TOWARD SUSTAINABILITY IN FERROALLOYS PRODUCTION

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ABSTRACT

Ferroalloys production is an energy-intensive industrial sector with significant CO_2 emissions. In this paper the current situation in ferroalloys processes are discussed from the standpoint of global environmental issues, trends and development. Progress and data of ferroalloys production are frequently compared with steel industry which is a closely related sector and the main user of ferroalloys. Emission factors of processes and electricity production are examined as well as possibilities and future scenarios how to diminish CO_2 emissions. As a part of this study a questionnaire was submitted to experts in the field of ferroalloys worldwide to survey opinions on ferroalloys industry today and in the near future (2020). Eighteen questions concerning raw materials, energy, environmental aspects, by-products and economic aspects were responded by seventeen experts, the answers were analysed and concluded finally in this paper.

1 INTRODUCTION

According to a definition sustainable production meets the present needs without compromising the ability of future generations to meet their own needs. Sustainability of a process can be evaluated by using environmental, economic and social indicators. In public debate environmental issues and CO_2 emissions have been in the central focus. Also this paper is discussing mostly on energy consumption and saving, carbon dioxide emissions and possibilities to decrease them in ferroalloys production. The related industrial branch, steel industry as the major customer and user of ferroalloys is often reviewed to benchmark its parallel progress.

Ferroalloys are defined as iron-bearing alloys with a high proportion of one or more other element, manganese, chromium, silicon, molybdenum, nickel etc. They are used as alloying additions in steel to improve the properties especially tensile strength, toughness, wear and corrosion resistance. Their production is thus firmly related to steel production. The approximate ratio of annual production of ferroalloys versus steel is roughly 2.5:100 which means an “average alloying degree” of 2%. In practise the distribution is not regular but the high majority of steels utilise these alloys only around 1 - 2 % and then there are groups of high alloyed steels, stainless steels as the most important group containing 10 to 30 % or more alloying elements. Concerning especially steels with high Cr, Ni, Mo, recycled material takes a remarkable fraction of the alloyed material balance.

As well-known, the world steel production had an unforeseen rapid growth since the end of 1990s until the recent recession. The world production grew up from the level of 800 million ton (Mt) to 1350 Mt in 2007 (Fig. 1[1]). It is, however, noteworthy that most of this tremendous growth was due to erection of numerous new steel plants in China, whereas the growth was rather calm in other countries. China´s production was in 2007 about 500 Mt steel. The future scenarios today are more conservative but due to presumable recovery in BRIC countries (Brazil, Russia, India and China) and inevitable progress in many developing countries enormous investments are required in infrastructure, housing, transportation etc. This must mean that steel consumption per capita will drastically grow in those countries, which leads to a clear and continuously growing demand of steel during the next decades [2].

Ferroalloys production, firmly connected to progress in steel industry also experienced a corresponding production growth from about 18 million tons in the 1990s to 34 Mt in 2007 (Fig. 2) [3]. As an example, FeCr production is presented separately showing a growth from 3-5 Mt to over 8 Mt in 2007.

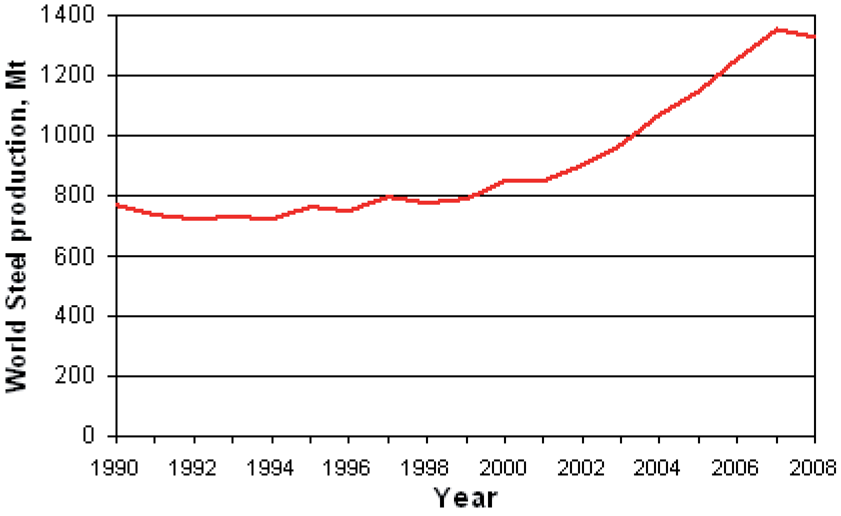


Figure 1: World crude steel production from 1990 to 2008 (million tons) [1]

