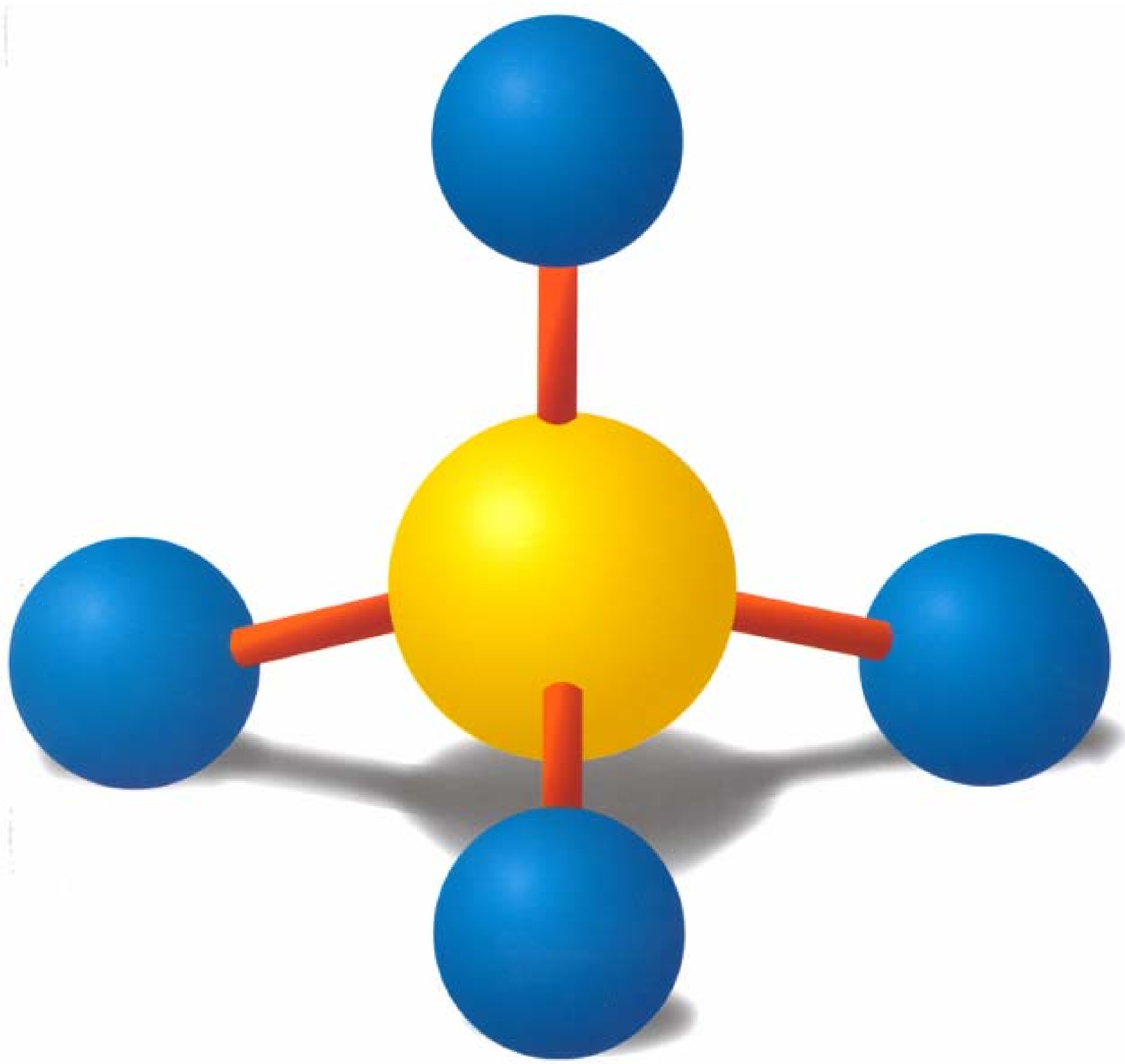
International **A**luminium **I**nstitute

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

RESULTS OF THE 2004 ANODE EFFECT SURVEY



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1. Introduction

The results of the analysis of the 2004 IAI anode effect survey data are presented here. The 2004 survey continues the series of surveys covering anode effect data from global aluminium producers over the period from 1990 through 2004. 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 2004. Participation in the 2004 survey accounted for just over 60 percent of overall global primary production, continuing the slight downward trend in participation in the anode effect survey in recent years. The deterioration in participation has been the result of the growing global share of Chinese production. Chinese and Russian producers do not yet participate in the survey and account for the major part of the gap in coverage.

	PFPB	**CWPB**	**SWPB**	**VSS**	**HSS**	**All**
Participating in Survey (tonnes)	14,028,921	1,041,854	690,324	1,894,801	370,672	18,026,572
Non-Participants (tonnes)	7,133,750	816,040	286,000	2,467,000	1,124,950	11,827,740
Participation (Percent of total)	66.3%	56.1%	70.7%	43.4%	24.8%	60.4%

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

Table 1 - 2004 Anode Effect Survey Participation by Technology Type

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 29.9 million tonnes in 2004. Chinese and Russian productions are included in Figure 1 from expert estimates. Figure 1 also illustrates that the increases in production between 1990 and 2004 are mainly due to increases in the lowest PFC emitting PFPB technology.

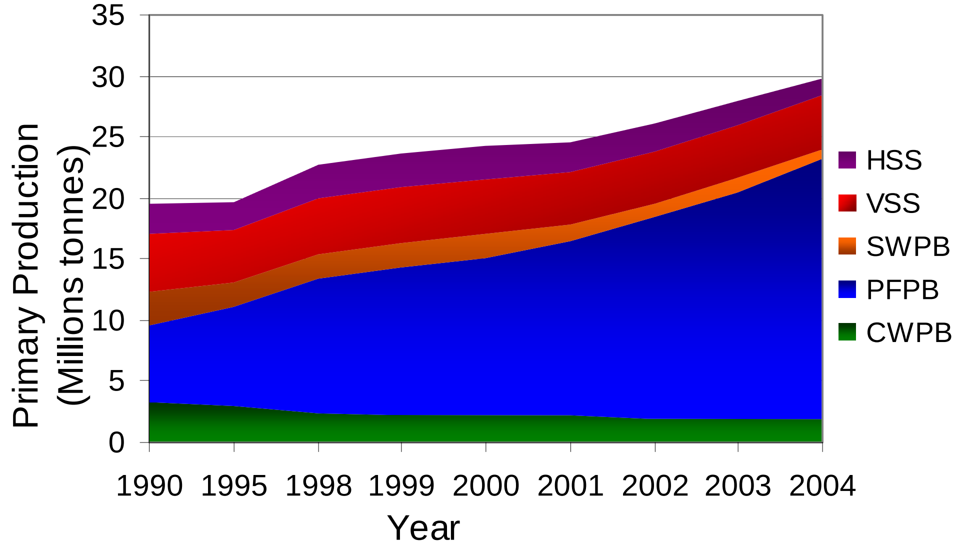

Figure 1 – Global Primary Aluminium Production by Technology Type, from 1990 through 2004

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.

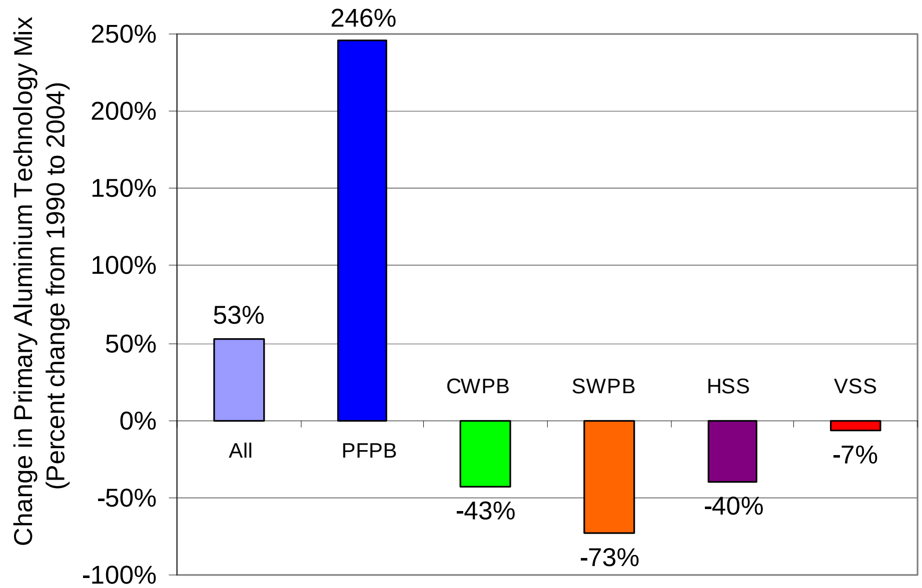

Figure 2 – Changes in Production by Technology Type from 1990 through 2004

Figure 2 shows that the production for CWPB and HSS technologies has decreased by approximately 40% over the period from 1990 to 2004. Over the same period production SWPB technology decreased by 73% while VSS production has decreased only slightly by 7 percent. The PFPB technology has grown by almost 2.5 times from 1990 to 2004, accounting for the overall growth in primary production of 53% over the same period.

