Euro Alliages

DECEMBER 2019

2050 VISION

for the European Ferro-alloys and Silicon Sector

EUROALLIAGES is the European Association of ferro-alloys and silicon producers, representing almost 100% of ferro-alloy and silicon production in Europe.

Membership includes 12 companies, operating 32 plants in 10 countries, with 4,300 employees and a combined turnover of 2.7 billion Euros.

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Executive Summary

Last year, the European Commission launched its strategic long-term vision for a prosperous, competitive and climate-neutral economy by 2050. This goal will be one of the main drivers of key policy areas, including a sustainable industrial-base in Europe.

The present document aims to present the vision of the European ferro-alloy and silicon sector in the run-up to 2050. As a starting point, EUROALLIAGES' members are committed to take part in the achievement of a sustainable European economy by 2050.

By providing a realistic overview of a European industry which is the first link in strategic value-chains for the EU, themselves paramount to achieving a low-carbon future, EUROALLIAGES intends to play an active role in the definition of feasible solutions to ensure the implementation of the highest environmental and social standards worldwide within its sector.

2050 as an opportunity

The European ferro-alloy and silicon industry plays a central role in our daily lives: it feeds major European economic sectors - key to growth - with raw materials, whilst facilitating progress and enabling innovation.

The core position of the European ferro-alloy and silicon sector in the European value chain allows it to operate in an efficient way. It is, today, a world leader with regard to efficient production processes; it implements the highest standards in terms of climate, energy and environment; it has generated important achievements in the area of emissions reduction.

Ferro-alloys and silicon are part of low-carbon value chains, as they provide essential qualities to steel and aluminium. Advanced High Strength Steel, with high manganese content, contribute to lowering the weight of vehicles. Silicon is also used in electronics, chemicals and solar panels. They thus play a strategic role in the reduction of CO_2 emissions, both in Europe and worldwide. The demand for ferro-alloys and silicon is expected to grow along with the demand for low-carbon technologies; this shift, therefore, presents an opportunity for European industry as our products are needed for the global society to achieve its goals: energy transformation, robust infrastructure and recirculation.

2050 as a challenge

At a time when Europe has lost a significant part of its industry, a level of confidence needs to be restored such as to allow industry to thrive and pursue its participation in the achievement of European policy goals. In a society where the manufacturing industry often has a negative image, it must be firmly borne in mind that industry creates wealth, growth and jobs. Our industry represents a potential for growth by developing products/equipment and services making it possible for other regions to create wealth in a sustainable manner..

In an environment where energy prices have increased to a critical level in energy-intensive industries, it is imperative that the ferro-alloy and silicon sector finds solutions in order to continue operating in conditions where its global competitiveness is preserved. In a global marketplace where a true level playing field has yet to come into being, the ferro-alloy and silicon industry faces unprecedented levels of unfair international competition.

Smart action is required urgently to ensure sustainable production whilst remaining globally competitive, without which there is a high risk of massive plant closures. Once closed, it is nigh-on impossible for an industrial plant to be re-opened in Europe. This will mean an irreversible loss of know-how and skills, of value and jobs, as well as an increased dependence on third countries.

For a thriving European ferro-alloys and silicon industry

Taking all of the elements described in this document into consideration, the European ferro-alloy and silicon sector calls on policymakers to create a supportive regulatory framework enabling its actors to remain in Europe, continue developing technological solutions such as waste heat recovery to produce hot water, steam or electricity, carbon capture and uses to produce carbonates, algae, hydrogen; use of charcoal or biomass as reductant; and take hence part in a sustainable future.

Introduction

EUROALLIAGES is the European association of ferro-alloy and silicon producers. Ferro-alloys and silicon provide essential qualities to steel and aluminium; silicon is also used in electronics, chemicals and solar panels. EUROALLIAGES' member companies are therefore part of strategic European value chains.

EUROALLIAGES represents almost 100% of Europe-based production (EU+EEA). The association has 12 member companies operating 32 plants in 10 countries, with approximately 90 furnaces in activity, a global turnover of € 2.7 billion, a Gross Value Added of € 480 million and a workforce of 4,300.

Ferro-alloys have been developed to improve the properties of steel and alloys by introducing specific quantities of alloying elements in the most feasible technical and economic manner.

Ferro-alloys are, namely, alloys of one or more alloying elements with iron, used to add chemical elements into molten metal (Gasik, 2013). Not a single grade of steel is produced without ferro-alloys (Wood, 2005).

Historically, the ferro-alloy production technology used in the 19th century was developed for blast furnaces, which at the time was the main process for the production of cast iron. In a blast furnace, however, it is not possible to produce ferro-alloys with elements that have a higher affinity for oxygen or with low carbon content.

This led to the development, at the beginning of the 20th century, of ferro-alloys to be manufactured (smelted) in electric furnaces. Today, almost all ferro-alloys are produced in submerged arc furnaces.

With the first experience of ferro-alloy smelting, it became evident that more research was needed to improve the understanding of the physico-chemical aspects of the process, as well as of the properties of the ferro-alloys. Later, the issues of better energy and resource utilisation, lower emissions requirements, and increasing demands to improve the purity and cost of ferro-alloys set new challenges for improving the quality and price competitiveness of ferro-alloys and their production processes (Gasik, 2013).

As a result, the plants remaining in the EU these days are among the most efficient globally in terms of energy usage and CO_2 emissions.

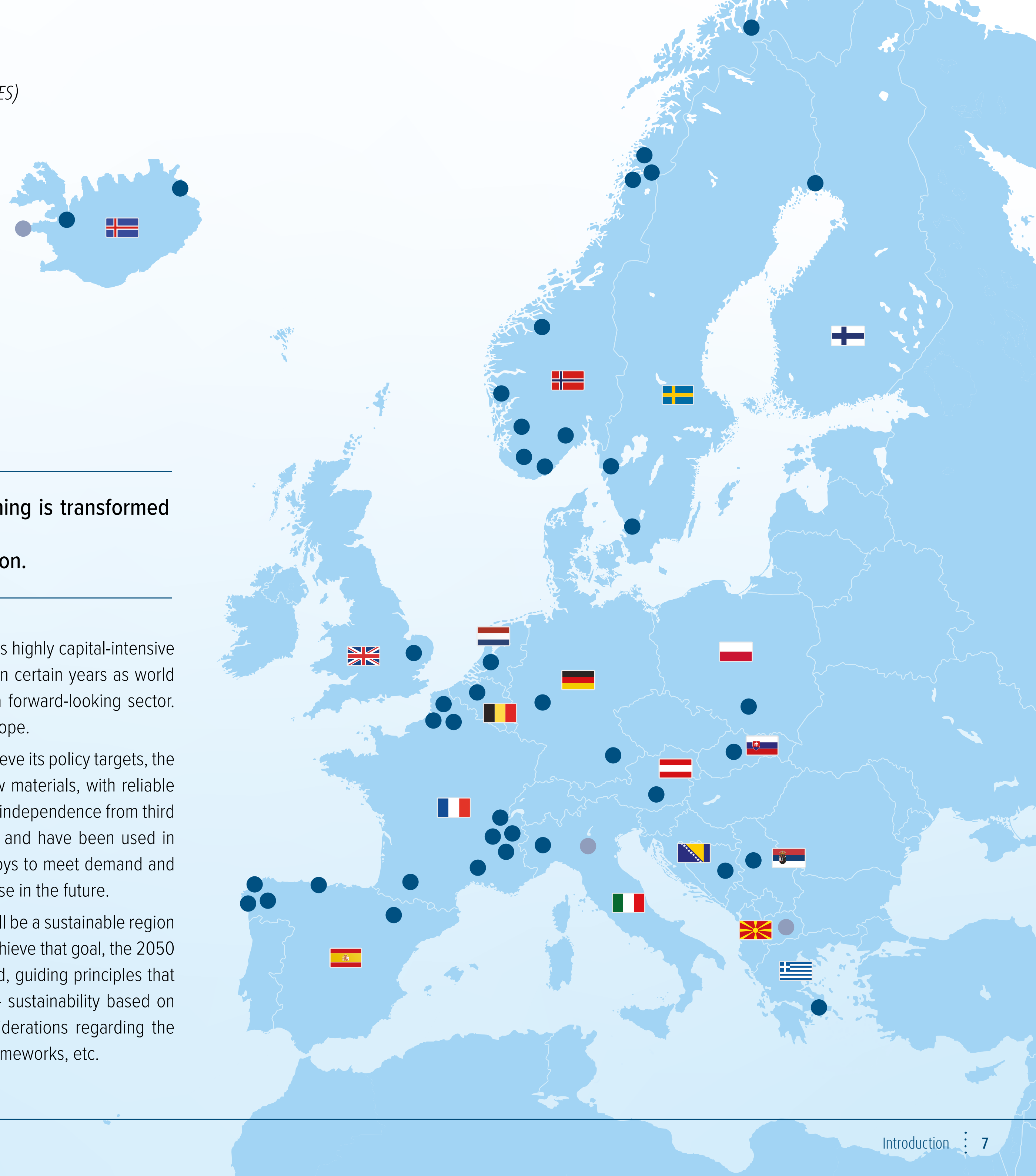
Today, ferro-alloys and silicon are at the centre of our modern society: they are part of strategic value chains which are necessary to decarbonising the economy. This will be all the more true in the near future, as recognised by the European Commission in its Communication" A Clean Planet for All". This Communication foresees a general increase in demand for low carbon technologies, and by extension for the raw materials essential to those technologies, including ferro-alloys and silicon. For instance, the demand for silicon metal used in the solar industry is expected to rise (JRC report 2016). Given the increase in the share of renewable electricity generation in Europe and worldwide, and the fact that silicon is - and should remain - the preferred technology in this area, its production will inevitably be favourably impacted.

Ferrochrome makes steel stainless and stainless steel is today essential material in different kind of renewable energy production. Without ferrochrome there is no modern low carbon energy production because other materials are not durable enough e.g. in harsh or wet conditions.

At the same time, there is an exponential increase of extra-EU supply and overcapacity abroad, as recognised among others by DG GROW (Internal Market, Industry, Entrepreneurship and SMEs) in its work on Critical Raw Materials as well as on overcapacities (Roskill, 2017). The upward trends regarding extra-EU supply are bound to continue and, therefore, put further pressure on the trading position of the European ferro-alloy and silicon industry in the coming years. Combined with the risk of carbon leakage is expected to remain a critical issue in the ferro-alloy and silicon sector.

