Influencing the resource requirement in Copper primary production by technique variation

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ABSTRACT

The implemented technology for Copper production has a significant influence on the resource requirement. By using newest technology, the environmental burden of products can be reduced. One way to evaluate the impact is using means of Life Cycle Assessment (LCA). Some initiatives working on LCA have been started in the metal industry in the last years. One of those initiatives is the collaborative research centre (CRC) 525 at University of Technology Aachen and the Forschungszentrum Juelich, Germany, which is dealing with the identification of options for resource-sensitive supply and use of metallic raw materials considering technical developments and economic, social and ecological aims. In this paper, based on the worldwide primary Copper production, the simulation of life cycles from concentrate to cathode production will be presented for different regions (Europe, North America, South America). In order to derive course of actions, which are influencing metallic raw materials, a scenario was developed where different technologies were exchanged (e. g. replacing reverberatory furnace by Outokumpu furnace; replacing Peirce-Smith converter by flash converter) until the year 2015. Possible consequences for the regions of this technology change will be shown for selected parameters (e. g. primary energy, SO_2-emissions, etc.).

INTRODUCTION

The global Copper production differs widely between the individual sites. Not only ore type and composition varies but also the installed technologies and the standard of these technologies. Consequently the potential for technical improvement depends on the region of production. In the report of the World Summit on Sustainable Development from Johannesburg 2002, it is claimed to start actions on all levels to improve the contributions of metals towards a sustainable development. For metals, focus is laid especially on transparency and accountability (1). In order to transfer the theoretical rules into practical purposes, there is a need to develop differentiated rules considering special aspects of the different regions.

Following the concept of regional differentiation, this paper selects as examples the environmental impact of production of Copper cathodes from concentrate in South America and North America, the two biggest producers worldwide and compares it to the European situation. The used technologies, technology standards and concentrate compositions in these regions are considered. The concept of technical progress for cathode production is introduced, giving a detailed description of the expected technical progress until 2015. The approach follows the modelling concept of a process chain analysis.

Due to variation of technology respectively and technology standards several potentials for optimisation can be developed. Using a scenario approach, the impacts of the implementation of modern technical concepts on resource use and emissions are quantified. Differentiated is the technical potential of full capacity replacement by newest technology and the smaller potential of reduced replacement in a certain timeframe, in which implementation is expected with consideration for financial and technical market aspects. This method is internationally accepted for the development description of technical systems and was used by the authors in previous work investigating the Aluminium flow (2, 3). The basis of this work was similar to the CRC 525, a study for the German Copper Industry from 1994 (4). The CRC 525 is the German collaborative research centre for resource-orientated analysis of material flow of metallic raw materials. The research of the last years dealt with the identification of options for resource-sensitive supply and use of metallic raw materials considering technical developments and economic, social and ecological aims.

DEVELOPMENT OF THE PROCESS CHAIN MODEL

The Copper production process is very complex and many production routes are used worldwide. Thus the material flow is separated into single processes, which are presented in Figure 1. To implement the process chain into the model, unit processes must be defined. A unit process describes the smallest section of the process chain for which data was gathered. The developed model includes the process groups: furnace, converter, gas treatment, anode furnace, anode casting, electrolytic refining and leaching SX/EW. Each process group is subdivided into technology related unit processes. For instance the process group “furnace” consists of the unit processes “Outokumpu furnace”, “Reverberatory furnace”, “Mitsubishi”, “Noranda/Teniente” etc. The unit operations are distinguished according to technological differences. The most important input and output flows of the model are also given in Figure 1. Hence the process chain model integrates the three major chains: pyrometallurgical Copper production, hydrometallurgical Copper production and Copper recycling. In Pyrometallurgy, the processes are classified according to the furnace type. In hydrometallurgy a classification is not performed due to missing relevant differences in the process technology. The difference is covered by the considered parameters.

