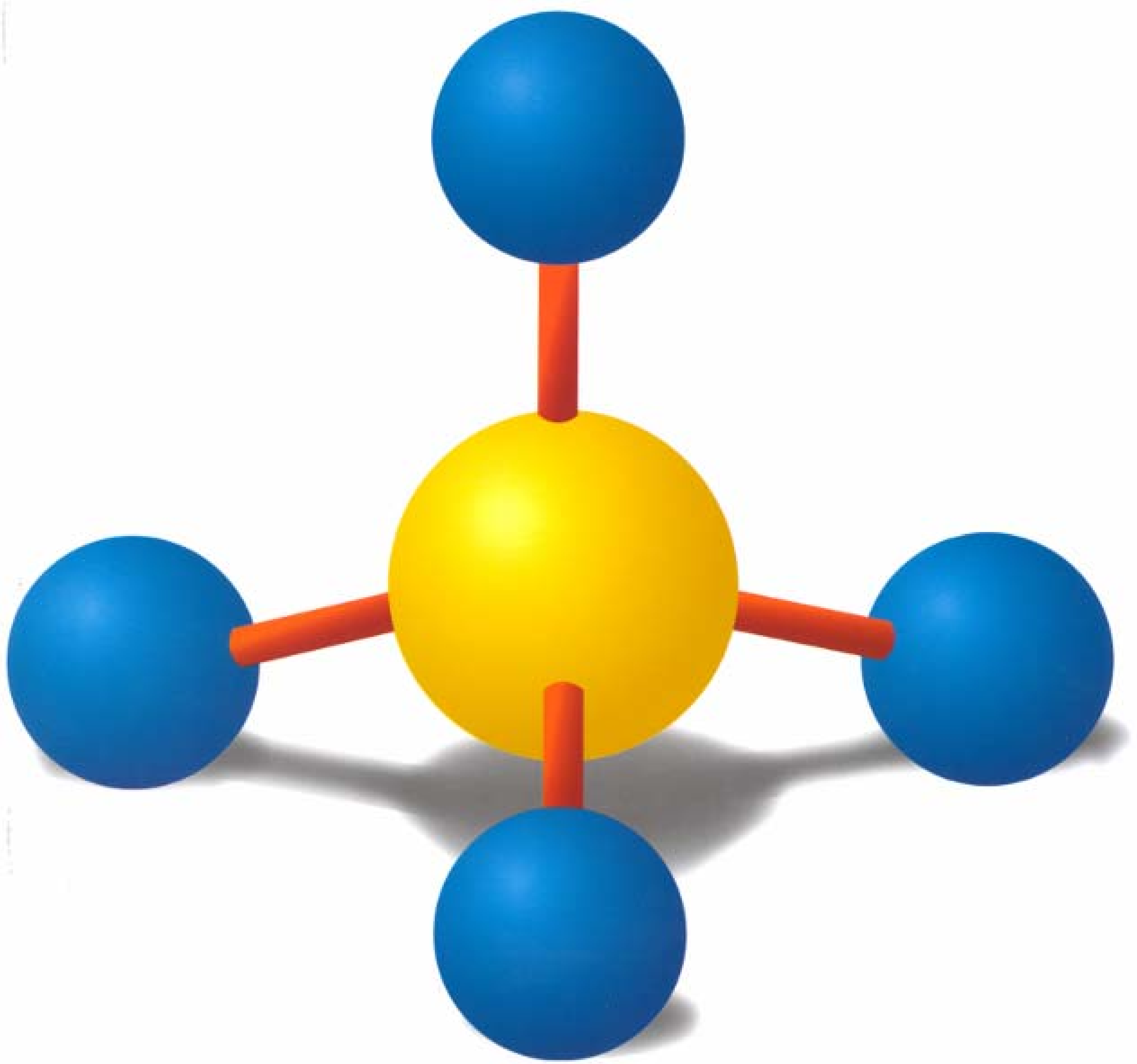
International Aluminium Institute

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

RESULTS OF THE 2006 ANODE EFFECT SURVEY



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Introduction

The results of the analysis of the 2006 International Aluminium Institute (IAI) Anode Effect Survey data are presented here. This report marks a milestone in that the analysis of the 2006 data shows that the global aluminium industry has met the objective, established by the Institute's Board of Directors, of a global reduction in perfluorocarbon (PFC) emissions per tonne of aluminium of eighty percent relative to the 1990 baseline. The 2006 survey report continues the series of reports on surveys covering anode effect data from global aluminium producers over the period from 1990 through 2006. 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, in order to improve the rate of data collection from these earlier years. Survey data have been requested annually since 2000. The survey results have proven to be a useful tool in communicating the excellent progress that the primary aluminium industry has made over the last two decades 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.

Survey Results

Production and Production Technology Trends

Table 1 shows a breakdown of primary aluminium production by reduction technology type for 2006. Participation in the 2006 survey accounted for just over sixty percent of overall global primary metal production. There is only limited participation in the survey by Chinese and Russian producers leaving some gaps in survey coverage of Point Fed Prebake (PFPB) and Vertical Stud Søderberg (VSS) production. Securing participation of a larger proportion of Chinese and Russian production capacity in the survey is important for the accuracy and credibility of results, because these two countries are major producers of primary aluminium, representing around 40% of global production.

	PFPB	**CWPB**	**SWPB**	**VSS**	**HSS**	**All**
Participating in Survey (tonnes)	15,521,589	1,167,638	615,616	2,707,361	393,874	20,406,078
Non- Participants (tonnes)	10,669,024	428,733	100,021	1,715,427	622,621	13,535,826
Participation (Percent of total)	59%	73%	86%	61%	39%	60%

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

Table 1 - 2006 Anode Effect Survey Participation by Technology Type

Figure 1 shows the growth in global annual primary aluminium production over the period from 1990, at almost twenty million tonnes, to 2006, when total primary metal production reached thirty four million tonnes. Figure 1 also illustrates that the increases in production between 1990 and 2006 were mainly due to investments in increasing capacity employing the lowest PFC emitting PFPB technology. Production figures for survey non-participants in Table 1 and in Figure 1 include some expert estimates.

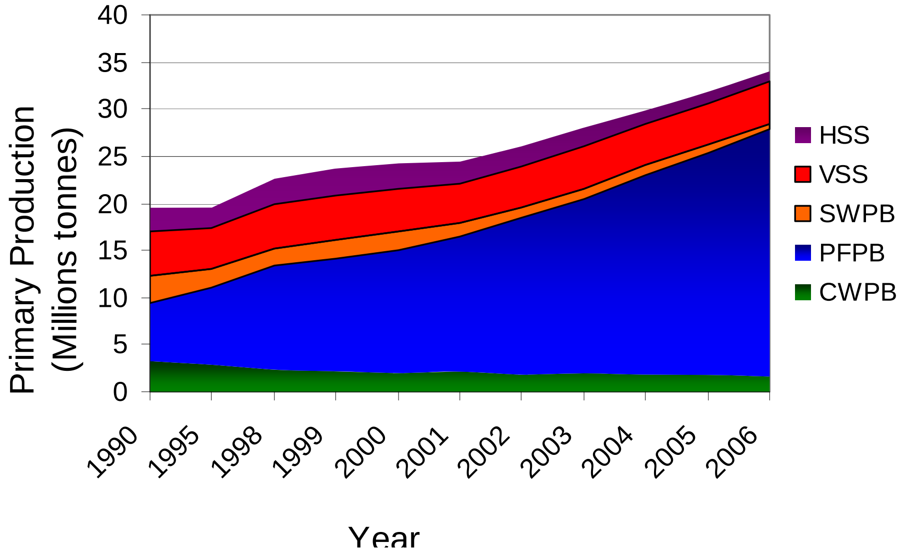

Figure 1 - Global Primary Aluminium Production by Technology Type from 1990 through 2006

Figure 2 shows in more detail the changes in production by technology type against a 1990 baseline. Aluminium production from CWPB, HSS and SWPB technologies decreased by between fifty and seventy five percent between 1990 and 2006. Over the same period VSS production decreased only slightly by six percent. The PFPB technology has grown by a factor of more than three, accounting for most of the overall growth in primary production of seventy four percent over the same period.

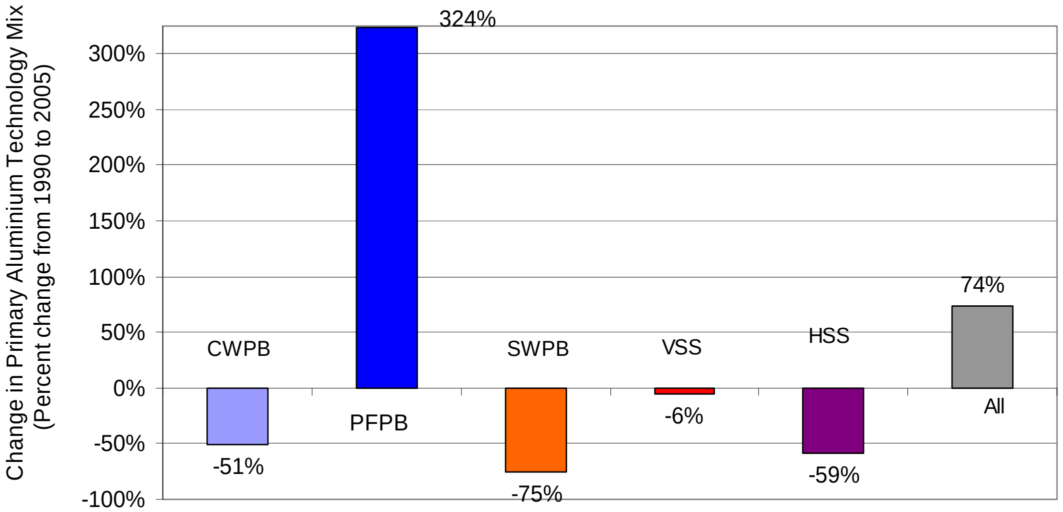

Figure 2 - Changes in Production by Technology Type from 1990 through 2006

Figure 3 shows the breakdown of the one hundred and nine reporting facilities by technology type. 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, in order 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.

