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Paths to increase efficiency in the steel industry

Figures and Facts
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German Steel Federation

Effective, economical and thus competitive steel production is only possible with sustainable and efficient production. Operators of plants to produce iron and steel have always made efforts to lower production costs and to manufacture high-quality steel products with increasing efficiency. Numerous plant and process developments have led to reduced consumption of raw materials and energy, increased yields and improved environmental protection. This development is directly coupled with the needs-oriented supply of high-quality raw materials. In a joint dialogue between raw material suppliers and steel producers it was customary, over several decades, that the qualities constantly improved and, in particular, the content of unwanted accompanying elements in the basic raw materials fell. In this regard, however, a new situation has arisen in recent years as a result of the extreme rise in demand for raw materials and changes in the deposits, creating new challenges for plant operators regarding the flexibility and quality of raw materials.

Efficiency in steel production

92 million tonnes of raw materials, such as iron ore, coal, scrap steel, additions, alloying materials, oil and refractory materials were used in 2008 to produce 45.8 million tonnes of crude steel in Germany, **Fig. 1**. From this, 43.9 million tonnes of finished steel products of various sorts and grades were manufactured for the direct or indirect supply of a variety of branches. The specific energy consumption was 18.0 GJ/tonne crude steel or 824 million GJ in the entire year. Sales totalled EUR 51.5 billion, while the workforce numbered over 90,000. This corresponds to about 490 tonnes of steel products per employee in 2008.

Compared to the year 1980 the use of raw materials for crude steel production in 2008 fell from 2336 to 2015 kg/tonne crude steel by 321 kg (-13.7%) or, in absolute terms, by 14.7 million tonnes per year, **Fig. 2**.

The use of steel scrap to produce steel is one of the oldest forms of recycling. In specific terms, the proportion of steel scrap used during the above-mentioned period rose from 370 to 452 kg/tonne crude steel.

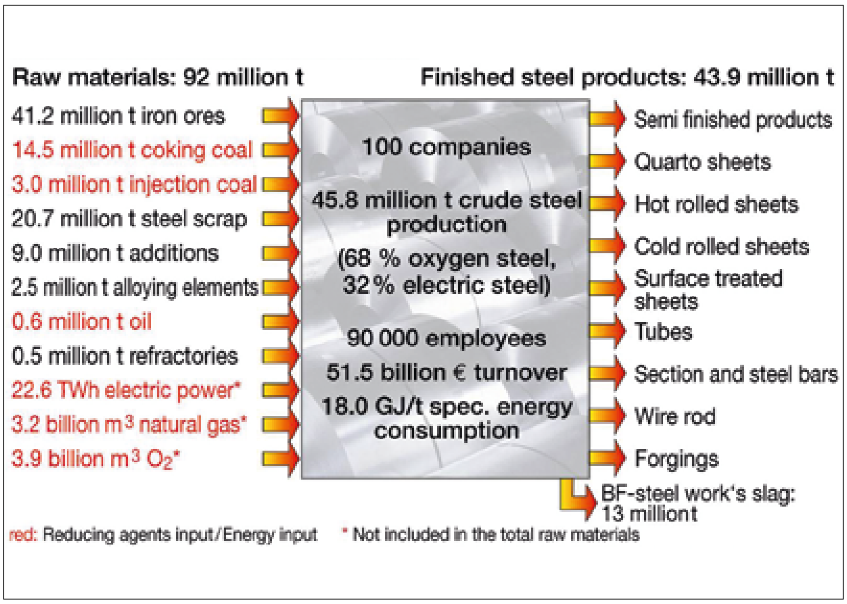


Fig. 1
Steel production in Germany, 2008

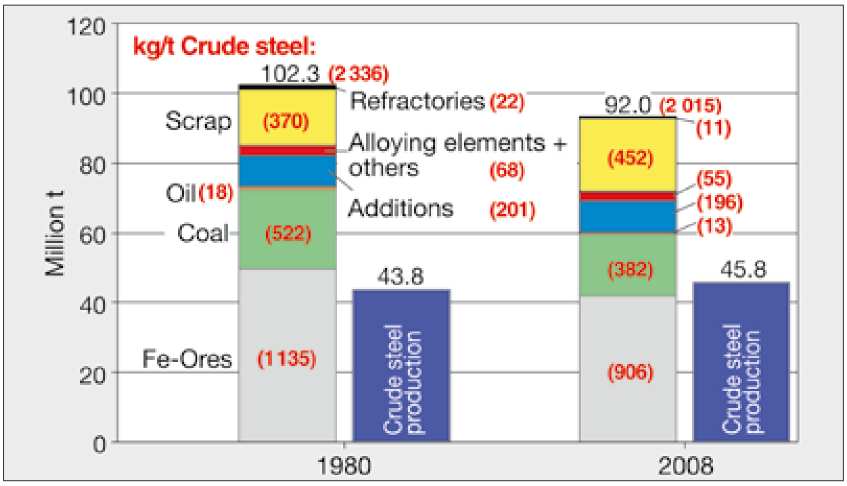
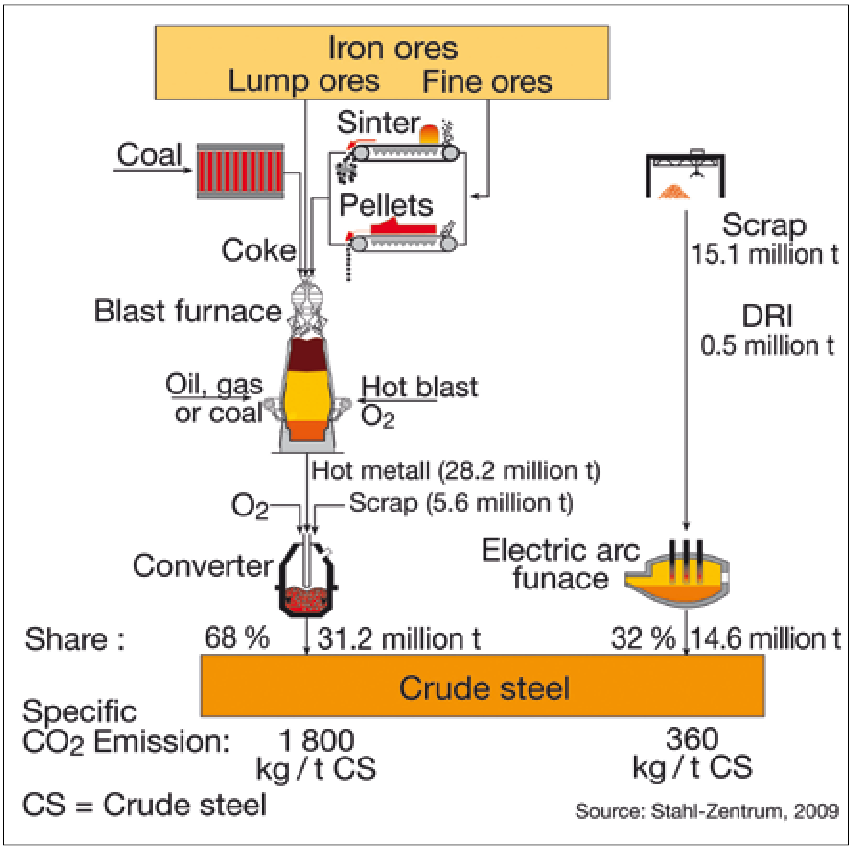


