



Sustainable Spent Pot Lining Management Guidance

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International Aluminium Institute (IAI)

Current IAI membership represents over 60% of global bauxite, alumina and aluminium production. Since its foundation in 1972, members of IAI have been companies engaged in the production of bauxite, alumina, aluminium, the recycling of aluminium, fabrication of aluminium, or as joint venture partners in such. The key objectives of IAI are to:

- Increase the market for aluminium by enhancing world-wide awareness of its unique and valuable qualities;
- Provide the global forum for aluminium producers on matters of common concern and liaise with regional and national aluminium associations to achieve efficient and cost-effective cooperation;
- Identify issues of relevance to the production, use and recycling of aluminium and promote appropriate research and other action concerning them;
- Encourage and assist continuous progress in the healthy, safe and environmentally sound production of aluminium;
- Collect statistical and other relevant information and communicate it to the industry and its principal stakeholders; and
- Communicate the views and positions of the aluminium industry to international agencies and other relevant parties.

Through the IAI, the aluminium industry aims to promote a wider understanding of its activities and demonstrate both its responsibility in producing the metal and the potential benefits to be realised through its use in sustainable applications and through recycling.

The IAI would like to acknowledge the following companies for their review and contribution to these guidelines.

Alcoa Corporation	Hindalco Industries Limited
Aluminerie Alouette Inc.	Rio Tinto Aluminium
Emirates Global Aluminium (EGA)	Tomago Aluminium
Norsk Hydro	United Company RUSAL

The IAI also acknowledges the contributions of the IAI SPL working group and Stephan Broek (HATCH) in the development of this guidance, as well as the support of regional associations, the IAI Environment and Energy Committee and the IAI Communication and Promotion Committee.

Disclaimer: The information contained in this publication is presented to the best of the IAI's knowledge but is without warranty. The application of the methods, systems and processes for spent pot lining management outlined in this publication is beyond the IAI's control and responsibility and should be taken in compliance with local and national regulatory requirements.

Summary of Guidelines for Sustainable Spent Pot Lining Management

In order to manage spent pot lining sustainably, the following guidelines have been proposed:

Long term planning

1. A documented SPL management plan that focuses on protecting human health and the environment from impacts associated with generation, storage, handling, treatment, transportation and disposal of SPL;
2. A risk assessment for each stage of the SPL management plan to identify all potential environmental, social, economic, health and safety risks;
3. Documented plans for management and monitoring to mitigate key risks;
4. A SPL management plan that considers the waste minimisation hierarchy;
5. A structured and systematic process to assess key environmental, social and economic factors associated with specific management options;
6. Consideration of specific SPL management issues that are individual to the site and situation (e.g. region, regulatory regime, SPL composition, local opportunities).

Good Governance

7. Transparency on company policies, procedures and processes, including decision-making;
8. Accountability for SPL activities at all stages and at different levels within the company;
9. Public disclosure of SPL management plans, activities and performance;
10. Compliance with government regulations and obtaining all necessary permits and approvals for activities.

Health and Safety

11. Use a risk-based approach to understand and manage health and safety impacts from the generation, handling, storage, transportation, treatment and disposal of SPL;
12. Include a system to manage and minimise health & safety hazards related to SPL management and control SPL-related risks;
13. Ensure the health and safety of all workers and local communities;
14. Ensure all workers are adequately qualified to undertake SPL activities and equipped with relevant equipment, manuals and protocols;
15. Provide regular health and safety training for workers to support them in their activities;
16. Work with the community, government and emergency services to develop, document and implement an emergency plan.

Environmental management

- 17. An environmental management system which identifies key risks and outlines measures to monitor and mitigate them;
- 18. Compliance with all environmental regulations as a minimum;
- 19. Baseline assessments and regular monitoring and reporting of key environmental risks.

Storage, Handling and Transport

- 20. A risk assessment to identify potential environmental, social, economic, health and safety risks associated with storage, handling and transport, and systems in place to mitigate these risks;
- 21. A documented protocol for handling and transportation of SPL available for all workers;
- 22. Regular training for workers on specific procedures related to storage, handling and transport of SPL;
- 23. Adherence to all applicable local, national and international laws including the Basel Convention, when handling and transporting SPL and any hazardous derivatives.

Treatment

- 24. Consideration of commercial solutions and their suitability based on site-specific issues, e.g. SPL characteristics, site location, regulatory regime, local industry opportunities.

Disposal and Landfilling

- 25. A risk assessment to identify all potential environmental, social, economic, health and safety risks associated with disposal or landfilling, and systems in place to monitor and mitigate these risks;
- 26. Consultation with relevant stakeholders including site owners, regulatory authorities and local communities to minimise impacts on the environment and human health;
- 27. Compliance with all relevant laws and permitting.

Utilisation of SPL

- 28. Consideration of the various utilisation options for SPL and their suitability based on site-specific issues, e.g. SPL characteristics, site location, regulatory regime, local industry opportunities;
- 29. Opportunities to utilise SPL in other industrial applications should be maximised where possible.

Executive Summary



Sustainable SPL Management Guidance: Executive Summary 1

- All industries are facing pressure to manage waste more effectively.
- The aluminium industry is seeking ways to improve the management of its wastes.
- Establishing sector-wide guidance identifying key elements of an effective SPL management plan is a step towards supporting producers in achieving acceptably low social and environmental impacts.
- The Guidance brings together recently published literature, case studies and data to support aluminium producers striving to manage waste sustainably and not just those seeking to achieve best practice.




2 cuts of SPL: the first cut, a carbonaceous layer, and the second cut, a refractory layer.

1.6 million tonnes of SPL is generated annually from primary aluminium production

25 kilograms of SPL is generated per tonne of aluminium produced

3 industrial processes currently use SPL as a feedstock material: cement, steel, mineral wool, road construction material



Sustainable SPL Management Guidance: Executive Summary 2

Sustainable SPL Management is not 'one size fits all'- SPL composition, local issues, environmental conditions, economic feasibility, government policies, the regulatory framework and, societal factors will differ for each site and need to be considered when developing SPL management plans.

Generally, sustainable SPL management should include:

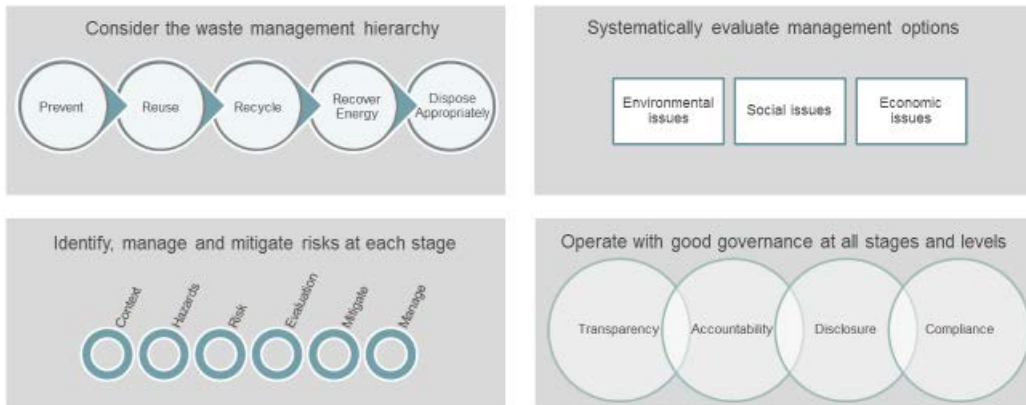
- A long term plan
- Good governance
- Health & safety risk management
- Environmental impact management
- Appropriate storage, handling & transport
- Appropriate treatment and/or landfill
- Maximisation of SPL utilisation where possible



Sustainable SPL Management Guidance: Executive Summary 3

Long term planning and governance

Sustainable SPL Management should:



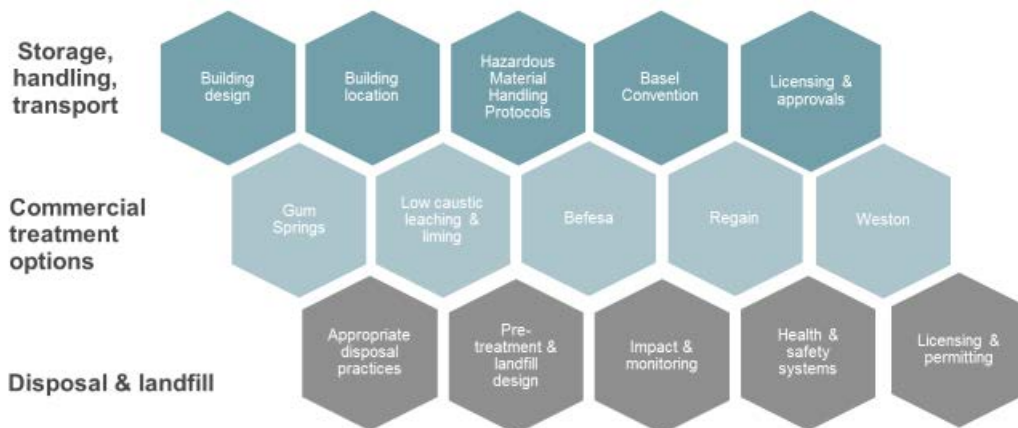
Sustainable SPL Management Guidance: Executive Summary 4

Health, safety and environment

Sustainable SPL Management should include:



Sustainable SPL Management Guidance: Executive Summary 5



Sustainable SPL Management Guidance: Executive Summary 6

Utilisation & ongoing research

Opportunities for utilisation of SPL in industrial processes or as a feedstock material should be maximised



Research & other initiatives: vacuum treatment, Oriens process, plasma vitrification, Engitec

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1. Introduction and Background

1.1 Aims and Objectives

All industries are facing pressure to manage waste more effectively. The aluminium industry is cognizant that establishing sector-wide guidance on sustainable management practices is an important step towards ensuring that the management of spent pot lining (SPL) is sustainable and achieves acceptably low social and environmental impacts.