Figure 1: Ferro-alloys/Silicon plants in the EEA (internal data EUROALLIAGES)

● Operating ● Closed



Nothing is lost, nothing is created, everything is transformed

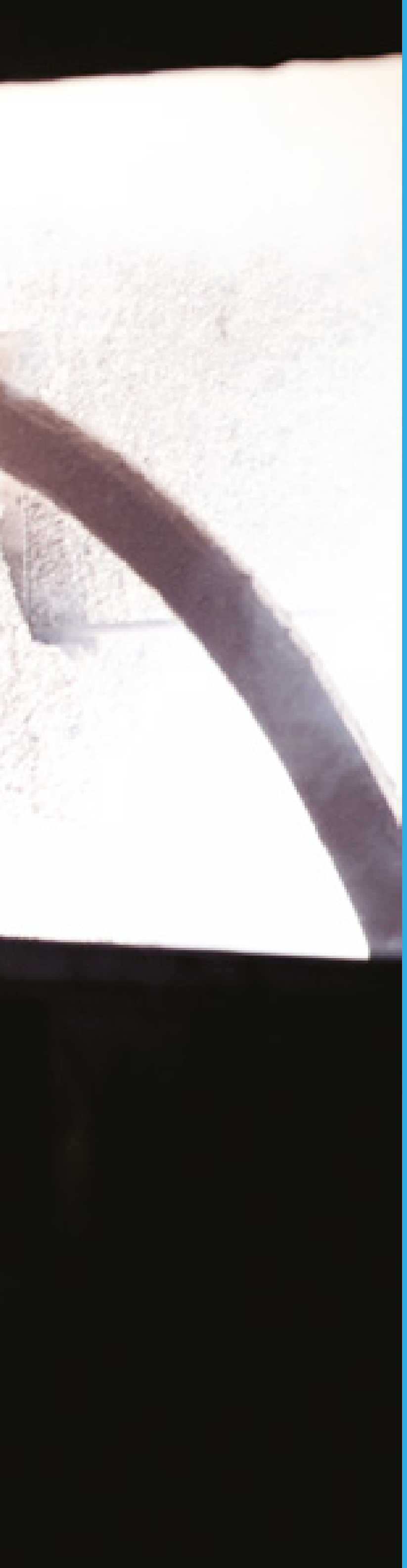
Law of mass conservation - Antoine-Laurent de Lavoisier, 1743-1794

The goal is to choose the right transformation.

Commodity markets are cyclical. Since the ferro-alloy and silicon sector is highly capital-intensive with significant fixed costs, profit margins can be negatively impacted in certain years as world prices rise and fall. The ferro-alloy and silicon industry is, by nature, a forward-looking sector. Positive signs need to emerge for this industry to be able to thrive in Europe.

Beyond the necessity for low-carbon value chains to allow Europe to achieve its policy targets, the European ferro-alloy and silicon sector provides access to strategic raw materials, with reliable and efficient supply. It also contributes to ensuring at least some level of independence from third countries. Ferro-alloys and silicon are undeniably crucial to innovation and have been used in the past to develop new products (e.g. development of new special alloys to meet demand and accompany the creation of new solutions); this will continue to be the case in the future.

EUROALLIAGES' vision is founded on the premise that in 2050, Europe will be a sustainable region in terms of climate and environment, as well as in terms of business. To achieve that goal, the 2050 perspective will be examined along the following lines: on the one hand, guiding principles that should govern a transition towards a low-carbon economy in Europe - sustainability based on three pillars (economy, environment, social); on the other hand, considerations regarding the global framework - global competition, consistency across regulatory frameworks, etc.



Global presentation of the European ferro-alloys and silicon sector

Global presentation of the European ferro-alloys and silicon sector

This presentation explores different pathways and possibilities for achieving low carbon and sustainable production of ferro-alloys and silicon, whose impact can also lead to a meaningful decrease in other emissions, as well as energy and use of natural resources. Before entering into details, it is essential to provide more background on the industrial context in which these reductions are advocated.

In the chapters below, more information is provided on the production processes and uses of ferro-alloys and silicon, as well as where the sector currently stands in terms of emissions reductions already achieved.

Manufacturing process at a glance

A ferroalloy is an alloy of iron with at least one other metal such as chromium, silicon, manganese, molybdenum, or titanium.

Primary ferro-alloys are principally produced in submerged EAF (electric arc furnaces). These furnaces, designed according to the best available technologies (BAT), are either open or semi-open (hooded furnace allowing the entry oxygen) or closed (hermetic system), depending on the production requirements for the various ferro-alloys.

The basic process involves the carbothermic reduction of oxidic ores or concentrates, in which carbon coming from a reductant in the form of coke (metallurgical coke), coal or charcoal is normally used as a reducing agent. In the EAF, the heating process is accomplished by passing current through electrodes (Söderberg or mixed) suspended in a cup-shaped (refractory-lined) steel shell, which are progressively consumed.

The carbon from the reductant (coke, coal or charcoal) captures the oxygen from the metal oxides to form CO_2, while the ores are reduced to molten base metals which then combine in the solution.

The consumption of raw material mainly depends on the metal content of the ore or concentrate, the metal yield in the furnace process, and the composition of the product, as well as losses during raw material and product handling (transport, screening, etc.) and treatment (refining, solidification, crushing, packing, etc.).


© Tommy Stefanussen

Figure 2: semi-open submerged electric arc furnace

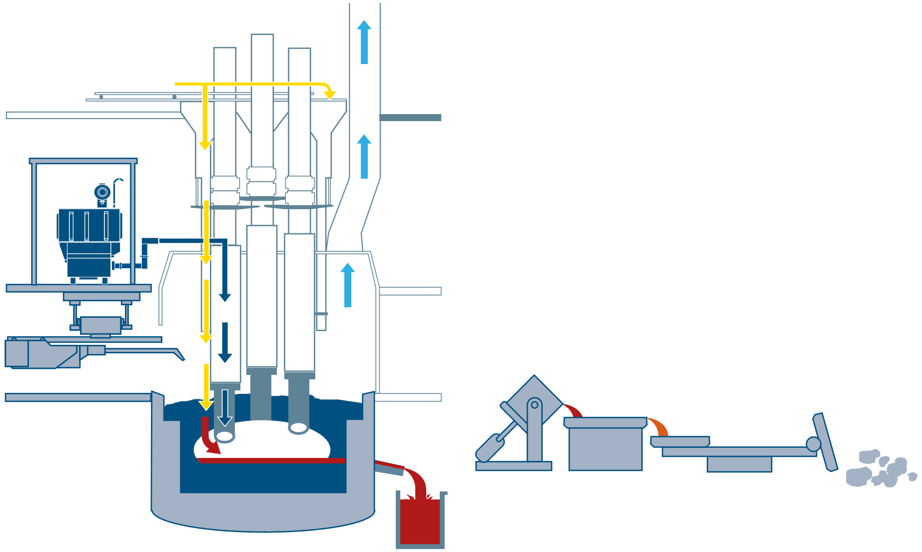


Figure 3: Submerged electric arc furnace (source: Elkem)

The product quality and process requirements impose major constraints in the choice of raw materials. Coal and coke are well-adapted reductants to both the EAF process and the high-level product quality. Their availability is expected to be reduced in the future. Natural gas cannot be used as a reducing agent in an industrial ferroalloy furnace, as the final reduction step to metal needs elementary carbon and gas injection is not available in current technology. The energy consumption per ton of metal differs greatly from one ferro-alloy to another.

The production of ferro-alloys is a highly energy-consuming process because high temperatures are needed for the reduction of metal oxides and smelting. Factors affecting the energy consumption are, among others, the quality of raw materials (such as ores, quartz and reducing agents) and their pre-treatment before smelting, the utilisation of energy reaction, as well as the heat content of the processes.

The energy used in the process is mainly electrical due to the necessity of achieving very high temperatures.

Ferro-alloy and silicon production results process emissions from carbothermic reduction of metal oxides which are the major source of carbon dioxide (CO_2), and which cannot be reduced beyond their physical limit. These process emissions represent incompressible CO_2 emission levels, resulting from the chemical reactions. The current CO_2 emission levels of the European sector are very close to the theoretical chemical and physical limits.

Silicon and ferro-alloys are key enablers for a low-carbon economy in Europe and for sustainable solutions globally.

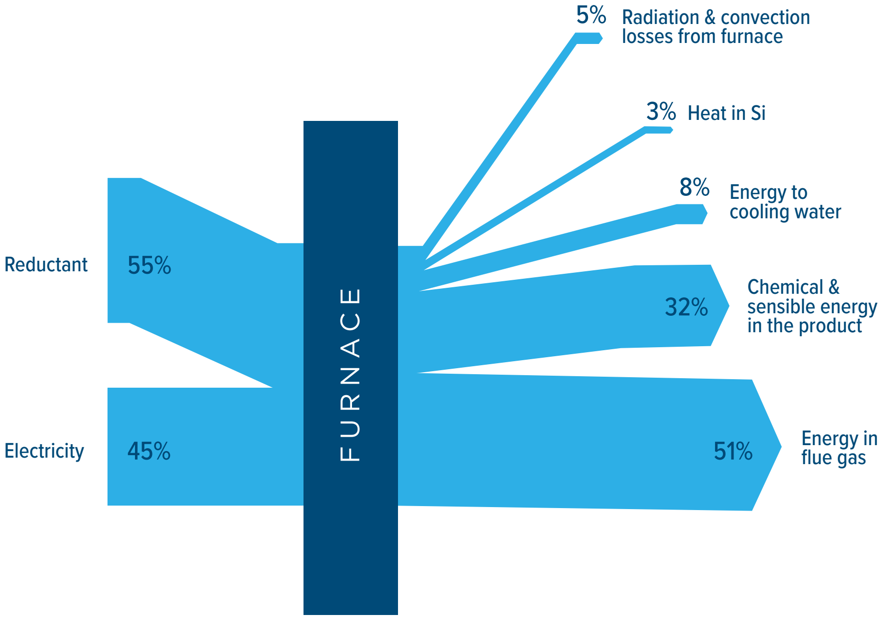


Figure 4: Sankey energy flow diagram (R. Valjor, Norsk Energi), an example of the ferro-silicon process (N.B. The exact numbers will vary with equipment type, size of furnace, mix of reducing agents, etc.).

Approximately half of the energy that goes into the process is released as heat in the off-gases (bottom right arrow).

As shown in the figure, ferro-silicon production is inextricably linked to the consumption of electrical energy. While the energy consumption in the ferro-silicon process is indeed considerable, there is also a potential saving if one is able to make use of the waste heat, depending on the industrial and local constraints (see chapter on Low Carbon/Energy Efficiency and related initiatives).

Market characteristics

Ferro-alloys and silicon are exchanged on a global level with globally set prices. European companies are price-takers. They face fierce and sometimes unfair competition from third countries. In this context, it is impossible for European companies to pass on CO_2 costs without a loss of market share.

Applications in value chains

Ferro-alloys are mainly used as master alloys in the iron, foundry and steel industry, which is the most economical and efficient way to introduce an alloying element into the steel melt. Ferro-alloys are used as alloying elements in steel production in order to improve the properties of the steel, especially the tensile strength, wear and corrosion resistance (see more detailed description of the products in Annex II as well as interactions with other industries in Annex IV).