Fig. 2
Raw material use for steel production in Germany, 1980 and 2008



Source: Stahl-Zentrum, 2009

Fig. 3
Two routes for the production of steel in Germany, 2008

The specific consumption of coal fell during this period by 140 kg or, in absolute terms, by 6.4 million tonnes. This alone already corresponds to a reduction in CO_2 emissions of about 18 million tonnes per year.

The increase in iron yield during steel production is a further indicator of increasing resource efficiency. Total yields of rolled steel compared to Fe consumption have risen by 24 per cent since 1960, from 65% to 89%.

The measures that the steel industry has taken to improve competitiveness and economic efficiency are effective. The specific energy consumption fell from almost 30 GJ/tonne crude steel in 1960, through 23 GJ in 1980, to the current 18 GJ/tonne crude steel (-40%). During the same period, specific CO_2 emissions fell 42% from 2.4 tonnes CO_2/tonne crude steel to 1.4 tonnes CO_2/tonne crude steel.

Just a few of the many measures taken by plant operators and constructors that have led to these successes, particularly regarding CO_2 reductions, are listed below, e.g.:

- the decrease in reducing agent consumption for hot metal production in blast furnaces,
- the increased proportion of electric steel production and process innovations,
- the introduction of new thin slab casting lines and direct strip production processes that conserve resources, and
- the constant optimisation of processes regarding energy input, through the recovery of energy and improved coupling energy management.

Steel production

Steel is the number one industrial material. There are two established routes for producing steel in Germany, **Fig. 3**. In the case of the process route via the blast furnace, with its preliminary steps in the coking and sinter plants, iron ore, coke and coal are used to produce hot metal which is then further processed into liquid crude steel in an oxygen converter after the addition of a small amount of scrap. Regarding gas supply, this process route is self-sustaining through the use of the energy content of the coupling gases from the coking plant, blast furnace and oxygen converter for underfiring and heating, as well as for the generation of electrical energy.

In the other route, via the electric arc furnace, steel scrap and/or direct reduced iron (DRI) – in comparatively small amounts however – is melted using electrical energy, input via an electric arc, to create liquid crude steel.

Energy must be imported because no coupling energy is generated via this process route.

Both processes are followed by further process steps in order to manufacture the desired steel grades. Two thirds of the steel produced in Germany is made via the blast furnace/converter route, one third in electric steelworks. Both processes for steel production are energy-intensive. 42% of Germany's steel production derives from steel scrap. This demonstrates the sustainability of steel production shown, in particular, by the closed circulatory system of steel scrap recycling.

Resource efficiency in production

The production routes from the raw materials to the finished steel products are very complex and every single process step has always been treated as a source of optimisation potential for plant constructors and operators. **Fig. 4** provides an overview of this broad field of measures for increasing the efficiency of the particular production steps, without claiming to be a complete description. The further developments that have taken place in automation and control technology have made an important contribution to the high level of efficiency and process reliability now achieved in all types of plants. The principal measures shown in Fig. 4 are explained below and identified in the diagram by the figures shown in brackets next to each of them.

Coking plants (1):

Coke is the most important reducing agent for the blast furnace process. It is made in hermetically sealed coke ovens by heating low-sulphur coal with good coking properties under exclusion of air.

