Environmental Aspects of the Ferro Alloy Industry

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Abstract

The paper focuses on some of the environmental challenges which are facing the ferroalloy industry. Some general instruments for environmental benchmarking and improvement are presented. There is also a discussion of the effect and consequences of the international agreement on greenhouse gases that was determined in Kyoto in December 1997. Some specific effluent data for silicon and ferrosilicon are given as Environmental Performance Indicators.

Introduction

Environment challenges are becoming increasingly important for all of us. It is understandable that the INFACON 8 conference has emphasized this as a focus for the conference. There are several reasons for the increased attentation given to environmental issues. There is growing concern about the environmental situation and the unwanted side-effects of human activities.
Stricter environmental regulations are introduced on national and international levels. New information systems like the World Wide Web give easy access to data. Some countries have even made the presentation of environmental information from mandatory industry. One example is the American Toxic Release Inventory (TRI) which provides specific information to the public.

The production of iron and steel as well as other materials, such as aluminum and materials for chemically-based products, is playing a substantial role for the environment we have created. This impact is related to total energy use and different kinds of pollution that may result during the various stages in the production of materials.

The production of ferroalloys is minor compared to base materials such as steel and aluminum. Nevertheless, the environmental aspects of silicon and ferroalloys has to be taken into account as part of the total man-made pollution. Nearly all aspects of the production and use of ferroalloys are energy-intensive and the processes themselves have an impact on the environment. Recognition of this fact is important for all producers and users of ferroalloys.

The Norwegian Ferro Alloy Association (FFF) has been working on environmental problems connected to ferroalloy processes during the last 10 years. The environmental part of the research work has become increasing important to FFF. The objectives for the research work are not only to describe the situation and level of effluents, but also to improve the basic knowledge about the processes and their environmental impact. Some of the environmental problems may be reduced though improved furnace operation, the choice of raw materials or by improved design of the processes. Some of the results from the work will be presented later in this paper.

At INFACON 7, environmental aspects of the ferroalloy industry were highlighted. The environmental standards and the ferroalloy industry was presented by Tor Faerden from the State Pollution Control Authority in Norway /1/. In this paper I will try to describe on what has happened after 1995 as well as to give some figures which can be used for environmental benchmarking the future. The concept of Best Available Technology (BAT) will probably prove to be important for the ferroalloy industry, and the importance of the transparency of information is emphasized in the Kyoto Protocol /2/.

Global warming, energy use and the consequences of the Kyoto agreement

The UN Convention on the Climate Change is based on the Rio Conference in 1992. There has been continuous work going on since which has resulted in an international agreement on the abatement of greenhouse gases, the Kyoto Protocol to the United Nations Framework Convention On Climate Change (UNFCCC) /2/. This protocol is important for the ferroalloy industry, and some of the information will be presented here and commented upon.

The climate change problem

The greenhouse effect is the energy balance between the incoming radiation from the sun and the energy sent back from earth into space as infrared radiation. The natural balance due to the greenhouse effect is 30 degrees centigrade. This natural global warming is a precondition for all human life. This balance may be altered if there is an increase in the amount of greenhouse gases in the atmosphere. Although water vapor is the most important greenhouse gas, an increase of the CO_2-content or other greenhouse gases may increase the global temperature. There are uncertainties about the status and the consequences of the man-made contribution to global warming. Nevertheless an agreement for greenhouse gas abatement was reached in Kyoto in December 1997 after 5 years of work.

The two-level protocol

One of the most controversial issues is the division between the 39 parties (called the Annex 1 parties where a party is one country or a group of countries) which are given quantified emission limitation and all the other countries have no limitations so far. The reduction commitment for the emission is given as a percentage of the base year 1990 and should be obtained before the commitment period of 2008 to 2012. The reduction commitments for some important ferroalloy countries are presented in Table 1.

Table 1 showing the quantified emission commitment for some countries.

PARTY (i.e. country or regional economic integration organization)	Greenhouse gas level in 2008-2012 vs. 1990
Australia	108 %
Canada	94 %
France *)	92 %
Germany *)	92 %
Iceland	110 %
Norway	101 %
Russian Federation	100 %
Spain *)	92 %
Sweden *)	92 %
Ukraine	100 %
United States of America	93 %

*) The European Union average may differ between the member states.

These commitments will ensure a greenhouse gas emission limitation of at least 5% below the 1990 levels for the Annex 1 countries. But according to the protocol each Party (country) is to have made demonstrable progress in achieving its commitments by 2005.

