Abstract
A description is given on the practice in the Steel Plant of SSAB Tunnplåt AB in Luleå and on the progress in recirculation of residuals and decreasing environmental impact.
An extensive study on greenhouse gas in steel production up to slabs was carried out by SSAB during the years 2000-2002. Present and new processes and possible alternatives were studied, as well as the effect of the product programme. Different emission alternatives were studied using global calculation (SSAB + CHP plant). Conclusions on long-term and short-term possibilities were discussed.
Major efforts have been made to develop the process integration technology. In Sweden, this has been realised within a national programme for the total process industry (steel, pulp and paper, petrochemicals, food). There are synergies, as the optimisation problem itself is relatively similar independent of industry sector. Similar efforts are made in other Scandinavian countries and a joint Scandinavian programme has been carried out.
Discussions on ore-based vs. scrap-based metallurgy are often based on the assumption that these roads are alternatives to each other. This is not the case; instead, ore-based metallurgy is the first step in a series of subsequent life cycles, and both roads are necessary to carry out the “cycle of cycles”. The philosophy of this is discussed.
The Scandinavian climate makes the use of residual heat energy for district heating and cooling economically important and a part of energy/sustainability considerations.
Significant R&D efforts are and have been made to increase recirculation. Two programmes/centres of excellence in this field are described.

Local Perspective: Material Flows and Recirculation at SSAB TUNNPLÅT AB in Luleå
SSAB Tunnplåt AB in Luleå is an integrated plant including Coke Ovens, Blast Furnace and a BOF steel making plant with 100 % Continuous Casting of Slabs. Slabs are transported by train to the rolling mills of SSAB Tunnplåt AB, which are situated approximately 800 km away. The surplus gas is used in the local CHP plant and covers the plant’s use of power and nearly all of the residential heating demand in Luleå. The price of district heating is the lowest in Sweden. The gas balance differs from many other integrated steel plants in the following ways: there are no reheating furnaces using fuel gas and the coke oven plant under firing is done with 100% coke oven gas. The recirculation of residual materials is shown schematically in Figure 1. There is a partial recirculation of dust and sludge. The dry dust from the blast furnace and the coarse fraction of the BOF sludge are recirculated as briquettes into the blast furnace. For the fine fraction of the BOF sludge and the BF sludge, there is no technique for recirculation, and those materials are presently being deposited as landfill. The BF slag is air-cooled and subsequently used for road building. The use of that slag varies from year to year, as it is dependent on ongoing road building projects in the area. With the present structure of the concrete industry, the market for slag cement is not sufficient to motivate slag granulation in Luleå. Approximately 2/3 of the BOF slag is recirculated to the BF, the rest is deposited as landfill. Limiting factors for recirculation are the accumulation of P and V in the system, and to some extent, the grain size of the slag. The ambition is to run the BF at a stable production rate. Fluctuations in the steel plant production sometimes produce a surplus that is cast as bay cast pig iron. Some of this pig iron is exported and some is used as scrap at the Luleå plant.
Daily process improvements, modern processes and cleaning equipment, etc have gradually decreased the environmental impact on the surroundings. The effect is visible both from studies of the direct effect on the surroundings (moss sampling) and from measured emission and landfill data. Some examples are shown in Figure 2.

Figure 1 Recirculation and use of residual materials at SSAB Tunnplät AB in Luleå in 2003.

a) Moss studies: Effect on surroundings  
b) Example of key values

Figure 2 Some effects of continuous work to minimise environmental impact. (Source Environmental report SSAB Tunnplät AB Luleå 2003)

