



# CODE OF PRACTICE TO REDUCE EMISSIONS OF FINE PARTICULATE MATTER (PM<sub>2.5</sub>) FROM THE PRIMARY ALUMINUM SECTOR



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Fax: 819-994-1412  
TTY: 819-994-0736  
Email: [enviroinfo@ec.gc.ca](mailto:enviroinfo@ec.gc.ca)

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## ABSTRACT

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This Code of Practice describes operational activities in the primary aluminium sector and concerns related to emissions of fine particulate matter (PM<sub>2.5</sub>) from these activities, including the production of aluminium from alumina using prebaked anode technology; prebaked anode production; green coke calcining and alumina production. It presents recommendations for the implementation of best practices to reduce emissions of PM<sub>2.5</sub>. These recommended practices can be used by the aluminium industry, regulatory agencies and the general public as sources of technical and policy guidance but they do not replace regulatory requirements.

## RÉSUMÉ

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Ce code de pratiques décrit les activités d'exploitation et les préoccupations liées aux émissions de particules fines ( $P_{2.5}$ ) du secteur de l'aluminium primaire incluant : les usines de production de l'aluminium à partir de l'alumine utilisant une technologie à anodes précuites; la production d'anodes précuites; les usines de calcination du coke vert et les usines de production d'alumine. Il présente des recommandations quant à la mise en œuvre des meilleures pratiques visant à réduire les émissions de  $P_{2.5}$ . Ces pratiques recommandées peuvent être utilisées par l'industrie de l'aluminium, des organismes de réglementation et le grand public en tant que sources d'orientation technique et stratégique, mais elles ne se substituent pas aux exigences réglementaires.

# TABLE OF CONTENTS

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<b>ABSTRACT</b> .....	<b>i</b>
<b>RÉSUMÉ</b> .....	
<b>EXECUTIVE SUMMARY</b> .....	
<b>1. INTRODUCTION</b> .....	<b>1</b>
1.1 Scope of the Code .....	2
1.2 Code development.....	3
1.3 Code structure .....	3
1.4 Sector description .....	3
<b>2. OPERATIONS AND SOURCES OF EMISSIONS</b> .....	<b>6</b>
2.1 Production of aluminium (electrolytic reduction) .....	6
2.2 Prebaked anode production .....	8
2.3 Green coke calcining.....	10
2.4 Alumina production .....	12
<b>3. RECOMMENDED PM<sub>2.5</sub> EMISSION CONTROL PRACTICES</b> .....	<b>15</b>
3.1 Aluminium production (electrolytic reduction) .....	18
3.1.1 Opening of electrolytic cell hoods.....	19
3.1.2 Gas extraction system.....	19
3.1.3 Prebaked anode changes .....	20
3.1.4 Crust covering the cryolite bath.....	20
3.1.5 Tapping of molten metal and cryolite bath.....	21
3.1.6 Cryolite bath spatter and spills .....	21
3.1.7 Skimming of carbon dust.....	22
3.1.8 Control of operating parameters.....	22
3.1.9 Casting of molten aluminium .....	23
3.1.10 Maintenance activities.....	23
3.1.11 Electrolytic reduction plant cleaning activities.....	24
3.1.12 Monitoring of scrubber operations .....	24
3.1.13 Maintenance of scrubbers, dust collectors and related systems .....	25
3.1.14 Monitoring of facilities and their outputs .....	26
3.1.15 Transportation of anode butts .....	27
3.2 Prebaked anode production .....	28
3.2.1 Baking furnace .....	28
3.2.2 Cleaning of anode butts .....	29
3.2.3 Frozen bath crushing .....	29
3.2.4 Maintenance activities.....	29
3.2.5 Monitoring of operations (FTC and PFTC) .....	30
3.2.6 Type of fuel .....	30

3.3	Green coke calcining.....	31
3.3.1	Maintenance activities.....	31
3.3.2	Monitoring of operations (pyroscrubber).....	31
3.3.3	Monitoring of operations (boiler followed by dust collector) .....	31
3.3.4	Monitoring of operations (venturi wet scrubber).....	32
3.3.5	Green coke storage.....	32
3.4	Alumina production .....	33
3.4.1	Maintenance activities.....	33
3.4.2	Red mud disposal .....	33
3.4.3	Consumption rate.....	33
3.5	Environmental management practices .....	34
<b>NOMENCLATURE .....</b>		<b>35</b>
<b>GLOSSARY .....</b>		<b>36</b>
<b>REFERENCES .....</b>		<b>40</b>

## LIST OF TABLES

---

Table S-1: List of recommendations.....	vii
Table 1-1: Distribution of PM <sub>2.5</sub> releases from industrial sectors in Canada in 2013.....	16
Table 1-2: Canadian primary aluminium facilities.....	19
Table 3-1: Potential sources of particulate emissions and recommendations, by activity .....	31

## LIST OF FIGURES

---

Figure 1-1: Schematic diagram of the activities associated with the primary aluminium sector.....	18
Figure 2-1: Schematic diagram of aluminium production (electrolytic reduction) illustrating the potential sources of particulate matter emissions .....	23
Figure 2-2: Schematic diagram of prebaked anode production illustrating the potential sources of particulate matter emissions .....	25
Figure 2-3: Schematic diagram of green coke calcining illustrating the potential sources of particulate matter emissions .....	27
Figure 2-4: Schematic diagram of alumina production (Bayer process) illustrating the potential sources of particulate matter emissions .....	29

## EXECUTIVE SUMMARY

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Federal, provincial and territorial ministers of the environment are taking action to better protect human health and the environment by endorsing and implementing the new Air Quality Management System (AQMS). The AQMS includes Canadian Ambient Air Quality Standards for fine particulate matter and ground-level ozone, base-level industrial emissions requirements (BLIERS) and air zone management by provincial and territorial jurisdictions. For the aluminium sector, quantitative BLIERS were developed for total particulate matter (TPM), polycyclic aromatic hydrocarbons (PAHs) and sulphur dioxide (SO<sub>2</sub>). Qualitative BLIERS were also developed for SO<sub>2</sub> and PM<sub>2.5</sub> and a PM<sub>2.5</sub> code of practice was developed and implemented. This Code of Practice (Code) applies to operational activities in the primary aluminium sector, including:

- production of aluminium from alumina (electrolytic reduction);
- prebaked anode production;
- green coke calcining; and
- alumina production.

In 2013, 13 facilities in Canada were carrying out at least one of these activities. These facilities include ten aluminium production plants, six prebaked anode production plants, three green coke calcining plants and one alumina production plant. Secondary activities, including port and/or rail services for transporting raw materials, regional hydroelectric plants and electrolytic cell relining centres are not covered by the Code, nor are activities associated with the electrolytic reduction process using Söderberg technology.

This Code was developed by Environment Canada in consultation with aluminium industry representatives and other stakeholders. Information on operating procedures and best practices is taken from various sources, including technical and scientific journals, as well as environmental codes of practice published by Environment Canada, the European Commission, the World Bank and the Light Metals Research Centre (LMRC) at the University of Auckland in New Zealand.

The Code describes potential sources of PM<sub>2.5</sub> emissions for each of the primary operational activities (Section 2) and makes recommendations to control and reduce these emissions (Section 3). These recommended practices can be used by the primary aluminium industry, regulatory agencies and the general public as a source of technical and policy guidance, but they do not replace regulatory requirements. The practices should be implemented in a continuous improvement context when they are required, relevant and applicable.

Table S-1 lists measures recommended to limit PM<sub>2.5</sub> emissions from each of the sectors' operational activities.

Owing to the constraints inherent in the technology, the Code does not aim to eliminate PM<sub>2.5</sub> emissions but rather to control them through effective measures and best practices. Furthermore, the Code does not recommend practices that would require an existing facility to make major technological changes.

When new facilities are being designed, other technologies can be taken into consideration to further reduce emissions, including high draft ventilation of pots activated when hoods are opened and a regenerative oxidation system to eliminate pitch emissions.



**Table S-1: List of recommendations**

Source	Recommendation	
<b>Production of aluminium from alumina</b>		
Opening of electrolytic cell hoods	R01	Optimize work methods to ensure that a minimum of hoods are opened simultaneously, and that they are opened only once work begins. Close hoods as soon as work is complete.
Gas extraction system	R02	Regularly assess the extraction efficiency of fans in relation to power supply, flow rate and pressure loss. Make adjustments as needed to maximize the extraction rate.
Changing of prebaked anodes	R03	Optimize work methods to minimize the time it takes to change anodes and cover them with anode cover material.
Crust covering cryolite bath	R04	Implement a program to monitor cracks in the crust by visual inspection or using an automated system. Ensure that the anode cover material is suitable and effective as a sealant.
	R05	Cover the taphole with anode cover material once the tapping or sampling work is complete.
Tapping of cryolite bath and molten metal	R06	During tapping operations, use flexible tubing to reroute fumes released from the crucible within the pot.
Cryolite bath spatter and spills	R07	Minimize and recover cryolite bath spills and spatter on the floor.
	R08	Pour the bath into the cell launder at an optimal speed to reduce pouring time and avoid spatter. Avoid pouring too slowly.
	R09	Minimize and recover cryolite bath residue in the launder when loading is complete.
Skimming of carbon dust	R10	Cool the hot carbon dust inside the pot or in a container with a cover. Minimize the amount of time carbon dust spends in the potroom.
Control of operating parameters	R11	Control and maintain an optimal bath level in the pot to prevent an unintended rise in bath temperature and direct contact with moist air. These two phenomena exacerbate the formation of fluorinated particles.
	R12	Prevent, control and minimize anode effect. After manually suppressing anode effects, cover cracks in the crust with anode cover material.
Casting of molten aluminium	R13	Minimize releases of particulate matter from the casting centre.
Maintenance activities	R14	Regularly, on a set schedule, inspect the aluminium production (electrolytic reduction) plant's facilities, including the condition of hoods, the gas exhaust ducts for each pot, the alumina supply system and the pot superstructure. In the event of breakdowns or malfunctions, make repairs or install appropriate replacement parts as soon as possible.

Source	Recommendation	
<b>Production of aluminium from alumina (cont.)</b>		
Maintenance activities	R15	Implement an employee training plan in support of an approach for preventing premature wear and breakdowns caused by improper operation of the facilities.
Cleaning activities (electrolytic reduction)	R16	Use a HEPA vacuum to clean the floor of the potroom and other buildings.
	R17	Regularly clean the suction inlet located inside the pot superstructure (slots, ventilation hoods section, etc.).
	R18	Regularly clear solid residues from the feeder/breaker to reduce the size of the hole in the crust after injection, thus decreasing emissions (corollary to Recommendation R05).
Monitoring of scrubber operations	R19	Regularly and periodically monitor the gas flow in each compartment of the scrubber while ensuring that it is uniform. Monitor pressure loss in order to identify anomalies requiring correction.
	R20	Adjust cleaning frequency and duration for the dust collectors and filtration media of the scrubber to balance gas flow for each compartment and maximize collection efficiency.
	R21	Where possible, depending on the production sector, limit the recycling of enriched or fluorinated alumina in GTC and FTC injection reactors, without influencing HF capture. Regularly and periodically monitor the recycling rate to ensure that it is optimal.
Maintenance of scrubbers, dust collectors and related systems	R22	Depending on the production sector and the filtration system, regularly inspect the following on a set schedule: the scrubber, including the collection system, sealing joints, fan (corollary to Recommendation R02) and alumina or calcined coke supply systems. Repair any breakdowns or malfunctions as soon as they are noted.
	R23	For the dust collector, replace the bags and other filtration media at the end of their service life. Do not wait until a breakdown occurs.
	R24	For the GTC, regularly inspect ducts where hard gray scale is likely to accumulate. Clean if too much has accumulated.
Monitoring of facilities and their outputs	R25	Monitor emissions of particulate matter from dust collectors. Investigate the causes of sudden increases in particulate matter emissions and make necessary adjustments.
	R26	Carry out visual inspections of pneumatic injection and mechanical handling systems according to a set schedule in order to detect leaks. Make repairs as soon as possible.
	R27	Periodically monitor and maintain dust collectors and replace filtration media at the end of their service life (corollary to Recommendations R22 and R23).
Transportation of anode butts	R28	Minimize air exposure time (and transport time) of anode butts in the potroom or outside of it. For example, make effective use of covered trays (or equivalent) to cool and transport anode butts (or crust and hot cryolite bath) to the storage room.

Source	Recommendation	
<b>Prebaked anode production</b>		
Baking furnace	R29	Maintain an effective system for filling baking furnace pits with packing coke to limit coke losses in the building. Train operators in order to standardize work methods for handling packing coke.
	R30	Monitor negative pressure at the FTC inlet or at the exit of the baking furnace.
Cleaning of anode butts	R31	Efficiently operate the collection, extraction and filtration systems for dust resulting from the anode butt cleaning process.
Crushing of frozen bath	R32	Filter emissions of fine particulate matter released from the crushing of frozen bath using dust collectors.
Maintenance activities	R33	Regularly inspect the following on a set schedule: the prebaked anode production facilities, including systems for anode butt cleaning, frozen bath crushing, and calcined coke grinding and sieving as well as the baking furnace. In the event of breakdowns or malfunctions, make repairs or install appropriate replacement parts as soon as possible.
	R15	Implement an employee training plan in support of an approach for preventing premature wear and breakdowns caused by improper operation of the facilities.
Monitoring of operations (FTC and PFTC)	R34	For the FTC only, operate the cooling tower so as to condense most of the tar contained in the baking gas. If necessary, add a prefilter (e.g., ceramic packing) to capture most particulate and condensable matter, including tar.
	R19	Regularly and periodically monitor the gas flow in each compartment of the scrubber while ensuring that it is uniform. Monitor pressure loss in order to identify anomalies requiring correction.
	R20	Adjust cleaning frequency and duration for the dust collectors and filtration media of the scrubber to balance gas flow for each compartment and maximize collection efficiency.
	R21	Wherever possible, depending on the production sector, limit recycling of enriched or fluorinated alumina in GTC and FTC injection reactors without influencing HF capture. Regularly and periodically monitor the recycling rate to ensure that it is optimal.
Type of fuel	R35	With regard to particulate matter emissions, use hydroelectric power instead of fossil fuels if possible with the current system. Otherwise, use natural gas instead of fuel oil (or another heavy fuel). For facilities that do not have access to hydro power, careful consideration should be given to other electric power sources before making a decision to switch the type of fuel.
Gas extraction system	R02	Regularly assess the extraction efficiency of fans in relation to power supply, flow rate and pressure loss. Make adjustments as needed to maximize the extraction rate.