The protocol deals with the anthropogenic carbon dioxide equivalent emission of six greenhouse gases which are; Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorcarbons (HFCs), Perfluorocarbon (PFCs) and Sulfur hexafluoride (SF_6). For the ferroalloy industry the most important gas is the Carbon dioxide. Both the energy, production industry and metal production are mentioned as important sectors in the agreement.

Many industrial managers in the Annex 1 parties are concerned that this agreement may result in increased costs and hence competitive disadvantages compared to the countries that are not effected. The discussion of abatement commitment from non-Annex 1 countries will continue in coming conferences inside the UNFCCC.

Other important parts of the Kyoto protocol

I will just quote some of the most relevant articles in the protocol:

The Annex 1 parties:

- *enhancement of energy efficiency in relevant sectors of the national economy*
- *promotion, research, development and increased used of new and renewable forms of energy.*
- *progressive reduction or phasing out of market imperfections, fiscal incentives, tax and duty exemptions and subsides in all greenhouse gas emitting sectors....*
- *...share their experience and exchange information on such policies and measures, including developing ways of improving their comparability, transparency and effectiveness.*
- *...removal by sinks resulting from direct human-induced land use change and forestry activities....*

All parties will:

- *Formulate, implement, publish and regularly update national or regional programs containing measures to mitigate climate change .... concerning energy, transport and industry sectors.*
- *...promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies, know-how, practices and processes pertinent to climate change, in particular to developing countries.*

Some possible consequences for the ferroalloy industry

The protocol is subject to ratification by 15 March 1999. It will enter into force after 55 parties including Annex 1 parties accounting in total for at least 55 per cent of the total carbon dioxide emissions for 1990 have ratified or approved the protocol

There has been some doubt whether some parties, such as the USA will enter the agreement. There is resistance both in US industry and the US Senate. Also other countries and interest groups are concerned regarding the agreement.

On the other hand, there is a growing awareness of some extreme climatic events in recent years. Although the linkage to global warming is not clear, such events may indicate what the weather will be like in the future. Especially the insurance industry and politicians who are faced with the cost of these events are advocating increased awareness with greenhouse gas emissions. If clearer signs of a global warming problem appear there is also a possibility that even stricter abatement policies may be discussed in years to come.

Although the reduction in the emissions of greenhouse gases is in the order of five per cent, which seems small, in many countries there has been an increase after 1990 which means that the reduction towards 2008-2012 will be larger than presented in Table 1.

If the Kyoto protocol is ratified and approved, some consequences may be indicated. The measures for greenhouse gas abatement may differ between countries. In the Annex 1 countries there has to be an increased cost of energy production giving CO_2-emission compared to other clean energy sources or to the cost of increased energy saving. The ferroalloy industry should also be aware of more indirect possible effects of the Kyoto protocol. It may change the competitiveness of the users of ferroalloys as well as the behaviour of the end user.

The protocol calls for sharing experience and exchanging information between the parties. This will call for even more transparency between ferroalloy producers. Some instruments for environmental benchmarking and technology transfer will therefore be presented next.

Life Cycle Assessment and other environmental descriptors

The Life-Cycle concept is becoming an important method for industry to understand, manage and reduce the environmental impacts associated with its processes, products and activities.

It is important to consider the environmental aspects of ferroalloy production from a broad view. Very often the only environmental consideration that is taken into account is the pollution from the production furnace itself. For a fuller understanding of the environmental problem it is now common to evaluate the environmental burdens associated with a product system from "cradle to grave" with a Life Cycle Assessment (LCA). The main purpose of an LCA study is to provide a holistic overview of resource, environmental, and health impacts on a system, assess the impact and evaluate and implement opportunities to effect environmental improvements. /3/

In a full Life Cycle Assessment all the resources used in the process from raw material production, transportation, and energy sources are included as a part of the environmental cost. The assessment consists of a goal definition and scope, an inventory of mass and energy flows in the system, and evaluation of the environmental impact for the full life cycle of a product. In the case of silicon-alloys this requires an assessment of the downstream product use. One complication with this approach is that there is considerable diversification in how the alloys are used. Another problem is that ferroalloy production normally is an early step in the entire production sequence. Figure 1 suggests that the many uses of silicon make a complete inventory extremely difficult.

