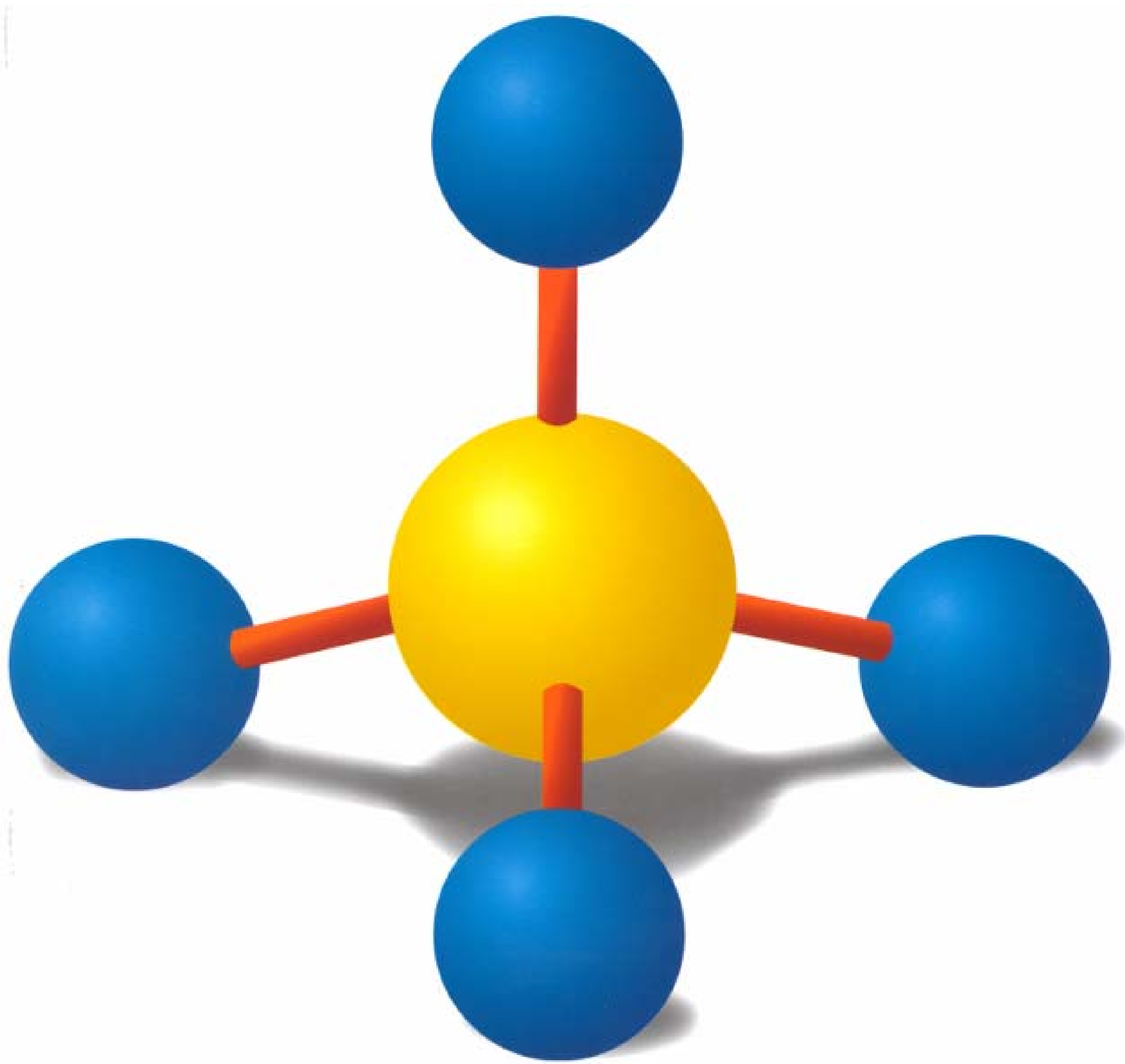
International **A**luminium **I**nstitute

THE INTERNATIONAL ALUMINIUM INSTITUTE REPORT ON THE ALUMINIUM INDUSTRY'S GLOBAL PERFLUOROCARBON GAS EMISSIONS REDUCTION PROGRAMME

RESULTS OF THE 2005 ANODE EFFECT SURVEY



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1. Introduction

The results of the analysis of the 2005 IAI anode effect survey data are presented here. The 2005 survey continues the series of surveys covering anode effect data from global aluminium producers over the period from 1990 through 2005. The first survey covered the period from 1990 through 1993. The second survey covered the period 1994 through 1997. The third survey covered the period from 1998 through 2000, and, also requested data for the base year 1990 and for 1995 to improve the rate of data collection from these earlier years. Survey data have been requested annually after 2000. The survey results have proven to be a useful tool in communicating the excellent results that the primary aluminium industry has made over the period from 1990 in reducing greenhouse gas emissions and has provided survey participants with valuable benchmarking information with which to judge current anode effect performance and to set improvement objectives.

2. Survey Results

Table 1 shows a breakdown of production by reduction technology type for 2005. Participation in the 2005 survey accounted for just over 63 percent of overall global primary production, somewhat higher than for 2004 due to the start of participation in the survey by UC Rusal. Participation in the survey by Chinese producers, and increased participation from Russia is important because these two countries are major global producers of primary aluminium.

Table 1 - 2005 Anode Effect Survey Participation by Technology Type

	PFPB	CWPB	SWPB	VSS	HSS	All
Participating in Survey (tonnes)	15,157,793	1,189,656	664,814	2,730,333	417,913	20,160,509
Non-Participants (tonnes)	8,304,179	648,928	286,000	1,672,000	826,000	11,737,107
Participation (Percent of total)	64.6%	64.7%	69.9%	62.0%	33.6%	63.2%

PFPB – Point Feed Prebake; CWPB – Bar Broken Center Work Prebake; SWPB – Side Work Prebake; VSS – Vertical Stud Søderberg; HSS – Horizontal Stud Søderberg

Figure 1 shows the growth in global annual primary aluminium production over the period from 1990, when total primary production was 19.5 million tonnes, to 31.9 million tonnes in 2005. Production figures for survey non-participants in Table 1 and in Figure 1 include some expert estimates. Figure 1 also illustrates that the increases in production between 1990 and 2005 are mainly due to increases in the lowest PFC emitting PFPB technology.

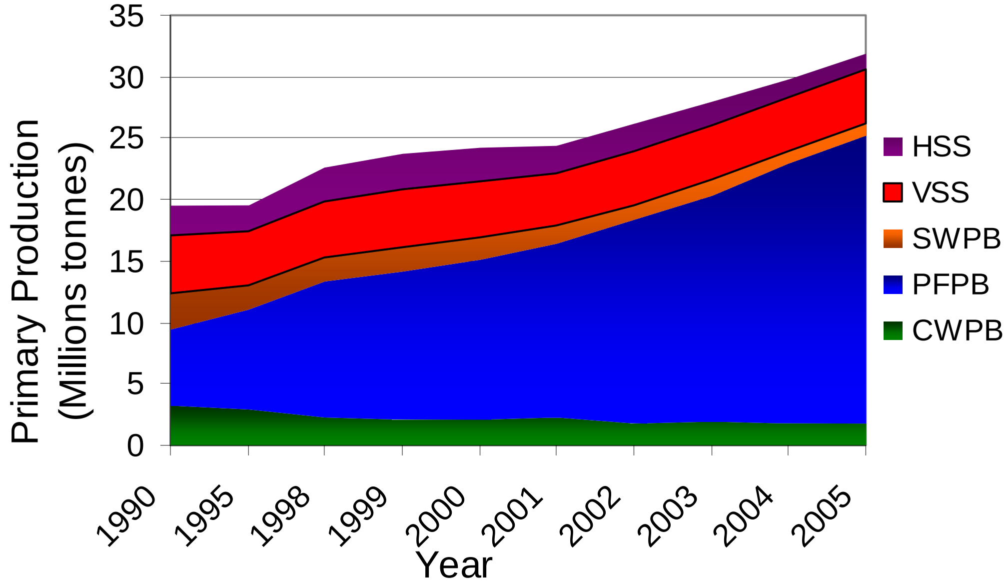

Figure 1 - Global Primary Aluminium Production by Technology Type from 1990 through 2005

Figure 2 shows a more detailed look at the changes in production by technology type. The figure shows the change in production by technology type with 1990 as a baseline.

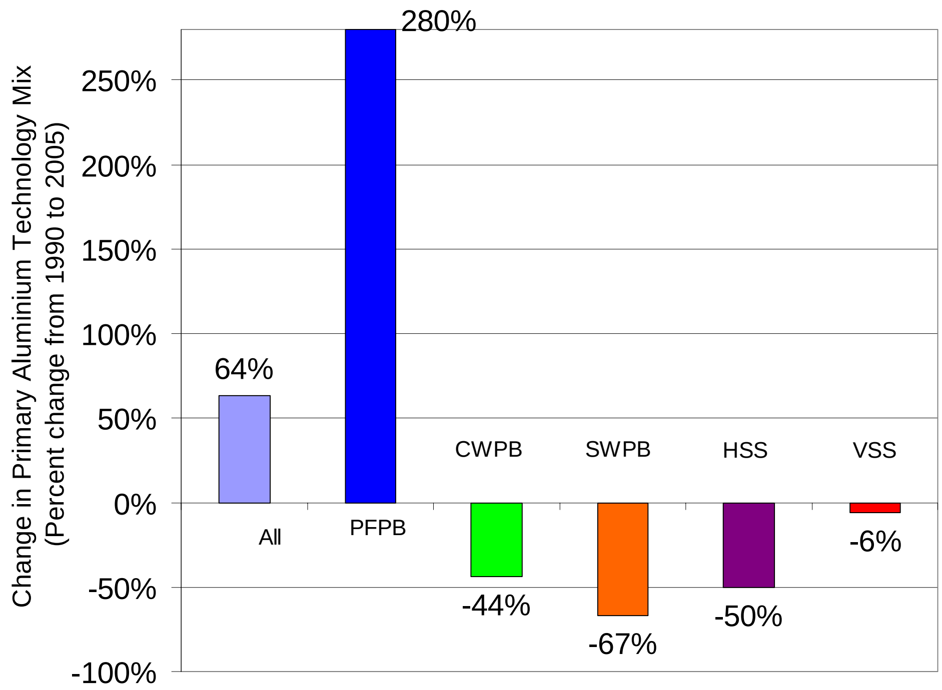

Figure 2 - Changes in Production by Technology Type from 1990 through 2005

Figure 2 shows that the production for CWPB, HSS and SWPB technologies has decreased by approximately 40% to 70% over the period from 1990 to 2005. Over the same period VSS production has decreased only slightly by 6 percent. The PFPB technology has grown by a factor of almost three times from 1990 to 2005, accounting for the overall growth in primary production of 64% over the same period.

