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CO_2 EMISSIONS IN THE STEEL INDUSTRY

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Global CO_2 emissions caused by the burning of fossil fuels over the past century are presented. Taking into consideration the total world production of more than 1,3 billion tons of steel, the steel industry produces over two billion tons of CO_2. Reductions in CO_2 emissions as a result of technological improvements and structural changes in steel production in industrialized countries during the past 40 years are described. Substantial further reductions in those emissions will not be possible using conventional technologies. Instead, a radical cutback may be achieved if, instead of carbon, hydrogen is used for direct iron ore reduction. The cost and the ensuing CO_2 generation in the production of hydrogen as a reducing agent from various sources are analysed.

Key words: metallurgy, steel industry, CO_2 emissions, direct iron ore reduction

CO_2 emisije u industriji čelika. Prikazane su globalne emisije ugljičnog dioksida tijekom proteklog stoljeća izazvane izgaranjem fosilnih goriva. Uzimajući u obzir ukupnu svjetsku proizvodnju čelika od više nego 1,3 milijardu tona, čelična industrija proizvodi preko dvije milijarde tona CO_2. Opisana su smanjenja emisija CO_2 tijekom posljednjih 40 godina u proizvodnji čelika industrijski razvijenih zemalja poboljšanjem učinkovitosti i strukturalnim promjenama. U postojećim tehnologijama daljnje bitno smanjenje CO_2 emisija neće biti moguće. Radikalno smanjenje moguće je postići zamjenom ugljika vodikom u postupku izravne redukcije željezne rudače. Provedena je analiza cijena i popratnog generiranja CO_2 u proizvodnji vodika kao redukcijskog sredstva iz različitih izvora.

Ključne riječi: metalurgija, industrija čelika, CO_2 emisije, izravna redukcija željezne rudače

INTRODUCTION

In the production and processing of steel, the prices of products and energy costs are strongly affected not only by labour costs, but also by the cost of raw materials and reducing agents. This has been especially evident at the time of the present fast industrial development of the countries like China and India. To enhance energy efficiency in the production of raw iron and steel, and to apply the conventional technologies with maximum efficiency have become focal points of interest worldwide.

In conditions of merciless economic competition the introduction, in certain countries, of a new tax relative to CO_2 emissions has proved to be of crucial importance. In steel production, the largest decrease in CO_2 emissions is attainable by substitution of carbon for hydrogen as a reducing agent. This work aims to show a possible technological development of iron ore reduction by hydrogen as well as its economic advantage in relation to reduction by carbon.

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TRENDS IN INTERNATIONAL CO_2 EMISSIONS

Global CO_2 emissions caused by the burning of fossil fuels to heat homes, to fuel vehicles, or to power the industry, have increased rapidly over the past century. Figure 1 shows that global CO_2 emissions increased ten times from 1900 to 2000 [1]. The rate of growth has been particularly high over the past fifty years, although it has slowed down to some extent in the past two decades.

Europe and North America were responsible for 87 % of global CO_2 emissions at the beginning of the twenty-first century, with Western Europe accounting for 52 % and North America for 35 %. Over the century, emissions increased more than three times in Western Europe and nearly nine times in North America. However, the combined share of global emissions of the two regions diminished to 41% at the end of the century, as emissions from other continents increased much faster having started from a low level. For instance, the Middle Eastern countries, with CO_2 emissions more than a thousand times higher than in 1900, contributed with 6 % of global emissions. Central Asia (mainly China) contributed with 14 % of global emissions following an increase of six thousand times over the century.