For many industrial materials which serve as raw materials for other products and processes, it may be more practical to perform only the inventory step of the LCA, often called a "cradle to gate" analysis or a Life Cycle Inventory (LCI). The LCI may be used as input to LCA for downstream processes and products. In the inventory stage all mass and energy flows through and out of the defined system are identified, quantified and normalized to some reference flow.

An example from the steel industry

Another application of Life Cycle Analysis is as a benchmark between processes. A benchmark is simply a structured comparison to find out if one process is better than another. The International Iron and Steel Institute has collected data from 43 steel plants around the world /4/ showing the energy use in GJ/metric tons of liquid steel. Also listed is the best available current technology as well as what could be achieved in the future. The average energy use today is 15.1 GJ/metric tons of liquid steel. The best present technology is 11.9 GJ/mt, and an ultimate process indicates that 10.4 GJ/mt might be possible. The data set presented in this way enables a steel plant to assess its own performance and examine process changes that may lead to improved the energy use.

Such numbers may be used to evaluate the best technology with respect to environmental impact. As an example, the LCA for steel may be compared with the LCA for aluminum used to manufacture specific products like trains or cars. In the case of an LCA for a train the higher energy required to produce aluminum should be valued against a possible weight reduction and attendant fuel-savings during operation.

Environmental Performance Indicators

For the day-to-day follow up and for communication purposes it may be useful to determine parameters that are of high relevance to the environmental performance. Such parameters are often referred to as Environmental Performance Indicators (EPIs). The EPIs should indicate the significant environmental problem areas, should be easy to interpret, and could serve as a reference point when presenting environmental production performance and development data. The EPIs could be used for environmental education and information at all levels within the organization, as well as for external use in environmental reporting.

The EPI presents the inventory for selected environmental parameters. An EPI may be expressed, for example as kg CO_2/ kg silicon or kWh/kg silicon.

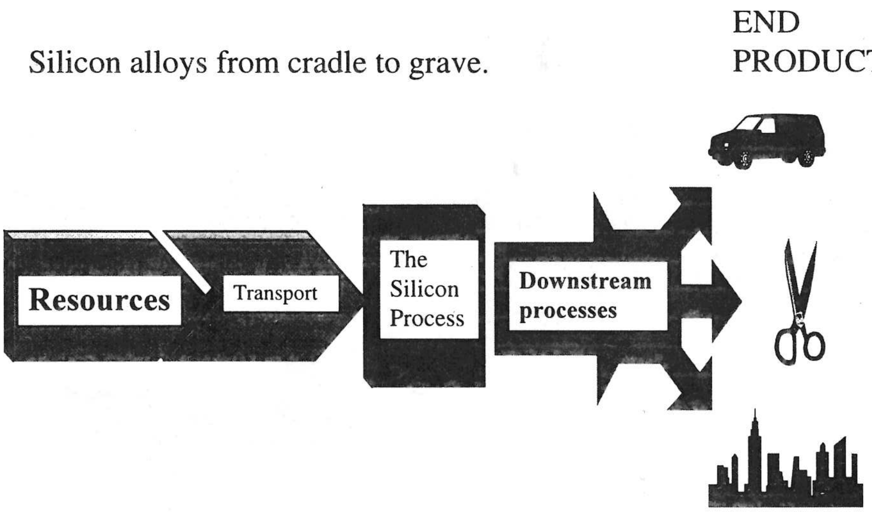

Figure 1 The life cycle of a silicon alloy. The diversification in the use of ferroalloys creates a barrier for a complete LCA-analysis.

The parameters identified as most important EPIs are SO_2, CO_2, NO_x and energy consumption. Figure 2 shows the main environmental challenges for silicon and ferrosilicon production. The ferroalloy process consumes a high amount of electric energy, and the environmental part of the electric energy production should be included.

Pollution aspects regarding the ferroalloy processes

Process emissions are often divided into three main categories, pollution to air, soil, and water. From the silicon process air pollution is probably most significant. On the other hand, an emission to the air may later convert to soil or water pollution. One example of this is sulfur dioxide (SO_2) in the off-gas, which will contribute to acid precipitation and consequently lead to water pollution. The most visible emission from the silicon process is the SiO_2 fume if there is no cleaning equipment. These are very small condensed particles from the process.

