ON PROBABLE WAYS OF STEELMAKING AND FERROALLOY INDUSTRY DEVELOPMENT

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ABSTRACT

This article gives an analysis of recent statistic data of the global industry development and forecasts on growth of production and consumption of steel and various ferroalloys. Some traditional views of metallurgists on alloying systems for some groups of steels are discussed. The results of calculations of the efficiency increasing at low frequency usage for steel and ferroalloy furnaces power supply are presented. The most spectacular achievements and the observed trends in the development of new steels that will cause a change in produced ferroalloys assortment are given and discussed.

1 INTRODUCTION

The theme of the article to a large extent was selected by the authors thanks to an interesting report of our Finnish colleagues Holappa L. and S. Louhenkilpi for the previous INFACON XIII Congress [1]. Their report consists of analysis of various aspects of the ferroalloys impact on the quality of steel in both historical and technical aspects: beginning from an open-hearth furnace and Bessemer converter to contemporary steelmaking and from simple carbon grades to modern high-alloyed steels.

There is an obvious link between the growth in steel production and a corresponding increase in the ferroalloys manufacturing. Assortment of ferroalloys is changing a bit slowly, but mainly following the change in steel grades. Equipment in steelmaking and ferroalloy plants is being improved. The list is being completed and it is not brief. Therefore we will try in our analysis of the relationship and mutual influence of steelmaking and ferroalloy production to limit ourselves by problem aspects which are closest to authors.

The most steelmakers today are well aware of the need to interact with the producers of ferroalloys for efficient dialogue to bring positions closer and to find a compromise, which is inevitable between the increased requirements to reduce a content of impurities in the ferroalloys and related price growth. However, mutual interest can and should be manifested not only in the harmonization of requirements to the final product, but also in the implemented technical innovations, transfer of best practice developed to improve the environmental conditions and energy efficiency in the allied productions.

2 STEELS AND FERROALLOYS PRODUCTION OUTLOOKS

Steel has been and remains the main structural material of mankind. The relationship between production volumes of steels and ferroalloys is quite obvious. However, in addition to direct connections, when the technology of a steel of certain chemical composition determines the purchase of necessary ferroalloys, there is also a number of subjective factors. These are issues of economic efficiency, environmental friendliness and production of steel and of ferroalloys, as well as trends in the steel grades changes. Therefore, we present some considerations on objective and subjective factors that have an effect on production of both steels and ferroalloys.

2.1 Statistical Data

Most recent Conferences (2014) of ferroalloys specialists [2-4] gave comprehensive material for analysis of published statistics on the production of steel and ferroalloys. It is obvious that the current INFACON XIV will specify these data. Nevertheless, we would like to discuss some recent data published by World Steel Association [5] for steel production. The world production of crude steel in 2014 amounted to 1.67 billion tons. In 2020, the global demand for steel is estimated as 1.85 billion tons of crude steel manufacturing, and it expected to be around 2.29 billion tons to 2030 (Fig. 1 [6]).

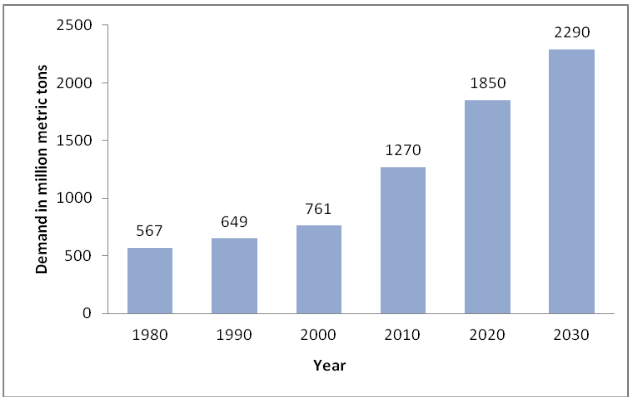

Figure 1: Demand for crude steel in million metric tons [6]

Since a growth of ferroalloys production is almost proportional to an increase in steel manufacturing, it can be expected to increase the production of ferroalloys in 2030 at least by 20-25%.

In recent years the relationship in steel and ferroalloys productions has become even more evident because of increasing steel production share by electric arc furnace using minimills, as well as in connection with the leading growth of special steels melting, especially in China.