Participation rate in the 2005 survey is highest for the facilities operating with Prebake technologies. The survey represents 62% of Vertical Stud Soderberg production, up from 43% in 2004 due to the start of participation in the survey by UC Rusal. Figure 3 shows the breakdown of the 111 reporting facilities by technology type. The PFPB technology is the largest group accounting for 70 of the reporting facilities. There is some double counting of facilities where survey data from two different technologies within the same plant boundary are reported. Reporting by individual reduction line is encouraged to provide as full a data set as possible. The data in figure 3 have been corrected to adjust for the facilities reporting data from multiple reduction lines of the same technology type.

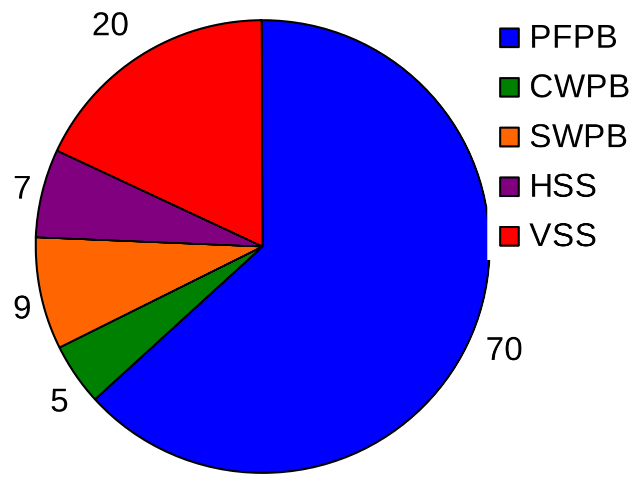

Figure 3 - Breakdown of 2005 Survey Reporting Facilities by Technology Type

The survey requested participants to report annual primary production, average anode effect frequency, average anode effect duration and, if applicable, average overvoltage. Overvoltage was specifically requested if operators employed AP-18 or AP-30 Point Feed Prebake cells, and, if Sidework cells were using control technology recording overvoltage rather than anode effect minutes. This anode effect performance data allow for the calculation of tetrafluoromethane, CF_4, and hexafluoroethane, C_2F_6 emission rates per tonne aluminium produced by the Intergovernmental Panel on Climate Change (IPCC) Tier 2 method.[1] Total PFC emissions were then calculated for each participating facility by multiplying emissions per tonne primary aluminium times the production level in tonnes. In order to improve the accuracy of the survey results, participants were also asked to report if a facility specific PFC measurement had been made and if an IPCC Tier 3 coefficient were available for calculating PFC emissions for the facility. Of the 111 reporting facilities, 22 respondents reported facility specific Tier 3 coefficients for the 2005 survey and these data were used in calculating PFC emissions per tonne aluminium produced for those facilities. The remainder of the PFC emissions data were calculated using IPCC Tier 2 methodology with industry average coefficients[2].

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[1] *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Primary Aluminium Production,* Chapter 3, Section 4.4, http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/3_Volume3/V3_4_Ch4_Metal_Industry.pdf.

[2] Greenhouse Gas Emissions Monitoring and Reporting by the Aluminium Industry, http://www.world-aluminium.org/environment/climate/ghg_protocol.pdf, p22, May 2003.

Overall progress in reducing PFC emissions per tonne aluminium produced is shown in Figure 4.

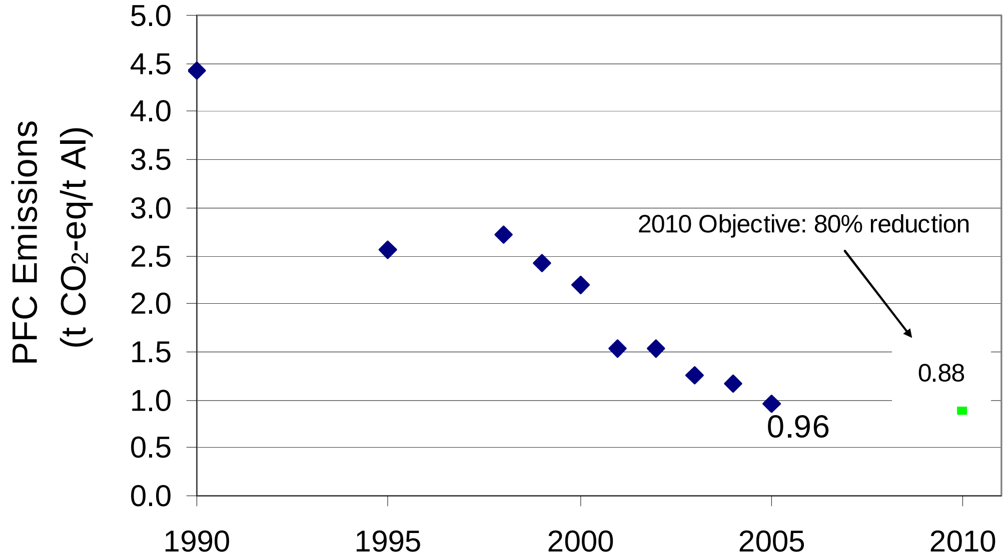

Figure 4 - Progress in Reducing PFC Emissions per Tonne Aluminium Produced

Figure 4 shows that global emissions have been reduced from 4.42 tonne equivalents CO_2 per tonne aluminium in 1990 to 0.96 in 2005, a reduction of 78%. The reductions achieved to date are measured against a goal set by the IAI Board of Directors to reduce PFC emissions per tonne aluminium by 80% by 2010 from the 1990 baseline. Good progress has been made to date; however, further reductions amounting to 8% of the 2005 PFC emissions must be achieved by 2010 to meet the Board's objective.

The global average PFC emissions per tonne aluminium produced was calculated as follows. First, the total tonnes of CF_4 and C_2F_6 emitted by survey participants for each technology category were calculated by multiplying the emissions per tonne aluminium by the aluminium production for each reporting facility. Next, the total tonnes CO_2 equivalent emissions for survey participants were calculated by multiplying the total tonnes of each PFC component emissions by the Global Warming Potential (GWP) values reported in the IPCC Second Assessment Report, 6500 for CF_4 and 9200 for C_2F_6.

Next, PFC emissions were estimated for primary production that did not report in the survey. The principle used was to apply the median PFC emission rates calculated for survey participants for each technology group to estimate total emissions from survey non-participants. Specifically, the median PFC emissions, as CO_2-eq, per tonne aluminium for survey participants were calculated for each technology type. For each technology category the tonnes aluminium from non-participating facilities were multiplied by the median PFC emissions in tonnes CO_2 equivalent per tonne aluminium to obtain the estimate of total CO_2 equivalent emissions for the non-participating production.

Total CO_2 equivalents for participants and non-participants were calculated by summing emissions from survey participants and non-participants. The global average CO_2 equivalents per tonne aluminium shown in Figure 4 were calculated by dividing the total CO_2 equivalents for participants and non-participants by the total global primary production.

Total global PFC emissions per year released to the atmosphere, including emissions from survey participants and non-participants, over the period from 1990 through 2005 are shown in Figure 5.

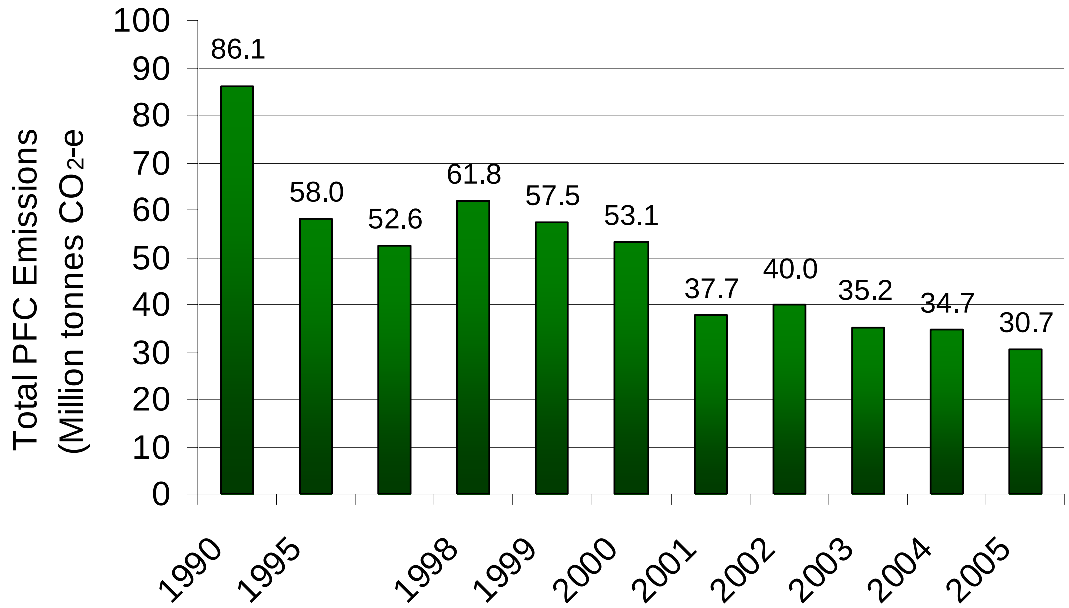

Figure 5 - Total PFC Emissions from Primary Aluminium Production by Year

The total emissions are a function of both the annual emissions per tonne aluminium of the two PFCs and the total primary aluminium production levels for each year. It is notable that the total emissions have been reduced from 86.1 million tonnes CO_2 equivalents in 1990 to 30.7 million tonnes CO_2 equivalents in 2005, a reduction of 64 percent, even though the total primary production has increased over that same period from 19.5 to 31.9 million tonnes, an increase of 64 percent. The PFC emissions calculated for 2005 are the lowest annual PFC emissions yet recorded for the period beginning in 1990.

Figure 6 shows the trend in median emissions of CF_4 per tonne aluminium produced over the period from 1990 through 2005 for each of the major 5 aluminium production cell types.

