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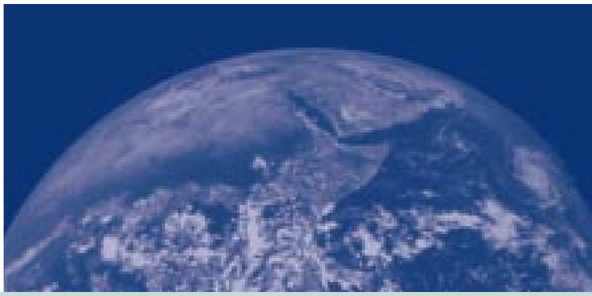
International Efforts to Reduce Perfluorocarbon (PFC) Emissions from Primary Aluminum Production



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Executive Summary

Perfluorocarbons (PFCs) are potent greenhouse gases, characterized by strong infrared radiation absorption and relative inertness in the atmosphere. PFCs are significant contributors to global climate change. The potential risks of climate change have led 179 nations (as of June 1999) to ratify the United Nations Framework Convention on Climate Change (UNFCCC), a landmark agreement with the ultimate objective of "stabiliz[ing] greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."

A major source of PFC emissions is primary aluminum production. PFCs are formed as intermittent by-products during the occurrence of anode effects in the production of primary aluminum. PFC emission reduction measures not only reduce PFC and other greenhouse gas emissions, but can also improve process efficiency. As a result, both industry and government have an interest in implementing these measures. This report provides a summary of international efforts by governments and industry to reduce PFC emissions from primary aluminum production.

Primary aluminum producers are well positioned to meet the challenge of global climate change. Current activities across many of the major aluminum producing countries have been successful in reducing PFC emissions from aluminum smelters. Countries with programs to reduce PFC emissions from primary aluminum production accounted for 54 percent of global primary production in 1997. Additional opportunity exists to make progress in other countries, including Russia and China, which are major producers of aluminum.

There is a wide range of currently available PFC mitigation technologies and practices. Among these are computerized controls and point-feeder systems, as well as improved operator practices that minimize anode effect frequency and duration. These technologies and practices vary in their cost-effectiveness and ability to reduce emissions. A promising technology that is currently in the development phase is the inert anode, which holds the potential for completely eliminating PFC emissions during the primary production process.

As of the beginning of 1999, 10 countries have undertaken industry-government initiatives to reduce PFC emissions from primary aluminum production: Australia, Bahrain, Brazil, Canada, France, Germany, New Zealand, Norway, the United Kingdom, and the United States. All of these countries have achieved significant reductions in the rate of PFC emissions. The PFC emission rate reductions achieved by the 10 countries are shown in Exhibit ES-1. It should be noted that a number of different methods to estimate PFC emissions and reductions are currently in use, which complicates comparison of emissions reductions across countries.

Exhibit ES-1. PFC Emissions Reductions

Country	t CO_2-e/ t Aluminum*		Years	Reduction	
	Start Year	End Year	Start-End	Overall %	% per year
Australia	3.9	0.9	'90-'97	78%	19%
Bahrain	1.5	0.8	'95-'98	47%	19%
Brazil	1.9	1.3	'94-'96	31%	17%
Canada	5.4	2.7	'90-'95	49%	13%
France	7.0	1.9	'90-'97	73%	17%
Germany	3.3	1.9	'90-'97	43%	5%
New Zealand	2.5	0.8	'90-'95	69%	21%
Norway	3.0	2.0	'90-'93	34%	13%
United Kingdom	9.0	2.8	'90-'96	69%	18%
United States	4.4	3.0	'90-'97	32%	7%

* Tonnes of CO_2 equivalent per tonne of aluminum.
Note: Emissions rates and reductions across countries may not be comparable due to different methods used to estimate emissions. See Section 3.4 for more detail.

Further action over time by all producers to minimize PFC emissions from primary aluminum production will give the public and government confidence that the aluminum industry is aggressively pursuing emissions reductions of greenhouse gases and minimizing the build-up of long-lived atmospheric chemicals. Expanding cooperation through the sharing of technical information, partnerships with government and further investigations into the PFC generation process are expected to result in additional cost-effective emissions reductions that will benefit both the industry and the environment.

1. Overview

The aluminum production process has been identified as one of the largest anthropogenic source of emissions of two perfluorocarbons (PFCs): tetrafluoromethane (CF_4) and hexafluoroethane (C_2F_6). PFCs are potent and long-lived greenhouse gases (GHGs). They contribute to global climate change due to their high infrared absorbing capacity and relative inertness in the atmosphere. Consequently, many efforts are underway to reduce emissions of these gases both on the national and international level.

The objectives of this report are to:

- summarize international efforts to reduce PFCs from aluminum production through government-industry initiatives;

- describe each producer nation's PFC emission reduction efforts, accomplishments, and challenges; and

- discuss future options for reducing PFCs from primary aluminum production.

The report is organized into the following sections:

Section 2 provides background on the PFC generation process in the primary aluminum industry and worldwide GHG emissions from primary aluminum production.

Section 3 describes ongoing activities, accomplishments and challenges to reduce PFC emissions from primary aluminum production. Methods to quantify emission reductions are discussed and difficulties in comparing emissions and reductions across countries are highlighted.

Section 4 presents an outlook for PFC emissions based on the PFC emission reduction efforts underway at the national and international level.

Annex 1 presents the profiles of individual country efforts to reduce PFC emissions and other GHG emissions from primary aluminum production.

Annex 2 presents data on individual smelters for each country profiled.

Annex 3 traces the treatment of PFC emissions in the United Nations Framework Convention on Climate Change (UNFCCC) from the Rio Summit in 1992 to the Kyoto Protocol in 1997.

2. PFCs and Primary Aluminum Production

This section discusses the atmospheric impact of PFC emissions, the scope of emissions worldwide, the process of PFC generation, and options for mitigating emissions.

2.1 Atmospheric Impact of PFC Emissions

CF_4 and C_2F_6 are potent greenhouse gases that are very stable in the atmosphere. While global annual emissions and current atmospheric concentrations of PFCs are relatively small compared to carbon dioxide (CO_2) and methane (CH_4), PFCs are removed very slowly from the atmosphere due to their long atmospheric lifetimes. The estimated atmospheric lifetimes for CF_4 and C_2F_6 are 50,000 and 10,000 years respectively.

The "global warming potential" (GWP) of these compounds, a measure that combines expected atmospheric lifetime and infrared absorbing capacity and provides a common unit for comparing the relative impacts of gases on global warming, is relatively high. One tonne of CF_4 and C_2F_6 emissions is equivalent to approximately 6,500 and 9,200 tonnes respectively of carbon dioxide emissions, when the warming is considered over a 100-year period.

2.2 PFC Generation and Mitigation

Primary aluminum is produced using the Hall-Héroult electrolytic process. In this process, aluminum production is carried out in a semi-batch manner in large electrolytic cells called pots with a direct current input of up to 280,000 amperes and about 5 volts. The pot is a rectangular steel shell typically 8 to 13 meters long, and 2.5 to 3 meters wide, and 0.75 to 1 meters high, and is lined with a refractory insulating shell upon which carbon blocks are placed to form a cathode. Steel collector bars are inserted into the cathode blocks to carry current away from the pot.

Molten cryolite (sodium aluminum fluoride) is placed in the cavity formed by the cathode blocks. Anodes, also of baked carbon, are immersed in the cryolite to complete the electric path. Anodes may be either pre-baked in a separate process and attached to connecting rods for immersion in the bath (termed prebake cells), or may be formed through self-baking from coal-tar and petroleum coke paste that is fed into the top of a steel casing above the cell (termed Soderberg design cells). Alumina (Al_2O_3) is fed in powder form into the pots (by various methods) and is dissolved in the cryolite bath.

Molten aluminum is produced while the anode is consumed in the reaction as follows:

$$Al_2O_3 + 3/2\ C \Rightarrow 2Al + 3/2\ CO_2 \qquad (1)$$

When the alumina ore content of the electrolytic bath falls below critical levels optimal for the above chemical reaction to take place, rapid voltage increases occur, termed "anode effects". During an anode effect, carbon from the anode and fluorine from the dissociated molten cryolite bath combine, producing CF_4 and C_2F_6. These gases are emitted from the exhaust ducting system or other pathways from the cell (e.g., the hood of the cell). The magnitude of PFC emissions for a given level of aluminum production depends on the frequency and duration of anode effects.

The frequency and duration of anode effects depend primarily on the cell technology and operating procedures. As a result, emissions of CF_4 and C_2F_6 vary significantly from one aluminum smelter to the next. As a result, to reduce PFC emissions each smelter must develop a strategy, including some or all of the following measures[1]:

- improving alumina feeding techniques by installing point feeders and regulating feed with computer control;
- training operators on methods and practices to minimize the frequency and duration of anode effects (for example, providing employees with measurement devices to monitor alumina feed rates and anode effects);
- using improved computer controls to optimize cell performance; and
- measuring PFC emissions and monitoring cell operating parameters to determine relationships between them.

A long-term industry initiative, which has significant potential to reduce emissions, is the development of non-consumable inert anodes. These inert anodes do not utilize carbon, thereby eliminating the source of carbon for PFC and process-related CO_2 generation. This technology is being pursued aggressively through government-industry research and development (R&D) efforts. Practical results are expected to require long-term research. For example, in the United States a joint R&D program has been established between the aluminum industry and the U.S. Department of Energy, but these efforts are not expected to result in a commercially viable anode design for at least the next ten to fifteen years.

2.3 CO_2 Emissions from Primary Aluminum Production

Carbon dioxide emissions also result from primary aluminum production, both directly from the electrolysis process and indirectly from the production of fossil-fuel based energy needed for the process. During electrolysis, CO_2 is produced as

[1] The applicability of these measures, as well as their performance, will vary between new and existing facilities.

a product of the chemical reaction between the carbon anode and the alumina. Emission factors, measured in metric tons of CO_2 per metric ton of aluminum produced, range from 1.5 for pre-baked cell technology to 1.8 for Soderberg cell technology (IPCC, 1997).

The production of electricity used in the smelting process is responsible for additional indirect GHG emissions. The level and type of emissions depends on the fuel or resource used to generate the electricity. Coal-burning power stations emit approximately 1 kg of CO_2 per kilowatt-hour (kWh), gas-fired generators will emit approximately 0.4 kg CO_2 per kWh, and hydroelectric generation has no associated CO_2 emissions (Huglen and Kvande, 1994). The current average electricity requirement for smelting purposes is about 15 kWh per tonne of aluminum (Huglen and Kvande, 1994). Therefore, CO_2 emissions per tonne of aluminum can range from approximately 15 tonnes CO_2 per tonne of aluminum if coal is used, to approximately 6 tonnes CO_2 per tonne of aluminum if gas is used, or zero if hydroelectricity is used. If the aluminum smelter is purchasing electricity from the grid, the electricity is likely to be generated from a mix of resources.

2.4 Global Aluminum Production and PFC Emissions

In 1997, 21.5 million metric tons of aluminum were produced worldwide (in 45 producer countries). Production has been on the rise through the 20^{th} century, with an increasing percentage of primary aluminum production occurring in the developing world. In 1997, however, the majority of aluminum was produced in industrialized countries and countries transitioning into market economies.

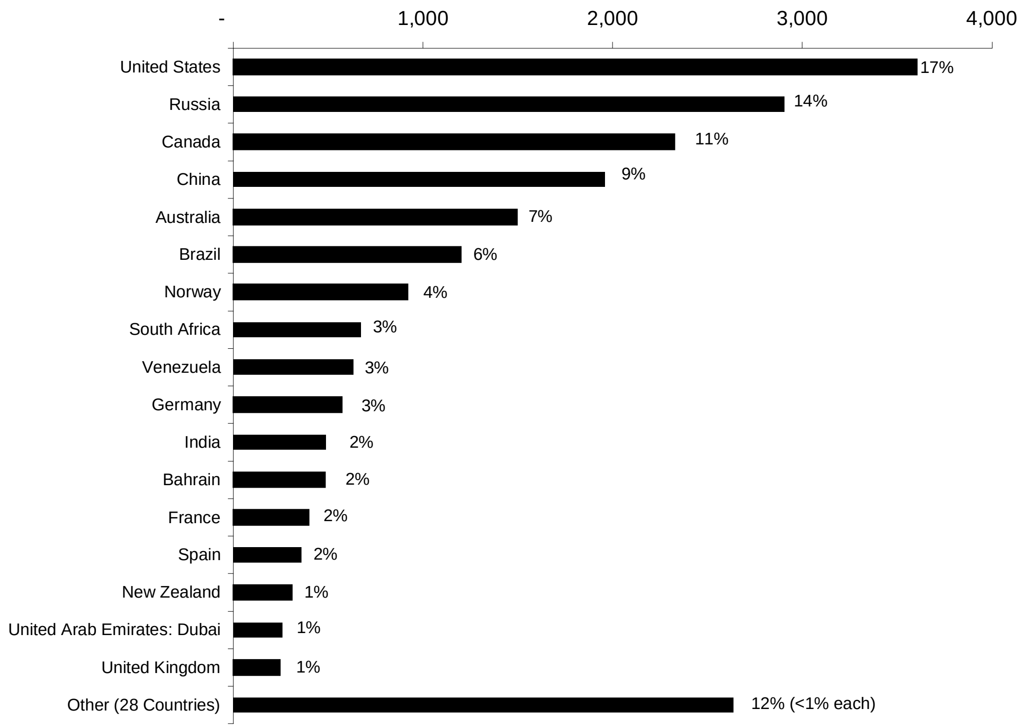
Exhibit 1 shows aluminum production and the share of global production for the leading producer nations in 1997. As shown in the exhibit, the USA topped the list producing 17% of the world's total primary aluminum, followed by Russia with 14% and Canada with 11%.