SSAB’s Greenhouse Gas Study

General
An extensive study on greenhouse gas in steel production up to slabs was financed by SSAB during the years 2000-2002 [2,4,15]. The aim was to study the possibilities to decrease the local emissions of greenhouse gases, especially CO₂, using already existing technology. The study should cover the total effect on the local system; i.e., the effects on the local CHP plant and district heating, etc. should be included. A group from MEFOS and SSAB carried out the work with a project manager from MEFOS. Present and new processes and possible alternatives were studied, as well as the effect of the product programme. Different emission alternatives were studied using global calculation (SSAB + CHP plant). Conclusions on long-term and short-term possibilities were discussed. The study consisted of five parts with the following main aims:

1. Historical processes for iron and steelmaking
2. Present processes for iron and steelmaking
3. New processes for iron and steelmaking
4. Effect of the product programme and its development
5. Calculation of the effect of different process constellations on the emissions from SSAB as well as from the total system.

The calculations in part 5 were carried out using a spreadsheet model including the units of the steel plant as well as the CHP plant and district heating. Figure 3 shows the structure of the model.

The different processes are represented by individual heat and mass balance models, which communicate with an interface model. The interface translates the material flows of the units into a net flow for the system. A separate CO₂ model converts the data into CO₂ emissions. One reason for making that calculation in a separate “box” was that the study should include both an inventory analysis (emissions from SSAB’s chimneys) and an impact assessment analysis (effect also on the emissions from surrounding systems). With the model of Figure 3 the different types of analysis could be carried out, using the same calculated material flows, simply by changing settings of the CO₂ calculation module.

The studies of different processes in parts 1-3 resulted in a database of process performance data and flow sheets. In part 5, different scenarios were studied by including these processes as an integrated part in the system, using the “New process” module in Figure 3.

**Possible improvements using the existing process route**

The potential effects of improvements within the existing process structure were calculated in the study. Some main results are shown in Figure 4. The upper part of the diagram shows that daily work on improvement of processes, yield, etc is important. The bar “hot metal logistics” refers to the practice of casting hot metal as bay-cast pig iron when there is a temporary imbalance between steel plant and hot metal production. When that cast iron is used in the steel plant, it carries a load of CO₂ from hot metal production and replaces scrap that has no such load. The amount of PCI seems to have almost no effect. For the SSAB case the effects of coke saving, PCI coal and oxygen for flame temperature compensation seem to match each other. Some energy-saving equipment could decrease the emissions, however the effect is limited.
Figure 4 Calculated effect of process improvements on climate gas emissions.

The two lowest bars demand cooperation with external users. The hot-water balance bar refers to the fact that the consumption of district heating in Luleå during the main part of the year is lower than the production capacity of the CHP plant. The bar shows the effect of a hypothetical case, where the system is expanded so that all heat is used to replace external fuel. The slag-granulation bar refers to a case where all BF slag is granulated and used as slag cement in concrete. The CO₂ gain occurs at the cement manufacturer. At present, that is not possible because of the existing structure of Swedish cement production and the market. Exploitation is possible only in cooperation with those parties.

**Possible improvements using another process route**

The effect on the CO₂ emission from the Luleå system was calculated for some scenarios where alternative iron and steelmaking processes were used instead of the BF-BOF route. In Figure 5 the main results of those calculations are compared to the results using the existing blast furnace route. The upper bar shows the span of CO₂ emission obtained with some different calculating alternatives using the BF route.

The second bar shows the emission if COREX is installed instead of the Blast Furnace. Corex is presently the only melting reduction process in practical production. The raw material in those cases is different from the high-Fe LKAB pellets available in Luleå. Thus, there is some uncertainty in the expected production values for the Luleå case. However, extensive model calculations on that case were carried out in a previous study on a possible COREX application at SSAB Tunnplåt in Luleå. Calculated data from that study were also used. These data represent the lowest calculated emissions in the COREX bar. However, even with those data, the emissions are much higher than those obtained for the blast furnace case. The main reason for this is a high amount of by-product fuel gas, together with the fact that there is insufficient use of that fuel in the local gas and energy balance.
Figure 5 Potential CO₂-saving with new process routes at SSAB Tunnplät AB in Luleå. The range of variation is shown for bars that include more than one case.