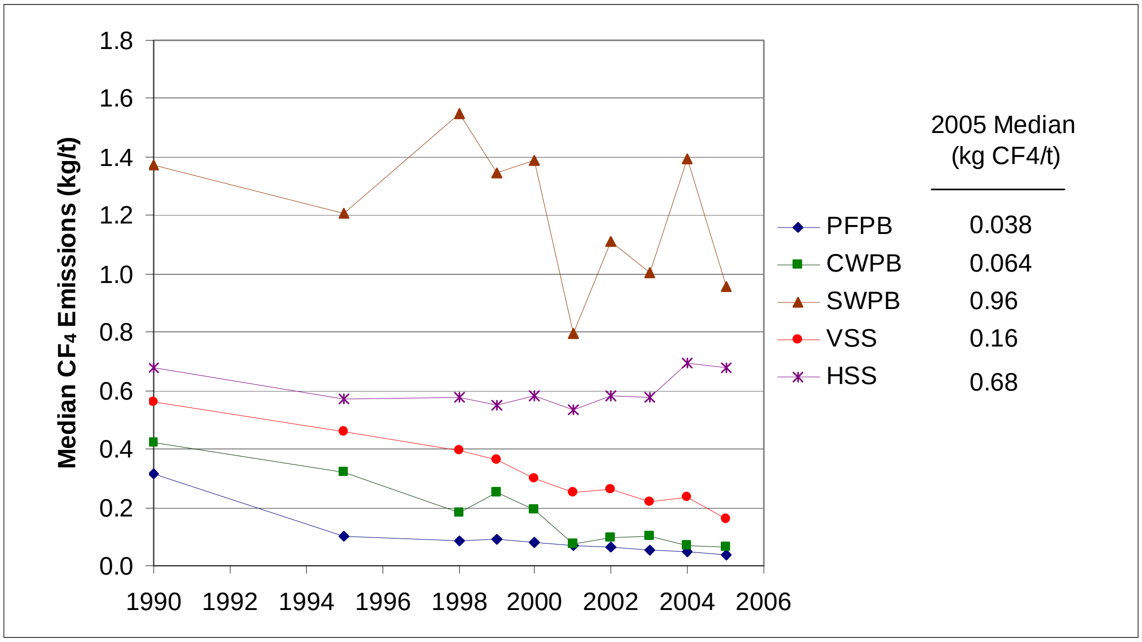

Figure 6 - Median CF4 Emissions per Tonne Aluminium Produced by Reduction Technology Type from 1990 through 2005

Record low emissions performance was repeated for PFPB, CWPB and VSS technology groups in 2005 with the lowest median emissions recorded since 1990. Median CF_4 emissions per tonne aluminium for SWPB cells decreased in 2005 and HSS technology showed a leveling off in 2005 after a step increase in 2004.

3. Comparison of Emission Results of OECD and non-OECD Countries

Outside stakeholders unfamiliar with the global aluminium industry often expect better PFC emissions performance from producers in OECD countries and assume that producers in non-OECD countries operate with technology that is less efficient than operations in OECD countries. Analysis of the IAI anode effect survey data shows that performances of non-OECD operators are very comparable with OECD-based operators. For those producers that responded to the IAI survey, 9.5 million tonnes were from non-OECD countries as compared with 10.7 million tonnes from OECD countries. As in 2004 producers in non-OECD countries set benchmarks for the PFPB and CWPB facilities in 2005. These benchmarks, 0.03 t CO_2-eq/t Al for PFPB and 0.17 t CO_2-eq/t Al, can be compared with median emissions for all survey respondents of 0.30 t CO_2-eq/t Al for PFPB and 0.56 t CO_2-eq/t Al for CWPB technology. The PFPB and CWPB are the most modern production technologies, capable of highest efficiency and lowest GHG emissions. The results are shown in Figure 7.

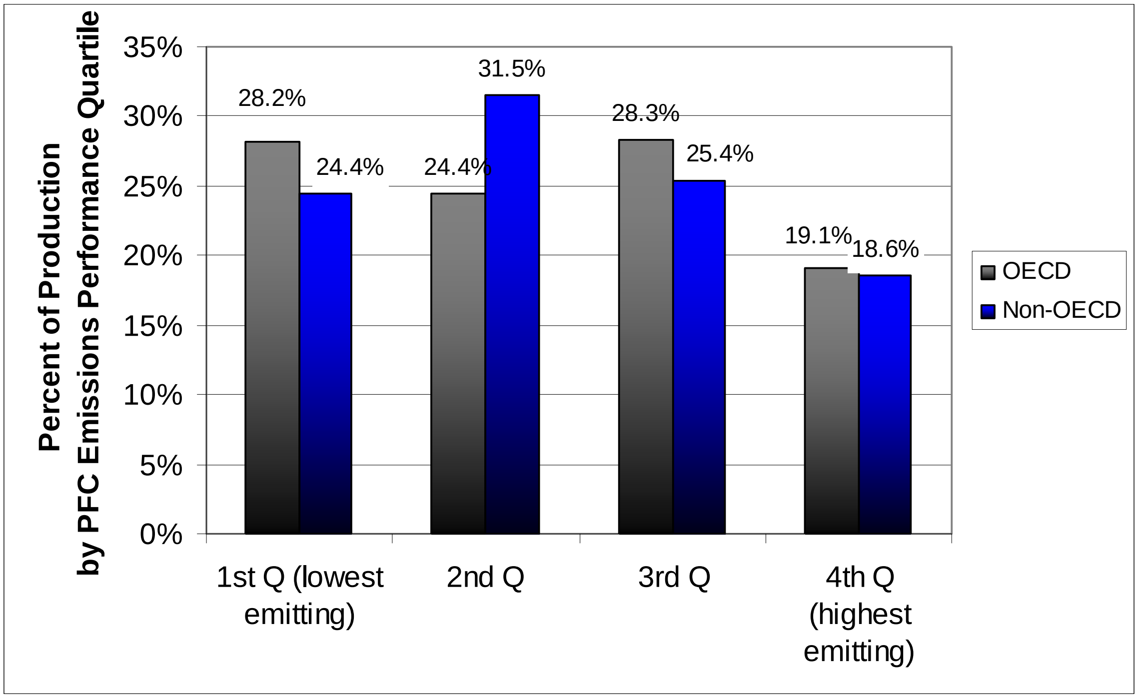

Figure 7 - Comparison of 2005 PFC Emission Performance of OECD and non-OECD Producers by Production

Figure 7 is the result of analyzing for each technology group the tonnes primary aluminium production that was in each of four quartiles from lowest PFC emitting to highest PFC emitting per tonne of aluminium produced. The sum of the production in each quartile for OECD countries was divided by the total production for OECD countries. Similarly, the sum of the non-OECD production in each quartile was divided by the total production from non-OECD countries. Figure 7 shows that performance from non-OECD countries is quite comparable in all four quartiles with that of OECD countries.

Another way of evaluating improved PFC emissions performance is to examine the rank ordered PFC emissions rate plotted versus the cumulative primary aluminium production. Figure 8 shows this analysis for 1990 and 2005. Figure 8 illustrates the increase in production since 1990 with low PFC emitting PFPB technology. This increase in PFPB production has had a major contribution in lowering the global average PFC emissions per tonne aluminium.

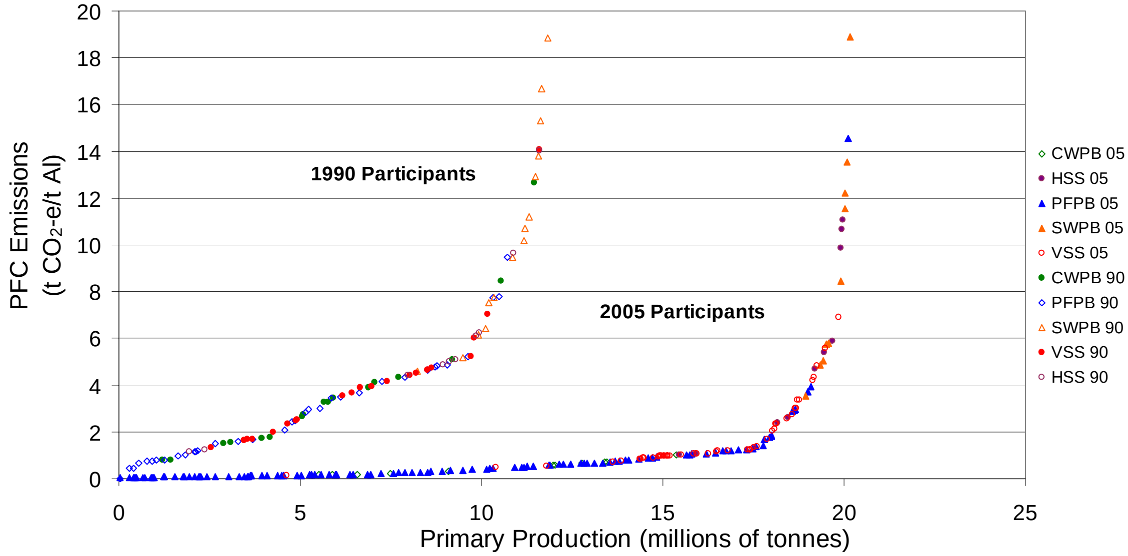

Figure 8 - Comparison of Rank Ordered 1990 and 2005 PFC Emissions per Tonne Aluminium Performance versus Cumulative Aluminium Production

4. Impact of Revisions in IPCC Equation Coefficients

The Intergovernmental Panel on Climate Change (IPCC) sets standards for methodology for inventory of greenhouse gases. The intent of these methods is to provide national governments guidance on good practices for developing annual national inventories of greenhouse gases as required under the United Nations Framework Convention on Climate Change (UNFCCC). These good practices are also influential in guiding the standard setting for many non-governmental entities for inventory of greenhouse gases. The 2000 IPCC Good Practices, published in 2000, has served as the basis for PFC calculations for this report. The IPCC 2000 good practices were also reflected in the IAI Protocol for Inventory of Greenhouse Gases from the Aluminium Sector.[3] The IPCC Good Practices have been revised in a multi-year process that was completed late in 2006. The IAI Climate Change Task Force, with the invitation of IPCC, worked on the revision to the Good Practices for inventory of greenhouse gases from aluminium production. The revised Good Practices document was adopted late in 2006. One outcome of the revision is an update to the equations that have been used to calculate PFC emissions. The revision takes into account a considerable number of new PFC measurements made at aluminium production facilities since the 2000 Good Practices were issued. The expanded database of measurements has resulted in a revision to the IPCC Tier 2 coefficients that have been used to calculate PFC emission rates in this annual report.