About 20 kg of various ferroalloys is consumed now for 1 ton of steel in average. This amount is made up by ferrochrome share about 20%; ferrosilicon - 18%, silicon manganese - 22%, high-carbon ferromanganese - 12%, refined manganese alloys and metal manganese - 5%, ferronickel - 4%, other ferroalloys altogether - 19%. But at the same time, the special steels output of 170 million tons (20% of world crude steel output) takes a share of 35% of the total consumption of ferroalloys, while ordinary steels melting (1.44 billion tons - 80% of world steel production) takes 65% of the total consumption of ferroalloys .

Within the masters' conferences on the mentioned ferroalloys the featured data were presented: world production of ferroalloys in 2013 was 62.3 million tons and in 2012 – 58.5 million tons. Ferroalloys production growth in the last five years has made 8.1%. These figures include the production of silicon metal, silicon carbide and various deoxidation agents (aluminium alloy), etc.

Interesting material shown in Figure 2 was given in the analysis [5].

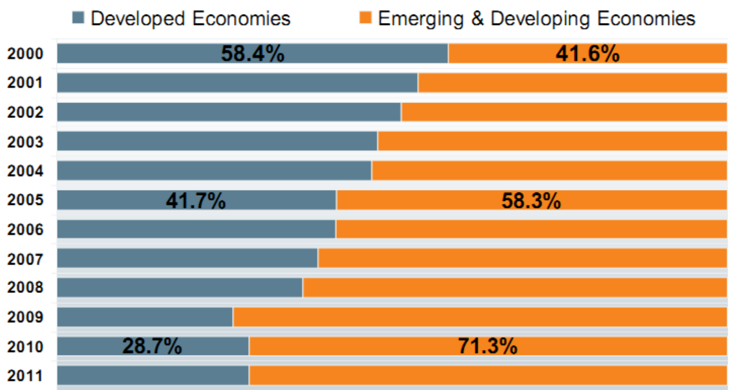

Figure 2: Regional share in the world steel demand [5]

The demand for steel in developing countries is steadily increasing and in 2010 exceeded by 70% the world steel production.

The forecast for population growth, GDP and steel consumption per capita in the largest developing countries [5] shows (Table 1) that it is them who will be the leaders in steel production in the next 5 years. In this regard, the enormous resources of India should be noted. India plans to bring domestic steel production to 200 million tonnes in the very near future. The problems which the country is facing in the implementation of these plans, including limitations in increasing the electricity generation, are known quite well.

Table 1: Developing world: strong fundamentals for growth

	Population, million		Urbanisation, %		GDP per capita, PPP$*		Steel use per capita, kg
	2011	2020	2011	2020	2011	2020	2010
Brazil	197	210			9,961	14,015	133
Mexico	115	126	76	77	13,224	16,911	140
Turkey	74	81			12,390	16,675	320
Indonesia	242	263	53	61	4,094	6,106	37
Thailand	70	72	34	39	7,648	10,884	202
Vietnam	89	96	30	35	2,981	4,803	141
India	1,241	1,387	30	34	3,195	5,895	52
China	1,347	1,388	51	61	7,503	14,306	427

If we compare these data with forecasts for production and consumption of electricity [7, 8], it is obvious that power engineering specialist expects a similar redistribution of electricity production and consumption in favour of developing countries in the next few years. Expected growth in electricity production (Figure 3) to 2030 makes more than 1.5 times [8] that practically coincides with the expected increase in steel production.

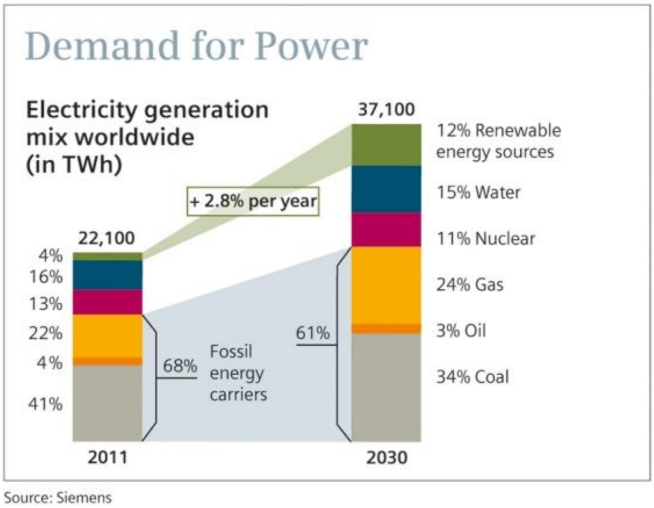

Figure 3: Forecast for electricity generation to 2030 [8]