Source	Recommendation	
<b>Prebaked anode production (cont.)</b>		
Maintenance of scrubbers, dust collectors and related systems	R22	Depending on the production sector and the filtration system, regularly inspect the following on a set schedule: the scrubber, including the collection system, sealing joints, fan (corollary to Recommendation R02) and alumina or calcined coke supply systems. Repair any breakdowns or malfunctions as soon as they are noted.
	R23	For the dust collector, replace the bags or other filtration media at the end of their service life. Do not wait until a breakdown occurs.
Monitoring of facilities and their outputs	R25	Monitor emissions of particulate matter from dust collectors. Investigate the causes of sudden increases in particulate matter emissions and make necessary adjustments.
	R26	Carry out visual inspections of pneumatic injection and mechanical handling systems according to a set schedule in order to detect leaks. Make repairs as soon as possible.
	R27	Periodically monitor and maintain dust collectors and replace filtration media at the end of their service life (corollary to Recommendations R22 and R23).

Source	Recommendation	
<b>Green coke calcining</b>		
Maintenance activities	R36	Regularly inspect the following on a set schedule: the green coke calcining and cooling facilities, including sealing joints and other mechanisms that could potentially lead to a gas leak and emissions of PM <sub>2.5</sub> . In the event of breakdowns or malfunctions, make repairs or install appropriate replacement parts as soon as possible.
	R15	Implement an employee training plan in support of an approach for preventing premature wear and breakdowns caused by improper operation of the facilities.
Monitoring of operations (pyroscrubber)	R37	Optimize the operating parameters of the pyroscrubber to maximize incineration of coke particles in addition to VOCs. As needed, follow up with a system designed to detect particles leaving the pyroscrubber and adjust accordingly.
Monitoring of operations (boiler followed by a dust collector)	R38	Optimize the performance of the cyclones and dust collector based on the total particle load. As needed, replace bags with more efficient ones.
Monitoring of operations (venturi wet scrubber)	R39	Regularly and periodically monitor the gas flow rate through the scrubber by measuring the water flow rate to the venturi inlet. The ratio of the two has a direct effect on pressure loss and the effective capture of particulate matter, including PM <sub>2.5</sub> . Optimize performance for the existing system.
Green coke storage	R40	Unload the green coke in a closed building at the coke calcining plant. Move green coke between various transfer points using closed conveyors or similar equipment or any other measures that can control dust emissions.
Gas extraction system	R02	Regularly assess the extraction efficiency of fans in relation to power supply, flow rate and pressure loss. Make adjustments as needed to maximize the extraction rate.
Maintenance of scrubbers, dust collectors and related systems	R22	Depending on the production sector and the filtration system, regularly inspect the following on a set schedule: the scrubber, including the collection system, sealing joints, fan (corollary to Recommendation R02) and alumina or calcined coke supply systems. Repair any breakdowns or malfunctions as soon as they are noted.
	R23	For the dust collector, replace the bags and other filtration media at the end of their service life. Do not wait until a breakdown occurs.
Monitoring of facilities and their outputs	R25	Monitor emissions of particulate matter from dust collectors. Investigate the causes of sudden increases in particulate matter emissions and make necessary adjustments.
	R26	Carry out visual inspections of pneumatic injection and mechanical handling systems according to a set schedule in order to detect leaks. Make repairs as soon as possible.
	R27	Periodically monitor and maintain dust collectors and replace filtration media at the end of their service life (corollary to Recommendations R22 and R23).

Source	Recommendation	
<b>Alumina production</b>		
Maintenance activities	R41	Regularly inspect the following on a set schedule: alumina calcining facilities and boilers at the alumina production plant. In the event of breakdowns or malfunctions, make repairs or install appropriate replacement parts as soon as possible.
	R15	Implement an employee training plan in support of an approach for preventing premature wear and breakdowns caused by improper operation of the facilities.
Red mud disposal	R42	Set up physical and/or chemical barriers for red mud disposal sites in order to minimize dusting when weather conditions are conducive to the dispersion of dust.
Consumption rate	R43	For boilers and alumina calciners, minimize natural gas or fuel oil consumption per tonne of alumina produced by using efficient heat recovery systems.
Monitoring of facilities and their outputs	R25	Monitor emissions of particulate matter from dust collectors. Investigate the causes of sudden increases in particulate matter emissions and make necessary adjustments.
	R26	Carry out visual inspections of pneumatic injection and mechanical handling systems according to a set schedule in order to detect leaks. Make repairs as soon as possible.
	R27	Periodically monitor and maintain dust collectors and replace filtration media at the end of their service life (corollary to Recommendations R22 and R23).
Type of fuel	R35	With regard to particulate matter emissions, use hydroelectric power instead of fossil fuels if possible with the current system. Otherwise, use natural gas instead of fuel oil (or another heavy fuel). For facilities that do not have access to hydro power, careful consideration should be given to other electric power sources before making a decision to switch the type of fuel.

Source	Recommendation	
<b>General</b>		
Environmental management practices	R44	Implementation of the recommendations set out in the Code should be integrated with the facility's environmental management plan, which should include analysis of the initial situation, a training plan, auditing protocols, and determination and implementation of corrective measures in a continuous improvement context.

# 1. INTRODUCTION

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Primary aluminium production is a major industry in Canada, ranking third worldwide with an annual production capacity of approximately 3 million tonnes (3.02 Mt in 2013)<sup>1</sup>, 90% of it in Quebec. Aluminium is produced by electrolytic reduction of dissolved alumina in a liquid aluminium fluoride and cryolite bath maintained at a temperature of approximately 960°C. Alumina is extracted from bauxite ore. Between 0.20 and 0.25 tonnes of aluminium is generally produced per tonne of bauxite. Aside from the electrolytic reduction process, the primary aluminium sector includes many related activities, such as the production of metallurgical-grade alumina, prebaked anode production and green coke calcining. All of these activities require the use of electricity, fuel and raw materials (petroleum coke, bauxite, aluminium fluoride, cryolite, tar pitch, etc.) which lead to emissions of air pollutants including sulphur dioxide (SO<sub>2</sub>), total particulate matter (TPM), polycyclic aromatic hydrocarbons (PAHs), total fluorides (TF) and nitrogen oxides (NO<sub>x</sub>).

Federal, provincial and territorial ministers of the environment are taking action to better protect human health and the environment by implementing the new Air Quality Management System (AQMS). The AQMS includes Canadian Ambient Air Quality Standards for fine particulate matter and ground-level ozone, base-level industrial emissions requirements (BLIERs) and air zone management by provincial and territorial jurisdictions. For the aluminium sector, quantitative BLIERs were developed for total particulate matter (TPM), polycyclic aromatic hydrocarbons (PAH) and sulphur dioxide (SO<sub>2</sub>). Qualitative BLIERs were also developed for SO<sub>2</sub> and PM<sub>2.5</sub> and a PM<sub>2.5</sub> code of practice was developed and implemented: *“The code of practice will facilitate and promote the continuous improvement of the environmental performance achieved by facilities in the sector in Canada and will give a detailed description of best practices that can be used to reduce PM<sub>2.5</sub> emissions in the aluminium sector (excluding Söderberg type plants). The code of practice must include, but is not limited to, the following elements: a description of the sector and the main sources of PM<sub>2.5</sub> emissions, and best practices for electrolysis, anode baking furnaces, alumina production and coke calcining.”*

With regard to dust emissions, fine particulates with an aerodynamic diameter smaller than 2.5 microns (PM<sub>2.5</sub>) can cause serious health problems when they are inhaled and enter the lungs. In Canada, roughly 45% of PM<sub>2.5</sub> emissions is generated by the stationary combustion of firewood and other fuels, and 20% by transportation activities (road, off-road, rail, sea, etc.). The remainder (35%) is the result of industrial activities. Table 1-1 presents the distribution of PM<sub>2.5</sub> releases from the industrial sector in Canada in 2013 as reported to the National Pollutant Release Inventory (NPRI). It can be seen that the aluminium industry is responsible for nearly 7% of industrial emissions of PM<sub>2.5</sub> in Canada.

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<sup>1</sup> The Aluminium Association of Canada

**Table 1-1: Distribution of PM<sub>2.5</sub> Releases from Industrial Sectors in Canada in 2013**

Industry	PM <sub>2.5</sub> releases (tonnes)	%
Upstream petroleum industry	10,676	16.1
Mining and rock quarrying	10,413	15.7
Pulp and paper industry	9,153	13.8
Cement and concrete industry	6,639	10.0
Wood industry	5,782	8.7
Foundries	5,163	7.8
Aluminium industry	4,372	6.6
Grain industry	2,333	3.5
Iron and steel industry	2,143	3.2
Non-ferrous smelting and refining industry	1,800	2.7
Downstream petroleum industry	1,750	2.6
Chemicals industry	1,343	2.0
Iron ore mining industry	1,072	1.6
Asphalt paving industry	1,039	1.6
Other industries	2,775	4.2
<b>Total:</b>	<b>66,453</b>	<b>100</b>

### 1.1 Scope of the Code

The Code applies to facilities in the primary aluminium sector, specifically those involved in the production of aluminium from alumina (electrolytic reduction), prebaked anode production, green coke calcining and alumina production. Other activities, including port and/or rail services for transporting raw materials, regional hydroelectric plants, and pot relining centres, are not covered by the Code, nor are activities associated with the Söderberg technology.

The Code was developed as part of the qualitative BLIERs established for Environment Canada's AQMS policy with the aim of facilitating and encouraging continuous improvement of the environmental performance of Canada's aluminium facilities. It describes the potential sources of emissions of fine particulate matter (PM<sub>2.5</sub>) for each of the primary activities covered by the Code and makes recommendations for reducing those types of emissions. Owing to the constraints inherent in the technology, the Code does not aim to eliminate PM<sub>2.5</sub> emissions but rather to control them through effective measures and work practices. Furthermore, the Code does not recommend practices that would require an existing facility to make major technological changes. When a new facility is being designed, other technologies capable of further reducing emissions can be incorporated, such as high draft ventilation of



pots activated when the hoods are opened and a regenerative oxidation system to eliminate pitch emissions.

Although the recommendations clearly specify the expected results, they should be applied where and when appropriate, depending on the particular circumstances of each facility. Accordingly, the Code does not seek to quantify the effect that each recommendation would have on PM<sub>2.5</sub> emissions. Rather, it should be considered a basic tool designed to enable facilities to develop a program of best practices without being subject to regulatory constraints. The recommendations in the Code in no way reduce the scope or application of the legal requirements of municipal, provincial and federal governments.

## **1.2 Code development**

The Code was developed by Environment Canada in consultation with aluminium industry representatives and other stakeholders. The information on operating procedures and best work practices is taken from various sources, including technical and scientific journals, as well as environmental codes of practice published by Environment Canada, the European Commission, the World Bank and the Light Metals Research Centre (LMRC) at the University of Auckland in New Zealand.<sup>2</sup> The Code presents a non-exhaustive list of recommendations based on the situation of Canada's primary aluminium sector in 2013, particularly with regard to existing air emission control technologies. Where relevant and applicable, facilities may consider implementing other measures for reducing particulate emissions.

## **1.3 Code structure**

The Code describes the operational activities and the particulate emissions that can result from those activities (Section 2). The recommended work practices intended to control fine particulate matter emissions are set out in Section 3.

## **1.4 Sector description**

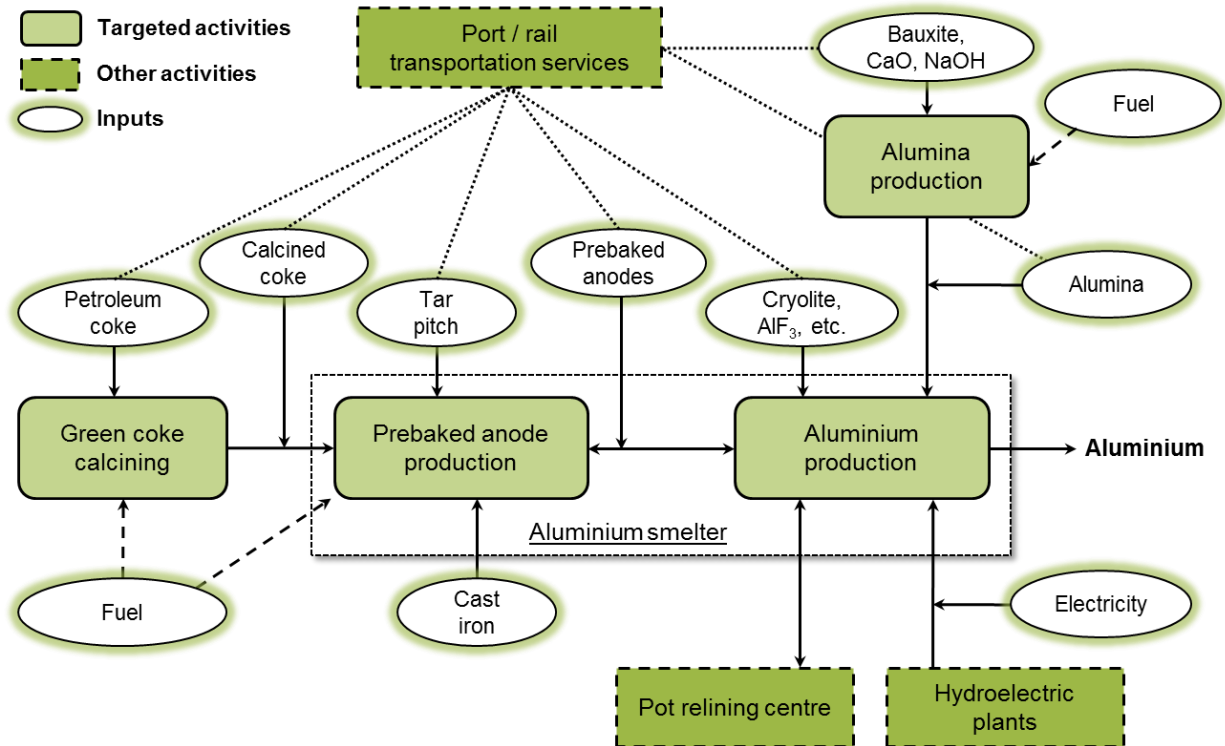
The primary aluminium sector encompasses many production activities that yield a finished product at a competitive cost (Figure 1-1). There are four key activities associated with aluminium production:

- production of aluminium (electrolytic reduction);
- prebaked anode production;
- green coke calcining; and
- alumina production.