Sustainable SPL management is not a single '*one-size fits all*' description – and this guidance is intended to assist stakeholders in managing each risk with the best available technologies and approaches appropriate to the specific circumstances. The best fit will be influenced by local climatic, geographic and environmental conditions, as well as economic feasibility, government policies, the regulatory framework and societal factors.

This guidance summarises a range of current and recently published literature with the intention of being relevant to all aluminium smelters generating SPL and waste management companies or industrial end-users that process SPL. The guidance is for those striving to manage waste sustainably and not just those seeking to achieve best practice.

SPL is the most significant solid waste from smelting and the second largest volume from the industry after bauxite residue. This guidance aims to identify the key elements of an effective SPL management plan and provide information and case studies to inform management plans and practices. Aspects relating to monitoring, risk and stewardship are not covered as separate issues but are instead integrated within the other sections in these guidelines.

These guidelines are primarily intended for use by those managing or involved with SPL activities including smelter employees, logistics providers, SPL processors or treatment providers and SPL consuming industries. Other stakeholders including representatives of non-government organisations (NGOs), local communities and government regulators may also find them useful.

1.2 SPL Generation & Terminology

SPL is a solid waste generated during the production of primary aluminium. Primary aluminium is produced via an electrolytic process called the Hall-Héroult process where the aluminium and oxygen in the alumina feedstock is separated by passing a large electric current through a molten bath mixture of cryolite, alumina and aluminium fluoride. This process occurs within carbon-lined steel pots (Figure 1) to produce molten aluminium metal. The lining of the pot is typically made of two layers - an insulating refractory lining and an interior carbon lining. Over time, the cell lining

wears and can form cracks that reduce its ability to hold the liquid metal in the cell. When the lining of the pot comes to the end of its life, typically after 4-7 years, it is classified as *spent pot lining (SPL)*. SPL is typically a mix of all cell lining materials; however, there is a shift in breaking the lining into the two separate cuts: the first cut (carbon lining), and the second cut (refractory lining). Although the exact composition of each cell lining can differ, typically SPL is composed of approximately 55% of the first cut carbon fraction and 45% of the refractory second cut.

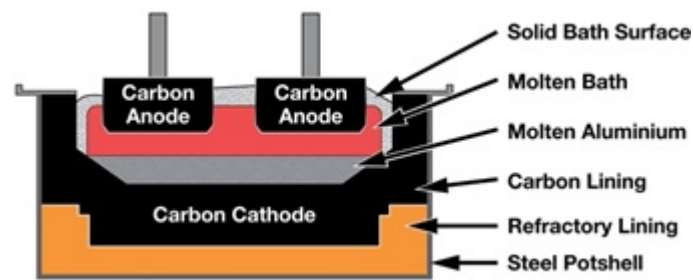


Figure 1: Cross section of aluminium pot (Regain 2019)

Aluminium is widely used in transport, construction (roofing, wall cladding, windows and doors), packaging (cans, aerosols, foil and cartons) and in the electrical sector. It is valued for being light, strong, durable, flexible, impermeable, thermally and electrically conductive and non-corrosive. Primary aluminium demand is strong and could grow at more than 4% per annum through until 2040. The growth in primary aluminium production over this period is expected to result in an increase in the total volume of SPL generated from primary aluminium production globally.

Summary of SPL Terminology

SPL (Mixed): An unsorted (or unspecified) combination of the first and second cut SPL.

First Cut SPL: Carbon-rich component of SPL - mainly the upper portion of material from the bottom block and side walls of the pot. It typically consists of a relatively homogeneous and very hard mix of materials including carbon, fluorine and a small amount of cyanide.

Second Cut SPL: Refractory component of SPL – mainly the lower portion of material from the bottom block. It is typically less homogeneous than the first cut and contains lower levels of cyanide and fluorine. Aluminium, silica and sometimes iron are also present.

1.3 Summary of Key SPL data

In 2018, approximately 1.6 million tonnes of SPL were generated from the production of primary aluminium (Figure 2). Although this is a small fraction of the United Nations' estimate of 500 million tonnes of hazardous waste produced on an annual basis globally, it is the most significant solid waste stream from the aluminium electrolysis process and the aluminium industry should manage it appropriately, and sustainably. Based on estimates in the published literature and IAI data collected from member companies, more than 50% of SPL generated annually is stored indefinitely or landfilled. Other options for managing SPL include treatment and use in other industries, as a direct feedstock material or fuel e.g. cement or steel production.

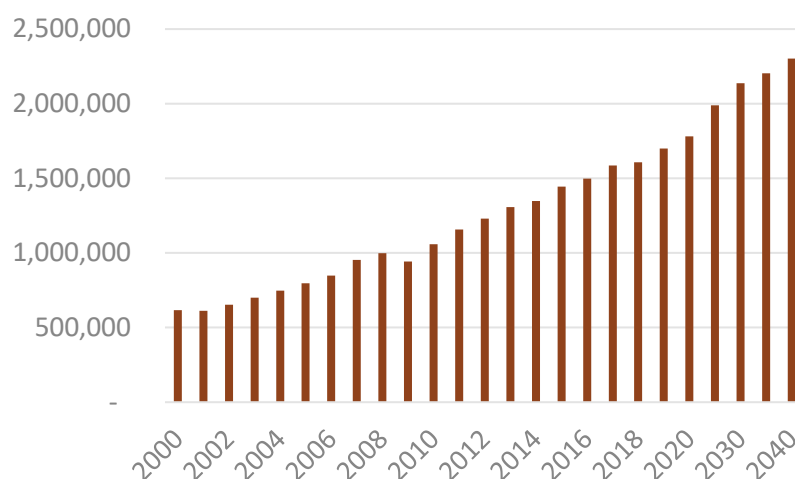
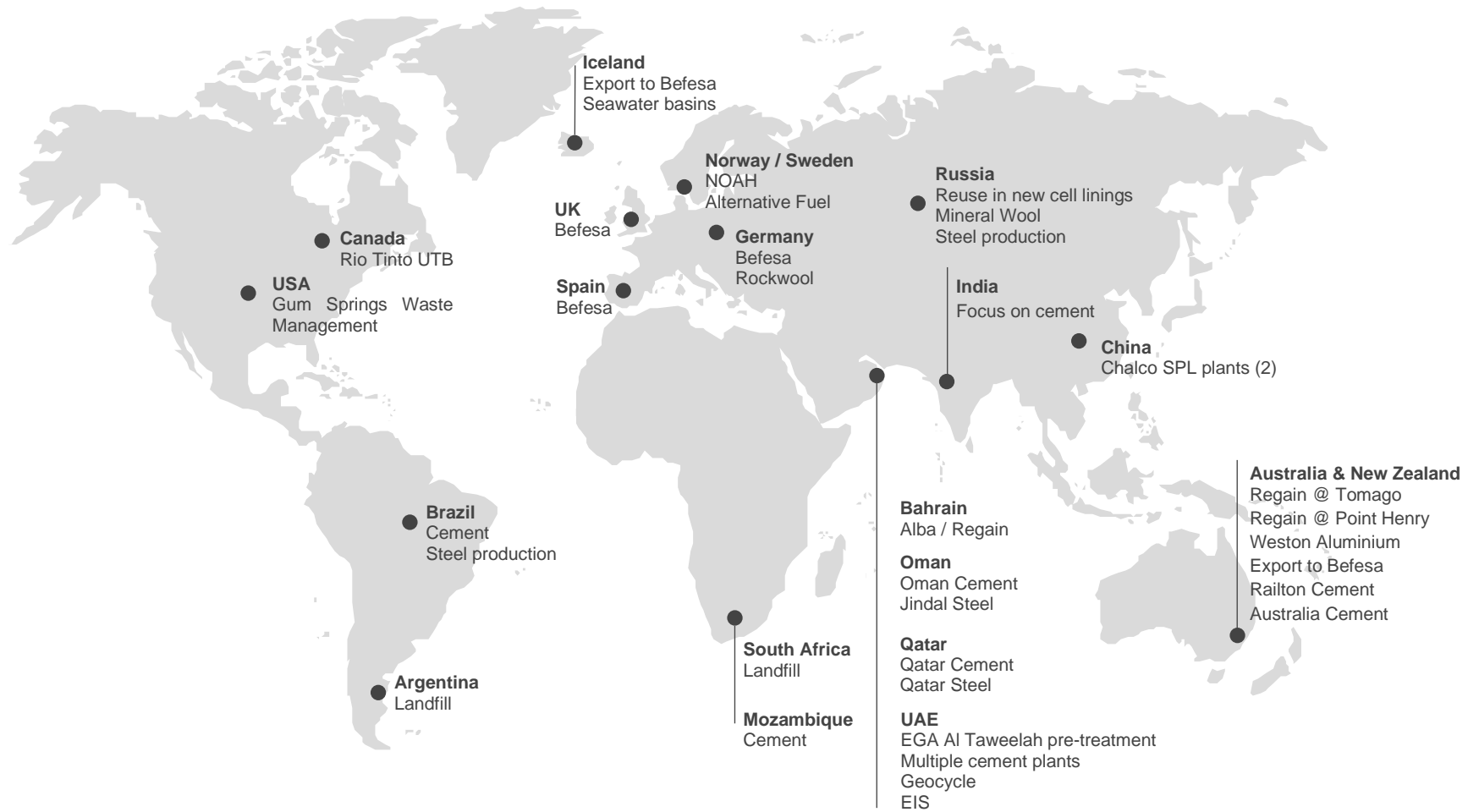


Figure 2: Estimate of annual tonnage of SPL generated from Primary Aluminium Production 2000 to 2040 (IAI 2017)

The IAI collects data directly from the aluminium industry on an annual basis through its Sustainable Development Indicators Survey. Every five years, a more comprehensive collection of data related to solid waste management, including SPL generation and management, is requested as part of the Life Cycle Inventory Survey. Although the response rate and data coverage for the surveys is limited, the data can be used to estimate global SPL generation.

