Exergy flows in in

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This article describes application of the exergy concept to a pulp and paper plant and to a steel mill. Its objective is to demonstrate the simplicity and value of employing the concept for analysis of industrial processes, as well as to assist in developing conventions and standards in this area. The major process losses revealed by use of an exergy consideration should be regarded as a challenge for technical improvement, rather than as an insuperable obstacle. **The work has been financed by STU.**

Introduction

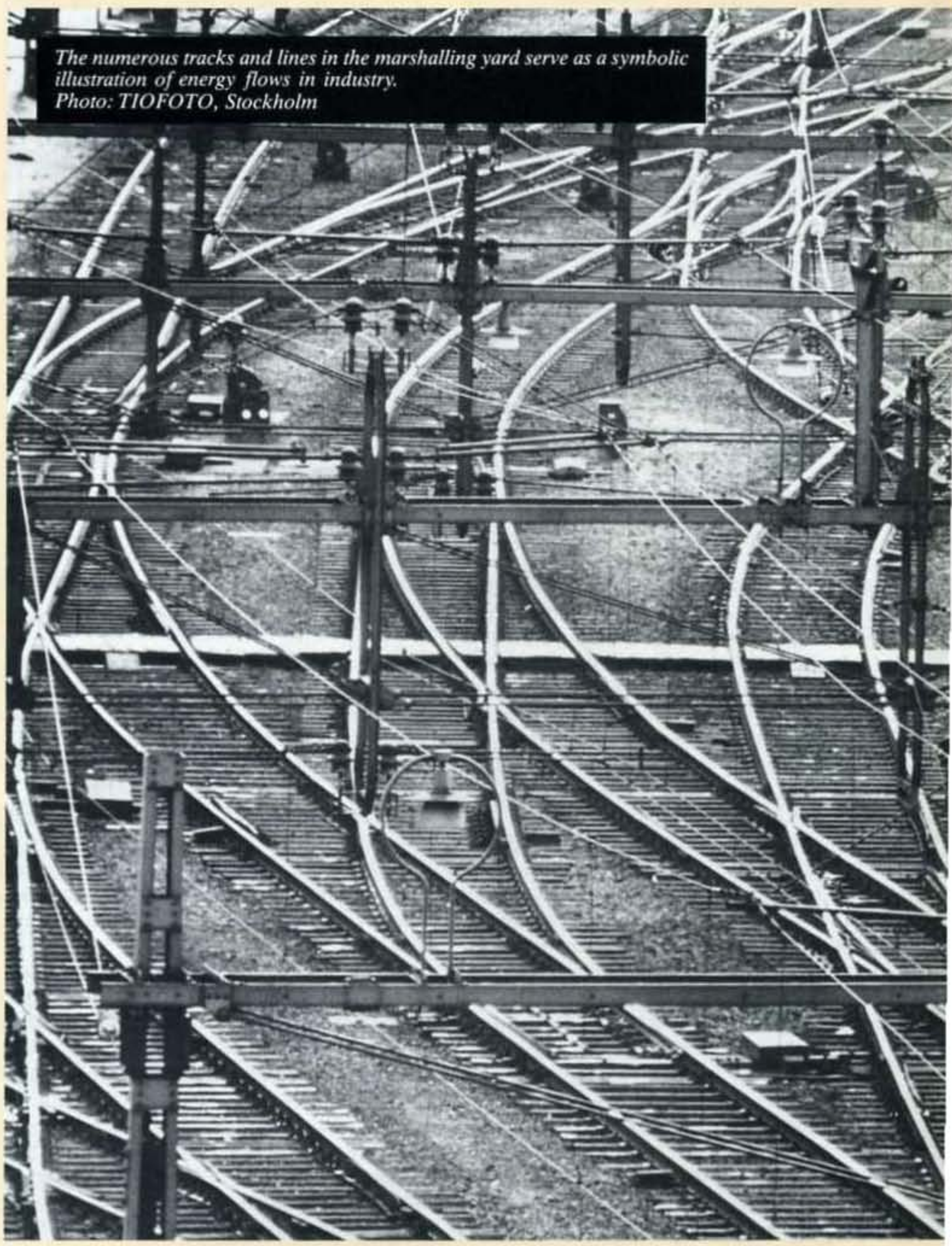
Our ability to see new ways of dealing with old problems is often restricted by the technology available. We often overestimate the superiority of modern technology in relation to yesterday's and tomorrow's. The most sophisticated modern computers, for example, appear uncomplicated in the extreme by any comparison with the simplest biological cell or with computers of the future. This should already be apparent from the rapid rate of development of computer technology. It is therefore important that problems should be defined in isolation from current technical limitations. Any such description must be based on scientific concepts such as exergy, if our view of reality is not to be distorted and constitute an obstacle in the way of important technical advances.

