice range.

Figure 8



For reference, Figure 9 below highlights the original six plants analysed in Stage 1 (compare Figure 3). It can be seen that these selected plants were indeed quite representative of the range of energy efficiency performance of the Vietnamese steelmaking sector as a whole.

Technology

Figure 10 below highlights four of the plants that have larger EAF steelmaking vessels (50 tonnes and above) and generally more advanced technology. This reinforces the argument that technology is important in achieving energy efficiency, but it is not enough. Performance depends on 'technology digestion', which is the capacity to introduce new technology effectively and achieve a high degree of process control, optimisation and continuous improvement.

Figure 9

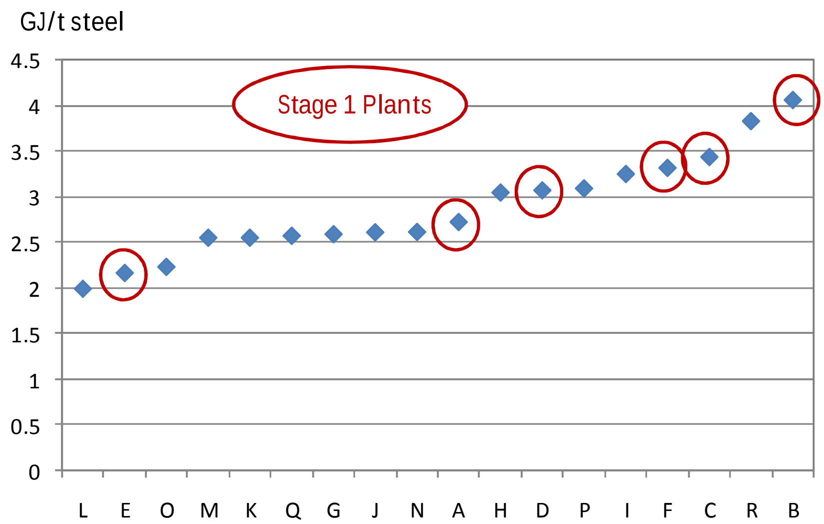
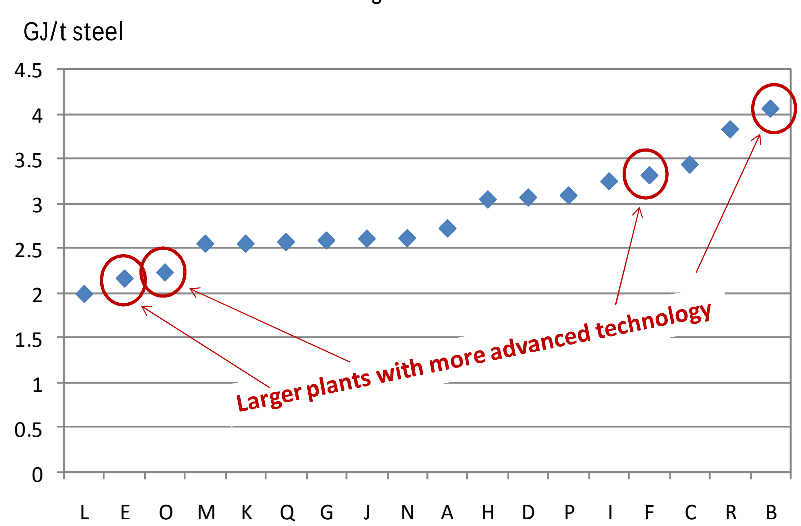