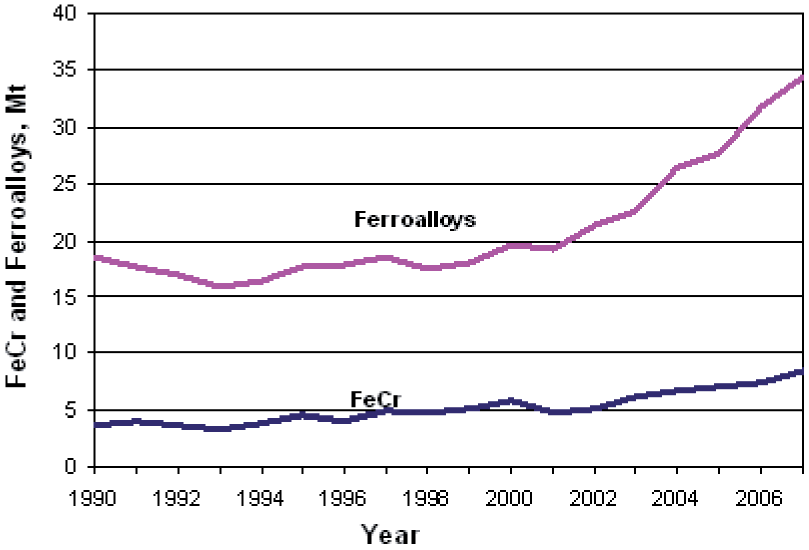


Figure 2: World production of ferroalloys and FeCr from 1990 to 2007 (million tons) [3]

2 ENERGY CONSUMPTION AND CO_2 EMISSIONS FROM PRODUCTION

2.1 General

According to IEA report the global energy use was 12 000 million tonnes of oil equivalent (Mtoe) in 2007 [4]. On the other hand the global CO_2 emissions were reported as 29 Gt in 2007 which is in good agreement with the energy figure when taking into account the distribution of different energy forms [4]. The industrial activities were responsible for 4.8 Gt CO_2 of which iron and steel production emitted 1.47 Gt CO_2 [4]. That is approximately 5% of total world CO_2 emissions. This figure concerns, however, only the primary energy use (coke, coal, gas, oil) but not indirect emissions due to e.g. electricity production. If they are taken into account higher figures are obtained for the iron and steel industry i.e. 6-7 % of the total CO_2 emissions [5].

2.2 Ferroalloys production

Ferroalloys production is regarded as an energy-intensive industry with high consumption of electricity and coke and minor amount of other fuels and reductants. That means also high CO_2 emissions. What is actually the role of ferroalloys industry in global emissions? Only quite few studies have discussed energy consumption and CO_2 emissions in ferroalloys production. The Intergovernmental Panel on Climate Change Report 2007 (IPCC [6]) has used the data by Sjardin (2003 [7]. In Table 1 the emission factors were adopted from Sjardin and combined with production figures of common ferroalloys in 2007 [3]. FeCr and FeMn include different grades (high, medium, low carbon) with different emission factors. FeSi also comprises of different grades with different Si-contents. The value 2.92 is a weighted mean value. Carbon dissolved in ferroalloys was not included as emission in FeCr production. For a comparison, emission factors from another publication are given too [8].

Table 1: Emission factors, production and estimated global emissions for common ferroalloys

Ferroalloy	Emission factor t CO_2 / t Fe-alloy [7] / [8]	Production (Mt/2007) [3]	Global CO_2 emissions (Mt)
Ferrochromium	1.63 / 1.6	8.503	13.860
Ferromanganese	1.79 / 1.3	5.194	9.300
Ferrosilicon	2.92 / 2.5-4.0	6.760	19.740
Silicomanganese	1.66 / 1.4	7.310	12.130
Total	**Avg. ~ 2**	**27.770**	**55.030**

As seen the total emissions from four main ferroalloys with 27.77 Mt production were about 55 Mt from which an approximate figure about 70 Mt CO_2 for the total ferroalloys production (34 Mt) can be estimated. That is about 5 % of the emissions of the global iron and steelmaking.