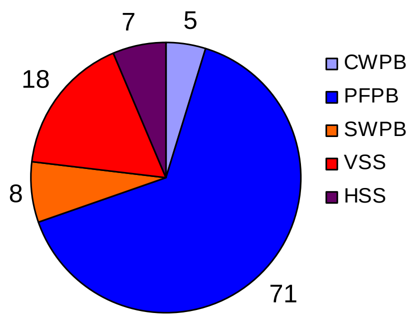

Figure 3 - Breakdown of 2006 Survey Reporting Facilities by Technology Type

The Anode Effect Survey requests participants to report annual primary production, average anode effect frequency, average anode effect duration and, if applicable, average overvoltage. Overvoltage is specifically requested from operators employing AP-18 or AP-30-x PFPB cells and SWPB cells using control technology recording overvoltage rather than anode effect minutes. These anode effect performance data allow for the calculation, by the Intergovernmental Panel on Climate Change (IPCC) Tier 2 method[1], of tetrafluoromethane (CF_4) and hexafluoroethane (C_2F_6) emission rates per tonne of aluminium produced. Total PFC emissions are then calculated for each participating facility by multiplying emissions per tonne of primary aluminium by the production level in tonnes. In order to improve the accuracy of the survey results, participants are also asked to report if a facility-specific direct measurement of PFC emissions had been made and if an IPCC Tier 3 coefficient is available for calculating PFC emissions from the facility. Of the one hundred and nine reporting facilities, twenty six respondents reported facility-specific Tier 3 coefficients for the 2006 survey and these data are used in calculating PFC emissions per tonne of aluminium produced for those facilities. The remainder of the PFC emissions data is calculated using IPCC Tier 2 methodology with industry average coefficients[2].

The IPCC adopted revised guidelines for the calculation of greenhouse gas inventories in November 2006. While the slope and overvoltage calculation methodology remained much the same for PFC emissions from primary aluminium production, there were substantial changes in some of the revised slope and overvoltage coefficients used in the equations to calculate PFC emissions per tonne of aluminium. The 2006 revised Tier 2 slope and overvoltage coefficients incorporate many of the facility-specific PFC measurements made since the last edition of the guidelines were published in 2000 and can be expected to give more accurate results than previous calculations.

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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/cache/fl0000127.pdf, p36, October 2006.

Progress in PFC Emissions Reduction

Overall progress in reducing PFC emissions per tonne of aluminium produced, calculated using the IPCC 2006 revised methodology is shown in Figure 4.

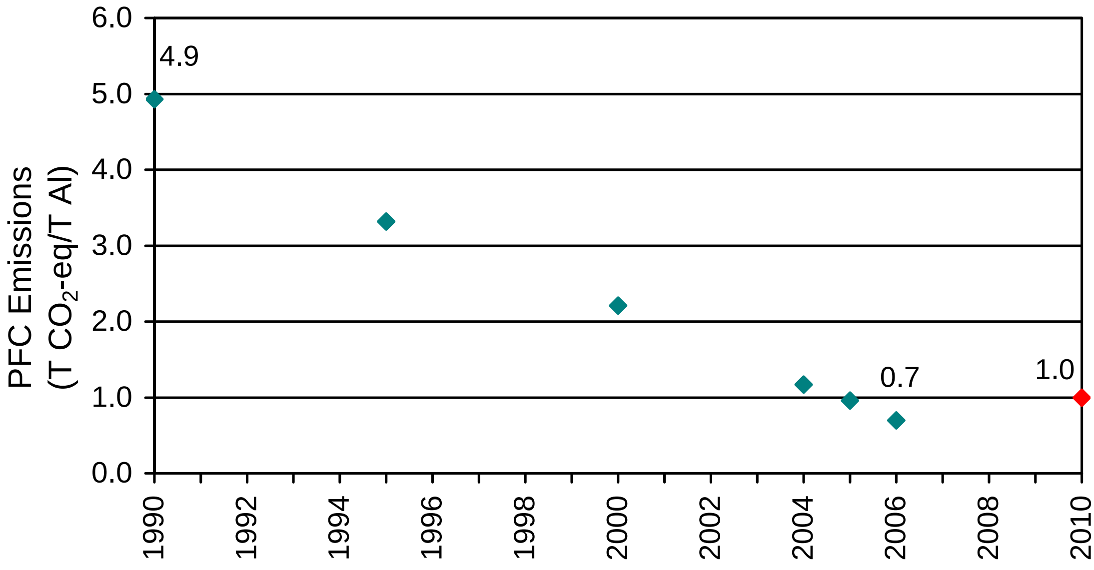

Figure 4 - Progress in Reducing PFC Emissions per Tonne of Aluminium Produced, 2006 IPCC Tier 2 Coefficients

Figure 4 shows that global emissions have been reduced from 4.93 tonne equivalents CO_2 per tonne of aluminium in 1990 to 0.70 in 2006, a reduction of 86%. The 86% reduction exceeds the aluminium industry voluntary objective, set by the IAI Board of Directors, to reduce global PFC emissions per tonne of aluminium by 80% between 1990 and 2010.

Calculation of PFC Emissions

The global average PFC emissions per tonne of aluminium produced were 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 of aluminium by the aluminium production for each reporting facility. Next, the total tonnes of 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[3], 6,500 for CF_4 and 9,200 for C_2F_6.

PFC emissions were estimated for aluminium production from facilities that did not report in the survey as follows. The median PFC emissions, as CO_2 equivalents, per tonne of aluminium for survey participants were calculated for each technology type.

[3] The IPCC Second Assessment Report GWP values are employed to maintain consistency with Kyoto Protocol conventions and Clean Development Mechanism (CDM) and Joint Implementation (JI) accounting.

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

Total global PFC emissions per year released to the atmosphere, including calculated emissions from survey participants and estimated emissions from survey non-participants, over the period from 1990 through 2006 are shown in Figure 5.

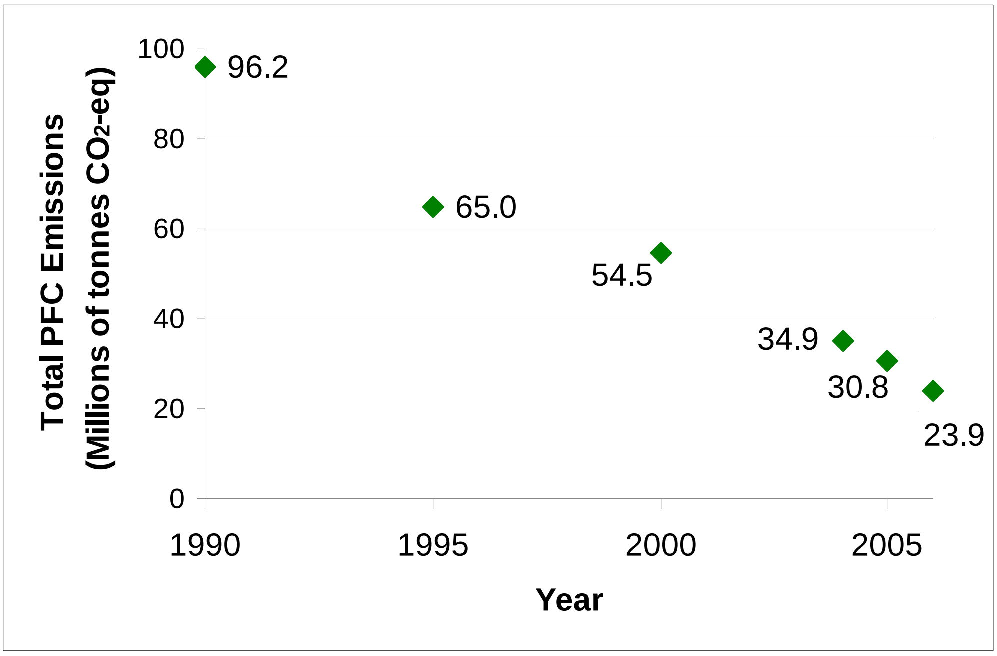

Figure 5 - Total PFC Emissions from Primary Aluminium Production by Year

Total emissions are a function of both the annual emissions per tonne of aluminium of the two PFCs and the total primary aluminium production levels for each year. It is notable that total emissions of perfluorocarbons have been reduced from ninety six million tonnes of CO_2 equivalents in 1990 to twenty four million tonnes CO_2 equivalents in 2006, a reduction of seventy five percent, even while total global primary aluminium production has increased over that same period from twenty to thirty four million tonnes, an increase of almost seventy five percent. The PFC emissions calculated for 2006 are the lowest annual PFC emissions from the aluminium industry yet recorded since 1990.

Comparison of Emission Results of OECD and non-OECD Countries

It is sometimes assumed that producers in non-OECD countries operate less efficiently than those in OECD countries. Analysis of the IAI Anode Effect Survey data indicates that the performance of non-OECD operations is comparable with OECD-based facilities. For those producers that responded to the 2006 survey, nine million tonnes of production was from non-OECD countries as compared with eleven million tonnes from OECD countries. While it is true that OECD producers set the PFC emission performance benchmarks in all technology categories in 2006, it is also the case that they also make up the majority of poorest performers. Overall, the emissions performance of OECD and non OECD producers are comparable. The primary factor affecting PFC emissions performance is not where facilities are located but rather the age of the facilities. Newer facilities with the most modern controls have the lowest emissions. The results comparing OECD and non OECD performance are shown in Figure 6.

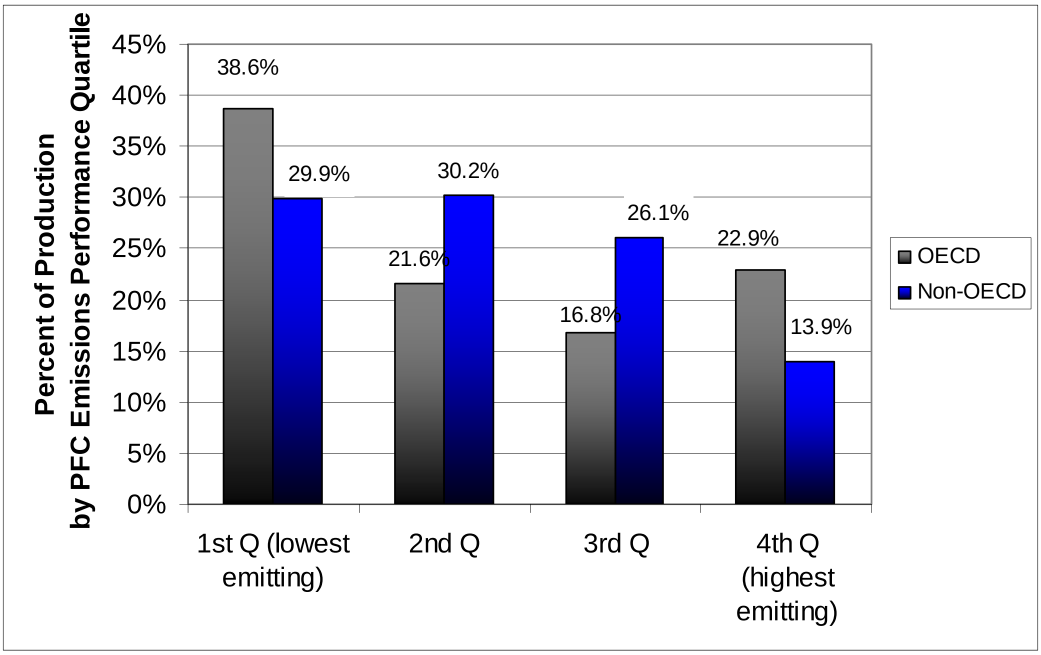

Figure 6 - Comparison of OECD and non-OECD Production by 2006 PFC Emission Performance

Figure 6 is the result of analysis, for each technology group, of the tonnes of primary aluminium production 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. Generally, PFC emissions performance is a direct function of the genre of technology, with the newest PFPB technologies giving far better PFC emissions performance than the older installations, regardless of location. New facilities are being sited where there is best access to low cost and long term stable sources of electrical power such as in the Arabian Gulf region and Russia.