Global primary aluminum production is projected to increase at a rate of about 1 to 2% per year over the next decade. New primary smelting capacity is expected to be built in areas with low cost electricity, chiefly from hydro-electric or naturalgas-fired energy sources, and may be concentrated in developing countries. Marginal increases in primary production capacity are expected in developed countries through process improvements. Also, new smelter capacity is expected in Canada, Iceland, and Australia.

Primary production in North America and Pacific Organization of Economic Cooperation and Development (OECD) countries is expected to increase at a rate of about 1% per year while production in Western Europe is expected to decline at a rate of about 1% per year. Production in Eastern Europe is expected to increase at about 1.5% per year. Developing countries are expected to have the highest growth rates, with a projected increase in production of more than 2%.

Exhibit 1. Primary Aluminum Producers: 1997

(Data in Thousand Metric Tons and % of Total)



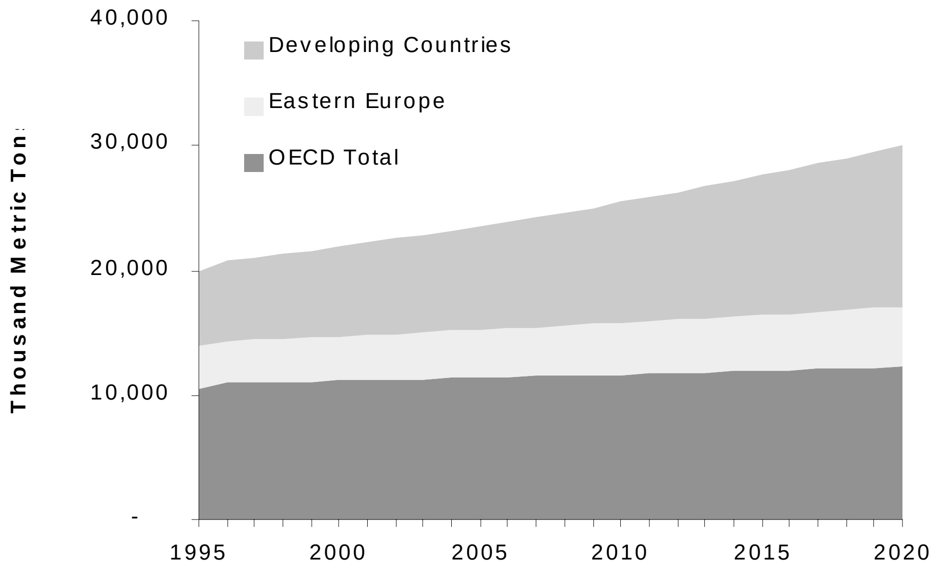
Other Producer Countries: Netherlands, Indonesia, Taijikstan, Egypt, Argentina, Italy, Romania, Ghana, Greece, Iran, Iceland, Sweden, Ukraine, Cameroon, Slovenia, Turkey, Poland, Slovakia, Serbia & Montenegro, Suriname, Croatia, Switzerland, Hungary, Japan, Mexico, Azerbaijan, Bosnia & Hertzegovina, and Nigeria.

Source: USGS Aluminum Industry Annual, 1998

Exhibit 2 illustrates projected aluminum production for the OECD, Eastern European, and developing countries based on the above assumptions (Victor et al., 1998, Anthony Bird Associates, 1998, Driscoll et al., 1997).

Despite projected growth in global aluminum production, it is technically feasible for PFC emissions per unit of product to be stabilized or decline. These reductions in PFC emission rates are anticipated because of industry-government emission reduction efforts in producer countries, the diffusion of modernized smelter technologies resulting from capital stock replacement, and the construction of state of the art facilities. Given the demonstrated progress of reduction programs, there is potential for absolute PFC emissions to decrease over time.

Exhibit 2. Projected Global Aluminum Production: 1995 - 2020



Source: Victor et al., 1998

3. PFC Reduction Efforts

Efforts to reduce PFC emissions from primary aluminum production include voluntary programs between industry and government and in some countries regulatory programs mandated by government. This section addresses the objectives, responsibilities, accomplishments, and challenges of stakeholders involved in such programs. Some individual companies have also independently undertaken steps to reduce emissions, however these efforts are not documented in this report.

3.1 Stakeholder Objectives

PFC emission reduction options have the potential to not only generate economic benefits for the aluminum industry, but also result in significant reductions in greenhouse gas emissions and benefit the global climate. In addition to generating PFC emissions, anode effects harm current efficiency and reduce productivity in the electrolytic process. During an anode effect, electricity consumption rises in the pot and aluminum production decreases thus raising the cost per unit of production. Therefore, reducing PFC emissions from primary aluminum production increases the efficiency of the process and reduces production costs.

3.2 Description of Programs

International PFC reduction programs include voluntary programs between industry and government and regulatory programs mandated by government. Voluntary partnerships seek to implement cost-effective, technologically feasible emission reduction options without government regulation. Existing regulatory programs mandate best available technology or performance standards.

As of November 1998, ten countries have undertaken industry-government initiatives to reduce PFC emissions from primary aluminum production: Australia, Bahrain, Brazil, Canada, France, Germany, New Zealand, Norway, United Kingdom, and United States. Of these, eight countries, representing over 50 percent of the world-wide production, have voluntary reduction programs and two, New Zealand and the United Kingdom, have regulatory programs.

The framework and requirements of voluntary programs vary; however, certain characteristics are common to all. Typically, stakeholders set emission reduction targets, either company-specific or industry-wide. Once the targets are set, a process to monitor and track progress toward achieving these reductions is established. Methods include monitoring programs and periodic reporting by industry. The government is responsible for improving the diffusion of relevant science and technology research and practices. In addition, the government may highlight the accomplishments of the program and publicly recognize participating companies.

The scope of emission reduction activities varies from country to country. In some countries, like the USA, the programs are restricted to PFC emissions from primary aluminum production. Other countries, such as Australia, Canada, and France, have included all GHGs and cover the entire aluminum industry, including alumina refineries and semi-fabrication facilities. In these countries, the programs cover energy consumption related CO_2 emissions, as well as direct CO_2 and PFC emissions associated with the primary aluminum production process.

While the scope of the programs varies across countries, the emission reduction activities undertaken at the company level are similar. The activities instituted to reduce PFC emissions can be divided into three categories: best management practices, technical initiatives, and research initiatives.

- **Best Management Practices.** These are activities related to operating practices which minimize the frequency and/or duration of anode effects. Best management activities include: educating employees on practices that reduce the frequency and duration of anode effects; supplying employees with training and the measurement devices to monitor alumina concentrations; and routine involvement of smelter operators to identify, develop and implement anode effect, voltage, and energy reduction measures.

- **Technical Initiatives.** These initiatives involve the use of state-of-the-art PFC emission reduction technologies, or best available technologies that have been successfully demonstrated in actual production environments. These technologies include computerized anode effect suppression systems that reduce anode effect duration and point feed systems that control alumina feed.

- **Research Initiatives.** Many countries are engaged in research directed at advanced technologies and practices that are expected to have a significant impact on PFC emissions in the next 10 to 20 years. A long-term industry initiative that is being pursued aggressively through government-industry research and development efforts in several countries is the development of the non-consumable inert anode, which would eliminate all PFC emissions.

In countries whose programs include CO_2 and PFCs, CO_2 emission reductions have been achieved largely due to actions taken to improve the energy efficiency of the production process. The actions include developing more efficient baking furnaces, improvements in pot-line design that will reduce per unit electricity requirements, and fuel switching. Exhibit 3 summarizes the country programs to reduce PFC emissions from primary aluminum production. The methods used by various countries to estimate emissions and these estimates are provided in Section 3.4.

Exhibit 3. Summary of International Efforts[1]

COUNTRY	PROGRAM TYPE	PROGRAM DESCRIPTION	PROGRAM COVERAGE	PROGRAM ACCOMPLISHMENTS
Australia	Voluntary	The Australian aluminum industry signed a voluntary "Framework Agreement" and joined the Greenhouse Challenge, an industry-government partnership, in 1995.	The program sets reduction targets for PFC and other GHG emissions from alumina refineries and aluminum smelters.	From 1990 to 1997, PFC emissions decreased an estimated 73 percent. During this same time period, energy efficiency improvements resulted in a 2.2 percent decrease in total CO_2 emissions.
Bahrain	Voluntary	Bahrain's sole aluminum producer has entered into a voluntary agreement to reduce GHG emissions with Bahrain's Ministry of Housing, Municipalities and Environment.	The program aims to reduce PFC and other GHG emissions from aluminum smelters.	From 1995 to 1998, Bahrain reduced the PFC emissions rate by 47%. By 1998, the PFC emissions rate from aluminum smelters was limited to 0.8 metric tons of CO_2 equivalent per metric ton of aluminum produced.
Brazil	Voluntary	The Brazilian Aluminum Association (ABAL) signed a voluntary agreement with Brazil's Ministry of Science and Technology (MST) to reduce GHG emissions.	The voluntary agreement targets PFC and CO_2 emissions from aluminum smelters.	In 1996, the average PFC emission factor was reduced 31 percent from 1994 levels.
Canada	Voluntary	Canada's Aluminum Industry Association participates in the Voluntary Challenge and Registry (VCR) Program initiated by the Canadian Government and the voluntary Canadian Industry Program for Energy Conservation (CIPEC).	The VCR program aims to reduce PFC and CO_2 emissions from aluminum smelting. The CIPEC program aims to improve energy efficiency in industry.	From 1990 to 1996, PFC emissions decreased an estimated 30 percent. Energy efficiency improvements resulted in a 10 percent decrease in energy consumption per tonne of aluminum produced.
France	Voluntary	Aluminum Pechiney, the sole aluminum producer in France, made a voluntary commitment to reduce its GHG emissions to the French government.	The voluntary commitment aims to reduce PFC emissions from aluminum smelters and CO_2 emissions from alumina refining, smelting, and recycling operations.	From 1990 to 1997, PFC emissions per metric ton of primary aluminum were reduced by 73 percent. During this same period, CO_2 emissions per metric ton of aluminum (both primary and secondary) were reduced by 19 percent.

Continued…

1. In the Netherlands, Iceland, Spain and Sweden, internal discussions on programs to reduce PFC emissions have begun, but no agreements are in place as of November, 1998. The Netherlands does have a voluntary program on energy reduction in the aluminum industry (Nordheim, 1998). In Iceland, a regulation on the use and emissions of fluorocarbons and some other persistent GHGs exists in a draft version in the Ministry for the Environment (Iceland, Ministry for the Environment, 1997).

Country	Program Type	Program Description	Program Coverage	Program Accomplishments
Germany	Voluntary	The German Aluminum Industry (GDA) pledged to reduce GHG emissions under a voluntary agreement with the Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMU) and under the Voluntary Declaration of German Industry.	The voluntary agreement with the BMU aims to reduce PFC emissions from aluminum smelters. The Voluntary Declaration of German Industry aims to reduce GHG emissions from the alumina refineries, smelters, and post-production processes.	From 1990 to 1997, CF_4 emissions per metric ton of primary aluminum were reduced by 43% from 0.44 kg CF_4 /t Al in 1990 to 0.25 kg CF_4 /t Al in 1997.
New Zealand	Regulatory	PFC emissions from New Zealand's sole aluminum smelter (NZAS) are regulated under the 1991 Resource Management Act. NZAS also participates in a voluntary agreement with the Ministry of Energy to reduce its CO_2 emissions.	Regulatory programs set process and technology standards to reduce PFC emissions. The voluntary agreement targets CO_2 emissions from NZAS.	From 1990 to 1995, New Zealand reduced PFC emissions from the aluminum smelting by 67 percent.
Norway	Voluntary	The Norwegian aluminum industry began negotiations with the Ministry of the Environment in 1996 to develop a voluntary program aimed at reducing PFC emissions and increasing energy efficiency.	The voluntary program aims to reduce CO_2-equivalent emissions from aluminum smelters.	From 1985 to 1993, PFC emissions from aluminum smelters have been reduced by 43 percent.
United Kingdom	Regulatory[2]	PFC emissions from the aluminum industry are regulated in the UK under the Integrated Pollution Control (IPC) regime, under the 1990 Environmental Protection Act.	Regulatory programs set technology standards to reduce PFC emissions from aluminum smelters.	From 1990 to 1996, the UK aluminum industry reduced the PFC emission rate, in CO_2 equivalents per metric ton of aluminum, by 69 percent.
United States	Voluntary	In 1995, 11 of 12 primary aluminum producers joined with the US Environmental Protection Agency (EPA) to form the Voluntary Aluminum Industrial Partnership (VAIP) to Reduce PFC Emissions.	The VAIP program aims to reduce PFC emissions from aluminum smelting where technically feasible and cost-effective.	From 1990 to 1997, the PFC emissions rate decreased an estimated 34 percent. PFC emission levels were reduced by 30 percent during this same period.