- Ferro-chrome (FeCr) is a key alloying element of stainless steels: it makes steel stainless and corrosion resistant.
- Ferro-silicon (FeSi) and silico-calcium (CaSi) are used as alloying elements in different industrial products. Ferro-silicon increases the strength of steel and is also used to remove dissolved oxygen from molten steel.
- Ferro-manganese (FeMn) is mostly used to improve the hardness and wear resistance of steel, FeMn acting as a deoxidizer and to counteract the undesired effects of sulphur in steel.
- Silico-manganese (SiMn) enhances the natural properties of steel, giving it increased strength and function, as well as improved aesthetic appeal.
- The major use of ferro-nickel (Fe-Ni) is in stainless steels for corrosion resistance.
- The largest applications of ferro-molybdenum (FeMo) are in construction steels to increase strength and corrosion resistance.
- Special ferro-alloys are also needed for the production of aluminium alloys and as starting material in specific chemical reactions.

Two grades of silicon exist: metallurgical grade silicon (typically around 99% silicon content), representing the majority of the volumes produced, and polysilicon (hyper pure silicon).

In metallurgy, silicon is mainly used as an alloying element in aluminium alloys for casting and extrusion. In the chemical industry, silicon is the starting point in the production of silicones, synthetic silica and silanes. Ultrapure silicon (called polysilicon) is used in the electronics industry, whilst silicon semiconductor wafers are the dominant material used in making solar cells. Silicon is also used in Li-ion batteries, which are currently the subject of extensive research with the aim of increasing their capacity.

Steel treatment by Ferro-alloys:

Upon addition of ferro-alloys to steel and cast-iron melts, the ferroalloy compounds are disintegrated, and the contained elements are dissolved by the surrounding melt. The contained elements then either form compounds with other dissolved elements or go into solid solution with the main phase of the steels or cast irons.

Low Carbon ferro-chrome (LC FeCR) is a strategic raw material used in special stainless steel for defence applications.

Figure 5: Raw materials in the European defence industry (JRC 2016)

European Commission Strategic Plan for Batteries (May 2018):

"Lithium-ion is currently the main chemistry of choice for electro-mobility and will dominate the market in the coming years. Various raw materials are required in lithium-ion batteries including lithium, cobalt, nickel, manganese, graphite, silicon, copper and aluminium."

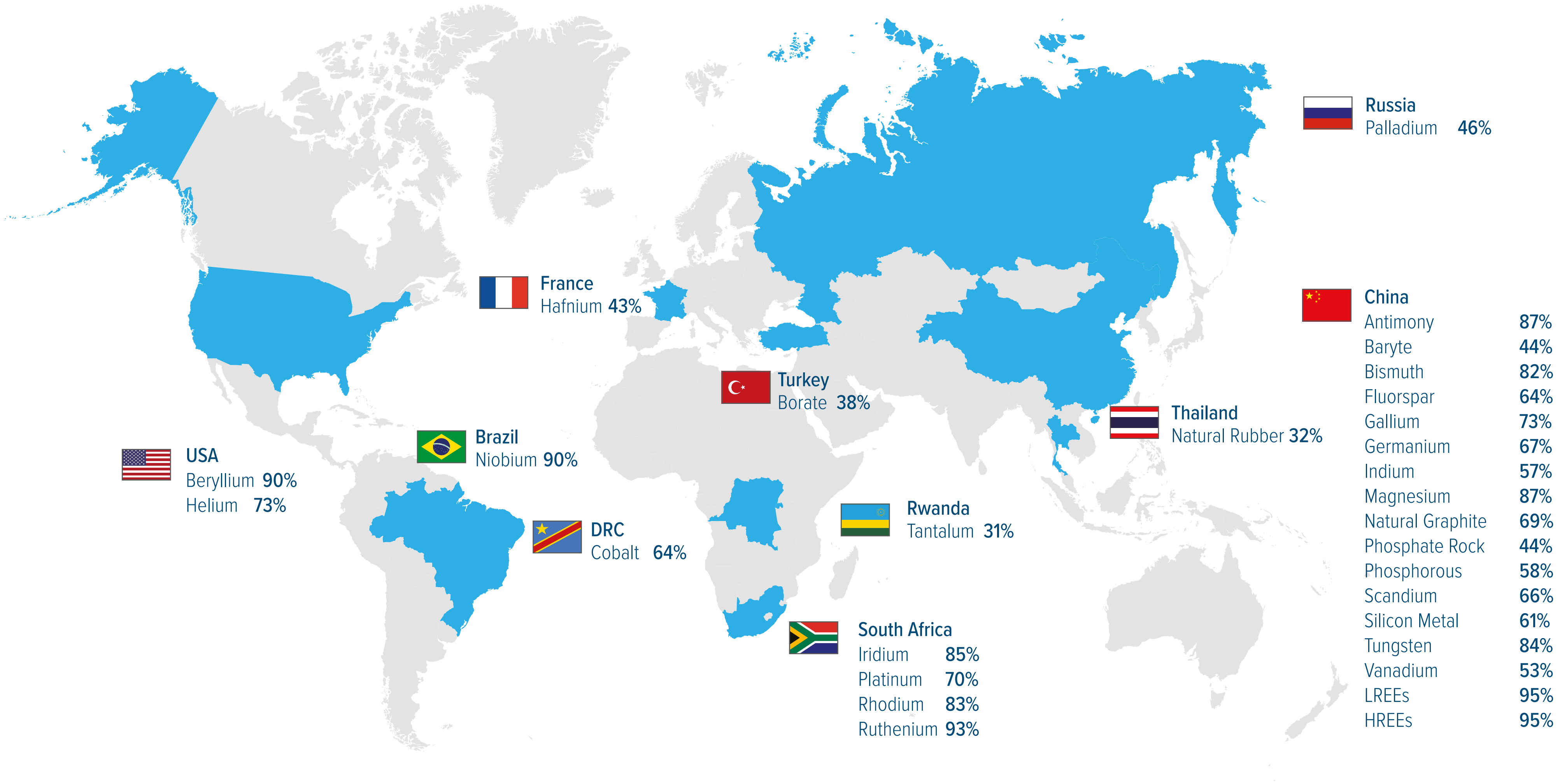
Critical Raw Materials and strategic materials

Ferro-alloys and silicon are essential elements in the production of a range of materials and have no substitute. Moreover, European producers have developed specific know-how, allowing them to provide their customers with special qualities and with tailor-made products.

Metallurgical silicon (also called silicon metal) has been recognized by the European Commission as a Critical Raw Material (CRM) due to its economic importance in a wide range of applications, for many of which there is no possible substitute. Indeed, CRMs are defined as commodities having a considerable impact on the EU economy as well as a high risk of supply shortage.

Among these, photovoltaic (PV) thin cells, wind turbine generators and lithium-ion batteries are among the most relevant green tech applications of CRMs. Europe's dependence on Critical Raw Materials has considerable implications for the competitiveness and independence of strategic industries.

Figure 6: Countries accounting for the largest share of global supply of Critical Raw Materials. N.B. China holds a dominant position for a large number of Critical Raw Materials, including Silicon.



The substitutability of ferro-alloys and silicon has recently been studied in the framework of the EU Critical Raw Materials List. Substitutability is defined as the possibility to substitute one product with another without performance loss and without price increase.

- Silicon has no substitute without a serious loss of performance or cost increase. It is indispensable to aluminum production. It is also an important raw material for the production of silicones by the chemical industry: there is no substitute for this end-use either. As regards solar applications, alternative technologies do exist, but which have a lower performance and represent only 8% of the EU market.
- Ferro-chromium is necessary for the manufacture of stainless steel and alloy steel, with specific qualities for aerospace and nuclear industries being provided by European companies.
- Manganese alloys and ferro-silicon have no suitable substitutes in their major applications, i.e. iron and steel production, to which they are essential.

According to the World Bank report on the “Growing Role of Minerals and Metals for a Low Carbon Future” (June 2017), global PV electricity production in 2013 was approximately 140 TWh and is projected to rapidly increase in all scenarios envisaged.

Many studies assume that the majority of future solar PV installations will be of the crystalline silicon variety. Solar PV cells are also predicted to become a crucial part of the overall energy mix, ranging from 2% of total energy production in the baseline scenario, to 25 % in the scenario that predicts the greatest penetration of renewable technologies. Yet this broad category encompasses at least four potential technology choices: crystalline silicon, CIGS, CdTe, and amorphous silicon.

The report also underlines that the low carbon technology requirements, and hence the related demand for metals, are rising rapidly.

The most significant example of this is electric storage batteries, where the rise in demand for relevant metals - aluminium, cobalt, iron, lead, lithium, manganese, and nickel - has grown more than 1000 % from a relatively modest level.

The following figure 7 of the report outlines the projection of the Solar PV Electricity until 2048.

Finally, the digital transformation of European business and society goes hand in hand with the need to provide the relevant raw materials to the related technologies, for example silicon for the electronics industry.

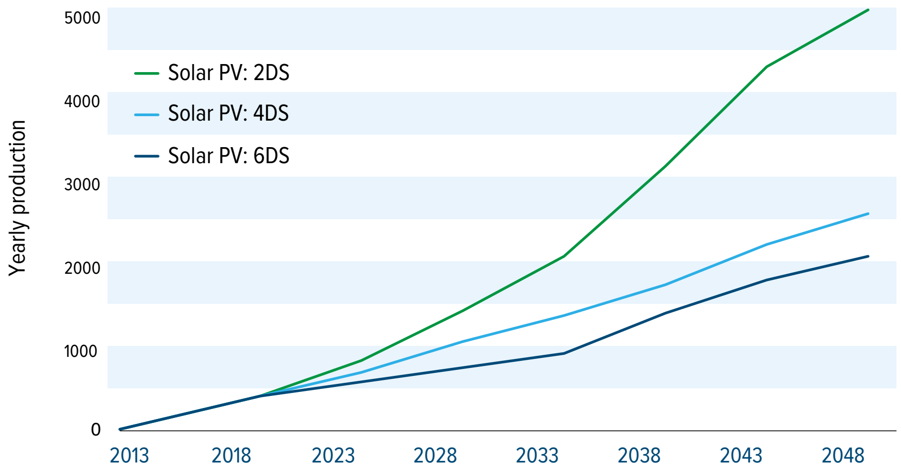
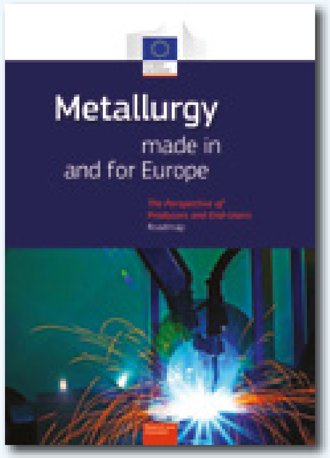


Figure 7: Solar PV Electricity Production (terawatt-hours/year)



Metallurgy
made in
and for Europe

Metallurgy made in and for Europe, European Commission (March 2015)

> “Over the last 30 years the popularity of metallurgy as a science area in academia has not mirrored its economic value. There is a consensus within the scientific community that there is a lack of focus into traditional metallurgical research and the effort for development of new metallic materials and alloys has been limited. To encourage metallurgical research and innovation requires more cooperation and collaboration between research organisations and industry, which also includes the need for an innovative and dynamic, European level Metallurgical Research Infra-structure”.