Comparison of 1990 and 2006 Cumulative PFC Emissions versus Cumulative Production

Another way of evaluating improved PFC emissions performance is to examine the rank ordered PFC emissions rate plotted against cumulative primary aluminium production. Figure 7 shows this analysis for 1990 and 2006, illustrating the increase in production since 1990 using low PFC emitting PFPB technology (horizontal shift). This increase in PFPB production has had a major contribution to the lowering the global average PFC emissions per tonne of aluminium (vertical shift). The distribution of PFC emissions performance can also be seen to have been improved in every technology group.

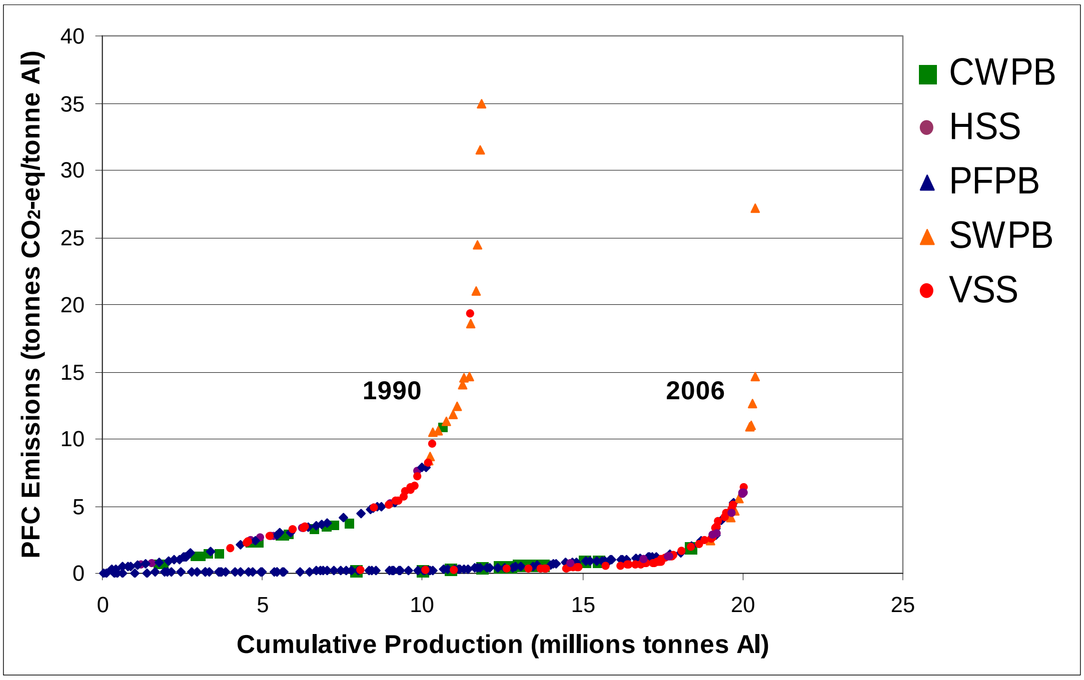

Figure 7 - Comparison of Rank Ordered 1990 and 2006 PFC Emissions per Tonne Aluminium Performance versus Cumulative Aluminium Production

Impact of Revisions in IPCC Equation Coefficients

The Intergovernmental Panel on Climate Change (IPCC) sets standards in methodologies for building inventories of greenhouse gases. The intent of these methods is to provide guidance to national governments 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 standards set by many non-governmental entities for the inventory of greenhouse gases. The previous edition of the IPCC guidelines, published in 2000, was revised and improved in 2006 and these revised standards were officially adopted by IPCC in November 2006. Accordingly, the newly revised guidelines serve as the basis for PFC calculations in this report. The

IAI GHG Protocol for Inventory of Greenhouse Gases from the Aluminium Sector has also been updated, based on the IPCC 2006 revised good practices.[4] The IAI Climate Change Task Force, at the invitation of IPCC, collaborated on the revision of the IPCC Good Practices for inventory of greenhouse gases from aluminium production. One outcome of the revision is an update to the coefficients used in the equations for calculation of PFC emissions. The 2006 revision takes into account a considerable number of new PFC measurements made at aluminium production facilities since the 2000 Good Practices were issued.

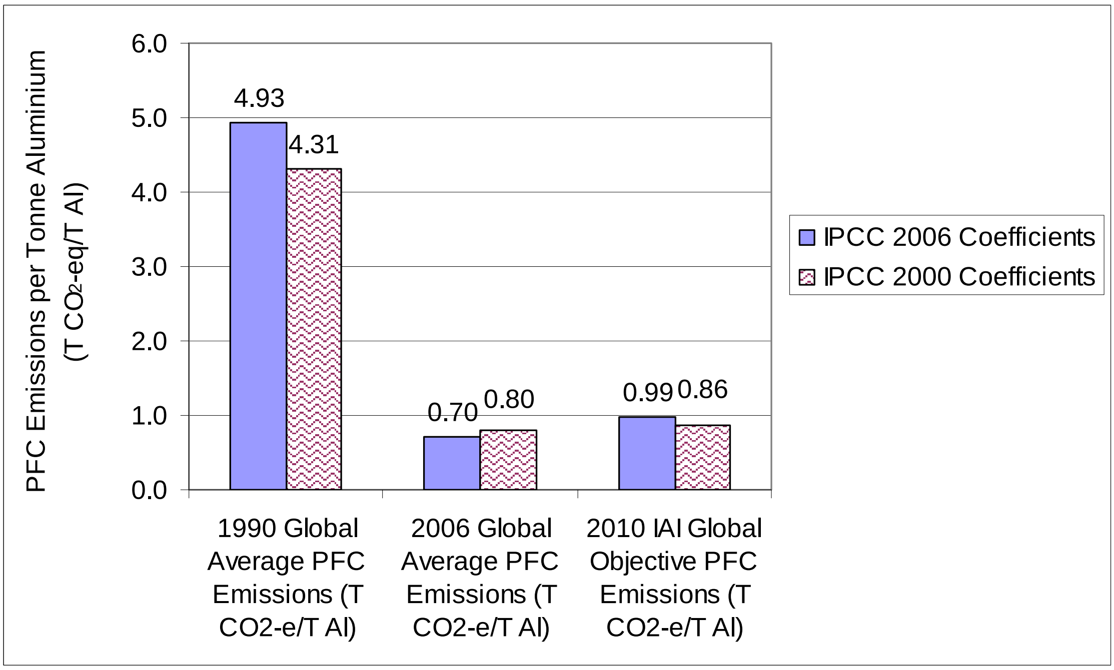

Figure 8 – Comparison of Global PFC Emissions Performance Calculated with IPCC 2006 Coefficients and with IPCC 2000 Coefficients

To assess the potential impact of the revised Tier 2 coefficients on the IAI voluntary objective to reduce PFC emissions per tonne of aluminium by eighty percent by 2010 from a 1990 baseline, the anode effect data from 1990 and from 2006 were recalculated using the coefficients in the revised Good Practices.[5] The results of the calculations are shown in Figure 8.

The impact of the IPCC revisions is an increase in the 1990 global baseline from 4.31 to 4.93 tonnes CO_2 equivalent per tonne aluminium, an increase of fourteen percent. The impact of the revisions on the 2006 PFC emissions is less, an increase of about thirteen percent. The 2010 objective, an eighty percent reduction from the 1990 baseline, is also increased from 0.86 to 0.99 tonnes CO_2 equivalent per tonne of aluminium produced, with the increase in the 1990 baseline.

[4] Greenhouse Gas Emissions Monitoring and Reporting by the Aluminium Industry, http://www.world-aluminium.org/cache/fl0000127.pdf

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

The difference between the impact of the revisions on 1990 and 2006 numbers is due to the relative change in technology mix over this period. As can be seen in Figure 2 there has been a 324% increase in PFPB production and, over the same time, a decrease in SWPB production of 75%. The greatest impact of using the 2006 IPCC revised Tier 2 coefficients is on HSS production, where the revised Tier 2 coefficient for CF_4 calculation was reduced by almost half. For VSS producers the Tier 2 CF_4 coefficient increased in the revised IPCC guidance by almost one-third from the previous value. There was no change in the Tier 2 CF_4 coefficient for CWPB and PFPB cells and only a very slight change in the Tier 2 CF_4 slope coefficient for SWPB cells. In contrast, the weight fraction of C_2F_6 increased by a factor of three for SWPB cells. When the 2000 Good Practices were developed there was no C_2F_6 measurement data available for SWPB cells and it was wrongly assumed that C_2F_6 emissions from SWPB cells would be similar to PFPB cells. The Tier 2 SWPB overvoltage coefficient for CF_4 also increased by a factor of almost two in the 2006 revised guidance. The 2000 IPCC Tier 2 SWPB overvoltage coefficient was based on a single measurement result available at the time that the 2000 guidance was developed. The overall impact of the revised coefficients is therefore a slight increase in the calculated PFC emissions levels for the 1990 baseline year and a slight decrease in 2006.

Using either the coefficients from the IPCC 2000 or the revised IPCC 2006 guidelines the data show that the IAI 2010 goal of an eighty percent reduction in PFC emissions per tonne of aluminium produced from the 1990 baseline was met and exceeded in 2006, with an eighty six percent reduction calculated with the 2006 IPCC methodology and an eighty percent reduction with the 2000 IPCC methodology. The overall average PFC emissions calculated with the 2006 IPCC coefficients for 2006 anode effect survey participants only was slightly higher than for the global average, 0.82 CO_2 equivalents per tonne of aluminium as compared to, 0.70 tonnes. , This amounts to a reduction of 83% from the 1990 average for survey participants. The difference in PFC emissions per tonne of aluminium for 2006 survey participants from the global average PFC emissions per tonne of aluminium arises from the convention of using the survey participants' median performance level to estimate emissions from survey non participants.