Participation rate in the 2004 survey is highest for the facilities operating with Point Feed Prebake technology while survey participation from Søderberg producers represented less than half of global Søderberg production. The low Søderberg participation rate results from the fact that Russian producers, which operate predominately with Søderberg technology, do not yet participate in the survey. Figure 3 shows the breakdown of the 112 reporting facilities by technology type. The PFPB technology is the largest group accounting for 72 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.

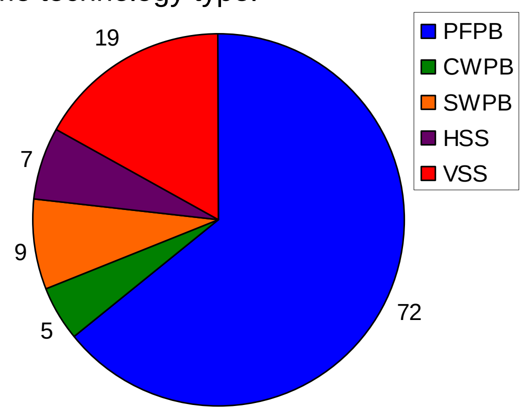

Figure 3 – Breakdown of 2004 Survey Reporting Facilities by Technology Type

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, AP-30 Point Feed Prebake cells and if Sidework cells utilized Alcan Pechiney control technology recording overvoltage. 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 a continuing effort to improve the accuracy of the survey results, participants were also asked to report if a facility specific PFC measurement had been conducted and if an IPCC Tier 3b coefficient were available for calculating PFC emissions for the facility. Of the 112 reporting facilities, 24 respondents reported facility specific Tier 3b coefficients 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].

[1] *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories,* Section 3.39, http://www.ipcc-nggip.iges.or.jp/public/gp/english/3_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.

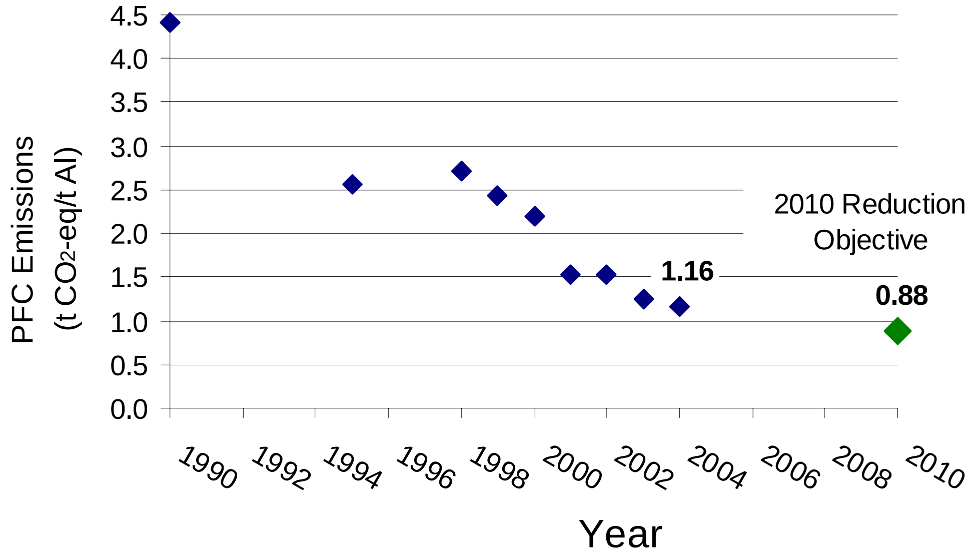

Figure 4 – Progress in Reducing PFC Emissions per Tonne Aluminium Produced

Figure 4 shows that global emissions have been reduced from 4.42 tonne equivalents CO_2 per tonne aluminium in 1990 to 1.16 in 2004, a reduction of 74%. 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 24% of the 2004 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 emissions calculated for survey participants for each technology group to estimate total emissions from survey non-participants. Specifically, the median CF_4 emissions per tonne aluminium for survey participants were calculated for each technology type. The corresponding C_2F_6 emissions per tonne aluminium for each technology type were then calculated by multiplying the median CF_4 emissions per tonne aluminium by the weight fraction of C_2F_6 to CF_4. These weight fractions were calculated for each technology category by dividing the slope values for C_2F_6 by the slope for CF_4. These median emissions for CF_4 and C_2F_6 were then converted to CO_2 equivalent emissions per tonne aluminium by multiplying by the GWPs, 6500 for CF_4 and 9200 for C_2F_6. 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 2004 are shown in Figure 5.

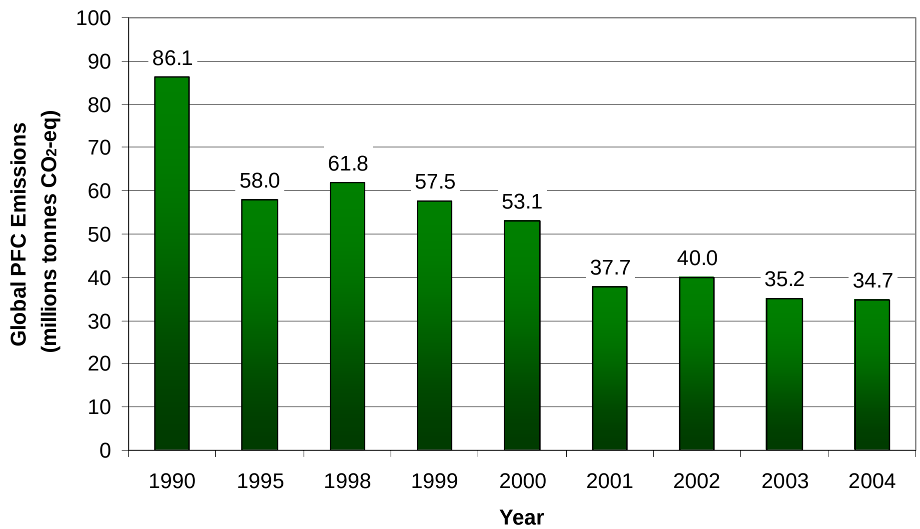

Figure 5 – Total PFC Emissions from Primary Aluminium Production by Year

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 34.7 million tonnes CO_2 equivalents in 2004, a reduction of 60 percent, even though the total primary production has increased over that same period from 19.5 to 29.9 million tonnes, an increase of 53 percent. The PFC emissions calculated for 2004 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 2004 for each of the major 5 aluminium production cell types.

Record low emissions performance was recorded for both PFPB and CWPB technology groups in 2004 with the lowest median emissions recorded since 1990. The median VSS PFC emissions per tonne aluminium remained essentially unchanged from 2003 and the SWPB and HSS technologies showed significant increases in emissions per tonne aluminium over 2003.