A Canadian aluminium smelter typically consists of an electrolytic reduction plant and a prebaked anode production plant; related activities may be carried out elsewhere. Three Canadian aluminium smelters buy their prebaked anodes from another supplier (anode producer) instead of manufacturing them on-site.

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<sup>2</sup> Light Metals Research Centre, *Fluoride Emissions Management Guide* (FEMG), Version 4, February 2011.



**Figure 1-1: Schematic diagram of the activities associated with the primary aluminium sector**

### Production of aluminium (electrolytic reduction)

In 2013, Canada's primary aluminium production sector comprised 10 smelters operated by three companies: Rio Tinto Alcan (RTA) with 46% of production capacity, Alcoa with 35%, and Aluminerie Alouette (AA) with 19% (see Table 1-2). Canadian aluminium production, which stood at just over 3.0 Mt in 2013, represented approximately 6% of global production.

### Prebaked anode production

In 2013, six of the nine Canadian smelters using prebaked anode technology produced their own anodes in a facility adjacent to the aluminium production (electrolytic reduction) plant (Table 1-2). Only the Laterrière and Baie-Comeau smelters and the Arvida AP60 Technological Centre obtain their prebaked anodes from an external supplier. The six prebaked anode production plants have an annual production capacity of roughly 1.3 Mt.

### Green coke calcining

RTA operates three petroleum coke (green coke) calcining plants at Kitimat, Arvida and Strathcona for the production of calcined coke, a component of green anode paste. The three calcining plants have a combined calcined coke production capacity of more than 500 kt/y (Table 1-2).

## Alumina production

In Canada, only RTA operates an alumina production plant, specifically the Vaudreuil plant in Jonquière, which produces approximately 1.5 Mt of metallurgical-grade alumina and specialty chemicals (e.g., aluminium fluoride and commercial hydrates) annually, thus supplying a large share of RTA's network of electrolytic reduction plants.

**Table 1-2: Canadian primary aluminium facilities**

Facility		Production capacity (2013) by activity (kt/y)				PM <sub>2.5</sub> emissions (t/y) <sup>a</sup>
		Aluminium	Prebaked anode	Calcined coke	Metallurgical-grade alumina	
Alcoa	Baie-Comeau plant (QC)	355 <sup>b</sup>				284
	Deschambault plant (QC)	260	150			113
	Bécancour plant (QC)	430	248			521
RTA	Grande-Baie plant, La Baie (QC)	224	250			169
	Alma plant (QC)	440	230			246
	Arvida plant, Jonquière (QC)	175	105	230		562
	Shawinigan plant (QC) <sup>c</sup>	74				1,248
	Kitimat Works, Kitimat (BC)	172 <sup>d</sup>		80		451
	Strathcona Works, Sherwood Park (AB)			195		247
	Laterrière plant, Chicoutimi (QC)	240				144
	Vaudreuil plant, Jonquière (QC)				1,500	50
Arvida plant, AP60 Technological Centre, Jonquière (QC)	60 <sup>e</sup>				1.8 <sup>e</sup>	
AA	Sept-Îles plant (QC)	590	310			336
<b>TOTAL</b>		<b>3,020</b>	<b>1,293</b>	<b>505</b>	<b>1,500</b>	<b>4,372</b>

**a** Values reported to the National Pollutant Release Inventory (NPRI) for 2013. See also the *NPRI Emission Estimate Guide for Primary Aluminium Producers*: <https://www.ec.gc.ca/inrp-npri/default.asp?lang=En&n=021CB492-1>

**b** Söderberg pot production has been shut down since September 2013.

**c** The plant ceased production in November 2013.

**d** Plant production has recently decreased (251 kt in 2008, 224 kt in 2009, 184 kt in 2010) due to the smelter modernization project under which the Söderberg cells are gradually being replaced, thereby increasing capacity to more than 400 kt of aluminium per year.

**e** The Arvida Aluminium Smelter, AP60 Technological Centre, started up operations in December 2013; its annual capacity is 60 kt.

## 2. OPERATIONS AND SOURCES OF EMISSIONS

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This section provides an overview of operational activities into the primary aluminium sector that are covered by the Code and may lead to releases of particulate matter to the atmosphere. The purpose of this section is to describe the nature and the scope of the activities in question, particularly those that raise concerns with regard to fine particulate matter emissions. Figures 2-1 to 2-4 illustrate the main processes pertinent to the Code and its associated particulate matter release. It should be noted that releases of particulate matter associated with other activities as discussed in Section 1.1 are not included.

It is important to note that this section identifies sources of total particulate matter, given the difficulty of separating out fine particulate matter, specifically  $PM_{2.5}$ . Best practices have been developed to control emissions of total particulate matter and have led to a complementary reduction in  $PM_{2.5}$  emissions. It is difficult, however, to establish with certainty the proportion of  $PM_{2.5}$  associated with each source of total particulate matter. Consequently, the specific  $PM_{2.5}$  control efficiency for each source is not discussed in this Code.

### 2.1 Production of aluminium (electrolytic reduction)

Aluminium is produced in special cells through the electrolytic reduction of alumina dissolved in a molten bath. Aside from electrolytic cells, an aluminium plant also contains an aluminium casting centre and a gas treatment centre (Figure 2-1).

Each electrolytic cell consists of a carbon cathode insulated with refractory bricks inside a rectangular steel shell in which carbon anodes are suspended. The cells are connected in series to form a potline. During operations, a continuous high-amperage current passes from the anode through the electrolytic molten bath (cryolite) to the cathode. From there, it goes through a busbar to the next cell. Alumina is added to the cells to maintain an alumina content of 2% to 4% in the molten bath. In modern plants, these additions are controlled by a computer. Fluoride compounds (e.g., aluminium fluoride) are also added to lower the electrolytic bath's melting point, which helps to maintain an operating temperature of about  $960^{\circ}C$  in the cells. The molten aluminium is deposited at the cathode on the bottom of the pot, while the oxygen from the alumina reacts with the carbon from the anode to form carbon dioxide.

Because the anodes are gradually consumed, they must be replaced periodically. The anode butts (rods with carbon residue covered in bath crust) are then sent to a treatment facility so that the bath coating can be scraped off and reintroduced into the electrolytic cells in the form of aggregate. The carbon residue is recycled to make anode paste.

The gases from the electrolytic reduction process are vented to a gas treatment centre (GTC) and treated before being released into the atmosphere. A dry scrubber with injection of fresh and recycled alumina is used for this purpose. The alumina that absorbs fluorinated gas is recovered with a dust collector that also captures particulate matter produced by the electrolytic reduction process. The "fluorinated" alumina that leaves the GTC is used as a raw material in the electrolytic cells. Alumina and bath handling systems are equipped with devices that treat particulate emissions.

Molten aluminium is regularly siphoned into a crucible and then transferred to a casting centre to be transformed into ingots or other products. The molten metal typically passes through a holding furnace to control its temperature.

## Sources of particulate matter

Of the various activities associated with the primary aluminium industry, the production of aluminium is the main source of air pollution. This pollution is mainly associated with the electrolytic reduction of the alumina dissolved in the cryolite bath and with anode consumption. These two processes release fluorinated gases (e.g., hydrogen fluoride [HF] and perfluorocarbons [PFC]), SO<sub>2</sub> and particulate matter. It has been shown that the particles released in the potroom originate mainly from chemical reactions and from pot operations, for example, dust emissions from the bath, cover material and alumina.<sup>3</sup> There is a complex relationship between the level of particulate emissions in the potroom, particulate-generating mechanisms and the factors that influence them (e.g., electrolytic reduction technology, quality of raw materials, work methods, transportation and handling).

Although few studies have been conducted on emissions of particulate matter from the electrolytic reduction process, it appears that fluorinated particulates (e.g., Na<sub>3</sub>AlF<sub>6</sub>, Na<sub>5</sub>Al<sub>3</sub>F<sub>14</sub>, NaAlF<sub>4</sub>, AlF<sub>3</sub>, CaF<sub>2</sub>) are emitted through vaporization and then condensation of the electrolyte, carried along with gases, or through a chemical reaction in the gas.<sup>4</sup> Approximately 30% to 50% of fluoride emissions from the electrolytic cells consists of particulate matter, a large portion of which is PM<sub>2.5</sub>. Therefore, given the known emission mechanisms, an aluminium smelter's operations can be considered a source of PM<sub>2.5</sub> emissions.

In an aluminium smelter, there are stationary sources of emissions (e.g., GTCs and dust collectors) and fugitive emissions resulting from the handling of solids (e.g., alumina) and the operation of electrolytic cells (e.g., replacement of anodes). The potential sources of particulate matter from the aluminium production process are shown in Figure 2-1.

For stationary sources, the amount of particulate emissions strongly depends on the efficiency of the filter system. The optimal operation and careful maintenance of the GTC and the dust collectors, for example, make it possible to minimize releases of particulate matter.

There are two subcategories of fugitive emissions: intermittent emissions occurring during operating activities (opening of hoods to change anodes, metal casting, etc.) and continuous emissions resulting from leaks (from the superstructure, the alumina handling system, etc.). In general, operations involving exposure of hot anode butts, molten bath-related materials (cavity cleanings), exposed bath (during anode changes, bath transfers, metal tapping, etc) have a greater impact on PM<sub>2.5</sub> emissions than raw materials handling operations (anode cover application, alumina loading, transportation of raw materials, etc.).<sup>5</sup>

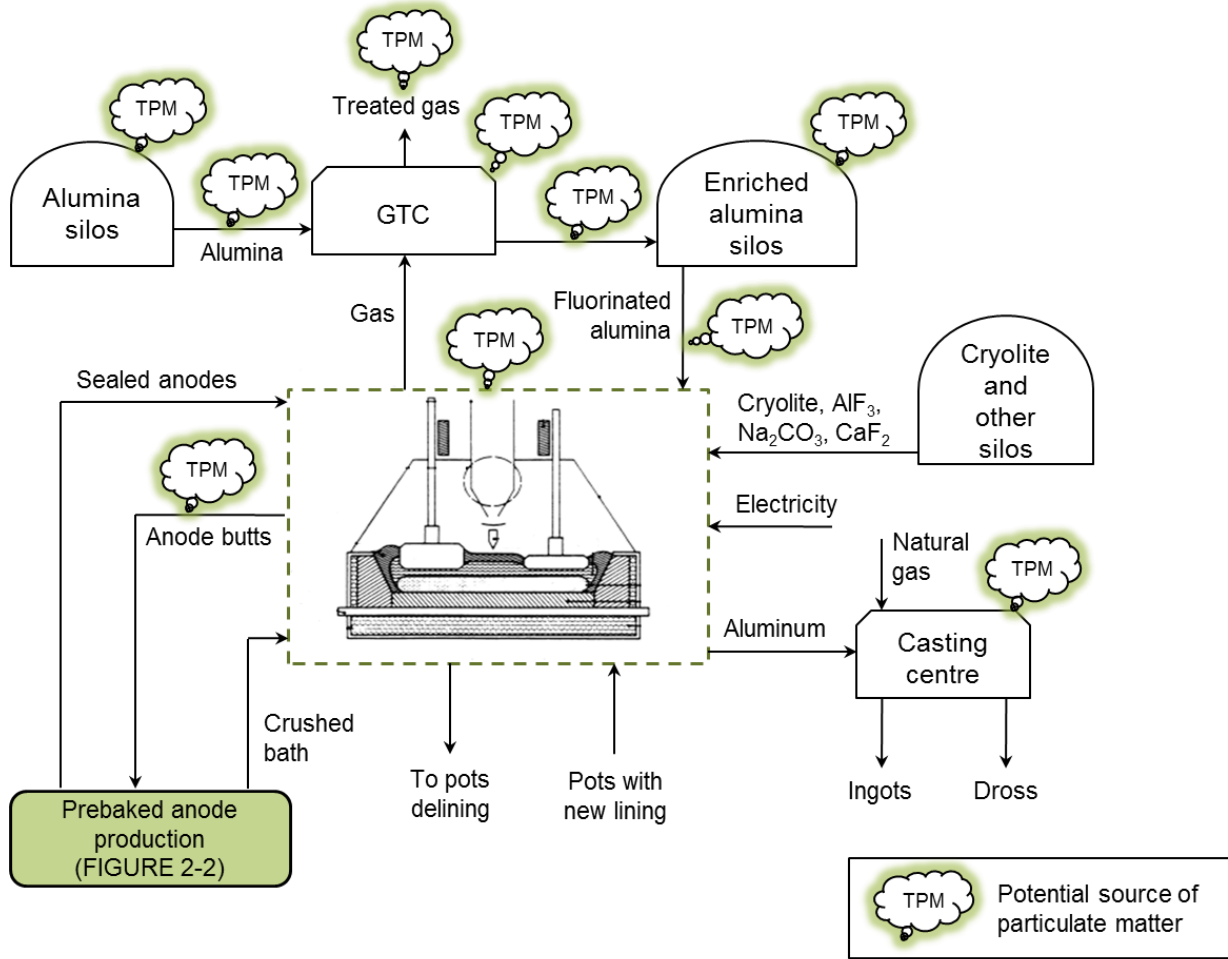
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<sup>3</sup> Wong, D.S., Tjahyono, N.I., Hyland, M.M., *Visualising the Sources of Potroom Dust in Aluminium Smelters*, Light Metals 2012, pp. 833-838.