Note that the projected decline of the overall share of fossil electric power stations does not mean reducing of fuel consumption. Even today, 32% of the world's annual consumption of fossil fuels (all types – natural and artificial) is burnt at power plants that is accompanied with environmental pollution by combustion products, including CO_2 (10.9 Gt) [9]. The volume of fuel combustion for electricity generation will continue to grow that will certainly lead to the need for additional measures for waste gas cleaning and CO_2 disposal. Consequently, we can expect that the cost of electricity will grow. This means that for the sustainable development of ferroalloys production, where energy consumption is very high, actual innovation in increasing of energy efficiency, resource saving, recycling and reduction of environmental hazards is required.

The most radical way of all savings is suggested by supporters of the so-called “Direct alloying” [10-12] who propose to exclude the production of ferroalloys. Recovery of oxide concentrates of alloying elements are made by carbon of molten iron or by reduction agent (usually aluminium or ferrosilicon) in thermite mixtures.

Despite the attractiveness of this approach, its use in the mass production of steel in the short term should not be expected. The first reason is, of course, the instability of the results even in the case of low-alloy steels manufacturing, where both the content and variety of alloying elements is small. In the production of high-alloyed steels the problems in thermal balance and increased content of reducing agent in the finished product will be faced. Besides, in this case the energy costs are just transferred to the production of reduction agent. Furthermore, in both cases there are problems of increasing the impurities content, while the methods of impurities removal are well developed and optimized in ferroalloy furnaces.

Finally, it is difficult to provide an exact hit in a given chemical composition of the steel grade, and even more so to ensure mass production of hundreds of grades of low-alloy and high-alloy steels in multi-ton units. At this stage of development of processes of direct alloying, apparently, it is advisable to apply it in small factories, foundries, and above all in order to return oxidized waste of high-alloy steels to own production cycle.

2.2 Some Features Of Technology And Equipment Of Steelmaking And Ferroalloys Production

Iron and steel industry, as well as many other sectors of human activity, has being developed in stages, substantially as the airplane takes off: climb, horizontal flight (like a power accumulation for the next climb), climb again, etc. There is, as dialectic says, the transformation of quantitative to qualitative changes.

We believe that the extraordinary changes that have occurred in the steel industry in connection with the advent of the continuous casting of billets, similar in size to the final rolled product, i.e. near net shape casting, is the very last rise step to new height. Apparently, in the near future, after a quarter-century span since Nucor had realized the thin slab casting, we should expect a new step up on the way of progress.

We think that it can be associated with the implementation of long-standing ideas for continuous steelmaking, and possible long-awaited breakthrough in direct iron manufacture. In this context, all directions of development that lead to cost savings in production of both the steels and ferroalloys seem particularly important. The problems of ecology and energy efficiency are multifaceted. Therefore, we will consider further just one aspect of this trend, namely some significant changes in technology and equipment design of the steelmaking electric melting furnace and ferroalloys production units.

Electric arc furnace (EAF) and ferroalloy submerged arc furnace (SAF) have much in common in the course of melting processes. The idea is that in EAF at certain stages of melting the arc is burnt under a slag layer – like at melting in submerged arc furnaces. Similarly, in the SAF in certain moments the arcing happens directly to open melt in the same manner as it occurs in the EAF.

Moreover, in both types of furnaces a kind of transitional periods exists, when there is no any arc (neither open, nor submerged) and electroslag process takes place, which is inherent to electroslag remelting furnaces (ESR). The attempts on the application of submerged arc furnace for steel manufacturing have been undertaken for a long time [13,14].

Recent data published by SMS about development of a highly efficient electric arc furnace that is capable for weeklong continuous operation (having a symbolic name S/EAF [15]) indicated the trend of convergence in structures of steelmaking and ferroalloy furnaces. The prospects of work can be confirmed by the data on the effectiveness of this new furnace in comparison with the most advanced EAF which is listed in the mentioned article. For example, the specific energy consumption is reduced by 20kWh/t, and the required capacity of a power transformer - by 20%.