1.4 Global SPL activities map – a snapshot of recent and current activities



Metric	Current Data	Source
Global Primary Aluminium Production (2018)	64 Mt	IAI
Solid Waste Generation from Primary Aluminium Production (2018)	170 Mt	IAI Life Cycle Inventory
SPL Generation per tonne of Primary Aluminium (2015)	25 kg	IAI Life Cycle Inventory
Global SPL generation (2018)	1.6 Mt	IAI Life Cycle Inventory

1.5 Properties

When SPL is extracted from the pot, it is often grey-brown in colour and can vary in size from large blocks to fine dust. During the aluminium production process, chemical compounds can infiltrate and form inside the pot lining resulting in variable and complex chemical compositions.

SPL typically contains aluminium metal, sodium metal, carbon, fluorides, carbides, nitrides, silica and cyanides in both the first cut and second cut. The presence of these chemical compounds gives SPL certain characteristics or properties. Research also shows that the presence of species also changes over time. Both the first cut and second cut of SPL contain hazardous compounds. SPL's classification as a hazardous waste primarily arises from its fluoride and cyanide content and the potential for these compounds to leach and impact the environment and human health. It can also be reactive with water to produce explosive gases. SPL is corrosive, it exhibits a high pH due to the presence of alkali metals and oxides.

The density of SPL is typically within a range of between 1.8 – 2.2 t/m³ and it has a compressive strength that averages 20 to 30Mpa with typical maximum strength approximately 50Mpa depending on the type of cathodes used.

1.6 Characterisation & Sampling

The characteristics of SPL can vary from smelter to smelter and even in batches within the same smelter. Typical ranges for chemical composition are outlined in Table 1. Determining the chemical composition of SPL is not a simple task. The highly variable nature of SPL means that it can be challenging to get a representative sample. Sites should consider which sampling techniques will be best suited when sampling SPL for characterisation and analyses and be aware of the various factors that can impact the results, e.g. specific cell lining materials, the time that the cell spent in operation and de-lining or dismantling procedures.

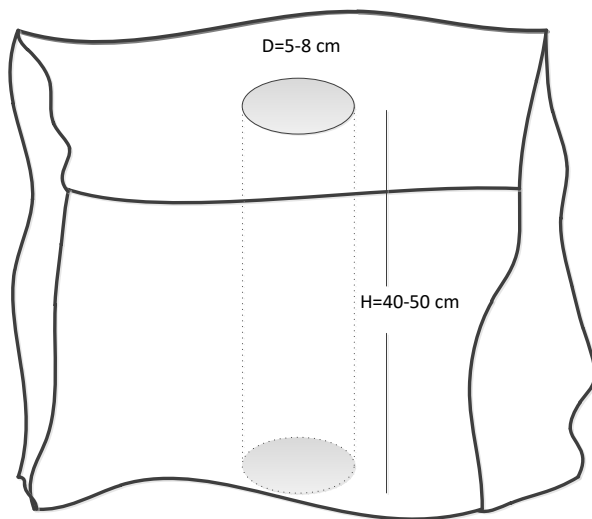
Compound	Carbon Lining 1st Cut Range wt %	Refractory Lining 2nd Cut Range wt %
Al₂O₃	0-10	10-50
C	40-75	0-20
Na	8-17	6-14
F	10-20	4-10
CaO	1-6	1-8
SiO₂	0-6	10-50
Metallic Al	0-5	0
CN total	0.01-0.5	0-0.1
CN free	0-0.2	0-0.05

Table 1: Chemical composition of SPL first cut and second cut (Hydro Aluminium, 2018)

**CASE STUDY: SAMPLING TECHNIQUES & ANALYTICAL METHODS FOR
CHEMICAL CHARACTERISATION OF SPL – HYDRO ALUMINIUM,
NORWAY**

In an effort to address some of the challenges related to sampling techniques, Hydro Aluminium has outlined two approaches it uses to try and collect representative samples from a single cathode:

- Core drilling from cathode and side block sampling (Figure 3); and
- Subfraction sampling from different parts of the cell (Figure 4)



Core sample dimensions:

- D = 6 cm
- H = 45 cm
- Total volume: 1272 cm³
- Total weight: ~2,8 kg

Total sample amount needed for characterization of 1st cut SPL based on core samples:

- Sideblocks (carbon or SiC): ~27 kg
- Cathode: 36 kg

Figure 3: Core drilling cathode and side block sampling example

- 3 subfractions of total 360 kg (3x120kg) taken from different parts of the cell (sorted material)
- Crush each subfractions separately to coarse fragments max. 5 cm diameter
- Take out 2 x 4 kg from different positions from each subfraction and mill down separately to finely divided powder. Typical particle size < 2 mm.
- Take out 2 samples from each of the 6 finely divided powder
- Split samples (50:50) one for analysis and one for archive
- Analyse samples (total 6 samples investigated). Milling necessary < 0.5 mm
- Archive 6 reference samples for possible future investigation

A sketch of the sampling plan is given on the right side.

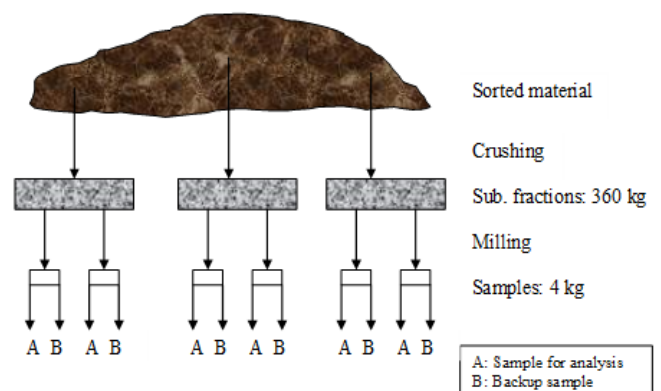


Figure 4: Subfraction sampling from different parts of the cell

Hydro highlights that even with this methodical approach towards sampling, this technique only provides samples representative of a single cell – it is not necessarily representative of the SPL from an entire potline or smelter. In order to conduct a comprehensive characterisation of the SPL at a given site, numerous samples would need to be taken along with analysis of other parameters such as cell lining material, time in operation etc., which can be an intensive and time-consuming process.

Sampling procedures can be challenging with respect to SPL's water-reactive nature and the potential for flammable gas accumulation. The highly alkaline nature of SPL and possible presence of sulphides may also pose challenges for sampling.

Once the samples have been collected, the analytical characterization methods although established through relevant ASTM and ISO standards, also require a high level of competence and skill at the laboratory level which can impact results.

Parameter	Reporting unit	Analytical Methods
S	wt%	ISO 9055: 1988
F	wt%	ASTM D3761 - 96(2002)
Na	wt%	ASTM D 3682
Al	wt%	ASTM D 3682
Ca	wt%	ASTM D 3682
Si	wt%	ASTM D 3682
C	wt%	ASTM 3172/73
Total cyanide	ppm or mg/kg	ISO 6703-1
Free cyanide	ppm or mg/kg	ISO 6703-2
Ash	wt%	ISO 8005
Calorific value	MJ/kg	ISO 1928
Heavy metals and trace elements	mg/kg	HR-ICP-MS

Table 2: Analytical methods for SPL characterisation

2. Long Term Planning

2.1 Developing Waste Management Plans

In developing a long-term management plan for SPL, it is important to consider a number of issues before defining a specific plan of action. Risk assessments are a key part at every stage in the development of the SPL management plan and should identify all potential environmental, social, economic and health and safety risks along with management and monitoring procedures to mitigate them. Relevant background information should be documented and reviewed, along with articulation of the current status or management approach. Finally, it is important that plans are reviewed regularly and that they should be adaptable, allowing for changes and course corrections as policies, issues or risks evolve.

Background	Current Status	Planning
Relevant legislation	Management options	Key assumptions
Specific objectives	Organisation & financing	Future generation & objectives
Stakeholder consultation	Broader objectives	Risk assessment

Figure 5: Example of waste management plan considerations
(adapted from EU Commission, 2012)

The key principles of a sustainable SPL WMP are like those for the management of other wastes. It should focus on protecting human health and the environment from impacts associated with generation, storage, handling, treatment, transportation and disposal of SPL. A SPL WMP should incorporate the waste management hierarchy in the following order of preference:

- *Avoidance* – minimising waste generated through the optimisation of processes;
- *Segregation* – separating wastes to increase reuse or recycling;
- *Reuse* – using SPL as a resource;
- *Recycling* – making SPL suitable for use in other processes;
- *Energy recovery* – conversion of waste materials into useable heat, electricity or fuel; and
- *Appropriate disposal* – with minimum impact on the environment and human health.