The use of the exergy concept is increasing rapidly in international literature. Recent years have seen publication of several textbooks, conference reports and scientific articles. Nevertheless, in spite of this, exergy analysis is not widely used in Sweden. I feel that this is regrettable, as I am fully convinced that it will become a standard working tool for all process analysis within the near future. Exergy is simple to understand and simple to use. Hopefully, this article can contribute to a better understanding of the concept of exergy, and increase its application, particularly for studies of industrial processes.

The exergy concept allows calculation of the theoretical minimum resource requirement (i e the energy and material requirements) for a process. In turn, this indicates the maximum savings that can be achieved using new technology and new processes. Neither new technology nor new processes develop spontaneously. By providing greater insight into a process, the exergy concept assists in providing a better understanding of where improvements are required and of the magnitude of savings that can be expected. An exergy audit, as a complement to present material and energy balances, can provide an increased and greater in-depth understanding of the process, along with wholly unexpected ideas for improvements, something which is particularly valuable for long-term planning of such aspects as necessary research for the most efficient utilisation of resources. However, it is important that standards should be developed in this sector as soon as possible in order to facilitate application within industry and for such purposes as energy planning.

Exergy

Energy is often expressed as work done or the ability to do work. This is wrong.



The numerous tracks and lines in the marshalling yard serve as a symbolic illustration of energy flows in industry.
Photo: TIOFOTO, Stockholm

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Instead, energy should be defined as *motion or the ability to move*. This is, admittedly, less specific, but it is correct. Energy is often an altogether inadequate concept. In the same way, exergy can be formulated as: *Exergy is work or the ability to do work* (see Energy Technology, No 1, 1983). Let us now apply this to two important industrial processes.
This description (Figure 1) is based on an energy study carried out at SCA-Nordliner in Munksund by Jan Fors and Börje Nord in 1980 (STU Information No 209-1981, and on information provided by mill manager Bo Häger. The mill has an annual output of 265 000 tonnes of unbleached kraft liner, produced from 210000 tonnes of unbleached sulphate pulp and 55 000 tonnes of waste paper, and mainly used as the raw material for corrugated fibre cases. The plant, which consists of a sulphate mill and a paper mill, is shown diagramatically in Figure 1. After cleaning, barking and chipping the incoming wood, the chips are cooked in a continuous digester to produce sulphate pulp. The bark is burnt together with oil to produce steam and electricity, used in the process. After digestion, the digester chemicals are washed out using waste liquor. Flash tanks, evaporation, a soda recovery boiler and a lime kiln recover most of the digester chemicals, while the black liquor is used for production of steam. The washed sulphate pulp is then passed to the paper mill where, after forming on a paper machine, it is dewatered, pressed, dried, cut and rolled into jumbo rolls for delivery.