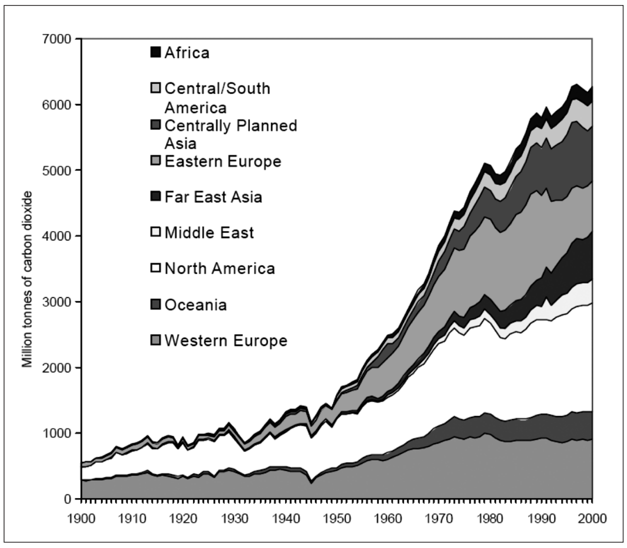

Figure 1. Trends in international CO_2 emissions from 1900 to 2000 [1]

Between 1990 and 2002 global CO_2 emissions grew by 16 %, according to the figures from the International Energy Agency [1]. Over the same period Western Europe noted a rise in emissions of about 3 %. The largest increases were recorded in Asia and the Middle East, with both regions showing a growth of over 75 % in their CO_2 emissions over that period, primarily as a result of economic growth and increased energy consumption. In the IEO2008 reference case [2], the world CO_2 emissions have been projected to rise from 28,1 billion tons in 2005 to 34,3 billion tons in 2015, and to 42,3 billion tons in 2030.

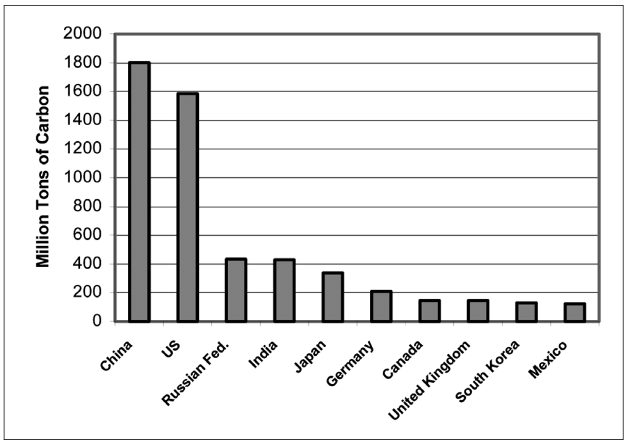

Figure 2. CO_2 emissions from fossil fuel burning, 2007 [2]

In 2007, the total global CO_2 emissions were million tons of carbon [2]. The countries responsible for the highest CO_2 levels were China, followed by USA, the Russian Federation, and Japan (Figure 2). All graphic outputs were made and prepared in terms of [3].

CO_2 EMISSIONS IN STEEL PRODUCTION

The past fifty years have seen a steady growth of total steel production. In the 1950s, the world steel production was about 200 million tons. In the past five years, the growth rate has accelerated. Total world crude steel production was 1,3435 billion tons in 2007 and 926,3 million tons in the first eight months of 2008. This is a 5,6 % increase over the same period in 2007. Geographic distribution of the world steel production was as follows: China 34,0 %, Japan 9,3 %, other Asia 10,5 %, EU (25) 15,9 %, other Europe 2,9 %, NAFTA (Argentina, Brazil, Venezuela and other Latin America) 10,5 %, CIS (Canada, Mexico, United States) 9,6 %, and others 7,2 %. The future growth in demand for steel will be driven mainly by the needs of the developing world. To satisfy those needs the steel industry must continue to grow by 3–5 % worldwide and by 8–10 % in China, India, and Russia [4].

In this century sustainable development will require a major increase in the volume of steel used and produced worldwide. On the other hand, in Kyoto, industrialized countries agreed to reduce their collective greenhouse gas emissions. The Kyoto protocol, ratified by the 183 parties to 2008, has set legally binding targets for cutting the emissions of six greenhouse gases – mostly pollutants caused by burning coal, oil, and other hydrocarbon fuels – by an aggregate 5,2 % from the 1990 levels between the years 2008 and 2012.

