RESOURCE CONSERVATION BY IMPROVEMENTS OF PRIMARY ALUMINIUM PRODUCTION

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Abstract

This paper presents the balance of mass flows due to the primary aluminium production from bauxite to molten metal and the identification of optimisation potentials. To balance the mass flows and energy requirements of the worldwide aluminium production the developed process chain is divided into technique specific modules. There are nearly 70 alumina refineries with a total capacity of 56 Mt/a of alumina and nearly 200 smelters with a total capacity of 26 Mt/a of aluminium in operation. Different smelter technologies are classified in terms of the specific energy demand, anode consumption and emissions like fluorides or SO_2. The specific electrical energy requirements for electrolysis range from 13.0 to 17.5 kWh/t of molten aluminium with a capacity weighted average of 14.9 kWh/t. Two case studies show that by an increase of the annual aluminium production of 8 Mt, the specific energy requirement will decrease to 14,1 kWh/kg Al due to the installation of new smelters and changes in the applied technology.

Introduction

Further developments of industrial sectors like aluminium production are often the subject of investigation. For a known market growth rate, future production can be extrapolated for years or decades. This is much more difficult to predict for technical progress, especially when considering technical and environmental aspects in the understanding of sustainable developments. Furthermore, technical progress is different for different steps of a process chain and for different locations and its application is not predictable generally. Nevertheless realistic assumptions for future technology can be made, when the estimation of the maximum technical potential, which is known today in every process step is divided from the forecasting of its application in a certain time. Then the combination of them together with site-related analysis could give reliable results. This paper will give an overview of energy and raw materials demand and process-related emissions of processes during aluminium production. Furthermore, the impact of progress and change in aluminium electrolysis is analysed in two case studies in terms of energy demand, anode consumption and emissions of CO_2, CF_4/C_2F_6, global warming potential and SO_2.

Alumina production by the Bayer process

Today the total capacity of alumina refineries approaches 56,326,000 t Al_2O_3, compared to a production of 46,379,000 t in 1997 and 41,745,000 t in 1994. The distribution of bauxite type used for alumina production, determined by the predominant alumina bearing mineral, in 1994 is shown in Table I [1, 2, 3].

Table I: Alumina production in % from ore type [1]

Bauxite type	Share of world alumina production (%)
Gibbsitic	54
Boehmitic	30
Diasporic	11
Nephelin (+ Alunite)	5

The type of bauxite determines the process technology from which the following results could be estimated:

Table II: Alumina production in % according to process technology [1]

Bauxite type	Share of world alumina production (%)
Bayer LTD & AD	48
Bayer HTD & Sweetening	12
Bayer HTD (partly with lime)	18
Bayer & soda lime sintering	17
Nephelin (+ Alunite) sintering	5

LTD: Low Temperature Digestion
AD: Atmospheric Digestion
HTD: High Temperature Digestion

Energy requirements for the Bayer process

Detailed data are not available relating to the average energy consumption of the different types of alumina plants. Table III shows the energy consumption of five different alumina plants. It can be seen that it is possible to reduce the energy consumption to 5.1 MJ/kg Al_2O_3 by using a tube digester, which has been in operation for 25 years in Stade, Germany. Despite of its advantages this technology is applied very rarely. Natural gas (40 %) as well as fuel oil (38 %) are the typical energy sources for the Bayer Process.

Table III: Energy requirements (MJ/kg Al_2O_3) for some alumina refineries [1]

Plant	Digestion	Evaporation	Others	Total	%
Stade	3.5	0.5	1.1	5.1	100
Wagerup	2.5	2.5	3.2	8.2	160
Gove	2.5	2.5	3.2	8.2	160
Damanjodi	1.4	3.6	4.7	9.7	190
HTD Autocl.	4.0	3.0	3.0	10.0	196

Calcination of alumina

The aluminium hydroxide produced in the Bayer process has to be calcined to aluminium oxide. This is done in stationary fluid bed calciners and rotary furnaces. An average of 4.8 MJ/kg Al_2O_3 is required for calcination in the rotary furnaces and only 3.3-3.1 MJ/kg in the stationary furnaces. Natural gas as well as heavy fuel oil can be used for the calcination. The share of rotary and stationary furnaces according to the total worldwide installed capacity is not well known, but we assume that one third of the alumina is calcined in rotary furnaces and two thirds in the stationary type. According to the data above, the world average energy consumption from both stationary as well as rotary furnaces is 4.3 MJ/kg Al_2O_3, amounting to 130 % of today's applied technical minimum.