[3] International Aluminium Institute, The Aluminium Sector Greenhouse Gas Protocol, http://www.world-aluminium.org/environment/climate/ghg_protocol.pdf, 2005.

To assess the potential impact of the revised Tier 2 coefficients on the IAI objective of reducing PFC emissions per tonne aluminium by 80% by 2010 from the 1990 baseline the anode effect data from 1990 and from 2005 were recalculated using the coefficients in the final draft of the revised Good Practices.[4] The results of the calculations are shown in Figure 9.

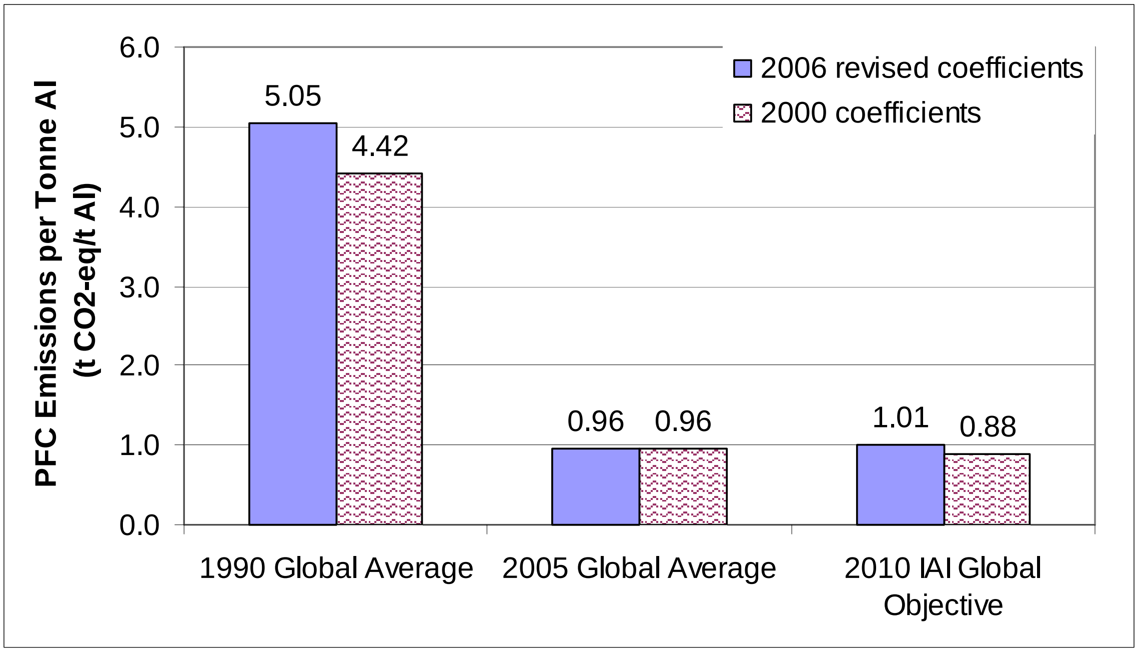

Figure 9 - Impact of Revised IPCC Tier 2 Coefficients on IAI Objective to Reduce PFC Emissions by 80% by 2010 from 1990 Base

The impact of the revised coefficients is to raise the 1990 baseline from 4.42 to 5.05 tonnes CO_2-eq per tonne aluminium, an increase of 14%. In contrast, the impact of the revisions on the 2005 PFC emissions is much lower, less than 1%. The difference in impacts of the revisions between 1990 and 2005 is due in major part to the relative change in technology mix from 1990 to 2005. As was seen in Figure 2 there has been a 280% increase in the PFPB production and over the same time there was a decrease in SWPB production of 67%. There were insignificant change in the Tier 2 coefficients for the PFPB cells; however, there were significant increases in the overvoltage coefficient for SWPB cells and also an increase in the fraction of C_2F_6 for SWPB cells. Both these factors act to increase the 1990 baseline while having little effect on the 2005 calculation. Also, the 2010 objective, as stated as an 80% reduction from the 1990 baseline, is also increased from 0.88 to 1.01 tonnes CO2-eq per tonne aluminium produced.

[4] The IPCC revised Good Practices was accepted by IPCC in late 2006.

5. Uncertainty in Emissions Projections

This section considers the uncertainty in calculations of PFC emissions from IAI survey participants, and, the uncertainty in projecting PFC emissions globally. Understanding sources of, and, magnitude of, uncertainty is important because the global Industry has made specific commitments to reduce PFC emissions per tonne aluminium produced by 80% by 2010 from the 1990 baseline. A high level of uncertainty has the potential of discounting the credibility of claims of emissions reduction. Potential significant sources of uncertainty include:

a. the uncertainty in the average industry IPCC Tier 2 calculation factors,
b. use of Tier 2 factors for calculating PFC emissions for survey participants where suitable facility specific measurements are not available, and,
c. estimates of emissions for producers that do not participate in the anode effect survey.

Uncertainty arises from the use of IPCC Tier 2 average industry factors due to the uncertainty in the mean slope and overvoltage coefficients. Additional PFC measurements will reduce the uncertainty of the mean coefficient values. However, for all technology groups there is considerable variance in the individual values of slope and overvoltage coefficients from which the means are calculated. For this reason calculations of PFC emissions with Tier 2 coefficients will be more uncertain than calculations made with Tier 3 coefficients calculated from PFC measurements made using good measurement practices. The overall uncertainty of the global average PFC emissions per tonne aluminium is approximately ± 20% at the 95% confidence level based on previous Monte Carlo simulations. The most efficient path to reducing the uncertainty of global PFC emissions is to include anode effect data from China and Russia production in the calculation, and, to have more facilities make the PFC measurements necessary to enable Tier 3 calculation of PFC emissions.

6. Benchmark Data

The IAI anode effect survey provides valuable benchmark information allowing global producers to judge their performance relative to others operating with similar technology. The benchmark data are presented in this section in the form of cumulative probability graphs for a rapid visual overview of the data. The detailed supporting data are tabulated in Appendix I of this report so that individual operators can identify their facilities from the data they submitted in response to the survey. The cumulative probability graphs show the benchmark parameter (PFC emissions per tonne aluminium, anode effect frequency, anode effect duration and overvoltage) on the horizontal axis and the vertical axis shows the cumulative percent of reporting facilities that perform at or below the level chosen on the vertical axis. For facilities reporting data from multiple potlines a data point is shown for each potline.

Figure 10 shows the 2005 benchmark data for PFC emissions per tonne aluminium produced by technology type.

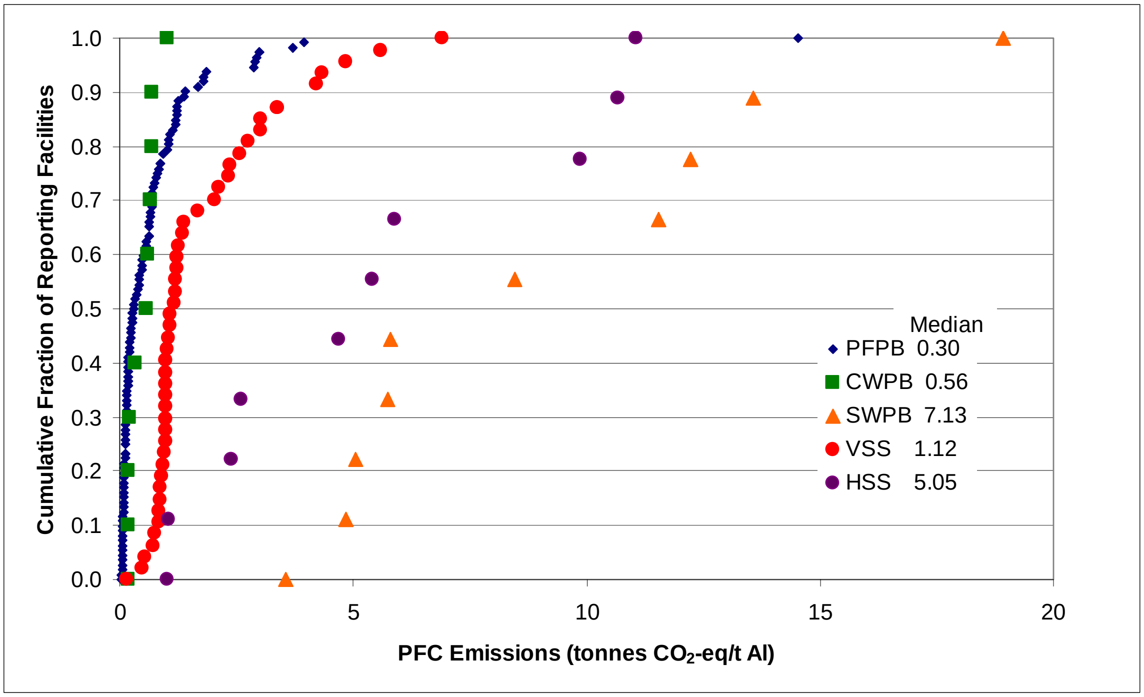

Figure 10 - Cumulative Probability Graph for PFC Emissions per Tonne Aluminium Produced for Survey Participants by Technology Type

To illustrate how the graph is interpreted, take for example in Figure 10 the 0.50 point on the vertical axis the VSS data point is 1.12 tonne CO_2-eq/tonne Al. The interpretation is that 50% of all operators reporting VSS anode effect data operate at or below PFC emissions per tonne aluminium produced of 1.12 tonne CO_2-eq/tonne Al. At 1.00 on the vertical axis the VSS point is 6.89. The interpretation is that all VSS facilities reported anode effect data that reflected PFC emissions performance at or below 6.89 tonne CO_2-eq/tonne Al, or, the maximum value calculated for VSS operators in 2005 was 6.89 tonne CO_2-eq/tonne Al. Figure 10 shows that the lowest PFC emissions per tonne aluminium produced are obtained from PFPB and CWPB operators. The Søderberg facilities show a distribution of values for PFC emissions per tonne aluminium higher than the PFPB and CWPB facilities and the highest PFC emissions per tonne aluminium produced result from the SWPB cells.

Figure 11 shows the distribution of anode effect frequency data for reporting facilities in 2005. As can be expected from the greater degree of control capability the PFPB anode effect frequency distribution is the lowest of the five technology groups. The remaining four technology groups show considerable overlap. The VSS facility with the lowest anode effect frequency, 0.13 anode effects per cell day, operates with point feeders and demonstrates the impact that installation of point feeders can have on anode effect frequency for Søderberg cells.