The world's leading coking plant constructors are located in Europe. The most modern coking plants are also operated here. With higher, longer and, above all, wider coke oven chambers, the chamber volumes of newly constructed coking plants doubled between 1970 and 1984 to 70 m³. The world's most modern coking plant, with by far the greatest chamber volume of 93 m³, went into operation in the Schwelgern area of Duisburg in 2003¹⁾. The plant produces 2.6 million tonnes of coke a year with 140 furnaces. Individual chamber pressure regulation (1.1) systems – Proven from DMT and Uhde²⁾ and Sopreco from Paul Wurth³⁾ – contribute towards preventing emissions via the coke oven doors. These systems are being operated at the Schwelgern coking plant in Duisburg (Proven) and at the new Battery No. 3 of the Saar Central Coking Plant (Zentralkokerei Saar) in Dillingen (Sopreco). Dust, CO, SO2 and H2S emissions need to be prevented or reduced during cooling of the coke. Significant progress has been achieved with the CSQ (Coke Stabilized Quenching) wet quenching process (1.2) developed by HKM (Hüttenwerke Krupp Mannesmann) and further improved in Schwelgern⁴⁾. The emission values achieved are comparable with those of the dry quenching process for coke, or in some cases better. The coke is stabilised and thus provides advantages in the blast furnace; the investment and operating costs are much lower. Optimisation measures in the operation of coking plants in recent years have lowered energy consumption for underfiring from 3.7 GJ/tonne of coke (dry) in 1998 to a current level of below 3.45, i.e. by 7.2%⁵⁾. The hydrogen-rich and energetically high-calorific coke oven gas is now used for heating purposes and for generating electricity.

Sinter plants (2):