2.3 Best available technologies

Best Available Techniques (BAT) were defined by EC Directive 96/61 in Article 2(11) as “the most effective and advanced stage in the development of activities and their methods of operation which indicates the practicable suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent, and where that is not practicable, generally to reduce the emissions and the impact on the environment as a whole”. This definition implies that BAT not only covers the technology used but also the way in which the installation is operated, to ensure a high level of environmental protection as a whole. BAT takes into account the balance between the costs and environmental benefits.

BAT studies were initiated by the Directive 96/61/EC on integrated pollution prevention and control (IPPC). Concerning Non-Ferrous industry including ferroalloys a comprehensive study was prepared in the turn of the millennium and published in December 2001 [9]. A revised version was later prepared and published as a working draft in July 2009 referenced to the codified IPPC Directive 2008/1/EC [10]. The report works are based on information and data from experts´ groups and are thus considered authentic. As an example some data of FeCr processes are reviewed here.

In ferrochromium production the main issue is the submerged arc furnace (SAF). The conventional furnace type is “open furnace” in which furnace off-gas is mixed with large amount of air. “Closed furnace” instead is designed to maintain CO-rich off-gas by collecting, cleaning and storage for further utilisation. An intermediate type “semi-closed” furnace is still common for FeSi and special alloys production. The furnace off-gas is also there possible to recover but is less calorific due to diluting with air. In Table 2 the two types, open and closed processes are compared for some crucial features. The IPPC Report represents also two other alternative processes namely use of pre-reduced pellets in close SAF and DC furnace without pre-reduction [10]. As the data of these were incomplete they are not discussed here.

The report gives also emission data to air and water. Of these only the CO_2 emissions are referred here. For HC FeCr in closed SAF the CO_2 emissions were reported in the range 1200-2000 kg/t FeCr including total emissions from pre-treatment, smelting and post furnace processes. The external use of CO gas was considered to reduce local emissions from the FeCr plant.

Table 2: Consumption of raw materials and energy when producing HC ferrochromium [10]

Raw material	Open SAF*	Closed SAF**
Chromite kg/t	2400-3000	2300-2400
Reducing agent kg/t	550-700	500-550
Fluxes kg/t	100-400	200-300
Electrodes kg/t	8-25	7-10
Remelts	0-300	-
Electricity kWh/t	3800-4500	3100-3500
Calculated potential energy by using coke kWh/t	4235-5390	3850-4235
Total energy input kWh/t	8035-9890	6950-7735

* Data for open SAF with lumpy and fine ore without agglomeration and preheating. **Data for closed SAF using preheated pellets. For the coke / electricity conversion a value 7.7 kWh/ kg coke was used.

In order to summarise most effective and advanced technologies for ferroalloy production line the following items are appropriate [9, 10]:

- concentrate sintering by utilising CO gas from smelting furnace
- preheating of charge material for smelting furnace by utilising CO gas
- pre-reduction might be a potential sub-process for certain ferroalloys in the future
- smelting in closed electric arc furnace with efficient off-gas recovery, filtering and energy utilisation in-plant as fuel, in neighbouring plants, society or for energy production
- semi-closed furnace (FeSi) if energy recovery can be performed from CO gas
- efficient gas cleaning for dust, heavy metals and toxic emissions
- closed water system with removal of particulates and harmful components
- recycling, reuse and/ utilisation of solid wastes like slags as by-products

3 POSSIBILITIES TO DECREASE CO_2 GENERATION

3.1 Steel industry´s commitment toward 2030

World Steel Association has published seven commitments to reduce steel-related greenhouse gas emissions [2]. Applying these statements to ferroalloys industry the following concepts could be written:

- Expanding best available technologies in ferroalloys industry to improve energy efficiency and to decrease CO_2 emissions. This is an economic way which also really decreases CO_2.
- Undertaking research and development for new technologies to radically reduce the specific CO_2 emissions for each ton of ferroalloy produced. Some aspects are discussed in 4.2.
- Improving recovery and winning of alloy metals by improved recycling systems, by improved melting technologies and in-plant recycling. Could the use of secondary raw materials intensified and increased in ferroalloys production?
- Maximising the value of by-products e.g. slags, dust etc from ferroalloys production.
- The principle of facilitating the use of the new generation steels to improve the energy efficiency of steel-using products could be adapted to ferroalloys industry by maximizing the value of ferroalloys for steelmaking via “tailored” products/alloys. The merit of increased lifetime of a steel product with less CO_2 emissions per annum could be “integrated” upstream to ferroalloys production as well.
- Adopting common and verified reporting procedures for CO_2 emissions (e.g. applying IPPC Directive 2008/1/EC [10]).
- Adopting a global sector-specific approach for ferroalloys industry in the post-Kyoto period.