<sup>4</sup> Gaertner, H., et al., *Particulate Emissions from Electrolysis Cells*, Light Metals 2011, p. 345.

<sup>5</sup> Wong, D.S., Tjahyono, N.I., Hyland, M.M., *The Nature of Particles and Fines in Potroom Dust*, Light Metals 2014, pp. 553-558.

Good dust collection, along with good ventilation and a good seal on pots, is essential to minimize fugitive emissions. In addition, it is essential for equipment to be properly designed, operated and maintained. Fugitive emissions of fine particles are released through potroom roof vents and are not subject to any particular treatment; they may be the primary source of fine particulate emissions from electrolytic reduction plants.



**Figure 2-1: Schematic diagram of aluminium production (electrolytic reduction) illustrating the potential sources of particulate matter emissions**

## 2.2 Prebaked anode production

The sealed prebaked anode manufacturing process involves several integrated steps that are carried out in separate facilities: facilities where green anodes are formed and baked, and where baked anodes are sealed (Figure 2-2). Air pollution control systems are installed on the production equipment used in these three steps of the process.

All Canadian aluminium smelters using prebaked anode technology recycle anode butts on-site or at a supplier's facility to recover the rods, cast iron and carbon residue. A preliminary butt-cleaning step using power tools is integrated into the process in order to recover as much residue from the fluorine-rich bath as possible, which is then crushed and reused as a raw

material in the electrolytic reduction cells. The carbon residue is sent to the green paste plant on-site (if the smelter has a prebaked anode production plant) or to an anode supplier, where it is crushed and then ground with fresh calcined coke. The ground coke is then preheated and mixed with coal tar pitch to produce hot green paste which is formed into compact blocks (green anodes) suited to the configuration of the electrolytic cells. The pitch fumes generated by the green anode manufacturing process are routed to the pitch fume treatment centre (PFTC), which uses a dry scrubber with calcined coke injection to capture the VOCs and PAHs contained in the fumes.

The green anodes are baked in a special furnace with mobile fire fuelled by natural gas or heavy oil. The furnace converts part of the pitch into elemental carbon through carbonization and eliminates the remainder through combustion, thereby producing an anode with minimum levels of aromatic hydrocarbons. The baking gas is normally treated using an alumina injection-based dry scrubber followed by a dust collector to capture particulate matter, PAHs and fluoride resulting from the recycling of carbon from the anode butts. The baked anodes are then sealed on clean rods with molten cast iron from an induction furnace.

### **Sources of particulate matter**

Particulate matter is released from a number of operations, particularly during coke and bath crushing and grinding, which can generate significant emissions. These emissions are, however, strictly controlled through capture at the source and filtration systems. Anode baking is also a significant source of particulate matter, but the emission rate depends on the configuration of the furnace (e.g., open top with horizontal flow or closed type with vertical flow) and on the effectiveness of the dust collection system in the fume treatment centre (FTC). The green anode production process and the pitch fume treatment centre (PFTC) are also responsible for particulate matter emissions.

The concentration of particulate matter in stack gases is low, but given the very large volume of off-gases, particulate emissions could become significant if this equipment is not operated properly. Other sources of particulate matter include pneumatic and mechanical handling systems for calcined coke and alumina (in the FTC), which are normally equipped with hoods and dust collectors at the various drop points.

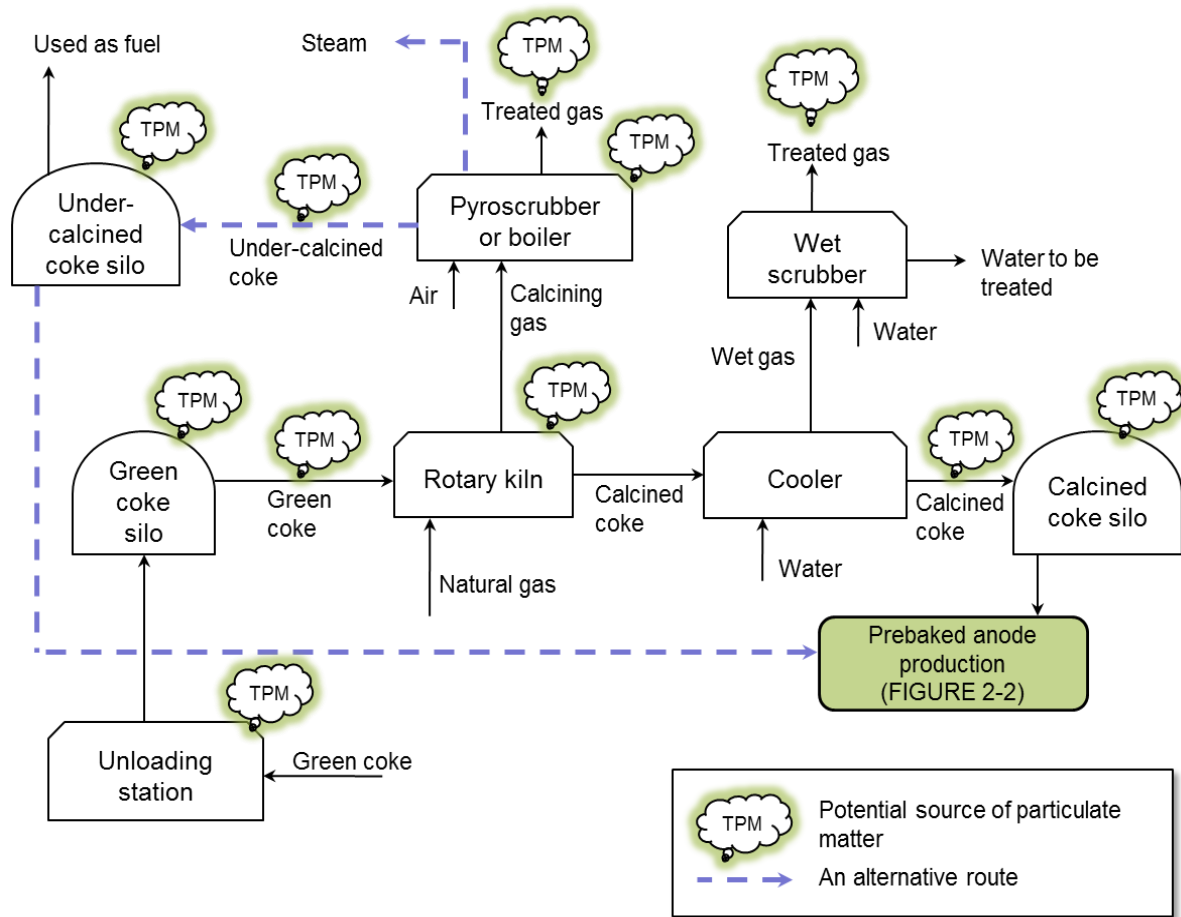




The gas stream at the kiln outlet includes combustion gases, unburned volatile compounds and large quantities of coke particles which must be removed before the gases are released into the atmosphere. Canadian plants use a gas combustion system (pyroscrubber or boiler followed by a dust collector) with an upstream expansion chamber to recover up to 80–95% of coarse particulate matter. This residual coke, in addition to the calcined coke recovered by dust collectors (under-calcined coke), is typically used as a fuel or raw material for the production of anode paste. The wet gas from the cooler is directed to a scrubbing system (e.g., venturi wet scrubber) to control the coke particles drawn into the flow of steam.

### **Sources of particulate matter**

Calcining gas treatment and cooling systems are designed primarily to control coke particulate matter carried by gas flows. Most of the post-treatment particulate matter comes from the pyroscrubber (or boiler plus dust collector), which must treat a larger amount of gas flow than the wet scrubber, which essentially treats the flow of steam. Other particulate emissions may occur, particularly during the handling of various forms of coke on a closed conveyor. At the various drop points, the conveyors are generally equipped with hoods and dust collectors, especially for calcined coke, which has a relatively powdery texture.



**Figure 2-3: Schematic diagram of green coke calcining illustrating the potential sources of particulate matter emissions**

## 2.4 Alumina production

The Vaudreuil plant in Jonquière uses the Bayer process, which involves alkaline extraction of alumina from bauxite. The general flow diagram is shown in Figure 2-4. Bauxite is an ore of variable structure that consists mainly of aluminium oxides (35–65%), iron (2–30%) and silica (1–10%). The composition of bauxite depends on the deposit from which it is extracted, with the main deposits located in Australia, South America, West Africa and Asia. The Bayer process has five successive steps: bauxite preparation, bauxite digestion, settling of red mud, crystallization and precipitation of alumina trihydrate, and calcination into metallurgical-grade alumina. It should be noted that few alumina refineries are identical: there are many subtle differences, particularly in the methods used to manage effluents and thermal energy.

Bauxite is generally ground to a fine powder and then mixed with a concentrated and preheated caustic soda (NaOH) solution (Bayer liquor), before being transferred to pressurized chemical reactors. The Vaudreuil plant uses a wet mill, where the liquor is mixed directly with the ore during grinding. At high temperatures (140–150°C), the alkaline mixture breaks down gibbsite or boehmite (aluminium oxides) into soluble sodium aluminate while the other

bauxite constituents (iron oxides, silica, etc.) persist as solid crystals. The liquid suspension then moves to the decantation stage (and possibly filtration; see Figure 2-4), where the solid residue called “red mud” is removed from the aluminate solution. The Vaudreuil plant generates roughly 0.7 tonnes of red mud per tonne of alumina extracted from bauxite. This mud is transported to waste disposal sites (red mud ponds) to be dried and piled.

The liquor is cooled to a point at which crystallization of the aluminate into hydrated alumina crystals can occur. Hydrated alumina (primer) is added to the mix to facilitate the formation of crystals. After a precipitation stage, the crystals are classified based on their size. “Small” crystals are recycled to increase their volume, while “large” crystals are dried and then calcined at approximately 1,000°C in a rotary kiln or a fluidized bed calciner after being washed. Under these conditions, the hydrated alumina breaks down into metallurgical-grade alumina through the elimination of water associated with the molecule. The sodium hydroxide liquor is recycled for use in the initial grinding stage.

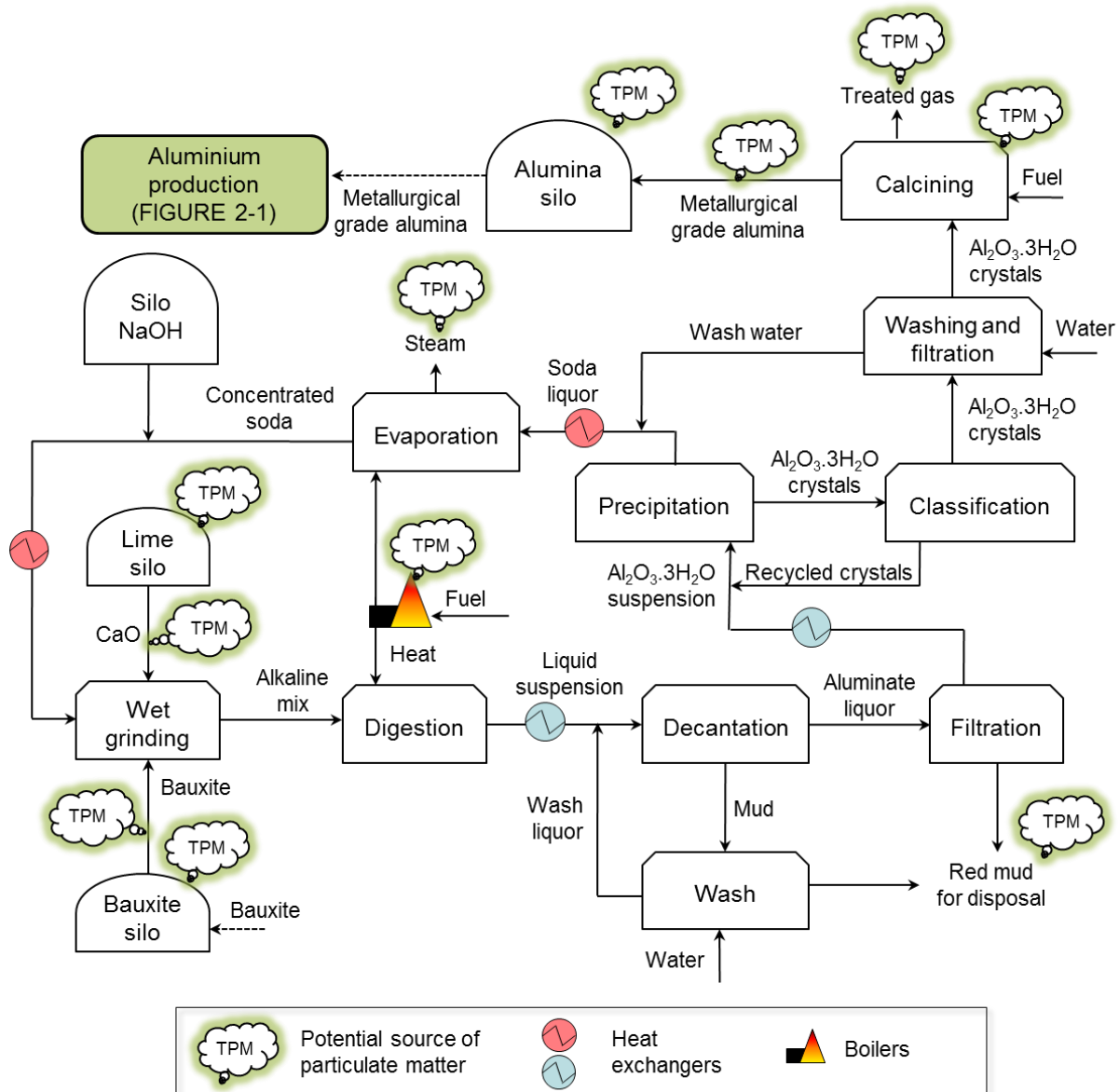
The Bayer process includes a number of heating and cooling stages for the various material flows. An alumina refinery has several boilers to provide the necessary heat for bauxite digestion. The Vaudreuil plant has six boilers, in addition to three alumina calciners. The plant also has a network of heat exchangers that minimize energy consumption.