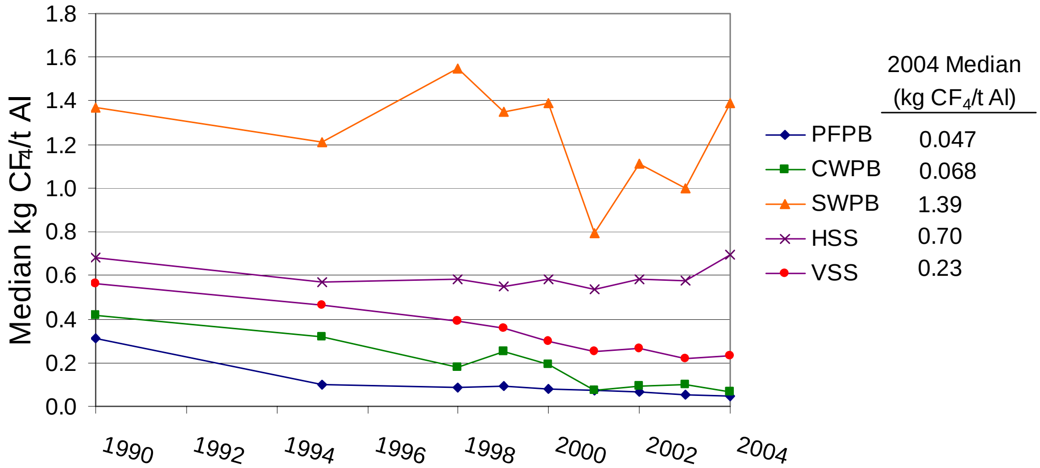

Figure 6 – Median CF_4 Emissions per Tonne Aluminium Produced by Reduction Technology Type from 1990 through 2004

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, 7.7 million tonnes were from non-OECD countries as compared with 10.3 million tonnes from OECD countries. Producers in non-OECD countries set benchmarks for the PFPB and CWPB facilities in 2004. These benchmarks, 0.020 t CO_2-eq/t Al for PFPB and 0.16 t CO_2-eq/t Al, can be compared with median emissions for all survey respondents of 0.36 t CO_2-eq/t Al for PFPB and 0.57 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 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 1 shows that non-OECD countries have a considerably larger share of production, 39.1% as compared with 27.0%, in the highest performing, lowest emitting quartile. There is still potential for improvement in the non-OECD producers in that the percent of non-OECD producers in the highest emitting quartile is also higher than that for OECD producers.

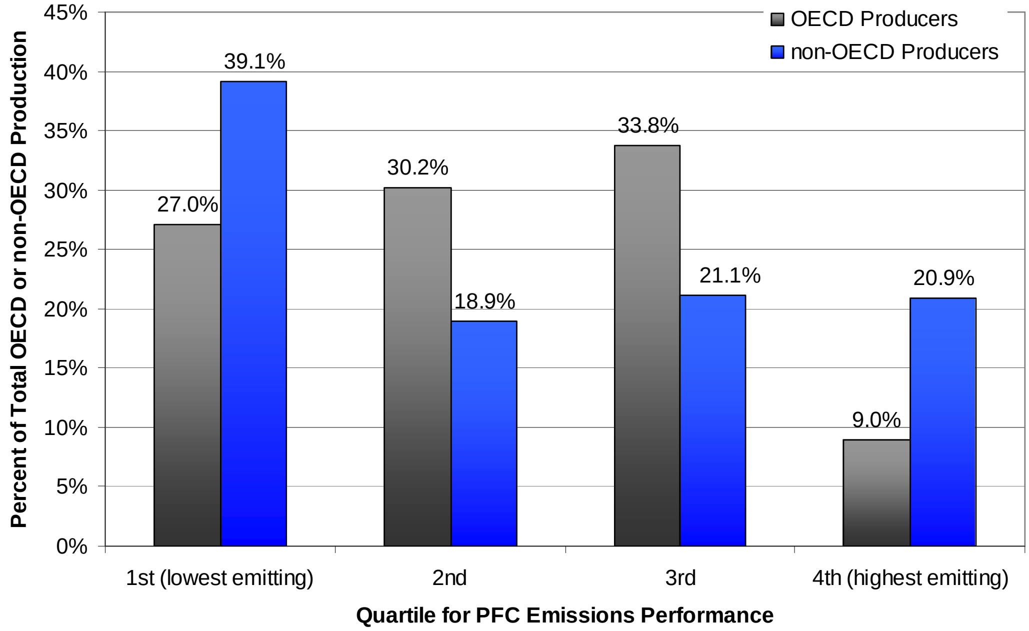

Figure 7 – Comparison of PFC Emission Performance of OECD and non-OECD Producers by Production

4. Impact of Anticipated Changes 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 last update to the IPCC Good Practices, published in 2000, has served as the basis for PFC calculations for this report. The IPCC 2000 good practices are also reflected in the IAI Protocol for Inventory of Greenhouse Gases from the Aluminium Sector.[3] The IPCC Good Practices are currently under revision. The IAI Climate Change Task Force, with the invitation of IPCC, has been working on the revision to the Good Practices for inventory of greenhouse gases from aluminium production. The revised document is scheduled to be adopted later 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.

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 2004 were recalculated using the

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

coefficients in the latest draft of the revised Good Practices.[4] The results of the calculations are shown in Figure 8.

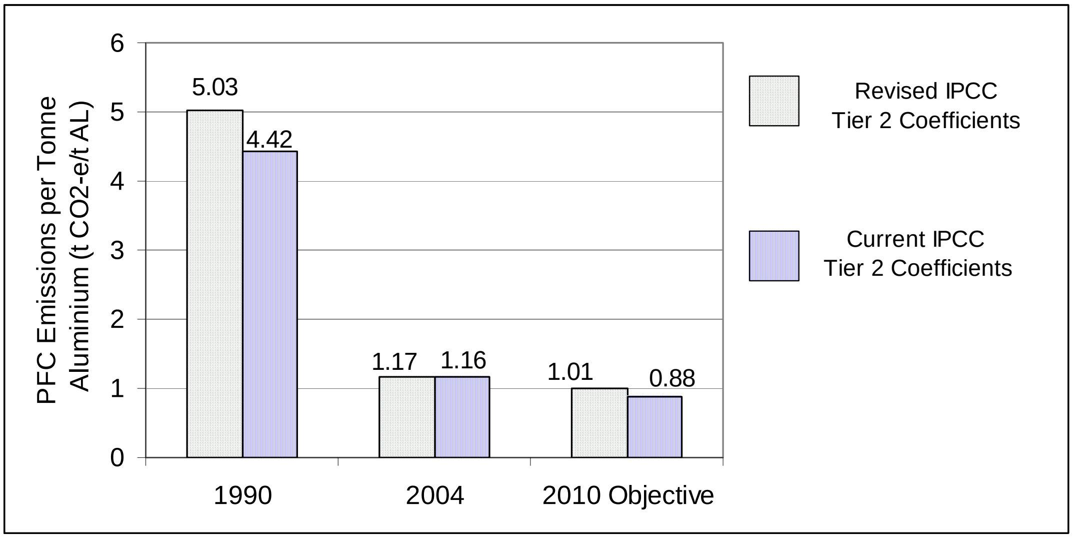

Figure 8 – Impact of Revised IPCC Tier 2 Coefficients on IAI Objective to Reduce PFC Emissions by 80% by 2010 from 1990 Base

The impact of the revised coefficients is to raise the 1990 baseline from 4.42 to 5.03 tonnes CO_2-e per tonne aluminium, an increase of 14%. In contrast, the impact of the revisions on the 2004 PFC emissions is much lower, only 9%. The difference in impacts of the revisions between 1990 and 2004 is due in major part to the relative change in technology mix from 1990 to 2004. As was seen in Figure 2 there has been a 246% increase in the PFPB production and over the same time there was a decrease in SWPB production of 73%. 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 2004 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.

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,

[4] The revised Good Practices is at the time of this report available as a pre-publication draft from http://www.ipcc-nggip.iges.or.jp/public/2006gl/ppd.htm.

c. estimates of emissions for producers that do not participate in the 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.

A Monte Carlo simulation was done comparing the 2004 IAI anode effect survey data with the survey data from 1990. Rather than using constant values for the IPCC Tier 2 coefficients in the equations for calculation of CF_4 and C_2F_6 emissions per tonne aluminium for survey participants, the Monte Carlo simulation uses multiple iterations of random possible values from a predefined distribution of potential values. The distributions for this analysis were determined from an analysis of the measurement database from which the 2006 revised IPCC Tier 2 coefficients were calculated. For non-participants, a uniform distribution of potential values of kg CF_4 per tonne aluminium was assumed with a minimum equal to the lowest CF_4 emissions per tonne aluminium reported in the survey and a maximum equal to the highest in the survey. The corresponding C_2F_6 per tonne aluminium was calculated by multiplying each calculated value for kg CF_4 per tonne aluminium by a randomly selected value for weight fraction C_2F_6 to CF_4 selected from the defined distribution of C_2F_6/CF_4 weight fractions by technology type. The results of the simulation are shown in Figures 9 and 10.

Figure 9 shows a comparison of 1990 and 2004 total emissions of PFCs as CO_2 equivalents.