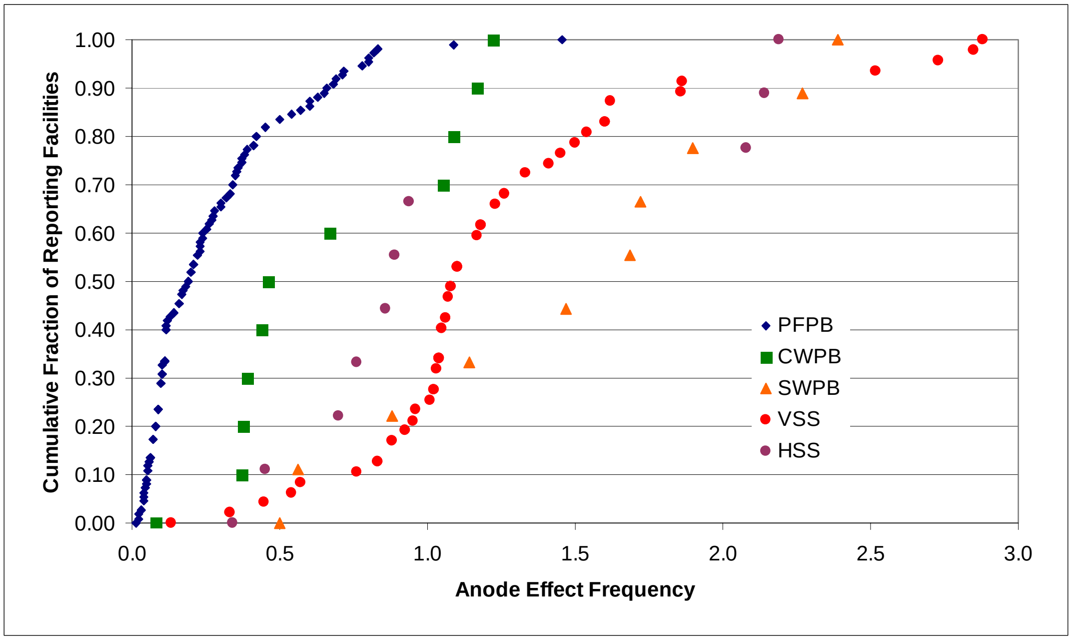

Figure 11 - Cumulative Probability Graph for Anode Effect Frequency for Survey Participants by Technology Type

Figure 12 shows comparative performance for anode effect duration performance for all reporting facilities.

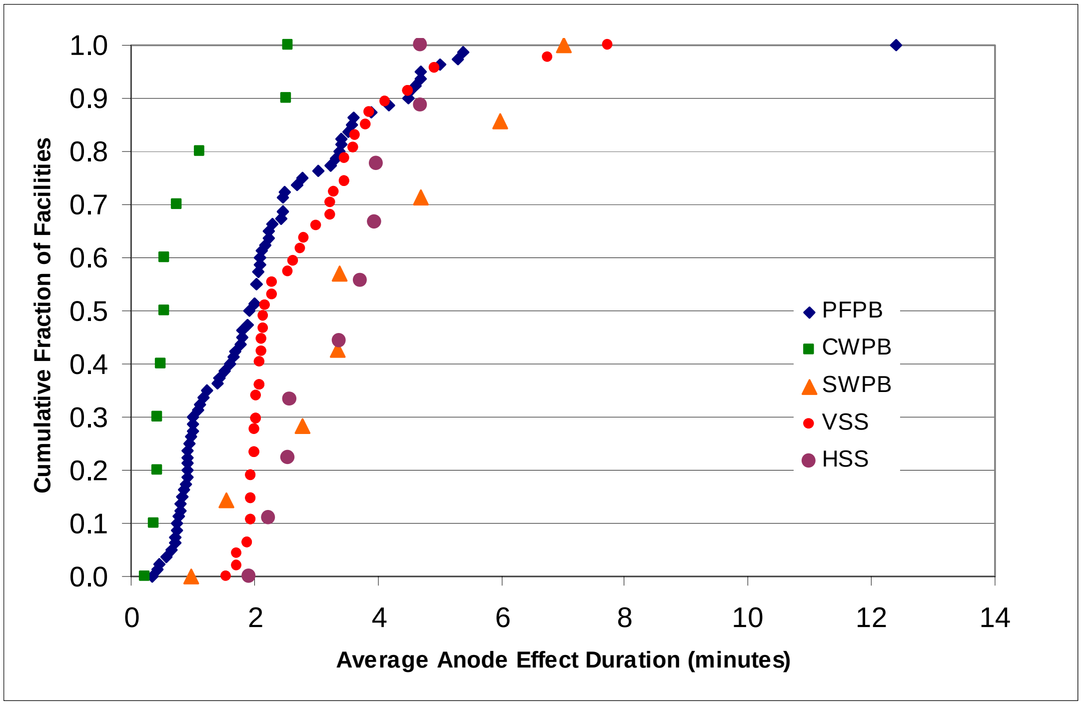

Figure 12 - Cumulative Probability Graph for Anode Effect Duration for Survey Participants by Technology Type

Several CWPB and PFPB facilities reported average anode effect durations of less than 30 seconds. Some care should be exercised in making comparisons of anode effect duration because different definitions are in use across IAI producers for duration, specifically relating to the voltage at which anode effects are declared, and, in the time interval over which if another voltage excursion occurs it is noted as a new anode effect. These differences in definition of duration do not impact the anode effect minutes per cell day, the important parameter relating to PFC emissions per tonne aluminium produced. Bar broken Prebake cells performed best on anode effect duration with median anode effect duration of 0.54 minutes. The point fed Prebake cells were next best performers with a median anode effect duration of 1.96 minutes in 2005. The median average anode effect duration performance for VSS cells was 2.17 minutes, while median durations for SWPB and HSS cells were 3.36, and 3.55 minutes respectively.

Figure 13 shows anode effect minutes per cell day benchmarking data for all technology groups that utilize the slope method for calculating PFC emissions per tonne aluminium.

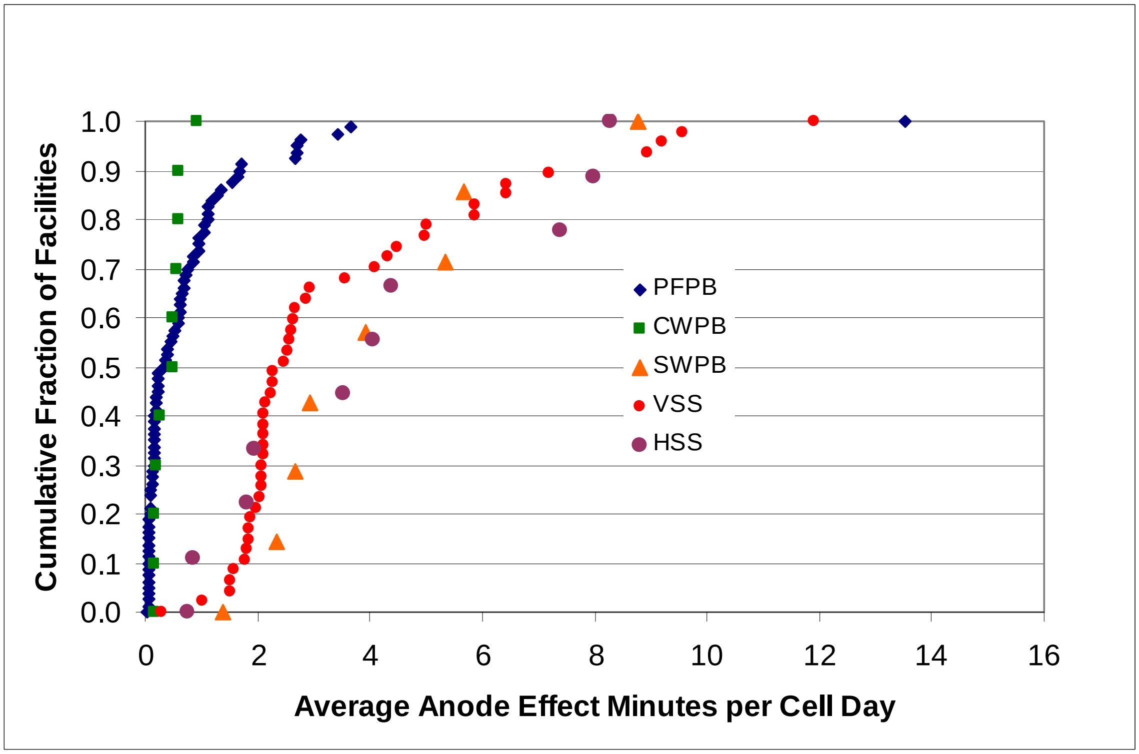

Figure 13 - Cumulative Fraction Graph for Anode Effect Minutes per Cell Day for Survey Participants by Technology Type

The anode effect minutes per cell day data shown in Figure 13 are the result of multiplying the average anode effect frequency times the average anode effect duration for each facility using the slope method for PFC calculation. Anode effect minutes per cell day relates directly to PFC emissions per cell day through the slope factor. Figure 13 shows that anode effect minutes per cell day form two broad families of data. There is similarity between the anode effect minutes per cell day data for PFPB and CWPB. Both these technology groups have the same value for slope, 0.14 kg CF_4/anode effect minute per cell day. Similarly, there is comparability in the anode effect minutes per cell day data for the SWPB, VSS and HSS cell technology groups; however, there are considerable differences in the slope parameter for these three technology groups. The slope value is highest for the SWPB technology group, 0.29 kg CF_4/anode effect minute per cell day. The comparable slope values for VSS and HSS are 0.068 and 0.18, respectively.

Figure 14 shows the benchmarking graph for anode effect overvoltage for PFPB cells operating with Alcan AP technology and who calculate PFC emissions from overvoltage process data. For these operators the overvoltage parameter relates directly to PFC emissions per tonne aluminium produced. Positive overvoltage reporting now predominates over algebraic overvoltage reporting. The positive overvoltage should give a better correlation with PFC emissions per tonne aluminium than algebraic overvoltage since algebraic overvoltage recording can result in subtractions of voltage during the anode effect treatment period that does not relate to PFC emissions.