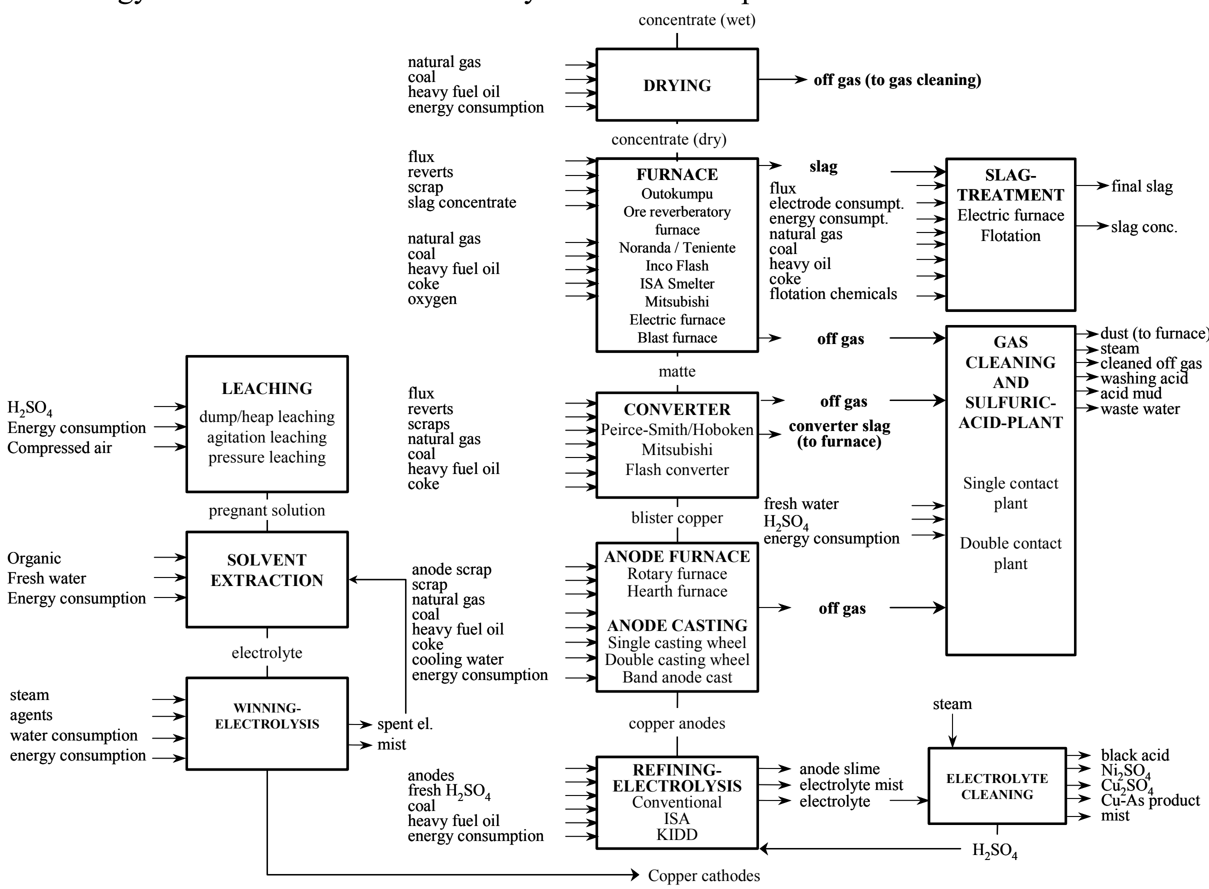

Figure 1: Material flow of Copper cathode production

The major part of the data was collected from literature sources and commercial databases. Most of the published sources refer to data from 2000. Older data (1995-1999) was assumed still to be valid in the case that no newer data was accessible. Nevertheless, complexity of the smelting operations makes data collection difficult. Often only data for the main mass flows respectively components can be found in literature and databases. This leads to an unbalanced situation as for some processes actual data and for other processes only older (more than five years) data was accessible.

The available data are gathered, analysed and modelled using commercial GaBi software (6). Missing data are partly calculated by mass balancing and seldom estimated. Obtained data was then harmonized with industrial partners.

Using this data the different unit operations can be calculated according to the related region. Thus Outokumpu furnace unit operations are obtained for Europe, South America and North America for example. The composition of the input material, material processing, smelting as well as subsequent influencing steps are considered in order to transfer the site-specific data into technique-related average values. The variation of the concentrates is high and depending on the origin mine. Thus the site-specific values are weighted according to the subsequent formula:

$$\text{data}_{\text{weighted}} = \text{data}_{\text{site}} \cdot \frac{\sum \left(\text{content}_{\text{element in concentrate site}} \cdot \text{annual production site}_{\text{cathode copper}} \right)}{\sum \left(\text{annual production}_{\text{cathode copper}} \cdot \text{considered sites} \right)} \quad (1)$$

An example overview of the considered parameters is given in Figure 2 for one unit process. The input and output flows are varying a little related to the unit processes. In principle every mass flow can be modelled if reliable data is available.