Today, the world steel industry accounts for between 4 % and 5 % of total man-made greenhouse gases. The average CO_2 intensity for the steel industry is 1,9 tons of CO_2 per ton of steel produced. Taking into consideration the global steel production of more than 1,3 billion tons, the steel industry produces over two billion tons of CO_2. Over 90 % of emissions from the steel industry come from iron production in nine countries or regions: Brazil, China, EU-27, India, Japan, Korea, Russia, Ukraine, and the USA [4].

The global problem of climate change requires a global solution. Policies to encourage improved energy efficiency and reduced CO_2 emissions are called for all over the world. The steel industry in industrialized countries, owing to efficiency improvements and structural changes, has made reductions in CO_2 emissions during the past 40 years.

A characteristic example is the iron and steel industry in the USA where primary steel production using inefficient open-hearth furnaces dropped from 44 million tons in 1970 to six million tons in 1982, to become completely extinguished by 1992. Primary steel production using the blast furnace (BF) and the basic oxygen furnace (BOF) fluctuated between 40 and 75 million tons over the same period. Secondary steel production, from scrap steel, pig iron, or direct reduced iron, using the electric arc furnace, more than doubled, growing from 18 to 38 million tons between 1970 and 1995 [5]. Between 1958 and 1994, the share of coal and coke as energy sources dropped from about 75 % to 57 % of total fuels, to be followed by a drop in the share of oil from 10 % to 3 %. The share of natural gas used in the industry increased from 10 % to 28 %. The share of electricity rose from 4 % to 11 % during the same period, mostly as a result of increased secondary steel production. Trends in CO_2 emissions followed those in the use of energy, with carbon emissions of 64 million tons in 1958, 96 million tons in 1973, and 45 million tons in 1994 [5].

Between 1958 and 1994 there was a drop of 27 % in energy consumption per ton of steel, from 35,6 GJ/t to 25,9 GJ/t. Analyses indicate that about two thirds of the decrease between 1980 and 1991 was due to improved efficiency, while the remainder was result of structural changes [5]. CO_2 intensity dropped from 0,82 t C/t steel (3 t CO_2/t steel) to 0,50 t C/t steel (1,8 t CO_2/t steel) during that period, reflecting a general decrease in energy use per ton of steel produced as well as fuel switching. The most important change concerned the growing use of scrap-based electric arc furnaces for secondary steel production, which rose from 17 % to 39 % of total steel production during that period. Efficiency improvement can be explained mainly by a higher rate of continuous casting, which grew from 0 % in 1971 to 89 % in 1994, and the closing of inefficient open-hearth furnace steelmaking, which dropped from 30 % in 1971 to 0 % after 1991. In addition, the increased use of pellets as blast furnace feed contributed to energy savings [5].

Technological advancements in the steel industry that have taken place over the past 25 years have made substantial reductions in CO_2 emissions possible. These advancements include: enhanced energy efficiency in the steelmaking process (e.g. application of a new technology integrating casting and hot rolling in one process), improved recycling of steel products (currently in excess of 60 % in developed countries), improved use of by-products from steelmaking, and better environmental protection techniques.

HYDROGEN FOR IRON ORE REDUCTION

There is no way of reducing CO_2 levels to where the scientists say these should be by 2050, unless radical new ways of making steel, the so-called breakthrough technologies, are identified, developed, and introduced.