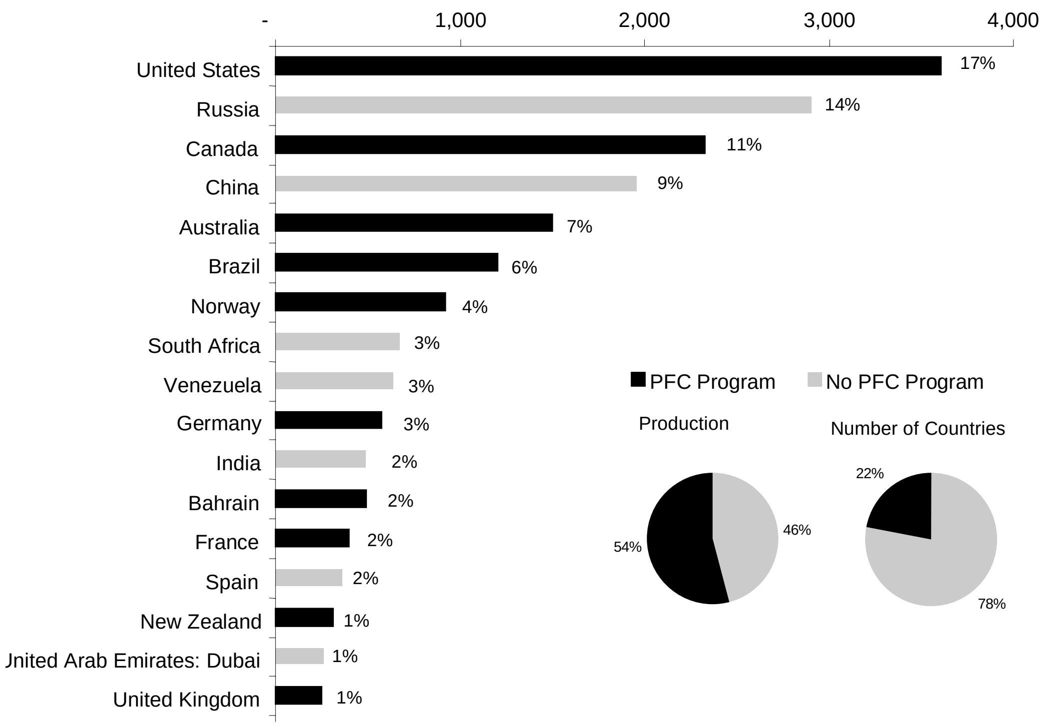
2. In the UK, much of the effort to reduce greenhouse gas emissions has been undertaken voluntarily by the aluminum industry in agreement with regulatory authorities such as the Environment Agency.

3.3 Worldwide PFC Reduction Efforts

Exhibit 4 highlights producer nations that have established programs to reduce PFC emissions and the portion of global production they represent. As shown in the exhibit, most major producer nations have programs to reduce PFC emissions from primary aluminum production. Countries with programs accounted for 54% of total production in 1997. Additionally, internal discussions on programs to reduce PFC emissions have begun in the Netherlands, Iceland, Spain, and Sweden, but no agreements are in place as of November, 1998 (Nordheim, 1998).

Exhibit 4. Countries with PFC Reduction Programs

(Data in Thousand Metric Tons and % of Total; 1997 data)



Other Producer Countries: Netherlands, Indonesia, Taijikstan, Egypt, Argentina, Italy, Romania, Ghana, Greece, Iran, Iceland, Sweden, Ukraine, Cameroon, Slovenia, Turkey, Poland, Slovakia, Serbia & Montenegro, Suriname, Croatia, Switzerland, Hungary, Japan, Mexico, Azerbaijan, Bosnia & Hertzegovina, Nigeria.

Source: USGS Aluminum Industry Annual, 1998 and country profiles (Annex 1)

China and Russia are two of the largest producers that do not have programs to reduce PFC emissions from primary aluminum production. These countries accounted for 23% of total production in 1997. In China, there are currently no regulations for PFC or other GHG emissions for the aluminum industry; however, the Chinese National Environmental Protection Agency regulates emissions of fluoride, chlorine, and other non-GHGs. In Russia, there are no specific programs to reduce GHG, including PFC, emissions in the aluminum industry at present. According to the State Committee on Environment Protection of the Russian Federation (SCEP), all sectors of the industry are involved in restructuring projects at the enterprise level with government support (SCEP, 1998). It is not clear how this restructuring will affect emissions.

3.4 Methods to Estimate PFC Emissions and Reductions

When evaluating the progress reported by different countries in reducing emissions, it should be recognized that emission estimation methods and the technology mix of the smelters differ across countries.

PFC estimation methods include continuous monitoring of emissions, the development of a smelter-specific relationship between emissions and operating parameters based on field measurements (e.g., the slope method and the Pechiney Over-Voltage Method) and the use of default emission factors.

- **Smelter measurements.** Continuous monitoring of emissions is the most accurate method for measuring emissions. Field measurements have been conducted in many countries, including Canada, Germany, Norway, and the USA. Field measurements may be time consuming and expensive relative to other emissions factor based estimation methods. Consequently, the data from these measurements are often only gathered to develop and validate models used to estimate emissions. Direct smelter measurements offer tangible technical and policy benefits by generating more accurate data and therefore enabling countries to improve their emissions inventory numbers.

- **Smelter-specific relationship.** Another estimation method is to develop and use a validated smelter-specific relationship between emissions and operating parameters based on measured data that are representative of long term operations. This method requires comprehensive measurements and on-going collection of operating parameter data (e.g., frequency and duration of anode effects) to develop the smelter-specific relationship.

  Slope Method. This method uses a linear relationship between anode effect (AE) minutes per cell-day and CF_4 emissions, expressed as:

  $$\text{kg } CF_4/\text{tonne of Al} = \text{slope x AE Minutes/cell-day}$$

  This relationship was first expressed by workers at Hydro Aluminium and Alcoa based on field measurements at their prebake facilities. Both companies independently arrived at a slope of 0.12 (IPAI, 1996). Recent field measurements in the USA also indicate a slope of 0.12 for prebake cells (Leber et al., 1998).

  To develop an accurate estimate of the slope, simultaneous measurements of CF_4 emissions and anode effect data are required. These measurements should be repeated over a range of anode effect minutes to ensure that the linear relationship holds for a range of anode effect minutes.

  The Slope Method is equivalent to one of the methods identified in *The 1996 Revised IPCC Guidelines* (IPCC, 1997) and proposed by Tabereaux (1994). This method assumes that the generation of CF_4 in an electrolysis cell follows Faraday's Law. Faraday's Law states that the quantity of PFC generated depends on the flow of electrical current in the cell. Using this method, PFC emissions can be calculated using the following equation:

$$\text{kg } CF_4\text{/tonne of Al} = 1.698 \times (p/CE) \times AEF \times AED$$

Where p is the average fraction of CF_4 in the cell gas during anode effects; CE is the current efficiency; AEF is the number of anode effects per cell day; and AED is the anode effect duration in minutes. Limiting the usefulness of this approach is uncertainty regarding how best to estimate p for various operating conditions and cell technologies. C_2F_6 emissions are assumed to be 10 percent of CF_4 emissions.

Pechiney Over-voltage Method. This method uses the anode effect over-voltage as the relevant process parameter since it integrates the fluctuation in voltage during an anode effect. The correlation formula was derived from numerous test measurements of PFC generation at different smelters with Pechiney technology.

$$\text{kg } CF_4\text{/tonne of Al} = 1.9 \times AEO / CE$$

Where AEO is the anode effect over-voltage in mV; CE is the current efficiency in percent (Bouzat et al., 1996).

One of the drawbacks of this method is that many smelter process systems do not have the capacity to collect the data required to compute the anode effect over-voltage. This limits the application of this method.

Other Methods. In addition to these methods, there are still others that are unique to certain countries. One such method is based on industry-average PFC emission factors, which is currently used by the USA (see country profiles for more detail).

- **Default emission factors**. Where a smelter-specific relationship between emissions and operating parameters has not been developed, but information on operating parameters and production is available, default technology-specific slope and over-voltage coefficients may be used. When these data are not available, default emission factors by technology type are provided by the Intergovernmental Panel on Climate Change (IPCC). The IPCC is in the process of updating these factors to reflect new measurement data available in the literature. This method is the most uncertain of the three approaches.

While each of these methods is useful in fitting measured emission rates to process parameters, all fall short of providing a robust predictor of emissions from process parameters monitored during standard production, across producers, across technologies, and for a range of anode effect durations (IPAI, 1996). Not only do the estimation methods vary, but the reporting of operating parameters also varies across smelters. For example, the anode effect duration reported at different smelters is often not comparable due to: different measurement equipment or methods and different definitions of process parameters (such as anode effect start time or end time). Data on the types of smelter technologies used in each country are presented in Annex 2.

No industry/government consensus on the most accurate ("best") PFC estimation method has been achieved. However, efforts to define a robust and generally accepted estimation model are ongoing, and include the work of the IPCC as well as country-based research programs designed to improve the understanding of the relationship between operating parameters and emissions. This type of work is extremely important because if industry and government can come to a consensus on the accuracy of estimation methods, then it will be easier to confidently compare and contrast emissions estimates developed by different methods.

Exhibit 5 presents PFC emission factors measured in tonnes of CO_2 equivalents per tonne of aluminum produced, percent reduction in the PFC emissions factors, and emission estimation methods reported by the individual countries. Using emission reductions reported by each country, PFC emissions rates were converted into a common unit, metric ton of CO_2 equivalents per metric ton of aluminum produced.

Exhibit 5. PFC Emissions Reductions

Country	t CO_2-*e*/ t Aluminum[1]		Years	Reduction		Estimation	Data
	Start Year	End Year	Start-End	Overall %	%/year	Method[2]	Source(s)[2]
Australia[3]	3.9	0.9	'90-'97	78%	19%	Slope Method	Australian National Greenhouse Gas Inventory (Workbook 8.2) and country contract.
Bahrain[4]	1.5	0.8	'95-'98	47%	19%	Pechiney Over-voltage	Country contact
Brazil[4]	1.9	1.3	'94-'96	31%	17%	Faraday's Law	Country contact
Canada	5.4	2.7	'90-'95	49%	13%	Smelter Measurements	National communication to UNFCCC and country contact
France[4]	7.0	1.9	'90-'97	73%	17%	Pechiney Over-voltage	National communication to UNFCCC and country contact
Germany[4]	3.3	1.9	'90-'97	43%	5%	Smelter Measurements	Country contact
New Zealand	2.5	0.8	'90-'95	69%	21%	NA[5]	National communication to UNFCCC
Norway	3.0	2.0	'90-'93	34%	13%	Smelter Measurements	National communication to UNFCCC
United Kingdom[6]	9.0	2.8	'90-'96	69%	18%	Other	Country contact
United States	4.4	3.0	'90-'97	32%	7%	Other	Country contact

1. The unit for the PFC emissions factor is tonnes of CO_2 equivalent per metric ton of aluminum. In general, both CF_4 and C_2F_6 are included. GWPs for CF_4 and C_2F_6 are 6,500 and 9,200 respectively.
2. See individual country profiles for information on the estimation method and country contact.
3. Emission factor estimates are based on 1) a linear regression model of emissions in USA and Norway; 2) IPAI international survey; and 3) an estimating model developed for an Australian smelter.
4. C_2F_6 emissions were not reported; for this analysis, it was assumed C_2F_6 emissions are 10% of CF_4 emissions.
5. Not available.
6. Specific method is unknown. Information gathered indicates that emission factors based on anode effect frequency and anode effect duration were developed.

Note: Emissions rates and reductions across countries may not be comparable due to different methods used to estimate emissions.

Ongoing research in the USA as well as other countries will continue to improve the understanding of the relationship between operating parameters and PFC emissions. The International Primary Aluminium Institute (IPAI) is collaborating with primary producers to collect and analyze anode effect data and share information on PFC emissions and measurement methods (IPAI, 1996). Additionally, in coordination with industry and government experts, the IPCC is currently working on refining methods to inventory greenhouse gas emissions, including PFCs.

3.5 Opportunities

Although most companies, countries, and programs have generally been successful in their PFC emission reduction efforts, further opportunities exist for reducing PFC emissions and improving our understanding of emissions estimates. Some of these include:

- **Making capital investments.** Increased process efficiency and reduced PFC emissions can provide additional incentives for companies to invest in new cell technologies and computerized systems. These technologies are profitable in the long-term, even though installation requires significant up-front investment. Access to capital is especially a problem in developing countries and countries with economies in transition. For example, in Russia, raising capital to make process improvements is difficult due to the current economic and political conditions.