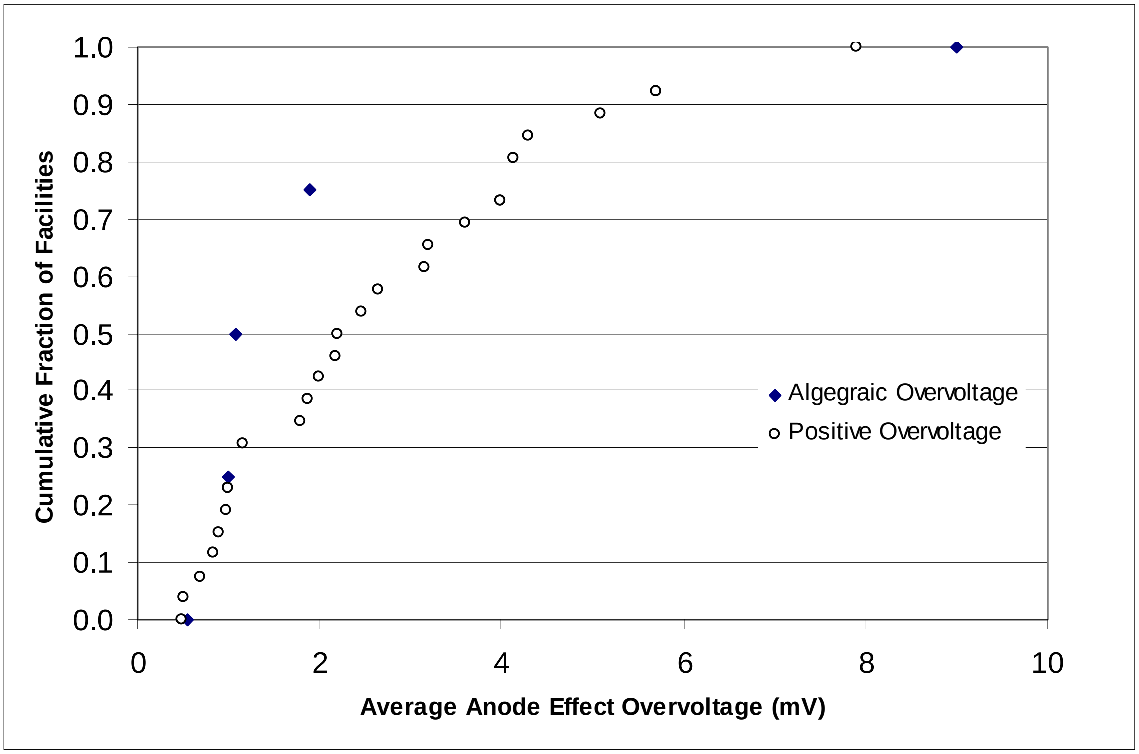

Figure 14 - Cumulative Fraction Graph for Anode Effect Overvoltage for Survey Participants Operating with Alcan AP Technologies

7. VSS Initiative

Following the precedent established for 2004 where special attention was given to the SWPB technology group, the VSS technology group was examined in detail during the past year to determine why some facilities operate with much better anode effect performance than do others. Figure 3 showed the breakdown of total production by technology type. On a global basis VSS technology makes up 14% of primary aluminium production. The analysis shown in Figure 15 for global PFC emissions by technology type illustrates that global VSS producers account for 23% of total PFC emissions from 14% of aluminium production.

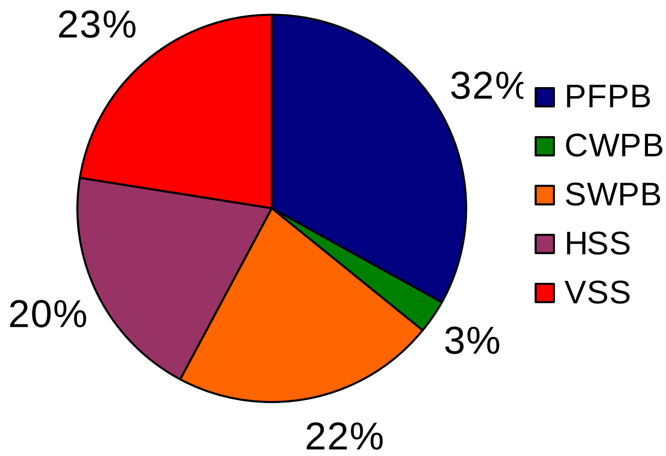

Figure 15 - Breakdown of 2005 Global PFC Emissions from Primary Aluminium Production by Technology Type

Figures 10 to 13 show the performance of the VSS cells relative to other technologies for parameters affecting PFC emissions. During 2006 a special focus was placed to understand how some VSS facilities achieve relatively better anode effect performance than others to enable acceleration of PFC emissions reductions. As part of the initiative, high performing VSS producers were polled as to factors that might contribute to their good performance. The key findings from the VSS study are:

- Upgrading traditional manually fed VSS cells with point feeders offers the potential for strong improvements in anode effect performance; however, very good performance can be achieved by careful examination of cell resistance data to anticipate anode effects and tailor feeding to prevent the occurrence of anode effects.
- Implementation of cell control algorithms that anticipate anode effects and initiate feeding action prior to the occurrence of anode effects can reduce the frequency of occurrence of anode effects.
- As for other types of cell technologies, bath chemistry control is important, as is liquid levels in the cells.
- Location specific work practices can impact anode effect duration substantially with a direct impact on PFC emissions.
- Scheduled anode effects are still viewed at many VSS production facilities as a very effective tool to control sludge formation, improve anode conditions by eliminating small spikes, elimination of carbon dust on the bath and to also provide a set point for alumina feeding.
- There is still considerable potential for PFC emissions performance improvement within the VSS technology group.

8. Summary and Conclusions

The 2005 IAI anode effect performance survey results continue the trend of reduced global PFC emissions, both as kilograms per tonne of aluminium produced and as total PFC emissions to the atmosphere. Projections of global PFC emissions per tonne aluminium produced that combine survey data with estimates of emissions from producers that do not participate based on applying the participants' median anode effect performance levels to non-participating production show a improvement to 0.96 t CO_2 equivalents/t Al. Total PFC emissions to the atmosphere in 2005 from primary aluminium production was calculated at 30.7 million tonnes CO_2 equivalents. This is the lowest emissions of PFCs to the atmosphere since IAI began its anode effect surveys.

IPCC Tier 2 coefficients used to calculate PFC emissions per tonne aluminium were revised in late 2006 and will impact IAI emissions projections for those facilities that have not yet made PFC measurements. Using the revised values for the IPCC Tier 2 coefficients analysis of 1990 and 2005 anode effect data were made. The results showed that the 1990 emissions were impacted more than 2005 emissions, raising the 1990 baseline from 4.42 to 5.05 tonnes CO_2 equivalents per tonne aluminium, an increase of 14%, while the 2005 emissions were essentially unchanged. The overall impact of the revised coefficients is a slightly improved position toward meeting the IAI goal of an 80% reduction in PFC emissions per tonne aluminium by 2010 from the 1990 baseline. PFC emissions reductions are 81.0 % with the revised coefficients as compared with 78.2% with the current calculations.

Uncertainty in global aluminium PFC emissions can be reduced by getting higher participation in the anode effect survey. In 2005 survey participation as a percentage of total primary production was slightly higher than in 2004 due to the start of participation in the survey by UC Rusal. Further participation in the anode effect survey, particularly by major Russian and Chinese producers, is needed to reduce uncertainty in emissions calculations and maintain credibility of results. Also, making PFC measurements at those facilities that have not yet made measurements will increase the accuracy of results by enabling the use of Tier 3 methods for those facilities.

There is still a considerable range of anode effect performance seen in the benchmark data for facilities operating with similar reduction technologies. This would indicate that there is still an excellent opportunity for making progress in reducing anode effects and the resulting PFC emissions through driving toward best work practices. A good record of PFC emissions reduction has been achieved by the global industry to date. Aggressive efforts are still necessary to hold the gains made to date and to capture the further potential emissions reductions highlighted by the wide range of anode effect performance benchmarking data amongst operators with similar technology.

Appendix I – 2005 Benchmark Data

A. PFPB Rankings

PFPB AEF

Data Point	Rank	AEF	Cum. Frac.
400	1	0.01	0.00
261	2	0.02	0.01
328		0.02	0.02
211	3	0.03	0.03
266		0.03	0.03
251		0.04	0.05
401	4	0.04	0.05
338		0.04	0.06
363		0.05	0.07
217		0.05	0.08
238	5	0.05	0.09
359		0.05	0.09
235		0.05	0.11
327		0.06	0.12
339		0.06	0.13
294	6	0.06	0.14
306		0.06	0.14
248		0.06	0.14
250		0.06	0.14
247		0.07	0.17
253	7	0.07	0.17
254		0.07	0.17
296		0.08	0.20
249	8	0.08	0.20
255		0.08	0.20
257		0.08	0.20
305		0.09	0.24
366		0.09	0.24
252	9	0.09	0.24
256		0.09	0.24
290		0.09	0.24
330		0.09	0.24
242		0.10	0.29
227		0.10	0.29
351	10	0.10	0.31
289		0.10	0.31
282		0.10	0.33
295		0.11	0.34
322		0.11	0.34
337		0.11	0.34
350	11	0.11	0.34
239		0.11	0.34
365		0.11	0.34
324		0.11	0.34
273		0.11	0.40
298	12	0.12	0.41
237		0.12	0.42
356	13	0.13	0.43
329	14	0.14	0.44
309		0.14	0.44
308	15	0.16	0.45
310		0.16	0.45
336	16	0.17	0.47
304		0.17	0.48
292	17	0.18	0.49
221	18	0.19	0.50
222		0.19	0.50
265	19	0.20	0.52
348		0.20	0.52
326	20	0.21	0.54
307		0.21	0.54
284	21	0.22	0.55
311		0.23	0.56
369	22	0.23	0.57
325		0.23	0.58
226	23	0.24	0.59
283		0.24	0.60
225	24	0.25	0.61
367	25	0.26	0.62
293	26	0.27	0.63
314		0.27	0.64
234	27	0.28	0.65
245	28	0.30	0.65
318		0.30	0.66
371	29	0.32	0.67
232	30	0.33	0.68
323		0.33	0.68
212	31	0.34	0.70
368		0.34	0.70
233	32	0.35	0.72
370	33	0.36	0.73
375		0.36	0.74
358	34	0.37	0.75
231		0.37	0.75
352	35	0.38	0.76
373	36	0.39	0.77
278	37	0.41	0.78
331		0.41	0.78
364	38	0.42	0.80
372		0.42	0.80
374	39	0.45	0.82
404		0.45	0.82
260	40	0.50	0.84
279	41	0.54	0.85
301	42	0.57	0.85
300	43	0.60	0.86
353		0.60	0.87
332	44	0.63	0.88
302	45	0.65	0.89
280	46	0.66	0.90
303	47	0.68	0.91
354	48	0.69	0.92
299	49	0.71	0.93
236	50	0.72	0.94
340	51	0.78	0.95
246	52	0.80	0.95
333		0.80	0.96
342	53	0.82	0.97
341	54	0.83	0.98
403	55	1.09	0.99
377	56	1.46	1.00