Fine-grained iron ores are agglomerated in sinter plants for

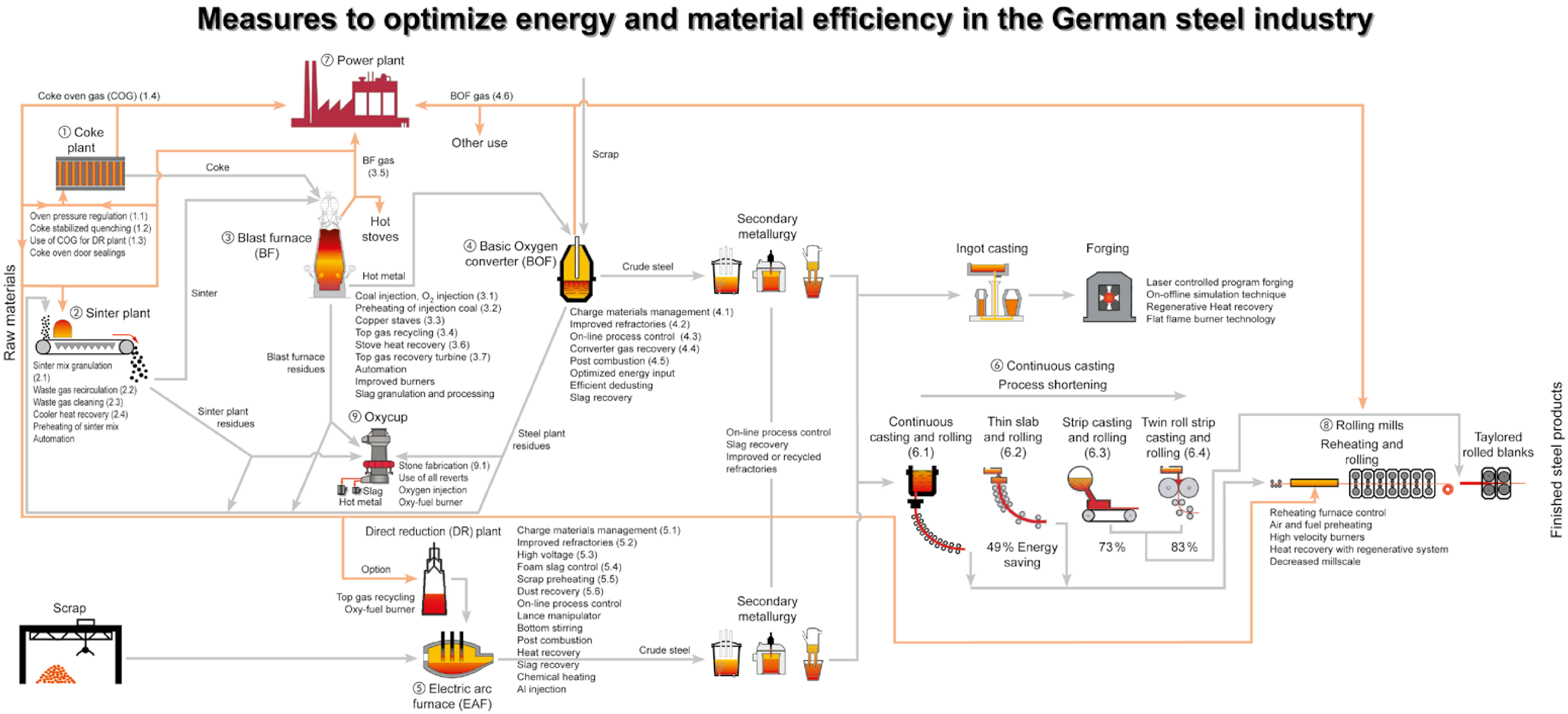


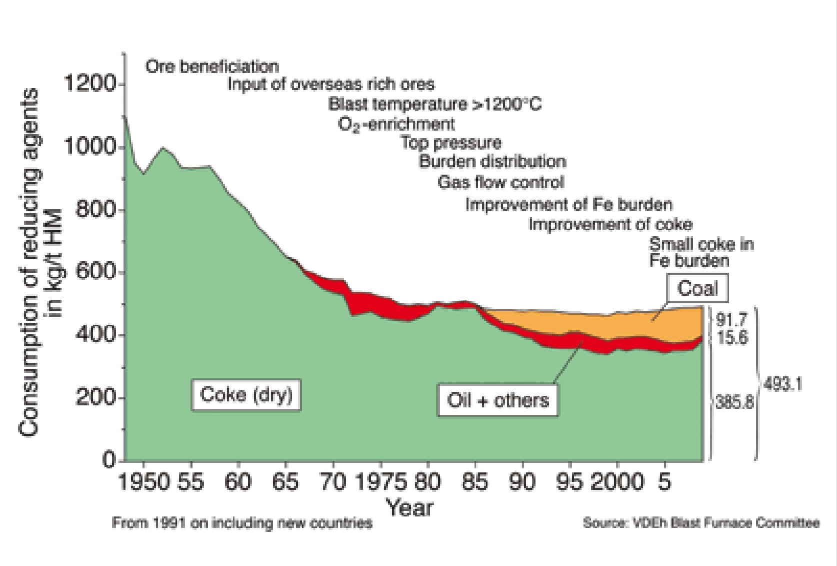
Fig. 4
Measures for optimising energy and material efficiency in the German steel industry

use in blast furnaces. The sinter process allows integration in the sinter of all the slag-forming constituents necessary for slagging of the gangue components of the charge materials in the blast furnace.

This saves energy in the blast furnace process. In addition, a majority of the residual materials – mostly iron-bearing – produced in an iron and steelworks can be recycled via the sinter plants. Trials are currently underway on measures involving preparation (2.1) and preheating (2.2) of the mixture to increase the efficiency of the sinter plants. Sinter plants are regularly the focus of discussions regarding environmental friendliness. Complicated technical solutions have been developed in recent years in collaborations between sinter plant operators and plant construction companies to further optimise the process and guarantee its continued existence – in order to make the sinter process as environmentally friendly as possible and to meet the requirements of the authorities[6)]. Values in the cleaned waste gas of sinter plants have meanwhile been achieved that were hardly considered possible a few years ago and that now meet the ambitious official targets. In addition to improvements to the electrostatic precipitators, these include selective waste gas recirculation (2.2) in the sinter process, as well as the retrofitting of highly efficient bag filter systems (2.3).

Blast furnaces (3):

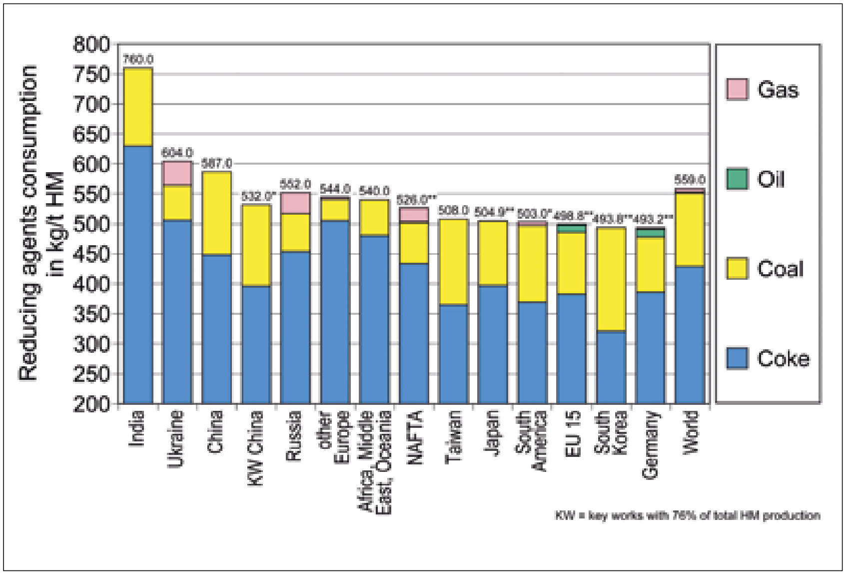
In the blast furnace process, a reducing gas (CO) is formed from carbon and oxygen which removes the oxygen from the oxidic iron ores. Whereby unwanted accompanying materials are largely removed from the charge materials and accumulated in the slag. Hot metal and slag are tapped in liquid form at a temperature of about 1500°C and separated from one another in the runner system of the casthouse. Since the 1960s, auxiliary reducing agents have been injected into the blast furnaces via the tuyères to reduce coke consumption in order to optimise the economic efficiency of the blast furnace process. Since the mid-1980s, this has increasingly been taking place by means



From 1991 on including new countries

Source: VDEh Blast Furnace Committee

Fig. 5
Development of average reducing agents consumption in Germany's blast furnaces



KW = key works with 76% of total HM production

Fig. 6
Average consumption of reducing agents in blast furnaces in various areas of the world, 2007/2008*/2009**

of the injection of pulverized coal (3.1) with oxygen enrichment of the blast or the injection of oxygen⁷⁾. The preheating of the injected coal (3.2) to optimise energy consumption is still under development. With in total 493.1 kg/tonne of hot metal in 2009, the consumption of reducing agents in Germany's blast furnaces has been cut by 40% compared to 1960 levels⁷⁾, **Fig. 5**.

In recent years, however, it can be seen that the curve has taken an asymptotic course. Given today's prerequisites regarding raw material supply, the potential process-related and physical minimum reducing agent consumption in blast furnaces has been achieved. In an international comparison, German and European blast furnaces have very low reducing agent consumption figures, **Fig. 6**.

The economic efficiency of the blast furnace process is also determined by the length of a furnace campaign (the time between two new relinings). A few years ago furnace campaigns lasted about 10 years, whilst campaigns of 15 to over 20 years can now be achieved. The copper staves (3.3) developed in Germany have made a contribution towards cooling the blast-furnace steel shell⁸⁾. As a result of their greater heat conductivity, they form a protective accretion in front of the stave bodies, allowing a reduction in the thickness of the refractory wall, and thus cutting the amount of refractory material required and simultaneously increasing furnace volume with an unchanged shell diameter.