Figure 9 compares the technology mix of survey participant production with that of the global production. It demonstrated that in 2006 the survey participants' technology mix was very similar to that of the global production mix. However, for 1990 the survey respondents' technology mix differs considerably from the global. PFPB and bar broken CWPB technologies are overrepresented in the 1990 survey responders in comparison with the global technology mix, while VSS and HSS technologies are underrepresented in the 1990 survey returns. If emission results from survey participants alone are considered, the 1990 calculated result would underestimate both PFC emissions per tonne of aluminium produced as well as total PFC emissions to the atmosphere because of the overrepresentation of the lower emitting PFPB and bar broken CWPB cells.

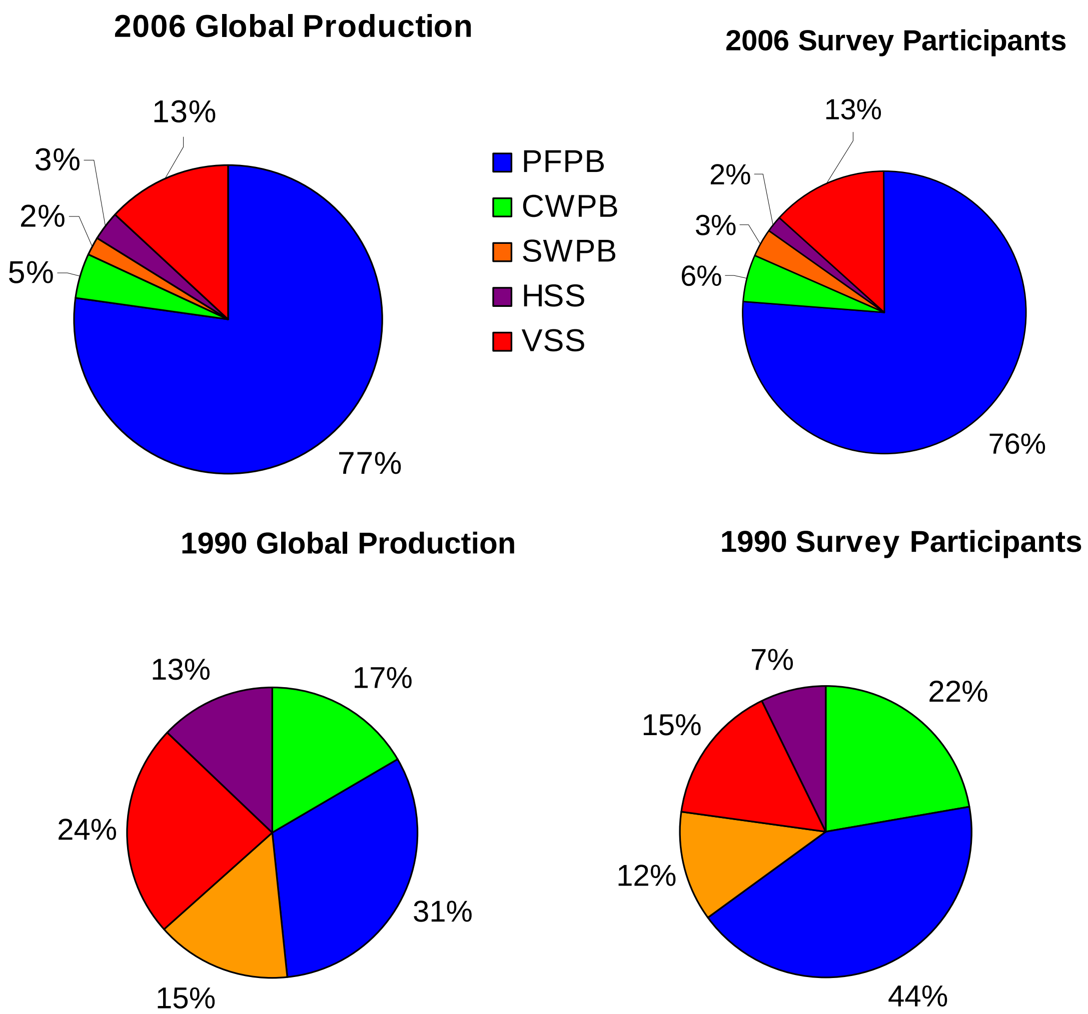

Figure 9 - Comparison of Technology Distribution of Survey Participants with that for Global Production

A global emissions profile of the industry is the most relevant to industry stakeholders. This global focus was embodied in the IAI 2010 objective of an eighty percent reduction in PFC emissions per tonne of aluminium produced from the 1990 baseline. The global approach has uncertainty in estimating emissions from survey non participants; however this uncertainty can be reduced by gaining increased participation from IAI member companies in Russia and China. Considering only the emissions from survey participants leaves open the larger question of the global aluminium industry impact on climate change.

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 and magnitudes of uncertainty is important because the global industry has made specific commitments to reduce PFC emissions per tonne of aluminium produced by eighty percent by 2010 from a 1990 baseline. A high level of uncertainty has the potential to discount the credibility of claims of emissions reduction. Potential significant sources of uncertainty include:

a. 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.

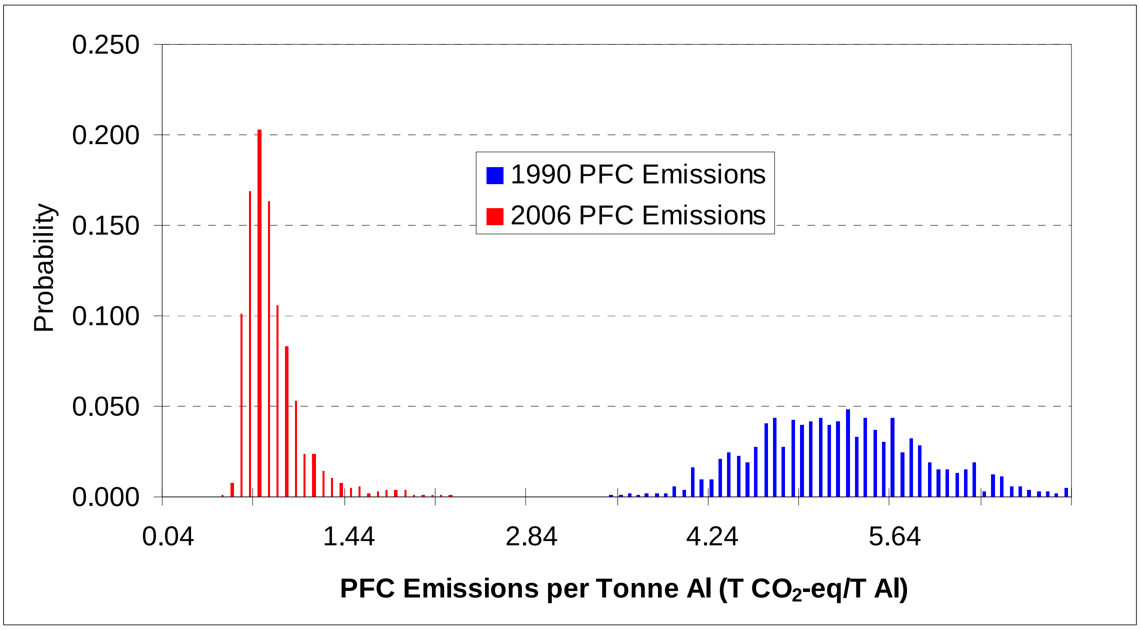

Figure 10 - Monte Carlo Simulation Comparing 1990 and 2006 PFC Emissions per Tonne Aluminium

The overall uncertainty of the global average PFC emissions per tonne aluminium can be simulated using a Monte Carlo simulation. The result of the analysis for both 1990 and 2006 PFC emissions are shown in Figure 10.

The analysis result shows a more narrow distribution of values for the 2006 PFC emissions than for the 1990 baseline emissions. The 95% confidence interval for the 2006 PFC emissions was 0.58 to 1.53 tonnes of CO_2 equivalent per tonne of aluminium compared with a 95% confidence interval of 4.09 to 6.67 tonnes of CO_2 equivalent per tonne of aluminium for 1990. The better definition of the 2006 PFC emissions is mainly due to two factors. First, there are a number of facilities that have made PFC measurements that allow the more accurate Tier 3 PFC calculation for 2006, while in 1990 there were no measurement data. Secondly, production in 2006 is dominated by PFPB technology for which the range of PFC emissions per tonne aluminium production is narrow compared to the other technologies.

Figure 11 shows the output of the simulation for the percent reduction in 2006 relative to 1990. The analysis shows a distribution of percent reduction results with a 95% confidence interval from 70.3% to 89.5%, with the mean predicted to be 84%. The analysis shows the highest probability is that the percent reduction is somewhat greater than 84%.

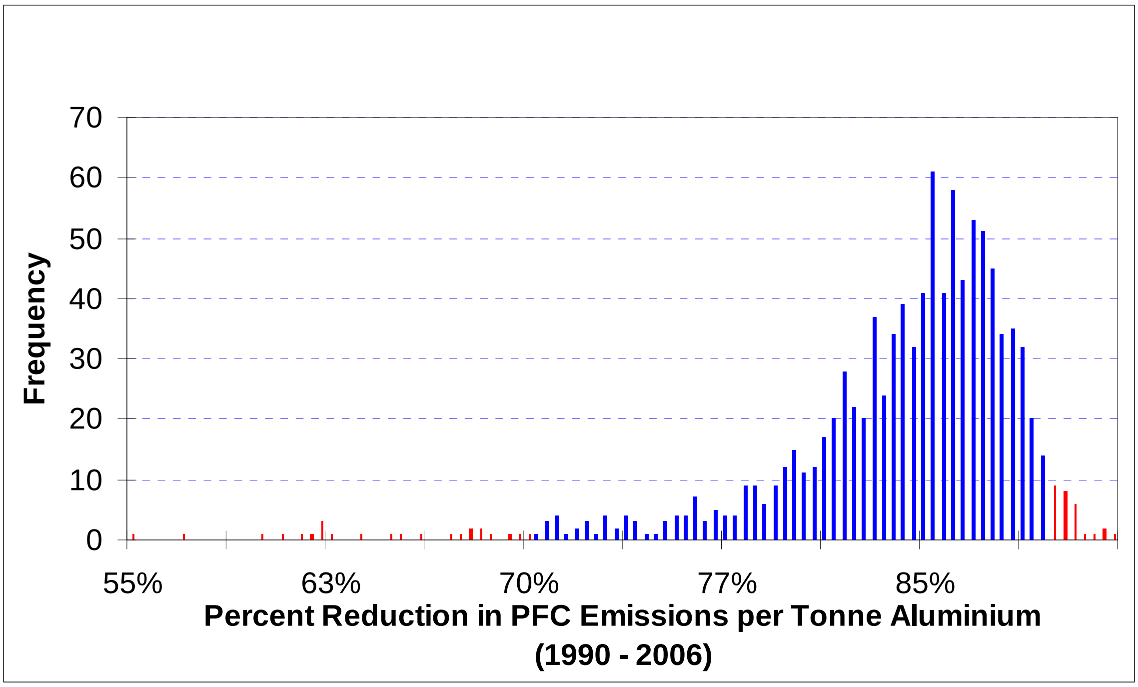

Figure 11 - Monte Carlo Simulation of 2006 Percent PFC Emissions Reduction from the 1990 Baseline

The simulations support the direct calculation result that the aluminium industry's 2010 voluntary objective was achieved in 2006. Considering survey participants only, the simulation predicts a more narrow distribution, with 95% confidence limits 79.2% to 83.2% and a mean of 81% reduction from 1990 to 2006.