Aluminium electrolysis

In 1997 there were worldwide nearly 200 smelters in operation with a total capacity of 26 Mio. t/a, of which the greatest is the Bratsk smelter in Siberia (800,000 t/a) and the smallest one (in the western world) the smelter at Kinlochleven, Scotland (11,000 t/a). The latter was shut down in the summer of 2000. Furthermore some 5,000 t/a or even smaller smelters exist in the PR China.

Different smelter technologies were examined with respect to the specific energy consumption and anode consumption as well as to emissions of CO_2, fluorides, SO_2 and CF_4/C_2F_6.

Aluminium smelting technology can be roughly divided into five different technologies:

- HSS: Horizontal Stud Söderberg
- VSS: Vertical Stud Söderberg
- SWPB: Side Worked Prebake
- CWPB: Centre Worked Prebake (with centre brake bar system for alumina feeding)
- PFPB: Point Feeder Prebake (with point feeder technology for alumina feeding)

Even at the same smelter location different technologies have been applied in different pot lines, e.g. at the smelters at Kurri Kurri in Australia and Sorocaba in Brazil.

For an analysis of current and future energy requirements and mass flow, considerable data on smelters around the world have been collected and analysed. Further, each smelting technology mentioned above has been divided into three categories of technical standard: Old Technology (OT), Present Technology (PT) and Newest Technology (NT). Criterion for the classification was purely the electrical energy requirement, following Table IV. Smelters for which the energy requirements were not available, were appointed to these technical categories using other criteria, such as start-up. Smelters, for which the technology was not available, were not examined and excluded from the following analysis. These are predominantly small smelters in PR China. With regard to the old technologies used in PR China smelters up to the present, the results on this analysis seem to be moderate.

Table IV: Energy requirements of different technical smelter categories

	Old Technology (OT) kWh/kg Al	Present Technology (PT) kWh/kg Al	Newest Technology (NT) kWh/kg Al
HSS	> 16.5	16.5 -> 14.5	≤ 14.5
VSS	> 16.5	16.5 -> 14.0	≤ 14.0
SWPB	> 15.5	15.5 -> 13.5	≤ 13.5
CWPB	> 15.5	15.5-> 13.5	≤ 13.5
PFPB	> 14.5	14.5 -> 13.5	≤ 13.5

By following these criteria, in 1997 a smelting capacity of nearly 22 Mt was analysed.

Table V: Installed capacities for each technical category and share of world production

Technology	Technical category	Capacity (t/a)	Share of total production (%)
HSS	OT	1,204,000	5.5
	PT	779,000	3.5
	NT	--	--
VSS	OT	1,916,000	8.73
	PT	2,698,000	12.3
	NT	--	--
SWPB	OT	--	--
	PT	1,455,000	6.6
	NT	572,000	2.6
CWPB	OT	1,060,000	4.8
	PT	2,165,000	9.7
	NT	--	--
PFPB	OT	2,106,000	9.6
	PT	4,502,000	20.5
	NT	3,485,000	15.9
Total		21,944,000	100.0

The electrical energy requirements and demand of anodes for each technical category and the total averages, weighted by the production, are listed in Table VI. Figure 1 shows the comparison of production share and energy requirements for each technical category in 1997.

Table VI: Installed production of each technical category and share of world production

Technical category	Elec. energy demand (kWh/kg Al)	Net anode consumption (kg/t Al)
HSS-OT	17.1	536
HSS-PT	14.9	557
VSS-OT	17.1	572
VSS-PT	15.8	529
SWPB-PT	14.5	427
SWPB-NT	13.2	409
CWPB-OT	16.4	474
CWPB-PT	14.7	431
PFPB-OT	15.1	436
PFPB-PT	14.0	426
PFPB-NT	13.3	410

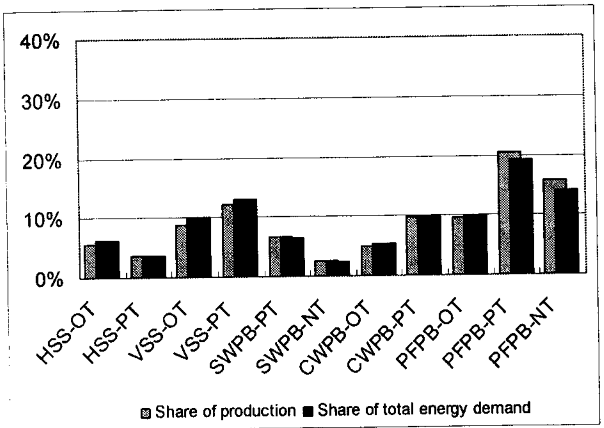

Figure 1: Share of production and total energy requirement for different technical categories of Al electrolyses cells in 1997.

Electrical energy case study 1 for the year 2010

To answer the question, how much energy will be required for each kg of aluminium in the future, some boundary conditions have to be defined.