3.2 Possibilities to decrease CO_2 emissions from ferroalloys production

In current ferroalloys production the main role of carbon (coke) is as reducing agent. Hydrogen (or natural gas) which is used for direct reduction of iron ore to metallic iron is not strong enough to reduce e.g. chromium, silicon or manganese from their oxides. Although carbon is necessary its need should be minimised and efficiency maximised. A key point in submerged arc furnace is a perfect recovery of furnace gas and its reasonable usage of maximal value. For FeCr, FeMn and SiMn closed furnaces are nowadays most common. In these processes the coke carbon is almost quantitatively converted to CO gas (except for carbon dissolved in ferroalloy). In an example case of FeCr process the gas contained 75-90 % CO, 2-15% H_2, 2-10 % CO_2 and 2-7 % N_2 [11]. The gas has high calorific value 10.1 – 11.5 MJ/Nm^3 and specific energy content 7200 – 8280 MJ/t FeCr (2.0 – 2.3 MWh/t FeCr). If the CO gas is treated as a credit the CO_2 emissions from the core process of FeCr smelting can be evaluated to be quite small, only about 600 kg/ t FeCr [11]. This is much lower than the emission factor value 1.6 given in Table 1 for FeCr. A reason for different values comes from the definition of system boundaries which is discussed more in the next chapter.

An important aspect is also the recovery of the alloy metal into a ferroalloy. There are still possibilities to improve yield e.g. for Cr in FeCr typical yield is 90-95 % and for Mn in FeMn production from under 80 % to over 90 % depending on the slag practice and recycling [10, 12]. Yield of alloy metals in smelting processes highly depends on slag chemistry, basicity being a central factor influencing distribution of certain metal between the slag and the formed liquid ferroalloy [13]. Also physical properties like viscosity are important because a significant part of yield losses exist as metal particulates dispersed in the slag. In both these aspects there are still potential and challenge for metallurgists to be improved.

3.3 Importance of system boundaries

As seen in the previous chapter and discussed in literature [14, 15] the energy consumption and CO_2 figures of a certain process can greatly depend on how the boundaries of the system were defined. Tanaka [14] has shown how the energy consumption per ton of crude steel can range from 16 to 21 GJ depending on the boundaries set for the system. "Measures of energy efficiency performance" (MEEP) can be estimated by physical-thermodynamic indicators, economic-thermodynamic indicators or pure economic indicators. Of these the first one "thermal efficiency" is the traditional "engineering" concept *energy output/energy input* or "energy consumption intensity" (unit or specific energy consumption) for instance *energy consumption per 1 ton product.* That makes comparison between different plants possible providing that boundary definition is similar. Applied to ferroalloys industry the smallest unit might be the smelting furnace e.g. comparison of open, semi-closed and closed furnaces. However, this reveals quite difficult as for instance the input raw materials are very different with different "energy history" too. Also valuation of gases can be problematic. A better way is to define the system consisting of the whole ferroalloy plant from raw materials to liquid ferroalloy (pre-treatments, sintering, pre-heating, smelting, gas cleaning and recovery). A manifest problem is the furnace off-gas (e.g. in FeCr process). It seems accepted that the fraction of CO-gas (which is not used inside the FeCr plant integrate) can be valuated as credit when used externally for electricity production, heating etc. In large integrated plants including FeCr and stainless steel production in the same site the CO-gas can be stored and effectively utilised for pre-heating of materials, reactors, ladles etc and then finally converted to CO_2 [11]. If the energy efficiency is then evaluated for the whole integrate site the CO-gas has its value as an energy rich and economic fuel.