The third bar shows the effect of applying one of the new melting reduction processes. The process chosen for the comparison was SIDCOMET. The reason for choosing that particular process was that it was pilot-tested, and that some indications on a possible test in production scale existed at that time. Also, the data published on fuel consumption were relatively favourable. Even with this data, the emission is higher than in the blast furnace case.

The lowest bar shows the emission with EAF using scrap or natural-gas-based DRI. The emission with scrap remelting is of course lower, as the material is already reduced. Also, natural-gas-produced DRI can give a low emission. That alternative involves DRI production close to the gas source, not in Luleå.

Sensitivity to calculation mode and electricity grid
The main calculations were carried out using impact assessment mode and an electricity grid with 0.6 kg CO₂/kWh. To study the effects of these parameters, the cases of Figure 5 were recalculated using both Impact Assessment and with electricity grids ranging from 0 to 0.6 kg CO₂/kWh. A comparison of the results showed that these changes influenced the absolute emission value, but the order between the cases was the same. I.e., The conclusions of the study would have been the same even with another choice of calculation mode or electricity grid.

General conclusions of the CO₂-study
At present the new ironmaking processes are no alternative for decreasing emissions. One reason is that they were not created for that purpose, but rather to make possible ironmaking with other materials, e.g., to avoid sintering processes. In the long-term perspective this can be expected to change as new processes are developed with the main aim to decrease climate gas emissions. Such developments demand an effort that is too large for a single company. For this reason, SSAB has decided to join the common European ULCOS project.

Ore-based vs Scrap-based Metallurgy
The remelting of scrap creates less CO₂ than producing new steel from ore. This leads to the question from community, environmentalists, etc: “Why do you not use scrap instead of ore?” The question in itself is logical. However, it is based on the misunderstanding that EAF
remelting is an alternative to ore-based steelmaking. It is not. Instead, both process routes are parts of a sequence of cycles, where ore-based steel is the first step and the following steps are based on remelting, e.g., in an EAF. Figure 6a shows the steel and CO₂ in the individual steps in such a cycle. The amount of steel corresponds to a case where 1 tonne is produced in the total sequence of life cycles. The CO₂ emissions from the two processes are those calculated in the previously described CO₂ study. Figure 6b shows the mean CO₂ emission from the total sequence with different percentages of recovery.

![Graph showing steel and CO₂ in individual cycles with 50% recovery in each step](image-a)

![Graph showing mean CO₂ emission for the total sequence with different recovery percentages](image-b)

**Figure 6** Stepwise production of 1 tonne of steel in a series of life cycles with BF/BOF in the first step and EAF remelting of the recovered scrap in the following steps

Obviously, the most important factor is to increase the recovery rate. Moving scrap melting The author is of the opinion that steel plants close to iron ore mines should use ore and those based on scrap melting should preferrably be localised close to the main scrap sources.

**District heating and cooling**

In Sweden district heating covers half the market for heat demand in buildings. Sweden is prominent regarding recovering of industrial waste heat into district heating. Half of the theoretical potential of industrial waste heat is used in district heating networks. That is a remarkably high level and can still be improved. Industrial waste heat is produced in all process-industry sectors, the food industry as well as pulp and paper and the iron and steel industries [6]. The energy-intensive industries are usually situated outside the heat-consuming population centres. A further expansion of recovery of waste heat for district heating is possible only by expanding the network into those centres. One obstacle is that environmental policy and legislation awards environmental “points” for waste incineration and use of “green fuels” but nothing for recovery of waste heat. If municipalities are rewarded for incinerating waste, they tend to favour that practice instead of using available industrial waste heat.

It is environmentally bad practice to allow surplus heat from industrial processes to be released as waste and then to generate the same amount of heat once again by incinerating waste. It would be better if waste heat were used where it is available and waste and green fuels were used where waste heat is not available. There has been some difficulty in communicating this to the legislators.
One possibility for improving the use of heat is to install adsorption coolers and use the surplus heat to produce cooling. This will also help to minimise seasonal variations, as the need for cooling is lowest when the need for heating is greatest, see Figure 7.