PFPB AED (minutes)

Data Point	Rank	AED (min)	Cum. Frac.
284	1	0.33	0.00
318	2	0.43	0.01
373	3	0.47	0.03
242	4	0.57	0.04
311	5	0.65	0.05
255	6	0.71	0.06
249	7	0.73	0.08
283	8	0.75	0.09
254	9	0.76	0.10
253		0.76	0.11
256	10	0.79	0.13
251	11	0.81	0.14
257	12	0.84	0.15
250	13	0.86	0.16
369	14	0.89	0.18
248		0.91	0.19
252	15	0.91	0.20
231		0.91	0.21
377	16	0.93	0.23
295		0.93	0.24
296	17	0.94	0.25
260	18	0.96	0.26
353	19	1.00	0.28
304	20	1.01	0.29
370		1.01	0.30
299	21	1.08	0.31
247	22	1.13	0.33
265	23	1.17	0.34
358	24	1.22	0.35
401	25	1.40	0.36
333	26	1.42	0.38
354	27	1.52	0.39
282	28	1.59	0.40
332	29	1.66	0.41
356	30	1.70	0.43
280	31	1.78	0.44
266	32	1.80	0.45
236	33	1.81	0.46
294	34	1.90	0.48
366		1.90	0.48
212	35	1.91	0.50
367		2.00	0.51
368	36	2.00	0.51
340		2.00	0.51
341	37	2.02	0.55
342		2.02	0.55
375	38	2.05	0.58
330	39	2.08	0.59
337	40	2.09	0.60
331	41	2.11	0.61
293	42	2.18	0.63
306	43	2.23	0.64
314	44	2.24	0.65
372	45	2.29	0.66
338	46	2.44	0.68
217	47	2.47	0.69
404		2.47	0.69
352	48	2.48	0.71
374		2.48	0.73
371	49	2.70	0.74
339	50	2.77	0.75
359	51	3.03	0.76
245	52	3.24	0.78
237	53	3.33	0.79
238	54	3.38	0.80
246	55	3.39	0.81
211	56	3.41	0.83
292	57	3.53	0.84
239	58	3.57	0.85
222	59	3.60	0.86
363	60	3.90	0.88
278	61	4.19	0.89
261	62	4.50	0.90
329	63	4.52	0.91
300	64	4.62	0.93
235	65	4.69	0.94
301	66	4.70	0.95
279	67	5.01	0.96
302	68	5.30	0.98
303	69	5.38	0.99
403	70	12.40	1.00

PFPB AE minutes/cell day

Data Point	Rank	AE min/cell day	Cum Frac.
251	1	0.03	0.00
250		0.05	0.01
254		0.05	0.03
253	2	0.05	0.04
266		0.05	0.05
248		0.05	0.06
242		0.06	0.08
255	3	0.06	0.09
401		0.06	0.10
249		0.06	0.11
257		0.07	0.13
256	4	0.07	0.14
284		0.07	0.15
296		0.08	0.16
247	5	0.08	0.18
252		0.08	0.19
261	6	0.09	0.20
211		0.10	0.21
295	7	0.10	0.21
338		0.10	0.24
294	8	0.11	0.25
217	9	0.12	0.26
318	10	0.13	0.28
306		0.13	0.29
311	11	0.15	0.30
359	12	0.15	0.31
339	13	0.16	0.33
282		0.16	0.34
238		0.17	0.35
366	14	0.17	0.36
304		0.17	0.38
363		0.18	0.39
283	15	0.18	0.40
373		0.18	0.41
330	16	0.19	0.43
369	17	0.21	0.44
356	18	0.22	0.45
337	19	0.23	0.46
265		0.23	0.48
235	20	0.24	0.49
231	21	0.34	0.50
370	22	0.36	0.51
239	23	0.39	0.53
237	24	0.40	0.54
358	25	0.45	0.55
260	26	0.48	0.56
367	27	0.52	0.58
293	28	0.59	0.59
353	29	0.61	0.60
314		0.61	0.61
329	30	0.63	0.63
292	31	0.64	0.64
212	32	0.65	0.65
368	33	0.68	0.66
222		0.68	0.68
375	34	0.74	0.69
299	35	0.77	0.70
371	36	0.86	0.71
331	37	0.87	0.73
352	38	0.95	0.74
372	39	0.96	0.75
245	40	0.97	0.76
332	41	1.05	0.78
354		1.05	0.79
404	42	1.11	0.80
374	43	1.12	0.81
333	44	1.14	0.83
280	45	1.17	0.84
236	46	1.30	0.85
377	47	1.35	0.86
340	48	1.56	0.88
342	49	1.66	0.89
341	50	1.68	0.90
278	51	1.72	0.91
301	52	2.68	0.93
279	53	2.71	0.94
246		2.71	0.95
300	54	2.77	0.96
302	55	3.45	0.98
303	56	3.66	0.99
403	57	13.52	1.00

PFPB Rankings (Continued)

PFPB AEO (mV)

Data Point	Rank	AEO (mV)	Algebraic or Positive	Cum Frac.
290	1	0.49	P	0.00
227	2	0.5	P	0.03
322	3	0.543	A	0.06
226	4	0.7	P	0.10
273	5	0.833	P	0.13
225	6	0.9	P	0.16
289	7	0.98	P	0.19
305		1	P	0.23
365	8	1	A	0.23
327		1	P	0.23
400	9	1.085	A	0.32
351	10	1.16	P	0.35
324	11	1.8	P	0.39
336	12	1.867	P	0.42
328	13	1.89	A	0.45
298	14	2.004	P	0.48
234	15	2.17	P	0.52
350	16	2.2	P	0.55
402	17	2.458	P	0.58
288	18	2.64	P	0.61
221	19	3.15	P	0.65
232	20	3.19	P	0.68
233	21	3.61	P	0.71
325	22	4	P	0.74
326		4	P	0.74
323	23	4.133	P	0.81
348	24	4.3	P	0.84
309	25	5.1	P	0.87
308	26	5.7	P	0.90
310		5.7	P	0.90
307	27	7.9	P	0.97
364	28	9	A	1.00

PFPB PFC Emissions (t CO2-eq/t Al)

Data Point	Rank	PFC Emissions (t CO2-eq/t Al)	Cum Frac.
251	1	0.03	0.00
273	2	0.04	0.01
351		0.06	0.02
250		0.06	0.03
254		0.06	0.04
253		0.06	0.04
266	3	0.06	0.05
248		0.06	0.06
242		0.06	0.07
255		0.06	0.08
401		0.06	0.09
249		0.06	0.10
305	4	0.07	0.11
257		0.07	0.12
290		0.08	0.13
365		0.08	0.13
256	5	0.08	0.14
227		0.08	0.15
284		0.08	0.16
296		0.08	0.17
247	6	0.09	0.18
252		0.09	0.19
261		0.10	0.20
322	7	0.10	0.21
298		0.10	0.21
226		0.11	0.22
211	8	0.11	0.23
295		0.11	0.23
338		0.11	0.25
350		0.12	0.26
294	9	0.12	0.27
336		0.12	0.28
217		0.12	0.29
225		0.14	0.29
318	10	0.14	0.30
306		0.14	0.31
289	11	0.15	0.32
327		0.15	0.33
311	12	0.16	0.34
359		0.16	0.35
400		0.17	0.36
339	13	0.17	0.37
282		0.17	0.38
238	14	0.18	0.38
366		0.18	0.39
304		0.19	0.40
363	15	0.19	0.41
283		0.19	0.42
373	16	0.20	0.43
330		0.20	0.44
356	17	0.24	0.45
337	18	0.25	0.46
265		0.25	0.46
235	19	0.26	0.47
348	20	0.27	0.48
324	21	0.28	0.49
328	22	0.29	0.50
369	23	0.30	0.51
234	24	0.33	0.52
231	25	0.36	0.53
402	26	0.38	0.54
288	27	0.41	0.54
239	28	0.42	0.55
237	29	0.43	0.56
221	30	0.48	0.57
358	31	0.49	0.58
232		0.49	0.59
260	32	0.52	0.60
370	33	0.53	0.61
233	34	0.55	0.62
367	35	0.56	0.63
325	36	0.61	0.63
326		0.61	0.63
293	37	0.63	0.65
323		0.63	0.66
353	38	0.65	0.67
314	39	0.66	0.68
329		0.68	0.69
292	40	0.68	0.70
364		0.68	0.71
212	41	0.70	0.71
368	42	0.73	0.72
222	43	0.74	0.73
309	44	0.78	0.74
375	45	0.79	0.75
299	46	0.83	0.76
308	47	0.88	0.77
310	48	0.88	0.77
371	49	0.93	0.79
352	50	1.02	0.79
372	51	1.03	0.80
245	52	1.05	0.81
331	53	1.07	0.82
354	54	1.13	0.83
404	55	1.20	0.84
374		1.20	0.85
307	56	1.21	0.86
332	57	1.22	0.87
333		1.22	0.88
280	58	1.26	0.88
377	59	1.38	0.89
236	60	1.40	0.90
340	61	1.68	0.91
342	62	1.78	0.92
341	63	1.80	0.93
278	64	1.85	0.94
301	65	2.88	0.95
279	66	2.91	0.96
246	67	2.92	0.96
300	68	2.98	0.97
302	69	3.71	0.98
303	70	3.93	0.99
403	71	14.54	1.00

B. CWPB Rankings

CWPB AEF

Data Point	Rank	AEF	Cum. Frac.
267	1	0.08	0.00
319	2	0.37	0.10
229	3	0.38	0.20
262	4	0.39	0.30
230	5	0.44	0.40
263	6	0.46	0.50
264	7	0.67	0.60
271	8	1.05	0.70
269	9	1.09	0.80
272	10	1.17	0.90
270	11	1.22	1.00