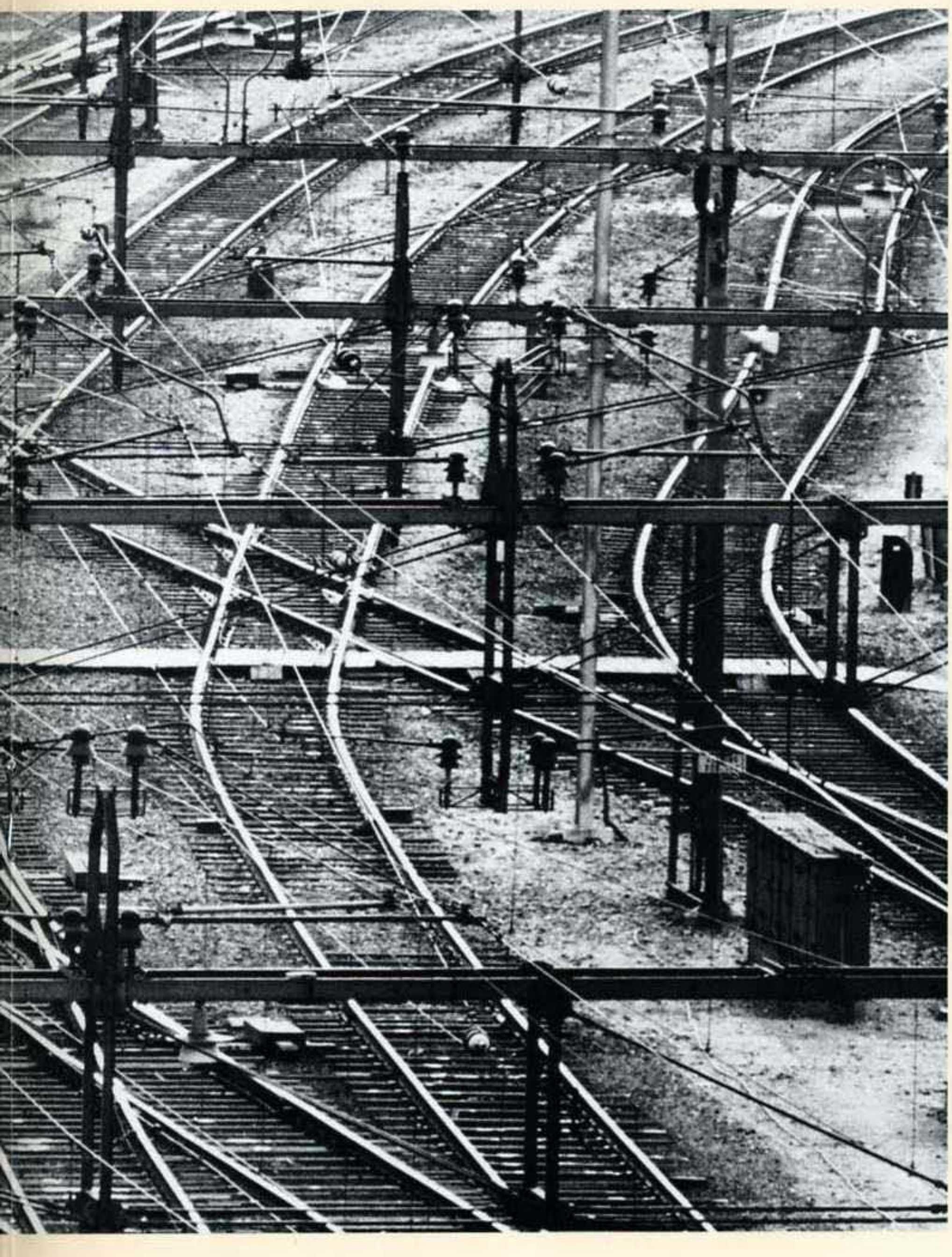

Figure 2 is an exergy flow balance for the entire process. Flows are expressed in exergy per tonne of paper produced (MJ/tp). Note, however, that additional fibres from waste paper are added in the paper mill, so that the true production of pulp in the pulp mill amounts to about 0.78 times the production of paper. (To express these quantities in tonnes of paper per tonne of pulp, multiply instead by 1.22.) Process yield, expressed as the quantity of dry wood (fibres) in the paper, is 57 %. It is of interest to compare this diagram with the corresponding energy flow (Fors & Nord, 1981). The most exergy-consuming processes can be easily identified. It is also interesting to note that large quantities of exergy circulate round the process in the form of digester liquor and black liquor. The process circuit for digester chemicals, consisting of waste liquor, mixed liquor, black liquor, green liquor and white liquor, is also easily identified. (In the energy case, the unused discharges constitute 57 % of total losses, but only 7 % in the exergy case. This indicates that the unused discharges in fact constitute a considerably smaller resource than is indicated by an energy balance calculation.)