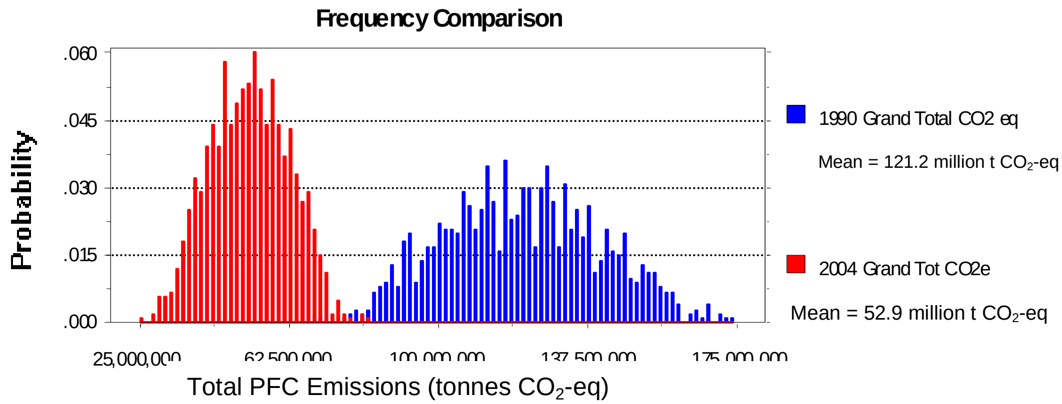

Figure 9 – Simulation Comparing 1990 and 2004 Total PFC Emissions Based on Proposed IPCC Factors

The analysis predicts that, with 95% confidence, 2004 PFC emissions lie between 34.6 and 71.3 tonnes CO_2-eq and 1990 PFC emissions lie between 85.7 and 158.7 tonnes CO_2-eq. Considering the mean values as most probable, the simulation predicts total emissions have been reduced by 56.3%. The simulation results can be compared with the mean results using the calculation methodology described on pages 4 and 5. In that calculation the projected total PFC emissions were 86.1

million t CO2-eq in 1990 reduced to 34.7 million t CO2-eq in 2004 for a reduction of 60%.

Simulations for PFC emissions per tonne aluminium produced are shown in Figure 10. The simulations result in means of 6.7 tonnes CO_2-eq per tonne aluminium for 1990 and 1.8 t CO2-eq/t Al in 2004.

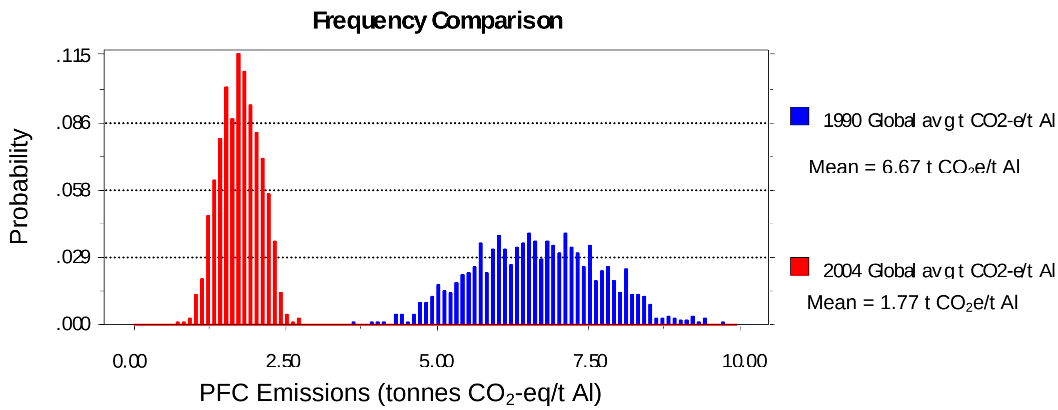

Figure 10 – Simulation Comparing 1990 and 2004 PFC Emissions per tonne Aluminium Based on Proposed IPCC Factors

The simulations illustrated in Figures 9 and 10 show the certainty of calculations of PFC emissions improving from 1990 to 2004. This increase in certainty is the combined result of several factors. First, the mix of technologies has changed substantially from 1990 to 2004 with a major increase in the percent of PFPB production technology. The uncertainty in the Tier 2 coefficients for PFPB technology is lower than for other technologies. In addition, the uncertainty in calculating the PFC emissions is lower for PFPB technology because the range of emissions from reporting survey participants is lower for this technology category than for the Søderberg and SWPB technology groups.

Another factor reducing the uncertainty over time has been the incorporation of a larger number of producers that have made PFC measurements, thus allowing calculation of PFCs by the IPCC Tier 3 method with inherently higher certainty than the Tier 2 methods. Finally, the certainty of the results is greatly affected by the percent of global aluminium production included in the survey. After participation steadily increased from 60.7% in 1990 to 68.8% in 1999, the lack of participation by Russian and Chinese producers has resulted in a steady decline in participation since 1999 to 60.4% in 2004. Survey participation dropped below the 1990 level for the first time in 2004. Certainty in calculations can be greatly improved with participation of these two major producers in the survey.

Figure 11 shows the result of a simulation in which the percent reduction in PFC emissions per tonne aluminium from 1990 to 2004 is calculated. The result of this simulation is a mean reduction of 75.6% with 95% confidence range from 66.2% reduction to 82.5% reduction. The mean reduction of 75.6% calculated from the simulation compares with 75.2% calculated by the established method described on pages 4 to 5.

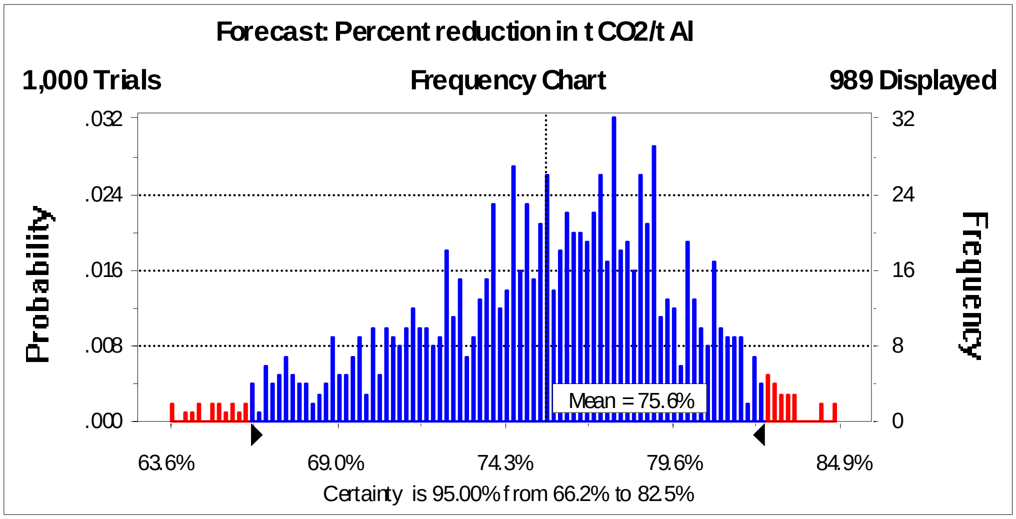

Figure 11 – Simulation of the Percent Reduction in PFC Emissions per Tonne Aluminium from 1990 to 2004

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.

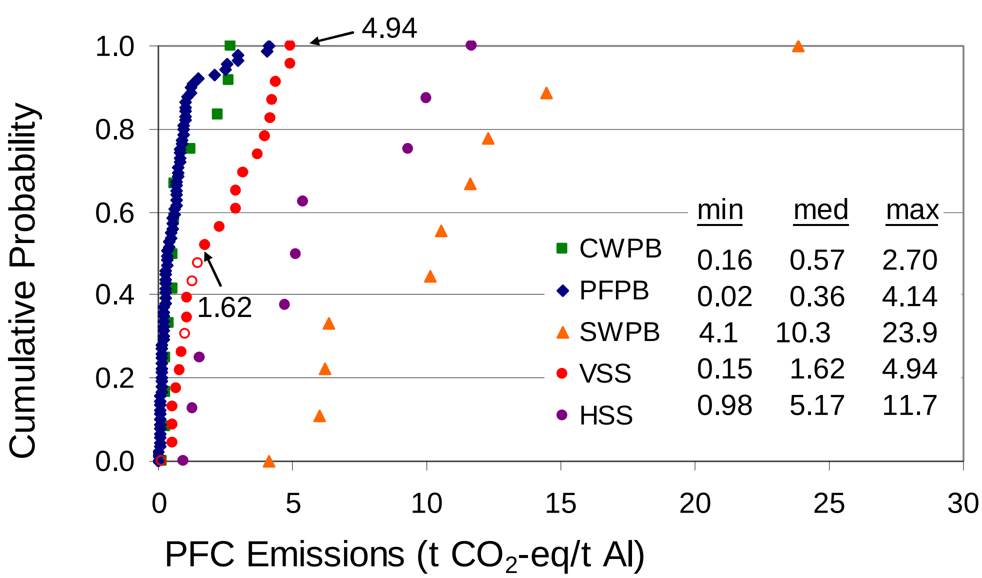

Figure 12 – Cumulative Probability Graph for PFC Emissions per Tonne Aluminium Produced for Survey Participants by Technology Type

Figure 12 shows the 2004 benchmark data for PFC emissions per tonne aluminium produced by technology type.