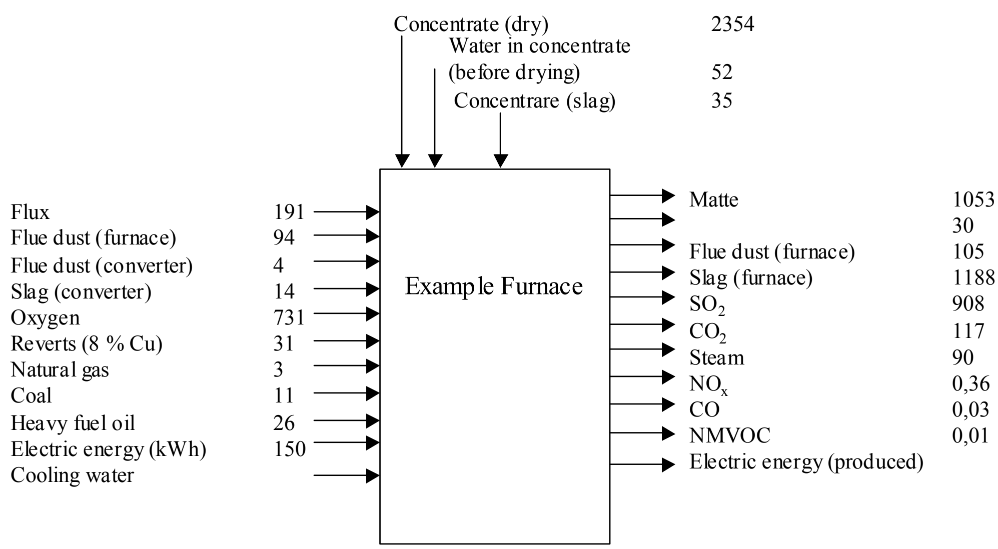

Figure 2: Example for scenario parameters (masses in kg)

Smelting and Refining

All important production routes are considered according to their share on the world production (see Figure 3).

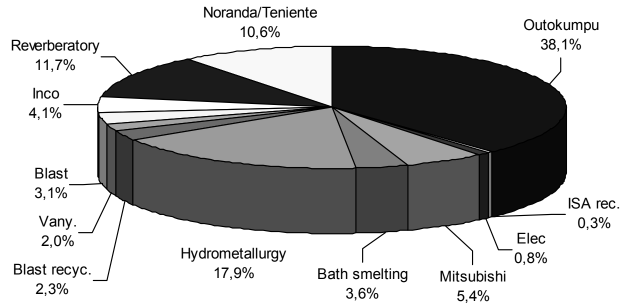

Figure 3: Share of processes on world Copper production 2000

In Table I the coverage of data for the individual technologies in the model is given. For all regions over 60 % of the producing sites are included in the model (year 2000). The distribution of the production processes is varying in the regions (Figure 4). In order to give a proper image of the actual situation a "mean"- regionalized Copper cathode was calculated according to this distribution. In other words a cathode produced in Europe consist of 49 % Outokumpu furnace produced cathode, 18 % reverberatory furnace etc.

Table I -: Technology coverage in Model

Technology	Europe Production [kt/a]			North America Production [kt/a]			South America Production [kt/a]		
	2000	In model	[%]	2000	In model	[%]	2000	In model	[%]
Bath smelting	-			188	188	100%	-		
Blast f. recyc.	273.8	262	96%	-			-		
Blast furnace	354	288	81%	-			-		
Electric furnace	114	114	100%	17.4	0	0%	-		
Inco	-			482	482	100%	-		
ISA recyc.	40	0	0%	-			-		
Mitsubishi	-			146	146	100%	-		
Noranda	-			200	200	100%	-		
Other	210	0	0%	-			-		
Outokumpu 60	952	927	97%	254	254	100%	1100	500	45%
Outokumpu 90	190	190	100%	-			-		
Reverberatory	67	67	100%	400	193	48%	242	0	0%
Teniente	-			-			1025	1025	100%
Sum	2200.8	1848	84%	1687.4	1275	76%	2367	1525	64%