In recent years, EAF DC began to be widely applied in electric steelmaking. One of the obvious advantages of such units in terms of energy efficiency is a decreasing of the overall electrical resistance (impedance) of the furnace due to eliminating of reactance losses.

It is clear that in the ferroalloys industry the energy efficiency is one of the key challenges of the time. It is understood also that the use of direct current in SAF is impractical due to electrolysis of the slag. However, SAFs with a reduced frequency of power supply that reduces the reactance of the furnace to almost zero begin to be increasingly used in the ferroalloy industry. Note also that low frequency has progressively been used in recent years for high power ESR furnaces.

We have performed some calculations to determine an expediency of industrial furnaces transformation for low frequency power supply for both steels and ferroalloys production. In the calculations the following assumptions were made:

1. Elements of high current loop are replaced by equivalent linear resistance and reactance.
2. Liquid bath and electrodes are considered as purely active resistance, and the inductive reactance of the bath is included into reactance of high current loop.
3. The power capacity of the furnace is taken the same for industrial and low frequency.
4. Electricity losses due to power distortion and losses in the frequency converter are not taken into account.

Note, the frequency of 10 Hz is chosen conditionally. In practice today it is possible to realize the adjustable low frequency, for example, from 0.1 to 10 Hz, which makes it possible not only to provide further reduction of the reactive losses, but also to avoid a possible overlap between the frequency of power source and frequency of the furnace natural vibrations in order to avoid entering of furnace structure into dangerous resonance vibrations.

Table 2 lists the specifications on three real electric furnaces with power supply from the transformer of industrial frequency 50Hz and data were calculated for operation of the same furnaces with power supply source of low frequency 10Hz.

Table 2: Electrical parameters of the given EAF, LF & SAF (Russian type РКЗ-81 MVA) units at 50 Hz and 10 Hz

Electric furnace type	Transformer impedance		High current loop impedance			Furnace impedance(on phase)			Cos φ at frequency	
	$R_т$, mΩ	$X_т$, mΩ	$R_{кс}$, mΩ	$X_{кс}$, mΩ at frequency		$R_{п.у.}$, mΩ	$X_{п.у}$, mΩ at frequency			
				50 Hz	10 Hz		50 Hz	10 Hz	50 Hz	10 Hz
EAF 200 t	0.072	0.094	0.56	3.56	0.712	4.01	3.42	0.806	0.761	0.98
LF 380t	0.05	0.239	0.381	1.724	0.3448	3.25	1.963	0.5838	0.856	0.984
SAF 81MVA	0.043	0.11	0.063	0.869	0.174	0.611	0.94	0.284	0.545	0.907

Calculations show that the change to a low frequency can significantly improve the efficiency of all three units, but the maximum effect will be received for the ferroalloy furnace as the most powerful one. Significant increase in the efficiency of the source is achieved, which can significantly reduce energy losses (Table 3)

Table 3: Efficiency of the given EAF, LF & SAF at 10Hz

Electric furnace type	Cos φ growth, %	Reduction of the resistance loss, MW/%	Reduction of the losses for 1 year, MWhour	Cost of frequency converter (rough estimation), USD
EAF 200 t	28.8	1.67 / 39.8	9621.2	2400000
LF 380t	14.9	1.25 / 24.4	7201.1	2000000
SAF 81MVA	66.4	1.53 / 63.9	19431.9	3200000

Even at a rather high appraised price of the frequency converter the payback period will be about 3 years. Taking into consideration the projected increase in electricity prices this period may be even shorter.

We believe that the positive experience of the low frequency application in SAF and ESR units will encourage steelmakers to use a low frequency in EAF. Moreover, developed technical solutions not to change the EAF design, which is an additional argument compared with the adoption of direct current.

Examples of mutual enrichment by technical solutions in steelmaking and ferroalloy production can be continued. There are necessary environmental measures (gas cleaning, waste management etc.) and methods to return the retrievable losses of heat, which are now used increasingly to generate own electricity and steam, etc. Let’s communicate and co-operate for better future.

2.3 New Emerging Steels And New Ferroalloys

The driving force behind any production improval is almost always an increase in requirements for manufactured products. Thus, steel production technologies which are widely used now were previously used in the manufacture of products for special purposes only - for aviation and other so-called critical applications. Increasing demand for steels purity entails a responsible growth of restrictions for the impurities content in ferroalloys. This side of the considered mutual influence of steelmaking and ferroalloys manufacturing also seems to be more or less studied and clear, especially in the part that deals with ferroalloys performances for high-alloyed steels.