- **Understanding the PFC generation process.** Key to identifying and implementing strategies to reduce PFC emissions is improvement of the fundamental understanding of the mechanism of PFC production during anode effects. The industry has done extensive work to understand anode effects. Research programs, such as the US PFC emissions measurement program, are currently underway to further refine relationships between PFC emissions and operation parameters. This progress will facilitate our ability to quantify emission levels and help to identify possible means to reduce these emissions.

- **Quantifying emissions and reductions.** Efforts to develop consistent and robust methods to quantify PFC emission rates are underway. With an established framework to quantify emission levels it will be possible to verify emission reductions and to make consistent comparisons between country's emission reduction claims. The IPCC good practice guidelines, expected to be issued in early 2000, will present methods to estimate PFC emissions from primary aluminum production. These good practice guidelines are likely to establish accepted methods for estimation and will help to create a framework to quantify PFC emissions and compare emission levels across countries.

4. Conclusion

The aluminum industry has been proactive and responsive to government initiatives aimed at reducing PFC emissions from primary aluminum production. PFC emission reduction measures not only reduce PFC and other GHG emissions, but also improve process efficiency. As a result, both industry and government have an interest in implementing these measures.

Many of the producer countries are implementing technologies and practices to reduce PFC emissions. As they continue to do so, emission rates will continue to decline in these countries. Additional opportunity exists to make progress in other countries, including Russia and China, which are major producers.

Further advances in PFC emissions reductions depend, in a large part, on the effectiveness of voluntary and regulatory programs to achieve emission reductions. Information transfer and international collaboration will facilitate and accelerate efforts to reduce PFC emissions internationally.

A key area where international collaboration will prove most useful is in the development of robust methods to quantify PFC emissions from primary aluminum production. Such methods will help in the following ways:

- help producing countries inventory their PFC emissions,
- help industry and government to identify strategies to reduce emissions,
- serve as a tool to verify emission reduction efforts, and
- allow for comparisons of PFC emission reduction efforts across countries, which will help to determine which policies, programs, or practices are most effective.

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Annex 1: Country Profiles

Annex 1 profiles each producer country that has undertaken industry-government initiatives to reduce PFC emissions from primary aluminum production. In order to identify and collect information on international efforts to reduce PFC emissions, the following steps were taken:

- Identified the top 25 aluminum producing countries. From this list, countries that have or were thought to have PFC emission reduction programs through industry networking and literature searches, were identified. Established industry or government contacts in each country were identified.

- Submitted questionnaire and/or conducted interviews with country contacts. Collected additional information from National Communications, industry literature, press releases, and other sources.

- Compiled information into a country profile. The information in each country profile represents that government/industry's interpretation of the PFC emission reduction efforts. Emission reductions are reported in the measure provided.

- Submitted the country profile to individual countries for review. In an iterative process, refined the profiles by incorporating new information and comments from the country contact.

Australia

Aluminum Industry Profile

Australia is the world's largest producer of bauxite and alumina. In 1997, Australia produced 1.5 million metric tons of aluminum making it the 5^{th} largest producer in the world. Production is projected to increase to 1.7 million metric tons by 2000.

There are 6 companies that produce aluminum in Australia:

Owner	% of Total Capacity
Alcoa & JVPs	19%
Alcoa AUS	10%
Capral	9%
Comalco	8%
Comalco & JVPs	29%
Tomago Al	24%

Note: JVPs means joint venture parters
Source: Anthony Bird Associates, 1998

Efforts to Reduce GHGs from the Aluminum Industry

National PFC Programs

Voluntary	Regulatory	Inventory
✓		✓

Aluminum Industry Initiatives

Sector	PFCs	Other GHGs
Alumina Refineries		✓
Aluminum Smelters	✓	✓
Post-Production[1]		

1. Includes semi-fabrication to distribution

GHG Reduction Achievements

Total PFC emissions decreased an estimated 73 percent from 1990 to 1997. The PFC emissions rate is estimated to have decreased from 3.9 to 0.9 tonnes of CO_2 equivalent per tonne of aluminum over this period, a reduction of 78 percent.

Energy efficiency and process management improvements resulted in a 2.2 percent decrease in total CO_2 emissions from 1990 to 1997, even though production rose by 20 percent.

National Greenhouse Gas (GHG) Initiatives

Australia became the 9^{th} country to ratify the United Nations Framework Convention on Climate Change on December 30, 1992. Australia signed the Kyoto Protocol on April 28, 1998. Australia's primary framework for addressing climate change is the Greenhouse Office, established in 1997, an outgrowth of the National Greenhouse Response Strategy, which was endorsed by Commonwealth, State and local governments in 1992.

To reduce emissions from the industrial sector, the Greenhouse Challenge, a government-industry initiative, was launched in 1995. This voluntary program, coordinated by the Australian Greenhouse Office (AGO), encourages industry to take a voluntary approach to reducing GHG emissions through improvements in energy efficiency, process efficiency, sink enhancement and effective use of resources.

Aluminum Industry Initiatives

The aluminum industry, represented by the Australian Aluminum Council, signed a voluntary "Framework Agreement" and joined the Greenhouse Challenge industry-government partnership in 1995. The Framework Agreement provides for aggregate forecasts of greenhouse gas emissions for the entire industry. Sectors of the industry make separate voluntary agreements under the Framework Agreement. Aluminum smelters and alumina refineries have already made such agreements.

The Framework Agreement targets all GHGs. Alumina refineries have agreed to reduce GHG emissions mainly by improving energy efficiency. Smelters are focusing on reducing PFC and other process emissions as well as improving energy efficiency.

Program Implementation

The agreement to reduce emissions from aluminum smelting, known as the Smelter Supplementary Agreement, was signed by all smelters in September 1996.

The agreement is implemented through individual action plans signed by industry partners with the support of the Australian government. Industry partners customize their goals based on facility-specific conditions, and these goals are reviewed periodically and revised if necessary. Industry partners identify options for reducing GHG emissions from the aluminum industry that are technically feasible and cost effective. Each industry partner submits an annual report to the Australian government detailing emission-reduction activities and estimated reductions achieved, along with a GHG inventory.

For its part, the Australian government agrees to overall program responsibilities and makes specific commitments to individual industry partners. The government agrees to streamline government policies to improve energy and process efficiency, provide technical material, run workshops and training programs on GHG reduction technologies and practices, and provide public recognition to partner companies.

Outcomes

The following emissions reduction initiatives were undertaken by Australian aluminum smelters and alumina refineries:

PFC reduction initiatives. Major improvements in equipment performance and reliability; job redesign; and training of smelter operators. As a result, PFC emissions decreased an estimated 73 percent from 1990 to 1997. Emission estimates are based on a method developed by the Australian aluminum industry, which incorporates (1) a linear regression model of emission measurement data from the USA and Norway; (2) an international survey by International Primary Aluminum Institute; and (3) an estimating model developed specifically for the technology used by one of the Australian smelters.

Energy efficiency initiatives. Investment in modernization of pot line design and operation; employee training; technology transfer; improved management of compressed air; and investments in upgrading the carbon bake facilities and operations. As a result, the energy and associated GHG emissions associated with processes other than direct smelting were reduced. Total CO_2 emissions decreased 2.2 percent from 1990 to 1997. Even though production rose by over 20 percent over the same period, PFC and CO_2 emissions, in CO_2 equivalents per tonne of aluminum, decreased 18.7 percent from 1990 to 1997. In addition to energy efficiency improvements in aluminum smelting, alumina refineries have invested in energy efficiency and other actions and have reduced CO_2 emissions by ten percent per metric ton of alumina between 1990 and 1997.

Next Steps

Australia's aluminum industry is considering a number of future actions that could result in GHG abatement, including:

- continued improvements in control of anode effects through the refinement of automated control systems and further improvements in operator training to manage the systems;
- improvements in pot line operation and pot design to further reduce the consumption of electricity per tonne of aluminum produced;
- improved design and materials for carbon anodes and improvements to the anode baking operations, including more efficient baking furnace gas consumption;
- reduction of energy consumption in auxiliary systems such as the dry scrubbers and compressed air reticulation;
- fuel switching in non-electricity energy consuming operations;
- long-term research into new low-energy cells, which could achieve 15 to 20 percent reductions in power consumption;
- investment in modernizing pot lines at older smelters, which would yield substantial greenhouse benefits due to the greater efficiency of more modern technology;
- further efforts to achieve greater powerhouse efficiency at alumina refineries including cogeneration; and
- measures to reduce energy requirements in the alumina refinery process.

Contact Information

For more information on Australia's efforts to abate GHGs (including PFCs) from aluminum smelting and alumina refineries, contact:

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Manuka, ACT, Australia 2603
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aac@aluminum.org.au

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Bahrain

Aluminum Industry Profile

In 1997, Bahrain produced 493,000 metric tons of aluminum, making it the world's 11th largest producer. Aluminum production is expected to increase to 500,000 metric tons by the year 2000.

There is one company that produces aluminum in Bahrain:

Owner	% of Total Capacity
ALBA	100%

Source: Anthony Bird Associates, 1998

Efforts to Reduce GHGs from the Aluminum Industry

National PFC Programs

Voluntary	Regulatory	Inventory
✓		

Aluminum Industry Initiatives

Sector	PFCs	Other GHGs
Alumina Refineries		
Aluminum Smelters	✓	✓
Post-Production[1]		

1. Includes semi-fabrication to distribution

GHG Reduction Achievements

By 1998, PFC emissions from aluminum smelters were limited to 0.8 tonnes of CO_2 equivalent per tonne of aluminum. From 1995 to 1998, Bahrain reduced the PFC emissions rate from aluminum smelting by 47%.

National Greenhouse Gas (GHG) Initiatives

Bahrain ratified the United Nations Framework Convention on Climate Change on December 28, 1994. The treaty entered into force on March 28, 1995. Bahrain has not yet signed the Kyoto Protocol (as of November 1998).

Aluminum Industry Initiatives

Bahrain's sole aluminum producer, Aluminium Bahrain, is implementing a voluntary program for PFC and CO_2 emissions reduction. The Ministry of Housing, Municipalities, and Environment through the Directorate of Environmental Affairs coordinates activities with Aluminium Bahrain.

Program Implementation

As part of the voluntary agreement, Aluminium Bahrain periodically measures its GHG emissions, implements measures to reduce emissions, and reports them to the Ministry of Housing, Municipalities and Environment.

For its part, the Government of Bahrain oversees overall environmental control responsibilities and provides public recognition to program participants.

Outcomes

The focus of PFC emissions reduction efforts is to reduce the frequency and duration of anode effects through automated control systems and improvements in operator training to manage the systems. Emissions are calculated every four weeks and refinements to the control systems and operations are subsequently made in order to improve system efficiency and reduce PFC emissions.

By 1998, PFC emissions from aluminum smelters were limited to 0.8 tonne of CO_2 equivalent per tonne of aluminum produced. From 1995 to 1998, Bahrain reduced the PFC emissions rate by 47%. The PFC emission levels are estimated using the Pechiney over-voltage model, which uses anodic over-voltage as the process parameter to predict PFC emission rates.

Next Steps

Bahrain's aluminum industry plans continued GHG reduction efforts, including:

- following international efforts to reduce GHG emissions;

- complying with any new international standard protocols for measuring and reducing emissions; and
- adopting proven technologies for reducing emissions.

Contact Information

For more information on Bahrain's efforts to reduce GHGs (including PFCs) from aluminum smelting, contact:

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General Manager, Aluminium Bahrain
P.O. Box 570
Manama, Bahrain
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Directorate of Environmental Affairs
Ministry of Housing, Municipalities and Environment
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Bahrain
Tel: (0973) 293-693 Fax: (0973) 293-694

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Brazil

Aluminum Industry Profile

In 1995, Brazil produced 1,188,000 metric tons of aluminum, making it the world's 6th largest producer.

There are 6 companies that produce aluminum in Brazil:

Owner	% of Total Capacity
Albras	28%
Alcan	9%
Alcominas	7%
Alumar	29%
CBA	18%
Valesul	8%

Source: Anthony Bird Associates

Efforts to Reduce GHGs from the Aluminum Industry

National PFC Programs

Voluntary	Regulatory	Inventory
✓		✓

Aluminum Industry Initiatives

Sector	PFCs	Other GHGs
Alumina Refineries Aluminum Smelters Post-Production[1]	✓	✓

1. Includes semi-fabrication to distribution

GHG Reduction Achievements

The PFC emissions rate is estimated to have decreased from 1.9 to 1.3 tonnes of CO_2 equivalent per tonne of aluminum from 1994 to 1996, a reduction of 31 percent.

National Greenhouse Gas (GHG) Initiatives

Brazil ratified the United Nations Framework Convention on Climate Change on February 28, 1994. Brazil signed the Kyoto Protocol on April 28, 1998. Brazil's framework for addressing climate change is a multi-institutional team, under the coordination of the Ministry of Science and Technology (MST).