A steel and rolling mill

In 1976, the Halmstad Steel Works had an annual capacity of about 280 000 tonnes of reinforcing steel. Two 50-tonne arc furnaces in the mill melted the raw materials, which was then cast in two continuous casting machines, each producing three strands. Two rolling mills (mill No 5 and mill No 6) rolled the strands into bars and wire sizes from 6 mm to 32 mm. (This data is based on monthly production statistics from March 1976, as described in STU Information No 88-1978, by Jan Fors and Rune Hardell.) Figure 3 is a schematic diagram of the process. The exergy flow is expressed per tonne of reinforcing steel output (MJ/ta), as shown in Figure 4. The total exergy inflow is about 12 700 MJ/tr, to produce an out-flow in the form of reinforcing steel of about 6800 MJ/tr. The unused outflows are equivalent to about 1000 MJ/tr, giving an exergy efficiency of 54 %. This diagram also provides a good overall representation of resource flows in the form of electricity, oil, heat and steel.

An energy balance calculation indicates that it is the losses in the unused outflows that are most important after the direct losses in the actual processes. A major difference is that the exergy balance shows that it is the conversion losses that are the most important. The unused outflows, such as waste heat and desulphurisation losses, are of less importance.

Conclusions

In the processes considered here, the use of exergy analysis reveals that it is the heating processes in particular that are inefficient. This result often becomes apparent when employing an exergy analysis, and is due to the fact that the exergy value of heat is often much lower than its energy value, particularly at temperatures near ambient. This means that higher-temperature processes such as smelting of steel are also more efficient, as their exergy values increase with tempera-

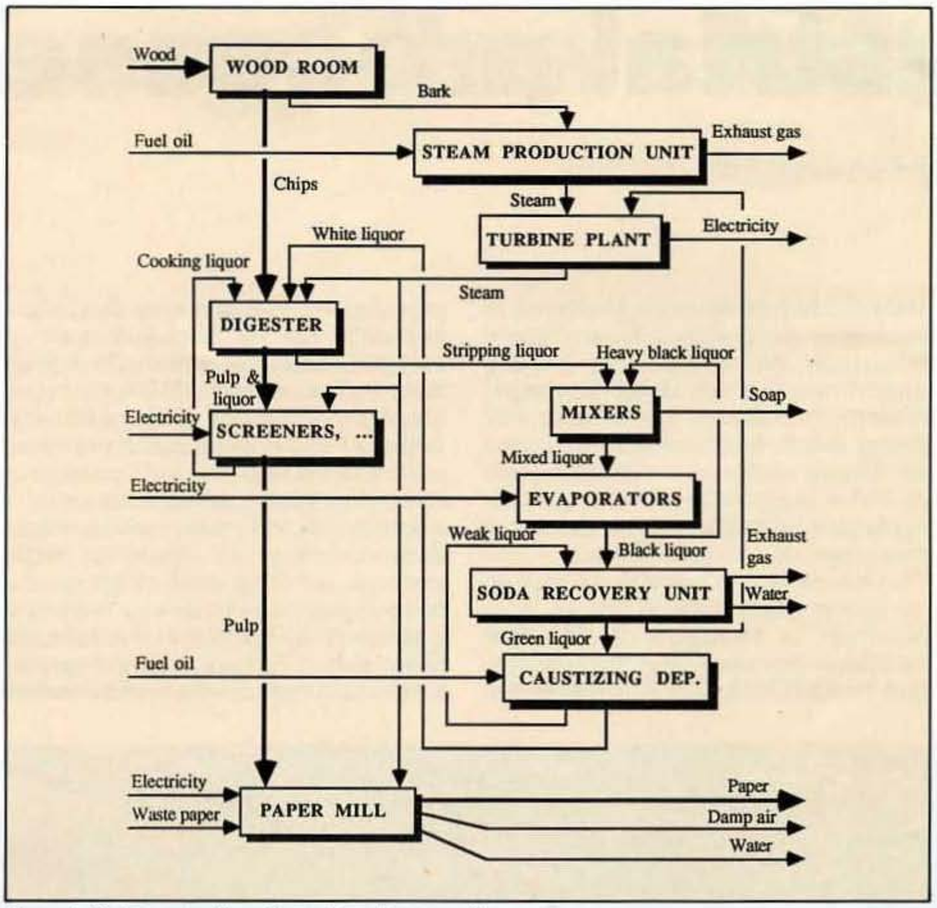

Figure 1. Main process flows in a pulp and paper mill.