The blast furnace process with recycling of top gas (3.4), cleaned of CO_2, for use as a reducing gas in the blast furnace is currently being prepared in pilot dimensions for trials as part of the European ULCOS project (Ultra Low CO_2 Steelmaking), **Fig. 7**. This process variant theoretically permits lower reducing agent consumption. For this purpose, oxygen is used instead of air, the CO_2 is washed out from the top gas, and the heated CO-rich top gas is re-circulated at two levels of the blast furnace.

The recycling and utilization of the top gas for iron ore reduction brings carbon savings of about 25% for the blast furnace⁹⁾. Given complete underground storage of the washed out CO_2 (CCS), a massive cut in CO_2 emissions would theoretically be possible during hot metal production. This new process variant with washing has been successfully tested in a very small experimental blast furnace in Sweden, producing 5 tonnes of hot metal per day. For the realization of industrial application at large volume blast furnaces having a daily hot metal production of over 10,000 tonnes with state-of-the-art plant, automation and measurement technology, development times of 15 years and more are to be expected.

This new holistic blast furnace concept has a major CO_2 reduction

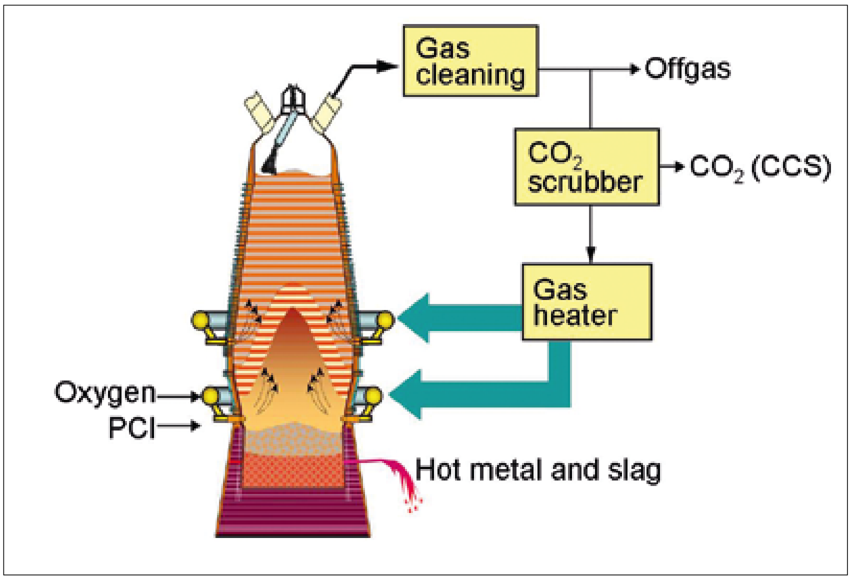


Fig. 7
Oxygen blast furnace with recycling of top gas

potential in combination with CCS, and would allow an increase in productivity for the same plant size compared to the conventional blast furnace process. But 80% less top gas available for the steelwork's energy network system would have consequences for the steelworks' energy supply and electricity generation[10)].

A huge plant and operation technology expenditure would be necessary to implement the new blast furnace technology on existing blast furnaces. The investment and operation costs are considerably higher than with conventional technology and would cause substantial competitive disadvantages were it to become compulsory in just one region, e.g. in the EU.

Steel production (4;5):
Numerous measures for optimising energy and material efficiency have been implemented in the areas of crude steel production, secondary metallurgy and continuous casting. Sophisticated management of the charge materials (4.1; 5.1) has led to increased yields of the individual materials. Alloying elements present in scrap are optimally exploited through appropriate charging, minimising the additional requirement for alloying materials. Refractory qualities have been considerably improved in recent years (4.2; 5.2). As a result, longer-lasting materials are now used and resource efficiency regarding refractory materials has been greatly enhanced. Large parts of the refractory material that have broken off from process aggregates and transport equipment are now treated and re-used.

In the basic oxygen steelmaking process (4) modern process regulation (4.3) prevents after-blow and thus reduces the oxygen requirement as well as loss of iron during converter operation[11)]. The recycling of converter gas (4.4) effectively saves fuel. The use of post-combustion (4.5) exploits the CO in the converter's flue gas to improve the heat balance of the aggregate.