Brazil's efforts related to GHG emissions reduction include research and development in the area of ethanol fuel derived from sugarcane, the development of hydro, wind, solar and thermal power plants, energy conservation, and suppression of forest fires.

Aluminum Industry Initiatives

The Brazilian Aluminum Association (ABAL) made a voluntary agreement to reduce GHG emissions. Their efforts are supported by Brazil's Ministry of Science and Technology (MST). The voluntary agreement targets PFC (CF_4 and C_2F_6) and CO_2 emissions from aluminum smelters.

Program Implementation

The aluminum industry has improved process control and upgraded technologies.

Outcomes

Brazil's aluminum industry has successfully reduced PFC emissions per tonne of aluminum produced through improved process control and the application of advanced technology. In 1996, the PFC emissions factor was 31 percent below the 1994 level. The table below illustrates Brazil's success at reducing PFC emissions per tonne of aluminum.

Year	Average PFC emissions (kg CF_4/tonne)	Soderberg PFC emissions (kg CF_4/tonne)	Pre-baked PFC emissions (kg CF_4/tonne)
1994	0.26	0.40	0.21
1995	0.21	0.35	0.17
1996	0.18	0.30	0.13

Emissions are estimated using Faraday's law and the method developed by Tabereaux in 1994. This is the primary estimation procedure; however, some smelters have measured their emissions using Fourier transform infrared spectrometry.

Next Steps

Brazil's aluminum industry plans to continue efforts to reduce GHG emissions.

Contact Information

For more information on Brazil's efforts to reduce GHGs (including PFCs) from aluminum smelting, contact:

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ABAL (1998). The Brazilian Aluminum Association. Correspondence, July 1998.

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Canada

Aluminum Industry Profile

In 1997, Canada produced 2.3 million metric tons of aluminum, making it the 3rd largest producer in the world. Production is projected to increase to about 2.8 million metric tons by 2001-2003.

There are 5 companies that produce aluminum in Canada:

Owner	% of Total Capacity
ABI	15%
Alcan	48%
Alouette Al	10%
Alumax	9%
Reynolds	17%

Source: Anthony Bird Associates

Efforts to Reduce GHGs from the Aluminum Industry

National PFC Programs

Voluntary	Regulatory	Inventory
✓		✓

Aluminum Industry Initiatives

Sector	PFCs	Other GHGs
Alumina Refineries		✓
Aluminum Smelters	✓	✓
Post-Production[1]		

1. Includes semi-fabrication to distribution

GHG Reduction Achievements

PFC emissions decreased an estimated 30 percent from 1990 to 1996. The PFC emissions rate is estimated to have decreased from 5.4 to 2.7 tonnes of CO_2 equivalent per tonne of aluminum over this period, a reduction of about 50 percent. Energy efficiency improvements resulted in a 10 percent decrease in energy consumption per tonne of aluminum produced from 1990 to 1996.

The industry objective is to reduce PFC emissions by 50 percent from 1990 levels by the year 2000 and reduce energy intensity by 0.3 percent per year until 2010.

National Greenhouse Gas (GHG) Initiatives

Canada ratified the United Nations Framework Convention on Climate Change on December 4, 1992. Canada signed the Kyoto Protocol on April 29, 1998. Canada's primary framework for addressing climate change is the Task Group on Climate Change, a multi-stakeholder group of government, business, labor, consumer and environmental members.

Canada's efforts to reduce GHG emissions include a range of policy instruments, including information and education initiatives, voluntary programs, research and development, and economic instruments. The majority of measures in Canada have been aimed at increasing energy efficiency and energy conservation or encouraging a switch to energy sources that are less carbon intensive.

Aluminum Industry Initiatives

The Aluminum Industry Association, which represents 100 percent of primary aluminum production in Canada, participates in the Voluntary Challenge and Registry (VCR) Program initiated by the Canadian Government (Natural Resources Canada and Environment Canada).

The VCR Program aims to reduce PFC and CO_2 emissions from aluminum smelting. The aluminum industry also endorses Ecogeste, a Quebec action plan for the implementation of the United Nations Framework Convention on Climate Change.

The aluminum industry also participates in the voluntary Canadian Industry Program for Energy Conservation (CIPEC), aimed at improving energy efficiency. (However, it is important to note that Canadian aluminum smelters operate entirely on hydroelectric energy, which is not a source of GHGs).

Program Implementation

The VCR Program is implemented through individual action plans designed by industry partners with the support of the Canadian government. Industry partners customize their goals based on facility-specific conditions, and these goals are reviewed periodically and revised if necessary. Industry partners identify technically feasible options for reducing GHG emissions from the aluminum industry, and implement only those options that promise to be cost-effective. Along with a GHG inventory, each industry partner submits an annual report to the Canadian government, detailing emissions and reductions.

For its part, industry regularly reports their GHG emissions to the VCR (specifically, Environment Canada and Natural Resources Canada) and Eco-geste (initiated by the Quebec Government). Each year, companies submit an action plan for energy efficiency to the Canadian Industry Program for Energy Conservation (CIPEC).

For its part, the Canadian government agrees to overall program responsibilities and partially funds research for energy efficiency.

Outcomes

Measures to reduce PFC emissions were identified through a large-scale measurement and research program financed by Canada's aluminum industry and by Environment Canada. The measures identified include improvement in the controls of processes to reduce the frequency and duration of anode effects. Due to implementation of these measures, PFC emissions from Canada's aluminum industry decreased an estimated 30 percent from 1990 to 1996. Emissions are calculated using average emission rates based on field measurements from a number of plants, representative of four types of aluminum-smelting technologies.

Additionally, energy efficiency improvements have resulted in a 10 percent decrease in energy consumption per tonne of aluminum produced from 1990 to 1996.

Next Steps

The aluminum industry's objective is to reduce PFC emissions by 50 percent from 1990 levels by the year 2000 and reduce the energy input per kilogram of aluminum produced by 0.3 percent each year until 2010.

While marginal efficiency can be made through process improvements, achieving energy efficiency within the aluminum sector is closely tied to the construction of new smelters and the replacement rate of old smelters. Thus, the major challenge facing the aluminum sector is to secure funding or investments to underwrite replacement of old, less energy-efficient smelters, and to expand existing new smelters.

The most important innovation on the horizon is the graphite cathode block, which will replace the carbon cathode block. While the replacement of carbon blocks by graphite blocks does not reduce emissions of PFC, it reduces the energy consumption per tonne of aluminum. Where electricity is generated from fossil fuels, CO_2 emissions would also be reduced. In Canada, however, the electricity grid is hydro based.

Canada is also making the recycling of aluminum a priority, as recycled aluminum requires only 5 percent of the energy used for primary aluminum.

Contact Information

For more information on Canada's efforts to reduce GHGs (including PFCs) from primary aluminum production, contact:

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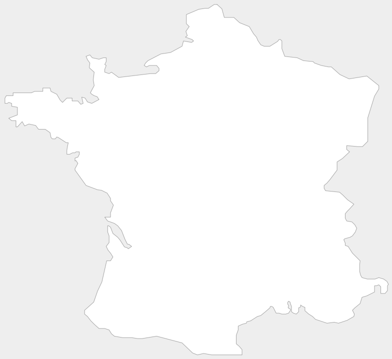
France



Aluminum Industry Profile

In 1997, France produced 399,000 metric tons of aluminum, an increase of 22 percent from 1990 levels. It is the world's 13th largest producer. Primary aluminum production is projected to increase to 447,000 tonnes by 2000. Secondary aluminum production is projected to increase from 107,000 tonnes in 1990 to 118,000 tonnes in 2000.

There is one company that produces primary aluminum in France:

Owner	% of Total Capacity
Aluminium Pechiney	100%

1997 data

Efforts to Reduce GHGs from the Aluminum Industry

National PFC Programs

Voluntary	Regulatory	Inventory
✓		✓

Aluminum Industry Initiatives

Sector	PFCs	Other GHGs
Alumina Refineries		✓
Aluminum Smelters	✓	✓
Post-Production; Recycling[1]		✓

1. Includes one secondary refining plant and two primary remelting plants.

GHG Reduction Achievements

Between 1990 and 1997, CF_4 emissions per metric ton of primary aluminum were reduced from 7 to 1.9 tonne of CO_2 equivalent per tonne of aluminum, a reduction of 73 percent, and CO_2 emissions per metric ton of aluminum (both primary and secondary) were reduced by 19 percent. This is in line with the 2000 targets in terms of specific emissions.

The goal is to reduce its emissions of CO_2 and CF_4 by a total of 34 percent (on a CO_2-equivalent basis) by the year 2000 relative to 1990 levels.

National Greenhouse Gas (GHG) Initiatives

France ratified the United Nations Framework Convention on Climate Change on March 25, 1994. France signed the Kyoto Protocol on April 29, 1998.

France's efforts to combat climate change include regulations aimed at encouraging energy savings (including regulation of heating in dwellings), economic instruments (including a fuel duty), public awareness activities, and the further development of nuclear power.

The French government has also worked with energy-intensive industries to develop voluntary commitments to reduce GHG emissions. As of November 1997, voluntary commitments had been signed by six partners (branches of industries).

Aluminum Industry Initiatives

In 1996, Aluminium Pechiney, the sole primary aluminum producer in France, made a voluntary commitment to reduce its emissions of CO_2 and CF_4 by a total of 34 percent (on a CO_2-equivalent basis) by the year 2000 relative to 1990 levels. Between 1990 and 1996, Pechiney reports a 19 percent reduction in CO_2 emissions from refining, smelting, and recycling operations, and a 73 percent reduction in CF_4 emissions from smelting, per tonne of aluminum (both primary and secondary) produced.

This reduction target is based on three assumptions: (1) primary aluminum production will increase 37 percent between 1990 and 2000; (2) secondary aluminum production will increase 10 percent between 1990 and 2000; and (3) the global warming potential (GWP) of CF_4 is 5100. However, the Intergovernmental Panel on Climate Change has since revised the GWP of CF_4 from 5100 to 6500. Aluminium Pechiney will adjust its commitment to reflect the revised GWP of CF_4, and is also likely to expand the commitment to include emissions of C_2F_6.

Program Implementation

To achieve its commitment to reduce CO_2 and CF_4 emissions, Aluminium Pechiney is implementing measures to (1) reduce the specific consumption of thermal and electric energy by 7% and 2.4% respectively compared with 1990, which is part of its commitment; and (2) reduce direct emissions of CO_2 and CF_4. These measures include:

- Improving the energy efficiency of aluminum production operations, including optimizing combustion equipment and investigating opportunities for fuel switching and cogeneration;

- Implementing electrolytic control measures;
- Improving fabrication processes;
- Improving alumina feed practices; and
- Conducting employee training and total quality management.

Aluminium Pechiney will fund the implementation of these measures, and will submit annual progress reports to the French government.

Outcomes

To reduce CF_4 emissions, Aluminium Pechiney has implemented point-feeding mechanisms that reduce the frequency and duration of anode effects. They report that between 1990 and 1997, CF_4 emissions per tonne of primary aluminum were reduced by 73 percent, which is matching the 2000 target. Reductions of CF_4 emissions are calculated using anode effect over-voltage as a process parameter and a formula based on test measurements of CF_4 and C_2F_6 emissions at four different pot lines.

To increase the energy efficiency of its operations, Aluminium Pechiney has upgraded its smelting production capacity with improved high-amperage electrolysis pots that reduce the electricity and carbon intensity of aluminum production. The company has also implemented process controls in anode baking and casthouse furnaces to reduce fuel consumption. Aluminium Pechiney reports that between 1990 and 1997, CO_2 emissions per tonne of aluminum (both primary and secondary) were reduced by 19 percent. Reductions of CO_2 emissions are determined by monitoring relevant process and energy consumption parameters, including electricity consumption through the average carbon intensity of power generation in France.

Next Steps

Aluminium Pechiney will continue to implement the measures described above to reduce emissions of CO_2 and CF_4. New additional steps are going to take place in 1999-2000 including implementation of electricity cogeneration in alumina production and restructuring of remelting activities. They are likely to provide additional improvements in terms of CO_2-specific emissions. However, the company reports that in France, the most significant emission reductions from implementing best-available technologies are likely to have been achieved by 2000, and that post-2000 emission reductions are unlikely to be significant unless aluminum production decreases.

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For more information on France's efforts to reduce GHGs (including PFCs) from primary aluminum production, contact:

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Germany

Aluminum Industry Profile

In 1995, Germany produced 575,000 metric tons of aluminum (3 percent of global production), making it the 9th largest producer in the world. Production is expected to remain constant through 2005.

There are 4 companies that produce aluminum in Germany:

Owner	% of Total Capacity
Essen Al	22%
Hamburger Al Werke	20%
Hoogovens	13%
VAW	45%

Source: Anthony Bird Associates

Efforts to Reduce GHGs from the Aluminum Industry

National PFC Programs

Voluntary	Regulatory	Inventory
✓		✓

Aluminum Industry Initiatives

Sector	PFCs	Other GHGs
Alumina Refineries		✓
Aluminum Smelters	✓	✓
Post-Production[1]		✓

1. Includes semi-fabrication to distribution

GHG Reduction Achievements

The aluminum industry reports that between 1990 and 1996, the PFC emissions rate decreased from 3.3 to 2.5 tons of CO_2 equivalent per tonne of aluminum, a reduction of 23 percent.