Nevertheless, there are certain changes in the practice of steel deoxidation that may lead to changes in the practice of ferroalloy production.

Heavy forgings for power generation technology of Vacuum Carbon Deoxidation widely used in the manufacture allowed to renounce the use of silicon and aluminium for deoxidation. Vacuum treatment now becomes widespread in the mass production of steel, aluminium and silicon deoxidation is minimized, and for some types of steel (wheel steels, cord wire steel etc.) deoxidation by aluminium is completely eliminated.

Steel treatment by calcium is a common practice in secondary metallurgy chain, where it is widely used as the filler of a powder wire. However, now silicocalcium is often replaced by ferrocalcium, thereby the silicon content in the metal is reduced.

High nitrogen steel with nitrogen content at and above the equilibrium value today is the focus of metallurgists, because nitrogen is a very promising alloying element which can replace nickel and provide steel properties unattainable in other alloying systems (first of all, excellent mechanical properties and corrosion resistance). Today the considerable experience in the application of various methods of nitrogen input at conventional production is already accumulated: from the atmosphere (the maximum efficiency is achieved at plasma-arc remelting process); by addition of nitrated ferroalloys of manganese, chromium, vanadium; by pure silicon nitride Si3N4 usage [16].

There is a tendency to complicate alloying and microalloying systems not just for high-alloyed steels but for low-alloyed structural steels (especially for heat resistant and HSLA grades of steels). In recent years, we see the new stage the successful use of microalloying by rare earth elements, boron, etc., which in the short term will cause the need for proper ferroalloys and complex ligatures.

There are new steel types which require new ferroalloys and masteralloys for their production.

For example, there is very interesting new plastic and lightweight steel of approximate composition Fe -10%, Al-15%, Mn-0.8%, C-5%, Ni. A recent article by Professor Hansoo Kim and his colleagues in “Nature” on this high-strength steel with FeAl intermetallic particles hardening [17] has caused a wave of publications far from the metallurgy. It is caused by understanding of the scientific aspects of the remarkable achievements of Korean colleagues as a promising combination of properties of the new structural material and the authors forecast that the new steel can enter the market within three years. Given the fact that the work is supported by one of the world's leading steel companies (Korean giant POSCO) we can expect that the forecast can come true.

The use of “exotic” metals expands. Thus, today power generation needs the high-alloyed nickel superalloys which contain in their composition 1.2- 1.5% Ti, 3.8-6.5% Cr, 11% Co, 0-1.4% Mo, 6.5-7.4% Ta, 5.0-6.0% W , 3.6-5.4% Re, 5.1-5.5% Al, 0.12-0.14% Hf and Ni up to 100 wt% [18].

In the essence new compositions are rhenium-cobalt superalloys [19]. Co-Re superalloys promise high potential for long service life at elevated temperatures (even above 1200°C).

Japanese researchers [20] developed cobalt-based superalloys with the addition of iridium, aluminium and tungsten, which are considered as candidates for high-temperature heat resistant materials of new generation.

High melting points of both rhenium and iridium are good for heat resistance properties providing for a superalloy, but this complicates the technology of melting, which appears to require the use of an alloying special masteralloys.

In this regard, once again we get back to work [1] where authors have suggested before us that in the very near future we should expect the appearance of masteralloys, including special ones providing a kind of melt modification by nanoparticles at solidification.

3 PRODUCTION OF LOW-TONNAGE FERROALLOYS FOR LOW-ALLOYED AND ALLOYED STEEL GRADES

This area of steelmaking progresses rapidly. The growth of steel consumption in the developing countries occurs first of all by increasing of carbon and low alloy structural steels output. Here we will not consider the production of manganese, silicon and chromium ferroalloys which will be produced and consumed in ever-increasing volumes throughout the world. The situation with these ferroalloys is more or less clear for us. Let’s consider those of ferroalloys which create special properties of steels and alloys, although their share in the finished steelmaking product (and in the output of ferroalloys in general) is often not so great.