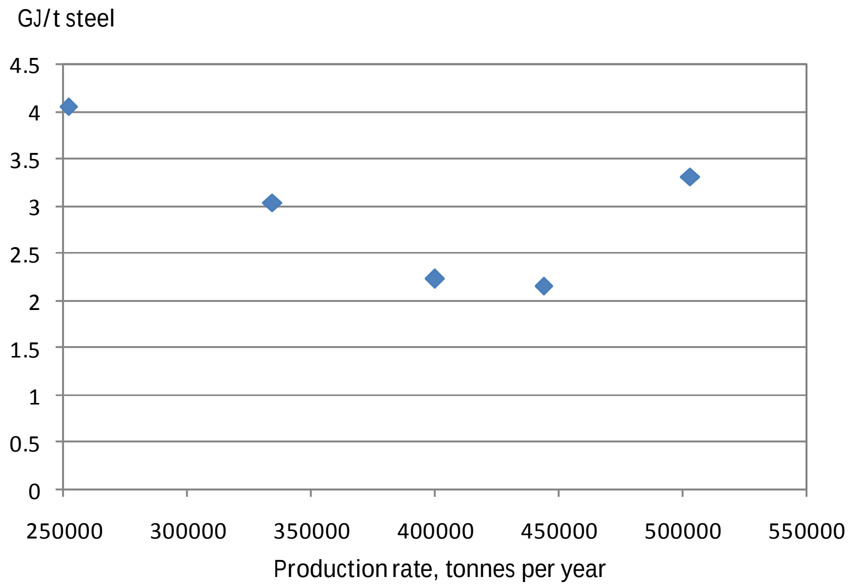
Figure 10



Productivity

The benefits of increasing productivity are shown in Figure 11 for larger facilities with production rates of 250,000 tonnes of billets per year. This shows a general trend for energy efficiency to improve (lower production energy intensity) as productivity increases. The exception, a Stage 1 plant with the highest production rate, is one where increased production and shorter tap to tap times have been achieved with considerable fuel inputs to the process; there is probably significant room here for optimisation of productivity and energy efficiency.

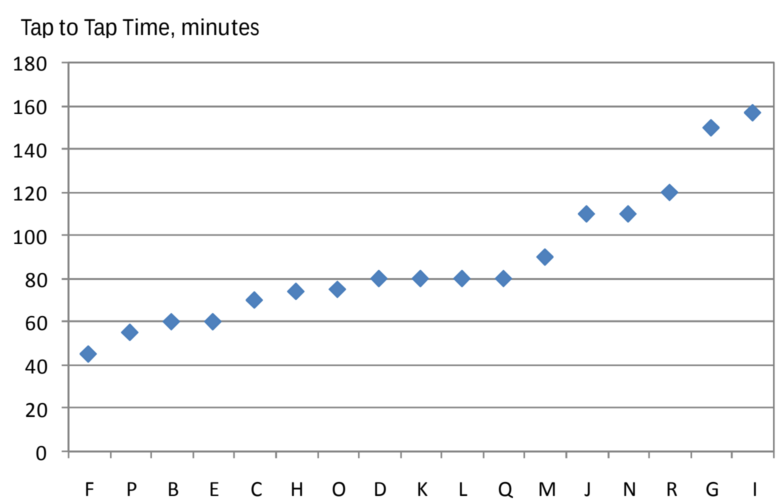
Figure 11



Tap to tap times

Tap to tap times in good practice operations are less than 60 minutes. In the Stage 1 plants, tap to tap times varied from 45 to 96 minutes (see Table 4). For the additional plants visited in Stage 2, seven had tap to tap times within that range and five had longer tap to tap times, as shown in Figure 12 below. Combined improvements in energy efficiency and productivity should be reflected in reduced tap to tap times, and considerable improvements are possible with progressive advances in operating and equipment capability.