National Greenhouse Gas (GHG) Initiatives

Germany ratified the United Nations Framework Convention on Climate Change on December 9, 1993. Germany signed the Kyoto Protocol on April 29, 1998. Germany's primary framework for addressing climate change is the CO_2 reduction Inter-ministerial Working Group, established in June 1990. Working parties have been established for the following areas: energy supply, transport, buildings and structures, new technologies, and agriculture and silviculture.

Many German industries have pledged to reduce CO_2 emissions as part of the Voluntary Declaration of German Industry, a voluntary government-industry initiative.

From 1990 to 1995, German emissions of CO_2 decreased 12 percent, CH_4 emissions decreased 16 percent, and N_2O emissions decreased 7 percent, as reported by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

Aluminum Industry Initiatives

On June 17, 1997, the industry trade association German Aluminum Industry (GDA) signed a voluntary agreement with the BMU to reduce PFC emissions from aluminum smelters. They have also agreed to the Voluntary Declaration with the BMU, which aims to reduce GHG emissions from the alumina refineries, smelters, and post-production processes. In addition, individual smelter-specific voluntary agreement targets PFCs (CF_4 and C_2F_6).

Program Implementation

The voluntary agreement is endorsed by the Primary Aluminum Smelters Group, which represents all German primary aluminum producers. German aluminum producers have voluntarily set a target of reducing:

- the PFC emission rate per kg of aluminum produced by about 50 percent from 1990 levels by the year 2005, and
- total PFC emissions from Germany's aluminum smelters by at least 50 percent from 1990 levels by the year 2005. This means reducing CF_4 emissions from 316 metric tons in 1990 to 158 tonnes or less in 2005, and reducing C_2F_6 emissions from 32 to 16 tonnes or less.

Germany's aluminum industry will voluntarily modernize aluminum smelters using the best available technology and will educate smelter operators on improved process management. The Primary Aluminum Smelters Group will submit annual progress reports to the BMU. A neutral institute will measure PFC emissions. The German Environment Ministry will recognize aluminum companies for participation and offer consultation support.

Outcomes

In 1996, a neutral measuring institute, in agreement with the authorities, measured emissions in all German primary aluminum smelters. From 1990 and 1996, CF_4 emissions per metric ton of primary aluminum were reduced by 23 percent from 0.44 kg CF_4/ t Al in 1990 to 0.34 kg CF_4/ t Al in 1996. In 1997, actual efforts reduced CF_4 emissions further to 0.25 kg CF_4 /t Al. This reduction brings Germany closer to their short-term target of reducing 1990 emissions by 50% by 2005.

The measuring institute determined the CF_4 emission factor in the following way:

- measuring the mean CF_4 concentration of an anode effect;
- determining the mean duration of an anode effect;
- multiplying the overall flow rate and the mean duration of an anode effect to yield the CF_4 flow rate per anode effect;
- multiplying the total number of anode effects (from documentation) and the CF_4 emission per anode effect to yield the total CF_4 emissions; and
- dividing the total CF_4 emissions by the tonnage of aluminum produced to yield the CF_4 emission per tonne aluminum.

Next Steps

According to the agreements, the aluminum industry will continue PFC reduction efforts to reach its target CF_4 emission factor of 0.22 kg CF_4/t Al by 2005. In 1999, the aluminum industry plans to evaluate the progress of the Voluntary Agreement and reassess target levels of GHG reduction.

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New Zealand

Aluminum Industry Profile

New Zealand produced 273,000 metric tons of aluminum in 1995, making it the world's 14^{th} largest producer.

There is one company that produces aluminum in New Zealand:

Owner	% of Total Capacity
NZAS	100%

Source: Anthony Bird Associates

Efforts to Reduce GHGs from the Aluminum Industry

National PFC Programs

Voluntary	Regulatory	Inventory
	✓	✓

Aluminum Industry Initiatives

Sector	PFCs	Other GHGs
Alumina Refineries Aluminum Smelters Post-Production[1]	✓	✓

1. Includes semi-fabrication to distribution

GHG Reduction Achievements

New Zealand PFC emissions from the aluminum industry were reduced from 89 metric tons in 1990 to 29 metric tons in 1995, a 67 percent reduction. The PFC emissions rate decreased from 2.5 to 0.8 tonnes of CO_2 equivalent per tonne of aluminum, a reduction of 69 percent.

Energy efficiency improvements are projected to reduce energy consumption per tonne of aluminum produced by 4 percent from 1990 to 1996.

National Greenhouse Gas (GHG) Initiatives

New Zealand ratified the United Nations Framework Convention on Climate Change on September 16, 1993, and signed the Kyoto Protocol on May 22, 1998. The country's primary framework for addressing climate change is the New Zealand Climate Change Programme, an inter-agency working group formed in 1988.

New Zealand's 1991 Resource Management Act provides a mechanism for local and regional governments to respond to climate change by developing plans and policies and by granting "resource consents" to industry. To be granted a resource consent, developers must use the best means practicable to minimize proposed GHG emissions. Resource consents have a time constraint and contain a review clause.

Since 1994, the New Zealand Ministry of Commerce has signed voluntary agreements to reduce CO_2 emissions with several industries, including aluminum, glass, steel, cement, methanol, and plaster board. Each agreement establishes a company's 1990 base year data and a target for the year 2000.

Aluminum Industry Initiatives

New Zealand Aluminum Smelters Ltd. (NZAS) owns and operates New Zealand's sole aluminum smelter. CO_2 and PFC emissions from the NZAS smelter are being minimized through a regulatory program, and CO_2 emissions from the NZAS smelter are also addressed in the voluntary program described above.

Program Implementation

PFC emissions from the NZAS smelter are subject to resource consent conditions issued under the 1991 Resource Management Act. These conditions ensure minimizing of emissions by the application of the most practicable process control and technology. In addition, the smelter must monitor PFC emissions according to a method agreed to by the consent agency and submit annual PFC emission reports to the consent agency (Southland Regional Council). The data are also made available to central government agencies on request.

NZAS signed a voluntary agreement to limit its smelter's CO_2 emissions with the Minister of Commerce on September 6, 1995. The voluntary agreement between NZAS and the Ministry of Energy involves GHG monitoring and government consultation to minimize GHG emissions.

Outcomes

NZAS significantly reduced PFC emissions from its aluminum smelter through changes in process control procedures, including upgrades to the reduction cell control system and changes to control strategies to reduce the frequency and duration of anode effects. PFC emissions were reduced from 89 metric tons in 1990 to 29 metric tons in 1995, a 67 percent decrease.

Additionally, energy efficiency improvements are projected to decrease energy consumption per tonne of aluminum produced by 4 percent from 1990 to 2000.

Next Steps

PFC emissions are projected to rise slightly to 34 metric tons in 2000 due to an increase in aluminum production and then stabilize at that level through 2010. New Zealand's aluminum industry plans continued GHG reduction efforts.

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For more information on New Zealand's efforts to reduce GHGs (including PFCs) from the aluminum industry, contact:

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Plume, H. (1998). Personal communication with Helen Plume, March 1998.

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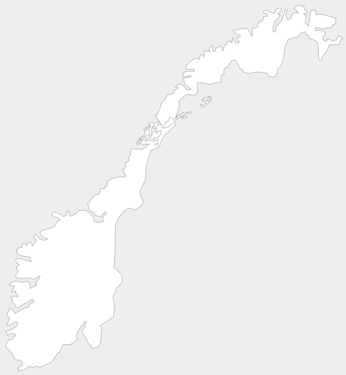
Norway



Aluminum Industry Profile

In 1996, Norway produced 800,000 metric tons of aluminum making it the 6th largest producer in the world. Production is projected to increase to 1 million metric tons by 2000.

There are 3 companies that produce aluminum in Norway:

Owner	% of Total Capacity
Hydro Al	69%
Elkem Aluminum ANS	21%
Soer-Norge	11%

Source: Anthony Bird Associates and S. Namdal

Efforts to Reduce GHGs from the Aluminum Industry

National PFC Programs

Voluntary	Regulatory	Inventory
✓		✓

Aluminum Industry Initiatives

Sector	PFCs	Other GHGs
Alumina Refineries Aluminum Smelters Post-Production[1]	✓	✓

1. Includes semi-fabrication to distribution

GHG Reduction Achievements

Total emissions of PFCs from aluminum smelters have been reduced by 43 percent between 1985 and 1993. From 1990 to 1993, the PFC emissions rate has decreased from 3 to 2 tonnes of CO_2 equivalent per tonne of aluminum, a reduction of 34 percent in this period.

Norway aims to reduce the PFC emission rate by 50 percent from 1990 levels by the year 2000 and 55 percent from 1990 levels by the year 2005.

National Greenhouse Gas (GHG) Initiatives

Norway ratified the United Nations Framework Convention on Climate Change on July 9, 1993. Norway signed the Kyoto Protocol on April 29, 1998. Norway's nationally established target to stabilize CO_2 emissions at 1989 levels by 2000 is an important guiding principle for Norwegian climate policy.

Norway's climate policy includes market-based incentives and voluntary government-industry partnerships. A CO_2 tax on oil, natural gas, and coal for energy use implemented in 1991 together with industry partnerships have lead to increased energy efficiency and reduced GHG emissions in the industrial sector.

Aluminum Industry Initiatives

In June 1997, the Norwegian aluminum industry entered into a voluntary agreement with the Ministry of the Environment and Industry aimed at reducing greenhouse gas emissions. The voluntary agreement has been signed by only the smelting portion of the aluminum industry. Under the agreement, the smelters agree to implement activities to reduce PFC emissions by reducing anode effects and reduce CO_2 emissions through increased energy efficiency.

Even prior to the establishment of the voluntary agreement with the government to reduce greenhouse gases, Norway's aluminum smelters have been implementing activities to reduce PFC emissions. These activities have included improving process controls and replacing older inefficient smelter technologies with the newer pre-bake technology.

Program Implementation

In the agreement, the primary aluminum producers have voluntarily set a target of reducing the PFC emission rate (PFC emissions per metric tonof aluminum produced) by about 50 percent from 1990 levels by the year 2000 and 55 percent below 1990 levels by the year 2005.

The agreement is on an industry basis rather than a smelter basis. Within the overall industry agreement, each smelter sets targets and produces an action plan. Smelters customize their goals based on facility-specific conditions. The goals are reviewed periodically and revised if necessary. Smelters identify technically feasible options for reducing GHG emissions and implement only those options that promise to be cost-effective. At the end of each year, an annual report detailing emission reduction activities and estimated reductions achieved is submitted to the Ministry of Environment and Industry.

Outcomes

It is too early to report on the progress of activities undertaken under the 1997 voluntary agreement. Among emissions reduction actions identified are the installation of point-feed systems, improvement of existing point-feed systems, and refinement of process control systems and routines.

As a result of ongoing efforts to reduce PFC emissions (prior to the agreement), aluminum smelters have reduced total PFC emissions by 43 percent between 1985 and 1993. Measurements and calculations performed by Norwegian production plants indicate that emissions per unit produced have been reduced from about 0.6 to 0.3 kg PFCs per metric ton aluminum during this period, a reduction of 50 percent.

A method to estimate GHG emissions has been set for both Soderberg and pre-bake technology and for anode production. Equation forms and constants have been agreed upon between industry and the government based on smelter measurements. The emission estimation methodology requires that industry report the following parameters to the government:

- CO_2 in metric tons for each plant and technology;
- CF_4 and C_2F_6 in kg or metric tons and in CO_2-equivalents for each plant and technology;
- Current intensity;
- Anode effect frequency; and
- Number of cell days and number of upstart cells for each plant and technology.

Norway's aluminum industry anticipates that PFC emissions can be reduced by 80-90 percent compared to the 1990 level by the year 2005. From 1990 to 2005, the potential reductions could be in excess of 1.5 million tonnes of CO_2 equivalents per year, or about 3 percent of the total emissions of GHGs in Norway.

Next Steps

The aluminum industry plans to evaluate the progress of the voluntary agreement in 2000. A reassessment of the target levels of GHG reduction will be discussed in 2005. The industry expects an increase in aluminum production of about 20% per year from 1995 to 2005. Emissions of CO_2 are expected to rise in conjunction with the production increases. Efforts to reduce GHG emissions on a plant-by-plant basis include the following measures: installation of point feeders, improvement of existing point feeders, and improved data equipment/control systems and routines.

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References

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United Kingdom

National Greenhouse Gas (GHG) Initiatives

The United Kingdom ratified the United Nations Framework Convention on Climate Change on December 8, 1993. The United Kingdom signed the Kyoto Protocol on April 29, 1998. The Department of the Environment is responsible for UK policy on climate change, however, other agencies have the lead on specific policies and measures. The UK Climate Change Programme includes economic instruments (including a road fuel duty), regulatory and deregulatory measures, voluntary action and public awareness programs.