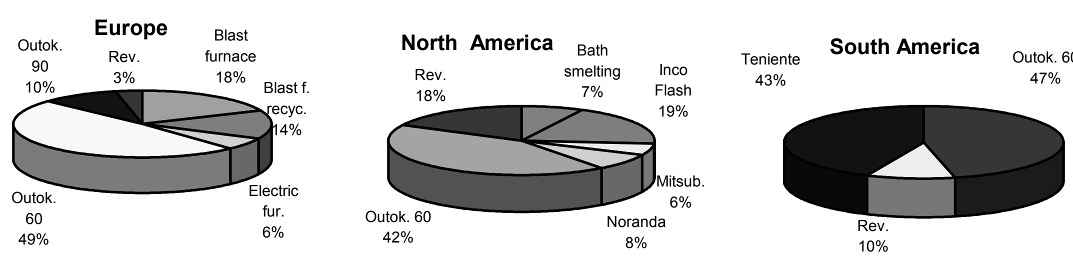

Figure 4: Use of furnaces in different regions

The conventional PS-converter represents this process step for all countries considering the particular region. It is assumed that all sites are operating sulphuric acid plants except reverberatory furnaces. The module of the sulphuric acid plant is equal for all regions neglecting the real situation. As consequence, no regional differences of sulphuric acid production process performances are taken into account. Due to missing information, no credits for steam production are considered. Consequently, the net energy demand for the process could be smaller than assumed. Furthermore credits are not given for the production of sulphuric acid or other by-products (e. g. Gold, Silver). For the pyrometallurgical process step "fire refining" only the rotary furnace could be modelled for each region. One world average module has been calculated for anode casting (process unit "casting wheel").

Electrolytic Refining

The distribution of the electrolytic refining technologies for the regions is given in Figure 5. For KIDD-technology not sufficient data was gathered in order to calculate reliable modules. Thus the data was included into the ISA unit operation. Again the share of different produced cathodes was included in the calculation according to the pyrometallurgical approach using formula (1).

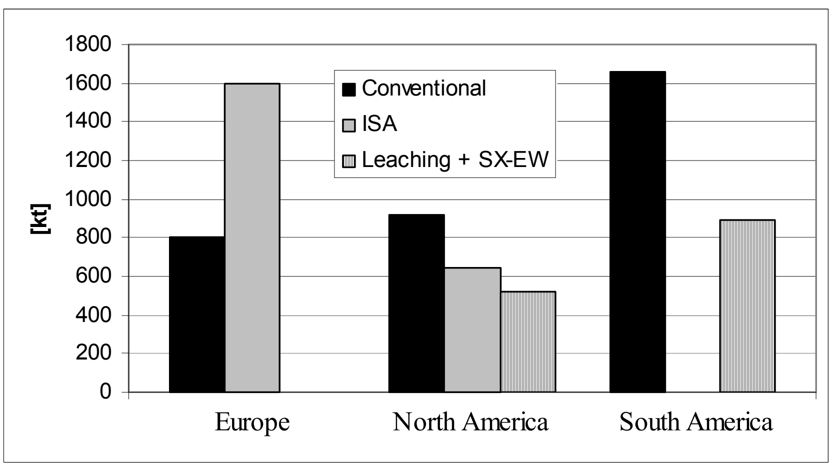

Figure 5: Production of electrolytic refining technologies in different regions

Energy

The calculation of the energy demand is one of the main objectives of most LCI-studies. In each module specific final energy demands (coal, oil, electric power, etc.) are requested. To describe the comparable energy consumptions, all final energies have to be transformed into primary energy values. The transformation factor is depending on the technical status of the energy conversion and supply. Investigating a system including different countries, the specific energy supply situation of each region has to be considered. Data for local overall efficiencies of supply for electric energy and thermal energy carriers are taken from CRC 525. These are highly sensitive assumptions as technical efficiency for electric energy supply differ considerably according to the conversion technology. Table II (left) indicates the specific overall efficiency for the supply of electric power. To assess the thermal energy carrier to a primary energy basis the following overall efficiency of supply parameters for the different energy carriers are considered (Table II, right). No distinctions for different countries are made.

Table II - Specific overall efficiency for the supply of electric energy for the different regions (left) and Overall efficiencies of supply for energy carriers (right) (5)

Europe	0.349
North America	0.318
South America	0.430

Natural gas	0.919
Heavy fuel oil	0.908
Diesel	0.905
Hard coal	0.955
Hard coal coke	0.826
Steam	0.735

SCENARIO DEFINITION

For the chosen regions, the changes in mass and energy flows due to technical progress and innovation and its impacts on the resource requirements were investigated. To separate effects and to distinguish between the maximum and an expected technical progress, a scenario approach is carried out using three levels of innovation:

1. The reference case shows the domestic market supply of Copper cathodes in the three regions for 2000 (including import of blister).
2. In a second case the maximum technical innovation potential through full capacity replacement is calculated considering the entire application of the today applied newest technology (2015 NT) for each process of the 2000 structure.
3. In a third case the expected replacement (2015 expected) is described taking into account financial and market aspects, which will limit realisation of the replacement

NT will replace looking at 2015 as the target year only a part of existing plants. Some plants will be upgraded and others will not be changed at all (2015 expect.). This differentiation is not a model result, but exogenously determined based on expert information. Following the process chain model several assumptions had to be made for the calculations.