Further, energy of CO-gas or other less intensive energy forms (steam, hot water, waste heat) can be utilised inside the plant or for neighbouring community. In the latter case they bring credit to the plant. One almost neglected energy source concerning ferroalloys industry are the latent heats of liquid ferroalloy and slag from the smelting furnaces. As far as is known, the only plants utilising latent heat of liquid FeCr as direct liquid charging in stainless steelmaking are Outokumpu Tornio Stainless in the integrated FeCr - stainless steel plant in Finland and Columbus Stainless in Middelburg, South Africa which gets liquid FeCr from neighbouring Samancor Middelburg Ferrochrome. Except for the enthalpy of liquid metal also liquid slag has remarkable heat content which is, evidently, not utilised in any systematic way. Outokumpu Tornio Works utilises heat content of slag to decompose cyanides in gas washing water in slag granulation [16]. Otherwise, the information on utilisation of latent heats of furnace products concerning other ferroalloys seems nil.

4 TOWARD SUSTAINABILITY

4.1 General

The influence of anthropogenic emissions on climate change is generally admitted. Growth of emissions increases CO_2 (in general GHG) content in the atmosphere which then causes global warming. Since the UN Framework Convention on Climate Change was adopted in 1992 in Rio de Janeiro, the imminent danger was universally recognised and corrective and limiting actions were started. Recently, the United Nations Climate Change Conference was held in Copenhagen in

December 2009 (COP15). It was loaded with ambitious targets but with 193 parties the meeting had problems to come into unanimous agreement on conclusions [17]. Due to imaginative diversity of parties (as to population, industrialisation, development level, economy, natural resources, cultural aspects etc) it is understandable that most of decisions were only indicative for next endeavours. As unambiguous and therefore important “techno-political clauses” there were underlined that “climate change is one of the greatest challenges of our time”. Further it was “agreed that deep cuts in global emissions are required according to science, and as documented by the IPCC Fourth Assessment Report with a view to reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius”. This target has been earlier defined to be consistent with the objective of limiting the long-term concentration of greenhouse gases in the atmosphere on the level of 450 ppm CO_2 equivalent (450 Scenario) [4]. This is a really challenging target which means holistic changes from high-carbon energy forms and technologies to low-carbon ones. It means transformations both in production, transportation and use of energy, “a veritable low-carbon revolution to put the world on the 450 ppm trajectory”.

4.2 Energy consumption and electricity generation

The world energy consumption is strongly based on fossil non-renewable sources representing totally over 80% of all energy used in 2004 ([18]: oil 38 %, coal 26%, gas 23%, total fossil 86%, hydro and nuclear both 6%). Thus decarbonisation of energy seems to play a central role in reducing emissions. Oil has a decisive role e.g. in transportation and heating. In publicity, oil has been considered non-renewable, depleting resource which has been forecast to end in few decades. The major position of “liquid fuels” has been predicted, however, to remain also in the near future, partly due to more efficient oil recovery technologies which increase production of conventional resources, partly due to emerging new unconventional oil resources (oil sands, extra heavy oil) and finally, due to drastic growth of “new non-petroleum” liquids, such as bio-fuels, coal-to-liquids and gas-to-liquids [19]. Easy to transport and user-friendliness are the central reasons why liquid fuels are foreseen to succeed.

Also use of coal has been predicted to strongly grow towards the year 2030 in North America and Asia whereas in Europe it is assumed to decrease [19]. The reasons for this progress are both from resources and energy-political. When using coal and liquid fuels, discussed above, CO_2 emissions will increase. As a solution carbon dioxide capture and storage or sequestration (CCS) are proposed. That has been planned for electricity production in coal power stations where it has been already tested in minor scale since 2008 but is still rather far from final industrial usage [20]. CCS for an end-user like steel industry is possible as well and has been studied e.g. in European ULCOS project [21]. Ferroalloys producers are relatively small direct emitters of CO_2 anyway, thus CCS application is not very realistic.

The share of natural gas is about 20 % and will remain about the same until 2030. There are huge unconventional resources whose exploitation is difficult. Anyway, it is believed that natural gas will increase and its share will slightly grow covering over 20 % of primary energy [19]. Exploitation of unconventional gas (coal bed and shale reservoirs) will increase especially in North America. Even an oversupply of gas is possible. Today a big user of gas in metallurgical industry is direct reduction of iron ore to metallic iron in solid state via shaft furnace and fluidised bed processes. Further potential users are evident. In ferroalloys production natural gas can be used for pre-heating, pre-reduction and different heating purposes thus decreasing coke and electricity consumption. It is notable that CO_2 emissions from natural gas are much lower than from coal or coke. In terms of emissions per energy unit the values for coke and natural gas are 108 and 56 kg CO_2/GJ, respectively [22].