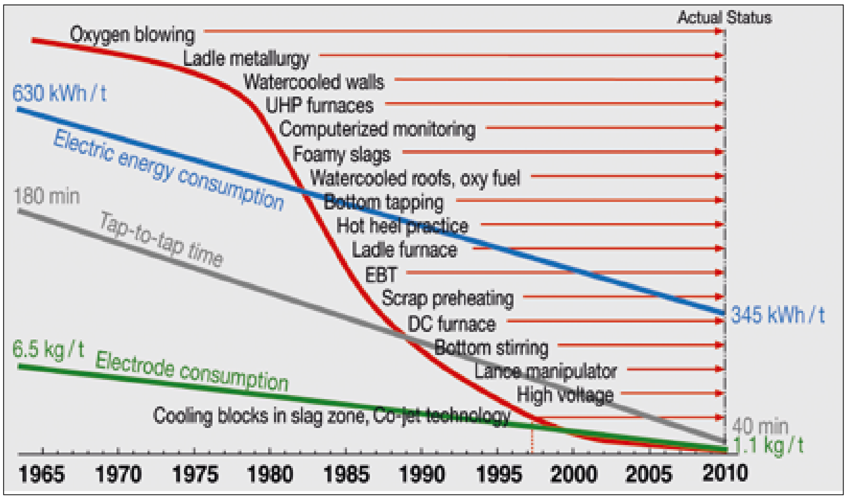


Fig. 8
Development of the electric arc furnace

The electric arc furnace (5) now uses higher voltages (5.3) to shorten the duration of the treatment of crude steel. Whereby numerous individual measures have led to an energy-related optimisation of the aggregate. Control of the foamed slag[12)] in the furnace is particularly important (5.4). As a result, heat and energy loss in the furnace is prevented to as great an extent as possible. The refining in the furnace reduces the continuing secondary metallurgical treatment to remove carbon from the crude steel. The energy of the flue gas can be used to preheat the scrap (5.5). In addition, valuable metallic materials such as zinc are separated from the flue gas of the electric arc furnace. A variety of preparation techniques are available to recover the zinc, such as the Wälz process or the Primorec process[13)]. In addition, recycling of the dust (5.6) to the furnace allows recovery of the iron that would otherwise be lost whilst also concentrating the zinc[14)].

Numerous individual technical measures have led to a significant improvement in the efficiency of electric steel production in recent decades.

As **Fig. 8** shows, the electric power consumption of individual plants has fallen by 45%, the time between two tappings has been reduced by 78% and the consumption of electrodes has gone down by 83%.

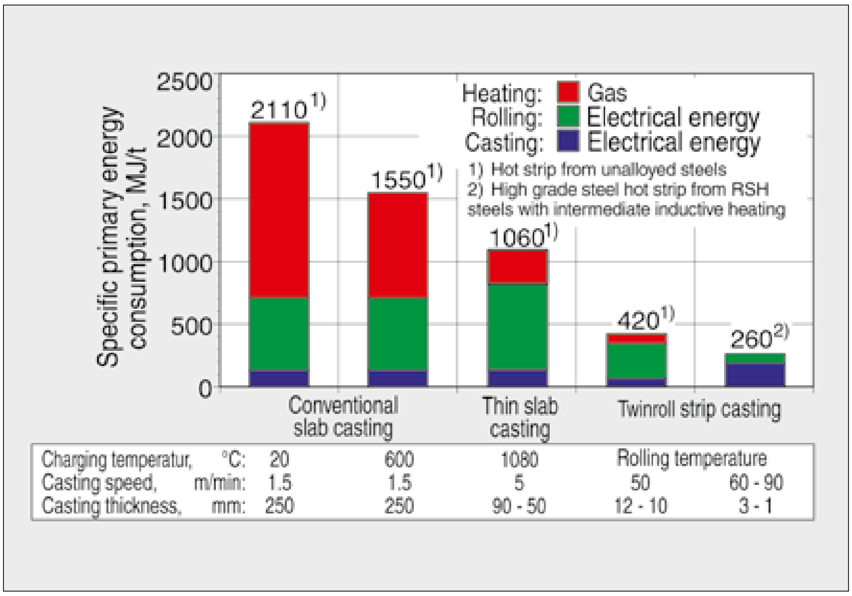


Fig. 9
Energy savings with continuous casting by shortening the process chain

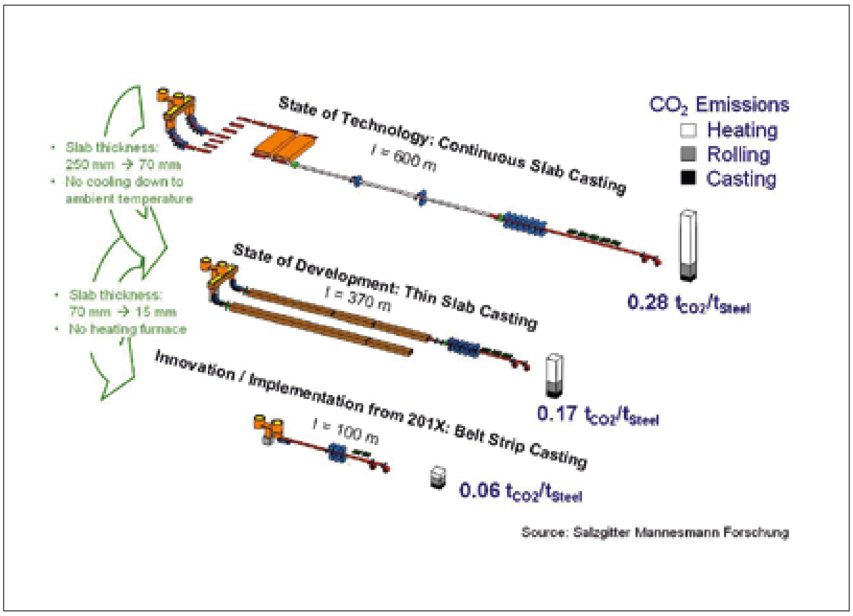


Fig. 10
Development of continuous casting – emission reduction through strip casting (Salzgitter Mannesmann Forschung GmbH)17)

Continuous casting (6):
The transition from the ingot casting process to the continuous casting process for slabs, billets and round material was a groundbreaking step in the early 1970s to reduce material consumption when casting and solidifying the liquid steel. 98% of the steel now produced in Germany is cast using the continuous casting process. In the conventional continuous casting process (6.1) solidified slabs of about 250 mm thickness, for example, are produced from the liquid steel, re-heated to a temperature of 1250° in a second process step in the rolling mill's furnace with the application of energy, and then rolled to the target thickness of 2 to 5 mm in the forming process. The amount of hot metal and scrap used to produce 1 tonne of cold sheet has been reduced by 0.18 tonnes with continuous casting technology, compared to the discontinuous ingot casting process. This corresponds to a reduction of CO$_2$ emissions of 245 kg/tonne of cold sheet. The development of thin slab continuous casting (6.2) and strip casting (6.3; 6.4) technology resulted in particular process and energy-saving progress. Thus the conventional process route involving continuous slab-casting plants / hot rolling mills requires about twice as much energy per tonne of hot strip as thin slab casting, **Fig. 9**. A thin slab plant using the compact strip production process (CSP) has been operating at what is now ThyssenKrupp Steel Europe AG in Duisburg since 1999[15].