Aluminum Industry Initiatives

PFC emissions from aluminum smelting are regulated in the UK under the Integrated Pollution Control (IPC) regime, which was introduced to regulate industrial pollution under the 1990 Environmental Protection Act.

Much of the effort to reduce greenhouse gas emissions has been undertaken voluntarily by the industry in agreement with the regulatory authorities such as the Environment Agency. The primary smelters in the UK presented a schedule of anticipated PFC reductions in the 1994 Climate Change Report, and the industry is planning to meet the targets projected to the year 2000.

Program Implementation

PFC emissions from aluminum smelting are regulated by the Environment Agency (EA) in England and Wales and by the Scottish Environment Protection Agency (SEPA) in Scotland. EA and SEPA ensure that emissions from aluminum smelting are as low as can reasonably be achieved through the use of BATNEEC (Best Available Technology Not Entailing Excessive Cost). EA and SEPA also consult aluminum smelters on improved operation and process control systems to minimize the occurrence of anode effects.

Outcomes

New computer controls of the primary pot lines at the three modern primary smelters in the UK have improved process control and have reduced anode effects. Over the period 1990 to 1997, the UK aluminum industry has achieved a 69 percent reduction in the PFC emission factor, in CO_2-equivalent emissions per tonne of primary aluminum produced from 9 tonnes to 2.8 tonnes. The PFC emissions estimation method is based on the number and duration of anode effects and emissions relevant to UK primary aluminum industry.

Aluminum Industry Profile

The UK produced 238,000 metric tons of aluminum in 1995, making it the 16^{th} largest producer in the world. Production is expected to increase to 300,000 tonnes per year by 1998 and then remain stable at 300,000 tonnes per year through 2010.

There are 2 companies that produce aluminum in the UK:

Owner	% of Total Capacity
Anglesey AL	42%
British Alcan	58%

Source: Anthony Bird Associates

Efforts to Reduce GHGs from the Aluminum Industry

National PFC Programs

Voluntary	Regulatory	Inventory
✓	✓	✓

Aluminum Industry Initiatives

Sector	PFCs	Other GHGs
Alumina Refineries		
Aluminum Smelters	✓	
Post-Production[1]		

1. Includes semi-fabrication to distribution

GHG Reduction Achievements

Over the period 1990 to 1996, the UK Aluminum industry has achieved a 69 percent reduction in the PFC emission factor, in CO_2 equivalent emissions per tonne of primary aluminum produced. The PFC emission factor decreased from 9 to 2.8 tonnes of CO_2 equivalent per tonne of aluminum from 1990 to 1996.

Next Steps

As a result of actions taken to minimize the occurrence of "anode effects" in the aluminum reduction cell, PFC emissions from the UK are expected to fall from 300 metric tons in 1990 to 30 tonnes in 2000, a 90 percent reduction. The UK aluminum smelting industry and the UK government plan continued GHG reduction efforts.

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For more information on the UK's efforts to reduce GHGs (including PFCs) from primary aluminum production, contact:

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United States

Aluminum Industry Profile

The USA is the world's largest producer of aluminum. From 1990 to 1997, primary aluminum production in the USA decreased from 4 million metric tons to 3.6 million metric tons. Production is projected to increase to 4.3 million metric tons by 2000.

As of 1999, there were 12 companies that produced aluminum in the USA.

Owner	% of Total Capacity
Alcan Ingot	4%
Alcoa Inc.*	31%
Alumax*	14%
Century Aluminum	5%
Columbia Falls	4%
Goldendale	4%
Kaiser Aluminum	7%
Noranda Aluminum	5%
Northwest	2%
Ormet Corp.	6%
Southwire Co.	4%
Reynolds Metals Co.	11%
Vanalco Inc.	3%

* Alcoa Inc. purchased Alumax in 1998.
Source: Aluminum Statistical Review, 1997

Efforts to Reduce GHGs from the Aluminum Industry

National PFC Programs

Voluntary	Regulatory	Inventory
✓		✓

Aluminum Industry Initiatives

Sector	PFCs	Other GHGs
Alumina Refineries Aluminum Smelters Post-Production[1]	✓	✓

1. Includes semi-fabrication to distribution

GHG Reduction Achievements

From 1990 to 1997, PFC emissions from aluminum smelting decreased an estimated 30 percent. The PFC emissions rate decreased from 4.4 to 3 tonnes of CO_2 equivalent per tonne of aluminum, a reduction of 34 percent.

National Greenhouse Gas (GHG) Initiatives

The USA ratified the United Nations Framework Convention on Climate Change on October 15, 1992. The USA signed the Kyoto Protocol on November 12, 1998.

The US government is committed to addressing the challenge of climate change with cost-effective policies that are good both for the environment and the economy. This approach involves three main goals: (1) to contribute to a necessary foundation in science; (2) to base US policies on partnerships with the private sector, states, localities, and non-governmental organizations; and (3) to strengthen international responses to the risks of climate change.

Aluminum Industry Initiatives

Eleven of the nation's 12 primary aluminum companies have partnered with the US Environmental Protection Agency (EPA) through the Voluntary Aluminum Industrial Partnership (VAIP) to reduce PFC emissions. Launched in April 1995, the VAIP represents 22 of the 23 smelters and 94% of the nation's production capacity. The Aluminum Association has been instrumental in facilitating the work of the partnership.

The VAIP aims to reduce PFC emissions from aluminum smelting where technically feasible and cost-effective. The program framework includes company-specific emissions reduction targets and periodic reporting of the progress toward achieving the targets. The goal is to reduce US PFC emissions from aluminum smelting by 30 to 60 percent from 1990 levels by the year 2000.

The industry has also formed a partnership with the US Department of Energy (DOE) to improve energy efficiency and environmental performance. The aluminum industry is one of the "*Industries of the Future*" for DOE's Office of Industrial Technology. A key element of the ongoing research in the DOE-industry partnership is the development of the advanced cell technology with inert anode and wettable cathode components.

Program Implementation

The VAIP is implemented through individual agreements between the primary aluminum producers and the EPA. Industry partners work jointly with the EPA to set targets that are based on facility-specific conditions.

Each industry partner agrees to provide information and data used to establish baseline emission estimate, periodic reports on their activities and estimated emissions reductions achieved.

The EPA agrees to:

- Improve the availability and distribution of information relevant to reducing PFC emissions;
- Encourage other aluminum-producing countries to endeavor to reduce PFC emissions and share technical information; and
- Provide recognition to companies participating in the VAIP and inform the public, including other federal agencies and Congress, regarding reductions made by the partner under the VAIP; and
- Hold any overall program responsibilities and any designated information provided by the partners confidential.

Outcomes

US PFC emissions from aluminum production are estimated to have declined from the equivalent of 18 million metric tons of CO_2 in 1990 to the CO_2 equivalent of 10.7 million metric tons in 1997, a reduction of 30%. This decline was both due to reductions in domestic aluminum production and actions taken by the VAIP partners to reduce the frequency and duration of anode effects (see Table I). The average PFC emissions rate for VAIP partners is estimated to have declined from the equivalent of about 4.4 tonnes of CO_2 per metric ton of aluminum in 1990 to the equivalent of about 3 tonnes of CO_2 per metric ton of aluminum in 1997, a reduction of about 32%. The change in emission rates is based on data on reductions in the frequency and duration of anode effects reported by the VAIP partners. As of 1997 the VAIP had achieved over 70% of its emission reduction goal (assuming a 45% reduction target and that production levels in 2000 will be similar to those in 1990).

Table I. Estimated PFC Emissions and VAIP Reductions: 1990 – 1997*

	1990	1991	1992	1993	1994	1995	1996	1997
Primary Production ('000 m tons)	4,048	4,121	4,042	3,695	3,299	3,375	3,577	3,603
Emissions Rate (m tons CO_2/ ton Al)	4.4	4.2	3.8	3.5	3.1	3.0	3.1	3.0
Emissions (m tons CO_2)	18.0	17.4	15.2	12.9	10.3	10.3	11.1	10.7
VAIP Reductions (m tons CO_2)		0.6	2.8	5.1	7.7	7.7	6.9	7.3
Reduction due to Production Decline		-0.2	0.3	1.4	2.4	2.0	1.6	1.6
Reduction due to Emissions Reduction Actions		0.8	2.5	3.7	5.3	5.7	5.3	5.7
% Change relative to 1990 levels								
Primary Production (%)		2%	0%	-9%	-19%	-17%	-12%	-11%
Emissions Rate (%)		-5%	-14%	-20%	-30%	-32%	-30%	-32%
Emissions (%)		-3%	-16%	-28%	-43%	-43%	-38%	-41%

* The U.S. is currently reevaluating its emissions estimates in line with the soon to be finalized IPCC revised guidelines. It is expected that once the new tiered approach is applied, the U.S. numbers will improve.

PFC emissions were estimated by multiplying annual primary aluminum production by a PFC emission rate that changes over time. US industry-average emission rates presented in the Climate Change Action Plan (CCAP) Technical Supplement -- 0.6 and 0.06 kg per metric ton of aluminum for CF_4 and C_2F_6 respectively -- are assumed for all smelters for the base year 1990. In subsequent years, PFC emission rates are assumed to decline over time as a result of VAIP progress. The rate of decline in the emission rate is equivalent to the rate of decline in the operating parameter targeted for reduction by each smelter (e.g., anode effect frequency or duration). To calculate VAIP reductions, estimated emissions were subtracted from "baseline" emissions, which are those anticipated in the absence of the VAIP program and assuming that the CCAP emissions rate remains constant over the period of analysis.

The VAIP has also initiated efforts to improve understanding of PFC production during aluminum smelting. These efforts include establishing a PFC emissions measurement program and conducting anode effect research.

In the area of energy efficiency, industry has continually improved the smelting process in order to reduce production costs and remain competitive. The average smelting energy requirement fell from 112 MMBTUs/metric ton of aluminum in 1990 to 109 MMBTUs/metric ton in 1995 (DOE, 1997).

Next Steps

The VAIP partners plan to continue efforts to reduce PFC emissions to meet the targeted reduction of 45% from 1990 levels by the year 2000 through continued improvements in control of anode effects. Efforts to reduce anode effects include refining automated control systems and improving operator training. Additional PFC emissions measurements are planned at smelters to better understand and quantify the relationship between emissions and operating parameters.

The industry, in cooperation with the Aluminum Association and DOE, has published the "*Aluminum Industry Technology Roadmap*" in 1997 that presents industry-wide performance targets for energy, environment, and market share, and describes the research and development strategy for achieving those targets. One of goals for the primary products sector includes reducing the energy intensity of aluminum production to 13 kWh/kg using retrofit technology. Another goal, pursued aggressively by industry, is the development of the advanced cell technology, with inert anode and wettable cathode components. An advanced cell will not only reduce the energy requirements, but will also eliminate the carbon anode thereby removing the source of carbon for perfluorocarbon generation.

Contact Information

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Annex 2: Smelter Characteristics by Country

Annex 2 presents the smelter characteristics for each country that has undertaken industry-government initiatives to reduce PFC emissions from primary aluminum production. The data presented are mostly extracted from a report by Anthony Bird Associates, "*Aluminium Annual Review 1998*". The data are reprinted with the consent of Anthony Bird.

Exhibit A2-1. Smelter Characteristics by Country

Country	Owner	Plant	Capacity ('000 metric tons)	Vintage	Process	Power Source
Australia	Alcoa AUS	Point Henry 1	80	1969	Prebake- PF[1]	Coal
	Alcoa AUS	Point Henry 2	101	1980	Prebake- PF	Coal
	Alcoa & Gov	Portland	328	1987	Prebake- PF	Coal
	Capral	Kurri Kurri 1	55	1969	Prebake-SW[2]	Coal
	Capral	Kurri Kurri 2	55	1979	Prebake-SW	Coal
	Capral	Kurri Kurri 3	55	1985	Prebake- PF	Coal
	Comalco	Bell Bay	138	1955	Prebake-CW[3]	Hydro
	Gladstone	Boyne Island 1	260	1982	Prebake-CW	Coal
	Gladstone	Boyne Island 2	230	1997	Prebake- PF	Coal
	Tomago Al	Newcastle 1	240	1984	Prebake- PF	Coal
	Tomago Al	Newcastle 2	140	1993	Prebake- PF	Coal
	Tomago Al	Newcastle 3	60	1998	Prebake- PF	Coal
Bahrain	Alba	Bahrain 1	255	1989	Prebake- PF	Gas
	Alba	Bahrain 2	244	1993	Prebake- PF	Gas
Brazil	Albras	Belem 1	175	1986	Prebake-SW	Hydro
	Albras	Belem 2	175	1991	Prebake-SW	Hydro
	Alcan	Saramenha	51	1945	Soderberg-HS[4]	Hydro
	Alcan	Aratu 1	28	1972	Soderberg-VS[5]	Hydro
	Alcan	Aratu 2	30	1982	Prebake-SW	Hydro
	Alcominas	Pocos de Caldas	92	1970	Soderberg-VS	Hydro
	Alumar	Sao Luis	358	1984	Prebake-PF	Hydro
	CBA	Mairinique 1	105	1955	Soderberg-VS	Hydro
	CBA	Mairinique 2	30	1983	Soderberg-VS	Hydro
	CBA	Mairinique 3	45	1986	Soderberg-VS	Hydro
	CBA	Mairinique 4	45	1992	Prebake-PF	Hydro
	Valesul	Santa Cruz	100	1992	Prebake-CW	Hydro