In Europe projects have been under way under the ULCOS programme, which is funded jointly by the European steel industry and the European Union. One of the main projects concerns a re-design of blast furnaces to optimize CO_2 production along with carbon capture and storage. The ULCOS programme also has to do with new smelting technologies, and even with the long-term potential of electrolysis for steel production. Many of these ideas depend on the availability of a carbon-free source of energy. Some of them imply a radical reduction of emissions of 50 % or even higher. Parallel programmes in Japan, funded by the Japanese Government with a major participation from the steel industry, are focussing on hydrogen and its potential as reducing agent in the steelmaking industry. In the United States the programmes funded by the Department of Energy and the steel industry are at an early stage but offer exciting potentials. There are also programmes under way in Korea and in Australia [4].

The hot metal production in the route: blast furnace – basic oxygen steelmaking generates about 1500 kg CO_2/t of liquid hot metal [6]. As the most widely used reductant, carbon is first converted by the solution loss reaction to carbon monoxide, which is responsible for actual reduction and is thereby oxidised to CO_2. A radical reduction in CO_2 emissions can be achieved if hydrogen is used for iron ore reduction. Ideally, hydrogen reduction would imply zero CO_2 emissions because the resulting off-gas, water, is easily separated by condensation.

In Figure 3, the compositions of the reducing gases, carbon monoxide and hydrogen, are compared on the basis of the well-known reaction equilibrium in iron ore reduction [7]. At temperatures above 850 °C, the power-reducing impact of hydrogen is even stronger than that of carbon monoxide.

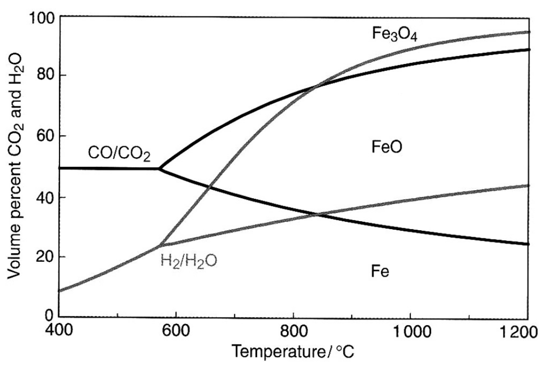

Figure 3. Gas compositions of reductants in equilibrium, with iron and iron-oxide phases as a function of temperature [7]

Atomically small and of high diffusivity hydrogen has been noted as the faster reductant offering a prospect of fast reduction processes devoid of greenhouse gas emissions [7].

Figure 4 compares current technologies for producing steel from directly reduced iron (solid sponge iron (DRI) or hot briquetted iron (HBI)), pig iron, and scrap steel, in respect to the reductant gas composition considering CO_2 emissions per ton of liquid steel [9–11]. It is evident that CO_2 emission in the steel production based on iron ore reduction by hydrogen is decreased, but not completely eliminated.

Today's steel production is 42,9 million tons, which is about 4,9 % of the total world pig iron production of 871,6 million tons [4]. At present, steelmaking cannot fully rely on direct ore reduction by hydrogen because of the high cost of hydrogen as a reducing agent. Hydrogen

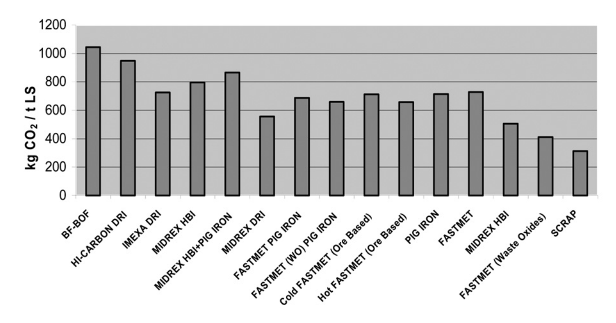

Figure 4. CO_2 emissions with current steelmaking technologies [10]

can be produced from fossil media (natural gas, oil, coal) by biomass gasification, and from non-fossil sources (e.g. by water electrolysis). Fossil sources and biomass are associated with a substantial mass fraction of carbon. Therefore, manufacturing hydrogen from such sources requires some extra process energy associated with CO_2 generation. CO_2 can be captured and stored when hydrogen is produced from fossil media but the cost increases when CO_2 emission is mitigated. If hydrogen is generated from other processes, e.g. by water electrolysis, its cost is closely tied to the price of electric energy reaching 20 €/GJ [11]. The diagram in Figure 5 shows the cost and CO_2 generation per 1 GJ in hydrogen production from various sources in comparison with carbon (black circle) as a reducing agent [12]. Although biomass is composed of hydrocarbons, the overall cycle is viewed as CO_2-neutral because the CO_2 produced by gasification and emitted into the atmosphere will be recovered by the growth of new biomass through photosynthesis.