Although coke is the main direct CO_2 source in ferroalloys industry electricity takes the major part of energy consumption (over 3000 kWh/ t FeCr). Therefore it is essential to reveal the origin of electricity and its indirect emissions depending on the type of the power station. Such a comparison is shown below in Table 3. The global average of electricity production was estimated as 504 kg CO_2 /MWh assuming a conversion ratio 1 MWh = 9.8 GJ [22].

Direct emissions mean emissions from combustion and indirect emissions from materials production (mostly steels and other metals), transportation and life-cycle emissions. Carbon capture and sequestration could cut in-site emissions into atmosphere with 90%, but taking into account the lower conversion rate due to extra energy for capture and storage and indirect effects the real reduction of emissions can be remarkably lower [24].

Table 3: Comparison of Greenhouse Gas Emissions from Electricity Production [23]

Primary energy/ Production system	**Direct emissions g CO_2/kWh**	**Including indirect emissions g CO_2/kWh**
Coal	790 - 1017	966 - 1306
Oil	650	~ 800
Natural gas	362 - 575	440 - 688
Solar power	-	100 - 280
Biomass	-	25 - 93
Wind	-	10 - 48
Hydropower	-	4 - 30
Nuclear	-	9 - 21

5 QUESTIONNAIRE ON FERROALLOYS PRODUCTION

5.1 Questionnaire performance

In order to obtain broader opinion about the importance of different factors concerning sustainable production of ferroalloys a questionnaire was prepared and mailed to 25 internationally well-known experts in the field of ferroalloys production. During summer and autumn 2009 totally 17 responses were received representing almost same number of enterprises or institutions on six continents and dealing with central ferroalloys (FeCr, FeMn and FeSi). The questionnaire consisted of 18 questions, of which 2 concerned raw materials and pre-treatment, 4 on energy issues, 5 on environmental, 3 on by-products and 4 on economic aspects. The importance of factors was marked with numbers 1…5 where 1 = not at all important and 5 = very important. Two time scales were asked to assess: “today” (2009/10) and “future” (2020). As an extra point “other items or opinions” were requested. Several respondents gave useful comments which were taken into account in the following discussion.

5.2 Observations on responses

The results are presented in Figure 3 and in Table 4. By looking at distributions and mean values the following conclusions can be drawn:

- Almost all the issues were considered important as indicated by the high average values (3.63/4.67) of all factors shown.
- The importance of most issues is still growing in the future (Δ mean value = +1.04; range +0.29…+1.65).
- Quality of raw materials is a key issue as the known ore reserves will be depleted. The role of pre-treatment (pelletising/sintering) is increasingly important when supply of ore fines will increase. Concentrate blending is also relevant.
- Electric energy is already today important and is still rising toward rating 5.
- Coke is important as well but other fossil fuels or reductants are less significant (2.29/3.06).
- Biomass has today quite low status (1.94) but is distinctly growing until 2020 (3.36)
- All environmental issues are of great importance and still strongly growing (Δ mean values in the range +1.05…+1.41)
- By-products including CO gas, efficient heat recovery and slag utilisation have the greatest potential to be improved in the future (Δ mean value = +1.53…+1.65)
- Economical issues, in general, have very strong weight and in 2020 close to value 5. The only deviant is Investment costs/size factor with high scatter in answers telling that even rather small units can be economical in favourable conditions

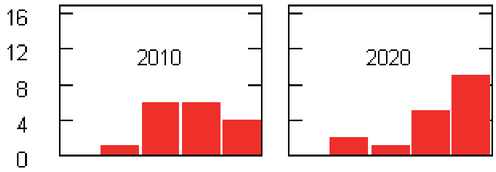
Other issues released by the correspondents to be important to focus on were:

- Better yield of alloy metal (Mn, Cr…)
- Low impurity level (S, P…)
- Skills of personnel; education, training
- Social and health issues, development of society, (HIV management)

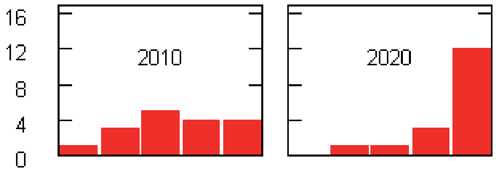
Table 4: Summary of Questionnaire on Ferroalloys Production