### **Sources of particulate matter**

The Bayer process operates mainly in wet conditions, which greatly limits the potential for fugitive emissions of particulate matter to the ambient air. The main sources of particulate matter are the alumina calciner and the boilers, which are fuelled by oil, natural gas or electricity at the Vaudreuil plant, depending on prevailing market conditions. Higher concentrations of particulate matter are associated with the use of fuel oil. Another major source is the lime kiln for the production of quicklime (CaO), which is used primarily to sequester phosphorus and improve the solubility of alumina in Bayer liquor. This process is not addressed in the Code, since the Vaudreuil plant does not operate a lime kiln.

The same applies to the wet grinding of bauxite (in the case of the Vaudreuil plant), which generates less particulate matter than ball mills. Lastly, the handling and storage of raw materials (bauxite, lime), calcined alumina and red mud may also lead to emissions of particulate matter, as all of these materials are powdery, with the exception of bauxite.

The Bayer process includes a number of crystal washing phases (Figure 2-4) which are designed to recover caustic soda and which cause gradual dilution of the Bayer liquor. The excess water must be eliminated through evaporation in order to maintain the NaOH concentration at an acceptable level for bauxite digestion. However, that may cause microscopic particles (aerosols) of caustic soda to be entrained in the water vapour. In the absence of empirical studies on the subject, it is impossible to establish best practices in this regard. It is nonetheless clear that these aerosols would be released into the atmosphere with the vapour.



Other plants may use certain variants not represented here.

**Figure 2-4: Schematic diagram of alumina production (Bayer process) illustrating the potential sources of particulate matter emissions**

### 3. RECOMMENDED PM<sub>2.5</sub> EMISSION CONTROL PRACTICES

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This section sets out recommended measures for mitigating emissions of particulate matter, including PM<sub>2.5</sub>, generated by the various processes associated with the primary aluminium sector. The 44 recommendations are presented in relation to four activities:

- production of aluminium from alumina (electrolytic reduction);
- prebaked anode production;
- green coke calcining; and
- alumina production.

Each recommendation is described briefly and linked to one or more of the sources of particulate matter emissions listed in Table 3-1. The recommendations outlined below should be implemented in a continuous improvement context, where required, relevant and applicable. Since emissions of PM<sub>2.5</sub> have not been quantified precisely for each of the sources identified in this Code, the order in which the recommendations are presented is subjective. The list of recommendations below is not exhaustive, and consequently aluminium smelters should consider implementing other measures to reduce PM<sub>2.5</sub> emissions, where relevant and applicable. The appropriate frequency for the monitoring, inspection and other practices described in the recommendations is determined based on an assessment of the initial situation in a continuous improvement context. When determining the appropriate frequency, consideration should also be given to the specific characteristics of each facility, such as equipment type and age, the manufacturer's recommendations and specifications, regulatory requirements, etc. The establishment of an inspection and monitoring schedule is recommended.

**Note:** In this section, the term “scrubber” means one of the following technologies: GTC, FTC, PFTC, pyroscrubber, boiler, followed by a dust collector and venturi wet scrubber.

**Table 3-1: Potential sources of particulate emissions and recommendations, by activity**

Activity	Operating procedures	Scrubbers	Materials storage and handling
<p><b>Production of aluminium from alumina (electrolytic reduction)</b></p>	<p>Changing of anodes (S01): R01-R05, R10-R11, R15-R18, R44</p> <p>Tapping and transferring of liquid cryolite bath from one pot to another (S02): R01-R02, R04-R09, R11, R15-R18, R44</p> <p>Tapping molten aluminium in a casting crucible (S03): R01-R02, R04-R06, R11, R15-R16, R18, R44</p> <p>Skimming and pouring molten aluminium (S04): R02, R13, R15-R16, R44</p> <p>Measuring and sampling in pots (S05): R01-R02, R04-R05, R11, R15-R16, R44</p> <p>Leaks from the superstructure and fume exhaust ducts (S06): R02, R14-R15, R44</p> <p>Handling and loading of anode cover material after anode change (S38): R01-R05, R12, R15-R18, R44</p>	<p>Post-treatment stack gas (S16): R02, R14-R15, R17, R19-R24, R25-R27, R44</p> <p>GTC leaks (S17): R02, R14-R15, R19, R22, R26, R44</p>	<p>Alumina dust collectors (S24): R02, R14-R15, R19-R20, R22-R23, R25-R27, R44</p> <p>Leaks from alumina handling systems (S25): R02, R14-R15, R19, R22, R26, R44</p> <p>Losses from storage silos (S26): R14-R15, R25-R27, R44</p> <p>Transport of anode butts and residual bath to prebaked anode production plant (S27): R15-R16, R28, R44</p> <p>Loading and delivery of alumina to cells, in particular from overhead crane (S39): R14-R16, R22-R23, R25-R27, R44</p>

Activity	Operating procedures	Scrubbers	Materials storage and handling
<b>Prebaked anode production</b>	<p>Cleaning of anode butts with power and blasting tools (S07): R15, R23, R25-R27, R31, R33, R44</p> <p>Crushing of frozen bath recovered during cleaning of anode butts (S08): R15, R23, R25-R27, R31-R33, R44</p> <p>Crushing, grinding and sieving of calcined coke (S09): R15, R23, R25-R27, R33, R44</p> <p>Baking furnace operations (S10): R15, R29-R30, R33, R35, R44</p> <p>Combustion gas from cast iron induction furnace (S11): R15, R33, R35, R44</p>	<p>Baking gas after FTC treatment (S18): R02, R15, R19-R23, R25-R27, R30, R33-R35, R44</p> <p>Stack gas after PFTC treatment (S19): R02, R15, R19-R20, R22-R23, R25-R27, R33, R44</p> <p>FTC and PFTC leaks (S20): R02, R15, R19, R22, R26, R33, R44</p>	<p>Alumina and calcined coke dust collectors (S28): R02, R15, R19-R20, R22-R23, R25-R27, R33, R44</p> <p>Alumina, calcined coke and crushed frozen bath handling system leaks (S29): R02, R15, R19-R20, R22, R26, R29, R31-R33, R44</p> <p>Losses from storage silos (S30): R15, R25-R27, R33, R44</p>
<b>Green coke calcining</b>	<p>Losses from rotary calcining kiln (S12): R15, R36, R44</p>	<p>Post-treatment calcining gas (S21): R02, R15, R22-R23, R36-R38, R44</p> <p>Post-treatment cooling gas (S22): R02, R15, R22-R23, R36, R39, R44</p> <p>Leaks from calcining gas treatment systems (S23): R02, R15, R19, R22, R36, R44</p>	<p>Calcined and under-calcined coke dust collectors (S31): R02, R15, R19-R20, R22-R23, R25-R27, R36, R38, R44</p> <p>Leaks from green, calcined and under-calcined coke handling systems (S32): R02, R15, R19, R26, R36, R44</p> <p>Losses from unloading station and storage silos (S33): R15, R25-R27, R36, R38, R40, R44</p>

Activity	Operating procedures	Scrubbers	Materials storage and handling
<b>Alumina production</b>	<p>Hydrated alumina calcining (S13): R15, R35, R41, R43-R44</p> <p>Combustion gas from steam boilers (S14): R15, R35, R41, R43-R44</p> <p>Bayer liquor evaporation (S15): R15, R41, R44</p>		<p>Bauxite and metallurgical-grade alumina dust collectors (S34): R02, R15, R19-R20, R22-R23, R25-R27, R41, R44</p> <p>Leaks from bauxite and metallurgical-grade alumina handling systems (S35): R02, R15, R19, R22, R26, R41, R44</p> <p>Losses from storage areas and silos (S36): R15, R25-R27, R41, R44</p> <p>Wind-induced transport of particulate matter from red mud disposal site (S37): R15, R42, R44</p>



### 3.1 Aluminium production (electrolytic reduction)

With the constant evolution of electrolytic reduction technologies, new plants can help to improve the environmental performance of the primary aluminium industry. Gas extraction efficiency from electrolytic cells could also be improved, thereby reducing fugitive emissions of particulates in the potroom, where the ambient air is not treated. Aside from installation of scrubbers, optimization of electrolytic cell operating methods and, to a lesser extent, the quality of raw materials (sealed prebaked anodes, cryolite bath, alumina) is the best approach for reducing air pollution from an existing facility. This is true not only for gas emissions, but also for fine particulate matter, which acts like a gas and remains suspended in ambient air.

#### 3.1.1 Opening of electrolytic cell hoods

**RECOMMENDATION R01** – Optimize work methods to ensure that a minimum of hoods are opened simultaneously, and that they are opened only once work begins. Close hoods as soon as work is complete.

*SOURCES TARGETED* – S01, S02, S03, S05, S38

The operation of an aluminium production plant entails periodic interventions involving the electrolytic cells, which may include changing anodes, tapping the molten metal or cryolite bath, and loading the cryolite bath. Each of these operations requires that the hoods be opened, which results in releases of fine particulate matter within the potroom.

It has been observed that HF emissions associated with these interventions account for approximately 60% of a plant's HF emissions, including those from the GTC.<sup>6,7</sup> Optimizing work methods to minimize the number of hoods opened simultaneously and the length of time they remain open is the best approach for controlling these emissions. HF emissions (and therefore PM<sub>2.5</sub>) increase with the number of hoods opened simultaneously.<sup>8</sup> Therefore, hoods should not be left open unnecessarily.

#### 3.1.2 Gas extraction system

**RECOMMENDATION R02** – Regularly assess the extraction efficiency of fans in relation to power supply, flow rate and pressure loss. Make adjustments as needed to maximize the extraction rate.

*SOURCES TARGETED* – S01-S06, S16-S25, S28, S29, S31, S32, S34, S35, S38

Gases and particulate matter released under the pot hoods are continually vented and routed to the GTC through a main duct. Gas extraction efficiency depends largely on the configuration and condition of the superstructure and the ventilation ducts, which should contain a minimum of gaps. This is important for maximizing the negative pressure in the pots based on the ventilation power of the back-end fan. When one or more of the hoods are open, the negative pressure decreases locally, leading to an increase in leaks within the building. Pots located at the potroom extremities (farthest from the fan) could be more prone to a decrease in fume

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<sup>6</sup> Broek, S., et al., *Considerations Regarding High Draft Ventilation as an Air Emission Reduction Tool*, Light Metals 2011, p. 361.

<sup>7</sup> Aljabri, N., et al., *HF Emission from Dubai's Electrolysis Cell*, Light Metals 2003, p. 487.

<sup>8</sup> Dando, N.R., Tang, R., *Impact of Tending Practices of Fluoride Evolution and Emission from Aluminium Smelting Pots*, Light Metals 2006, p. 203.

extraction capacity. A decrease in the existing system's efficiency can reduce the rate of extraction of particulates to the GTC. In this regard, it is recommended that a fan monitoring and maintenance program be established in order to maintain maximum extraction flow at all times (depending on applied power). This recommendation applies to all gas scrubbers that use a fan.

### 3.1.3 Prebaked anode changes

**RECOMMENDATION R03** – Optimize work methods to minimize the time required to change anodes and cover them with anode cover material.

*SOURCES TARGETED* – S01, S38

Anode changing is one of the largest sources of fugitive emissions in the potroom. It generally involves opening the pot hood, breaking the crust around the anode butt, marking the height of the anode butt in the pot, removing the anode butt, cleaning the cavity with an adapted extractor (e.g., Pacman type) and placing a new anode in the cavity. This procedure generally takes more than 10 minutes and must be carried out carefully to prevent operational problems.<sup>9</sup> It is therefore advisable to develop and apply an effective work method that minimizes the amount of time it takes to change the anodes (e.g., cleaning the cavity with the extractor immediately after removing the anode butt, and placing the anode butt tray and bath residue close to the pot).

### 3.1.4 Crust covering the cryolite bath

**RECOMMENDATION R04** – Implement a program to monitor cracks in the crust by visual inspection or using an automated system. Ensure that the anode cover material is a suitable and effective sealant.

**RECOMMENDATION R05** – Cover the taphole with anode cover material once the tapping or sampling work is complete.

*SOURCES TARGETED* – S01-S03, S05, S38

An important factor affecting the rate of fluoride emission from pots relates to the integrity of the alumina and cryolite crust that covers the cryolite bath, since the crust acts as a physical barrier against gas migration.<sup>10</sup> Poor coverage of new anodes can lead to gaps. It has been shown repeatedly that the intensity of emissions correlates with the extent of the holes and cracks in the crust.<sup>11</sup> These gaps are created when alumina is injected using the feeder/breaker, when the molten metal or bath is siphoned through the taphole, and when work is done to suppress the anode effect. A monitoring program (visual or automated) can help to ensure that the crust contains and sustains a minimum of cracks, thus reducing the emission of particulate matter at the source. Where applicable and relevant, as it may result in the tap door being open longer, it is recommended that the tapholes be covered with anode cover material as soon as sampling or tapping of the molten metal/cryolite bath is complete.

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<sup>9</sup> Lindsay, S.J., *Effective Techniques to Control Fluoride Emissions*, Light Metals 2007, p. 199.

<sup>10</sup> Tarcy, G.P., *The Affect of Pot Operation and Work Practices on Gaseous and Particulate Fluoride Evolution*, Light Metals 2003, p. 193.

<sup>11</sup> Slaughaupt, M.L., et al., *Effect of Open Holes in the Crust on Gaseous Fluoride Evolution From Pots*, Light Metals 2003, p. 199.

The composition of the anode cover material may vary and have a direct impact on the quality of the crust.<sup>12</sup> In addition to implementing a crack monitoring program, it is also advisable to carefully monitor the anode cover material to prevent the chronic appearance of cracks in the crust.

### 3.1.5 Tapping of molten metal and cryolite bath

**RECOMMENDATION R06** – During tapping operations, use flexible tubing to reroute fumes released from the crucible within the pot.