Between 1997 and 2003 some smelters already have or will restart their shut-down capacities, also some new smelters have come online, or will go online until 2003 (e.g. the Alma project of Alcan, the Ikot Abasi smelter in Nigeria or the Maputo smelter in Mozambique). Some other smelters will shut down their capacity (e.g. Isle Maligne in Canada). This will result in an increase of worldwide primary aluminium production of 3 Mt/a. Beside these changes we assume an increase of primary aluminium production worldwide of another 3 Mt/a before 2010, so that the total aluminium production will increase from 22 Mt in 1997 to 28 Mt in 2010, resulting in a yearly increase of nearly 2 %. This seems to be a moderate and conservative value in comparison to other studies. It is assumed that the new projects will be exclusively PFPB-NT technology. Furthermore, we assume that the other smelters will not change technology and energy requirements.

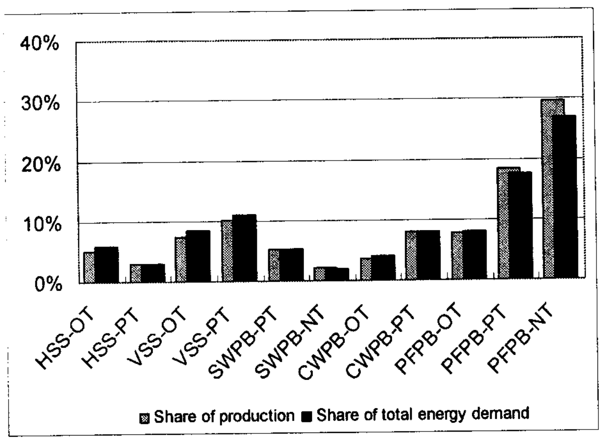

Figure 2: Share of production and total energy requirement for different technical categories of Al electrolysis cells in 2010 according to case study 1.

Under these conditions, the average electrical energy requirements will decrease from 14.9 kWh/kg in 1997 to 14.6 kWh/kg in 2010 (amounting to 98.2 % of the 1997 value), caused only by the installation of new smelters and shut- down of some smaller less efficient capacities.

The relationship of production and energy requirements for this case study 1 is shown in figure 2.

Electrical energy case study 2 for 2010

What is the impact if the technology in the existing smelters changes? It seems most likely that smelters will optimise their operation and decrease their energy consumption by installation of automatic pot control or optimisation of the manual work at the pots, in order to minimise direct costs further

We assume that all changes from 1997 to 2010 will take place as described in the case study 1. Additionally, some smelters will change their technical categories shown in Table VII. These changes consider that it is not possible to change the pot type from HSS or VSS to PB technology without accepting and paying for substantial changes in the superstructure of the pot. It is also difficult to change from SWPB to PFPB, but easier to change from CWPB to PFPB technology. Moreover, it is difficult, or impossible, to decrease the energy demand of PFPB-OT/PT to the demand of a large, magneto-hydrodynamic compensated cell typical of the PFPB-NT technology.

Table VII: Change of technical categories of Al electrolysis cells in case study 2

1997	HSS-OT	VSS-OT	SWPB-OT	CWPB-OT	CWPB-PT	PFPB-OT
2010	HSS-PT	VSS-PT	SWPB-NT	PFPB-PT	PFPB-PT	PFPB-PT

These changes result in a decrease of the average energy demand to 14.1 kWh/kg Al (or 94.9 % of the 1997 value).

Figure 3 shows the share of production and energy requirements for each technical category in 2010 according to case study 2.

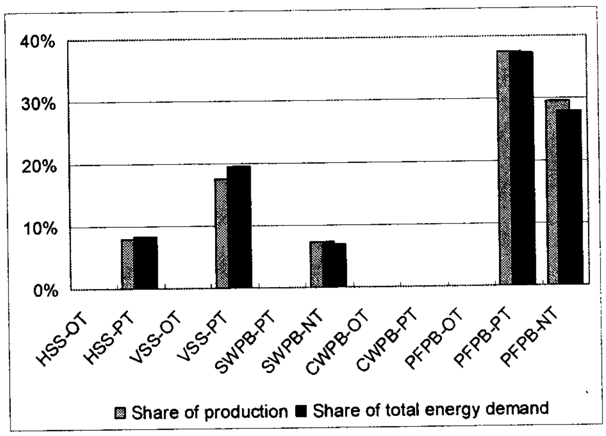

Figure 3: Share of production and total energy requirements of different technical categories of electrolysis cells in 2010 according to case study 2.