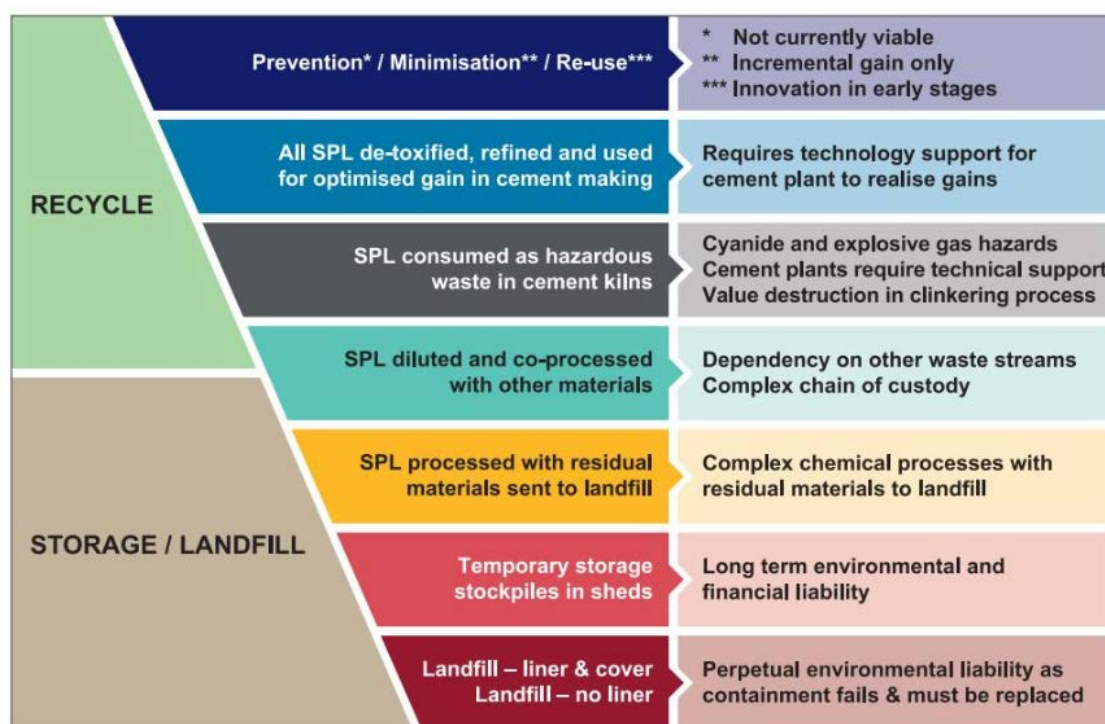


Figure 6: SPL disposal and waste management hierarchy
(Aluminium International Today, 2018)

2.2 Evaluating sustainable solutions

Whether a solution is ‘sustainable’ is dependent on several factors which are individual to each site and situation. To identify the best-suited SPL management practices, a structured, systematic process is useful. It is good practice to consider environmental issues, social issues and economic issues associated with each option. An example evaluation framework is outlined below.

	Solution A	Solution B	Solution C
Environmental Issues	Score	Score	Score
Environmental footprint	1 to 5	1 to 5	1 to 5
Both cuts of SPL	1 to 5	1 to 5	1 to 5
Elimination of hazardous compounds	1 to 5	1 to 5	1 to 5
Social Issues			
Worker health & safety	1 to 5	1 to 5	1 to 5
Community health & safety	1 to 5	1 to 5	1 to 5
Chain of custody	1 to 5	1 to 5	1 to 5

	Solution A	Solution B	Solution C
Economic Issues			
Cost for pre-treatment SPL	1 to 5	1 to 5	1 to 5
Cost for processing by 3rd party	1 to 5	1 to 5	1 to 5
Transportation cost and other fees	1 to 5	1 to 5	1 to 5
Liabilities	1 to 5	1 to 5	1 to 5
Contribution to the local economy	1 to 5	1 to 5	1 to 5
SCORE	Total for A	Total for B	Total for C

Table 3: Example of comparative evaluation framework for SPL options
(adapted from Broek and Øye, 2018 and Regain, 2018)

Although example criteria are included in Table 3, these guidelines do not specify specific criteria as exactly what is critical will differ across companies and sites. It is important to adopt a collaborative approach when defining the criteria to gather input from people with different expertise. This will ensure a broad range of issues are considered. The criteria themselves can be based on company waste management policies or aligned with broader objectives. The framework is intended to allow flexibility in incorporating local, specific issues, but provide a structured approach to assessment and evaluation.

Long Term Planning

Sustainable SPL management should include:

- A documented SPL management plan that focuses on protecting human health and the environment from impacts associated with generation, storage, handling, treatment, transportation and disposal of SPL;
- A risk assessment for each stage of the SPL management plan to identify all potential environmental, social, economic, health and safety risks;
- Documented plans for management and monitoring to mitigate key risks;
- A SPL management plan that considers the waste minimisation hierarchy;
- A structured, and systematic, process to assess key environmental, social and economic factors associated with specific management options;
- Consideration of specific SPL management issues that are individual to the site and situation (e.g. region, regulatory regime, SPL composition, local opportunities).

CASE STUDY: STRATEGIC PARTNERSHIPS - EMIRATES GLOBAL ALUMINIUM, UNITED ARAB EMIRATES

EGA's SPL management approach has focused on two key areas: 1) improvement in SPL facilities and infrastructure; and 2) strategic partnerships to turn SPL from an unwanted waste into a valuable feedstock. This case study focuses on how EGA has developed strategic partnerships over the past decade to create a new market and opportunities for SPL recycling – reducing environmental impacts and bringing benefits for EGA and SPL consumers.

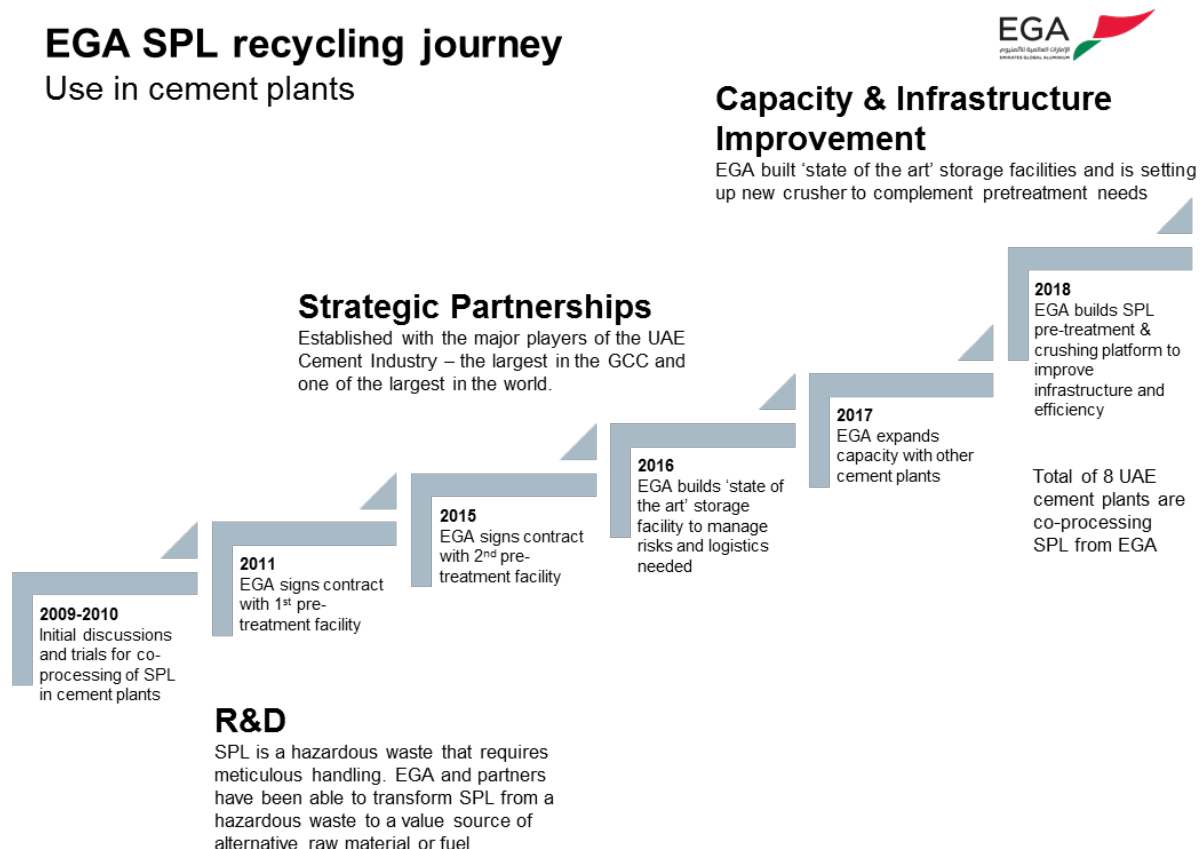


Figure 7: Development of EGA's relationship with cement manufacturers in the UAE (EGA,2018)

Since 2010, EGA has worked with a number of cement companies based in the UAE exploring the potential for the use of SPL in the cement manufacturing process and benefits it can bring to the process. The carbon contained in SPL reduces the energy requirements in the kiln during the cement production process. At the same time, the refractory material reduces requirements for virgin feedstock of quarried rock. Lastly, the fluoride enhances the formation of alite, the key ingredient of Portland cement.

Between 2010 and 2018, EGA formed a number of strategic partnerships with major UAE cement producers. These strategic partnerships and agreements developed from initial collaborative trial periods of testing which allowed parties to adapt and refine processes and specifications. Over time, as the collaborations proved successful, EGA built momentum with cement producers in the region and their approach to develop strategic relationships directly with cement companies has reduced a reliance on third party SPL pre-processors.

The collaboration between EGA and the cement companies also fits well with the objectives in the *UAE Vision 2021* which promotes the utilisation of waste in other industrial processes. Eight UAE cement plants are currently co-processing SPL from EGA. Recognising the advancements made in the commercial utilisation of SPL through the strategic partnerships, in 2017, the UAE Minister for Climate Change and Environment recognised EGA and five UAE cement companies for their work.



Figure 8: EGA's SPL infrastructure investments and a recent award for its work on SPL utilisation in cement (EGA, 2018)

CASE STUDY: SUSTAINABLE BUSINESS FRAMEWORKS & INITIATIVES – HINDALCO, INDIA

Aditya Birla Group (ABG), the parent company of Hindalco, India has developed a Group Sustainable Business Framework which includes a Solid and Hazardous Waste Management policy, technical standard and guidelines. Recognising the increasingly stringent legislative landscape, ABG has identified the need for sustainable waste management practices across its portfolio and aims to move its companies towards complete waste elimination.



Figure 9: Aditya Birla Group Sustainable Business Framework (ABG, 2019)

Hindalco developed its '*Value from Waste*' initiative in line with the overarching aims of the ABG Sustainable Business Framework. Hindalco aims to achieve 100% utilization of key wastes (including SPL) by 2025 and in order to do this has a WMP based on the hierarchy of waste management. In order to identify the best approach for each site, a self-assessment questionnaire is conducted at sites and heat maps have been developed to identify and help address gaps in waste management practices. Compilation of detailed waste inventories and a review of infrastructure requirements for segregation, storage, handling and transport are also ongoing. As part of the initiative, various avenues for utilization of SPL along with other process wastes (bauxite residue, fly ash and aluminium dross) have been identified.