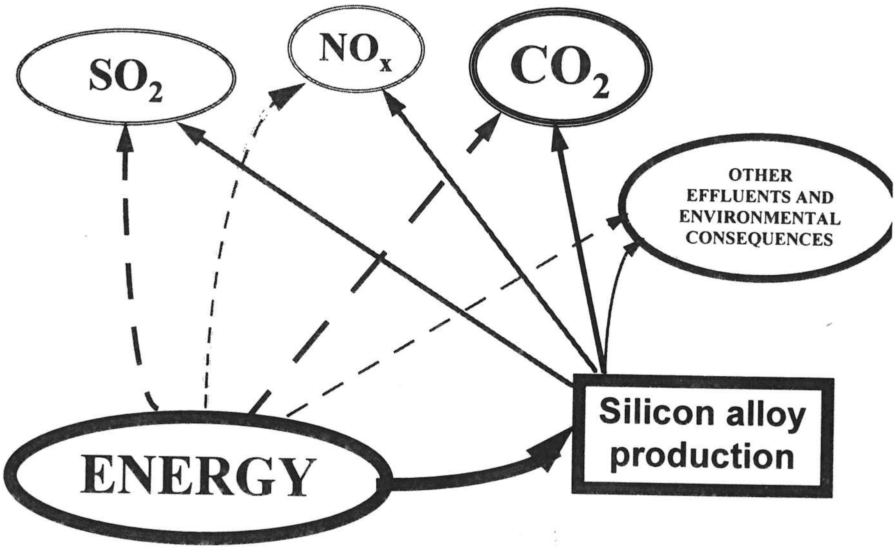

Figure 2 The main environmental challenges in the production of ferro alloys. This may be used for defining Environmental Performance Indicators.

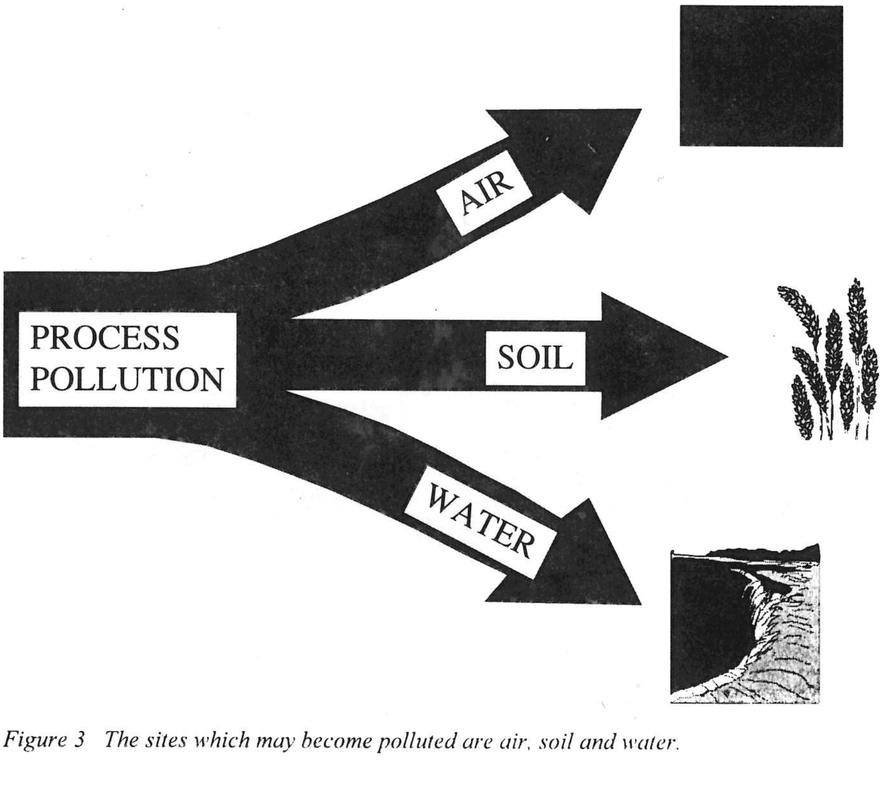

Figure 3 The sites which may become polluted are air, soil and water.

As the fate of the various process streams become known, a mass balance for each element can be an efficient tool to describe the level of pollution. However, this may not always be the case. Some emissions are a result of the process itself and are not dependent on the amount or collection of elements fed to the process. One example concerns NO_x emissions from the silicon process. The amount of NO_x is very small compared with the large amount of nitrogen and oxygen present in the cooling air drawn into the furnace hood.