Anode consumption (status and case studies)

The average anode consumption in 1997 is 463 kg/t Al (Söderberg and Prebake). Generally, the share of anode consumption is higher for Söderberg technology and less for Prebake technology compared to their share of production (excluded for CWPB-OT, but there are few data available). This situation does not change in case studies 1 and 2. The average anode consumption will decrease in case studies 1 and 2 to 424.1 and 415.6 kg/t Al, respectively, amounting to 98.1 % and 96.9 % of the 1997 value.

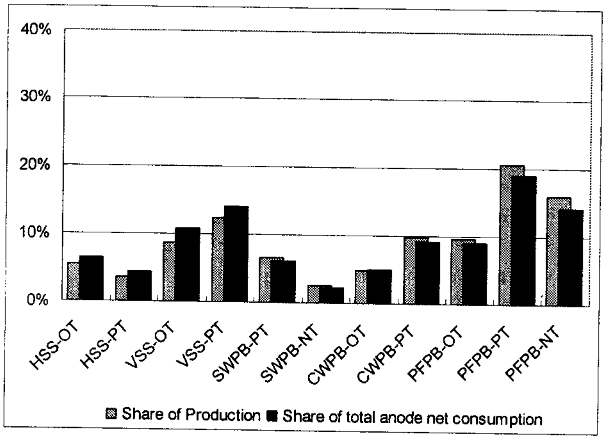

Figure 4: Share of production and total anode consumption of different technical categories of Al electrolysis cells in 1997.

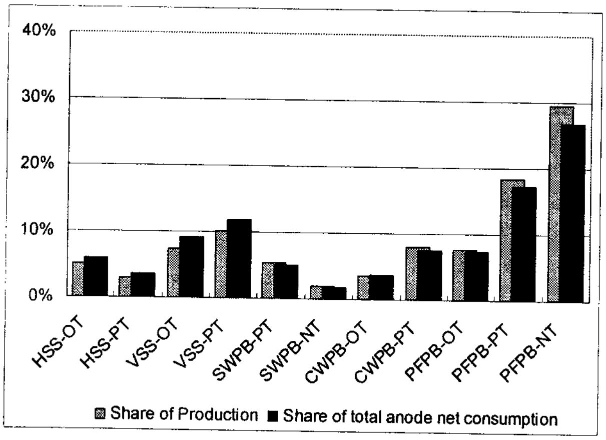

Figure 5: Share of production and total anode consumption of different technical categories of Al electrolysis cells in 2010 according to case study 1.

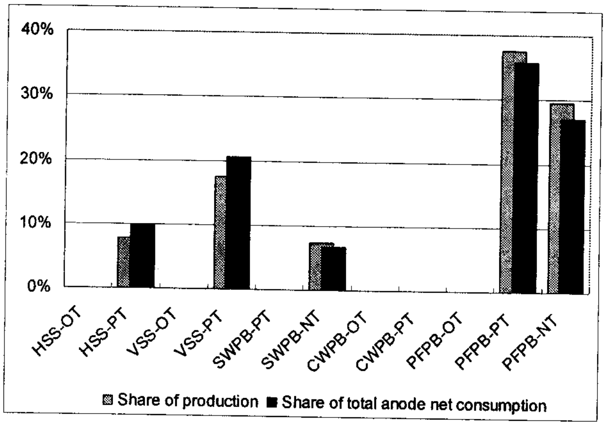

Figure 6: Share of production and total anode consumption of different technical categories of Al electrolysis cells in 2010 according to case study 2.

Emissions of greenhouse gases

CF_4 emission in 1997

What amount of CF_4/C_2F_6 is emitted today from primary aluminium smelters?

CF_4 and C_2F_6 are emitted from electrolysis cells only during the so-called anode effect. The specific amount of the emissions depends of the anode effect frequency, duration of the anode effect, cell amperage and current efficiency. We assume that the different technical smelter categories lead to the following specific amounts of CF_4/C_2F_6 emitted to the atmosphere. The data were taken from [4, 5] and modified.

Table VI: Specific emissions of CF_4/C_2F_6 caused by different technical categories of Al electrolysis cells

Technical category of Al electrolysis cells	CF_4 (kg/t Al)	C_2F_6 (= 10% of CF_4) (kg/t Al)
PFPB-NT	0.05	0.005
PFPB-PT	0.30	0.030
PFPB-OT	0.50	0.050
CWPB-PT	0.30	0.030
CWPB-OT	0.50	0.050
SWPB-NT	0.70	0.070
SWPB-PT	1.20	0.120
VSS-PT	0.55	0.055
VSS-OT	1.10	0.110
HSS-PT	0.07	0.007
HSS-OT	0.40	0.040

In 1997 primary aluminium smelters emitted 10,032 t of CF_4 and 1,003 t of C_2F_6, corresponding to an average specific emission rate of 0.46 kg/t Al. The comparison of CF_4 emissions and total Al production shows that some technical categories emit much more CF_4 compared to their share of production, especially VSS-OT, SWPB-PT and PFPB- PT.