![Figure 7 Seasonal variation in district heating](image)

One obstacle is the capital investment. The technique also requires a certain minimum volume (in the range of around 1 MW) and the individual users must be smaller. Perhaps a unit that is somewhat too large for the first user would be preferable to encouraging other, smaller users to connect to the system.

**National efforts on process integration**

The material and energy balances in and around a modern integrated steel plant form a very complicated system with interactions both within the plant and between the plant and the surrounding community. Thus, global optimisation is needed to avoid sub-optimisation. The importance of this for energy saving was realised in the mid-'70s. A separate science, PROCESS INTEGRATION, was formulated to study the problems of global energy optimisation of industrial systems. National programmes have been formulated and carried out in all the Scandinavian countries. A Nordic research programme was carried out in cooperation between the Scandinavian national programmes. Also, international cooperation on specific areas was organised within the IEA. The Swedish national programme was carried out as a cooperative effort with partners from the Swedish Energy Agency, process industry and academic research. The programme was common for all the entire Sweden process industry. The background is that optimisation problem as such is similar between industry sectors, even if the processes are different. The programme was financed by the Energy Agency with industrial co-financing of the development projects. For the steel industry, SSAB Tunnplåt AB constituted a major case study. An optimisation technique, the MIND model, based on mathematical programming, was developed and applied on different energy optimisation problems for the system SSAB-CHP Plant-District heating. It was shown that this was a forceful tool with practical application. The tool includes a non-linear optimisation procedure. It was shown that the use of that procedure gave better results than just a global simulation of predefined cases. It was realised, during the cooperative research on recirculation (MIMER see below), that this technique could also be of value in bringing about a global minimisation of the environmental impact of metallurgical production systems. The existing steel-plant model was modified into a total model for optimisation of CO2 emission, energy and landfill. It was shown that the model was useful and produced valuable results. In this case, the work was also carried out using both simulation of predefined cases and the built-in automatic optimisation.

In Figure 8 the effect of using the optimisation tool is illustrated using data from that study. The decrease of landfill was the main issue. The use of the optimisation procedure has...
resulted in reduced landfill, and it has enabled a practice whereby not only landfill, but also CO2 and energy are minimised.

This type of co-optimisation is necessary if the industries are to meet future demands on a sustainable practice. This will require further development of the process integration technology for this type of case. As that type of optimisation is theoretically and practically complicated, it will also demand increased knowledge and qualified people both in institutes and in the industries themselves. A concentrated effort on theoretical and practical R&D is necessary to create both knowledge and new cadres.

MiMeR effort on Recirculation of raw materials

MiMeR (Minerals and Metals Recycling Research Centre), a centre for research and development of recycling of minerals and metals, is one of 28 Swedish centres of excellence that were founded in 1995. The total financing is approximately MSEK18/year with 33% each from VINNOVA (state funding), by industry and LTU (Luleå University of Technology). Researchers from Swedish and Finnish industry, LTU, Mefos (the Metallurgical Research Foundation) and CBI (the Swedish Cement and Concrete Research Institute) carry out the work. MiMeR has presently 22 member companies and research foundations from different industry sectors: metals and minerals producers, mining, energy producers, cement industry, companies dealing with recycling, by-product processing and scrap treatment, and suppliers to steel industry. The projects are divided into demonstration projects and long-term research studies. PhD students are involved in both types of projects. There are three programme areas: I, Dry and wet fine particle materials, II: Slag and ashes and III: Metals. The focus is on areas I and II.