The most efficient path to reducing the uncertainty of global PFC emissions is to include anode effect data from the remaining Chinese and Russian production in the calculation and for more facilities to make the PFC measurements necessary to enable Tier 3 calculation of PFC emissions.

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 of 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 shows the 2006 benchmark data for PFC emissions per tonne of aluminium produced by technology type.

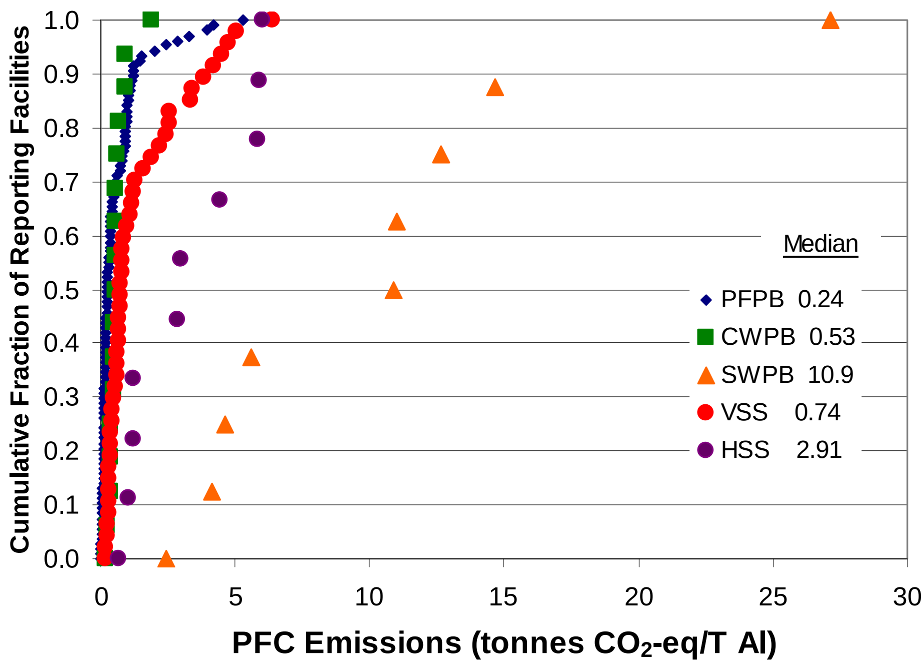

Figure 12 - Cumulative Probability Graph for PFC Emissions per Tonne of Aluminium Produced for Survey Participants by Technology Type

To illustrate how the graph in Figure 12 is interpreted consider, for example, the 0.5 point on the vertical axis, at which the VSS data point is 0.74 tonnes of CO_2 equivalent per tonne of aluminium. The interpretation is that 50% of all operators reporting VSS anode effect data operate at or below 0.74 tonnes of CO_2 equivalent of PFC emissions per tonne aluminium produced. At 1.0 on the vertical axis the VSS point is 6.41 tonnes of CO_2 equivalent per tonne of aluminium. The interpretation is that all VSS facilities reported anode effect data that reflected PFC emissions performance at or below 6.41 tonnes of CO_2 equivalent per tonne of aluminium or, in other words, the maximum value calculated for VSS operators in 2006 was 6.41 tonnes of CO_2 equivalent per tonne of aluminium. Figure 12 shows that the lowest PFC emissions per tonne of aluminium produced are obtained from PFPB and

CWPB operators. The VSS facilities show a distribution of values for PFC emissions per tonne of aluminium somewhat higher than the PFPB and CWPB facilities and the highest PFC emissions per tonne of aluminium produced result from the HSS and SWPB cells.

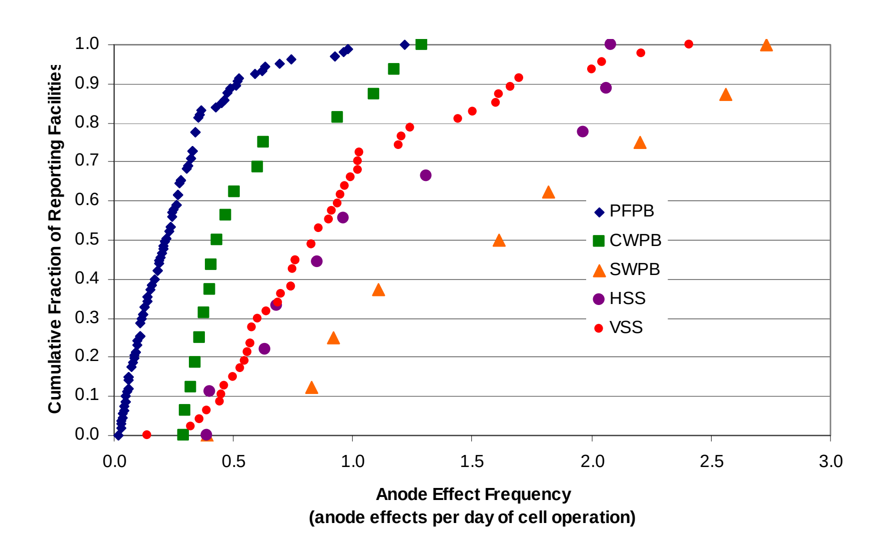

Figure 13 - Cumulative Probability Graph for Anode Effect Frequency for Survey Participants by Technology Type

Figure 13 shows the distribution of anode effect frequency data for reporting facilities in 2006. As can be expected from the greater degree of control capability in this technology group, the PFPB anode effect frequency distribution is the lowest of the five groups. Anode effect performance of the bar broken CWPB cells was slightly poorer than the PFPB cells. Anode effect frequency of Søderberg cells, both VSS and HSS, were next in performance. The VSS facility with the lowest anode effect frequency, 0.14 anode effects per cell day, operates with point feeders and demonstrates the considerable improvement in PFC emissions performance that installation of point feeders can have on Søderberg cells.

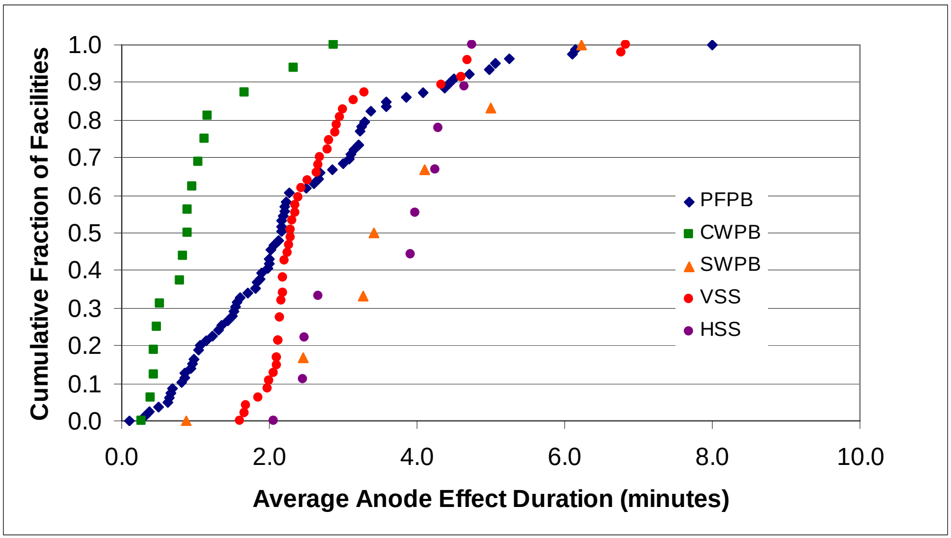

Figure 14 - Cumulative Probability Graph for Anode Effect Duration for Survey Participants by Technology Type

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

Several CWPB and PFPB facilities reported average anode effect durations of less than thirty 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. The differences in definition of whether a voltage increase is part of a prior anode effect or is a new anode effect does not impact the anode effect minutes per cell day, the important parameter relating to PFC emissions per tonne of aluminium produced. Differences in the voltage point at which cells are declared on anode effect can, however, impact recorded anode effect minutes. Bar broken CWPB cells performed best on anode effect duration, with median anode effect duration of 0.89 minutes. The PFPB cells were next best performers with median anode effect duration of 2.14 minutes in 2006. The median average anode effect duration performance for VSS cells was 2.30 minutes, while median durations for SWPB and HSS cells were 3.42, and 3.95 minutes respectively.

Figure 15 shows anode effect minutes per cell day benchmarking data for all technology groups that utilize the slope method for calculating PFC emissions per tonne of aluminium.