To illustrate how the graph is interpreted, take for example in Figure 12 the 0.50 point on the vertical axis the VSS data point is 1.62 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 1.62 tonne CO_2-eq/tonne Al. At 1.00 on the vertical axis the VSS point is 4.94. The interpretation is that all VSS facilities reported anode effect data that reflected PFC emissions performance at or below 4.94 tonne CO_2-eq/tonne Al, or, the maximum value calculated for VSS operators in 2004 was 4.94 tonne CO_2-eq/tonne Al. Figure 12 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 13 shows the distribution of anode effect frequency data for reporting facilities in 2004. 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.

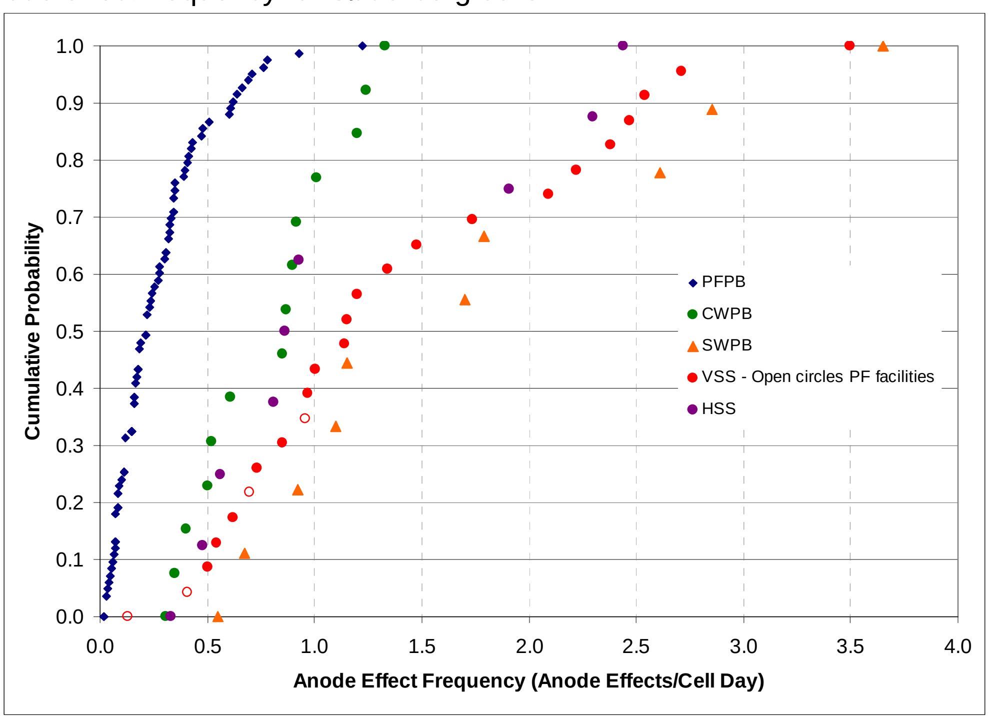

Figure 13 - Cumulative Probability Graph for Anode Effect Frequency for Survey Participants by Technology Type

Figure 14 shows comparative performance for anode effect duration performance for all reporting facilities.

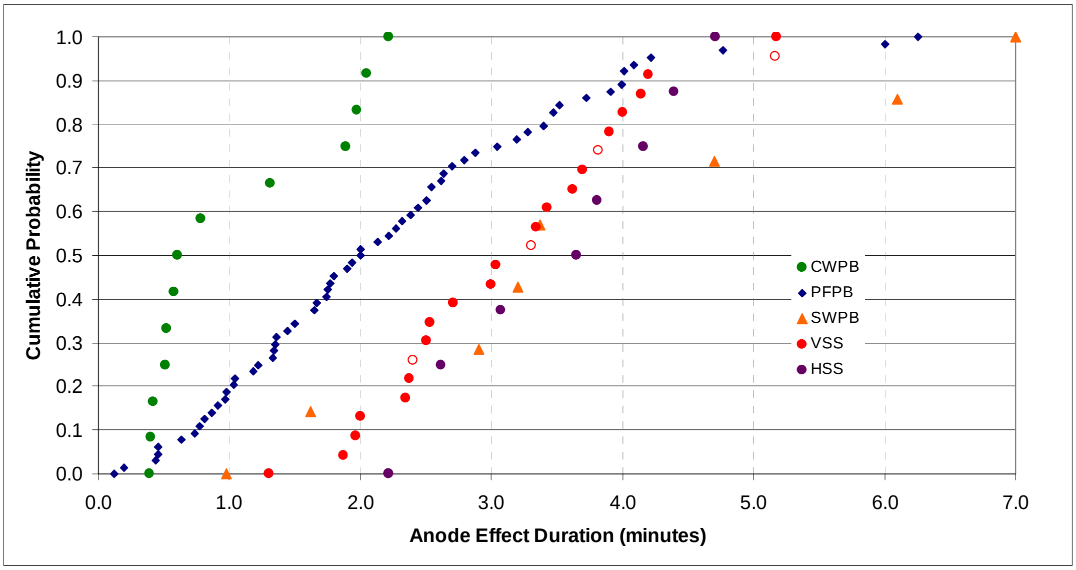

Figure 14 - Cumulative Probability Graph for Anode Effect Duration for Survey Participants by Technology Type

The very shortest average anode effect durations, 7 and 11 seconds, respectively, are recorded for two PFPB facilities. Next in order of anode effect duration performance is the bar broken CWPB cells. The median anode effect duration of the CWPB cells was 36 seconds. This can be compared with the median anode effect duration for PFPB cells of 120 seconds. The SWPB, VSS and HSS cells have the longest anode effect duration; however, one VSS facility operated with an average anode effect duration of 78 seconds.

Figure 15 shows benchmarking data for all technology groups that utilize the slope method for calculating PFC emissions per tonne aluminium.

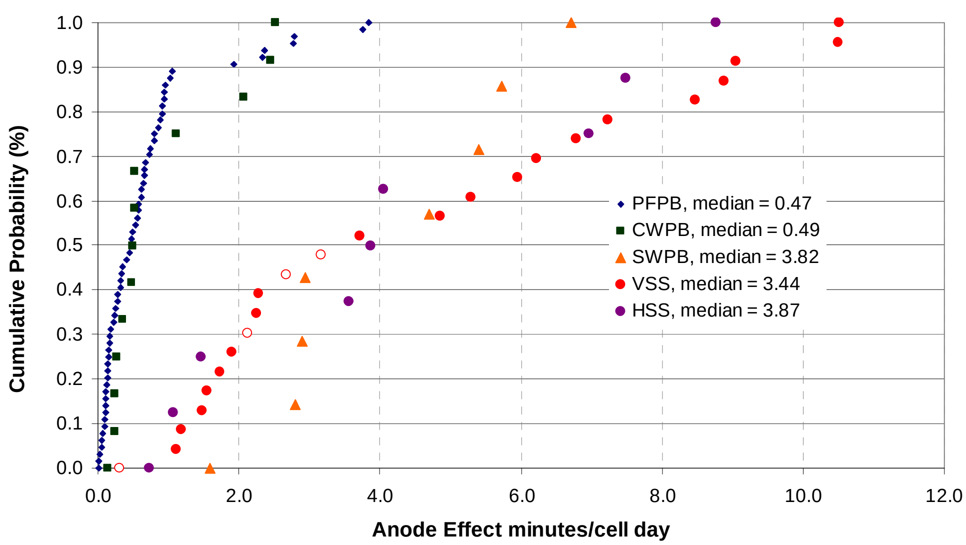

Figure 15 - Cumulative Probability Graph for Anode Effect Minutes Per Cell Day for Survey Participants by Technology Type

The anode effect minutes per cell day data shown in Figure 15 is the result of multiplying the average anode effect frequency parameter times the average anode effect duration. Anode effect minutes per cell day relates directly to PFC emissions per cell day through the slope factor. Figure 15 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 16 shows the benchmarking graph for anode effect overvoltage for PFPB cells operating with Alcan AP technology. For these operators the overvoltage parameter relates directly to PFC emissions per tonne aluminium produced. Operators recording positive overvoltage reported a considerably larger range of overvoltage than do operators measuring algebraic overvoltage. This is to be expected since long anode effects requiring multiple bridge movements are more likely to have subtracted voltage.