The aim of area I is to minimise landfill through increased recycling and decreased generation of residues. Energy is also taken into consideration. Gas cleaning dust and sludge, mill scale, mill scale sludge, pickling sludge and waste material from treatment of scrap are studied. Demonstration projects are carried out on dust generation mechanisms and on pickling sludge/hydroxide sludge. Long-term research work is carried out on recycling of fine particle materials within integrated steel-plants, use of alternative reducing agents, pre-treatment techniques and on distribution of critical elements in recycling processing.

The aim of area II is to find new applications and develop existing applications for slag and ashes in order to minimise the amount of materials landfilled and to create extra value for member companies and for environmental aspects. Demonstration projects are carried out on use of slag and ashes, e.g., for road construction, binder in cement, eco clinker and landfill cover. Long-term research work is carried out on modification of slag, leaching mechanisms for Cr, Mo, F and optimisation of hydraulic properties of slag. One possibility for using large volumes of slag is to replace natural rock with slag, especially blast furnace slag, in road
construction. The leaching behaviour of slag has been compared with leaching behaviour of natural rock materials. The results are widely used among member companies and authorities.

Fundamental and applied research has been carried out and resulted in a large number of publications for scientific journals and conference proceedings as well as in four doctoral theses and seven licentiate theses. Three projects have led to extensive trials in industrial-scale or pilot-scale and are either introduced or considered for introduction in full-scale operations. They deal with recycling of hydroxide sludge, recycling of metallurgical residues from scrap-based steelmaking and recycling of metallurgical residues from ore-based steelmaking. An extensive national and international network of university and industry researchers, university researchers in different disciplines and industries has been developed. This has been accomplished through organisation of workshops, reference group meetings and participation in different meetings. An international conference on recycling was arranged June 2002. MiMeR staff is engaged in the organisation of several new conferences. MiMeR has also participated in several EU-funded projects and networks.

**Jernkontoret’s effort towards a Closed Steel Ecocycle**

The background is illustrated in Figure 9. Steel is recirculated and has several lives: the first unit is created from ore, mainly through the BF-BOF route and then recirculated and remelted and lives several new lives. An R&D effort was initiated to minimise the environmental impact of the steel and steel production during this total cycle of subsequent lives. This is a complicated process involving several areas of knowledge. To cope with this, the planning started with a request to the Swedish universities and institutes, asking them to suggest R&D activities in the area. 15 institutes answered giving a total of 50 suggested projects and a cost of around MSEK 200 (M€19). Then, industrial people made an evaluation. 50 people at high management and/or expert level in 15 industrial companies evaluated the following parameters on a scale of 1 to 5: new knowledge, environmental value and industrial value. After that, 15 projects remained. A synthesis resulted in a final R&D programme in the magnitude of MSEK 74 (M€6.6). It is in the final stage of financing and planning, and it is expected to be launched during the period 2004 –2008.

![Figure 9 Steel ECOCYCLE (source Jernkontoret)](image)

**Project B1. Improved steel scrap quality using new sorting methods.** Electronic sorting using laser technique for instant sample preparation and analysis. Sorting of shredder material
**Project B2.** A major effort on new techniques for combined scrap preheating and cleaning, especially from Zn.

**Project B3. New Metallurgical technologies.** Retention, Recovery and Recycling of Valuable Metals. New Slag Systems for Minimized use of Energy, Raw materials and Environmental Impact. Special effort on treatment of slags to recover metals especially V. This can also create a residual slag that is free from those accumulating elements and thus can be recirculated into the process.

**Project B4. Product design and new steel products.** The project consists of three parts: steel development to optimise the re-use of alloy elements in new steel products; improving the production of high-strength steels with energy efficient process routes, and improved technique for weight optimisation using high-strength steels in the final product.

**Project B5. Recycling of steel in the society.** Presently, the knowledge of the degree of recirculation and the mechanisms are meagre. The project aims to increase that knowledge.

**Project B6. Evaluation of environmental values.** Integrated models for decision-making, taking into account both economy and environmental impact. Efforts will be made to integrate the knowledge obtained in the national process-integration effort.

**References**

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