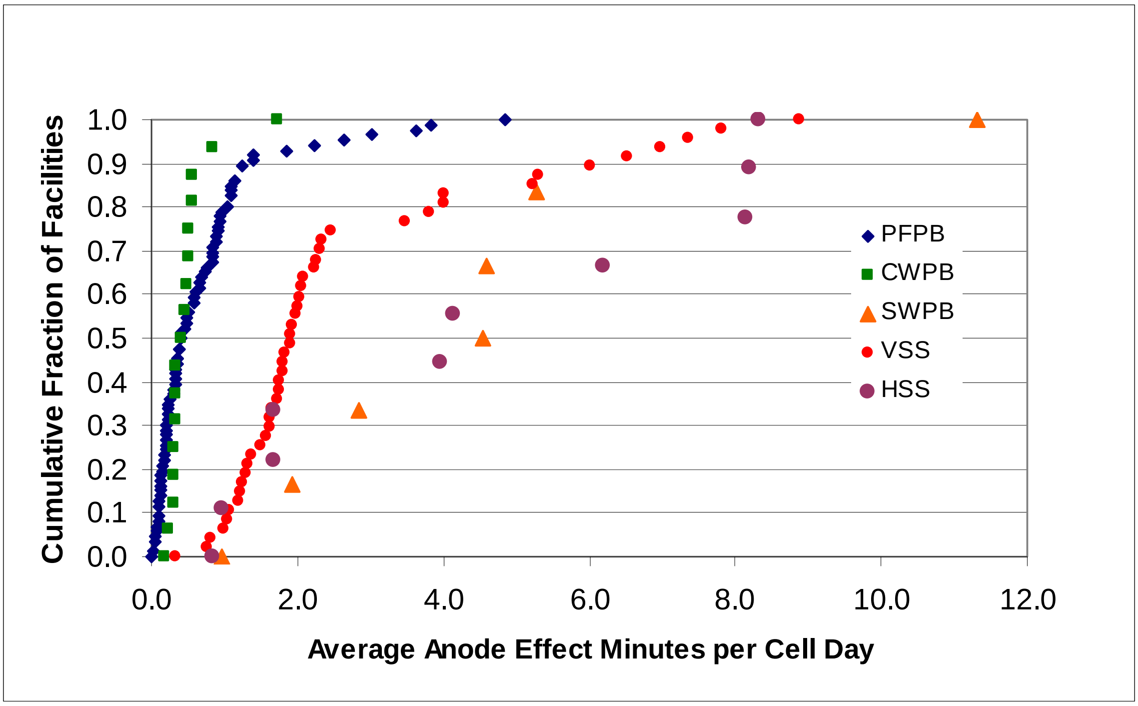

Figure 15 - Cumulative Fraction Graph for Anode Effect Minutes per Cell Day for Survey Participants by Technology Type

The anode effect minutes per cell day data shown in Figure 15 are the result of multiplying the average anode effect frequency by the average anode effect duration for each facility that uses the slope method for PFC calculation. Anode effect minutes per cell day relate directly to PFC emissions per tonne of aluminium produced 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 technologies. Both these technology groups have the same value for slope, 0.141 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 IPCC Tier 2 slope parameter for these three technology groups. The slope value is highest for the SWPB technology group, 0.272 Kg CF_4/anode effect minute per cell day. The comparable slope values for VSS and HSS are 0.092 and 0.099, respectively.

Figure 16 shows the benchmarking graph for anode effect overvoltage for PFPB cells operating with Rio Tinto 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 of aluminium produced. Positive overvoltage reporting now predominates over algebraic overvoltage reporting. The positive overvoltage should give a better correlation with PFC emissions per tonne of aluminium than algebraic overvoltage since algebraic overvoltage recording can result in subtractions of voltage during the anode effect treatment period that do not relate to PFC emissions.

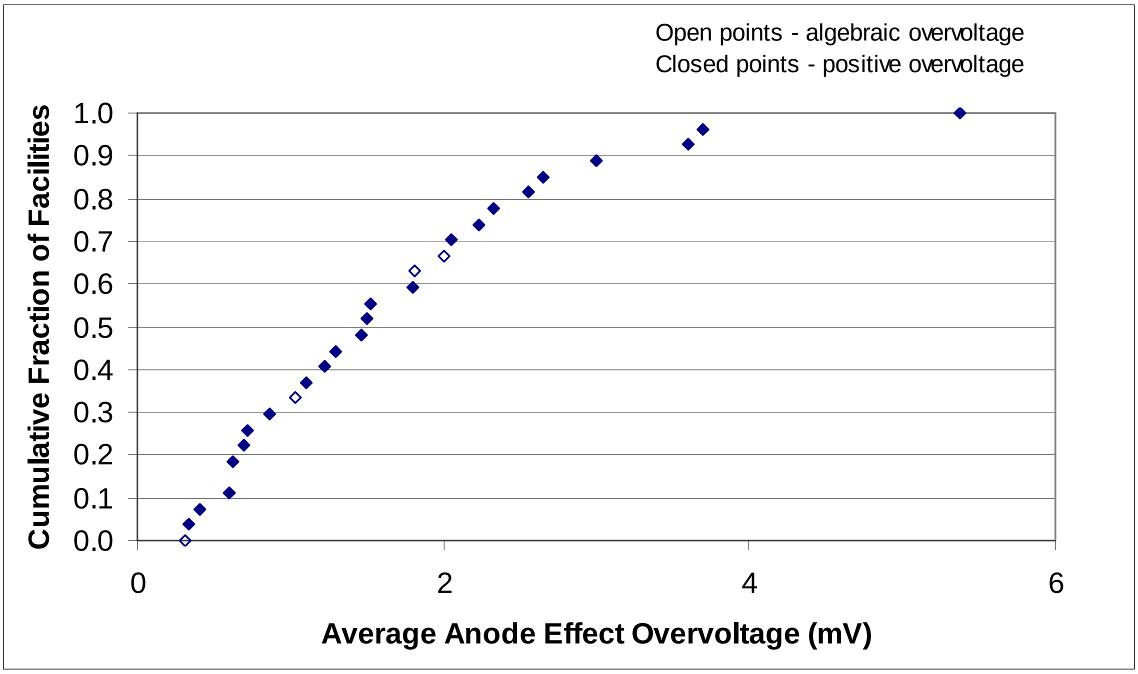

Figure 16 - Cumulative Fraction Graph for Anode Effect Overvoltage for Survey Participants Operating with Alcan Rio Tinto AP Technologies

Summary and Conclusions

The results of the 2006 IAI Anode Effect Survey show that the 2010 goal of an eighty percent reduction in PFC emissions relative to the 1990 baseline was met in 2006. The 2006 results continued the trend of reduced global PFC emissions, both as kilograms per tonne of aluminium produced and as total PFC emissions to the atmosphere. Calculation of global PFC emissions per tonne of aluminium produced, including survey participants and non-participants, shows an improvement to 0.70 tonnes of CO_2 equivalent per tonne of aluminium, an eighty six percent decrease from the 1990 baseline year. The overall average PFC emissions calculated for those who participated in the 2006 IAI anode effect survey was slightly higher, 0.82 of CO_2 equivalent per tonne of aluminium. However, this is still a reduction of eighty three percent from the 1990 average for survey participants.

Total PFC emissions to the atmosphere in 2006 from primary aluminium production were just under twenty four million tones of CO_2 equivalent. This represents the lowest level of emissions of PFCs to the atmosphere since IAI began its anode effect surveys, despite a growth in aluminium production of almost eighty percent over the same period.

The revised 2006 IPCC Tier 2 coefficients were used to calculate PFC emissions per tonne of aluminium for the first time in this report. The revised Tier 2 coefficients impacted PFC emissions calculations for those facilities that have not yet made PFC measurements that enable the use of the more accurate, facility-specific, Tier 3 method. Making measurements that allow moving to the more accurate Tier 3 calculation of PFC emissions is recommended for all producers.

The current uncertainty in calculations of global aluminium PFC emissions per tonne of aluminium can be best reduced by securing increased participation in the annual Anode Effect Survey. In 2006 survey participation represented sixty percent of total primary production. Further participation in the Anode Effect Survey, particularly for VSS production from Russian plants and Chinese PFPB producers, will reduce uncertainty in emissions calculations and maintain the credibility of results. In addition, making PFC measurements at those facilities that have not yet done so 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 indicates 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. Now that the goal set for 2010 has been met the industry looks forward to setting a new PFC emissions reduction voluntary objective that will drive the industry toward further PFC emissions performance improvement.

Appendix I – Performance Rankings by Technology

A. PFPB Technology

PFPB AEF

Data Point	AEF	percent rank	Rank
412	0.02	0.00	1
486	0.02	0.00	
345	0.03	0.02	2
327	0.03	0.03	3
300	0.03	0.04	4
350	0.04	0.05	5
389	0.04	0.06	6
422	0.04	0.07	7
378	0.05	0.08	8
382	0.05	0.08	
338	0.05	0.08	
421	0.05	0.10	9
333	0.05	0.11	10
411	0.06	0.12	11
487	0.06	0.12	
423	0.06	0.14	12
329	0.06	0.15	13
390	0.06	0.15	
443	0.06	0.15	
408	0.07	0.18	14
451	0.08	0.19	15
305	0.08	0.20	16
450	0.09	0.21	17
373	0.09	0.22	18
380	0.09	0.22	
420	0.10	0.24	19
392	0.10	0.25	20
372	0.11	0.25	
328	0.11	0.25	
330	0.11	0.25	
414	0.11	0.25	
309	0.11	0.29	21
366	0.12	0.30	22
371	0.12	0.31	23
375	0.12	0.31	
391	0.13	0.33	24
393	0.13	0.33	
357	0.14	0.35	25
435	0.14	0.36	26
440	0.14	0.36	
314	0.15	0.38	27
407	0.16	0.39	28
456	0.16	0.39	
379	0.17	0.41	29
394	0.17	0.41	
432	0.18	0.42	30
434	0.18	0.42	
398	0.19	0.44	31
406	0.19	0.45	32
410	0.20	0.46	33
336	0.20	0.47	34
409	0.21	0.48	35
388	0.21	0.49	36
449	0.21	0.50	37
368	0.22	0.51	38
413	0.22	0.51	
376	0.23	0.53	39

PFPB AED

Data Point	AED (minutes)	percent rank	Rank
380	0.11	0.00	1
379	0.32	0.01	2
402	0.38	0.03	3
333	0.51	0.04	4
395	0.63	0.05	5
455	0.64	0.06	6
367	0.67	0.08	7
454	0.69	0.09	8
457	0.81	0.10	9
323	0.86	0.11	10
437	0.86	0.13	11
388	0.93	0.14	12
338	0.95	0.15	13
334	0.98	0.16	14
335	0.98	0.16	
442	1.05	0.19	15
344	1.06	0.20	16
463	1.15	0.22	17
456	1.22	0.23	18
383	1.31	0.24	19
487	1.34	0.25	20
366	1.44	0.27	21
417	1.51	0.28	22
368	1.52	0.29	23
336	1.55	0.30	24
349	1.56	0.32	25
438	1.60	0.33	26
451	1.70	0.34	27
425	1.81	0.35	28
416	1.84	0.37	29
377	1.89	0.38	30
440	1.90	0.39	31
490	1.98	0.41	32
426	2.00	0.42	33
350	2.01	0.43	34
414	2.01	0.43	
424	2.02	0.46	35
301	2.06	0.47	36
421	2.12	0.48	37
462	2.12	0.48	
378	2.16	0.51	38
422	2.16	0.52	39
398	2.17	0.53	40
459	2.18	0.54	41
415	2.20	0.56	42
460	2.21	0.57	43
390	2.23	0.58	44
423	2.23	0.58	
461	2.27	0.61	45
305	2.51	0.62	46
391	2.60	0.63	47
458	2.67	0.65	48
436	2.70	0.66	49
376	2.86	0.67	50
453	3.00	0.68	51
337	3.09	0.70	52
491	3.10	0.71	53