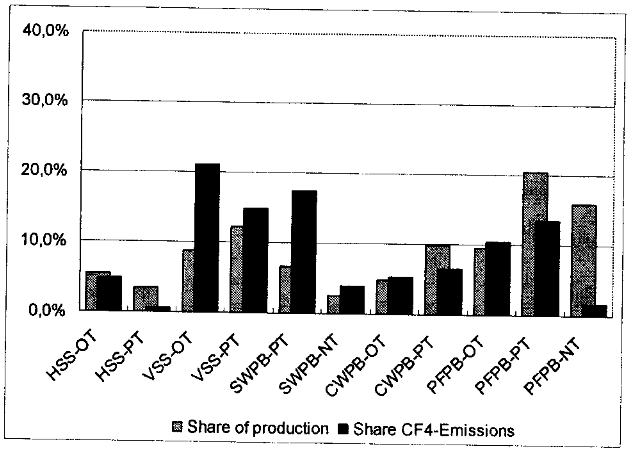

Figure 7: Share of production and total anode consumption of different technical categories of Al electrolysis cells in 2010 according to case study 1.

CF_4/C_2F_6 emission case study 1 for 2010

How much will the emissions of CF_4/C_2F_6 change by 2010?

Under the conditions outlined in the **electrical energy case study 1** described above, the total emitted amount of CF_4/C_2F_6 will increase to 10,907 t/a CF_4 by 2010, representing an increase of 8.7 % of the total amount in 1997. The specific emitted amount will decrease to 84.8 % of the 1997 value, or 0.39 kg/t Al of CF_4. The comparison of production and emission share with respect to technology is only slightly different to 1997.

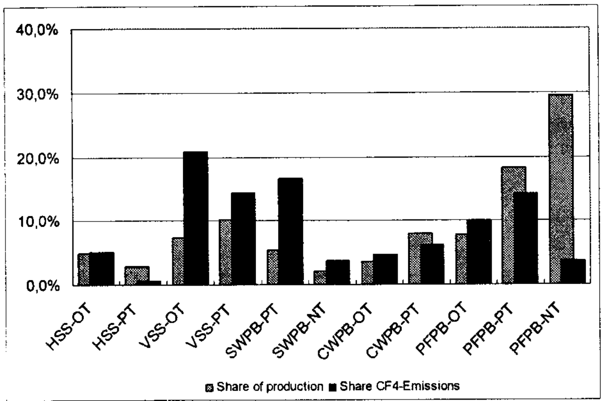

Figure 8: Share of production and total CF_4 emissions of different smelter categories in 2010 according to case study 1.

CF_4/C_2F_6 emission case study 2 for 2010

Under the conditions outlined in **electrical energy case study 2** described above, the total emitted amount of CF_4/C_2F_6 will decrease to 7,914 t/a CF_4 by 2010, corresponding to a decrease of 21.1% of the total amount in 1997. The specific emitted amount will decrease to 60.9 % of the 1997 value or 0.28 kg/t Al of CF_4.

Figure 9 shows that nearly 35 % of the total amount is emitted from the VSS-PT pots, which produce only 17 % of the aluminium. On the other hand, the PFPB-NT pots produce nearly 30 % of the world aluminium production and emit only 5 % of the total CF_4 amount. This is mainly due to an ongoing reduction of the number of anode effects extending almost to 2010.

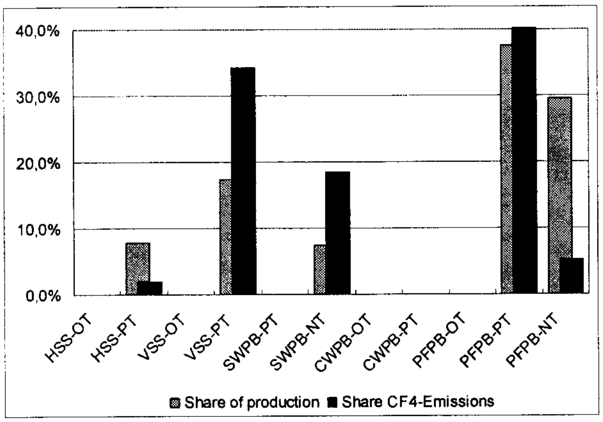

Figure 9: Share of production and total CF_4 emissions from smelters of different technical categories in 2010 according to case study 2 .

Comparison of CF_4/C_2F_6 and CO_2 emissions

The GWP of CF_4/C_2F_6 is very high, at 6,500 and 9,200 times that of CO_2, respectively, on a 100 year basis.