Factors	Average values		
	2009/2010	2020	Difference
Raw materials – ore quality	3.76	4.24	0.48
Raw materials pre-treatment (pellet./sintering)	3.41	4.53	1.12
Energy consumption – electricity	4.24	5	0.76
Energy consumption - coke	3.82	4.47	0.65
Energy consumption – coal, other fossil	2.29	3.06	0.77
Energy consumption – biomass, charcoal	1.94	3.35	1.41
Environmental – CO2 emissions kg /t Fe-alloy	3.29	4.59	1.30
Environmental – emissions to air	3.71	4.76	1.05
Environmental – emissions to water	3.24	4.53	1.29
Environmental – heavy metals emissions	3.18	4.35	1.17
Environmental – amount of final waste	2.71	4.12	1.41
By-products - CO-gas	2.94	4.59	1.65
By-products – heat recovery	2.82	4.35	1.53
By-products – slag utilisation	2.76	4.35	1.59
Economic aspects – operational costs	4.65	4.94	0.29
Economic aspects – investment costs/size factor	4.12	4.47	0.35
Economic aspects – availability of plant facilities	4.29	4.76	0.47
Economic aspects – total production costs	4.59	4.94	0.35
Total average	**3.63**	**4.67**	**1.04**

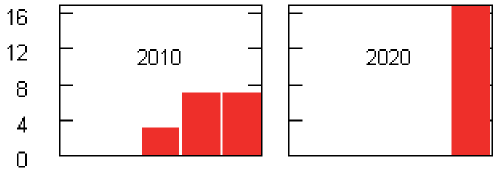
All average values grew from 2009/2010 to 2020 and the differences were marked with + sign. All the score frequencies and distributions can be found in Figure 3. The columns represent frequency of given marks 1, 2, 3, 4, 5 from left to right in each figure.



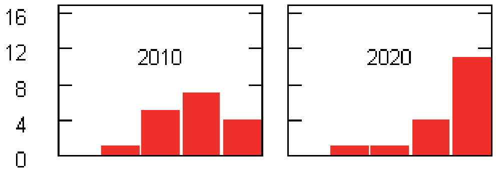
Raw materials - ore quality



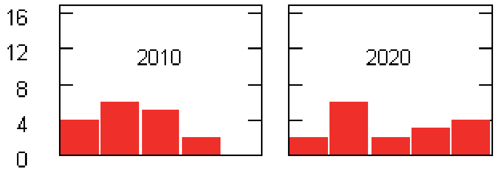
Raw materials pre-treatment - pelletizing, sintering



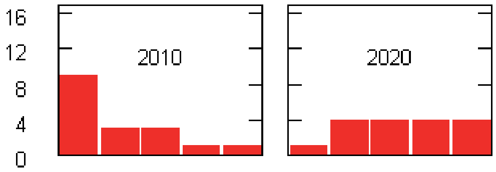
Energy consumption - electricity



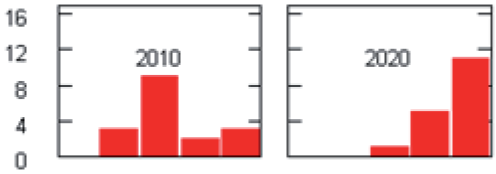
Energy consumption - coke



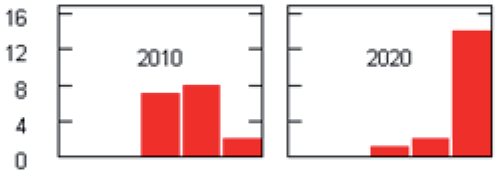
Energy consumption - coal, other fossils