Finance

The smelting process is highly capital intensive as it relies on expensive machinery and a skilled workforce. Important investments are expected in relation to clean energy. These investment costs are particularly burdensome to the significant part of the sector made up of SMEs.

Access to finance will, therefore, be of critical importance for the sector to be able not only to fully play its role in key supply chains, but also to make its key contribution to the environmental and energy/low carbon transformation.

The sector is supportive of the objective of the 'Sustainable Finance Action Plan' as long as the environmentally sustainable investment criteria as foreseen in the "Taxonomy" proposal take account of the life cycle thinking. In addition, long-term investment scenarios need to be able to rely on a safe and attractive financial market to gain access to the necessary capital.

Skills for the smelting industry

Access to a skilled workforce is equally as important for ferro-alloy and silicon companies as access to markets or finance. The workforce is at the forefront of know-how in the industry, but it has become a major problem for industrial operators to find enough qualified and readily available scientists, engineers, and technicians on the EU market.

There is a risk involved in employing staff from other countries as, when these workers leave EU/EEA companies, an important part of the know-how leaves with them, often moving to non-EU companies which compete in the same market. This endangers the viability of EU companies in the medium and long run.

The future development of the ferro-alloys and silicon industry is also at stake. The closure of an EU/EEA company means an irreversible loss of the know-how developed over many years, whilst the return on European innovation investments will accrue to competitors outside Europe.

One solution is to be found in the education systems put in place by the different countries and regions. A better alignment of school and university programmes to industry needs is a must.

An associated issue is the visibility and reputation of the industry. The decision on career orientation is based largely on the sustainability and reliability of the future job. Due to many factors, the young people are not attracted by a career in metallurgy or in primary industries.

> The ferro-alloys and silicon companies support the blueprint for sectoral cooperation on skills.

Main contributions to a low-carbon and sustainable economy

Main contributions to a low-carbon and sustainable economy

Reduction of CO_2 emissions

The European companies producing ferro-alloys and silicon have a positive track record in terms of reducing their CO_2 emissions, which have decreased over the years thanks to substantial research and investment efforts.

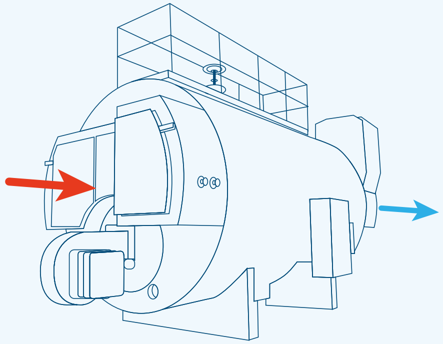
Various technologies have been adopted or are being considered by producers for direct and indirect emissions (see Annex III):

- Heat recovery to produce hot water (own and nearby community consumption)
- Heat recovery to produce steam (nearby industrial consumption)
- Heat recovery to produce electricity
- Carbon capture and use as fuel or in industry parks
- Carbon capture and use for algae farming to produce biofuels
- Use of energy in off-gas - drying / heating of raw materials
- Improvement of computers and electronic monitoring systems
- Increased use of clean energy.

Today, the emissions levels have almost reached the theoretical stoichiometric limits (see explanation on page 11).

The ferro-alloy and silicon sector entered the EU ETS in terms of direct emissions in phase 3 (2013-2020) and is therefore subject to greenhouse gas emissions reduction regulations. However, the progress in terms of emissions reduction in the sector started well before. The less efficient installations in terms of both CO_2 emissions and energy consumption have closed, since those two factors heavily impact production costs. The remaining companies are among the world leaders in terms of CO_2 and energy efficiency, and they continue to improve their track record.

The total volume of emissions in the ferro-alloy and silicon sector (EU + EEA) in 2015 was 4,657kt CO_2.



There are multiple industrial processes that require steam for one or more steps in the overall process for digestion, evaporation hydrolysis, drying or distillation... The location of such industrial plants is of much importance, a key factor is the distance to the steam source.

Figure 8: Typical Boiler layout for steam production – 1-16 bar (Source: Norsk Energi)

The following table shows the order of magnitude of CO_2 emissions per main alloy:

Data per tonne produced (EU+EEA):		1997	2005	2013
Silicon	Electricity Input (MWh)	13.2	12.1	12.4
	Direct Emissions (CO_2/t)	4.7	4.2	4.3
Ferro-Silicon	Electricity Input (MWh)	9.2	9.3	8.9
	Direct Emissions (CO_2/t)	3.6	3.3	3.3
Ferro-Manganese	Electricity Input (MWh)	2.9	3.0	3.0
	Direct Emissions (CO_2/t)	1.1	0.6	0.5

Table 1: Historical figures on emissions and electricity consumption (data in key milestone years - internal data of Euroalliages)

Ferro-Silicon, 2015:	Direct and indirect emissions, kgCO$_2$/t	World share of FeSi-related CO$_2$ emissions
EU + EEA	4,975 (average)	3.33% (total)
China	12,913	78.18%

Table 2: EEA (France, Spain, Poland, Slovakia, Norway and Iceland) and China CO$_2$ emissions of FeSi (Source: AlloysConsult, 2016)

The sector has today almost reached the physical limits for improvement!

Today, European producers have the lowest carbon footprint in the world, direct and indirect emissions combined. An illustration can be drawn from the Environmental Contribution Index. This index for a particular product is defined as a country's share of world production divided by its share of world CO$_2$ emissions derived from production of that product. It appears from figure 9 that the EU has the highest Environmental Contribution Index among its major competitors for ferro-silicon, valid also for other ferro-alloys.

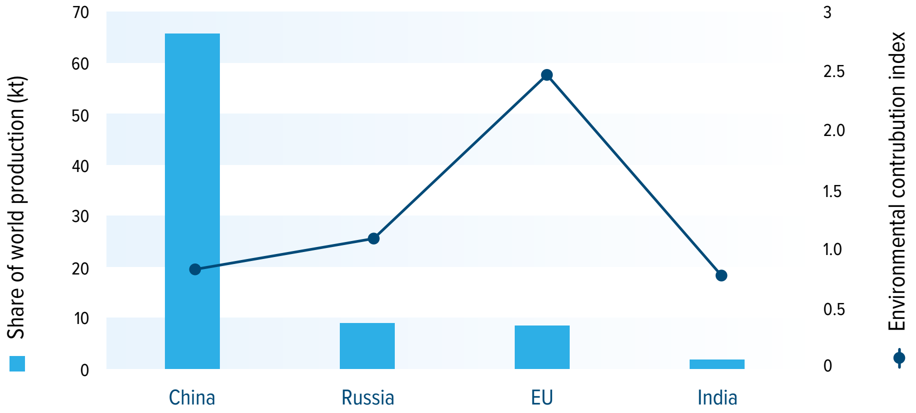


Figure 9: Environmental Contribution Index for Ferro-Silicon Production 2015(source: AlloyConsult)

Energy efficiency

Given the fact that the potential of reduction of direct CO$_2$ emissions with state-of-the-art technologies is almost exhausted, the European ferro-alloy and silicon producers have turned to energy efficiency to further reduce their environmental footprint.

Significant efforts have already been made in the industry. Harvesting additional gains in energy efficiency comes, though, at a high cost relative to the additional savings.

Electro-intensity varies in function of the product. The most energy-intensive product in the EUROALLIAGES' portfolio is silicon (around 12MWh/tonne).

It goes without saying that energy is one of the main input costs in the ferro-alloy and silicon industry. Being energy efficient is a matter of competitiveness and is crucial for the companies in this sector. EUROALLIAGES' members have therefore been early movers in implementing various and creative technologies and projects in order to reduce energy consumption as far as possible.

Since 2005, the cumulated investment in energy efficiency in silicon and silicon alloys has amounted to €350 million, which is a substantial amount for the ferro-alloy and silicon sector. Further investments are foreseen for the 2020-2030 period (R&D, energy efficiency and other investment), reaching several hundred million €.

million €	2005-2009	2010-2014	2015-2019
Silicon	30	40	105
Ferro-silicon	25	115	n/a
Ferro-chromium	10	1	2

Table 3: Investments in energy efficiency (backward and forward looking)

Other investments to improve energy efficiency have also recently taken place, e.g. in the recycling of ferro-alloys.

The companies continuously invest in energy efficiency projects. An example of a recent project is the installation of an ORC (Organic Rankine Cycle) to transform waste heat into electricity. The cost of such a project is very high (in this case, 12M€ to produce 3MW, i.e. 5% profit at plant level).

Any replication can only be economically viable if there is financial support, for instance at the investment stage or through a guaranteed purchase price of the electricity produced which is higher than the market price. Any obligation to invest without financial support would jeopardise the survival of the European ferro-alloy and silicon industry.

Based on the companies' experience, investments in energy efficiency should be taken into account by policy-makers only when and where they are economically viable and geographically feasible. While European ferro-alloy and silicon companies have come up with creative solutions over the years, local conditions (e.g. remote plants) should be taken into consideration. The cost-benefit ratio of those investments, which often represent a huge financial burden for the companies and is not necessarily rapidly compensated by the level of savings it triggers, must be taken into account.

Historically, several ferro-alloy producing installations have been located near hydropower plants (e.g. Norway, Sweden, France, Spain) thus becoming a part of energy-intensive industrial clusters.

Today, renewable energy sources continue to play an important role and corporate renewable PPAs (power purchase agreements) are of major interest. To date, one company has effectively subscribed to a PPA and several others are currently exploring the possibility of doing so. One major hurdle is the uncertainty regarding state aid rules.

The European ferro-alloys and silicon industry is fully electrified.

Carbon is used in the process only for its chemical properties and not for its energy content. Therefore, there can be no differentiation based on the electrification aspect of the production process.

As pointed out above, ferro-alloy and silicon production are electro-intensive. Energy costs account for a large part of production costs, around 30% and in some cases even higher. It is well recognized by literature that CO_2 costs are passed on to electricity prices; these are the so-called indirect emissions costs.

As a consequence, European ferro-alloy and silicon producers have been subjected to such costs increase, which third country competitors do not have to bear, since 2005 (First EU-ETS trading period Phase I). These additional costs, therefore, heavily impact European production costs and negatively erode the competitiveness of the EU industry.

Industrial emissions

EU producers have already implemented technologies to reduce their environmental and carbon footprint according to the Best Available Technologies (BAT). A series of technologies have been published in the BAT conclusions for the sector under the Non-Ferrous Metal BREF, as required by the Industrial Emissions Directive. The applicability of these technologies depends upon a series of factors, such as local conditions (presence of district heating, industry parks etc.).

With substantial investments in abatement technologies, the sector has achieved significant air emissions reductions. As outlined by the European Commission during the Green Week in May 2019 (Fig. 11 here below), the ferro-alloy and silicon sector has significantly contributed to the global achievement of industrial emissions reductions: 76% NOx, 48% NOx, 28% dust, as outlined below.