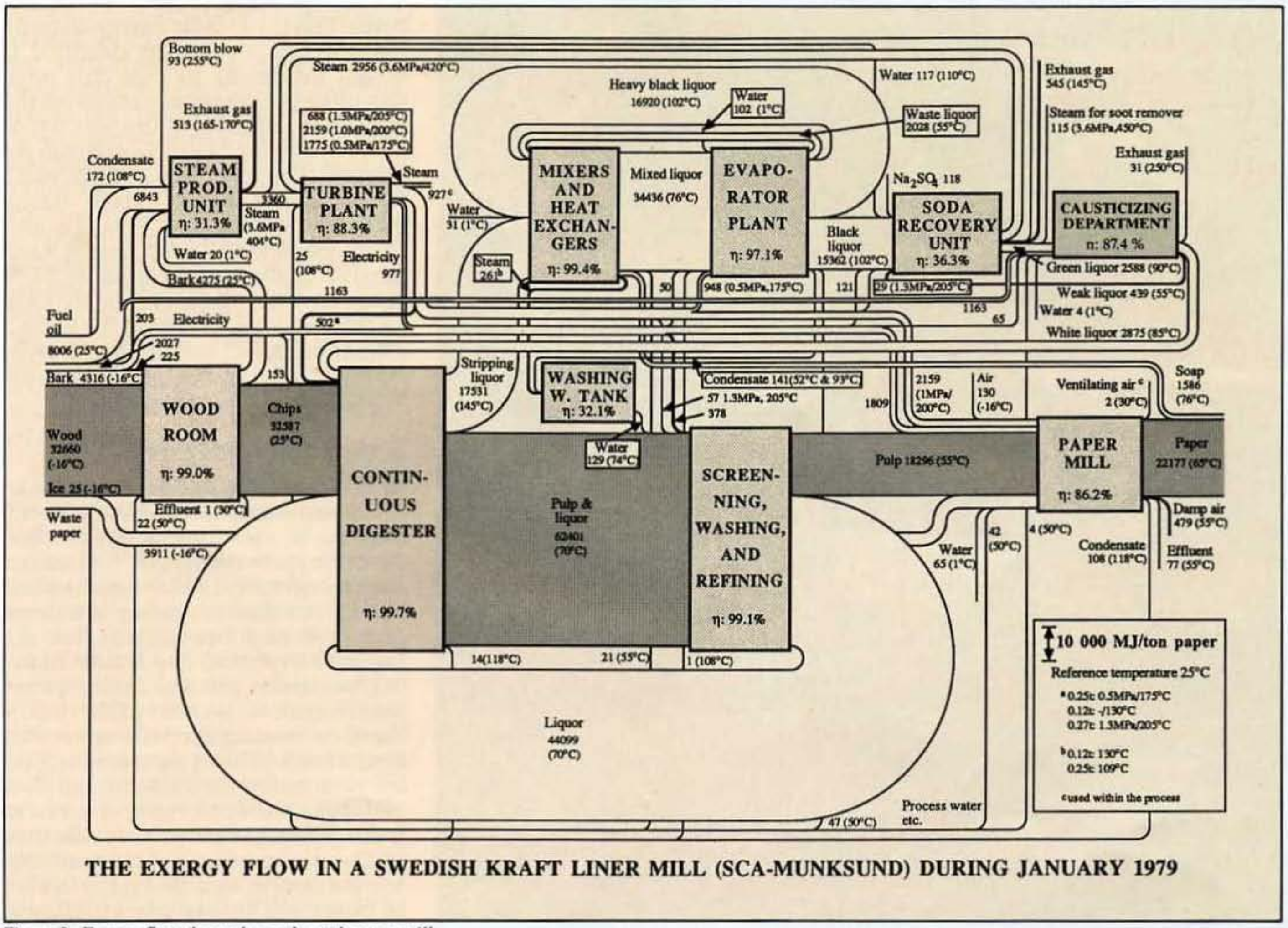

Figure 2. Exergy flow through a pulp and paper mill.