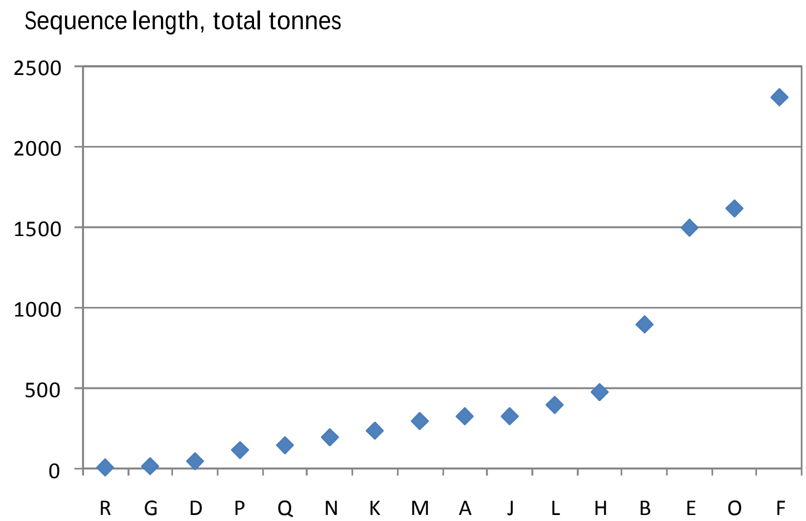
Figure 12



Sequence lengths

Three plants have demonstrated the capacity to achieve sequence casting lengths above 20 ladles without interruption. Figure 13 below shows sequence lengths for the eighteen plants, expressed in terms of total tonnes cast. This is an area where Vietnamese plants generally are far below global good practice (see discussion around Table 5), due primarily to small EAF furnace sizes.

Figure 13



Apparent metallic feed losses

Stage 1 highlighted the importance of scrap quality in achieving good performance in steelmaking (see discussion around Table 6). High apparent metallic feed losses are a reflection of 'dirty' scrap, which requires more fluxing and reduces yield. Figure 14 below shows the apparent metallic feed losses for all eighteen plants, all well above the good practice reference plant.

Figure 14

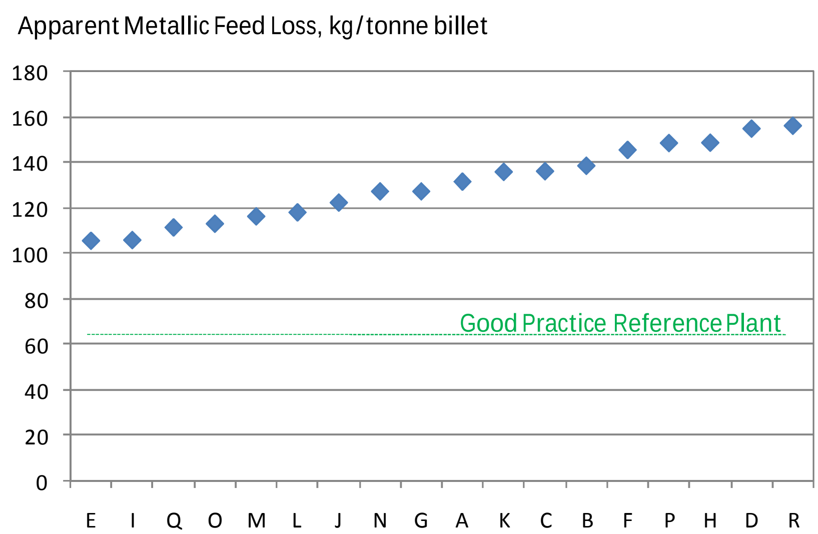


Figure 15 below shows the general trend for lime additions to increase with higher apparent metallic feed losses.