In the future, if low-cost electric power becomes available from large-scale hydro-electricity projects, the estimated price of hydrogen from electrolysis will be in the range of 7–14 €/GJ [13]. But in that case, direct electrolytic reduction of ore melts might be an alternative to the longer hydrogen route [14].

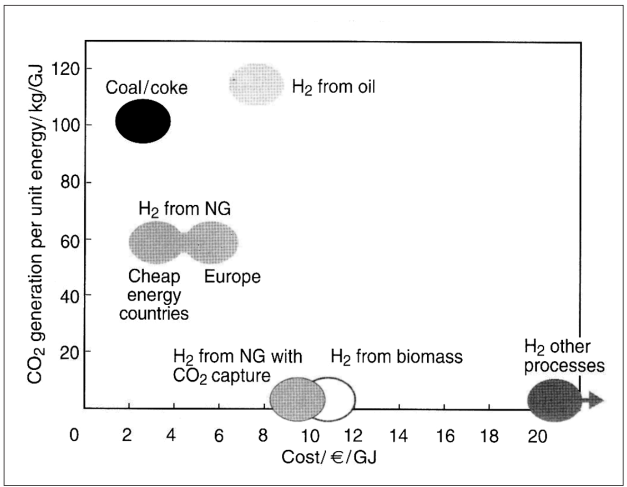

Figure 5. Diagram of cost–CO_2 generation in hydrogen production from various energy sources [12]

CONCLUSIONS

Most of the CO_2 generated by today's steel industry comes from the chemical interaction between carbon and iron ore in blast furnaces. This process, known as iron reduction, produces molten iron which is converted to steel. The maturity and efficiency of the conventional technology imply that with the most advanced facilities, the iron-reduction process operates close to the thermodynamic limits. Therefore, substantial further reductions in CO_2 emissions will not be feasible if only conventional technologies are used.

A major reduction in CO_2 emissions in today's steel production can be achieved by use of electric arc furnaces as well as by direct ore reduction using hydrogen. An increase in steel production by means of an electric process requires cheaper electric energy, which, in the future, might be achievable either from alternative energy sources or from nuclear energy. In this way, the current share of 32 % of the steel production by an electric process could become higher without involving CO_2 emissions. So far this has not been possible because the quantity of the presently available scrap steel is not sufficient to meet the demand for steel on the market. A possible solution is to increase the share of charge for electric arc furnaces produced by ore reduction by hydrogen. In the past five years, the price of scrap steel has nearly doubled. In the future, an additional growth should be expected. The price of pellets or briquettes from the ore reduced by hydrogen is currently relatively high because of the high cost of hydrogen as reductant. In the next 30 years, the cost of hydrogen production is expected to fall, but it will still be higher than the ore reduction by carbon. Therefore, in the near future, steel production is still expected to rely largely on the reduction by carbon. With the current technologies of direct ore reduction using the gases hydrogen and carbon monoxide, CO_2 emissions have been reduced but not eliminated. As the majority of iron ore reduction technologies using hydrogen are subject of continuous development, their current technological level and efficiency are not taken to be final. However, an essential change in the technology of steel production could occur only in the case of hydrogen production from the water as an unlimited resource, at an acceptable price. This might also lead to further revolutionary changes in production technologies.

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Note: The responsible translator for English language is prof. Neda Banić