Sources of pollution

The main sources for pollution in the silicon process are:

- Electric energy delivered to the process. A variety of environmental problems may arise from the production of electricity
- Reduction materials - coke, coal and woodchips. The carbon necessary for the reduction process will inevitably be converted to CO or CO_2 gas. Some minor elements in the ash will be found in the off-gas, slag or in the alloy.
- Quartzite minerals. These silica sources normally contain minor elements besides the SiO_2. Some of these elements may be carried with the off-gas to the environment. Other elements will end up in the metal or slag.

The large amount of air sucked into the hot combustion zone in the furnace may produce nitrogen-bearing gases.

Pollution from the process

In the process itself, the various effluent pollutants can be formed at different stages. Table 2 summarizes the main pollutants and the regions where they are formed in the process. The principal environmental issues related to the process are listed in Table 3.

Pollution to the air

Unwanted discharges to the air tend to be the most common environmental effect of silicon production. This type of pollution consists both of particles from the process as well as gaseous compounds. The main visible effluent is associated with gray silica-particles consisting of approximately 85-95% SiO_2. This dust pollution is normally cleaned in filters connected to the furnace off-gas system.

Table 2 Main process regions where emissions are formed.

Process region	Pollution type formed	Comments
Reaction zone	• Metals with boiling points below the process temperature, approximately 1900 °C. • CO gas • SO_2	In the reaction zone the process will form CO and SiO gases. Low boiling point metals will escape as gases and then condense or oxidize to form impurities in the amorphous silica-dust from the furnace.
Combustion zone	• Amorphous silica particles • Nitrogen-bearing gases • CO_2 gas • Elutriated particles from the raw materials • Carbonaceous soot-formation	In the combustion zone SiO gas oxidizes to form solid amorphous SiO_2-particles. The reaction is vigorous and some nitrogen-bearing gases are formed. The off gas velocity may mechanically entrain some raw material fines into the off-gas.
Cooling water system	• Loss of energy • Hot water pollution	Waste energy from silicon production is normally quite significant. Loss of energy may be considered as a form of pollution. Hot water discharge into surroundings may be unwanted.
Tapping area	• Tapping fumes, mainly amorphous silica-particles • Some slag	The tapping and casting processes may be sources of internal environment problems or waste material generation.

Table 3 The main possible environmental emissions from the silicon process.

POLLUTION TO	Pollution types	Pollution	Geographical Area Impact	Potential Environmental Effect:
Air	Gases	• CO_2 gas • Sulfur-oxides (SO_x) • Nitrogen oxides (NO_x) • Volatile Organic Compounds (VOC)	• Global • Regional/local • Regional/local • Regional/local	• Global warming • Health hazard • Acidification and health impact • Acidification and health impact • Ground near ozone formation
	Oxides	• Visible amorphous silica particles	• Regional/local	• Visual/smoke formation
	Metallic Components	• Mercury and other heavy metals	• Local	• Health hazard
	Others	• Polycyclicaromatic hydrocarbon PAH • Chlorinated Hydrocarbons	• Regional/local • Regional/local	• Health hazard • Severe health hazard, dioxins bioaccumulates in the food chain
Soil		• Small amounts of slag • Disposal from dust cleaning • Conversion of some of the pollutants in the air to soil pollution.	• Local • Regional/local • Regional/local	• Local water/ground pollution • Local water/ground pollution • Local water/ground pollution
Water		• Hot water from the process • SO_2 may lead to acid precipitation • Conversion of air pollutants to water pollution.	• Local • Regional/local • Regional/local	• Increase local water temperature • Acidification • Surface water and ground water contamination

Pollution to the soil and surface and ground water:

The silicon process is, in principle, slag-free and, hence, there should be minimal slag discharge to soil and water. Nonetheless, some minor contamination may occur. Disposal of dust from the filters may lead to water or soil pollution. The formation of skull in a ladle, for example, may create an off-grade mixture of metal refractory which must be disposed. Finally, some of the air pollutants may be carried to the soil or water.

In the case of slag producing ferroalloy processes like the production of manganese and chromium ferroalloys, slag storage and landfills may create pollution to the soil or water. The use of wet cleaning equipment for the off-gas may also create water pollution.

Other possible environmental challenges

There may be other environmental challenges than the main effluents CO_2 ,SO_2 and NO_x which are discussed above.

There have been recent measurements of several possible effluents from different ferroalloy processes in Norway /7/. The program includes the measurement of PAHs, VOCs, mercury and chlorinated hydrocarbons. The results are reported to the State Pollution Control Authority.