Smelting and Refining Scenarios

The Copper mass flows of the regions are modelled by connecting the particular modules representing the 2000 reference year. For the three regions, the amount of imported blister and Copper cathodes is included. For the NT case, it is assumed that Blast, Reverberatory and Electric furnaces will be fully replaced by the technologies with the highest share in the related region and Blast recycling exchanged by ISA recycling furnaces. All other technologies will increase their specific throughput by 10 %. The overall production capacity will be increased by 40 % in 2015 and by 20 % in 2015 expect. corresponding to 2000. It is considered that small production plants with a yearly capacity of less that 150,000 t will be either closed or upgraded until 2015. Reverberatory and Electric furnaces will be fully replaced (e. g. Mitsubishi North America). The assumed share of the different smelting technologies for the three cases is given in Table III.

Table III - Share of Furnace Technologies for Europe, North and South America in Scenario 2000, 2015 NT and 2015 expect. in [%]

	Europe			North America			South America		
	2000	2015 NT	2015 expect.	2000	2015 NT	2015 expect.	2000	2015 NT	2015 expect.
Outokumpu 60	48.8	76.2	64.4	42.7	54.8	54.3	46.5	42.3	44.2
Outokumpu 90	9.7	9.5	12.5						
Reverberatory	3.4			17.5			10.2		
Blast furnace	18.2		8.5						
Blast rec./ISA rec.	14.0	14.3	14.6						
Bath smelting				7.4	11.3	8.7			
Electric furnace	5.9								
El Ten./Noranda				7.8	11.3	13.0	43.3	57.7	55.8
Mitsubishi				5.7		6.5			
Inco				18.9	22.6	17.4			
Total production [kt]	2298	3150	2405	2024	2050	1800	2077	2600	2250

It is assumed that until 2015, flash converters in both cases will cover 10 % of converter capacity. No improvement for the acid production, the rotary anode furnace and the casting wheel until 2015 is implemented. As described the used technologies differ from region to region, e.g. in Europe neither Teniente nor Mitsubishi or Inco technology are operating. The relatively high increase in Europe for 2015 is due to increased recycling capacities, which are expected. Contrary to this situation in North America, the pyrometallurgical share will be constant in 2015 and decrease for 2015 expected as a consequence of increased hydrometallurgical operations. In South America, the expected production will increase slightly for 2015 also because of the hydrometallurgical increase.

Electrolytic Refining Scenarios

In Europe the remaining conventional process is replaced by ISA, whereas in North and South America the increased production is expected to be with ISA technology. Furthermore smaller plants below 100 kt/a are closed or upgraded. For both pyrometallurgical process types (Conv. and ISA) the specific throughput is assumed to increase by 5% until 2015. The performance of the hydrometallurgical route will not be changed due to missing information. Nevertheless, the share in production will alter. In Table IV the shares of the electrolysis technologies and electrowinning are presented.

Table IV - Share of Electrolysis Technologies and Electrowinning for Europe, North and South America in 2000, 2015 NT and 2015 expect. in [%]

	Europe			North America			South America		
	2000	2015 NT	2015 expect.	2000	2015 NT	2015 expect.	2000	2015 NT	2015 expect.
Conv.	36.7			42.4	23.6	21.3	67.0	25.6	25.3
ISA	63.6	100.0	100.0	30.0	54.4	49.2		30.2	28.9
SX/EW				27.6	22.0	29.5	33.0	44.2	45.8
Total production [kt]	2190	3150	2660	2090	3600	2600	2550	4900	4600

SX/EW is commonly used in South and North America. A further significant increase of existing plants capacities is expected especially for South America. Additionally new plants will be realised in the next years. In Europe no SX/EW is used and also in future there will be no SX/EW.

RESULTS

Using the process chain model inputs and outputs and according changes in the three scenario cases are calculated. For all three regions the primary energy demand is investigated. Also, selected output parameters namely CO_2 and SO_2 emissions and the production of sulphuric acid are taken into account. The chosen parameters are covering the most important aspects related to the Copper production. Additional parameters are easily derivable from the database.