CWPB AED (minutes)

Data Point	Rank	AED (min)	Cum. Frac.
264	1	0.24	0.00
263	2	0.38	0.10
262	3	0.43	0.20
272	4	0.44	0.30
270	5	0.49	0.40
271	6	0.54	0.50
269	7	0.55	0.60
229	8	0.74	0.70
230	9	1.13	0.80
319	10	2.52	0.90
267	11	2.54	1.00

CWPB AE minutes/cell day

Data Point	Rank	AE min/cell day	Cum. Frac.
264	1	0.16	0.00
262	2	0.17	0.10
263	3	0.18	0.20
267	4	0.20	0.30
229	5	0.28	0.40
230	6	0.49	0.50
272	7	0.51	0.60
271	8	0.57	0.70
269	9	0.60	0.80
270		0.60	0.90
319	10	0.93	1.00

CWPB PFC Emissions (t CO2-eq/t Al)

Data Point	Rank	PFC Emissions (t CO2-eq/t Al)	Cum Frac.
264	1	0.17	0.00
262	2	0.18	0.10
263	3	0.19	0.20
267	4	0.22	0.30
229	5	0.32	0.40
230	6	0.56	0.500
272	7	0.59	0.60
271	8	0.66	0.70
269	9	0.69	0.80
270	10	0.70	0.90
319	11	1.00	1.00

C. SWPB Rankings

SWPB AEF

Data Point	Rank	AEF	Cum. Frac.
287	1	0.50	0.00
317	2	0.56	0.11
285	3	0.88	0.22
316	4	1.14	0.33
376	5	1.47	0.44
312	6	1.68	0.56
349	7	1.72	0.67
268	8	1.90	0.78
335	9	2.27	0.89
357	10	2.39	1.00

SWPB AED (minutes)

Data Point	Rank	AED (min)	Cum. Frac.
357	1	0.98	0.00
349	2	1.55	0.14
287	3	2.77	0.29
285	4	3.35	0.43
312	5	3.37	0.57
316	6	4.70	0.71
376	7	5.98	0.86
317	8	7.00	1.00

SWPB AE minutes/cell day

Data Point	Rank	AE min/cell day	Cum. Frac.
287	1	1.39	0.00
357	2	2.34	0.14
349	3	2.67	0.29
285	4	2.95	0.43
317	5	3.93	0.57
316	6	5.36	0.71
312	7	5.68	0.86
376	8	8.79	1.00

SWPB PFC Emissions (t CO2-eq/t Al)

Data Point	Rank	PFC Emissions (t CO2-eq/t Al)	Cum Frac.
287	1	3.56	0.00
268	2	4.85	0.11
357	3	5.04	0.22
349	4	5.74	0.33
285	5	5.79	0.44
317	6	8.47	0.56
316	7	11.53	0.67
312	8	12.22	0.78
335	9	13.56	0.89
376	10	18.92	1.00

D. VSS Rankings

VSS AEF

Data Point	Rank	AEF	Cum. Frac.
276	1	0.13	0.00
343	2	0.33	0.02
334	3	0.45	0.04
259	4	0.54	0.06
315	5	0.57	0.09
355	6	0.76	0.11
347	7	0.83	0.13
388		0.83	0.13
389	8	0.88	0.17
291	9	0.92	0.19
385	10	0.95	0.21
395	11	0.96	0.23
391	12	1.01	0.26
386	13	1.02	0.28
392		1.02	0.28
215	14	1.03	0.32
213		1.04	0.34
344	15	1.04	0.34
394		1.04	0.34
381	16	1.05	0.40
379	17	1.06	0.43
384		1.06	0.43
393	18	1.07	0.47
380	19	1.08	0.49
382		1.08	0.49
214		1.10	0.53
216	20	1.10	0.53
399		1.10	0.53
387	21	1.17	0.60
286	22	1.18	0.62
378		1.18	0.62
383	23	1.23	0.66
397	24	1.26	0.68
398		1.26	0.68
390	25	1.33	0.72
396	26	1.41	0.74
274	27	1.45	0.77
258	28	1.50	0.79
275	29	1.54	0.81
240	30	1.60	0.83
241		1.60	0.83
281	31	1.62	0.87
361	32	1.86	0.89
362		1.86	0.91
360	33	2.52	0.94
346	34	2.73	0.96
345	35	2.85	0.98
228	36	2.88	1.00

VSS AED (minutes)

Data Point	Rank	AED (min)	Cum. Frac.
215	1	1.55	0.00
213	2	1.71	0.02
214	3	1.72	0.04
216	4	1.90	0.06
385		1.90	0.06
393	5	1.94	0.11
395		1.94	0.11
392	6	1.95	0.15
382		1.95	0.15
390	7	1.96	0.19
399		1.96	0.19
381	8	2.00	0.23
384		2.00	0.23
391	9	2.01	0.28
394	10	2.02	0.30
398		2.02	0.30
386	11	2.03	0.34
389	12	2.09	0.36
396		2.09	0.36
380	13	2.10	0.40
387	14	2.11	0.43
397	15	2.12	0.45
383	16	2.14	0.47
379	17	2.16	0.49
378	18	2.17	0.51
334	19	2.30	0.53
276		2.30	0.55
388	20	2.54	0.57
315	21	2.65	0.60
344	22	2.76	0.62
259	23	2.81	0.64
258	24	3.00	0.66
345	25	3.23	0.68
275	26	3.24	0.70
346	27	3.28	0.72
361	28	3.45	0.74
362		3.45	0.74
274	29	3.47	0.79
281	30	3.62	0.81
286	31	3.65	0.83
360	32	3.80	0.85
291	33	3.87	0.87
228	34	4.13	0.89
240	35	4.50	0.91
241		4.50	0.91
347	36	4.93	0.96
343	37	6.77	0.98
355	38	7.72	1.00

VSS AE minutes/cell day

Data Point	Rank	AE min/cell day	Cum. Frac.
276	1	0.31	0.00
334	2	1.02	0.02
315	3	1.51	0.04
259	4	1.52	0.06
215	5	1.60	0.09
213	6	1.78	0.11
385	7	1.81	0.13
389	8	1.84	0.15
395	9	1.86	0.17
214	10	1.89	0.19
392	11	1.99	0.21
391	12	2.03	0.23
386	13	2.07	0.26
393	14	2.08	0.28
216	15	2.09	0.30
381	16	2.10	0.32
394		2.10	0.34
382	17	2.11	0.36
388		2.11	0.38
384	18	2.12	0.40
399	19	2.16	0.43
343	20	2.23	0.45
380	21	2.27	0.47
379	22	2.29	0.49
387	23	2.47	0.51
398	24	2.55	0.53
378	25	2.56	0.55
390	26	2.61	0.57
383	27	2.63	0.60
397	28	2.67	0.62
344	29	2.87	0.64
396	30	2.95	0.66
291	31	3.58	0.68
347	32	4.09	0.70
286	33	4.31	0.72
258	34	4.50	0.74
275	35	4.99	0.77
274	36	5.03	0.79
281	37	5.86	0.81
355	38	5.87	0.83
361	39	6.42	0.85
362	40	6.43	0.87
240	41	7.20	0.89
241		7.20	0.89
346	42	8.95	0.94
345	43	9.21	0.96
360	44	9.56	0.98
228	45	11.89	1.00

VSS PFC Emissions (t CO2-eq/t Al)

Data Point	Rank	PFC Emissions (t CO2-eq/t Al)	Cum Frac.
276	1	0.14	0.00
334	2	0.48	0.02
259	3	0.54	0.04
315	4	0.71	0.06
215	5	0.75	0.09
213	6	0.84	0.11
385	7	0.85	0.13
389	8	0.86	0.15
395	9	0.87	0.17
214	10	0.89	0.19
392	11	0.93	0.21
391	12	0.95	0.23
386	13	0.97	0.26
393		0.97	0.28
216	14	0.98	0.30
381		0.99	0.32
394	15	0.99	0.34
382		0.99	0.36
388		0.99	0.38
384	16	1.00	0.40
399	17	1.01	0.43
343	18	1.05	0.45
380	19	1.07	0.47
379	20	1.08	0.49
387	21	1.16	0.51
398	22	1.20	0.53
378		1.20	0.55
390	23	1.22	0.57
383	24	1.24	0.60
397	25	1.25	0.62
344	26	1.35	0.64
396	27	1.38	0.66
291	28	1.68	0.68
286	29	2.02	0.70
258	30	2.11	0.72
275	31	2.34	0.74
274	32	2.36	0.77
347	33	2.56	0.79
355	34	2.76	0.81
361	35	3.02	0.83
362		3.02	0.85
240	36	3.38	0.87
241		3.38	0.87
346	37	4.20	0.91
345	38	4.32	0.94
281	39	4.84	0.96
228	40	5.59	0.98
360	41	6.89	1.00

E. HSS Rankings

HSS AEF

Data Point	Rank	AEF	Cum. Frac.
320	1	0.34	0.00
297	2	0.45	0.11
223	3	0.70	0.22
224	4	0.76	0.33
277	5	0.86	0.44
321	6	0.89	0.56
313	7	0.94	0.67
218	8	2.08	0.78
220	9	2.14	0.89
219	10	2.19	1.00

HSS AED (minutes)

Data Point	Rank	AED (min)	Cum. Frac.
297	1	1.93	0.00
320	2	2.22	0.11
224	3	2.56	0.22
223	4	2.57	0.33
219	5	3.37	0.44
220	6	3.73	0.56
321	7	3.95	0.67
218	8	3.98	0.78
277	9	4.70	0.89
313		4.70	1.00

HSS AE minutes/cell day

Data Point	Rank	AE min/cell day	Cum. Frac.
320	1	0.75	0.00
297	2	0.87	0.11
223	3	1.80	0.22
224	4	1.95	0.33
321	5	3.52	0.44
277	6	4.04	0.56
313	7	4.40	0.67
219	8	7.38	0.78
220	9	7.98	0.89
218	10	8.28	1.00

HSS PFC Emissions (t CO2-eq/t Al)

Data Point	Rank	PFC Emissions (t CO2-eq/t Al)	Cum Frac.
320	1	1.01	0.00
297	2	1.06	0.11
223	3	2.40	0.22
224	4	2.60	0.33
321	5	4.70	0.44
277	6	5.40	0.56
313	7	5.88	0.67
219	8	9.86	0.78
220	9	10.66	0.89
218	10	11.06	1.00