It can be seen from figure 10 that the share of greenhouse gases emitted from the smelters depends on technical category and differs from their share of production. The most critical seems to be the smelters of VSS-OT and SWPB-PT technical categories. Their share of greenhouse gas emissions is twice as large as their share of production, most of it coming from CF_4.

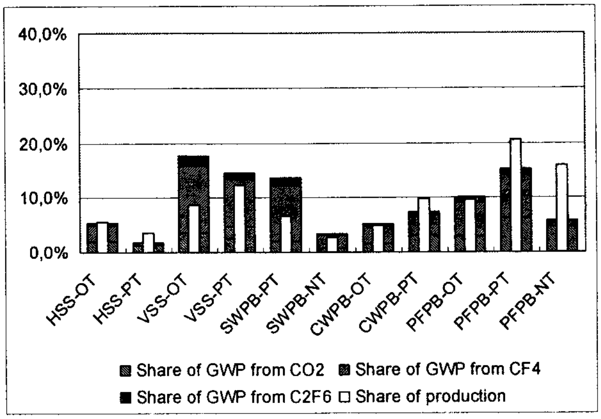

Figure 10: Share of production and emissions of CO_2 and CF_4 caused by different technical smelter categories in 1997.

An average of 5.1 t/t Al of GWP is emitted from aluminium smelters, including 1.7 t directly as CO_2 from consumption of the anode.

What will happen by 2010?

Emission of GWP gases case study 1 for 2010

Under the conditions of case study 1, with no change of smelter technology and an additional production of 5 Mt/a Al the production share of PFPB-NT smelters will increase to nearly 30 %. There is little difference in the share of production and GWP emissions, compared with the situation in 1997.

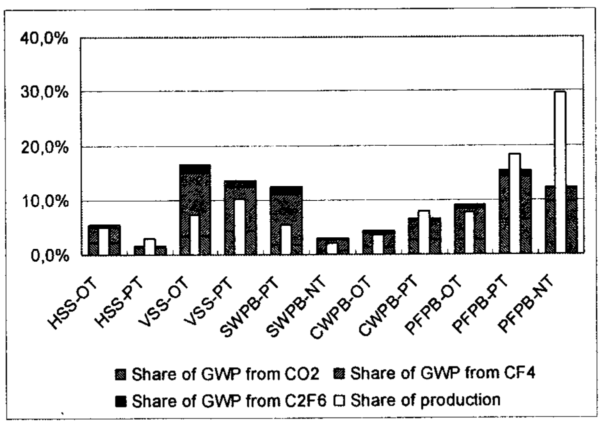

Figure 11: Share of production and emissions of CO_2 and CF_4 caused by different technical smelter categories in 2010 according to case study 1.

The total amount of GWP emitted from smelters increases to 114.4 % of the 1997 value. Certainly the specific amount of GWP emitted decreases to 4.5 t/t Al corresponding to 89.2 % of the 1997 specific value, including 1.7 t/t Al directly as CO_2 arising from anode consumption.

Emission of GWP gases case study 2 for 2010

In case study 2 there is an assumed change in the smelter technology, so aluminium is only produced by smelters in the

HSS-PT, VSS-PT, SWPB-PT, PFPB-PT and PFPB-NT categories.

The total amount of GWP emitted from smelters decreases to 94.0 % of the 1997 value. The specific amount of GWP emitted decreases to 3.7 t/t Al corresponding to 73.2 % of the 1997 specific value, including 1.6 t/t Al directly as CO_2 from anode consumption.

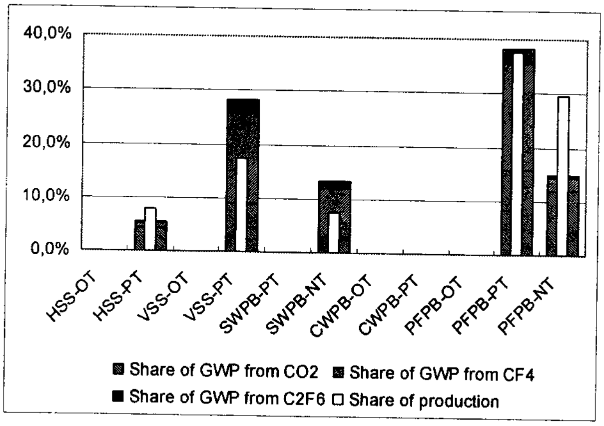

Figure 12: Share of production and emissions of CO_2 and CF_4 caused by different technical smelter categories in 2010 according to case study 2.