Primary energy demand

The energy demand is one major parameter to represent technical progress. In Table V the resulting energy consumption of the relevant energy carriers are listed comparing the scenario cases. It shows the different use of energy carriers in the three regions but also a shift of energy types within the three cases. While most of the demands for final energy in Europe decline between the 2000 and 2015 scenarios, the demand for heavy fuel oil and electric power increases in the expected case. In contrast for North American the demand for heavy fuel oil decreases significantly. In South America natural gas is even totally substituted due to the replacement of the reverberatory furnaces. In contrast the natural gas demand increases for North America. The reason for the higher electric power demand for North America and South America compared to Europe lies in the application of SX/EW technology, which has a higher specific energy demand than the pyrometallurgical processing.

Table V: Final energy demand for the different regions considering the three scenario cases

[MJ/$t_{cathodes}$]	Europe 2000	Europe 2015 NT	Europe 2015 expect.	North America 2000	North America 2015 NT	North America 2015 expect.	South America 2000	South America 2015 NT	South America 2015 expect.
Steam	1430	620	600	1180	780	700	730	470	450
Hard coal	310	40	50	500	360	350	330	50	20
Hard coal coke	1590	750	1140	130	190	210	0	0	0
Heavy fuel oil	3330	3020	3700	350	10	20	5600	3280	4830
Natural gas	1670	960	1320	1540	1850	1790	30	0	0
Electric power	1470	1440	1590	3460	3030	3560	4120	4310	4360

To compare the energy consumption of the various regions, as discussed in the previous chapter, the final energy values must be converted into a primary energy demand. Figure 6 shows the absolute values of primary energy demand of the different scenario calculations. As could be expected, the improvements in the NT case are bigger than those, which can be, expected due to a reduced replacement of old technology.

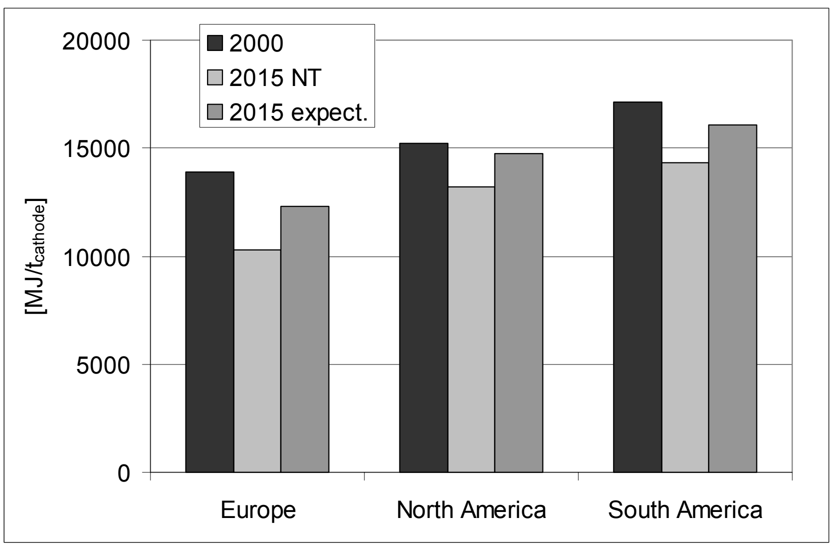

Figure 6: Primary energy demand for Copper production in three scenario cases

The European system has the smallest primary energy demand with nearly 14 GJ/$t_{cathodes}$ in 2000. Nevertheless, the reduction potential to the 2015 cases is the highest. For the NT case the energy demand is assumed to go down by 26 % to 10 GJ/$t_{cathodes}$ and for the 2015 expect. case to 12 GJ/$t_{cathodes}$ (11 %).

The primary energy demand for North America is higher than the European demand but smaller than that for South America for all three cases. The expected reduction is only 3 % and the maximum reduction potential is modelled to be 13 %. This is mainly due to the increasing share of electrowinning. South America has the highest primary energy demand. The demand in the NT case is still higher than that for the current European situation.

The use of the process chain model also allows the distinction between the process steps. In Figure 7 the share of the process steps in the overall primary energy demand is described.