*SOURCES TARGETED – S02, S03*

Aluminium produced through electrolytic reduction is deposited on the surface of the cathode at the bottom of the pot and is generally extracted daily to maintain an optimum level. A heat-insulating crucible equipped with a siphon is used for this purpose. The procedure normally involves opening the pot hood, preparing a taphole in the crust, connecting the vent pipe and the compressed air to the crucible, placing the siphon in the taphole, tapping the metal from the crucible, removing the crucible once the tapping is complete, sealing the taphole and closing the hood. Tapping of the cryolite bath follows the same basic procedure and is done primarily to maintain the bath height, which is instrumental for thermal equilibrium and alumina dissolution. The extent of the fugitive emissions associated with this work is closely linked to the amount of time the hoods are open (see Recommendation R01) as well as the gas expelled through the crucible's air exhaust. This gas is composed of air mixed with cryolite vapours. It is therefore recommended that the gas be transferred into the pot to be captured and treated at the GTC instead of being expelled into the potroom.

### 3.1.6 Cryolite bath spatter and spills

**RECOMMENDATION R07** – Minimize and recover cryolite bath spills and spatter on the floor.

**RECOMMENDATION R08** – Pour the bath into the pot launder at an optimal speed to reduce pouring time and avoid spatter. Avoid pouring too slowly.

**RECOMMENDATION R09** – Minimize and recover cryolite bath residue in the launder when loading is complete.

*SOURCE TARGETED – S02*

After being tapped from a pot, the liquid cryolite bath may be transferred to another pot where the bath height is low. This normally involves opening the hood, positioning the launder, positioning the crucible near the launder and opening the crucible spout, pouring the bath into the pot down the launder and through the taphole, removing the crucible and launder when loading is done, and closing the hood. Particulate matter emissions associated with loading of the cryolite bath are closely linked to the opening of the hoods (see Recommendation R01) and the exposure of the hot cryolite bath in the launder located outside the ventilation hood perimeter. An increase in emissions is inevitable if the cryolite bath is spilled during pouring or if the residual bath in the launder is not cleaned immediately after pouring. Cryolite bath may also be spilled on the floor during anode changing. A work method that prevents these circumstances would reduce the rate of emission within the potroom.

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<sup>12</sup> Tessier, J., et al., *Image Analysis for Estimation of Anode Cover Material Composition*, Light Metals 2008, p. 293.

### 3.1.7 Skimming of carbon dust

**RECOMMENDATION R10** – Cool the hot carbon dust inside the pot or in a container with a cover. Minimize the amount of time carbon dust spends in the potroom.

*SOURCE TARGETED – S01*

The dispersion of carbon dust in the electrolytic bath is dependent on the quality of the anodes and on operating conditions. Selective oxidation of tar pitch releasing coke grains, cathode wear and the addition of carbon from the anode cover material and the enriched alumina are the main mechanisms leading to carbon accumulation.<sup>13</sup> Carbon dust may cause an increase in the electrical resistance in the bath, resulting in a higher temperature and reduced current efficiency, not to mention an increase in the anode consumption rate. It is therefore essential to remove carbon dust regularly and to complete the operation as quickly as possible. Freshly collected hot carbon dust is impregnated with cryolite, amplifying the release of fluorinated particulate matter to the ambient air. With some cell technologies, there is a metal plate just inside the tap door at floor level where the carbon dust can be left to cool. If applicable, it is recommended that the carbon dust be allowed to cool inside the pot so as to capture a maximum amount of PM<sub>2.5</sub> emissions, which can then be vented to and treated in the GTC. Carbon dust can also be left to cool outside the pot in a container with a cover.

### 3.1.8 Control of operating parameters

**RECOMMENDATION R11** – Control and maintain an optimal bath level in the pot to prevent an unintended rise in bath temperature and direct contact with moist air. These two phenomena exacerbate the formation of fluorinated particles.

*SOURCES TARGETED – S01-S03, S05*

From an environmental perspective, it is recommended that the liquid bath have little or no contact with the air under the crust in order to limit the formation of HF and fluorinated particulates through moisture-related mechanisms.<sup>14</sup> In addition, controlling bath height and crust thickness allows thermal equilibrium to be maintained more easily, thus preventing an unwanted increase in temperature and in emissions of HF and fluorinated microparticles.

**RECOMMENDATION R12** – Prevent, control and minimize anode effect frequency and duration. After manually suppressing anode effects, cover cracks in the crust with anode cover material.

*SOURCE TARGETED – S39*

The anode effect is a phenomenon that adversely affects electrolytic reduction by causing a sudden increase in voltage and a decrease in amperage. This is due to the presence of a gas film on the surface of the anode which must be cleared either manually by an operator (with a long wooden rod or pole) or using an automated pot control system. Automated suppression of the anode effect eliminates the need to open the pot hoods and allows gas to be channelled to the GTC. In both cases, the crust is affected in that cracks begin to form, increasing the rate of

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<sup>13</sup> Gudmundsson, H., *Anode Dusting from a Potroom Perspective at Nordural and Correlation with Anode Properties*, Light Metals 2011, p. 471.

<sup>14</sup> Light Metals Research Centre, *Fluoride Emissions Management Guide (FEMG)*, Version 4, February 2011.

emissions. The operator should therefore minimize the anode effect and seal cracks with anode cover material as soon as they appear (see Recommendation R04). As a general rule, modern aluminium smelters prevent anode effects by automatically injecting alumina as soon as the voltage in the pot increases.

### 3.1.9 Casting of molten aluminium

**RECOMMENDATION R13** – Minimize releases of particulate matter from the casting centre.

*SOURCE TARGETED – S04*

Liquid aluminium in the crucible is transported to the casting centre where it is transferred to a holding furnace and possibly alloyed with other metals. The molten metal is gradually moved to a casting machine to form ingots of various shapes, depending on the client's specifications. Aluminium casting is a very minor source of emissions of metal particles.<sup>15</sup> From an environmental standpoint, the optimization of fuel consumption in the casting centre can help reduce the generation of air pollutants, including particulates.

### 3.1.10 Maintenance activities

**RECOMMENDATION R14** – Regularly inspect the following on a set schedule: the aluminium production (electrolytic reduction) plant's facilities, including the condition of the hoods, the gas exhaust ducts in each cell, the alumina supply system and the pot superstructure. In the event of breakdowns or malfunctions, make repairs or install appropriate replacement parts as soon as possible.

*SOURCES TARGETED – S06, S16, S17, S24-S26, S39*

Aluminium production pots based on prebaked anode technology are not completely airtight, which means that fugitive emissions can continuously escape through gaps. Fugitive emissions of particulates and other contaminants occur not only during operational activities, but also as a result of gaps caused by premature (or expected) wear of the structure and equipment in contact with process gases. With age, the superstructure can also lose its seal, exacerbating the problem. These gaps can be reduced to a minimum, provided that the equipment is properly designed, operated and maintained. It should be noted that most fugitive emissions are evacuated through roof vents in the potroom and are not subject to any particular treatment.

Therefore, expansion joints, rubber seals, gaskets and the like should be inspected periodically and repaired promptly if found to be defective. Other trouble spots include the junction between the superstructure and the main gas duct, cracks in the alumina supply duct, and damage to the superstructure.<sup>16</sup>

**RECOMMENDATION R15** – Implement an employee training plan in support of an approach for preventing premature wear and breakdowns caused by improper operation of the facilities.

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<sup>15</sup> European Commission, *Integrated Pollution Prevention and Control – Draft Reference Document on Best Available Techniques for the Non-Ferrous Metals Industries*, July 2009.

<sup>16</sup> Lindsay, S.J., *Effective Techniques to Control Fluoride Emissions*, Light Metals 2007, p. 199.

### *SOURCES TARGETED – S1-S39*

Many defects (not all) may be caused by improper installation or operation. It is therefore advisable to establish both an infrastructure inspection and repair program and an employee training plan on the proper approach for preventing these situations.

#### **3.1.11 Electrolytic reduction plant cleaning activities**

**RECOMMENDATION R16** – Use a HEPA vacuum to clean the floor of the potroom and other buildings.

*SOURCES TARGETED – S01-S05, S27, S38, S39*

**RECOMMENDATION R17** – Regularly clean the suction inlet located inside the pot superstructure (slots, ventilation hoods section, etc.).

*SOURCES TARGETED – S01, S02, S16, S38*

**RECOMMENDATION R18** – Regularly clear solid residues from the feeder/breaker to reduce the size of the hole in the crust after injection, thus decreasing emissions (corollary to Recommendation R05).

*SOURCES TARGETED – S01-S03, S38*

Cleaning of the potroom floor should be included in a maintenance program. Systems that may disperse dust particles from the floor into the ambient air should be avoided. Using a vacuum is therefore recommended and preferable to cleaning with compressed air or with a mechanical sweeper. Regular cleaning of the pots ceiling area where cryolite bath residues accumulate over time is also advisable to control their dispersion into the potroom when the hoods are opened.

#### **3.1.12 Monitoring of scrubber operations**

The gases and particulate matter released under the pot hoods are continually vented and routed to the GTC. A typical GTC collects pot gases through a main duct and then distributes them into vertical reactors into which fresh and fluorinated alumina is injected at the base. The primary objective is to intercept fluorinated compounds, which are harmful to the environment. Whether an alumina injection or fluidized bed system is used, the scrubbed gas must be dedusted in order to recover the “fluorinated” alumina, which is used as a raw material in the electrolytic cells. The dust collector consists of filtration media which, depending on its configuration and operating parameters, captures most of the process particles (> 99%).<sup>17</sup> This process is considered the best practice for treating gas from electrolytic cells. Nonetheless, the GTC and any other gas treatment system must be configured and operated properly in order to maximize performance.

**RECOMMENDATION R19** – Regularly and periodically monitor the gas flow in each compartment of the scrubber while ensuring that it is uniform. Monitor pressure loss in order to identify anomalies requiring correction.

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<sup>17</sup> Light Metals Research Centre, *Fluoride Emissions Management Guide (FEMG)*, Version 4, February 2011.

*SOURCES TARGETED* – S16-S20, S23-S25, S28, S29, S31, S32, S34, S35

A gas treatment centre is composed of many parallel compartments (typically 12 to 14), including injection reactors and filtration units. The gases leaving the compartments are combined and sent to the stack, while the adsorbent (alumina) is directed to a storage silo. The filtration capacity of the dust collector is determined by the air-to-cloth ratio, and requires a constant flow of gas and maximum speed to ensure optimal performance. A variable flow (within a given range) between compartments caused by variable pressure loss reduces filter performance.

It is important to regularly monitor pressure loss and flow in the compartments to avoid premature wear of the bags. Measurement and monitoring of the fluoride concentration in the alumina may also be considered.

**RECOMMENDATION R20** – Adjust cleaning frequency and duration for the dust collectors and filtration media of the scrubber to balance gas flow for each compartment and maximize collection efficiency.

*SOURCES TARGETED* – S16, S18, S19, S24, S28, S29, S31, S34

An increase in pressure loss is caused primarily by flow resistance in the gas ducts, injection reactor and baghouse. Bag cleaning helps to control this pressure loss and maintain the flow within the design parameters of the baghouse. It is therefore important to adjust cleaning frequency and duration to maintain balanced flow in each compartment. Ideally, the flow of each compartment should be controlled by adjusting each dedicated fan or, in the case of a centralized fan, by adjusting the control valve of each compartment.

**RECOMMENDATION R21** – Where possible, depending on the production sector, limit the recycling of enriched or fluorinated alumina in GTC and FTC injection reactors, without influencing HF capture. Regularly and periodically monitor the recycling rate to ensure that it is optimal.

*SOURCES TARGETED* – S16, S18

In the GTC and FTC, a large portion of the enriched alumina is recycled in the reactors for the purpose of controlling its level of production while taking into account the size of the silos and the needs of the electrolytic reduction plant. However, the alumina undergoes continuous attrition during the process, thus increasing the proportion of fine particulates in the GTC's and FTC's supplies and, therefore, PM<sub>2.5</sub> emissions from the stack.<sup>18</sup> Frequent optimization of the recycling rate is therefore required in order to maximize HF capture and minimize recycling of enriched alumina. The optimization of recycling should be based on the concentration of HF emissions at the GTC and FTC stacks. The recycling rate should normally be higher during the summer than in winter. This recommendation does not apply to the PFTC since the enriched coke is generally not recycled but is instead returned to the green paste facility.

### **3.1.13 Maintenance of scrubbers, dust collectors and related systems**

**RECOMMENDATION R22** – Depending on the production sector and the filtration system, regularly inspect the scrubber on a set schedule, including the collection system, the sealing

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<sup>18</sup> Iffert, M., et al., *Reduction of HF Emissions from the Trimet Aluminium Smelter*, Light Metals 2006, p. 195.

joints, the fan (corollary to Recommendation R02) and the alumina (or calcined coke) supply systems. Repair any breakdowns or malfunctions as soon as they are noted.

*SOURCES TARGETED* – S16-S25, S28, S29, S31, S34, S35, S39

**RECOMMENDATION R23** – For the dust collector, replace the bags and other filtration media at the end of their service life. Do not wait until a breakdown occurs.

*SOURCES TARGETED* – S07-S09, S16, S18, S19, S21, S22, S24, S28, S31, S34, S39

Maintenance of the scrubbers is essential for consistent performance. Regular inspections can help to identify breaches in the structure that could lead to leakage of particles (e.g., break in alumina duct or gas duct). Wear on the fan (e.g., blower wheel) and the various sealing joints of the superstructure must also be taken into consideration when monitoring is performed (corollary to Recommendation R02). The baghouse bags and other filtration media also deteriorate over time and must be changed regularly before tears appear, to avoid an increase in stack emissions.

**RECOMMENDATION R24** – For the GTC, regularly inspect ducts where hard gray scale is likely to accumulate. Clean if too much has accumulated.

*SOURCE TARGETED* – S16

The formation of an amorphous material made up of alumina, bath residue and water (hard gray scale) on the walls of the steel ducts is a problem that can affect the performance of the GTC and the service life of the filtration media.<sup>19</sup> Hard gray scale can form in injection reactors, dust collectors, fluidized bed reactors and enriched alumina ducts. Among other things, it can increase pressure loss, lower the quality of the gas/alumina mix and create an imbalance in the gas flow between compartments. To prevent these situations, it is highly recommended that at-risk areas be monitored and that the ducts be cleaned if a harmful accumulation of hard gray scale is observed.