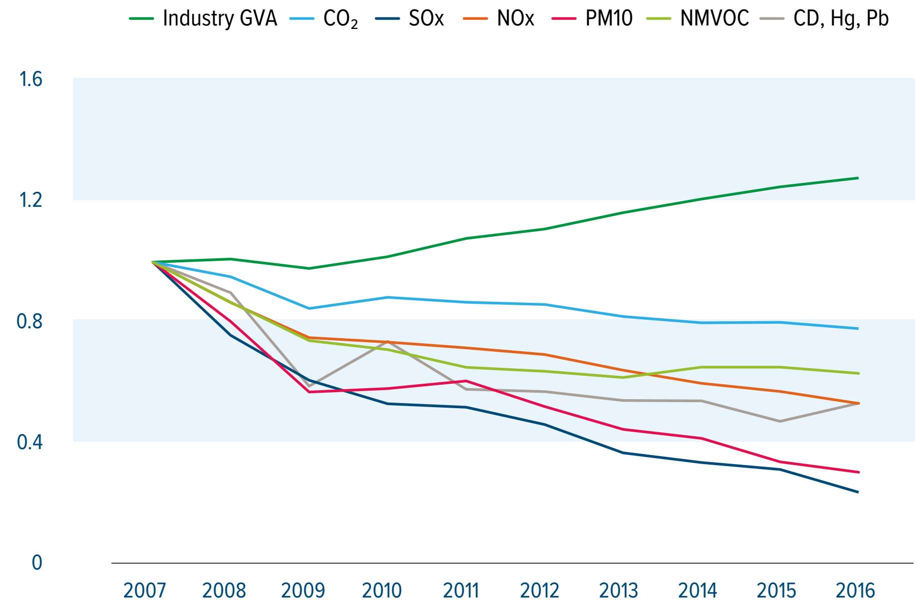


Figure 10: Releases of air pollutants and gross value added (GVA) for industry (EEA-33)

There have been no green field investments in the ferro-alloy and silicon sector in Europe in the last decades (except for Iceland, where the CO_2 component in electricity prices is not an issue). The major investments that have taken place are limited to refurbishment and maintenance of existing facilities.

In contrast, there has been huge increase in ferro-alloy and silicon production capacity in third countries (China, India, Malaysia, etc.), where the energy mix is based on a high proportion of coal.

The biggest achievement in the last decade has been the development of a new technology for purity silicon production for use in silicon wafers in 2009. This technology (hydrometallurgical process) uses 75% less energy as compared to the traditional technology (gasification process).

New Technology for the production of hyper pure Silicon

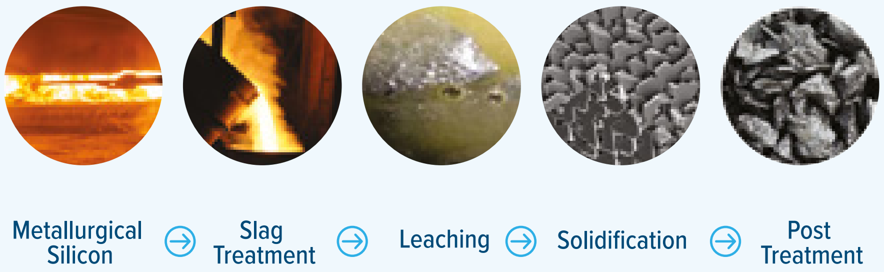


Figure 11: ELKEM Solar process

Ferroglobe's project for silicon purification, known as Ferrosolar, started building the industrial plant in 2018.

Circular economy

Recovery of ferro-alloys and silicon scrap

Ferro-alloys and silicon used respectively in the steel and aluminium industries are largely recycled with the recycling of steel and aluminium scrap. Indeed, about 50 % of the total EU steel production is derived from recycled steel scrap and nearly 75 % of all aluminium and aluminium alloys ever produced are still in use today.

Within the industry which buys metallurgical grade silicon, recycling streams and separate or specialised processes for utilisation of any side streams already exist. Silicon used in the electronics industry is of higher quality than for other applications. Most of the silicon scrap generated during crystal ingot and wafer production for electronics applications can, therefore, be used in the photovoltaic industry. The huge annual growth in consumption of photovoltaics, where silicon is the dominant PV material, is boosting research activities to recover waste containing silicon, thus constituting a growing potential silicon feedstock. All ferrochrome is used as alloy for stainless steel or special steel grades. These steels are the most recycled materials and e.g. the stainless-steel melting shops are the biggest material recyclers in Europe.

Silica Fume – a success story

Silica Fume, a by-product of silicon and ferro-silicon production, is a success story resulting from decades of investment, research, innovation and applications of the ferro-alloy and silicon industry. These combined initiatives have created major construction project opportunities which have contributed to job creation. Silica fume is captured through a dust collection system (baghouse filters) which reduces atmospheric emissions and hence significantly improves workplace conditions, whilst at the same time preventing valuable material from ending up in landfill.

Several hundred thousand tons of silica fume (also called microsilica) are used in both the European and third country markets. This material is an internationally tradable product used in different industrial applications. Silica fume improves the sustainability of buildings and contributes to reducing their carbon footprint (as outlined in the Environmental Product Declaration (EPD – based on ISO 14025), as well as to bringing buildings into the Circular Economy. This success story helps to meet the objectives of the industrial emissions, carbon footprint, resource efficiency, circular economy, workplace legislation, industrial specifications, waste, air and innovation policies, and has been fully recognized as such by the European Commission Electro-intensity.

A dedicated website has been created for silica fume: www.microsilicafume.eu

Silica Fume

Silica fume, a by-product of the production of silicon and ferro-silicon, has been recognized as a pozzolanic admixture that is effective in greatly enhancing mechanical properties of construction materials. Silica Fume is mainly used as concrete additive. A number of countries, including Japan, Australia, France, Brazil etc., have developed standards for the local use of silica fume. A European Working Group (WG9) has been established under the Committee for Concrete and Related Products (TC 104) within CEN. Numerous scientific papers have been published on silica fume.

Figure 12: Use use of bubble-decks in building (Elkem)

Figure 13: Two qualities of Silica Fume

Figure 14: The Great Belt Link, Denmark

MOR fumes' applications in various industries

In the process of refining FeMn in the Manganese Oxygen Refining (MOR) process, MOR fumes are produced as a by-product. Almost all production is used as colouring agent in various building materials, in particular bricks and roof tiles, or as microfine weight material for drilling and oil-well cementing fluids. These applications reduce the CO_2 emissions in users of the by-products as opposed to them having them produced specifically.

Slags: by-products from silicon & ferro-alloys production

The production of ferro-alloys by the smelting of ores generates slag (oxides content). The ratio of slag per tonne of ferro-alloy produced depends on the type of ferro-alloy in question. It has been estimated that around 1.4 million tons of final slag are generated from the EEA's production of ferro-alloys (British Geological Survey, internal data of Euroalliages). The main applications of slag are in road construction (use in asphalt and concrete), landfill cover and drainage, embankment fills, as raw material for the production of insulation material, in construction material for building - foundations, freeze insulations, surface drainage systems... , and for sandblasting. Slags from the production of Mn alloys are recycled within the sector to recover the metal content.

> The conflicting status between product and waste at national level jeopardizes valuable use projects (i.e. construction road applications) which would enable considerable amount of slags to be diverted from landfilling, contradicts circular economy as well as reduced CO_2 emissions objectives.

European Standards relevant for slag are:

EN 197: Cement;

EN 206: Concrete;

EN 13139, 12620 etc.: Aggregates;

EN 13383: Armourstones;

EN 12945: Fertiliser;

EN 13285: Unbound mixtures;

EN 14227: Slag bound mixtures;

EN 15167: GGBS in Concrete.

FeCr are subject to compliance with standardized specifications such as EN 13242:2002+A1:2007 - Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction.

Ferromolybdenum slag can be successfully used in the production of concrete blocks substituting natural aggregates. All properties meet the required values in order to certify these blocks according to BENOR in Belgium

> Sustainable development has three pillars: Economic, Environmental and Social. To achieve sustainable development, policies in these three areas have to work together and support each other
>
> (Source: European Commission).

Furnace electrodes using a by-product from the coal industry

Coal tar pitch high temperature (CTPHT) is used for the production of Søderberg or composite electrodes for electric arc furnaces with submerged electrodes (SAF or EAF) in ferroalloy plants (smelting process). The Søderberg electrode, used in electrometallurgical furnaces worldwide, was invented by the Norwegian engineer C.W. Søderberg, whilst composite electrodes were developed by the Ferroglobe company in Spain. CTPHT is, in fact, a by-product of the distillation of coal tar, itself originating from the production of coke and coal gas from coal. CTPHT ceased being considered a waste product decade ago, as it has found key applications in many energy intensive industries.

Chemicals and other EHS Policies

The sector is fully compliant with the chemical and EHS regulations and in particular REACH and CLP, having been engaged in the process since the early days. Consistency between EHS/Non-Toxic Environment, Climate Change and Circular Economy regulations is needed so as to avoid the transfer of pollution/cross-media effects. For example, reducing levels of pollutants to very low limits or removing impurities to values close to or even below detection limits necessitates the use of additional energy-consuming equipment. The overarching principles of sustainability should always guide decision makers.

Vision of a sustainable future for the European ferro-alloys and silicon sector

Vision of a sustainable future for the European ferro-alloys and silicon sector

Low-Carbon Innovation: From ideas to viable solutions

Introduction

The central question for the development of a 2050 vision for the European ferro-alloy and silicon sector is how this industry can contribute to Europe's low-carbon (or carbon neutral) economy.

Innovation is not straightforward, as it is often subject to trial and error, and beset by the need to identify the inevitable "dead ends" in the struggle towards carbon-neutral or sustainable production.

As an electro-intensive industry and supplier of raw materials upstream of supply chains, the ferro-alloy and silicon sector has been engaged in innovation activities for decades in order to develop new processes and products in a climate-friendly and more resource-efficient way.

At the level of the production processes, even if the principles of metallurgy have not fundamentally changed, technological developments have engendered increased control and efficiency, which in the European Economic Area have now reached a high level of optimisation.

There are, however, physical constraints which cannot be overcome: these are the incompressible processing emissions (see explanation on page 11). The existence of, and the impossibility of reducing, these process emissions has been recognised by the European Commission in the "Clean Planet for All" Communication. Process emissions are taken into account in the various scenarios and are considered as an area for emissions compensation on the path towards carbon neutrality.

At the level of the supply chains, the sector will always have a key role to play in respect of the innovation and development of future technologies for the European iron and steel, aluminium, chemical, electronic and solar industries, which are its main customers. Indeed, the degree of quality and innovation, and hence the success of the products of these downstream producers, are influenced by the quality of the raw materials supplied, such as ferro-alloys and silicon.

So far, no breakthrough technology has been identified to face the basic physical constraints of smelting. The sector is therefore concentrating on other means to reduce its emissions and is working to squeeze out the last drops of available potential.

In addition to reducing emissions in the manufacturing phase, there is an opportunity to do so also in downstream operations.

Changes in the composition and use of the products contribute to emissions reduction and need to be taken into account.