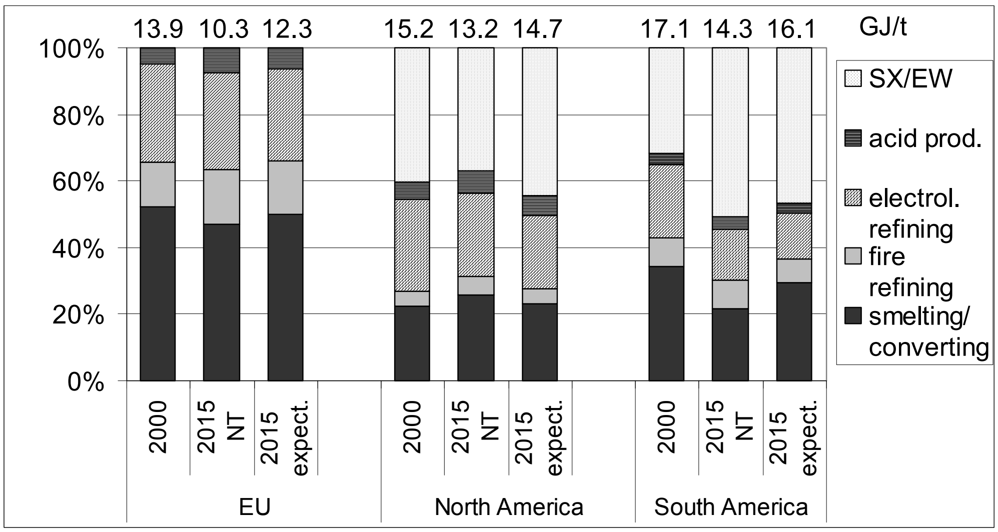

Figure 7: Share of different process steps in the primary energy demand for the different regions

In the European system the smelting and converting process step has the highest share of nearly 50 % followed by the electrolytic refining. The increasing share of fire refining and acid production is due to the missing performance in these steps assumed in the model. The North and South American systems show the importance of the hydrometallurgical route. Although less than 30 % is produced following these routes in North America, about 40 % of the primary energy is demanded. For the NT case the hydrometallurgical production will go down to 22 %, which leads to an increase of the share of the pyrometallurgical processes.

In South America the production share of electro winning is even higher than in North America (33 – 46 %), nevertheless the primary energy demand is comparable to the North American system. This is caused by a higher energy demand of the pyrometallurgical processes in South America, also yielding in the higher overall demand.

CO_2 Emissions

Close related to the energy demand is the discussion about CO_2 emissions. It must be distinguished between those emissions that are directly related to the processes and those related to the energy supply. The first can be influenced by the Copper industry itself, by selection of technology or handling of the processes. The second can only be influenced indirectly by alternation of the energy supplier. Figure 8 describes the CO_2 emissions connected to the domestic supply of Copper cathodes for the three regions, distinguishing between direct and indirect determined emissions.

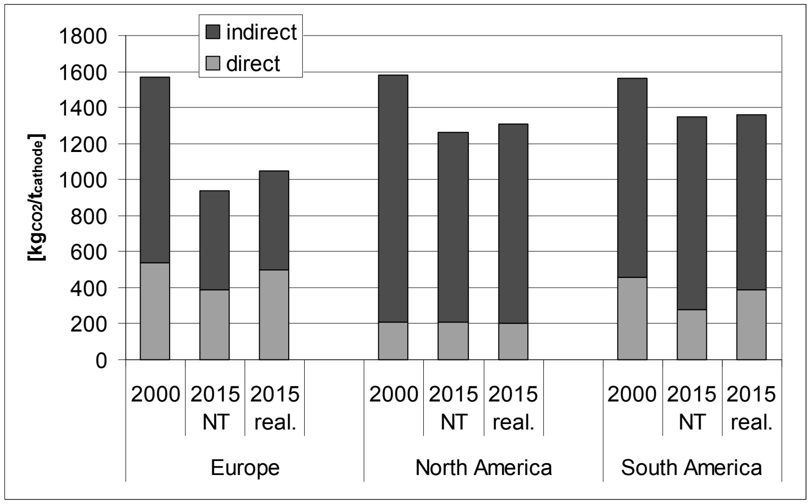

Figure 8: Directly and indirectly determined CO_2 emissions for the different regions

It can be seen that the share of the indirect determined CO_2 emissions is in all three cases and all three regions dominating. This is especially conspicuous for North America. It is strongly connected with the electric energy demand due to hydrometallurgical processes, which is consumed in both American regions. Again, it can be shown that in Europe the improvement potential is significantly higher than in the other regions and that it will be mostly implemented until 2015.