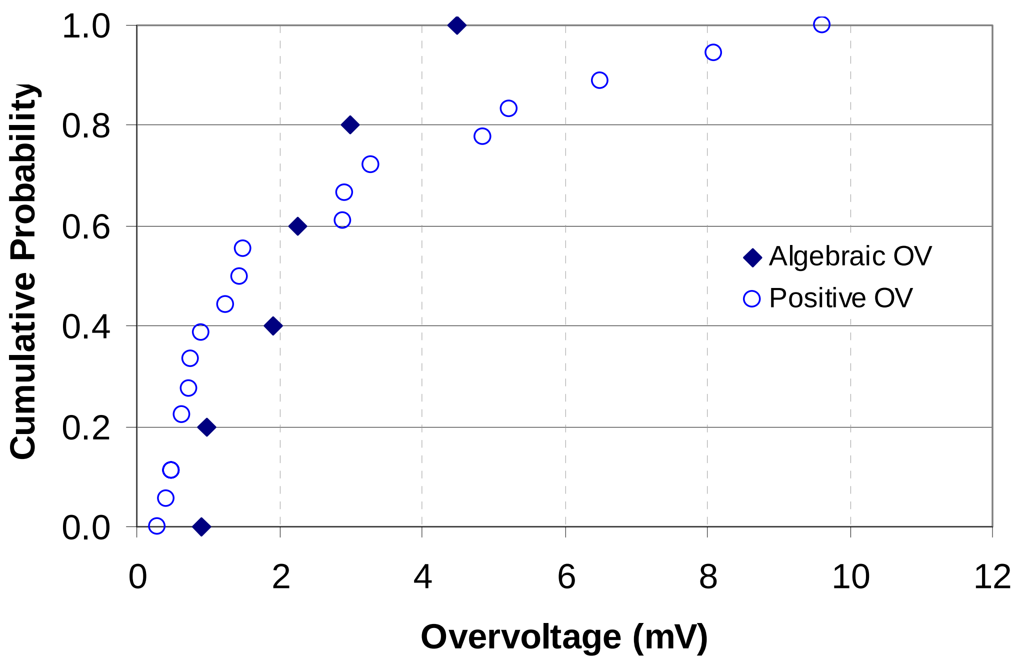

Figure 16 - Cumulative Probability Graph for Anode Effect Overvoltage for Survey Participants Operating with Alcan AP Technologies

7. SWPB Initiative

Analysis of 2004 survey data shows, as did the 2003 survey, that the SWPB technology group results in emissions that are disproportionate to the tonnes aluminium produced. Figure 3 showed the breakdown of total production by technology type. In Figure 3 SWPB technology makes up just 3% of global primary aluminium production. A similar breakdown in Figure 17 for global PFC emissions by technology type shows that SWPB producers account for 26% of total PFC emissions from aluminium production.

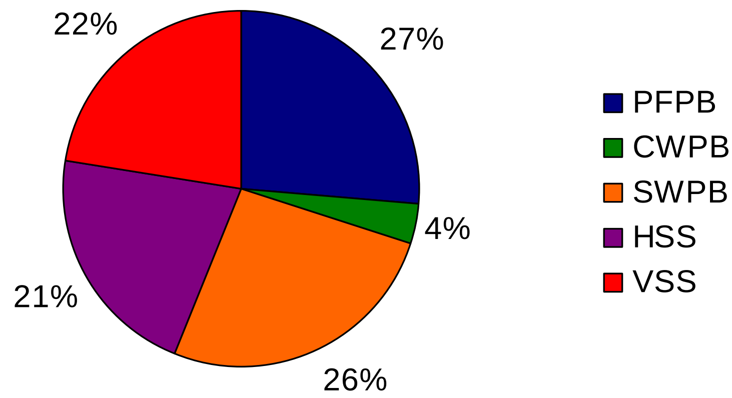

Figure 17 – Breakdown of Global PFC Emissions from Primary Aluminium Production by Technology Type

Figures 12 to 15 show the performance of the SWPB cells relative to other technologies for parameters affecting PFC emissions. During 2005 a special focus was placed on SWPB facilities to achieve reductions at these facilities to accelerate emissions reductions. As part of the initiative, SWPB producers were surveyed as to factors that might contribute to the high rate of PFC emissions from these cells. The key findings from the SWPB study are:

- SWPB cells differ considerably in cell design among the facilities and are inherently unstable and difficult to operate.
- 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.
- Bath chemistry control is important, particularly for those operators who use lithium fluoride in the bath.
- Location specific work practices can impact anode effect duration substantially with a direct impact on PFC emissions.
- PFC measurements and Tier 3 calculation methods are particularly important for SWPB facilities because the equation coefficients give the highest emissions per unit time on anode effect for any technology.
- There is still considerable potential for PFC emissions performance improvement within the SWPB technology group.
- Retrofitting SWPB facilities with point feeders offers dramatic reductions in PFC emissions not only because of a reduction in the frequency and duration of anode effects, but, also because the PFC emissions per minute of anode effect are halved.

The producers focus on reducing emissions from the SWPB technology group should be visible in the 2005 anode effect survey results. A similar focus is planned for Søderberg cell technology in 2006.

8. Summary and Conclusions

The 2004 IAI anode effect performance survey results continue the trend of reduced global PFC emissions. Projections of global PFC emissions per tonne aluminium produced based on applying the participants' median anode effect performance levels to non-participating production show a improvement to 1.16 t CO_2 equivalents/t Al. Calculation of total global emissions of PFCs to the atmosphere in 2004 from primary aluminium production showed the lowest emissions of PFCs to the atmosphere over the period of the study from 1990, 34.7 million tonnes CO_2 equivalents.

IPCC Tier 2 coefficients used to calculate PFC emissions per tonne aluminium are being revised and will impact IAI emissions projections for those facilities that have not yet made PFC measurements. Using the current proposed values for the revised IPCC Tier 2 coefficients analysis of 1990 and 2004 anode effect data were made. The results showed that the 1990 emissions were impacted more than 2004 emissions, raising the 1990 baseline from 4.42 to 5.03 tonnes CO_2-e per tonne aluminium, an increase of 14% while the 2004 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 with 2004 reductions at 76.7% with the revised coefficients as compared with 73.8% with the current calculations.

Uncertainty in global aluminium PFC emissions can be reduced by getting higher participation in the anode effect survey. In 2004 survey participation fell for the first time to a level lower than for the 1990 survey. Participation in the anode effect survey by 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 make the further reductions necessary to achieve the IAI Board's goal of an 80% reduction in PFC emissions by 2010 from the 1990 baseline.