Country	Owner	Plant	Capacity ('000 metric tons)	Vintage	Process	Power Source
Canada	ABI	Becancour	362	1986	Prebake-PF	Hydro
	Alcan	Arvida	232	1972	Prebake-SW	Hydro
	Alcan	Beauharnois	48	1943	Soderberg-HS	Hydro
	Alcan	Grande Baie	200	1982	Prebake-PF	Hydro
	Alcan	Isle Maligne	73	1953	Soderberg-VS	Hydro
	Alcan	Kitimat	280	1958	Soderberg-VS	Hydro
	Alcan	Laterriere	214	1991	Prebake-PF	Hydro
	Alcan	Shawinigan	84	1940	Soderberg-HS	Hydro
	Alumax	Deschambault	220	1992	Prebake-PF	Hydro
	Alouette Al	Alouette	229	1992	Prebake-PF	Hydro
	Reynolds	Baie Comeau 1	160	1982	Soderberg-VS	Hydro
	Reynolds	Baie Comeau 2	240	1985	Prebake-PF	Hydro
France	Al Dunkerque	Dunkirk	220	1992	Prebake- PF	Nuclear
	Pechiney	Auzat	44	1973	Prebake-SW	Hydro
	Pechiney	Lannemezan	44	1979	Prebake- PF	Hydro
	Pechiney	St. Jean 1	35	1980	Prebake- PF	Hydro
	Pechiney	St. Jean 2	95	1986	Prebake- PF	Hydro
Germany	Essen Al	Essen	136	1970	Prebake-PF	Mixed
	Ham. Al Werke	Hamburg	125	1973	Prebake-CW	Nuclear
	Hoogovens	Voerde	80	1971	Prebake-CW	Mixed
	VAW	Norf	212	1984	Prebake-CW	Mixed
	VAW	Stade	70	1973	Prebake-SW	Nuclear
New Zealand	NZAS	Bluff	313	1996	Prebake-CW	Hydro
Norway	Hydro Al	Ardal 1	60	1963	Soderberg-VS	Hydro
	Hydro Al	Ardal 2	140	1971	Prebake- PF	Hydro
	Hydro Al	Ardal 3	12	1998	Prebake- PF	Hydro
	Hydro Al	Hoyanger 1	27	1915	Soderberg-VS	Hydro
	Hydro Al	Hoyanger 2	47	1981	Prebake- PF	Hydro
	Hydro Al	Karmoey 1	113	1967	Soderberg-VS	Hydro
	Hydro Al	Karmoey 2	108	1982	Prebake- PF	Hydro

Country	Owner	Plant	Capacity ('000 metric tons)	Vintage	Process	Power Source
Norway (cont'd)	Hydro Al	Karmoey 3	45	1997	Prebake- PF	Hydro
	Hydro Al	Sunndalsora 1	69	1954	Soderberg-VS	Hydro
	Hydro Al	Sunndalsora 2	69	1969	Prebake-SW	Hydro
	Mosal	Lista	85	1988	Soderberg-VS	Hydro
	Mosal	Moesjoen 1	55	1988	Soderberg-VS	Hydro
	Mosal	Moesjoen 2	70	1988	Prebake- PF	Hydro
	Soer-Norge	Husnes 1	92	1965	Prebake- PF	Hydro
	Soer-Norge	Husnes 2	14	1998	Prebake- PF	Hydro
UK	Anglesey AL	Holyhead	135	1987	Prebake- PF	Nuclear
	British Alcan	Kinlochleven	11	1907	Soderberg-VS	Hydro
	British Alcan	Lochaber	38	1981	Prebake- PF	Hydro
	British Alcan	Lynemouth	140	1972	Prebake- PF	Coal
USA	Alcan	Sebree KY	180	1974	Prebake- PF	Coal
	Alcoa	Alcoa TN 1	40	1975	Soderberg-VS	Coal
	Alcoa	Alcoa TN 2	80	1975	Prebake- PF	Coal
	Alcoa	Alcoa TN 3	80	1979	Prebake- PF	Nuclear
	Alcoa	Badin NC 1	57	1961	Prebake- PF	Hydro
	Alcoa	Badin NC 2	58	1965	Prebake- PF	Mixed
	Alcoa	(A) Massena NY	131	1976	Prebake- PF	Hydro
	Alcoa	Rockdale TX	310	1970	Prebake- PF	Coal
	Alcoa	Warrick IN	300	1960	Prebake- PF	Coal
	Alcoa	Wenatchee WA 1	85	1966	Prebake- PF	Hydro
	Alcoa	Wenatchee WA 2	125	1966	Prebake- PF	Hydro
	Alcoa	Mt. Holly SC	181	1980	Prebake- PF	Coal
	Alcoa	Frederick MD 1	100	1970	Prebake-SW	Coal
	Alcoa	Frederick MD 2	65	1976	Prebake-SW	Coal
	Alcoa	Bellingham WA	280	1966	Prebake-SW	Hydro
	Kaiser	Mead WA	200	1942	Prebake-CW	Hydro
	Kaiser	Tacoma WA	73	1942	Soderberg-HS	Hydro
	Columbia Falls Al	Columbia Falls MT	168	1955	Soderberg-VS	Hydro

Country	Owner	Plant	Capacity ('000 metric tons)	Vintage	Process	Power Source
USA (cont'd)	Noranda	New Madrid MO 1	130	1971	Prebake-CW	Coal
	Noranda	New Madrid MO 2	90	1982	Prebake- PF	Coal
	Goldendale Al	Goldendale WA 1	109	1971	Soderberg-VS	Hydro
	Goldendale Al	Goldendale WA 2	59	1982	Soderberg-VS	Hydro
	Northwest Al	The Dalles	83	1958	Soderberg-VS	Hydro
	NSA	Hawesville KY	190	1969	Prebake-CW	Coal
	Alcan	Hannibal OH	255	1958	Prebake-CW	Coal
	Century Al	Ravenswood WA	168	1957	Prebake-CW	Coal
	Reynolds	Longview WA	205	1941	Soderberg-HS	Hydro
	Reynolds	(R) Massena NY	123	1959	Soderberg-HS	Hydro
	Reynolds	Troutdale OR	121	1942	Prebake-CW	Hydro
	Vanalco	Vancouver WA	115	1940	Prebake-CW	Hydro

Note: In some cases, different parts of a smelter have been built or replaced at different times. This produces more than one vintage at the same plant. Those plants followed by a number (e.g., Point Henry 1, Point Henry 2), indicate different parts of the same plant.

1. PF = Point Feed
2. SW = Side Worked
3. CW = Center Worked
4. HS = Horizontal Stud
5. VS = Vertical Stud

Annex 3: United Nations Framework Convention on Climate Change (UNFCCC)

The risks posed by climate change have led virtually every nation to sign the United Nations Framework Convention on Climate Change (UNFCCC). The goal of the UNFCCC is to "stabiliz(e) greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." As of June 1999, 179 countries have ratified the UNFCCC.

To further the objectives of the UNFCCC, the Kyoto Protocol was drafted in December 1997 and sets quantified emission limitations and reduction targets. The Kyoto Protocol will become legally binding ("enter into force") ninety days after the date on which not less than 55 Parties to the Convention ratify, and must include at least 55% of the 1990 total CO_2 emissions from Annex I Parties[2]. As of the middle 1999, 84 countries have signed and 14 have ratified the treaty[3].

UN Framework Convention on Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC) commits signatory governments to undertake voluntary actions aimed at reducing emissions of greenhouse gases to 1990 levels. The key provisions and responsibilities of this agreement pertaining to PFC emissions include:

- Article 4.1 requires all parties to the UNFCCC to develop national inventories of all anthropogenic greenhouse gas emissions and sinks not covered under the Montreal Protocol.[4] While the UNFCCC does not delineate specific GHGs, the definition includes PFC emissions.

- Article 4.2 (a) and 4.2 (b) state that Annex I Parties shall aim to reduce emissions of CO_2 and other GHGs not controlled by the Montreal Protocol to 1990 levels by the year 2000. This definition includes PFC emissions.

- Article 12.1 requires parties to submit national communications, which shall include an inventory of all anthropogenic GHG emissions and sinks not covered under the Montreal Protocol. This definition applies to PFC emissions.

- Article 12.2 (a) and (b) require Annex I parties to submit a detailed description of the policies and measures that it has adopted to implement its commitment under Article 4.2(a) and 4.2(b); and a specific estimate of the effects that these policies and measures will have on anthropogenic emissions by its sources and removals by its sinks of greenhouse gases during the period referred to in Article 4.2(a).

Emissions Inventories

When the UNFCCC entered into force in 1994, Annex I Parties were required to submit National Communications to describe their climate change mitigation strategies and to estimate GHG emissions and sinks. The Conference of the Parties (COP) adopted the Intergovernmental Panel on Cli-

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[2] Annex I Parties include Organization for Economic Cooperation and Development (OECD) member countries, except Mexico, and countries with economies in transition to market economies.

[3] After signing the agreement a government must ratify it, often with the approval of its parliament or legislature. Those that ratified the protocol by August 1999 include: Antiqua and Barbuda, Bahamas, Cyprus, El Salvador, Fiji, Georgia, Jamacia, Maldives, Micronesia, Niue, Panama, Paraguay, Trinidad and Tobago, Tuvalu.

[4] The Montreal Protocol on Substances that Deplete the Ozone Layer, adopted in Montreal on 16 September 1987 regulates the production and use of CFCs, halons, and carbon tetrachloride, which in addition to depleting the ozone layer are also greenhouse gases.

mate Change (IPCC)[5] guidelines on methods for the preparation of national greenhouse gas inventories. The first IPCC Guidelines, published in November 1994, were designed to ensure that emission inventories submitted to the UNFCCC are consistent and comparable across sectors and between nations. While methods to estimate emissions from GHGs other than CO_2, CH_4, and N_2O were not originally included in IPCC guidelines, the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* include methodologies for estimating emissions from additional sources and sinks, and additional gases, including PFCs (IPCC, 1997).

The *Revised Guidelines* include a method to estimate PFC emissions from primary aluminum production. Because PFC emissions vary significantly from one smelter to the next, the IPCC encourages obtaining actual, smelter-specific emissions measurements. Recognizing that this process is resource intensive, the IPCC recommends collecting measurements of anode effect frequency and duration and using an estimation method based on Faraday's law. Where actual measurements of process parameters are not feasible, the guidelines provide default emission factors, in kg CF_4 per tonne of aluminum produced, for four different smelting technologies: Modern Prebake, Horizontal Stud Soderberg, Older Prebake, and Vertical Stud Soderberg. In January 1999, the IPCC convened a group of industry, government, and academic experts to further refine the estimation methodologies included in the *Revised Guidelines*. This IPCC Aluminum Expert Group is in the process of developing good practice guidelines for inventory management of PFC emissions from primary aluminum production. This guidance document, expected to be issued in early 2000, will supplement the *Revised Guidelines* and include updated estimation methods and emission factors.

As of the beginning of 1999, thirty-seven countries have submitted inventories of GHGs under the UNFCCC. Of these 37, eleven national GHG inventories include PFC emissions from primary aluminum production. These countries are: Australia, Canada, France, Germany, Iceland, Italy, Netherlands, New Zealand, Norway, Sweden, the UK, and the USA (UNFCCC, 1998).

Kyoto Protocol

The Kyoto Protocol, drafted in 1997, calls for Annex B Parties to prepare inventories, report national GHG mitigation efforts, and set timetables for reducing emissions.[6] The protocol includes six GHGs: CO_2, CH_4, N_2O, hydrofluorocarbons (HFCs), PFCs, and sulfur hexafluoride (SF_6). Emissions targets for the USA, the EU, and Japan have been set at 7%, 8%, and 6% respectively below 1990 emissions levels for all six gases. Emission reductions will be measured against a baseline, which has been agreed as the 1990 emission levels. A provision has been made for HFC, PFC and SF_6 emissions in which countries can use either 1990 or 1995 as the baseline year for these gases. It is up to each country to decide which baseline to use based on their specific circumstances. The commitment period for Annex B Parties has been established for the years 2008-2012.

References

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[5] The IPCC was established in 1988 by the World Meteorological Organization and the UN Environment Programme. It conducts rigorous surveys of the world-wide technical and scientific literature and publishes assessment reports that are widely recognized as the most credible sources of information on climate change. The IPCC also works on methods to estimate GHG emissions from industrial and non-industrial sources and responds to specific requests from the UNFCCC's subsidiary bodies.

[6] Annex B countries include Annex I countries except Belarus and Turkey (Australia, Austria, Belgium, Bulgaria, Canada, Czechoslovakia, Denmark, European Economic Community, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Spain, Sweden, Switzerland, Ukraine, the UK, and the US), Croatia, Liechtenstein, Monaco, and Slovenia.

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