#### **3.1.14 Monitoring of facilities and their outputs**

**RECOMMENDATION R25** – Monitor emissions of particulate matter from dust collectors. Investigate the causes of sudden increases in particulate matter emissions and make necessary adjustments.

*SOURCES TARGETED* – S07-S09, S16, S18, S19, S24, S26, S28, S30, S31, S33, S34, S36, S39

**RECOMMENDATION R26** – Carry out visual inspections of pneumatic injection and mechanical handling systems according to a set schedule in order to detect leaks. Make repairs as soon as possible.

*SOURCES TARGETED* – S07-S09, S16-S20, S24-S26, S28-S36

Particulate matter emissions are generated not just by the process, but also during the handling and transportation of solids entering or exiting the process. For instance,

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<sup>19</sup> Dando, N.R., Lindsay, S.J., *Hard Gray Scale*, Light Metals 2008, p. 227.



metallurgical-grade alumina, which is generally dense and powdery, must be protected from the elements when being stored and transported to feed electrolytic cell hoppers; otherwise, material losses and fugitive emissions would result. A closed conveyor handling system equipped with dust collectors is normally used.

The following raw materials, products and by-products typically pass through screw or pneumatic conveyors (or the equivalent) between the various transfer points (e.g., storage silo and hopper): fresh alumina, enriched alumina, fresh calcined coke, enriched calcined coke, under-calcined coke, ground frozen bath and bauxite. It is true that most of the coarse particulates emitted from these materials are larger than 2.5 microns; however, with the installation of dust collectors, the fraction of PM<sub>2.5</sub> at the outlet may increase.<sup>20</sup> The optimization of dust collectors is therefore a solution for minimizing PM<sub>2.5</sub> emissions resulting from the handling and storage of various powdery materials.

Screw and pneumatic conveyors—closed systems equipped with hoods and baghouses—are used at various transfer points (e.g., loading of coke onto scales in the green paste facility). To maintain the efficiency of particulate matter capture, it is advisable to have a system to monitor particulate matter emissions at the outlet of the dust collector (e.g., visual, mechanical or electronic system equipped with an alarm). In the event of a sudden surge in emissions, the operator could investigate the cause, make the necessary adjustments and thus minimize particulate emissions. In addition, visual inspections of the handling systems should be carried out on a regular schedule so that any breaks and/or leaks can be repaired.

**RECOMMENDATION R27** – Periodically monitor and maintain dust collectors and replace filtration media at the end of their service life (corollary to Recommendations R22 and R23).

**SOURCES TARGETED** – S07-S09, S16, S18, S19, S24, S26, S28, S30, S31, S33, S34, S36, S39

Refer to Section 3.1.13.

### 3.1.15 Transportation of anode butts

**RECOMMENDATION R28** – Minimize air exposure time (and transport time) of anode butts in the potroom and outside of it. For example, make effective use of covered trays (or equivalent) to cool and transport anode butts (or crust and hot cryolite bath) to the storage room.

**SOURCE TARGETED** – S27

When anode butts are removed from the pots, they are at a temperature of about 960°C. At this temperature (> 700°C), part of the bath evaporates to form, among other things, NaAlF<sub>4</sub>, which then hydrolyzes in the presence of moisture to form HF.<sup>21</sup> The condensation of certain fluorinated species in the air generates PM<sub>2.5</sub>. Anode butts can be covered with a closed tray, granular material or the like to cut off the air required for combustion of the butt or bath and to contain emissions, which are more intense during initial cooling.<sup>22</sup> When the butts have completely cooled, they can be removed from the tray and treated. The gases and PM<sub>2.5</sub> in the

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<sup>20</sup> Environment Canada, NPRI Toolbox, Alumina and Aluminium, Aluminium Spreadsheet.

<sup>21</sup> Girault, G., et al., *Investigation of Solutions to Reduce Fluoride Emissions from Anode Butts and Crust Cover Material*, Light Metals 2011, p. 351.

<sup>22</sup> Gagné, J.-P., et al., *Update on the Evaluation of HF Emission Reduction Using Covered Anode Trays*, Light Metals 2010, p. 291.

tray will nonetheless be released. It is therefore advisable to have a ventilation system in the anode butt storage room and, where possible, to route the gas stream to the GTC.

### 3.2 Prebaked anode production

Prebaked anode production plants use raw materials such as coal tar pitch (or equivalent) and calcined coke (and possibly under-calcined coke), which releases particulate matter throughout the manufacturing process. Projections occurring during mechanical cleaning of anode butts and frozen bath crushing generate a mixture of alumina, cryolite and carbon particles. Most anode manufacturing stages produce particulates that cannot be easily avoided or reduced at the source without affecting the process and the quality of the anodes. This applies to stations for the mechanical cleaning of anode butts, crushing of frozen bath, and crushing, grinding and sieving of calcined coke. These stations require particle ventilation and scrubber systems to provide a safe work environment and environmental protection. The anode baking furnace is also a major source of stationary and fugitive emissions of particulates.

#### 3.2.1 Baking furnace

**RECOMMENDATION R29** – Maintain an effective system for filling baking furnace pits with packing coke to limit coke losses in the building. Train operators in order to standardize work methods for handling packing coke.

*SOURCES TARGETED* – S10, S29

A conventional baking furnace is composed of many sections, each containing several pits into which green anodes are placed and covered with packing coke, which provides good thermal exchange and protects the anodes from air oxidation. When the baking cycle is finished for one section, a special overhead crane sucks up the packing coke, stores it in a hopper and removes the baked anodes. The crane then loads new green anodes and injects packing coke from the hopper. To avoid particulate emissions during these operations, the crane should be equipped with an efficient coke dust control system.<sup>23</sup>

**RECOMMENDATION R30** – Monitor negative pressure at the FTC inlet or at the exit of the baking furnace.

*SOURCES TARGETED* – S10, S18

Anodes are baked in a closed environment that is not completely airtight since the furnace sections must be removed regularly to load and unload the anodes. Monitoring of negative pressure at the furnace exit is essential for safety reasons but also to minimize releases of fine particulates in the furnace building. Effective sealing is required in order to achieve optimal negative pressure for operations. For example, special attention should be given to the condition of port plates, which prevent the entry of cold air into the heated section and can prevent condensation of volatile compounds, formation of corrosive chemical species (e.g., HF, H<sub>2</sub>SO<sub>3</sub>) in the gas lines and incomplete combustion.<sup>24</sup>

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<sup>23</sup> de Vasconcelos, P.D.S., Mesquita, A.L.A., *Environmental Improvements During the Handling of Packing Coke at the Albras' Bake Furnace*, Light Metals 2009, p. 1049.

<sup>24</sup> Mahieu, P., et al., *High Performance Sealing for Anode Baking Furnaces*, Light Metals 2011, p. 881.

### 3.2.2 Cleaning of anode butts

**RECOMMENDATION R31** – Efficiently operate the collection, extraction and filtration systems for dust resulting from the anode butt cleaning process.

*SOURCES TARGETED* – S07, S08, S29

Spent anode butts from the electrolytic reduction process are cooled and placed in storage. They are subsequently placed on an overhead conveyor that transfers them to the anode sealing facility where the frozen bath material is extracted during successive stages of pre-cleaning (fragmentation of the frozen bath using power tools), cleaning (rotary brushing of carbon blocks) and grit blasting. These steps produce 4–5 kg of fragmented bath per anode, on average, and generate a lot of dust.<sup>25</sup>

At each of these stations, the butt is placed inside a sealed enclosure to reduce environmental impacts and protect the mechanical and hydraulic systems from the dust. It is therefore recommended that effective air extraction (compartmentalized or not) and dust collection systems be operated. Continuous or semi-continuous monitoring of particulate emissions from dust collectors would help to ensure their effectiveness. When a sudden increase in emissions is observed, it is important to promptly investigate the cause and make the necessary adjustments as soon as possible (refer to Recommendation R25).

### 3.2.3 Crushing of frozen bath

**RECOMMENDATION R32** – Filter emissions of fine particulate matter released from the frozen bath crushing process using dust collectors.

*SOURCES TARGETED* – S08, S29

Bath residues removed from anode butts during the various cleaning stages are recovered from beneath the equipment and then transferred to a crusher to produce granular material that can be recycled in the electrolytic cells as anode cover material. Operators should therefore operate dust collectors to treat the air released from the crusher.

### 3.2.4 Maintenance activities

**RECOMMENDATION R33** – Regularly inspect the following on a set schedule: the prebaked anode production facilities, including systems for anode butt cleaning, frozen bath crushing, and calcined coke grinding and sieving as well as the baking furnace. In the event of breakdowns or malfunctions, make repairs or install appropriate replacement parts as soon as possible.

*SOURCES TARGETED* – S07-S11, S18-S20, S28-S30

See also recommendations R15, R22, R23, R24 and R27.

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<sup>25</sup> Dupas, N., *New Rodding Shop Solutions*, Light Metals 2008, p. 899.

### 3.2.5 Monitoring of operations (FTC and PFTC)

Prebaked anode production plants use the FTC to treat green anode baking fumes which contain particles, in addition to fluorinated compounds from anode butt residues. For the treatment of pitch fumes, anode plants operate a dry scrubber with calcined coke injection which is specially designed to capture organic compounds. Pitch fumes are routed to and treated in the PFTC. A large portion of the particulates emitted to the PFTC stack, including a small fraction of PM<sub>2.5</sub>, comes from the injected coke.

**RECOMMENDATION R34** – For the FTC only, operate the cooling tower so as to condense most of the tar contained in the baking gas. If necessary, add a prefilter (e.g., ceramic packing) to capture most particulate and condensable matter, including tar.

*SOURCE TARGETED – S18*

The FTC for treating anode baking fumes uses a process very similar to the GTC, except for the cooling tower located upstream of the reactors and dust collectors. This stage involves the injection of a non-saturating amount of water that reduces the temperature of the gas. As a result, most of the tar is condensed and is later adsorbed onto the alumina injected into the reactor. A minimal quantity of tar residue, including a small fraction of incoming solids, is collected at the bottom of the tower. Removal of the tar is also critical for the proper operation of the alumina injection reactor and the dust collector, where agglomerates may form in the presence of the tar. In such a case, the performance of the dust collector, where most particulate matter is captured, would be affected.

See also recommendations R02, R19, R20, R21, R25 and R26.

### 3.2.6 Type of fuel

**RECOMMENDATION R35** – With regard to particulate matter emissions, use hydroelectric power instead of fossil fuels if possible with the current system. Otherwise, use natural gas instead of fuel oil (or another heavy fuel). For facilities that do not have access to hydro power, careful consideration should be given to other electric power sources before making a decision to switch the type of fuel.

*SOURCES TARGETED – S10, S11, S13, S14, S18*

Fossil fuels are normally required as a source of heat in a process. As they burn, they emit particulate matter, which consists mainly of PM<sub>2.5</sub>. The type of fuel used and the consumption rate therefore have a direct effect on PM<sub>2.5</sub> emissions. In the primary aluminium sector, these emissions are associated with holding and homogenization furnaces, anode baking furnaces, induction furnaces, boilers, and coke and alumina calciners.

The combustion of fuel oil and other heavy fuels is known to generate higher levels of particulate emissions. Using natural gas instead of a light oil would reduce microparticle emissions, even if all the particulate matter released from the combustion of natural gas were PM<sub>2.5</sub>.<sup>26</sup> Strictly from the perspective of PM<sub>2.5</sub>, all other things being equal, the use of hydro power, followed by natural gas, is preferable to liquid or solid fossil fuels.

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<sup>26</sup> Environment Canada, NPRI Toolbox, Alumina and Aluminium, Aluminium Spreadsheet.

### 3.3 Green coke calcining

In Canadian coke calcining plants, hot calcining gases including combustion gases, unburned organic compounds and coke particles are scrubbed using a pyroscrubber or boiler followed by a dust collector. Since cooling gas is essentially a vapour stream, it is treated with a venturi-type wet scrubber adapted to wet conditions.

#### 3.3.1 Maintenance activities

**RECOMMENDATION R36** – Regularly inspect the following on a set schedule: the green coke calcining and cooling facilities, including sealing joints and other mechanisms that could potentially lead to a gas leak and emissions of PM<sub>2.5</sub>. In the event of breakdowns or malfunctions, make repairs or install appropriate replacement parts as soon as possible.

*SOURCES TARGETED* – S12, S21-S23, S31-S33

See also recommendations R15, R22, R23 and R27.

#### 3.3.2 Monitoring of operations (pyroscrubber)

**RECOMMENDATION R37** – Optimize the operating parameters of the pyroscrubber to maximize incineration of coke particles in addition to VOCs. Where necessary, follow up with a system designed to detect particles leaving the pyroscrubber and adjust accordingly.

*SOURCE TARGETED* – S21

The pyroscrubber has a closed combustion chamber lined with refractory brick which is maintained at a temperature above 1,000°C and receives an injection of air through several openings to optimize combustion.<sup>27</sup> It is sized according to the gas flow to be treated, the residence time necessary to complete combustion (10–12 s) and the configuration of the equipment. The temperature and oxygen concentration in the pyroscrubber must also be controlled to achieve maximum performance. Moreover, strict monitoring of the pyroscrubber operating parameters is advised in order to mitigate the effect of calciner variations on its performance. Nonetheless, a fraction of the particulate matter, most of which is PM<sub>2.5</sub>, is not incinerated.<sup>28</sup> Clearly, optimizing and monitoring the operating parameters are the best ways to reduce these emissions, aside from installing a new, more effective scrubber.

#### 3.3.3 Monitoring of operations (boiler followed by dust collector)

**RECOMMENDATION R38** – Optimize the performance of the cyclones and dust collector based on the total particle load. When necessary, replace bags with more efficient ones.

*SOURCES TARGETED* – S21, S31, S33

The purpose of the boiler is to produce steam by reducing the temperature of the calcining gas to an acceptable level for the dust collector downstream (typically < 200°C). The dust collector captures coke particles whose concentration is barely affected by the boiler. PM<sub>2.5</sub> is

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<sup>27</sup> SNC-Lavalin Environment, *Description des procédés de fabrication d'anodes et de coke calciné utilisés dans les alumineries canadiennes*, prepared for Environment Canada, March 2011.