Sulphuric acid and SO_2 emissions

The increasing awareness for environmental protection has lead to a high sensitivity towards the emission of sulphur dioxide. A high share of plants in the world already uses sulphuric acid production. In Europe the coverage is 100 %. In Table VI the calculated results for the production of H_2SO_4 and the related emission of SO_2 after H_2SO_4 production is illustrated. The production of sulphuric acid is representing the net production of acid considering the demand of sulphuric acid for the hydrometallurgical route.

Table VI: Emitted SO_2 and net sulphuric acid production for the different regions in [kg/$t_{cathodes}$]

	Europe			North America			South America		
	2000	2015 NT	2015 expect.	2000	2015 NT	2015 expect.	2000	2015 NT	2015 expect.
H_2SO_4	1600	1790	1750	1290	1510	1390	1180	930	580
SO_2	3.6	1.5	1.9	51.6	0.7	0.7	44.3	2.1	1.8

The relative small output of SO_2 in North America for 2015 and 2015 expect. compared to Europe is due to the high share of hydrometallurgy. In South America the higher share of hydrometallurgy for 2015 leads to a higher SO2 output in comparison to 2015 expect. The capture of SO_2 in Europe in 2000 is already quite high. For the year 2015, it is assumed that sulphuric acid plants will be installed in all regions with 100 % coverage. Therefore, the acid production will increase. The reduction in net H_2SO_4 production for South America is due to an increase of hydrometallurgical cathode production that needs sulphuric acid as an input.

SUMMARY AND CONCLUSION

This study shows the calculated influence of technique variation according to resource requirement in Copper primary production. As an example, the production of Copper cathodes is modelled in Europe, South America and North America in order to reduce the complexity of Copper production. The method of technical progress has been introduced, giving detailed description of expected values until the year 2015. The approach followed the modelling concept of a process chain analysis. The process chain for Copper production was modelled using both industrial and literature data. Modelling was performed using unit processes as smallest process chain steps. With the collected data 84 % of Copper production in Europe was covered for year 2000, whereas for North America 75 % were reached respectively 64 % for South America. Using a scenario approach and differentiating between the maximum and predicted technical potential the impacts of the implementation of modern technical concepts on resource use and emissions were quantified. Three cases were defined. The first case covered the reference year 2000 showing the domestic market supply for Copper in the three regions. In a second case the maximum technical potential through full capacity replacement has been calculated considering the exclusive application of newest technology for each process of the 2000 structure. In a third case financial and market aspects were taken into account, which leads to a partial replacement respectively upgrading of the existing plants. Depending on plant capacity and used technology some sites are closed. Additionally new plants are implemented in order to consider the increasing Copper production.

The European system has the biggest reduction potential for primary energy demand although starting from the lowest value. This reduction potential is only due to the replacement or improvement of the smelting/converting and electrolytic replacement. This leads also to the highest reduction potential in CO_2 emissions. Although most of the reduction is connected with electricity production and can only be influenced indirectly by the Copper industry. For the American systems the importance of the hydrometallurgical processing becomes obvious. About 40% of the primary energy demand is due to this processing route. In North America the reduction potential of SO_2 is the highest. Showing a decrease in emitting SO_2 in South America also, the net production of sulphuric acid declines due to the increase/consumption in hydrometallurgical processing. South America needs most of the primary energy for production of Copper cathodes. While current CO_2 emissions are nearly the same in all regions the reduction potential for the American systems is smaller due to increasing electricity consuming SX/EW processes.

However the principle functionality of the model has been shown. The calculated results are in the range of comparable studies. The reduction potentials for the three regions have been shown. Thus the model may be used in order to predict possible trends in Copper production as well as to demonstrate applications where the production may be influenced. Nevertheless the results must be treated carefully as several assumptions were made as well as certain data gaps exist, which leads to an uncertainty. In order to obtain improved and more reliable results the handling of ore concentration, credit for steam and other by-products should be considered. Due to the July 2003 stopped financial support of the formerly funding organisation the continuing research work in Aachen will be unfortunately very limited.

ACKNOWLEDGEMENTS

The authors are members of the German Collaborative Research Centre 525 "Resource-orientated analysis of metallic raw material flows", established in 1997. The integrated approach of the CRC 525 offers the opportunity to address and cope with these challenges by supporting sustainable development-based decision-making. The target of the research program is the identification of options for resource-sensitive supplying and processing of metallic raw materials in the area of conflict of technical developments and economic and ecological aims. An integrated resource management system for important metallic raw materials is to be designed and tested by the CRC 525. Thanks are due to the German Research Council (DFG) for financial support.

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