Figure 15

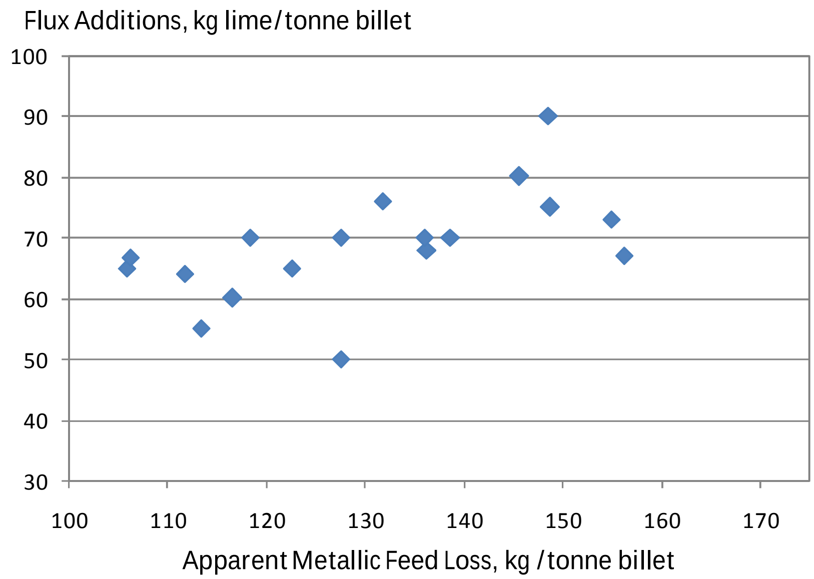
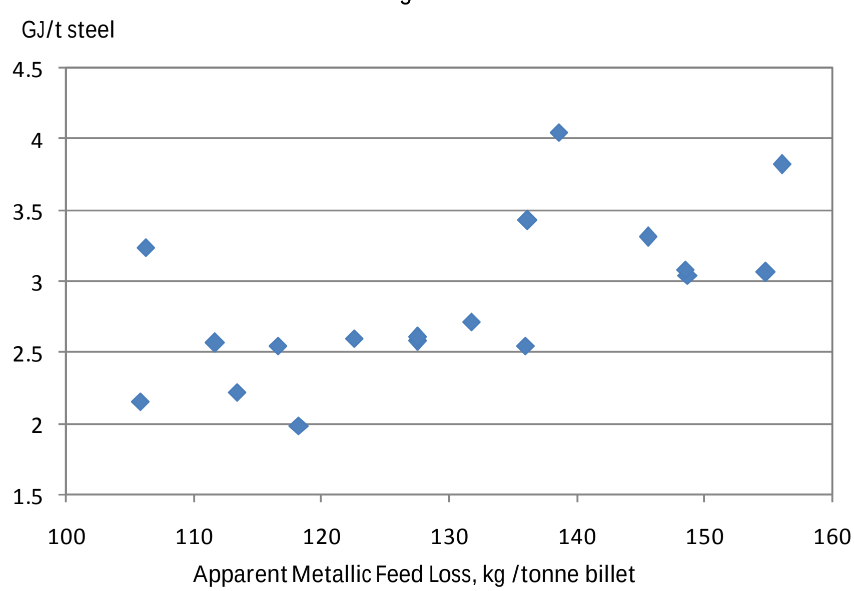


Figure 16 shows a general trend for energy efficiency to improve (lower EAF production energy intensity) with better scrap quality (lower apparent metallic feed losses). The three most energy efficient plants (production energy below 2.5 GJ/t steel) have relatively low metallic feed losses within the overall range.

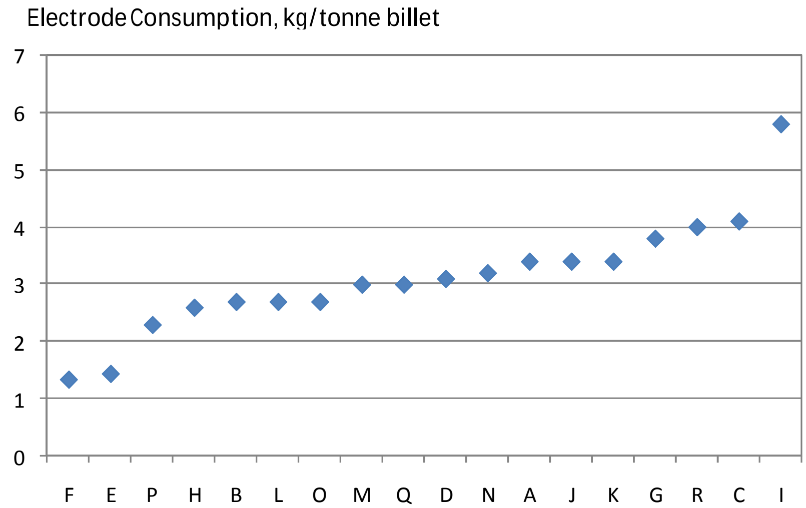
Figure 16



Electrode consumption

Low electrode consumption is a reflection of stable operations (see discussion around Table 7). Figure 17 shows EAF electrode consumption for the eighteen Vietnamese plants[41].