These opportunities can be guided by sound policies that acknowledge and assess the CO_2 footprint along the whole value chain and over the life-cycle (including end-of-life) of the end-product.

Low-Carbon Projects and field constraints: an overview

Technological development, market forces, national policies and climate change are global issues which influence the way factories operate. The configuration of the smelting plant, the development of the national energy sector and the related percentage of green electricity, the presence of local sources of raw materials, the transmission capacity of electricity and the predictability of the energy market influenced the ways in which factories were developed, how they are working and how they consider their future in the low carbon economy.

The Algae Project

The project concept covers the production of diatom biomass by sequestration of CO_2 and NOx from factory fumes and differs from other conventional initiatives with respect to the choice of organisms, photobioreactor type, illumination, cultivation technology and processing. The main product is fish feed, but bioprospecting and other applications are included. This initiative has been integrated into the production line of the ferrosilicon factory at Finnfjord in Norway.

The ground-breaking feature is the integration of the "mineral world" and the "organic world" within the same industrial site by linking the "mineral" and the "organic" value chains with the conversion of CO_2 to fish fodder or fuel. The bioeconomy was envisioned as an emerging business field with great opportunities for both financial and environmental gain. In contrast to the fossil economy, the bioeconomy would be based on organic, renewable raw materials (Knutsen, 2017).

Biocarbon strategy

This concept aims to replace fossil coal with biocarbon as a chemical reduction agent in the ferro-alloy and silicon production process. Most producers have initiatives in this field. Elkem has launched a research programme known as Carbon Neutral Metal Production (CNMP), whose concept is to produce charcoal in the same production facility as ferrosilicon or silicon, connecting this to an energy recovery unit which produces electricity from the excess heat.

The local conditions are favourable with green hydropower, local wood-chips production and significant forests. This project required the cooperation of different industries in a cluster, as one company alone cannot set this up. A considerable level of research, cooperation and funding are required, as well as a holistic approach utilising all side streams (fines, pyro-gas, condensate): wood chips production and drying, novel pyrolysis process to transform these chips

The Algae Project:

Marine algae produce roughly 50 per cent of the oxygen in the Earth's atmosphere. Because global air currents transport CO_2 towards the North and South Poles, algae in the polar regions have adapted to absorbing larger amounts of CO_2 than their relatives around the equator.

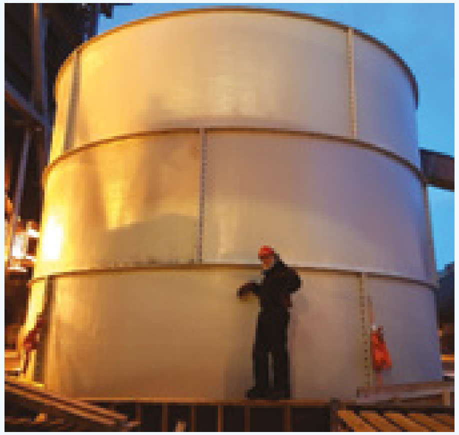


Figure 15: Mass cultivation of diatoms at Finnfjord as upscaling to pre-industrial level

Figure 16: Laboratory cultivation of algae

Biocarbon strategy

The goal of Elkem is to increase the use of biocarbon to 40% in the Norwegian smelters by 2030, and ultimately to achieve carbon-neutral production of silicon and ferrosilicon.

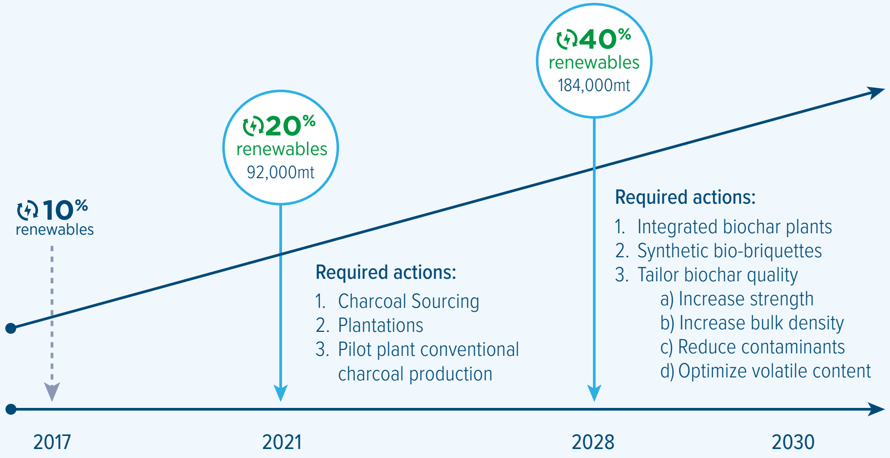


Figure 17: Biocarbon strategy of Elkem

into charcoal and off-gas, use of the off-gas e.g. by heat transfer and of the charcoal by local consumers. The challenges are the type of biomass for carbonisation, land use and biodiversity, centralised vs. decentralised charcoal production, the low charcoal yield, storage and transport.

Eramet Norway is planning a full-scale test work to use biocarbon in its production and participates in several R&D initiatives as well as cooperation with potential producers.

Manifesto of Dunkirk

The Aluminium, Ferro-alloys and Steel industry CEO's have signed an Industrial Pact in Dunkerque to recall the mobilization of industrial and port stakeholders to innovate, experiment, work together to reduce CO_2 emissions while continuing to produce. They call for budgets to be devoted to the projects of the territory, with research and development to reduce emissions at the source, capture, store or recover CO_2 but also control the transfer and exchange of energy flows, hydrogenation for the production of green fuels but also anaerobic digestion and recovery of fatal heat.

Other projects

A low hanging fruit with some potential estimated of around 5% CO_2 reduction is to limit the amount of carbonated materials in the charge of Mn alloy producing furnaces. In some conditions, one can limit the use of limestone and dolomite. The industry is also evaluating the options of using non-carbonated lime sources, coming for other industries by-product (e.g. concrete wastes).

Other projects are technically feasible or look promising at the test phase, but imply i.a. high CAPEX such as:

- Carbon Capture and Usage (CCU) based on gas fermentation – ethanol (one example being the LanzaTech process)
- CCU to produce lipids for feed ingredients
- CCU of CO gas for other purposes (fuel, electricity, chemicals)
- Carbon Capture and Storage (CCS), separation of CO_2 from other gases (= capture) and ground storage
- Pre-reduction of ores in industrial off-gases and solar thermal energy in a separate unit in manganese alloy production (EU SPIRE, project PREMA)
- The development of capability and methods to utilise hydrogen in FeSi and Si-production processing.

Or have a low CO_2 potential reduction such as:

- Using of SiMn slag in the cement industry
- Carbonation of SiMn slag for carbon capture

The production of Mn alloys by electrolysis with hydrogen in the pre-reduction phase is being studied. This long-term technology does not require the use of a submerged electric furnace and would not produce CO_2. This would, however, require huge investments.

Hydrogen replacement of carbon
is not a one-fit-all solution.

Exploration of technology and limitations

Hydrogen – H_2

Using Hydrogen instead of Carbon as reducing agent - like in steel - is not possible in ferro-chromium production:

The reduction process to transform a metal oxide into a metallic form are governed by laws of thermo-dynamics. The more G (Gibbs constant) is high, the more difficult is the reaction. Constants Gibbs & equilibrium K are favourable for reduction by H_2 of iron ore and are very unfavourable for Cr/Mn/Si ores as the energy to accomplish the reaction is much higher than to keep it in equilibrium. Energy to produce H_2 should also be taken into account. (Fig 18 & 19)

Methane – CH_4

CH_4 is a theoretical candidate to replace carbon (67% less CO_2 emission). But it induces generation of carbon black with huge risk of explosion. The technology is unfeasible today.

Silicon Carbide – SiC

SiC is also a theoretical candidate but its production requires a lot of energy.

Alternative productions for Silicon

Electrolyse, metallothermic reduction (Al/Mg/Ca/Zn), carbo-chlorination or Hydrogen, have as common challenge that it is not competitive as long as there is no global level playing field on CO_2 emissions requirements.

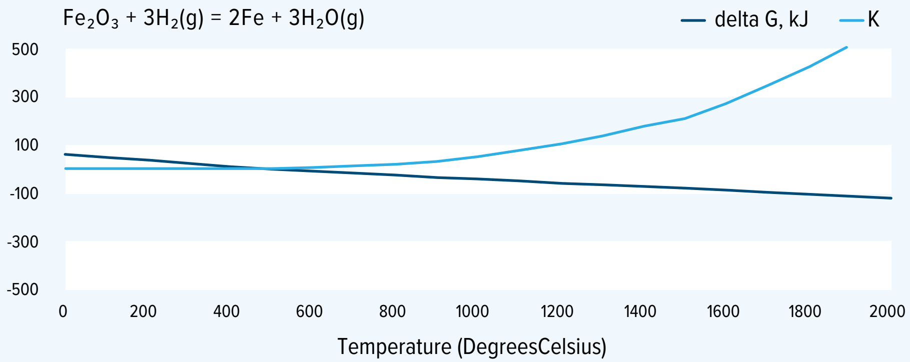


Figure 18: Hydrogen reduction of iron

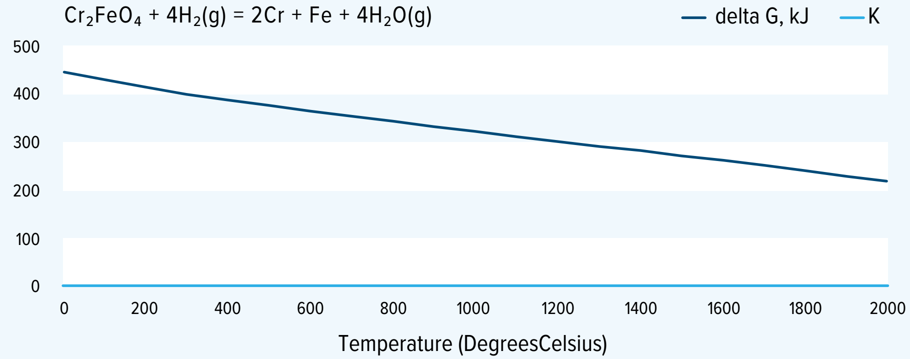


Figure 19: Hydrogen reduction of chromium

Promising technology – improving capacity of Li-Batteries

Battery production is a strategic imperative for a transition to clean energy and the competitiveness of the European automotive sector.

Lithium-ion batteries will play a central role as they are not only widely used for portable electronic devices and mobile phones, but also show great potential for more demanding applications such as electric vehicles. Lithium-ion batteries still lack the level of energy storage required to meet the demands of electric vehicle applications.

Among the advanced materials which are being studied, silicon nanoparticles have demonstrated great potential as an anode material to replace the commonly used graphite.