ture difference above ambient. Waste water, at a temperature of only a few degrees above ambient, contains practically no exergy.

Nevertheless, industrial processes are efficient in comparison with processes such as domestic space heating, for which the efficiency is only 1.5 – 5 %: see EnergyTechnology No 1, 1983. One explanation for this could be the fact that competition and profitability require industry to make better use of its resources. Less emphasis is often placed on profitability in non-industrial processes.

In conclusion, it must also be mentioned that application of the exergy principle primarily provides information of value for long-term planning for resource management. Ample skills and experience for short-term planning can be drawn upon today. However, coupled with lack of expertise for more long-term planning, this has sometimes stood in the way of development of new, efficient technology. The exergy concept provides a valuable complement in this application.

This is described more fully, together with details of computer programs, in the publication "Exergy – A Useful Concept", available from the author (330 pages, SEK 100:–).

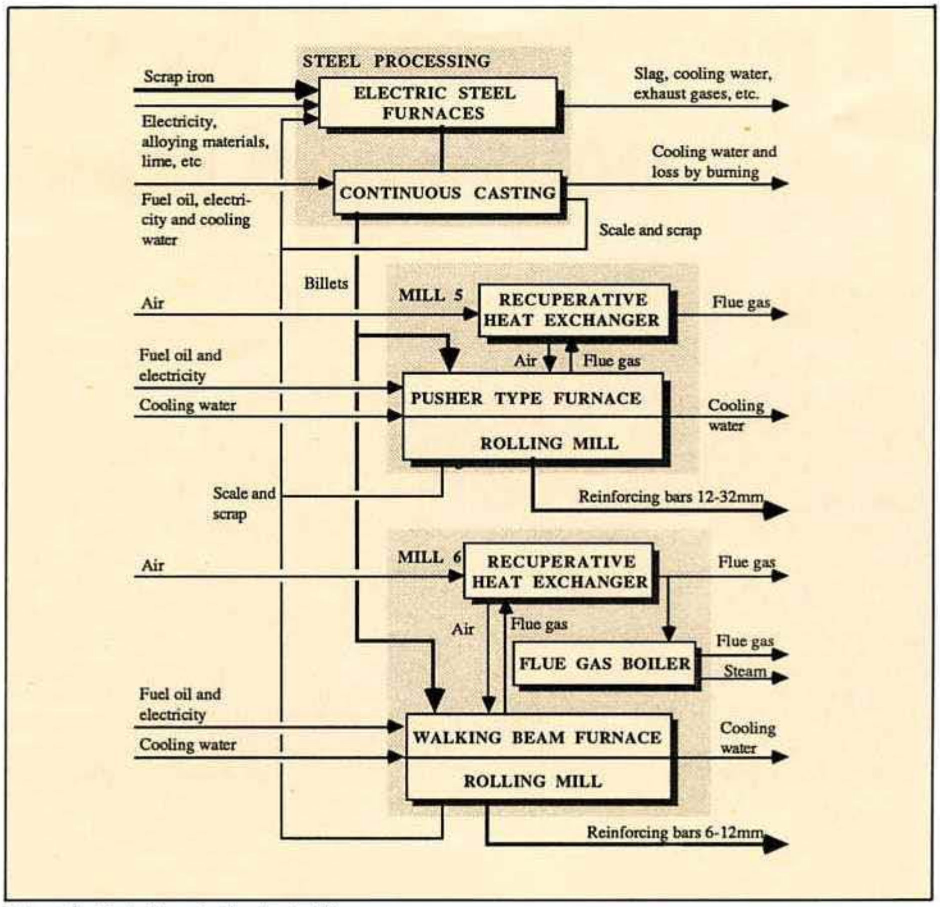

Figure 3. Main flows in the steel mill.