3. Good Governance

3.1 Key Factors for Good Governance

Governance relates to how institutions conduct their business affairs and manage resources. It includes the process of decision-making and processes by which those decisions are implemented. Transparency and accountability are essential for good governance and the disclosure of information is vital in holding responsible parties to account. There should be accountability for SPL activities at all stages, and at different levels, within the company, from senior management through to operators and contractors. Good governance can have a significant impact on the way SPL activities are managed.

More broadly, good governance should include:

- A set of values and code of ethics applicable to employees, suppliers and for relationships with authorities and other stakeholders;
- Training for employees on transparency, accountability and ethical conduct;
- Having systems in place to ensure compliance with all legal and regulatory requirements;
- Payment of all applicable local, national and regional taxes and duties;
- Development and promotion of open communication channels for employees and other stakeholders to provide feedback, raise concerns or discuss issues;
- Public disclosure of SPL management plans, activities and performance; and
- Documentation of corporate policies and procedures including business decision-making.

3.2 Regulatory Compliance

Operators must take responsibility for complying with all applicable local and national laws and for meeting the performance standards set by government regulators. Regulatory requirements will vary between, and often within, countries.

SPL activities will typically require more than just environmental permitting and its hazardous waste classification in several jurisdictions will mean it is subject to stringent regulations. Other such permits or approvals that may need to be considered could include:

- Storage area feasibility study approvals
- Social Impact assessments for permits
- Communication plans with stakeholders and other effected parties
- Land use permits
- Waste disposal licences
- Assessment of risks
- Permits or approvals for transport of SPL
- Permits or approvals for recycling or use of SPL in other processes or products

Good Governance

Sustainable SPL management should include:

- Transparency on company policies, procedures and processes, including decision-making;
- Accountability for SPL activities at all stages, and at different levels within the company;
- Public disclosure of SPL management plans, activities and performance;
- Compliance with government regulations and obtaining all necessary permits and approvals for activities.

4. Health and Safety

4.1 Health and Safety Considerations

All health and safety risks and hazards related to SPL management should be assessed to characterise the risks and guide the development and implementation of suitable controls. These should be documented in a health and safety plan and could include issues such as:

- General workplace health and safety
- Personal Protective Equipment
- SPL health and safety training
- Safety Data Sheets (SDS)
- Fitness for work
- Machinery operation and protection
- Physical hazards
- Hazardous waste
- Storage, handling and transport practices
- Water-reactivity
- Flammable gas evolution
- Ventilated storage
- Cyanide
- Fluoride salts
- Respirable crystalline silica dust
- Toxic gas release
- Other substances: nitrides, carbides, phosphides, sulphides

A risk-based approach should be adopted to understand and manage potential health and safety impacts from SPL activities. Guidance and training should be provided to ensure workers are informed of the health and safety risks associated with SPL management and equipped with skills, strategies and information to mitigate these risks. Companies should provide safe and healthy working conditions for employees, taking all practical and reasonable measures to eliminate workplace fatalities, injuries and diseases, including implementing and maintaining a health and safety system. This system should include:

- A health and safety rights policy for all employees and contractors in order to recognise their rights in accordance with all relevant national standards;
- A documented occupational health and safety management system set up as part of this policy. This should be compliant with applicable national and, ideally, international standards, and must seek to identify, manage, mitigate and monitor risks;
- SDS datasheets;
- A regular audit of this system as well as certification to an international standard such as OHSAS 18001 or ISO 45001; and
- An evaluation and report on the site's health and safety performance.

Public and community health and safety should also be considered as part of an SPL management plan. Monitoring and public reporting programmes should be used to demonstrate health and safety compliance and facilitate discussion about public or community health and safety concerns.

4.2 Procedures & Policies

An operating manual outlining the procedures and policies associated with each SPL activity should be maintained and made available to all employees and contractors. In addition to providing written manuals, employees and contractors should receive regular training in their area of responsibility or operation. It is recommended that the following issues be included in written operating manuals and operator training programmes:

- Operator's role and responsibilities
- Specific health & safety risks
- Key indicators to monitor operations
- Personal protection equipment
- Pot de-lining protocols
- SPL handling & storage procedures
- Storage design safety features
- Gas monitoring systems
- Scheduled equipment maintenance
- Reporting protocols for issues or incidents

4.3 Specific Occupational Health Hazards and Risks

Some key occupational health issues related to SPL activities are outlined below. The main risks associated with SPL are typically outlined in industry safety data sheets (SDS) – see Appendix A for examples. A comprehensive overview of occupational health hazards and risks associated with primary aluminium production is available in the Journal of Occupational and Environmental Medicine (Wesdock and Arnold, 2014).

Beryllium

Beryllium is naturally present in some bauxite ores and can become concentrated in the alumina feedstock. During electrolysis, it is then concentrated in the molten cryolite bath and subsequently in the pot crust and SPL. As a result, aluminium smelter workers, and those working with SPL, have the potential for beryllium exposure. High exposure through dust and fume inhalation can cause beryllium sensitization, an immune-mediated response, and chronic beryllium disease, an immune-mediated lung disease. Studies have found the incidence rate of these illnesses to be at very low rates in aluminium smelter workers and relatively lower compared with other industries where beryllium is used in the industrial process. Occupational exposure to Beryllium should be monitored and controlled as appropriate, e.g. well-ventilated environment and/or suitable PPE.

Fluorides

The fluoride compounds contained in SPL mostly originate from the cryolite and sodium fluoride in the electrolyte used during the electrolysis process. When SPL comes into contact with acids it can release toxic gases including hydrogen fluoride (HF). Inhalation of HF can cause irritation to the skin, eye and upper respiratory tract. Asthma in primary aluminium smelters has most consistently been linked with fluoride exposures however this has not been definitively determined. Risks related to SPL contact with acids should be managed through appropriate storage and handling protocols and occupational exposure to fluorides should be monitored and controlled.

Respirable Crystalline Silica

Respirable crystalline silica can be generated during SPL handling and processing (e.g. grinding, drying). Prolonged or significant inhalation of respirable crystalline silica dust may cause lung fibrosis, commonly referred to as silicosis. The symptoms of silicosis include coughing and breathlessness. The relative risk of lung cancer is increased in persons with silicosis and so systems should be in place to manage occupational exposure, e.g. well-ventilated work areas, suitable PPE and monitoring to keep exposure below recommended limits.

4.4 Emergencies

Responding effectively to emergencies is essential for companies to protect employees, local communities and other stakeholders. An emergency action plan should be in place for all SPL activities to ensure that in the event of an incident, appropriate actions can be taken. A timely and effective local response may be crucial in limiting injuries to people and damage to property or the environment. An emergency action plan should outline the steps to be taken in order to minimise the health and safety risks and the impact on the environment. It is good practice to develop an emergency action plan in consultation with responsible parties, local or regional authorities, local communities and emergency services.

Emergency action plans should consider:

- Conditions that could lead to an emergency incident e.g. natural disasters, malicious acts, equipment or system failures and the areas/people that may be directly affected;
- Procedures that may be necessary to isolate people and property from hazards including warning systems or protocols for alerting people to the incident;
- Immediate actions that may be required to mitigate impacts including notifying key people, evacuation procedures or clean-up plans;

- Systematic protocols to alert responsible parties, emergency services and others;
- The emergency response training required for responsible parties and workers;
- Putting comprehensive SDS datasheets in place and actively manage those;
- A regular review and update process.

Health and Safety

Sustainable SPL management should:

- Use a risk-based approach to understand and manage health and safety impacts from the generation, handling, storage, transportation, treatment and disposal of SPL;
- Include a system to manage and minimise health & safety hazards related to SPL management and control SPL-related risks;
- Ensure the health and safety of all workers and local communities;
- Ensure all workers are adequately qualified to undertake SPL activities and equipped with relevant equipment, manuals and protocols;
- Provide regular health and safety training for workers to support them in their activities;
- Work with the community, government and emergency services to develop, document and implement an emergency plan.

5. Environmental Management and Performance

5.1 Environmental Management

The main issue related to SPL management and the environment is the potential for leaching of hazardous chemical compounds including fluoride and cyanide. There are also environmental risks related to SPL's water-reactivity and the potential for accumulation of flammable gases (hydrogen, methane, ammonia and phosphine).

Companies should assess their SPL activities and infrastructure to ensure all environmental risks are identified and any impacts on the environment are minimised. Environmental management systems should be in place to mitigate against risks and manage environmental issues. All environmental permitting and regulations should be complied with as a minimum. Baseline environmental assessments and regular monitoring and reporting of the following should be considered as part of the environmental management of SPL activities:

- Surface and groundwater levels and water quality;
- Water content and geochemistry of foundation soils and rocks in or near storage areas;
- Air quality and dust management;
- Assessment of noise level (e.g. crushing or mechanical activities) ;
- Suitability of storage site(s) including underlying geology and hydrological features ;
- Climatic conditions and potential for extreme meteorological events;
- Surveys and impact assessments on terrestrial and aquatic fauna and flora.

5.2 Fluorides

Fluorides are present in both cuts of SPL with typical ranges of between 5-20 wt.%. Fluoride tends to be concentrated in the bottom carbon block at the contact point with the molten fluoride salt. There are several factors that can affect fluoride concentration in SPL including: alumina quality, lining quality and age of the steel pot. The main environmental management concerns around fluoride relate to its potential for leaching and contamination of groundwater or the surrounding environment.

5.3 Cyanides

Concentrations of total cyanide in SPL can vary significantly. Cyanide is usually present in both cuts of SPL and there can be variability in cyanide concentrations within the pot. Higher concentrations of cyanide are often found at the side wall where the carbon fraction is exposed to air that can penetrate the lining through the space around collector bars. Total cyanide may vary significantly within a single pot as a result of several factors including alumina quality, the age of the pot or

de-lining process. The main environmental management concerns around cyanide relate to its toxicity, potential for leaching and contamination of groundwater and surrounding environment.