Some of the emissions are in very small quantities and may even be difficult to measure. New tests have to be carried out in order to determine the total effluent level from the processes.

Effect of changing process parameters on the degree of pollution:

There exist clear dependencies between process parameters and some types of pollution from ferroalloy production processes. This means that, in some instances, effluents from a process may be reduced by changing process parameters.

The single, most important process parameter is the silicon yield from the ore to the metal. An improved silicon yield will lower the use of carbon materials and electric energy per ton of silicon product. This may lead to a reduction of most of the other parameters mentioned above.

One indirect method to lower the specific energy use is to recover waste energy from the process. Such energy recovery has been successfully demonstrated in several plants /5/.

The formation of NO_x seems to be associated with the oxidation of the SiO gas emanating from the furnace. According to /6/ there seems to be a relationship between the amount of NO_x gas from the furnace and the amount of SiO_2 particles.

The objectives for research work conducted by the Norwegian Ferro Alloy Association are not only to describe the situation and level of effluents, but also to improve basic knowledge about the processes and their environmental impact and hence improve process performance. Such knowledge may lead to a change in process operation and even a future change in process design.

Environmental Performance Indicators for the silicon process

Table 4 presents selected measured parameters for a silicon process /7/.

Table 4 Measured values for selected parameters in the silicon and ferrosilicon process which may serve as Environmental Performance Indicators (EPIs).

Environmental element	Silicon	75% Ferrosilicon
Electric energy	12 MWh/1000 kg Si.	8,2 MWh/1000 kg FeSi
Fossil CO_2	4300 kg/1000 kg Si	2800 kg/1000 kg FeSi
Biological CO_2	1800 kg/1000 kg Si	340 kg/1000 kg FeSi
SO_2	13 kg/1000 kg Si	20 kg/1000 kg FeSi
NO_x	11 kg/1000 kg Si	15 kg/1000 kg FeSi

The environmental effect of the production of the electric energy has to be assessed. All methods of generating electrical energy will affect the environment to one degree or another. The main processes for the electric energy production are:

Renewable energy sources:

- Hydropower - using waterfalls or flowing water
- Other energy sources such as wind, direct sunlight or biological carbon energy.

Non-renewable energy sources:

- Nuclear power from fission of nuclear material
- Coal-powered steam generation
- Natural gas-powered gas and steam generation.

The environmental effects of these generation methods are presented in Table 5.

Table 5 The environmental effects of electric energy generation:

Electric Energy Source	Potential Environmental Problems:
Hydroelectricity	• River dams may degrade biological habitat. • Water loss due to evaporation • Competition with other uses of water resources.
Nuclear electric power	• Nuclear reactor safety concern • Nuclear waste storage
Coal power	• CO_2-emission • Other pollutants as NOx, SOx and ash
Natural gas power	• CO_2-emission
Renewable energy sources	• Local aesthetic or habitat effects • Often low energy output per unit area.

Using the CO_2-emission for coal power the total emission for the production of silicon and 75% ferrosilicon has been calculated by /8/. The results are presented in Table 6.

Table 6 Specific CO_2-emission from ferroalloy processes:

Electric power	Total specific CO_2-emission (kg CO_2/kg alloy produced)	
	Silicon	75% ferrosilicon
Hydro power/nuclear power	4.3	4.4
Gas power	10.6	8.5
Coal power	17.7	13.5

In Table 6 it is assumed that more biological carbon is used in the production of silicon than of ferrosilicon. Some authorities consider that biological carbon does not contribute to CO_2-emission. From a global reference, CO_2-emission from a process using biological carbon combined with hydropower should be very small if there is a balance between the carbon used in the process and the growth of the trees used to produce the biological carbon. The data in Table 6 clearly show the environmental effect of the electric power generation used in silicon production.

This result will also be similar for other pollutants. The coal power industry is working to improve the other environmentally-related problems.

It seems clear that there is a strong link between the energy use and the environment in the production of silicon-alloys. This implies that improving the energy consumption for the silicon and ferroalloy processes is likely to provide a direction for improving the environmental standard for the overall process.

Conclusions

The ferroalloy industry is small compared to the energy industry and the base metal industry. But some of the international agreements like the Kyoto protocol, national policy as well as the industry's own development will effect environmental standards in the ferroalloy industry. This means there is a need for environmental and energy standards for the ferroalloy production industry.

Environmental Performance Indexes and Best Available Technology should be defined and approved by the ferroalloy industry.

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