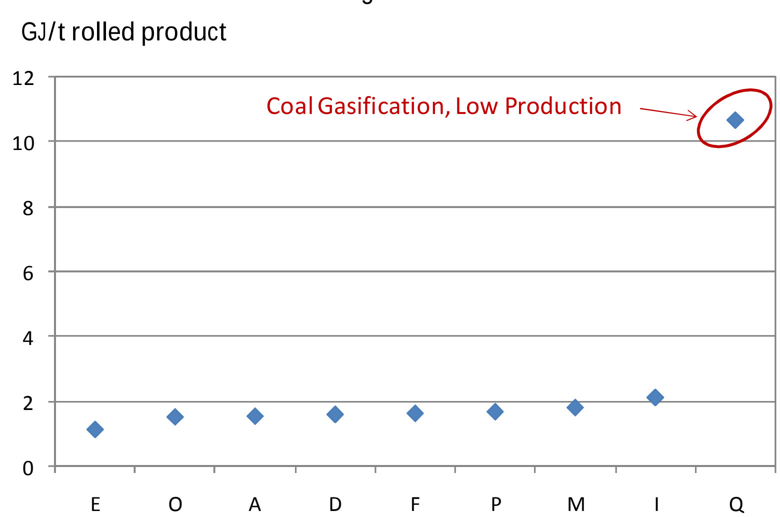
Figure 17



Rolling mill energy consumption

The production energy associated with rolling is presented in Figure 18 below. The plant with exceptionally high energy use (Plant Q) is one where the reheat furnace energy is provided by gasification of coal and where production is far below capacity due to poor market conditions.

Figure 18

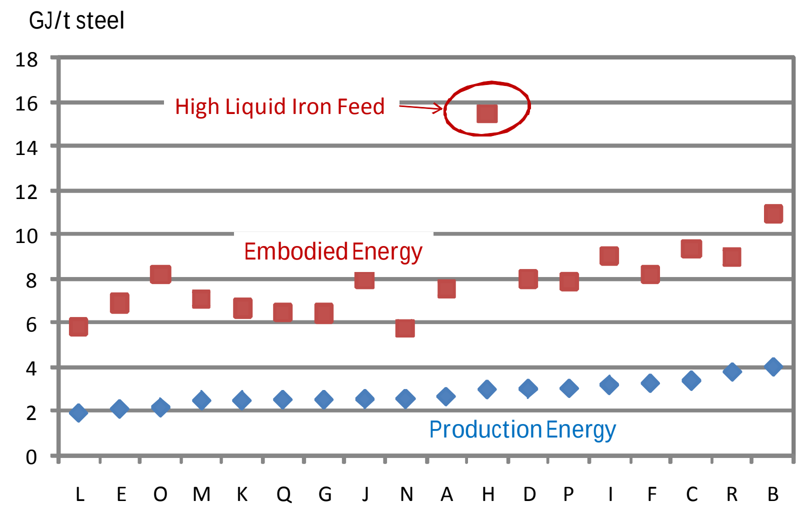


[41] Note the good practice reference plant had an EAF electrode consumption rate of 0.45 kg per tonne of billet

Embodied energy

Production energy is only that which is used on site directly in operations. Embodied energy is a Life Cycle measure of the total energy of production, when one includes the off site energy needed to generate electricity and so forth (see discussion around Tables 8 and 9). Figure 19 shows both the direct Production Energy and the full Embodied Energy for EAF steelmaking at the eighteen plants. The variations in embodied energy are mainly linked to the different amounts of pig iron used in steelmaking. The plant with exceptionally high embodied energy (Plant H) is one where liquid iron is charged to the EAF, at a rate of around half a tonne per tonne of steel.