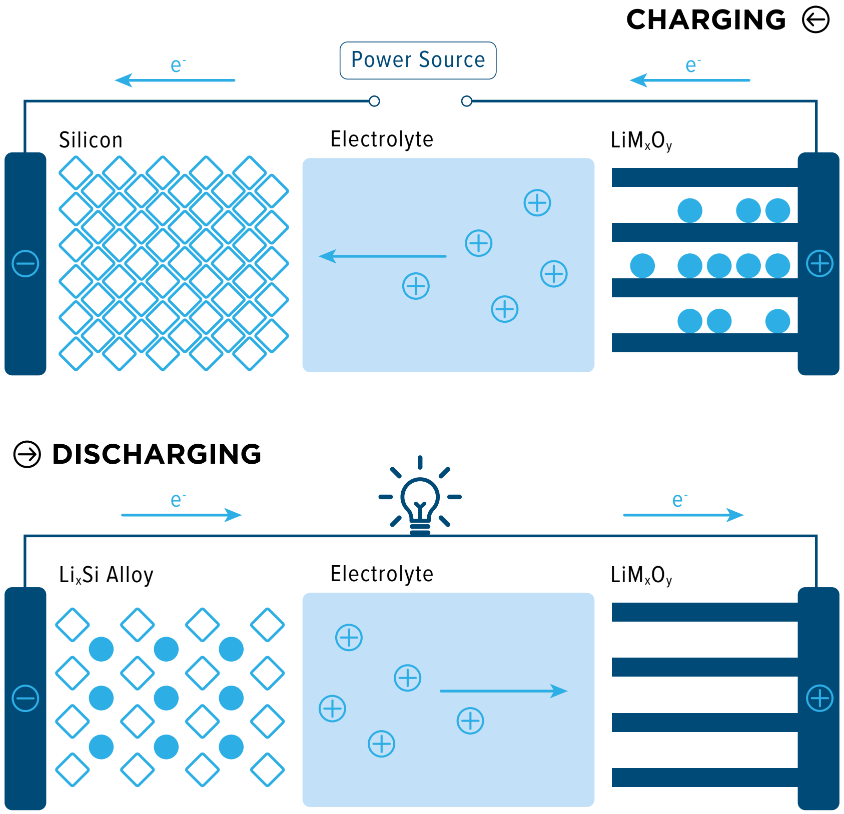


Figure 20: Illustration of a Li-ion battery with Silicon (Journal of Power Sources, 2014).

> Any debate about the smelting industry needs to consider not only how their products are made, but also what services they provide to the supply chains and hence to society.

Summary of the strategic importance of the sector

Starting point of low-carbon European value chains

The ferro-alloy and silicon sector is a strategic European industry:

- A historical integration exists along the European industrial value chains; this integration makes all the more sense today, in a globalised but also polarized and highly competitive world;
- European producers are reliable actors in these value chains in terms of both access to raw materials and quality of the products;
- The sector produces strategic materials for a low-carbon / carbon-neutral economy:
- Silicon is necessary for ‘green energy’ production and storage: solar panels, batteries;
- Silicon & ferro-alloys are irreplaceable for electric vehicles and electronic industries (digitalisation);
- Ferro-alloys are vital for steel and subsequent value chains, e.g. there is no modern energy production or hygienic food production without ferrochrome as alloy in stainless steel;
- Silica fume is a major asset for sustainable construction.

The European ferro-alloy and silicon sector, therefore, deserves more attention and support in the framework of a sound European industrial policy.

Low-carbon and energy efficiency can be incompatible

Key framework conditions to be taken into account in future policies

In order to ensure a successful transition to a low-carbon / carbon neutral economy, European policy has to ensure:

- That the existing potential of the European ferro-alloy and silicon sector is exploited in accordance with the climate targets
- Whilst its global competitiveness is duly preserved.

Based on the solutions being explored by the companies active in the sector, this document also aims at outlining key framework conditions through which European policy can effectively and efficiently support the transition to a low-carbon / carbon-neutral economy.

Two overarching issues need to be mentioned:

- The transition will take place in a highly competitive and dynamic international environment. As previously outlined, ferro-alloys and silicon are traded on a global market and today face fierce international competition, which is also often unfair.
- The path to 2050 is very short in terms of investment cycles, and crucial decisions need to be made right now. The capital-intensive nature of the ferro-alloy and silicon industry has to be understood in order to allow for the necessary accompanying measures to be taken and support to be given to enable the transformation requested by 2050.

Four major areas have been identified where European policy will be instrumental in making a success of the industrial transformation.

A sound European climate and energy policy

The European climate and energy policy is key for the future of the European ferro-alloy and silicon sector, especially in respect of its energy-intensive character. The policy must be feasible and balanced.

The sector has been an early mover in terms of emissions and energy efficiency. The physical limitations determined by intrinsic and incompressible levels of process emissions have, today, almost been reached, and must be adequately taken into account in order to build a realistic and feasible policy for future improvements, as the “Clean Planet for All” Communication has already recognised.

The 2015 Paris Agreement set the scene for a global carbon market. This agreement has, however, yet to be enforced and may not be enforced in the near future, especially against the background of geopolitical tensions resulting from national policies which can be neither predicted nor controlled. Therefore, there is a need to maintain a global level playing field in terms of climate regulations and their related costs. Europe must lead by example, which implies a successful industrial policy measured by the level of both innovation and global competitiveness of European industrial sectors, thriving at global level whilst being able to afford to abide by stringent climate policies.

Energy efficiency is a key element of competitiveness for every energy-intensive industry. The European ferro-alloy and silicon producers have made considerable efforts in this area, and remain committed to pursue energy efficiency projects, as long as they are economically viable. In the light of the fundamental laws underlying the production processes, the potential for higher energy efficiency should be the reference point for setting realistic targets and measuring the achievements.

One meaningful way to reduce emissions for an energy-intensive sector such as ferro-alloys and silicon is to use renewable energy sources, but this is constrained by the availability, the reliability and most of all the cost of these energy sources. A sound energy policy should, therefore, ensure affordable clean energy costs. The scope of this policy should also cover instruments such as compensation for the costs of indirect emissions while keeping an EU level playing field.

The “Clean Planet for All” Communication points to the electrification of several big energy-intensive sectors as a pathway towards emissions reduction. Whilst supporting this target, the ferro-alloy and silicon sector, which is already electrified, emphasizes the need to correctly evaluate future energy demand and to carefully estimate the supply, taking into consideration the enormous costs of both generation and infrastructure.

A situation should be avoided where there is competition for energy resources within Europe, and, by the same token, policies should not be elaborated which result in further undermining the global competitiveness of European industry by imposing burdensome energy-related costs.

Future developments in industry depend on innovation and creative thinking. The European ferro-alloy and silicon sector, though, is peculiarly not an area where breakthrough technologies can be implemented in the short run.

Continuous efforts, however, have been and are still taking place to explore creative solutions, often ad hoc and adapted to local conditions, allowing both improved emissions reduction and energy efficiency. In this context, the concept of ‘negative emissions’ could be further explored and would benefit from political and regulatory support.

An adapted circular economy policy

European ferro-alloy and silicon producers are committed to pursue their past and current efforts to reduce landfill by enhancing the recovery and utilisation of by-products and working with recycling companies specially dedicated to the sector. Producers are prepared to increase recycling activities in the future but, in order to be able to do so, the energy needs of recycling activities must be duly taken into account. Harmonization of the wastes and products policies, as well as national and local implementing rules, is imperative. Reducing the hurdle of administration of cross border wastes or by-products transport is needed in the context of performing R&D work whose purpose is to develop sustainability in the context of circular solutions.

Steps towards the achievement of a global level playing field

The European ferro-alloy and silicon sector has made major investment efforts to achieve a higher environmental performance. However, these efforts have led European industry to incur economic disadvantage compared to third country producers. At the same time, the sector is struggling against a background of barely sustainable and unfair international competition with companies that do not abide by the same environmental, social and financial standards, and consequently do not bear comparable costs. This reality needs to be considered in the elaboration of European policies, including trade, climate, energy, environment, raw materials and employment.

These three major policy areas need to work in symbiosis in order to avoid them becoming mutually counter-productive. Such a symbiosis can be ensured by putting in place a sensible and wide-ranging European industrial policy, which should be one of the main priorities of the European institutions over the coming years, and which should allow Europe to remain a global leader not only at the economic level, but also at the level of environmental and social protection policies, by setting a successful example at home.

The European ferro-alloy and silicon producers are committed to being valuable partners of the European institutions on this path, and to continue contributing to innovation and growth in Europe and globally.

Support of investment and innovation development for low carbon solutions

The EU should have means and incentives to support the early movers in the industry which are willing to make some step changes to significantly reduce their footprints and need some support (financial in particular, but maybe also competence) to make it happen. Further financial support should be directed towards R&D programs for CO2 reduction, and SME’s developing innovative solutions for the ferroalloy industry.

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Annex I: Distribution of products per company

Company (name)	Product(s)	Location
Befesa Valera	Recycling of ferro-alloys	France
Eramet	Manganese alloys	France, Norway
Elektrowerk Weisweiler	Ferro-Chromium	Germany
Elkem	Silicon, Ferro-Silicon	Norway, Iceland
Ferroglobe	Silicon, Ferro-Silicon, Calcium-Silicon, Manganese alloys	France, Norway, Spain
Finnfjord	Ferro-Silicon	Norway
Huta Laziska	Ferro-Silicon	Poland
OFZ	Ferro-Silicon, Calcium-Silicon, Manganese alloys	Slovakia
Outokumpu	Ferro-Chromium	Finland
RW Silicium	Silicon	Germany
Sadaci	Ferro-Molybdenum	Belgium
Vargön Alloys	Ferro-Chromium	Sweden

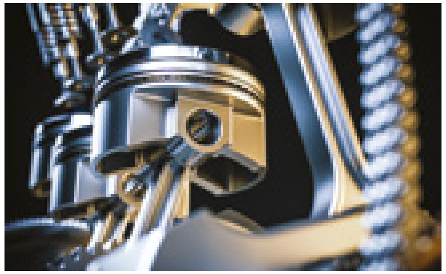
Annex II: Applications of main ferro-alloys and silicon and their supply chains

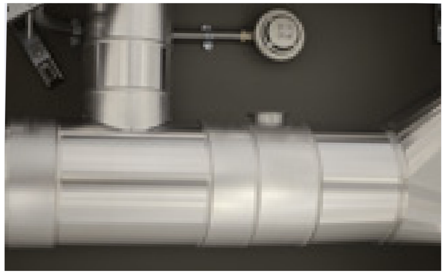
Silicon (Si)

Aluminium Industry applications

Silicon is mainly used as an alloying element for aluminium alloys for casting and extrusion by enhancing the mechanical properties, the two main applications are for the automotive industry and in wrought alloys.

Si is also used to produce several highly specialized silicon containing products for numerous applications. Silicon powder is used in aluminium brazing to produce heat exchangers in the automotive industry, such as radiators, and indoor applications, such as air conditioning and refrigeration.





Chemical Industry

Silicon is the starting point in production of silicones, synthetic silica and silanes.