<sup>28</sup> Environment Canada, NPRI Toolbox, Alumina and Aluminium, Aluminium Spreadsheet.

therefore controlled by the dust collector, even though these particulates can be expected to represent over 90% of the residual particles in the stack.<sup>29</sup> There are few options for reducing residual PM<sub>2.5</sub> except in cases where the dust collector is not being used to its full potential. Strict monitoring of operating parameters would therefore help to minimize PM<sub>2.5</sub> emissions, depending on the system in place.

The replacement of filters with more efficient ones for capturing micrometric and submicrometric particles (e.g., synthetic filters with a membranous polytetrafluoroethylene (PTFE) coating) could also be considered.<sup>30</sup> These filters would, however, have to be adapted to the existing system. Recommendations R19 and R20 also apply to this technology.

See also recommendations R02, R25 and R26.

### 3.3.4 Monitoring of operations (venturi wet scrubber)

**RECOMMENDATION R39** – Regularly and periodically monitor the gas flow rate through the scrubber by measuring the water flow rate to the venturi inlet. The ratio of the two has a direct effect on pressure loss and the effective capture of particulate matter, including PM<sub>2.5</sub>. Optimize performance for the existing system.

#### *SOURCE TARGETED – S22*

A wet scrubber uses a liquid to clean a gas stream. When the gas is fed into a narrow (venturi-type) neck, the flow accelerates and the injected water is atomized. The gas/liquid mist is then fed to a cyclonic stripping column where the wash water is recovered and then partially recycled in the venturi neck. The effectiveness of this wet scrubber is highly dependent on the size of the particles to be recovered and on the pressure loss applied to the venturi neck. Collection efficiency is usually very high for fine particulate matter (e.g., +99% for PM<sub>10</sub>) but an exponential decrease is observed for ultrafine particulates (e.g., 40–99% for PM<sub>1</sub>). An increase in pressure loss generally improves efficiency.<sup>31</sup> It is therefore advisable to monitor and optimize the operation of the wet scrubber.

### 3.3.5 Green coke storage

**RECOMMENDATION R40** – Unload the green coke in a closed building at the coke calcining plant. Move green coke between various transfer points using closed conveyors or similar equipment or any other measures that can control dust emissions.

#### *SOURCE TARGETED – S33*

Green coke transported by truck from a port or train station is unloaded at a central station from which it is carried by conveyor to the storage silos from which coke is fed to the calciner. Because of its granular and hydrated texture (e.g., average size of 6 mm), green coke is not likely to generate particles when exposed to air. Coke projections can, however, occur when trucks are moving or being unloaded and at coke drop points on the conveyor. To counter these emissions, it is advisable to equip trucks with tight-fitting covers and to operate the

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<sup>29</sup> U.S. EPA Environmental Technology Verification Program, The Evolution of Improved Baghouse Filter Media as Observed in the Environmental Technology Verification Program, June 2008.

<sup>30</sup> Idem.

<sup>31</sup> U.S. EPA, Section 6 – Chapter 2: Wet Scrubbers for Particulate Matter in EPA Air Pollution Control Cost Manual – Sixth Edition (EPA/452/B-02-001), July 2002.

unloading station as well as the conveyor in a closed building. The proportion of microparticles in green coke is negligible, which is not the case for calcined coke.

### 3.4 Alumina production

#### 3.4.1 Maintenance activities

**RECOMMENDATION R41** – Regularly inspect the following on a set schedule: alumina calcining facilities and boilers at the alumina production plant. In the event of breakdowns or malfunctions, make repairs or install appropriate replacement parts as soon as possible.

*SOURCES TARGETED* – S13-S15, S34-S36

See also recommendations R15 and R27.

#### 3.4.2 Red mud disposal

**RECOMMENDATION R42** – Set up physical and/or chemical barriers for red mud disposal sites in order to minimize dusting when weather conditions are conducive to the dispersion of dust.

*SOURCE TARGETED* – S37

Discharges of red mud at the disposal site adjacent to the alumina production plant may lead to a particulate emissions problem, especially if the mud is dumped when weather conditions are unfavourable (warm, dry and windy). The industry is working on improving storage conditions through practices such as dewatering the mud in order to reduce the risk of infiltration into the soil and increase the site's storage capacity. However, the mud dries faster under warm, dry and windy conditions, which can promote dusting (red mud particles smaller than 1 mm, 70% of which are PM<sub>10</sub>).<sup>32</sup> To prevent particulate emissions, it is advisable to put in place physical or chemical dusting "barriers," including embankments (or other means of blocking the wind), soil erosion control facilities and application of a chemical binder to the soil.

#### 3.4.3 Consumption rate

**RECOMMENDATION R43** – For boilers and alumina calciners, minimize natural gas or fuel oil consumption per tonne of alumina produced by using efficient heat recovery systems.

*SOURCES TARGETED* – S13, S14

The operation of alumina calciners and boilers at an alumina production plant requires a large quantity of fuel. Unlike green coke calcining, which uses energy from the VOCs contained in green coke, alumina calcining is a process with a high energy consumption rate (3–5 GJ/t of alumina).<sup>33</sup> The heat contained in calcined alumina and calcining gas is recovered mainly from the steam, and that heat makes it possible to minimize the plant's use of energy, derived essentially from fossil fuels.

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<sup>32</sup> Beaulieu, C., *Revue de la littérature portant sur les boues rouges*, École polytechnique de Montréal, 2002.

<sup>33</sup> European Commission, *Integrated Pollution Prevention and Control – Draft Reference Document on Best Available Techniques for the Non-Ferrous Metals Industries*, July 2009.

For boilers, a significant reduction in a plant's steam use (e.g., through exhaust heat recovery) would also help to prevent particulate emissions, as would regular boiler maintenance. With proper maintenance, a boiler will continue to operate at its design efficiency at all times (thus minimizing its fuel consumption) and its service life will be prolonged.

See also recommendations R25, R26 and R35.

### **3.5 Environmental management practices**

***RECOMMENDATION R44*** – Implementation of the recommendations set out in the Code should be integrated with the facility's environmental management plan, which should include analysis of the initial situation, a training plan, auditing protocols, and determination and implementation of corrective measures in a continuous improvement context.

*SOURCES TARGETED – S1-S39*



## NOMENCLATURE

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### ABBREVIATIONS

AA	Aluminerie Alouette
$\text{Al}_2\text{O}_3 \cdot x\text{H}_2\text{O}$	Hydrated alumina
$\text{AlF}_3$	Aluminium fluoride
AQMS	Air Quality Management System
BLIERs	Base-level industrial emissions requirements
$\text{CaF}_2$	Calcium fluoride
$\text{CaO}$	Calcium oxide
FTC	Fume treatment centre
GTC	Gas treatment centre
$\text{H}_2\text{SO}_3$	Sulphurous acid
HF	Hydrogen fluoride
LMRC	Light Metals Research Centre
$\text{NaAlF}_4$	Sodium tetrafluoroaluminate
$\text{NaF}$	Sodium fluoride
$\text{NaOH}$	Sodium hydroxide (caustic soda)
$\text{NO}_x$	Nitrogen oxides
NPRI	National Pollutant Release Inventory
PAHs	Polycyclic aromatic hydrocarbons
PFCs	Perfluorocarbons
PFTC	Pitch fume treatment centre
TPM	Total particulate matter
$\text{PM}_{10}$	Particulate matter (less than 10 microns in diameter)
$\text{PM}_{2.5}$	Fine particulate matter (less than 2.5 microns)
$\text{PM}_1$	Ultrafine particulate matter (less than 1 micron)
PTFE	Polytetrafluoroethylene
RTA	Rio Tinto Alcan
$\text{SO}_2$	Sulphur dioxide
U.S. EPA	United States Environmental Protection Agency
VOCs	Volatile organic compounds

## GLOSSARY

Aluminate	A compound containing aluminium, sodium and oxygen that is found in Bayer liquor in a precipitated or dissolved state, following bauxite digestion.
Anode butt	Residue of prebaked anode (comprising the rod, carbon residue and cryolite bath crust) following consumption in the electrolytic cell.
Anode cover material	Solid mix of alumina and crushed cryolite bath used to cover prebaked anodes after installation in the electrolytic cell. Also used to plug holes in the crust.
Anode effect	Phenomenon causing a sudden increase in voltage and decrease in amperage in electrolytic cells due to the presence of a gas film on the surface of the anode.
AQMS	Air Quality Management System: Canadian policy on air quality management.
Baghouse	Type of dust collector that uses filtering bags to capture particles contained in gas.
Bath/electrolytic bath	Molten liquid at a temperature of around 960°C composed primarily of aluminium fluoride ( $\text{AlF}_3$ ) and cryolite ( $\text{Na}_3\text{AlF}_6$ ).
Bauxite	Ore varying in structure which is composed predominantly of aluminium oxides, iron and silicon.
Bayer process/liquor	Process for the alkaline extraction of alumina contained in bauxite which uses Bayer liquor (concentrated sodium hydroxide solution). It involves preparing and digesting bauxite, red mud settling, crystallization and precipitation of aluminate, and calcining of hydrated alumina.
Boehmite/gibbsite	Polymorphic aluminium oxides ( $\text{AlO}(\text{OH})$ , $\text{Al}(\text{OH})_3$ ) that make up bauxite.
Busbar	Low impedance conductor bars to which the electrical circuits of the electrolytic cells are attached.
Calcined coke	A form of petroleum coke that has undergone calcining. Primary raw material of green/prebaked anode.
Casting centre	Facility in an aluminium production plant where liquid aluminium from electrolytic cells is transformed into a semi-finished solid product.

Casting machine	System used to transform molten aluminium into ingots, according to the required specifications.
Carbon dust	Dust that accumulates in the cryolite bath and is generated primarily by prebaked anodes.
Coal tar	By-product of coal coking or gasification.
Crushed frozen bath	Crushed cooled cryolite bath, or a crushed mixture of cryolite, alumina and carbon recovered from anode butts.
Crust	Solidified bath and alumina mix covering the cryolite bath in electrolytic cells.
Cryolite	Main chemical compound ( $\text{Na}_3\text{AlF}_6$ ) of the cryolite bath in electrolytic reduction cells that reduces the melting temperature of aluminium.
Dry scrubber	Gas cleaning system consisting of several vertical reactors into which an adsorbent (calcined coke or alumina) is injected.
Dust collector	Processing unit designed to capture most particles contained in gas.
Enriched alumina	Alumina that has been used in the GTC or FTC to capture fluorinated gas. It is enriched with fluorides.
Feeder/breaker	Automated system that feeds metallurgical-grade alumina into electrolytic cells using a breaker that breaks the crust before injecting the alumina into the liquid bath.
FTC	Treatment system for combustion gases from the baking furnace. Composed of a dry scrubber with alumina injection followed by a dust collector.
Green (petroleum) coke	Product derived from the delayed coking of refined crude oil.
Green anode	Compact block formed from green paste, which is a mixture of calcined coke and tar pitch.
Green paste (facility)	Section of the prebaked anode production plant that produces green anode paste, a mix of calcined coke and tar pitch.
Grit blasting	Technique for cleaning a surface that involves blasting microbeads against anode butts to break off cryolite bath residue.

GTC	Treatment system for gases from aluminium production (electrolytic reduction) cells. It consists of a dry scrubber with alumina injection followed by a dust collector.
Hard gray scale	Amorphous solid product consisting of alumina, cryolite and water which accumulates on the inner walls of some ducts in a GTC or FTC using an alumina injection system.
Hydrated alumina	A form of alumina chemically bonded to water molecules ( $\text{Al}_2\text{O}_3 \cdot x\text{H}_2\text{O}$ ).
Induction furnace	Furnace in which the heat required to melt metal is supplied through induction between two electric coils.
LMRC	Light Metals Research Centre: research and consultation centre in Auckland, New Zealand that studies the smelting of aluminium, magnesium and other light metals.
Metallurgical-grade alumina	A form of alumina containing very few or no water molecules ( $\text{Al}_2\text{O}_3$ ).
Packing coke	Calcined coke inserted into baking furnace pits with green anodes to protect them against oxidation by the combustion air, and to promote good heat exchange.
PFTC	Treatment system for pitch fumes from the green paste facility. It consists of a dry scrubber with calcined coke injection followed by a dust collector.
Potroom	Building in which electrolytic cells connected in series are operated.
Pyroscrubber	Cleaning system for gases from the calcining of green coke that incinerates volatile organic compounds.
Red mud	Solid by-product of the Bayer process containing mainly iron oxides as well as aluminium, silicon, titanium, sodium and calcium oxides.
Sealed prebaked anode	Final product of prebaked anode production consisting of one or two blocks of anodes attached by means of cast iron to a rod that conducts electric current. The anodes are used in electrolytic reduction pots.
Sealing facility	Area of the prebaked anode production plant where carbon blocks are attached to rods that conduct electric current.
Self-ignition	Occurs when the energy necessary for calcining comes from green coke alone, without an external fossil fuel.

Söderberg process	Electrolytic reduction process that uses carbon briquettes (or paste) and is characterized by <i>in situ</i> baking in the electrolytic cell.
Superstructure	Electrolytic cells, doors, hoods and the system that extracts gas to the GTC.
Taphole	Opening in the crust through which molten aluminium or cryolite bath is extracted from the pot.
Tar pitch	By-product of the distillation of coal tar which is used as a binder in the production of green anode paste.
Under-calcined coke	By-product of coke recovered by dust collectors from calcining gas released from the green coke calciner.
Venturi wet scrubber	Gas cleaning system that atomizes wash water, thereby improving particle capture.

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Additional information can be obtained at:

Environment Canada

Inquiry Centre

10 Wellington Street, 23rd Floor

Gatineau QC K1A 0H3

Telephone: 1-800-668-6767 (in Canada only) or 819-997-2800

Fax: 819-994-1412

TTY: 819-994-0736

Email: [enviroinfo@ec.gc.ca](mailto:enviroinfo@ec.gc.ca)