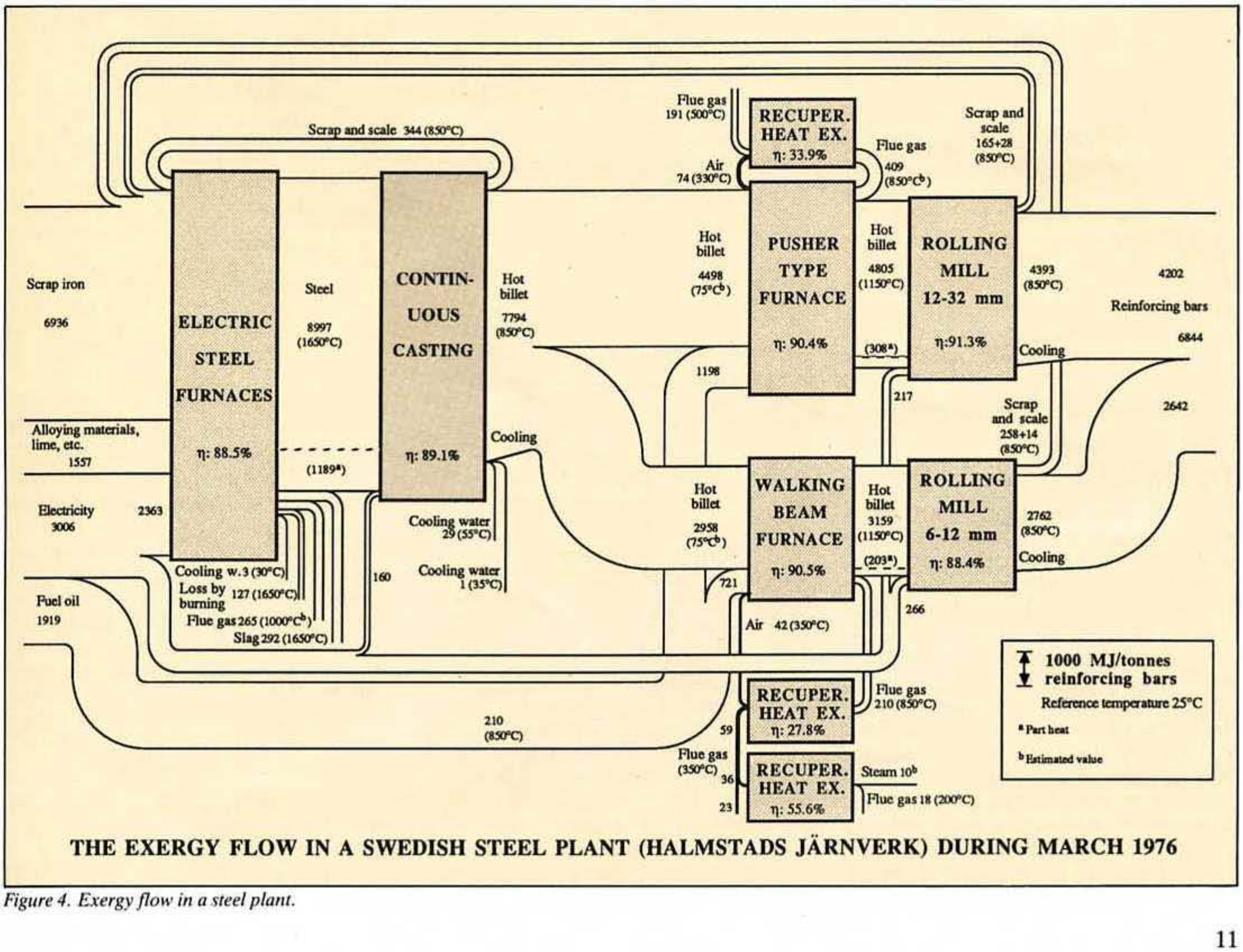

Figure 4. Exergy flow in a steel plant.