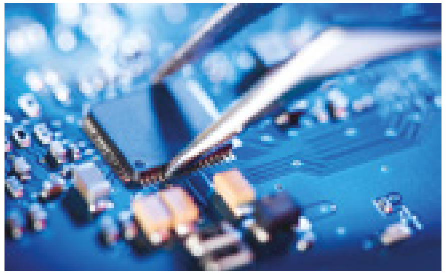
Silicone products have a wide area of applications in e.g. construction, automotive, personal care and household goods. Silicones act as surfactants, lubricants, sealants and adhesives.

Synthetic silica is used as additives in silicone rubbers to increase the mechanical strength and elasticity. Silanes are used in the glass, ceramic, foundry and painting industries.

Silicon (Si)

Electronic industry

Silicon can be chemically refined to an ultrapure semiconductor material (polysilicon); integrated circuits based on silicon are at the core of computers and modern electronic devices.



Solar Industry

Silicon semiconductor wafers are also the dominant material used for solar cells production. Silicon-based solar cells are the dominant technology today and this is not expected to change in the short and medium term.

Batteries Industry

Silicon is used in Li-ion batteries to increase their capacity.

Silico-manganese alloys (SiMn)

SiMn alloys imparts tensile strength in steel that is used in applications in which great toughness and wear resistance is required, such as gyratory crushers, jaw-crusher plates, railway points and crossover components (railways).

The second large application for manganese is as an alloying agent for aluminium to increased resistance against corrosion. Aluminium-manganese alloys are applied in various products such as beverage cans, kitchenware, roofing, car radiators and transportation.

SiMn is also used for specific applications. A titanium-base alloy with 8% manganese was used for the Gemini re-entry control module in the 1960s.

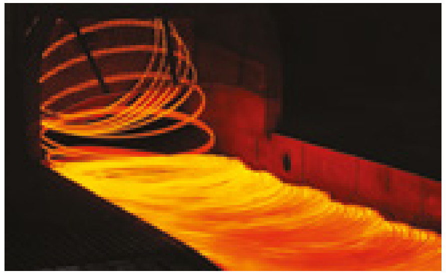
Ferro-manganese alloys (FeMn)

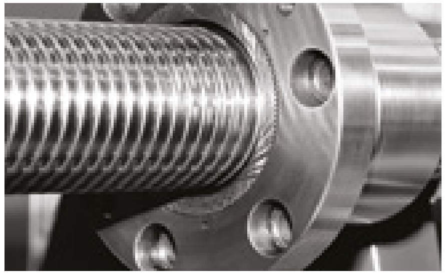
High Carbon (HC) FeMn is one of the most versatile and most used manganese ferroalloys for steel production. It improves the mechanical properties and the hardenability of steel, while increasing its abrasion resistance.

There is a wide range of applications for the HC FeMn, but it is most commonly used in steels for structural shapes, hot rolled sheets and plates.

Medium Carbon (MC) FeMn is used in the production of low carbon ones, high resistant and ductile steels, as well as it is efficiency in welding and deep drawing steels. Specifically, it is used to produce cold rolled sheets, low carbon slabs, and welding and automotive wire rods.

Low Carbon (LC) FeMn is generally used to produce very low carbon steels, as well as austentic stainless steels, which are resistant to deformation caused by high temperatures, for instance, the internal combustion engine escape valves.





Ferrosilicon (FeSi)

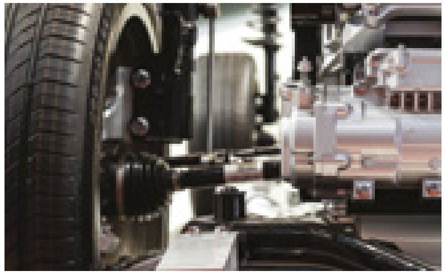
Si-based ferroalloy (FeSi) is an alloy of silicon and iron and it is specifically designed for making steel, in particular electrical, stainless steel, and special steels used in the production of a wide applications such as transmission, storage or pipes.

FeSi is used to remove dissolved oxygen from molten steel.

FeSi increases the strength of steel (needed to produce wire cords for tyres or ball bearings), and wear resistance, elasticity (spring steels), scale resistance (heat resistant steels) and lowers electrical conductivity and magnetostriction (electrical steels). It is used to produce high-permeability steel for electric transformers.

Inoculants are FeSi based alloys which contain carefully balanced amounts of active elements designed to control the microstructure and mechanical properties of cast irons. These special silicon alloys are used in the production of special steel qualities.

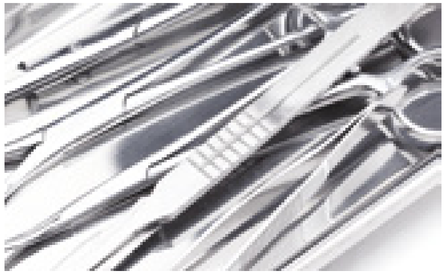
Electrical steel is used to produce magnetic cores for motors used in hybrid and electric vehicles, generators and transformers (electrification system).



Ferrochromium (FeCr)

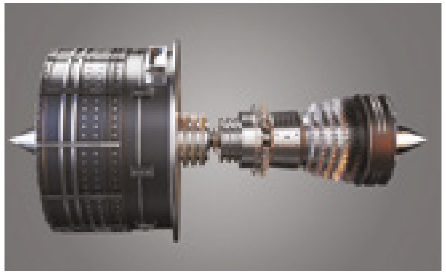
FeCr is an essential element in stainless steel to improve the tempering quality, hardness, resistance to wear and heat resistance. Stainless steel is mainly used in constructions, water pipe, renewable energy technologies (including solar, geothermal, hydro and wind power), household fittings, surgical apparatus and chemical equipment;

FeCr is used also in chrome steel (marine and electrical engineering aircraft parts ...); and in nickel-chromium alloys (electric wires, toasters and other electrical appliances).



Ferro-molybdenum (FeMo)

FeMo imparts toughness and tensile strength in steel use for the manufacture of high-speed tools and machine parts, including parts of gas turbines and jet eng



Annex III: Summary of potential technologies for the reduction of emissions in ferro-alloys and silicon manufacturing

The following table outlines some examples of projects that are being developed by the ferro-alloys and silicon industry. Some are well established technology, some are already implemented on an industrial scale. Other projects or elements of processes still require substantial development that cannot be detailed here.

*Technology readiness levels (TRL). Where a topic description refers to a TRL, the following definitions apply, unless otherwise specified:

TRL 1: basic principles observed

TRL 2: technology concept formulated

TRL 3: experimental proof of concept

TRL 4: technology validated in lab

TRL 5: technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)

TRL 6: technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)

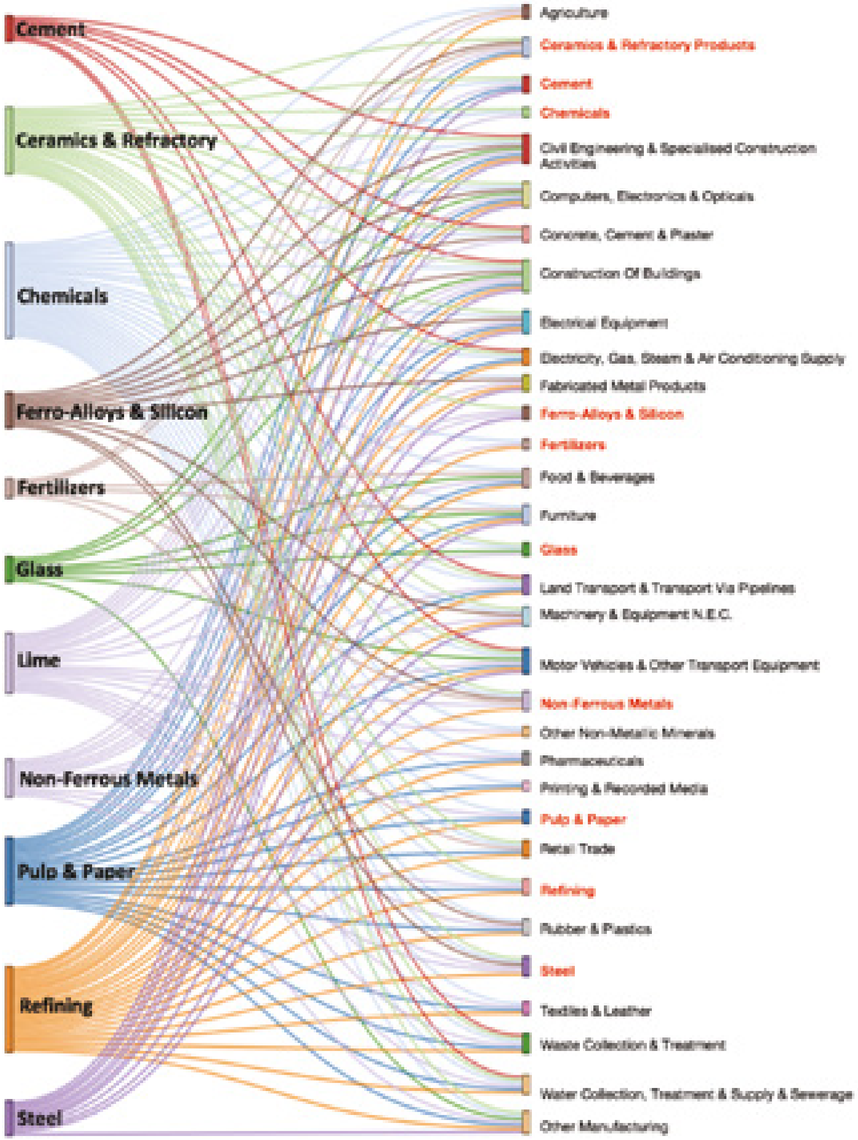
TRL 7: system prototype demonstration in operational environment

TRL 8: system complete and qualified

TRL 9: actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

Category of potentials	Technology	TRL* Depending on the company
CCU	Use of off-gas to produce food & oil (algae)	7
	Use of off-gas for the production of Hydrogen	3-4
	Bind CO_2 to minerals to produce carbonates (CCS)	4
	Use of CO_2 to produce lipids for feed ingredients	4
	(CCU) gas fermentation – ethanol (LanzaTech process)	6
	Carbonation of slag for capture (ex. SiMn slag)	1
	Mixture of CO_2 and H_2 to produce hydrocarbons (Methane and Methanol)	7
Process	Raw materials pre-heating	
	Waste heat recovery – use of hot water	9
	Waste heat recovery –use of steam	9
	Waste heat recovery – production of electricity	9
	Pre-reduction of ores in separate unit	9
	Pre-treatment of raw material	9
Switch to carbon-neutral energy	Switch to carbon neutral reductants	9
Circular economy	(Use of charcoal or biomass as reductant)	8-9
	Electrolysis (ex. molten oxide electrolysis (MOE), FFC Cambridge process, etc)	9
	Use of slag in cement industry	9
	Use of slag in construction roads	9
	Valorization of slags (heat and residual contents)	9
CCS	Separation of CO_2 from other gases (= capture) and store in the ground	6-9

Annex IV - Value chain links of energy intensive industries to other sectors in the economy and other energy intensive industries (Study IES, 2018)



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