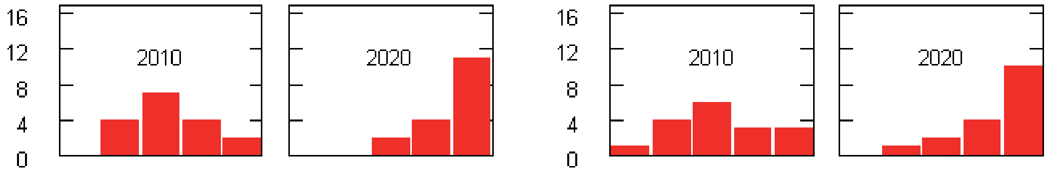
Energy consumption - biomass, charcoal



Environmental aspects - CO2 emissions kg/t Fe-alloy

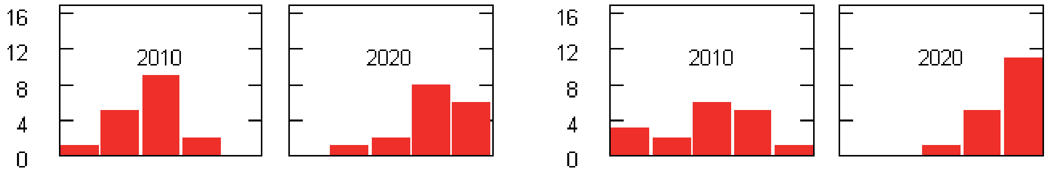


Environmental aspects - emissions to air



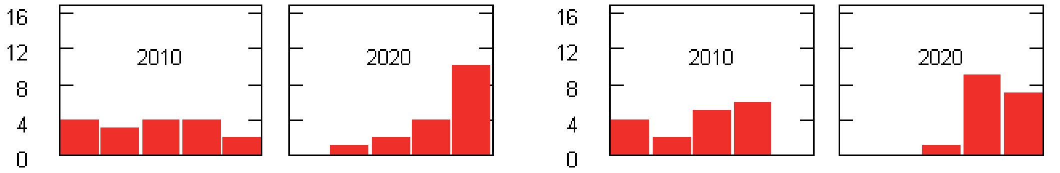
Environmental aspects - emissions to water

Environmental aspects - heavy metals emissions



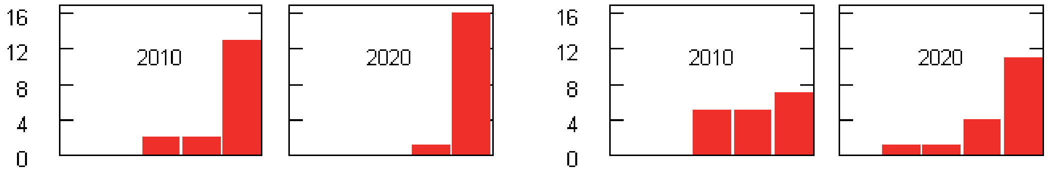
Environmental aspects- amount of final waste

By-products - CO gas



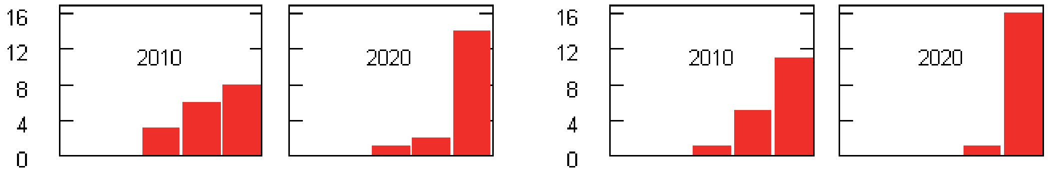
By-products - heat recovery

By-products - slag utilisation



Economic aspects - operational costs

Economic aspects - investment costs/size factor



Economic aspects - availability of plant facilities

Economic aspects - Total production costs

Figure 3: Distribution of scores in the responses of experts concerning importance of different factors in ferroalloys production today (2010) and in the near future (2020).

6 CONCLUSIONS

Results of the exhaustive survey of endeavours toward sustainability universally, and in steel and ferroalloys industry are briefly concluded here.

- It seems indisputable that our planet cannot continue on the route of continuous growth in energy consumption and CO_2 emissions but quite radical actions are needed.
- That means better energy efficiency and saving via regulating and directing consumption by pricing, taxation or other actions.
- Transfer from fossil high-carbon fuels must take place to less-carbon energy sources and to renewable energy forms.
- In the intermediate phase carbon capture and storage is a potential but not any final solution.
- In steel and ferroalloys industry the challenges, means and actions are parallel.
- Saving energy and materials, utmost utilisation of energy via integration are still of first priority
- Transfer from fossil to low-emitting and renewable energy should be followed and promising applications actively absorbed to ferroalloys sector.
- Comprehensive analysis and radical extension of system boundaries from smelter site to up- and downstream processes including also evaluation of products and energy production and utilisation will most effectively influence emissions in global scale.

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