In the next few years an increase of niobium consumption is expected. Ferroniobium is used for the high-strength structural steel assortment, especially for high-strength steel pipes, automotive steel, stainless steel (co-alloyed with titanium and chromium) etc. Now this market is practically monopolized by Brazilian company SBMM (84% of world production). World production and consumption of ferroniobium in 2014 makes more than 80 thousand tons, and predicted growth could reach 4.9% annually in the next five years. Ferroniobium prices (recalculated on niobium metal) have prospects for 4-6% growth per year as well.

Active and even sometimes aggressive promotion of ferroniobium has led to its widespread use, even where it is not quite reasonable. To some extent this is also applicable to HSLA steels usually alloyed by vanadium, and, rarely, by molybdenum.

Vanadium is niobium analogue in its main effect on steel, and a growing demand for ferrovanadium is associated with above-mentioned increase in HSLA grades production, which consumes 59% of ferrovanadium produced. Besides, vanadium is used for special steels and superalloys. World production (and consumption) of ferrovanadium is about 90 thousand tons, and this value is constantly increasing. It is predicted that by 2020 it will increase to 140 thousand tons.

In connection with the grow of HSLA production, we refer to our own experience in the production of steel for gas pipes of the main gas pipelines such as X70-X100. The fact is that the use of the so-known controlled rolling and/or heat treatment has been effective for carbon steels of low impurity (sulphur, phosphorus and oxygen). In particular, for plates 15...20 mm thick made of structural steel with carbon contents 0.08 – 0.1% alloyed by 1.5 -1.7% manganese only we succeed to provide the same level of strength and ductility after controlled rolling, quenching and tempering, which is regulated for the X70-X80 type of steel alloyed by niobium, and in some cases by the entire triad – niobium, vanadium and molybdenum! This experience gives reason to suppose that the alloying and microalloying of HSLA steels requires further in-depth study. It is primarily about the rational use of vanadium, molybdenum and niobium both apart and together for these types of steels. We believe that the problem is linked not only to the objective lack of our knowledge about these types of steels and their hardening mechanisms, but also to the action of subjective factors like certain inertia of thinking, traditions etc.

Ferrotungsten production expands now because of the widening of this element use for high-speed tool steels, high carbon steels for various purposes, heat-resistant steels and alloys for gas and steam turbines and petrochemical industries. Today the output of ferrotungsten is about 16 thousand tons (about 20% of produced tungsten materials).

World prices for ferromolybdenum are constantly rising, which is widely used to increase hardness, hardenability, wear resistance in tool steels, as well as to improve the heat resistance and creep properties, especially in superalloys. The largest producer of molybdenum in the world is the Climax Molybdenum (USA), and about one-third of production is provided by Chilean company Molymet, the third largest player is China's having second mineral deposits.

The demand for nickel for melting of special, especially stainless steels is satisfied mainly by electrolytic nickel having been produced in non-ferrous metallurgy. At the same time, with the development of new technologies in steel production (a combination of EAF and BOF with different option of oxygen and fuel), the new alloying materials come to the nickel market. This product is called Nickel Pig Iron (NPI). NPI application is particularly effective for stainless steel melting by AOD- process.

The high-nitrogen materials occupy a special place in product assortment of both steelmaking and ferroalloy production. Steel alloying by nitrogen stabilizes the austenitic matrix that allows reducing of manganese and nickel content, but maintains or improves the steel properties, including found effect of nanostructures formation after thermomechanical treatment. Great interest in these steels supports the growth of production of nitrated ferroalloys of manganese, chromium and vanadium.

Completing our review of low-tonnage ferroalloys, we point again to increasing trend to use a complex alloying and microalloying both for special steels and for structural ones (including HSLA). New grades of structural steel gain a widespread use, where along with traditional elements (Mn, Si and Cr) the minor quantity of nickel, molybdenum, copper (for precipitate hardening) etc. is also included (to 0.5% Ni, 0.5% Mo, 0.5 Cu).

4 CONCLUSIONS

The problem of the relationship between ferroalloy and steelmaking industry raised in this paper certainly does not fully reflects all state-of-the-art. However, certain conclusions made by authors seem to be useful for both steelmakers and ferroalloys specialists.

General trends in the development of industry and steelmaking indicate an increase in the production of most types of ferroalloys in the foreseeable future.

We guess that a next approaching leap in steelmaking technology will also affect the ferroalloy production. This will affect both designs of ferroalloy units and product assortment. There will be a convergence of structures of electric furnaces of steelmaking and masteralloys of traditional elements and of elements that were practically not used previously.

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