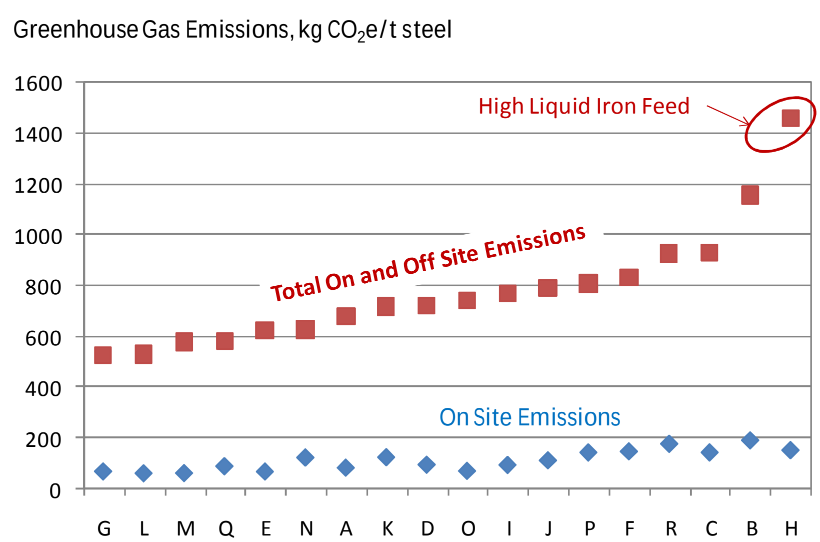
Figure 19



Greenhouse gas emissions

Figure 20 below shows the greenhouse gas emissions associated with steelmaking at the eighteen plants (see discussion around Table 10). This shows both the direct on site emissions and the full Life Cycle emissions, on and off site.

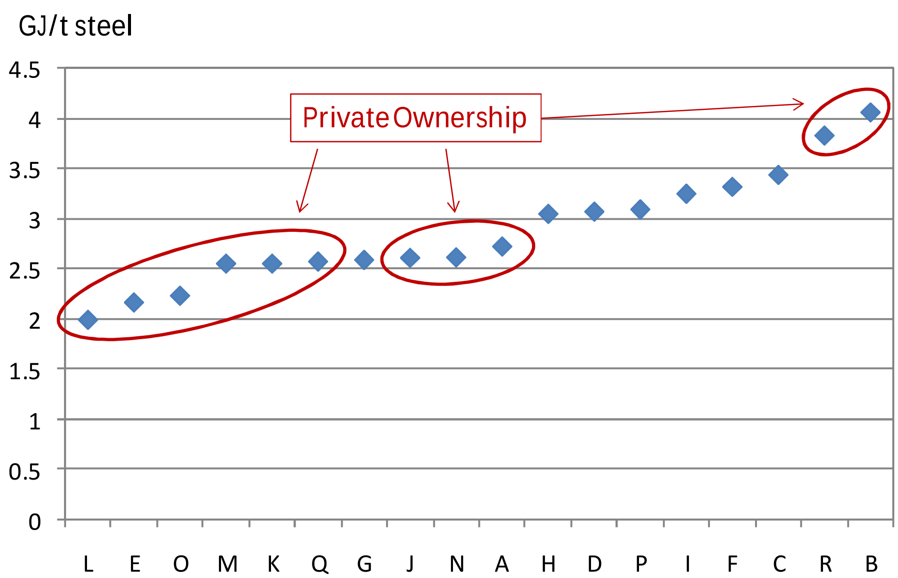
Figure 20



Public and private ownership

Figure 21 distinguishes between those plants which are 100% privately owned and those that are wholly or partly state-owned. There is a clear trend emerging where private companies tend to be more energy efficient. For instance, nine of the ten most energy efficient Vietnamese plants are privately owned. However, it is also true that the two least efficient plants are also privately owned, but these are new plants with considerable room for improvement as operational capabilities improve.

Figure 21



4. CONCLUSIONS AND RECOMMENDATIONS

Knowledge sharing

The industry should consider ways to enhance best practice and knowledge sharing between different plants to improve the performance and global competitiveness of the Vietnamese industry. The priority should initially be in EAF-based steel making, where there is the greatest room for improvement. This should include feed materials supply as well as process and equipment performance. It should cover plant operations from scrap preparation to billet production.