5.4 Alkalinity

SPL has a high pH due to the presence of alkali metals and oxides that have penetrated the lining materials or have been formed from chemical reactions. There are several environmental considerations with regards to the alkaline nature of SPL that should be managed.

The main environmental concern is related to the reaction of water with various species in SPL. Sodium oxide (formed from sodium reacting with water) will form sodium hydroxide in the runoff water which makes it highly caustic and thus corrosive. Storage of SPL should consider water contact with SPL and systems to divert or collect water should be in place to ensure leaching and groundwater contamination risks are minimised.

Even small amounts of rainwater can react with nitrides in the SPL to produce ammonia. If the ammonia becomes concentrated in areas where workers or communities are present, systems should be in place to manage the related risks. Carbides in the SPL can also react to form hydrogen which has risks related explosions in a confined space. Other gases such as ethylene can also be released but require similar management to hydrogen. Overall, the gas formation potential of SPL from its alkalinity requires storage areas that are well ventilated.

Environmental Management

Sustainable SPL management should include:

- An environmental management system which identifies key risks and outlines measures to monitor and mitigate them;
- Compliance with all environmental regulations as a minimum;
- Baseline assessments and regular monitoring and reporting of key environmental risks.

CASE STUDY: *GROUNDWATER & EFFLUENTS MONITORING - RIO TINTO KITIMAT, CANADA*

SPL is one of the most significant hazardous waste materials generated at Rio Tinto's Kitimat smelter. Since 2018, all the SPL generated at Kitimat is transported to the Rio Tinto SPL Treatment Plant in Saguenay, Quebec. Prior to 1989, approximately 460,000 m³ of SPL were disposed of at the landfill site as per permit limits. The landfill was decommissioned in the fall of 1989 and initially capped with a low permeability cover. Over the next decade, the three subsections were capped with polyvinyl chloride (PVC) liners. The capping significantly reduced surface water infiltration, thus reducing contaminant loading into the environment. A variety of monitoring programs are carried out related to groundwater quality and flow.

Groundwater monitoring has been carried out in accordance with the requirements of the multi-media permit and the SPL management plan. The existing program consists of a quarterly monitoring program where selected wells are visited to monitor water level trends. In addition to monitoring water levels, a geochemical sampling campaign that occurs in the fall of each year also occurs as part of the annual program. The information collected is used to assess groundwater quality for any significant changes in chemistry that may exceed previous year's results.

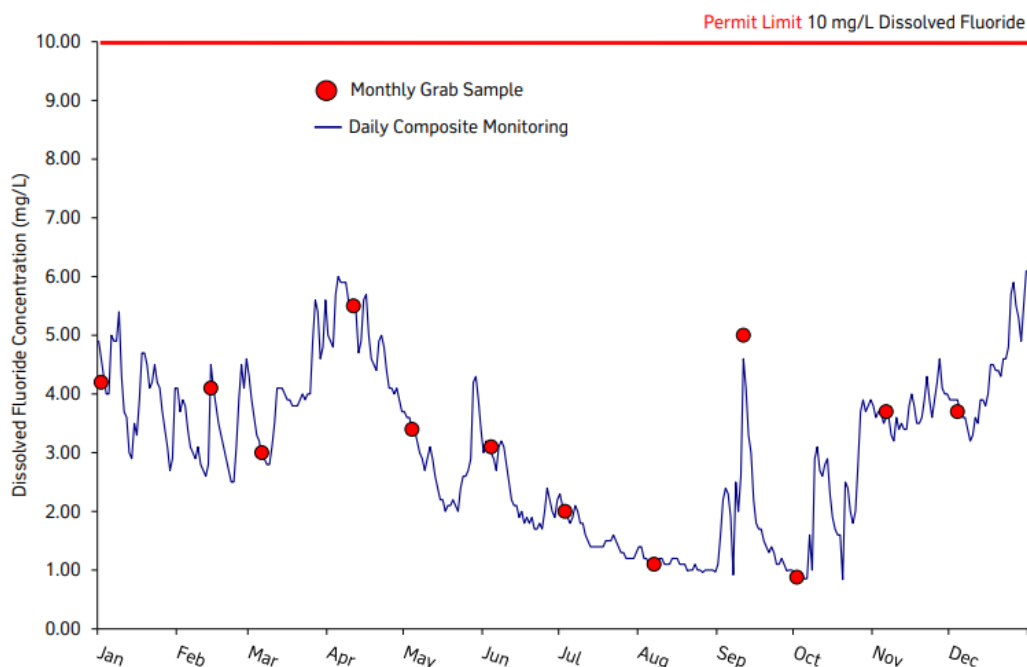


Figure 10: Example of dissolved fluoride monitoring in effluent at Kitimat (Rio Tinto, 2018)

Surface runoff from the smelter site, originating as snowmelt and rain, accounts for most of the water discharge. Seasonal precipitation varies significantly, and total discharge can be over 100,000 m³ per day during fall and winter storms. Effluent water quality is monitored annually for the following parameters: flow variability, dissolved fluoride, dissolved aluminium, TSS, cyanide, temperature, conductivity, hardness, toxicity, acidity and Total PAH. Of these parameters, dissolved fluoride and cyanide are monitored for long term trends and are meaningful performance indicators of plant effluent water quality. 50 % of the dissolved fluoride in the effluents was estimated coming from the leaching of the landfill formerly used to dispose of spent pot lining. Other sources of fluoride are raw material losses around the smelter.

Dissolved fluoride is monitored continuously through daily composite sampling and monthly grab sampling, as illustrated in Figure 10. Daily composite and grab samples are sent to an outside laboratory for analysis. The permit specifies a maximum concentration of 10 mg/L of dissolved fluoride in effluent; this level was not exceeded in 2018. Average dissolved fluoride concentration for the year derived from composite sampling was 3.02 mg/L.

Cyanides are generated by the interaction of groundwater and the bottom of the SPL landfill lining. This leachate impacts the effluent. The permit specifies a maximum concentration of 0.5 mg/L of strong acid dissociable cyanide (more abundant, although less toxic) in the effluent. Concentrations are determined from monthly grab samples. As shown below in Figure 11, the permit level was not exceeded. Weak acid dissociable cyanide is also monitored, although there is no permit requirement.

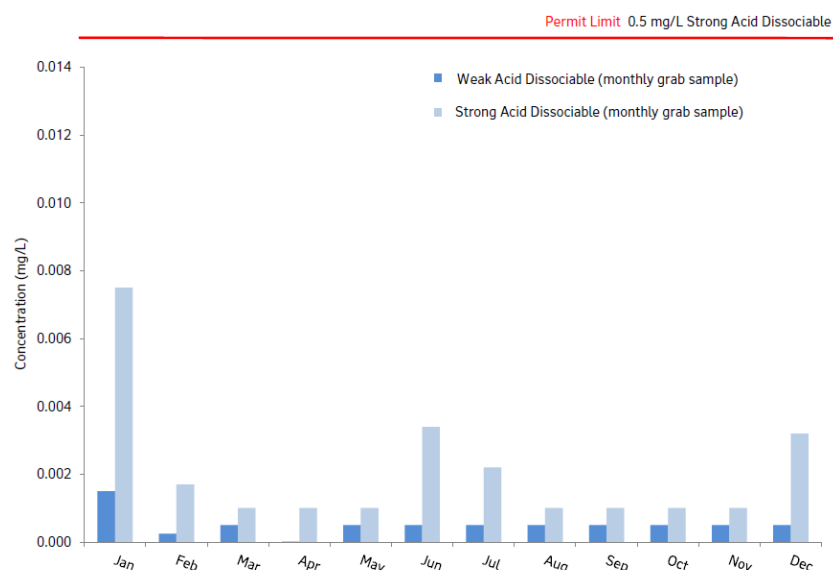


Figure 11: Example of cyanide monitoring in effluents at Kitimat (Rio Tinto, 2018)

6. Handling, Storage & Transportation

6.1 On-site Handling Procedures

The main risks associated with on-site handling and transportation are typically outlined in industry safety data sheets (SDS) – see Appendix A for examples. SPL should be handled in a manner which controls and prevents the leakage of hazardous materials and mitigates the risks associated with its reactivity in contact with water and acids. For example, protocols should be in place to advise against transport of SPL in inclement weather.

After pot de-lining, SPL is typically loaded into standard waste containers (drums, roll-off containers, railroad cars and tank trucks) and transported to pre-treatment processing areas or storage areas. The containers that are used should be clearly labelled, provide enough cover to keep the SPL dry and consideration should be given to any ventilation requirements to prevent the build-up of flammable gases. In some cases, it may be useful to have designated areas or multiple bays of containers to allow for the separate handling of the two cuts of SPL.

Companies should provide written guidelines and training on specific procedures related to SPL activities. The guidelines should include:

- Safety data sheets;
- Health and safety procedures, including hygiene;
- Ventilation management and monitoring systems;
- Handling and storage practices e.g. away from water, acids, bases and intense heat;
- Water-reactivity and transportation risks;
- Flammable gas management and monitoring systems;
- Occupational exposure management and monitoring (e.g. fluorides, dust).