PFPB AE minutes/cell day

Data Point	AE min/cell day	percent rank	Rank
380	0.01	0.00	1
333	0.03	0.01	2
338	0.05	0.03	3
379	0.05	0.05	4
350	0.07	0.06	5
487	0.08	0.07	6
422	0.10	0.08	7
378	0.10	0.09	8
300	0.10	0.12	9
421	0.11	0.13	10
402	0.12	0.14	11
423	0.13	0.15	12
390	0.13	0.16	13
345	0.14	0.17	14
451	0.14	0.19	15
395	0.15	0.20	16
327	0.16	0.21	17
366	0.17	0.22	18
455	0.18	0.23	19
329	0.19	0.24	20
454	0.19	0.26	21
388	0.19	0.27	22
456	0.20	0.28	23
443	0.20	0.29	24
305	0.21	0.30	25
457	0.22	0.31	26
414	0.22	0.33	27
367	0.22	0.34	28
334	0.24	0.35	29
440	0.27	0.36	30
323	0.31	0.37	31
336	0.31	0.38	32
392	0.33	0.40	33
335	0.33	0.41	34
368	0.33	0.42	35
391	0.34	0.43	36
442	0.35	0.44	37
328	0.35	0.45	38
330	0.35	0.45	
349	0.37	0.48	39
398	0.40	0.50	40
437	0.41	0.51	41
377	0.45	0.52	42
375	0.49	0.53	43
301	0.49	0.55	44
344	0.52	0.56	45
460	0.57	0.58	46
393	0.58	0.59	47
415	0.62	0.60	48
394	0.65	0.62	49
376	0.66	0.63	50
462	0.68	0.64	51
459	0.74	0.65	52
461	0.77	0.66	53
425	0.83	0.67	54
436	0.84	0.69	55
438	0.84	0.70	56

PFPB Technology (Continued)

PFPB AEF

Data Point	AEF	percent rank	Rank
301	0.24	0.54	
334	0.24	0.54	40
349	0.24	0.54	
377	0.24	0.57	41
395	0.25	0.58	42
447	0.25	0.58	
325	0.26	0.59	
362	0.26	0.59	43
460	0.26	0.59	
324	0.27	0.62	
326	0.27	0.62	44
457	0.27	0.62	
452	0.27	0.65	45
415	0.28	0.66	
454	0.28	0.66	46
455	0.28	0.66	
402	0.31	0.69	47
436	0.31	0.70	48
491	0.31	0.70	
313	0.32	0.72	49
462	0.32	0.72	
312	0.33	0.74	
367	0.33	0.74	
442	0.33	0.74	50
448	0.33	0.74	
458	0.33	0.74	
335	0.34	0.78	
363	0.34	0.78	51
459	0.34	0.78	
461	0.34	0.78	
364	0.35	0.82	52
323	0.36	0.83	53
453	0.36	0.84	54
490	0.43	0.85	55
426	0.45	0.86	56
424	0.46	0.87	57
425	0.46	0.87	
437	0.48	0.89	58
344	0.49	0.90	59
416	0.51	0.91	60
385	0.52	0.92	61
438	0.52	0.92	
387	0.59	0.93	62
384	0.62	0.94	63
386	0.63	0.95	64
383	0.69	0.96	65
417	0.93	0.97	66
489	0.96	0.98	67
337	0.98	0.99	68
463	1.22	1.00	69

PFPB AED

Data Point	AED (minutes)	percent rank	Rank
364	3.14	0.72	54
328	3.20	0.73	
329	3.20	0.73	55
330	3.20	0.73	
363	3.22	0.77	56
300	3.26	0.78	57
392	3.30	0.80	58
452	3.30	0.80	
443	3.38	0.82	59
385	3.58	0.84	60
384	3.59	0.85	61
394	3.85	0.86	62
375	4.09	0.87	63
362	4.37	0.89	64
393	4.43	0.90	65
345	4.50	0.91	66
413	4.70	0.92	67
447	4.97	0.94	68
489	5.06	0.95	69
327	5.26	0.96	70
386	6.10	0.97	71
387	6.15	0.99	72
448	8.00	1.00	73

PFPB AE minutes/cell day

Data Point	AE min/cell day	percent rank	Rank
490	0.84	0.71	57
458	0.88	0.72	58
426	0.90	0.73	59
452	0.90	0.74	60
383	0.91	0.76	61
424	0.93	0.77	62
416	0.94	0.78	63
491	0.96	0.79	64
413	1.03	0.80	65
453	1.09	0.83	66
363	1.09	0.84	67
364	1.10	0.85	68
362	1.14	0.86	69
447	1.24	0.90	70
417	1.40	0.91	71
463	1.41	0.92	72
385	1.86	0.93	73
384	2.23	0.94	74
448	2.64	0.95	75
337	3.03	0.97	76
387	3.63	0.98	77
386	3.84	0.99	78
489	4.86	1.00	79

PFPB Technology (Continued)

PFPB AEO (mV)

Data Point	AEO (mV)	Algebraic/ Positive	percent rank	Rank
486	0.313	A	0.00	1
408	0.330	P	0.04	2
389	0.410	P	0.07	3
406	0.600	A	0.11	4
407	0.600	P	0.11	
373	0.625	P	0.19	5
314	0.700	P	0.22	6
382	0.717	P	0.26	7
420	0.860	P	0.30	8
450	1.030	A	0.33	9
313	1.100	P	0.37	10
372	1.225	P	0.41	11
312	1.300	P	0.44	12
309	1.470	P	0.48	13
371	1.500	P	0.52	14
357	1.518	P	0.56	15
411	1.800	P	0.59	16
412	1.810	A	0.63	17
449	2.000	A	0.67	18
435	2.050	P	0.70	19
488	2.231	P	0.74	20
326	2.325	P	0.78	21
325	2.559	P	0.81	22
324	2.656	P	0.85	23
432	3.000	P	0.89	24
410	3.600	P	0.93	25
409	3.700	P	0.96	26
434	5.370	P	1.00	27

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

Data Point	PFC emissions (T CO2-e/T Al)	percent rank	Rank
380	0.011	0.00	1
389	0.028	0.01	2
486	0.029	0.02	3
333	0.030	0.03	4
382	0.036	0.04	5
338	0.050	0.05	6
420	0.057	0.06	7
373	0.058	0.07	8
379	0.059	0.07	
314	0.065	0.08	9
408	0.071	0.09	10
450	0.078	0.10	11
350	0.079	0.11	12
357	0.079	0.12	13
487	0.085	0.13	14
435	0.097	0.14	15
313	0.102	0.15	16
422	0.103	0.16	17
378	0.106	0.17	18
300	0.113	0.18	19
372	0.114	0.19	20
392	0.115	0.20	21
421	0.115	0.21	22
391	0.118	0.21	
312	0.121	0.22	23
402	0.127	0.23	24
406	0.129	0.24	25
407	0.129	0.24	
371	0.139	0.26	26
423	0.143	0.27	27
390	0.146	0.28	28
345	0.147	0.29	29
451	0.148	0.30	30
309	0.152	0.31	31
449	0.152	0.32	32
395	0.167	0.33	33
411	0.167	0.34	34
412	0.168	0.35	35
455	0.172	0.36	36
327	0.177	0.36	
366	0.182	0.37	37
454	0.186	0.38	38
432	0.186	0.39	39
456	0.188	0.40	40
393	0.201	0.41	41
488	0.207	0.42	42
329	0.209	0.43	43
457	0.210	0.44	44
388	0.210	0.45	45
326	0.216	0.46	46
443	0.221	0.47	47
394	0.228	0.48	48
305	0.230	0.49	49
325	0.238	0.50	50
414	0.241	0.50	
367	0.241	0.51	51
324	0.247	0.52	52

PFPB Technology (Continued)

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

Data Point	PFC emissions (T CO2-e/T Al)	percent rank	Rank
334	0.256	0.53	53
440	0.290	0.54	54
434	0.293	0.55	55
410	0.335	0.56	56
323	0.335	0.57	57
336	0.337	0.58	58
409	0.344	0.59	59
335	0.363	0.60	60
368	0.364	0.61	61
442	0.377	0.62	62
328	0.383	0.63	63
330	0.383	0.64	64
349	0.408	0.64	
398	0.439	0.65	65
437	0.448	0.66	66
377	0.495	0.67	67
375	0.534	0.68	68
301	0.538	0.69	69
344	0.562	0.70	70
460	0.626	0.71	71
376	0.716	0.72	72
462	0.739	0.73	73
415	0.763	0.74	74
459	0.807	0.75	75
461	0.840	0.76	76
425	0.906	0.77	77
436	0.910	0.78	78
438	0.910	0.79	79
490	0.917	0.79	
447	0.935	0.80	80
458	0.959	0.81	81
426	0.980	0.82	82
452	0.984	0.83	83
383	0.987	0.84	84
424	1.012	0.85	85
491	1.046	0.86	86
416	1.092	0.87	87
413	1.126	0.88	88
453	1.186	0.89	89
363	1.192	0.90	90
364	1.196	0.91	91
362	1.237	0.92	92
463	1.435	0.93	93
417	1.521	0.93	94
385	2.027	0.94	95
384	2.423	0.95	96
448	2.874	0.96	97
337	3.297	0.97	98
387	3.950	0.98	99
386	4.184	0.99	100
489	5.288	1.00	101

B. CWPB Technology

CWPB AEF

Data Point	AEF	percent rank	Rank
320	0.29	0.00	1
318	0.30	0.06	2
316	0.32	0.13	3
322	0.34	0.19	4
403	0.36	0.25	5
315	0.38	0.31	6
346	0.40	0.38	7
319	0.41	0.44	8
321	0.43	0.50	9
317	0.47	0.56	10
347	0.51	0.63	11
351	0.60	0.69	12
348	0.63	0.75	13
354	0.94	0.81	14
355	1.09	0.88	15
353	1.17	0.94	16
356	1.29	1.00	17

CWPB AED (minutes)