UNIDO should give consideration to bringing in an international consultant in the area of high performance steelmaking. Such an expert should have a strong technical and practical understanding of EAF steelmaking and also a proven track record in improving performance, expanding production and introducing new technology. It would be very important for the expert to have considerable experience and understanding of continuous improvement methodologies, such as Total Quality Management (TQM), applied to steelmaking. A mission to Vietnam of such an expert could combine visits to individual plants and a sector wide Workshop on improving the efficiency and performance of EAF-based steelmaking plants from scrap supply to billet production.

Setting targets

The Vietnamese steelmaking plants should consider setting some joint targets for improving energy efficiency relative to global benchmarks. The scale and speed of improvements would need to be agreed between the companies. For example, each company could try to close the gap between the actual energy efficiency at a plant and global good practice by some agreed amount each year[42]. Energy efficiency improvements should be driven by activities that improve the effectiveness of management and operating systems as well as projects that expand facilities and introduce better technology. Improving energy efficiency should be seen as an integral part of continuously reducing costs per tonne and increasing total production.

Demonstration projects

The steel industry is central to Vietnam's economic development, hence there should be opportunities to get funding for showcase projects at selected sites to demonstrate energy and resource efficiency initiatives. Whilst the projects might be operated from one site, they should be managed to maximise knowledge sharing. Lessons learnt at demonstration sites could be transferred across the industry. Demonstration projects would be an effective way to publically highlight the industry's efforts to improve performance. Demonstration projects could be established around new ways to improve scrap quality, to improve process efficiencies, to increase production, to decrease greenhouse gas emissions, to upgrade facilities or to introduce new technologies.

[42] Say for example the improvement target for EAF operations was 10%. Then an EAF plant with production energy of 3.8 GJ/t compared to Global Good Practice of 2.1 GJ/t would try to reduce energy use by (3.8 – 2.1) divided by 10 = 0.17 GJ/t in the first year. A plant with energy use in steelmaking of 2.6 GJ/t would try to reduce this by (2.6 – 2.1) divided by 10 = 0.05 GJ/t.

Organisational structure

Effective collaboration across the Vietnamese steel industry to improve efficiency and productivity will need some basic organisational structure, some sort of forum to share ideas and coordinate activities. The industry should consider setting up a formal network with representatives from all steelmaking plants, for instance a "Steel Industry Efficiency Forum", to take the UNIDO/VSA initiative forward from here.

This could agree and set industry wide improvement targets and provide consolidated reports on progress. It could coordinate best practice and knowledge sharing activities across the sector, develop training tools, hold education workshops and coordinate visits by international experts and technology suppliers. It could develop and promote special initiatives and demonstration projects. It could facilitate engagement with the government and other stakeholders around energy and climate change policies. It could help raise the public profile of the industry in these important areas.

Any formal network that is established should of course work very closely with the Vietnam Steel Association. VSA could provide the overarching coordination structure. In the formative stages, it is recommended that UNIDO remain actively involved in the initiative, as part of its ongoing commitment to Green Industry. Any steering committee that is formed should have representatives from the private and state owned companies, as well as VSA and UNIDO.

These are matters for the industry to discuss and decide. A foundation meeting could be held with representatives from all the steelmaking companies to discuss the purpose and value of setting up a formal network and the appropriate structure. Such a meeting could elect a steering committee and set priorities for the coming year. It would also be an opportunity to report on the initiative to date, with the analysis extended to all eighteen plants. There may also be an opportunity to combine such a meeting with a one-day educational workshop with an international consultant, for instance on high performance EAF steelmaking.

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Acknowledgement

I would like to express his gratitude for the opportunity to visit Vietnam and work closely with the UNIDO team, the National Consultant and VSA, during ten very busy days in December 2010. I would particularly like to thank the people in the plants for their hospitality and openness with data. I have no doubt that the future for the Vietnamese industry will be one of growth and continuous improvement. I hope this report can make a small contribution to that journey.

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