CO_2-emissions caused by anode production

The production of prebaked anodes causes emissions of GWP gases, in particular CO_2 from the combustion of baking furnace fuel. In 1997 8.7 Mt of anodes were produced, corresponding to 568 kg anodes/t Al. Under the conditions of case studies 1 and 2, by 2010 the production of anodes will increase to 11.7 Mt and 11.5 Mt, respectively, corresponding to 560 and 548.9 kg anodes/t Al, respectively. As 140 kg of CO_2 are actually emitted during the production of 1 t of anodes, the total CO_2 emissions will increase from 1.2 Mt CO_2 to 1.6 Mt by 2010 (case studies 1 and 2). The specific emissions caused by the lower consumption of anodes in the electrolysis will decrease from 79.6 kg CO_2/t Al in 1997 to 78.4 kg/t Al and 76.8 kg/t Al in 2010 in case studies 1 and 2 respectively. The data are compared in figure 13 relative to the 1997 data.

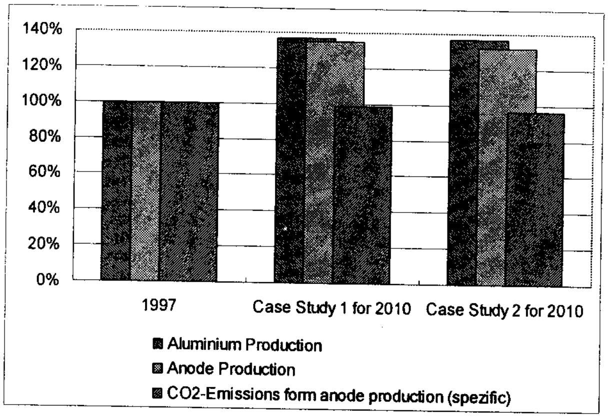

Figure 13: Comparison of aluminium production, anode production and specific CO_2 emissions due to anode production.

SO_2 Emissions from Smelters

The SO_2 emissions from cells depend on the S content of the petroleum coke, the net anode consumption, the cell hooding efficiency and the type of gas cleaning. With dry gas cleaning as the state of the art, no SO_2 fixation may be expected. If prebake cell technology is applied, there is also an amount of SO_2 emitted from the baking furnaces (20 % of the total emissions) if sulphur-containing fuels are used for baking. In 1997 ca. 10 Mt of anodes were consumed. This results in 406,000 t of SO_2 emitted from the cells, corresponding to 18.5 kg of SO_2/t Al based on an S content in the anode of 2 %. Not all of this SO_2 is emitted to the atmosphere, as some smelters clean their off- gas with wet scrubbers.

The fraction of smelters using wet scrubbing is not well known, but assuming 30 % of the world smelter capacity is doing this, the world average of specific SO_2 emissions to the atmosphere decreases to 13.5 kg SO_2/t Al. The total world emissions of SO_2 are shown in figure 14 for different shares of smelters operating with wet scrubbers. It is assumed that the efficiency of the scrubbers is 90 % in removing SO_2 emitted from the cells.

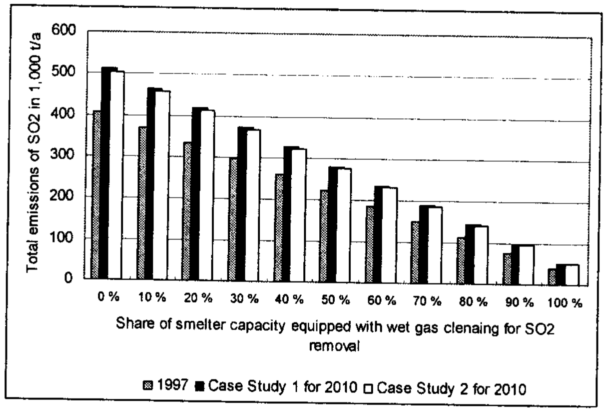

Figure 14: Total amount of SO_2 emitted to the atmosphere depending on the proportion of smelters operating with wet gas cleaning, assuming 2% sulphur in anodes.

What will happen in the future?

SO_2 emissions in 2010 case studies 1 and 2

In case study 1 the SO_2 amount emitted from the cell will decrease slightly to 18.2 kg SO_2/t Al due to the decreasing specific consumption of anodes (an S content of 2 % in the anode is also assumed for this case). If 30 % of the smelters apply wet scrubbers, the world average specific SO_2 emissions will also decrease to 13.3 kg/t Al. The total emissions of SO_2 depending on the proportion of smelters operating with wet scrubbers, are shown in figure 14.

In case study 2, the specific amount of SO_2 emitted from the cells will decrease to 17.9 kg/t Al due to the decreasing world average net anode consumption (again assuming an S content of 2 % in the anode). If 30 % of the smelters apply wet scrubbers, the world average specific SO_2 emissions will also decrease to 13.1 kg/t Al. The total emissions of SO_2, depending on the number of smelters operating with wet scrubbers, are shown in figure 14.