Data Point	AED (minutes)	percent rank	Rank
348	0.27	0.00	1
353	0.39	0.06	2
356	0.43	0.13	3
347	0.44	0.19	4
355	0.47	0.25	5
354	0.51	0.31	6
346	0.78	0.38	7
319	0.83	0.44	8
317	0.89	0.50	9
315	0.90	0.56	10
316	0.96	0.63	11
318	1.05	0.69	12
320	1.12	0.75	13
321	1.17	0.81	14
322	1.66	0.88	15
403	2.34	0.94	16
351	2.87	1.00	17

CWPB AE minutes/cell day

Data Point	AE minutes/cell day	percent rank	Rank
348	0.17	0.00	1
347	0.22	0.06	2
316	0.31	0.13	3
318	0.32	0.19	4
346	0.32	0.25	5
320	0.32	0.31	6
319	0.34	0.38	7
315	0.34	0.44	8
317	0.42	0.50	9
353	0.46	0.56	10
354	0.48	0.63	11
321	0.50	0.69	12
355	0.51	0.75	13
356	0.56	0.81	14
322	0.56	0.88	15
403	0.83	0.94	16
351	1.72	1.00	17

PFC Emissions (T CO2-eq/T Al)

Data Point	PFC emissions (T CO2/T Al)	percent rank	Rank
348	0.187	0.00	1
347	0.243	0.06	2
346	0.344	0.13	3
319	0.391	0.19	4
315	0.393	0.25	5
317	0.480	0.31	6
316	0.497	0.38	7
318	0.510	0.44	8
320	0.526	0.50	9
353	0.534	0.56	10
354	0.556	0.63	11
321	0.578	0.69	12
355	0.593	0.75	13
356	0.647	0.81	14
403	0.908	0.88	15
322	0.914	0.94	16
351	1.873	1.00	17

C. SWPB Technology

SWPB AEF

Data Point	AEF	percent rank	Rank
370	0.39	0.00	1
369	0.83	0.13	2
401	0.92	0.25	3
400	1.11	0.38	4
396	1.61	0.50	5
433	1.82	0.63	6
441	2.20	0.75	7
352	2.56	0.88	8
419	2.73	1.00	9

SWPB AED (minutes)

Data Point	AED (minutes)	percent rank	Rank
441	0.88	0.00	1
370	2.45	0.17	2
396	3.27	0.33	3
369	3.42	0.50	4
400	4.10	0.67	5
401	5.00	0.83	6
433	6.22	1.00	7

SWPB AE minutes/cell day

Data Point	AE minutes/cell day	percent rank	Rank
370	0.96	0.00	1
441	1.94	0.17	2
369	2.84	0.33	3
400	4.55	0.50	4
401	4.60	0.67	5
396	5.26	0.83	6
433	11.32	1.00	7

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

Data Point	PFC emissions (T CO2/T Al)	percent rank	Rank
370	2.45	0.00	1
352	4.15	0.13	2
441	4.64	0.25	3
369	5.57	0.38	4
400	10.92	0.50	5
401	11.03	0.63	6
396	12.63	0.75	7
419	14.69	0.88	8
433	27.15	1.00	9

D. VSS Technology

VSS AEF

Data Point	AEF	percent rank	Rank
360	0.14	0.00	1
474	0.32	0.02	2
427	0.36	0.04	3
342	0.39	0.06	4
418	0.44	0.09	5
399	0.45	0.11	6
343	0.46	0.13	7
472	0.50	0.15	8
480	0.53	0.17	9
473	0.55	0.19	10
439	0.56	0.21	11
471	0.57	0.23	12
475	0.57	0.23	
340	0.58	0.28	13
341	0.60	0.30	14
466	0.64	0.32	15
374	0.69	0.34	16
469	0.70	0.36	17
428	0.74	0.38	18
431	0.74	0.38	
477	0.75	0.43	19
468	0.76	0.45	20
470	0.76	0.45	
465	0.83	0.49	21
467	0.83	0.49	
481	0.86	0.53	22
485	0.90	0.55	23
476	0.91	0.57	24
484	0.94	0.60	25
478	0.95	0.62	26
482	0.97	0.64	27
464	0.99	0.66	28
483	1.02	0.68	29
302	1.03	0.70	30
479	1.03	0.72	31
303	1.19	0.74	32
304	1.21	0.77	33
365	1.24	0.79	34
358	1.44	0.81	35
359	1.50	0.83	36
331	1.60	0.85	37
446	1.61	0.87	38
445	1.66	0.89	39
332	1.70	0.91	40
339	2.00	0.94	41
444	2.05	0.96	42
429	2.21	0.98	43
430	2.41	1.00	44

VSS AED (minutes)

Data Point	AED (minutes)	percent rank	Rank
304	1.61	0.00	1
302	1.68	0.02	2
303	1.70	0.04	3
365	1.86	0.06	4
342	1.98	0.09	5
485	1.99	0.11	6
466	2.07	0.13	7
484	2.10	0.15	8
428	2.11	0.17	9
471	2.11	0.17	
469	2.13	0.21	10
481	2.13	0.21	
482	2.13	0.21	
343	2.15	0.28	11
472	2.15	0.28	
468	2.17	0.32	12
477	2.18	0.34	13
479	2.18	0.34	
476	2.19	0.38	14
478	2.19	0.38	
483	2.20	0.43	15
473	2.25	0.45	16
465	2.28	0.47	17
467	2.29	0.49	18
360	2.30	0.51	19
470	2.32	0.53	20
418	2.35	0.55	21
464	2.36	0.57	22
475	2.40	0.60	23
480	2.43	0.62	24
474	2.53	0.64	25
374	2.64	0.66	26
359	2.67	0.68	27
399	2.68	0.70	28
358	2.79	0.72	29
340	2.82	0.74	30
430	2.90	0.77	31
341	2.92	0.79	32
429	2.95	0.81	33
339	3.00	0.83	34
445	3.15	0.85	35
446	3.30	0.87	36
444	4.34	0.89	37
331	4.60	0.91	38
332	4.60	0.91	
431	4.69	0.96	39
439	6.78	0.98	40
427	6.84	1.00	41

VSS AE minutes/cell day

Data Point	AE minutes/cell day	percent rank	Rank
360	0.32	0.00	1
342	0.77	0.02	2
474	0.81	0.04	3
343	0.99	0.06	4
418	1.04	0.09	5
472	1.08	0.11	6
471	1.20	0.13	7
399	1.21	0.15	8
473	1.24	0.17	9
480	1.29	0.19	10
466	1.32	0.21	11
475	1.37	0.23	12
469	1.49	0.26	13
428	1.56	0.28	14
477	1.64	0.30	15
340	1.64	0.32	16
468	1.65	0.34	17
302	1.72	0.36	18
341	1.75	0.38	19
470	1.76	0.40	20
485	1.79	0.43	21
374	1.81	0.45	22
481	1.83	0.47	23
465	1.89	0.49	24
467	1.90	0.51	25
304	1.94	0.53	26
484	1.97	0.55	27
476	1.99	0.57	28
303	2.02	0.60	29
482	2.07	0.62	30
478	2.08	0.64	31
483	2.24	0.66	32
479	2.25	0.68	33
365	2.31	0.70	34
464	2.34	0.72	35
427	2.46	0.74	36
431	3.47	0.77	37
439	3.80	0.79	38
359	4.01	0.81	39
358	4.02	0.83	40
445	5.23	0.85	41
446	5.31	0.87	42
339	6.00	0.89	43
429	6.52	0.91	44
430	6.99	0.94	45
331	7.36	0.96	46
332	7.82	0.98	47
444	8.89	1.00	48

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

Data Point	PFC emissions (T CO2/T Al)	percent rank	Rank
474	0.18	0.00	1
360	0.21	0.02	2
472	0.24	0.04	3
471	0.27	0.06	4
473	0.28	0.09	5
342	0.28	0.11	6
480	0.29	0.13	7
466	0.30	0.15	8
475	0.31	0.17	9
469	0.33	0.19	10
343	0.36	0.21	11
468	0.37	0.23	12
470	0.39	0.26	13
465	0.42	0.28	14
467	0.43	0.30	15
464	0.52	0.32	16
340	0.59	0.34	17
477	0.60	0.36	18
341	0.63	0.38	19
485	0.66	0.40	20
418	0.67	0.43	21
481	0.67	0.45	22
484	0.72	0.47	23
476	0.73	0.49	24
482	0.76	0.51	25
478	0.76	0.53	26
399	0.78	0.55	27
483	0.82	0.57	28
479	0.82	0.60	29
428	1.00	0.62	30
302	1.10	0.64	31
374	1.16	0.66	32
304	1.24	0.68	33
303	1.30	0.70	34
427	1.58	0.72	35
365	1.91	0.74	36
431	2.17	0.77	37
439	2.44	0.79	38
359	2.57	0.81	39
358	2.58	0.83	40
445	3.36	0.85	41
446	3.42	0.87	42
339	3.86	0.89	43
429	4.19	0.91	44
430	4.49	0.94	45
331	4.73	0.96	46
332	5.03	0.98	47
444	6.41	1.00	48

E. HSS Technology

HSS AEF				HSS AED (minutes)				HSS AE minutes/cell day				HSS PFC Emissions (T CO2-eq/T Al)			
Data Point	AEF	percent rank	Rank	Data Point	AED (minutes)	percent rank	Rank	Data Point	AE minutes/cell day	percent rank	Rank	Data Point	PFC emissions (T CO2/T Al)	percent rank	Rank
404	0.39	0.00	1	381	2.07	0.00	1	381	0.83	0.00	1	404	0.69	0.00	1
381	0.40	0.11	2	311	2.46	0.11	2	404	0.96	0.11	2	381	1.01	0.11	2
310	0.63	0.22	3	404	2.47	0.22	3	311	1.67	0.22	3	311	1.21	0.22	3
311	0.68	0.33	4	310	2.66	0.33	4	310	1.68	0.33	4	310	1.21	0.33	4
361	0.85	0.44	5	308	3.91	0.44	5	361	3.95	0.44	5	361	2.85	0.44	5
405	0.96	0.56	6	307	3.98	0.56	6	405	4.13	0.56	6	405	2.98	0.56	6
397	1.31	0.67	7	306	4.24	0.67	7	397	6.19	0.67	7	397	4.47	0.67	7
306	1.96	0.78	8	405	4.30	0.78	8	308	8.13	0.78	8	308	5.86	0.78	8
307	2.06	0.89	9	361	4.65	0.89	9	307	8.20	0.89	9	307	5.91	0.89	9
308	2.08	1.00	10	397	4.74	1.00	10	306	8.33	1.00	10	306	6.00	1.00	10