The first (pre-)industrial scale two-roller strip casting plant is the so-called Eurostrip plant that commenced operation at ThyssenKrupp Nirosta in Krefeld in 1999[16]. Here, the hot strip is directly cast from the liquid steel over two opposing rotating, cooled rollers to a thickness of 1 to 3 mm and sheeted inline. Two-roller strip casting promises energy consumption that is about 20% that of conventional slab-casting.

Nevertheless, there are still process-related difficulties to be solved before the process can be converted to the necessary technical standard.

Fig. 10 shows the development from conventional continuous slab casting, via thin slab casting to the strip casting of the future[17)]. Belt strip casting technology, currently developed to an expanded technical scale, allows the casting of steel in thicknesses of 8 to 15 mm due to a fundamentally different casting concept. In a process conceived by Salzgitter Mannesmann Forschung, the liquid steel is cast on a special horizontal conveyor travelling at casting speed, instead of vertically in a mould. As a result of the low casting thickness, considerably shorter time intervals are necessary for setting the temperature distribution before the directly connected inline rolling process. CO_2 emissions are approx. 0.06 tonnes per tonne of strip steel produced and thus only about one quarter of that generated during production in conventional continuous casting. This new technology is currently implemented in a first (pilot) production plant. A substitution of conventional casting technology can, like thin slab technology, only take place in the medium or long term. In addition to cutting emissions during production, the special technological aspects of strip casting allow the production of new high-strength steel qualities that cannot be produced using conventional processes, or only to a very limited extent. Such high-strength and ductility steels (HSD steels) are high-tensile steels with very good forming properties and can be used for the light construction of vehicles, and offer optimised material exploitation.

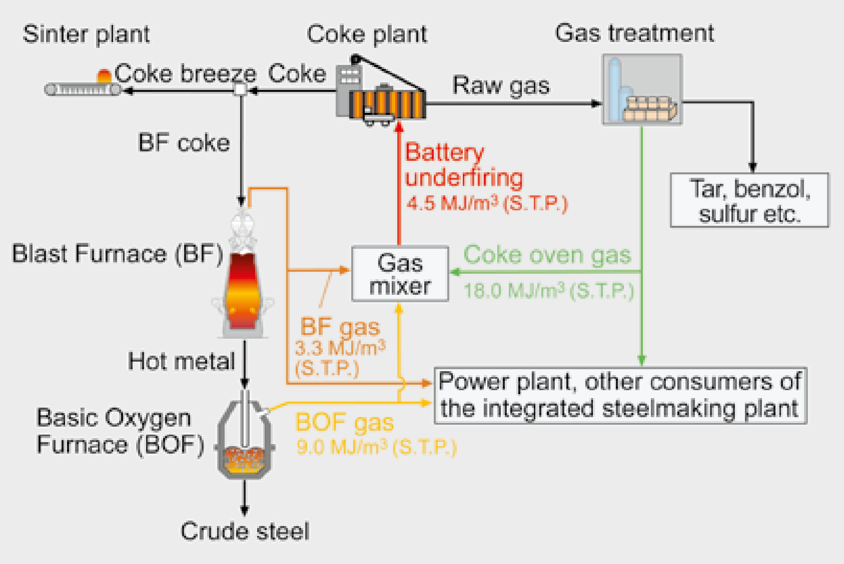


Fig. 11
Typical flow diagram for the use of differing gases in coke and hot metal production

Energetic process optimisation through energy recovery and improved coupling energy management

Energy management and the ecological significance of the energy network of an integrated steelworks is principally dependent on being able to economically exploit the coupling energies generated by coke oven gas, blast furnace gas and converter gas from the process line coking plant, blast furnace and oxygen steelworks, **Fig. 11**.

Coke oven gas is above all used for the underfiring of the coking plant (1), for heating the ignition furnace of sinter plants (2), in further processing steps such as hot rolling mills (8) and for secondary energy generation in power stations (7). The blast furnace gas (3.5) is employed for heating the blast for the blast furnaces (3), for underfiring the coking plant

(1), and in the power station (7). As a result of its thermal properties, the low-sulphur converter gas (4.6) released in the oxygen steel process (4) as a result of the oxidation of the carbon-saturated hot metal (4.7% C) with oxygen is suitable for use in the reheating furnace of the rolling mills (8), as well as in the power station.

This energy network management is a classic example of synergy, and profits from the great leeway for optimisation of combined process steps, supply plants and auxiliary plants, and ensures a high level of residual energy use whilst minimising all energy-related emissions.

Processes for reclaiming heat and energy were developed and successfully introduced to save primary energy during steel production steps in the 1980s[18]. Thus the heat of the waste gas produced when heating the blast for blast furnaces (3.6) is reclaimed via a thermo-oil circulatory system and used for preheating the burning medium of the hot stoves. This allows blast heating without the addition of rich gas. The sinter cooler (2.4) of the sinter plant is another heat source. The heat decoupled here is used, for example, for preheating the combustion air of the ignition furnace. On many blast furnaces, the pressure difference between the blast furnace and the gas network is used to generate an electric power in top gas expansion turbines (3.7). About 130 million kWh of electricity can be generated annually on one large blast furnace. In 2008, 400 million kWh of electrical energy was generated on 8 blast furnaces in Germany via top gas expansion turbines, without causing CO_2 emissions[19]. This is equivalent to preventing CO_2 emissions of 240,000 tonnes according to the CO_2 equivalent of electricity generation in Germany, taking into account the national fuel mix.