Conclusions

Most of the data from the case studies are shown in Table VII. For case studies 1 and 2 we assume that primary aluminium production will increase from nearly 22 Mt in 1997 to over 28 Mt in 2010, corresponding to 128.2 % of the 1997 amount. With no change in cell operations (case study 1) the specific electrical energy requirements will decrease to 14.6 kWh/kg Al, corresponding to 98.2 % of today's energy consumption, due to the installation of a modern smelter capacity of 3 Mt. At the same time the total electrical energy demand will increase to 126 % of the 1997 amount. With changes and optimisation of the smelter technologies (case study 2) the specific energy amount will decrease to 94.9 %, and the total energy consumption will increase to 121.6 % of the 1997 value. The decrease in the specific energy demand appears to be not very spectacular, but this is based only on the energy requirements of smelters, which are in operation today. Further developments in electrolysis technology are not included, such as larger cells and drained cells with wettable cathodes. Furthermore, 50 % of the aluminium is already produced in PFPB –smelters. Thus the major decreases have been made over the last 20 years due to the installation of this technology. On the other hand the decrease in emissions of gases with global warming potential is much larger, particularly the decrease of CF_4/C_2F_6 emissions. In case study 1, without any change in smelter technology, the specific emissions of CF_4/C_2F_6 will decrease to 85 % of the current value, with a slight increase to 108.7 % of total emissions. If recent existing smelters are optimised (shown in case study 2), the specific as well as the total emissions of CF_4/C_2F_6 will decrease to 61.5 % and 78.9 %, respectively, of the 1997 value. This leads to a decrease of total GWP emissions (including CF_4, C_2F_6 and CO_2 from anode consumption) to 94 % of the 1997 value. The specific GWP emissions can be reduced to 73.4 % of the 1997 value.

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References

1. Karoly Solymar: Alumina refineries of the next decade. 8th international congress of ICSOBA, Milan, 1997, 2-15.

2. World bureaux of metal statistics: Metallstatistik 1988-1998. Ware, England, 1999.

3. Rudolf Pawlek: Bauxite and alumina activities at the turn of the year. Aluminium 76 (2000) 6, 507-509.

4. Harnisch, J.: Wing, I.S.; Jacoby, H.D.; Prinn, R.G.: Primary Aluminium Production: Climate Policy, Emissions and Costs. MIT Joint Programme on the Science and Policy of Global Change, Report No. 44, December 1998.

5. Schwarz, W.: Leisewitz, A.: Aktuelle und künftige Emissionen treibhauswirksamer fluorierter Verbindungen in Deutschland. Öko-Recherche, Büro für Umweltforschung und-beratung GmbH, Frankfurt/Main, im Auftrag des Umweltbundesamtes, Forschungsbericht 106 01 074/01, December 1996.

Table VII: Energy demand, anode net consumption, CO_2, CF_4 and C_2F_6 emissions from smelters for 1997, case study 1 and 2.

		1997		Case Study 1 for 2010		Case Study 2 for 2010	
Production	t	21,943,639	100.0%	28,138,639	128.2%	28,138,63	128.2%
Electrical energy	total MWh	326,648,478	100.0%	411,437,178	126.0%	397,304,652	121.6%
	kWh/kg Al	14.9	100.0%	14.6	98.2%	14.1	94.9%
Anode net consumption	t	10,158,939	100.0%	12,784,597	125.8%	12,616,797	124.2%
	kg/t Al	463.0	100.0%	454.3	98.1%	448.4	96.8%
CO_2 from anode consumption	t	37,249,442	100.0%	46,876,855	125.8%	46,261,589	124.2%
	kg/t Al	1,698	100.0%	1,666	98.1%	1,664	98.0%
CF_4	t	10,032	100.0%	10,907	108.7%	7,913	78.9%
	kg/t Al	0.457	100.0%	0.388	84.9%	0.281	61.5%
C_2F_6	t	1,003	100.0%	1,091	108.8%	791	78.9%
	kg/t Al	0.046	100.0%	0.039	84.8%	0.028	60.9%
GWP from CF_4	t	65,208,182	100.0%	70,896,657	108.7%	51,438,479	78.9%
	kg/t Al	2,972	100.0%	2,520	84.8%	1,828	61.5%
GWP from C_2F_6	t	9,229,466	100.0%	10,034,604	108.7%	7,280,523	78.9%
	kg/t Al	421	100.0%	357	84.8%	259	61.5%
Total GWP	t	111,687,090	100.0%	127,808,115	114.4%	104,980,591	94.0%
	kg/t Al	5,090	100.0%	4,542	89.2%	3,737	73.4%