Appendix – 2004 Benchmark Data

A. PFPB Rankings

Data Point	Rank	AEF	Cum Frac.
1		0.02	0.00
35	1	0.02	0.00
88		0.02	0.00
135	2	0.03	0.04
123	3	0.03	0.05
136	4	0.04	0.06
38	5	0.05	0.07
100	6	0.06	0.08
63	7	0.06	0.10
101	8	0.06	0.11
22	9	0.07	0.12
32		0.07	0.13
125	10	0.07	0.13
24		0.07	0.13
57		0.07	0.13
4	11	0.07	0.18
121	12	0.08	0.19
56		0.08	0.19
90	13	0.084	0.22
77	14	0.09	0.23
89	15	0.10	0.24
65		0.11	0.25
27		0.11	0.25
66	16	0.11	0.25
76		0.11	0.25
110		0.11	0.25
73	17	0.12	0.31
118		0.15	0.33
109	18	0.15	0.33
56		0.15	0.33
86		0.15	0.33
87	19	0.16	0.37
127	20	0.16	0.39
99		0.16	0.39
52	21	0.17	0.41
61	22	0.17	0.42
156		0.18	0.43
53	23	0.18	0.43
78-3		0.18	0.43
79	24	0.19	0.47
6	25	0.19	0.48
64		0.21	0.49
30	26	0.21	0.49
78-4		0.21	0.49
51	27	0.22	0.53
10	28	0.23	0.54
62	29	0.24	0.55
126	30	0.24	0.57
82	31	0.25	0.58
78-2	32	0.27	0.59
18	33	0.28	0.60
106	34	0.28	0.61
152	35	0.30	0.63
78-1	36	0.31	0.64
18		0.31	0.64
37	37	0.32	0.66
84	38	0.33	0.67
111	39	0.33	0.69
155	40	0.33	0.70
120	41	0.34	0.71
124		0.34	0.71
132	42	0.34	0.73
128	43	0.35	0.75
153	44	0.35	0.76
154	45	0.39	0.77
131	46	0.40	0.78
92	47	0.41	0.80
130	48	0.41	0.81
129	49	0.42	0.82
2	50	0.43	0.83
31	51	0.47	0.84
116	52	0.48	0.86
48	53	0.51	0.87
150	54	0.60	0.88
112	55	0.61	0.89
23	56	0.62	0.90
72	57	0.64	0.92
71	58	0.66	0.93
149	59	0.69	0.94
47	60	0.71	0.95
70	61	0.77	0.96
93	62	0.78	0.98
134	63	0.93	0.99
151	64	1.22	1.00

Data Point	Rank	t CO2/t Al	Cum frac.
136	1	0.020	0.000
65	2	0.023	0.011
53	3	0.023	0.022
14	4	0.046	0.033
44	5	0.050	0.044
76	6	0.052	0.056
35	7	0.054	0.067
57	8	0.065	0.078
32	9	0.066	0.089
110	10	0.068	0.101
1	11	0.075	0.112
56	12	0.077	0.123
13	13	0.077	0.134
123	14	0.084	0.146
125	15	0.100	0.157
64	16	0.104	0.168
52	17	0.114	0.179
63	18	0.114	0.191
73	19	0.117	0.202
12	20	0.138	0.213
79	21	0.146	0.224
135	22	0.150	0.235
38	23	0.150	0.247
84	24	0.152	0.258
101	25	0.161	0.269
86	26	0.165	0.280
27	27	0.170	0.292
109	28	0.180	0.303
100	29	0.183	0.314
127	30	0.190	0.325
137	31	0.194	0.337
4	32	0.200	0.348
124	33	0.228	0.359
56	34	0.229	0.370
118	35	0.242	0.382
156	36	0.256	0.393
24	37	0.256	0.404
77	38	0.279	0.415
88	39	0.295	0.426
99	40	0.299	0.438
66	41	0.300	0.449
121	42	0.303	0.460
106	43	0.310	0.471
22	44	0.349	0.483
18	45	0.355	0.494
90	46	0.360	0.505
51	47	0.383	0.516
89	48	0.438	0.528
98	49	0.449	0.539
120	50	0.490	0.550
62	51	0.508	0.561
126	52	0.516	0.573
155	53	0.532	0.584
18	54	0.589	0.595
82	55	0.621	0.606
92	56	0.651	0.617
37	57	0.668	0.629
152	58	0.669	0.640
112	59	0.673	0.651
87	60	0.691	0.662
23	61	0.700	0.674
61	62	0.715	0.685
30	63	0.721	0.696
6	64	0.745	0.707
132	65	0.784	0.719
78-3	66	0.802	0.730
70	67	0.802	0.741
153	68	0.824	0.752
111	69	0.856	0.764
116	70	0.862	0.775
10	71	0.920	0.786
48	72	0.960	0.797
151	73	0.967	0.808
131	74	0.986	0.820
128	75	0.987	0.831
78-4	76	1.000	0.842
129	77	1.012	0.853
93	78	1.029	0.865
130	79	1.111	0.876
78-2	80	1.245	0.887
2	81	1.249	0.898
154	82	1.305	0.910
78-1	83	1.477	0.921
31	84	2.068	0.932
47	85	2.505	0.943
134	86	2.541	0.955
149	87	2.981	0.966
71	88	2.992	0.977
150	89	4.036	0.988
72	90	4.136	1.000

Data Point	Rank	AE Dur	Cum frac.
53	1	0.12	0.00
65	2	0.19	0.02
84	3	0.44	0.03
64	4	0.46	0.05
136	5	0.46	0.06
52	6	0.63	0.08
79	7	0.74	0.09
151	8	0.78	0.11
127	9	0.81	0.13
32	10	0.87	0.14
73	11	0.92	0.16
156	12	0.97	0.17
70	13	0.98	0.19
112	14	1.03	0.20
23	15	1.05	0.22
18	16	1.18	0.23
93	17	1.22	0.25
125	18	1.33	0.27
120	19	1.34	0.28
2	20	1.35	0.30
92	21	1.36	0.31
27	22	1.44	0.33
118	23	1.50	0.34
155		1.50	0.34
51	24	1.65	0.38
116	25	1.67	0.39
99	26	1.74	0.41
48	27	1.75	0.42
63	28	1.77	0.44
152	29	1.80	0.45
153	30	1.90	0.47
37	31	1.94	0.48
126	32	2.00	0.50
62	33	2.00	0.52
132	34	2.13	0.53
129	35	2.22	0.55
82	36	2.27	0.56
131	37	2.32	0.58
101	38	2.38	0.59
111	39	2.44	0.61
35	40	2.50	0.63
130		2.50	0.63
134	41	2.54	0.66
4	42	2.62	0.67
128	43	2.63	0.69
154	44	2.70	0.70
38	45	2.79	0.72
77	46	2.88	0.73
100	47	3.04	0.75
30	48	3.19	0.77
47	49	3.28	0.78
24	50	3.40	0.80
123		3.40	0.80
1	51	3.47	0.83
121	52	3.52	0.84
10	53	3.72	0.86
61	54	3.91	0.88
89	55	3.99	0.89
90		3.99	0.89
149	56	4.01	0.92
31	57	4.09	0.94
71	58	4.22	0.95
22	59	4.77	0.97
72	60	6.00	0.98
150	61	6.25	1.00

PFPB Rankings (Continued)

Data Point	Rank	AE min/cell da	Cum frac.
136	1	0.018	0.00
65	2	0.021	0.02
53	3	0.022	0.03
35	4	0.050	0.05
32	5	0.061	0.06
1	6	0.069	0.08
125	7	0.093	0.09
64	8	0.096	0.11
52	9	0.106	0.13
63		0.106	0.14
73	10	0.109	0.16
123	11	0.116	0.17
127	12	0.130	0.19
79	13	0.136	0.20
38	14	0.140	0.22
84	15	0.141	0.23
101	16	0.150	0.25
27	17	0.158	0.27
100	18	0.170	0.28
156	19	0.175	0.30
4	20	0.186	0.31
118	21	0.225	0.33
24	22	0.238	0.34
77	23	0.259	0.36
99	24	0.278	0.38
121	25	0.282	0.39
22	26	0.324	0.41
18	27	0.330	0.42
90	28	0.335	0.44
51	29	0.356	0.45
89	30	0.407	0.47
120	31	0.456	0.48
62	32	0.473	0.50
126	33	0.480	0.52
155	34	0.495	0.53
152	35	0.540	0.55
92	36	0.558	0.56
82	37	0.577	0.58
2	38	0.581	0.59
37	39	0.621	0.61
112	40	0.625	0.63
23	41	0.651	0.64
61	42	0.665	0.66
153	43	0.665	0.67
30	44	0.670	0.69
132	45	0.728	0.70
70	46	0.746	0.72
111	47	0.796	0.73
116	48	0.802	0.75
10	49	0.856	0.77
48	50	0.893	0.78
131	51	0.916	0.80
128	52	0.918	0.81
129	53	0.941	0.83
151	54	0.947	0.84
93	55	0.956	0.86
130	56	1.033	0.88
154	57	1.053	0.89
31	58	1.922	0.91
47	59	2.329	0.92
134	60	2.362	0.94
149	61	2.772	0.95
71	62	2.782	0.97
150	63	3.752	0.98
72	64	3.845	1.00