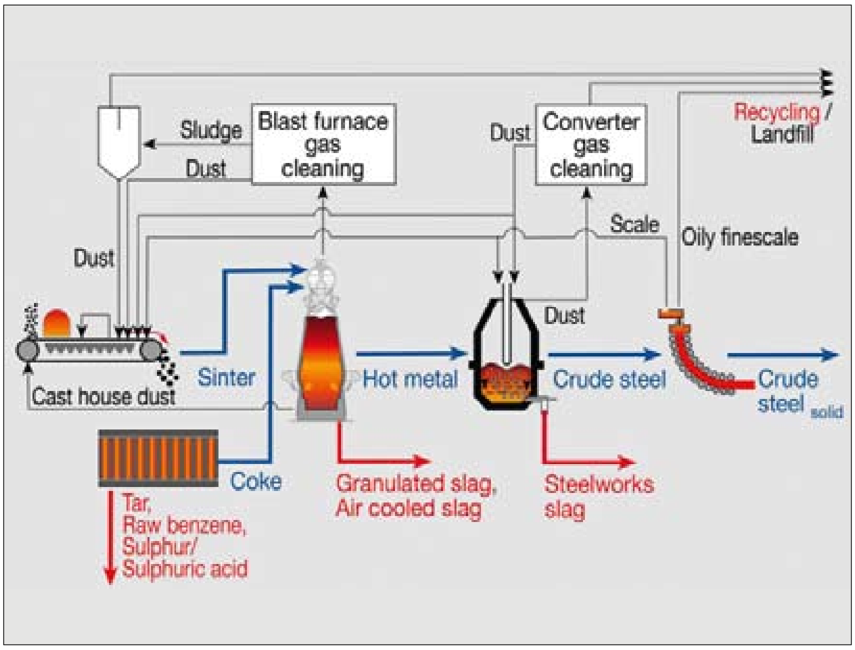


Fig. 12
Material management in the steel industry

The use of by-products and residual materials from steel production

The steel industry makes wide-ranging use of the raw materials it exploits. By-products and residual materials – which as a result of their chemical composition and physical properties can be used as resources – are also produced during the manufacture of hot metal, crude steel and finished steel products, **Fig. 12**[20]. The range of these resources is just as great as their potential uses.

Slags, produced during all metallurgical smelting processes, absorb the unwanted accompanying elements of the raw materials or intermediate products and thus keep them away from the steel products. Slags have defined compositions and properties. They are not waste, but by-products whose quality is monitored, over 95% of which is highly efficiently exploited for building purposes or as raw materials. In Germany, over 80%

of blast furnace slag, for example, is granulated and used as a raw material for cement production.

It thus replaces a corresponding quantity of clinker production, and saves one tonne of CO_2 per tonne of granulated blast furnace slag used in cement production – an average of over 6 million tonnes CO_2/year since 2006.

Tar, sulphuric acid and benzene, for example, are produced by recovering from coke oven gas during coke production, and fully exploited. The variety of products made from these coal by-products range from absorption oil, through shampoo, to Lego bricks and CDs.

Other materials, such as dusts, sludges, mill scale, and accretions, contain either recyclable iron components, slag carriers or carbon. For process-related reasons not all residual materials can be recycled via the sinter plant. The Oxycup process (9) of ThyssenKrupp Steel Europe AG, for example, is ideal for this purpose[21)]. The residual materials are agglomerated to stones (9.1) and processed to hot metal in Oxycup. The DK process[22)] was deliberately aligned towards returning ferrous by-products, that could not be directly used in steel companies, to the value creation circulatory system. Foundry pig iron of the most varied of qualities is produced from the dusts and sludges of the iron and steel industry with a small sinter plant and two blast furnaces with an operating volume of 580 and 460 m³. As a result of its adapted method of operation with high top gas temperatures it is simultaneously possible to produce a high-purity zinc concentrate that the zinc industry uses as a raw material. 470,000 tonnes of by-product were recycled in 2008, for example. Whereby 275,000 tonnes of foundry pig iron of differing qualities and 10,000 tonnes of zinc concentrate (dry) were reclaimed. Many by-products from the steel industry are used as secondary raw materials in other industrial sectors, e.g. to obtain zinc.

Conclusions

The steel industry in Germany has achieved a high level of raw material and energy efficiency as a result of plant- and process-related further developments and optimisations. This is also linked with environmental protection and the reduction of CO_2 emissions to an extent that a few years ago was hardly believed possible. The constant further development of process lines for hot metal and steel production, particularly secondary metallurgy and continuous casting technology, now make it possible to provide an extensive and customised range of steel grades meeting ever more stringent customer requirements. The modern material steel makes a major contribution towards reducing emissions. A study by the Boston Consulting Group (BCG) answers questions regarding steel’s contribution towards reducing CO_2 emissions for climate protection in new product applications by 2020. The results speak for the material steel[23)]. In the application cases selected by BCG, the savings potentials through the use of steel, amounting to 74 million tonnes of CO_2 in 2020, are greater than the total annual emissions from Germany’s total steel production. In a conservative estimate, the examples examined would on average save six times as much CO_2 as is emitted by production. These good prospects are a motivation to make further efforts in the development of new steel sorts. Specialists have long agreed that the potential of the material “steel” has by no means been exhausted.

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