6.2 Storage in buildings

Dedicated SPL storage buildings located on or near the smelter site can store SPL from the point of de-lining until transportation to a treatment facility or other end point. The basis for planning of a SPL storage area should include comprehensive SPL characterisation of the chemical and physical properties of the material as well as assessment of the suitability of the proposed site, e.g. hydrological, environmental and social risks. Planning an SPL storage building should involve the regulatory authorities and local communities/stakeholders. There are a number of features that should be considered in the planning, design and construction phase:

Impermeable Building Design:

- **Elevation:** if there is a risk that rising water from creeks, rivers or wadies can flood the building, the building should be placed on a talud to minimise the risk of flooding.
- **Floor design:** direct contact with any water must be prevented and if any water enters the building, there should be a system for collecting it and diverting it away from the stored SPL. Concrete is typically the material of choice for the floor and side walls of SPL storage buildings. The design should aim to reduce the risk of leakage - a protective membrane can also be installed beneath the concrete floor to seal the building from the ground. Hydrological studies to assess the risks related to storm surges or sea level rise should be considered.
- **Side-wall design:** to minimise risk of leakage, walls can be designed to be integrated with the floor. In some cases, sides-walls are best in a free-standing design. If mechanical ventilation is in place, then fans to push air inside the building are typically positioned within the sidewalls.
- **Roof design:** To ensure the stored SPL is kept dry, but well ventilated, an overhanging roof with natural ventilation openings along the sidewall can be designed. The roof should be sloped to allow water to run off and typically a water collection or redirection system should be in place to manage the water flow.

Health and Safety Systems & Considerations:

- **Dust management systems:** precautions should be taken to reduce exposure to dust from SPL including respirators and other relevant PPE for personnel entering the building. Enclosing SPL storage and process areas reduces the risk of dust escaping to the environment. Within the storage areas themselves, the use of dust filters can manage the air quality and reduce the risk of dust exposure. Simple solutions such as truck and mobile equipment washing when leaving the storage or de-lining facilities can also help to manage dust.

- **Gas Monitoring:** the ventilation of the building should be designed so that there is enough air flow to minimise the levels of methane and hydrogen gases. A risk assessment to determine the risk related to the tonnage of SPL stored should be conducted. A hazardous area classification should also be undertaken. Unless the risk assessment and hazardous area classification show otherwise, storage areas that are designed to hold large volumes of SPL should have a gas detection system to monitor toxic or flammable gases in place to alert personnel if gas levels exceed acceptable limits. In some cases, these monitoring systems can initiate an automated response to improve air circulation.
- **Electrical systems:** unless the risk assessment and hazardous area classification show otherwise, electrical equipment within the SPL storage building should be kept to a minimum to reduce the risks related to the evolution of flammable gases from SPL. If the SPL storage buildings are classed as Zone 2 Hazardous areas (ATEX/IECEx) then electrical equipment inside the building should be rated explosion proof where possible.
- **Fire protection and explosion proofing:** a fire detection system should be in place within the storage building. Only dry methods (including CO₂) of firefighting should be permitted in SPL storage areas and communication with local fire authorities should indicate the specific nature of the fire risks related to SPL.

CASE STUDY: *SPL STORAGE BUILDING DESIGN - EMIRATES GLOBAL ALUMINIUM, UNITED ARAB EMIRATES*



Figure 12: EGA SPL Storage Facilities (EGA 2019)

In 2016, EGA built a new SPL storage building at its Al Taweelah site in the Khalifa Industrial Zone, Abu Dhabi. The building has a storage capacity of 50,000 tonnes and is intended to assist EGA with the risk management and logistics associated with SPL processing and recycling.

As part of the building planning and design process, a building review study was commissioned to outline the risks and hazards associated with building a long-term storage facility. The study focused on two key risks - toxic gas release and the explosion potential inside the SPL storage building.

The building design incorporates a number of safety features highlighted in the study as essential features to minimise risks. The building includes both natural and mechanical ventilation systems to ensure sufficient air flow to keep methane and hydrogen gases at suitable levels and prevent gas accumulation. The mechanical ventilation system provides the equivalent to two air changes per hour. The gas detection system sounds an alarm to alert personnel if gas levels exceed safe levels and there is an automated response by the system which initiates mechanical ventilation based on the set lower explosive limit (LEL) level.

Several precautions have also been taken to mitigate the risk of water seepage or contact with the SPL stockpiles. The building is watertight with impermeable walls and floor. The base of the storage facility is also built at approximately 0.5m above road level to reduce the risk of any surface run-off or storm water seepage.

CASE STUDY: ASSESSING CRITICALITY AND RISK - EMIRATES GLOBAL ALUMINIUM UNITED ARAB EMIRATES

In 2016, EGA commissioned a study during the planning phase for its new SPL storage building at its Al Taweelah site. The study included risk analyses for two incident scenarios: toxic gas release and building explosion. The risk assessment was undertaken in accordance with the Abu Dhabi guidelines and a risk rating was determined based on:

1. The consequence of the hazard (e.g. severity and its impact on land, aquatic environments, atmosphere, culture and heritage, site production and economic/financial consequences); and
2. The probability of occurrence (i.e. rare, possible, likely, often or frequent)

Probability	Consequence				
	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
1 Rare	1	2	3	4	5
2 Possible	2	4	6	8	10
3 Likely	3	6	9	12	15
4 Often	4	8	12	16	20
5 Frequent	5	10	15	20	25
15 - 25	Extreme Risk		Activity or industry should not proceed in current form		
8 – 12	High Risk		Activity or industry should be modified to include remedial planning and action and be subject to detailed EHS assessment		
4 – 6	Moderate Risk		Activity or industry can operate subject to management and/or modification		
1 - 3	Low Risk		No action required unless escalation of risk is possible		

Figure 13: Criticality matrix: risk rating based on probability and consequence of event/incident (EGA, 2016)

Using a criticality matrix framework (Figure 13), the study concluded:

- SPL building toxic gas release, for a worst-case scenario had a level of risk considered moderate for site workers (4 to 6). The use of appropriate PPE, a loader equipped with a closed cabin for the operator, and an alarm set at 25ppm NH₃ in the building, reduced exposure risks to dust and ammonia.

SPL building explosion had a level of risk considered low (1) – this was deemed a rare event. The location of the building would also mean no risk to nearby populations or facilities and risks could be mitigated with building design features to ensure suitable management of the risks. It was also established that the classification was Class 1 Water-Reactive in NFPA standard No. 400.

6.3 Hazardous Waste Classification

Spent Pot Lining is classified as a hazardous waste in a number of jurisdictions. In most cases, this classification means that SPL is subject to further treatment prior to storage or disposal. The treatment standards mostly relate to the destruction of cyanides and recovery of fluorides from the SPL to minimize risks associated with leaching and groundwater contamination. The hazardous waste categorisation and subsequent management protocols only apply once the waste has left the generation site in some instances. Details on the hazardous waste classifications of SPL in a number of key jurisdictions and by international bodies are outlined below.

Australia: SPL is classified as a hazardous waste across all Australian states and must be treated prior to landfilling and/or receive the necessary licences/approvals for disposal. A summary of current SPL waste classification in Australia is included in Table 4:

	Most relevant legislation	Jurisdictional hazard classification of SPL				Regulatory consequence
		1 st cut SPL	Due to	2 nd cut SPL	Due to	
NSW	<i>Protection of the Environment Operations (Waste) Regulation 2005</i>	Hazardous waste	<ul style="list-style-type: none"> • Australian Code for the Transport of Dangerous Goods by Road & Rail (ADGC), Div. 4.3 • Fluoride 	Hazardous waste	<ul style="list-style-type: none"> • ADGC Div. 4.3 • Fluoride 	Both 1 st & 2 nd cuts cannot go to direct to landfill. Immobilisation approval must be obtained and require chemical treatment of SPL to reduce the hazardous properties of SPL before landfilling.
Qld	<i>Environment Protection Regulation 2008</i>	Regulated waste	<ul style="list-style-type: none"> • ADGC Div. 4.3 • Fluoride, cyanides 	Regulated waste	<ul style="list-style-type: none"> • ADGC Div. 4.3 • Fluoride, cyanides 	Regulated waste in QLD. Individual landfill licence conditions determine acceptance of SPL.
Tas	<i>Environmental Management and Pollution Control (Waste Management) Regulations 2010</i>	Controlled waste	<ul style="list-style-type: none"> • ADGC Div. 4.3 • Fluoride 	Controlled waste	<ul style="list-style-type: none"> • ADGC Div. 4.3 • Fluoride 	The handling of controlled waste requires approval from the Director, EPA.

	Most relevant legislation	Jurisdictional hazard classification of SPL				Regulatory consequence
		1 st cut SPL	Due to	2 nd cut SPL	Due to	
Vic	<i>Environment Protection (Industrial Waste Resource) Regulations 2009</i>	Prescribed industrial waste, Category A	<ul style="list-style-type: none"> • ADGC Div. 4.3 • Fluoride 	Prescribed industrial waste, Category A	<ul style="list-style-type: none"> • ADGC Div. 4.3 • Fluoride 	Both 1st & 2nd cuts cannot go to direct to landfill. Immobilisation or other treatment to destroy /reduce hazard must occur.

Table 4: Summary of current SPL waste classification in Australia (Black 2016)

Canada: SPL is classified as Hazardous material in all the provinces of Canada due to its leachable and toxic contents (fluoride and cyanide) and its reactivity with water (see Règlement sur les matières dangereuses (Q-2, r.15.2) du Québec). The federal government regulates transboundary movements of hazardous waste and hazardous recyclable material, in addition to negotiating international agreements related to chemicals and waste. Provincial and territorial governments establish measures and criteria for licensing hazardous-waste generators, carriers, and treatment facilities, in addition to controlling movements of waste within their jurisdictions. According to the Transportation of Dangerous Goods Program of Canada, SPL is classified as a Hazardous Waste that is a Class 4.3 and it has a shipping name of "UN, 3170, ALUMINUM SMELTING BY_PRODUCTS (Spent Potlining), Class 4.3, Packing Group III".

On a federal level SPL is listed in schedule 4 (item 104) in the Export and Import of Hazardous Waste and Hazardous Recyclable Material Regulations. This regulation and two others (Interprovincial Movement of Hazardous Waste Regulations (SOR/2002-301) and PCB Waste Export Regulations, 1996 (SOR/97-109)) will be incorporated (expected publication in 2020) into the proposed Cross-border Movement of Hazardous Waste and Hazardous Recyclable Material Regulations.