Data Point	Rank	OV (mV)	Cum frac.	Alg/Pos
86	1	0.909	0.00	A
135	2	0.975	0.20	A
88	3	1.92	0.40	A
66	4	2.26	0.60	A
124	5	3	0.80	A
87	6	4.5	1.00	A
14	1	0.3	0.00	P
57	2	0.42	0.06	P
13	3	0.5	0.11	P
56		0.5	0.11	P
44	4	0.6493	0.22	P
106	5	0.74	0.28	P
76	6	0.77	0.33	P
12	7	0.9	0.39	P
137	8	1.26	0.44	P
110	9	1.44	0.50	P
56	10	1.49	0.56	P
18	11	2.89	0.61	P
98	12	2.923	0.67	P
109	13	3.3	0.72	P
6	14	4.85	0.78	P
78-3	15	5.22	0.83	P
78-4	16	6.51	0.89	P
78-2	17	8.1	0.94	P
78-1	18	9.61	1.00	P

B. CWPB Rankings

Data Point	Rank	AEF	Cum Frac.
15	1	0.31	0.00
146	2	0.35	0.08
17	3	0.40	0.15
84	4	0.50	0.23
147	5	0.52	0.31
148	6	0.61	0.38
42	7	0.85	0.46
41	8	0.87	0.54
40	9	0.90	0.62
43	10	0.91	0.69
29d	11	1.01	0.77
38	12	1.20	0.85
29b	13	1.24	0.92
29c	14	1.33	1.00

Data Point	Rank	t CO2/t Al	Cum frac.
146	1	0.16	0.00
148	2	0.26	0.08
15	3	0.28	0.17
147	4	0.29	0.25
40	5	0.41	0.33
43	6	0.55	0.42
42	7	0.57	0.50
17	8	0.60	0.58
41	9	0.61	0.67
84	10	1.19	0.75
29d	11	2.23	0.83
29b	12	2.63	0.92
29c	13	2.70	1.00

Data Point	Rank	AED	Cum frac.
148	1	0.39	0.00
40	2	0.40	0.08
146	3	0.42	0.17
43	4	0.52	0.25
147	5	0.52	0.33
42	6	0.58	0.42
41	7	0.60	0.50
15	8	0.78	0.58
17	9	1.31	0.67
29c	10	1.89	0.75
29b	11	1.97	0.83
29d	12	2.05	0.92
84	13	2.22	1.00

Data Point	Rank	AE min/cell da	Cum frac.
146	1	0.147	0.00
148	2	0.238	0.08
15	3	0.242	0.17
147	4	0.270	0.25
40	5	0.357	0.33
43	6	0.472	0.42
42	7	0.488	0.50
41	8	0.523	0.58
17	9	0.524	0.67
84	10	1.110	0.75
29d	11	2.071	0.83
29b	12	2.443	0.92
29c	13	2.514	1.00

C. SWPB Rankings

Data Point	Rank	AEF	Cum Frac.
55	1	0.55	0.00
141	2	0.67	0.11
54	3	0.92	0.22
133	4	1.10	0.33
140	5	1.15	0.44
80	6	1.70	0.56
108	7	1.79	0.67
39	8	2.61	0.78
119	9	2.85	0.89
95	10	3.65	1.00

Data Point	Rank	t CO2/t Al	Cum frac.
55	1	4.09	0.00
119	2	6.02	0.11
108	3	6.24	0.22
54	4	6.33	0.33
141	5	10.11	0.44
39	6	10.55	0.56
140	7	11.63	0.67
80	8	12.33	0.78
133	9	14.44	0.89
95	10	23.85	1.00

Data Point	Rank	AED	Cum frac.
119	1	0.98	0.00
108	2	1.62	0.14
55	3	2.90	0.29
54	4	3.20	0.43
80	5	3.37	0.57
140	6	4.70	0.71
133	7	6.10	0.86
141	8	7.00	1.00

Data Point	Rank	AE min/cell da	Cum frac.
55	1	1.595	0.00
119	2	2.798	0.14
108	3	2.900	0.29
54	4	2.944	0.43
141	5	4.697	0.57
140	6	5.405	0.71
80	7	5.729	0.86
133	8	6.710	1.00

D. VSS Rankings

Data Point	Rank	AEF	Cum Frac.
139	1	0.13	0.00
102	2	0.41	0.043
83	3	0.50	0.09
94	4	0.55	0.13
34	5	0.62	0.17
117	6	0.70	0.22
103	7	0.73	0.26
3c	8	0.85	0.30
55	9	0.96	0.35
3b	10	0.97	0.39
57	11	1.01	0.43
3d	12	1.14	0.48
105	13	1.15	0.52
3a	14	1.20	0.57
45	15	1.34	0.61
24	16	1.48	0.65
142	17	1.74	0.70
49	18	2.09	0.74
143	19	2.22	0.78
122	20	2.38	0.83
144	21	2.47	0.87
15	22	2.54	0.91
145	23	2.71	0.96
33	24	3.50	1.00

Data Point	Rank	t CO2/t Al	Cum frac.
139	1	0.15	0.00
3c	2	0.52	0.04
83	3	0.56	0.09
34	4	0.56	0.13
94	5	0.69	0.17
103	6	0.81	0.22
3b	7	0.89	0.26
102	8	1.00	0.30
3a	9	1.05	0.35
3d	10	1.07	0.39
117	11	1.26	0.43
55	12	1.49	0.48
57	13	1.74	0.52
45	14	2.28	0.57
24	15	2.92	0.61
122	16	2.94	0.65
142	17	3.18	0.70
105	18	3.73	0.74
144	19	3.98	0.78
143	20	4.17	0.83
145	21	4.25	0.87
49	22	4.37	0.91
33	23	4.93	0.96
15	24	4.94	1.00

Data Point	Rank	AED	Cum frac.
3c	1	1.30	0.00
3a	2	1.87	0.04
3b	3	1.96	0.09
3d	4	2.00	0.13
83	5	2.35	0.17
103	6	2.37	0.22
139	7	2.40	0.26
34	8	2.50	0.30
49	9	2.53	0.35
94	10	2.71	0.39
33	11	3.00	0.43
122	12	3.04	0.48
55	13	3.30	0.52
145	14	3.34	0.57
144	15	3.43	0.61
45	16	3.62	0.65
57	17	3.69	0.70
117	18	3.82	0.74
142	19	3.90	0.78
143	20	4.00	0.83
15	21	4.14	0.87
24	22	4.20	0.91
102	23	5.17	0.96
105	24	5.18	1.00

Data Point	Rank	AE min/cell da	Cum frac.
139	1	0.312	0.00
3c	2	1.105	0.04
83	3	1.183	0.09
94	4	1.477	0.13
34	5	1.550	0.17
103	6	1.730	0.22
3b	7	1.901	0.26
102	8	2.120	0.30
3a	9	2.244	0.35
3d	10	2.280	0.39
117	11	2.674	0.43
55	12	3.168	0.48
57	13	3.711	0.52
45	14	4.851	0.57
49	15	5.288	0.61
105	16	5.957	0.65
24	17	6.216	0.70
142	18	6.782	0.74
122	19	7.231	0.78
144	20	8.472	0.83
143	21	8.880	0.87
145	22	9.051	0.91
33	23	10.500	0.96
15	24	10.516	1.00

E. HSS Rankings

Data Point	Rank	AEF	Cum frac.
138	1	0.33	0.00
66	2	0.48	0.13
97	3	0.56	0.25
81	4	0.81	0.38
46	5	0.86	0.50
85	6	0.93	0.63
6c	7	1.91	0.75
6a	8	2.30	0.88
6b	9	2.44	1.00

Data Point	Rank	t CO2/t Al	Cum frac.
138	1	0.98	0.00
66	2	1.30	0.13
97	3	1.57	0.25
81	4	4.76	0.38
85	5	5.17	0.50
46	6	5.41	0.63
6c	7	9.29	0.75
6b	8	10.00	0.88
6a	9	11.70	1.00

Data Point	Rank	AED	Cum frac.
66	1	2.22	0.00
138		2.22	0.00
97	2	2.62	0.25
6b	3	3.07	0.38
6c	4	3.65	0.50
6a	5	3.81	0.63
85	6	4.16	0.75
81	7	4.39	0.88
46	8	4.71	1.00

Data Point	Rank	AE min/cell da	Cum frac.
138	1	0.733	0.00
66	2	1.066	0.13
97	3	1.467	0.25
81	4	3.564	0.38
85	5	3.869	0.50
46	6	4.051	0.63
6c	7	6.957	0.75
6b	8	7.491	0.88
6a	9	8.763	1.00