China: In China the government maintains the National Hazardous Waste Inventory. In the inventory SPL is classified under no. 321-023-48 as a hazardous waste with toxicity (T). The definition is "Waste residue from repair and disposal of electrolytic cell in aluminium electrolysis process". The standard for pollution control on hazardous waste storage (GB18597-2001) specifies the general requirements for hazardous waste storage, including the requirements for the site selection, site design, operation, safety, monitoring and site closure. It covers not only the packaging and storage facilities for hazardous waste, but also reuse of hazardous waste, or the process of detoxication, and treatment prior to final disposal. The standard for pollution control on the security landfill site for

hazardous wastes (GB18598-2001), specifies landfill criteria, including site selection, site design, construction, operation, closure, and environmental monitoring when landfilling hazardous wastes.

European Union: A Union list of hazardous waste (“List of Waste”) was established by EU Council Decision 94/904/EC. It was later replaced by Commission Decision 2000/532/EC. In 2008 this was updated with certain attributes in Directive 2008/98/EC. SPL is listed in the current EU Waste Catalogue under No. 16 11 01 “Carbon-based linings and refractories from metallurgical processes containing dangerous substances” and No. 16 11 03 “Other linings and refractories from metallurgical processes containing dangerous substances”.

India: In India SPL is on the list of process generating hazardous wastes. It is identified as waste no. 11.2 “Cathode residues including pot lining wastes”. It is a Class A material that can leach hazardous constituents and for each constituent there is a limit of the concentration in the leachate. For fluoride (A8) this is 150 mg/litre and for cyanide (A15) the limit is 5 mg/litre, respectively.

United States of America: In 1998, the US EPA classified SPL as a hazardous waste under its Land Disposal Restrictions (LDR) program in section 40 CFR Part 268. The decision meant that landfilling of untreated SPL was no longer permitted, and that SPL had to be treated to set standards for fluoride and cyanide prior to disposal. In Title 40 of the Code of Federal Regulations SPL is marked as waste K088. It is listed in Subpart D Section 261.32 as a specific hazardous waste.

Basel Convention: For any transboundary movement of hazardous wastes, including spent potlining, signatory countries to the Basel Convention apply the convention to transport of SPL to other states or countries. Under the convention SPL is categorized as waste material A4050 “Waste that contains inorganic cyanide”.

United Nations: The number assigned by the United Nations Committee of Experts on the Transport of Dangerous Goods is UN3170 and the sub-classification is class 4.3, which is used to mark the containers for transport by truck. This is universally adopted to all countries that have permitted SPL to be transported.

6.4 Regional and International Transport including Basel Convention

The classification of SPL as a hazardous waste in many jurisdictions means that its transportation outside of the smelter site is typically highly regulated. When transportation of SPL is being planned, the major risks associated with the movement of hazardous material should be considered as part of a risk assessment. Spillage risks are high during loading, transportation and unloading processes and off-site transportation issues will require consideration as part of the transportation plan:

- Appropriate packaging including a leakproof container
- Labelling of container and transport vehicle
- Handling equipment
- Transportation vehicle specifications
- Transporter technical competence
- Licencing and permits
- Emergency precautions and procedures

The classification of SPL as a hazardous waste also makes it subject specific to The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal. The Basel Convention was adopted in 1989 by the Conference of Plenipotentiaries in Basel, Switzerland, after the discovery that toxic wastes were being dumped in developing countries. The main objective of the Basel Convention is to protect human health and the environment against the adverse effects of hazardous wastes. The Convention was ratified in 1992 when 20 countries acceded to the Convention. As of 2018, 186 countries and the European Union are parties of the convention.

SPL is subject to the rules of the Basel Convention (Amber Control Procedure) based on the A4050 Basel entry – *Waste that contains inorganic cyanide*. In cases where the cyanides have been destroyed then SPL is assigned to AB120 due to the inorganic fluorine compound content.

The transport of SPL across borders is highly regulated in most jurisdictions. Each shipment of SPL should adhere to all local, national and international laws and as part of any SPL management plan, procedures should be in place to ensure the following issues are considered:

- Licensing & authorised status for all parties (importer/exporter/authorised trader)
- Valid written contracts & financial guarantees for each SPL shipment
- Notification procedures including notification of competent authorities
- Tracking procedures & movement documents
- Acknowledgement of receipt procedures
- Objections by competent authorities including classification/interpretation differences between parties

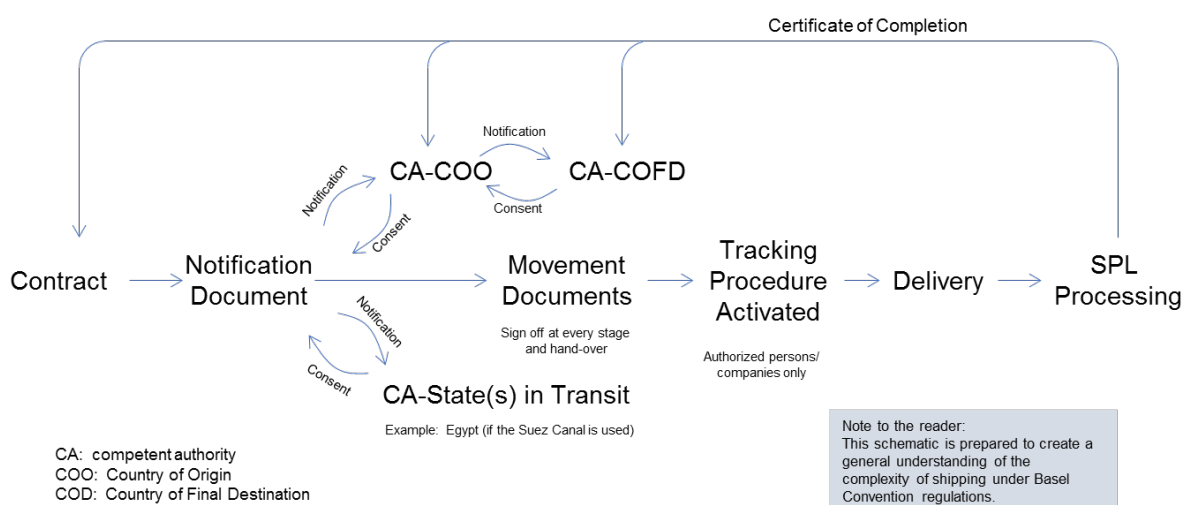


Figure 14: Schematic representation of the complexity of shipping SPL under Basel Convention regulation. (Hatch, 2017)

Storage, Handling and Transport

Sustainable SPL management should include:

- A risk assessment to identify potential environmental, social, economic, health and safety risks associated with storage, handling and transport and systems in place to mitigate these risks.
- A documented protocol for handling and transportation of SPL available for all workers.
- Regular training for workers on specific procedures related to storage, handling and transport of SPL.
- Adherence to all applicable local, national and international laws including the Basel Convention when handling and transporting SPL and any hazardous derivatives.

7. Treatment

7.1 Different options for treatment of SPL

There are treatment options for processing SPL. This section focuses on some of the most widely used options that are currently commercially available to treat SPL. Key features of the main treatment options are summarised in Table 5 below. A number of other treatment options that are currently under development, have limited commercial availability or are the subject of further research, e.g. in pilot test phase are outlined in Section 1.

	Uses first cut or second cut or both	What happens to the fluorides?	What happens to the cyanides?	Any residues/waste after treatment?
Gum Springs	Both	Insoluble Calcium Fluoride	Destroyed	Yes
Low-caustic leaching and liming	Both	Insoluble Calcium Fluoride	Destroyed	Yes
Befesa	Both	Insoluble Calcium Fluoride	Destroyed	No
Regain	Both	Remains as useful in end- use	Destroyed	No
Weston Aluminium	Both	Remains as useful in end- use	Destroyed	No

Table 5: Summary of SPL treatment options and key features

7.2 Pre-treatment - Crushing and Grinding

Before SPL is treated, recycled or disposed, it is often sorted or screened and then crushed to a finer gauge. This pre-treatment can occur on site or at the SPL treatment facility or end-user site.

Wherever the location, there are a number of risks associated with the use of screening equipment, conveyors and mechanical crushers (jaw crushers, impact mills and hammer mills etc.). These are aligned with those for other mining and mineral crushing and grinding operations and include:

- Electrical hazards (including high voltage electrical supplies);
- Moving equipment & collisions or injuries, e.g. transportation equipment, bulk loading equipment, overhead cranes, and operating equipment;
- Noise and vibration;
- Other health and hygiene hazards – chemical exposure, toxic fumes and dusts.

In order to mitigate these risks and those specific to the crushing and grinding of SPL, it is important to consider the following:

- Environment, health and safety training for all employees and contractors;
- Dust control measures e.g. dust covers, enclosed processing areas, dust filtering systems;
- Separation of vehicles and machinery from workers where possible e.g. safety gates or designated walkways.;
- Noise and vibration mitigation e.g. enclosing noisy machinery, location of noisy machinery away from sensitive areas, screening barriers etc;
- The presence of metal fragments in SPL (steel or aluminium) which could get lodged in crushing equipment or be subjected to high speeds resulting in safety issues;
- The presence of metallic sodium and the potential for new flammable gas evolution should be mitigated.

**CASE STUDY: *PRE-TREATMENT AND CRUSHER FACILITY FOR SPL IN CEMENT -
EMIRATES GLOBAL ALUMINIUM, UNITED ARAB EMIRATES***

In 2016, EGA decided to build a SPL pre-treatment and crushing platform adjacent to its SPL storage building at its Al Taweelah site, Abu Dhabi. The facility was intended to improve the efficiency of EGA's SPL management. SPL generated by EGA's operations are typically in the size range of 300mm to 1200mm, but cement producers often require SPL to be below 40mm in size.

In 2019, the new treatment and crushing facility was commissioned. It is the largest structure of its kind in the Gulf and can process up to 60,000 tonnes of SPL per year. The plant has been designed with features to mitigate key health and safety risks, for example, it has a dust collection and baghouse filtration unit, designed to emit maximum of 5 mg/Nm³ particulates and maximum equipment noise levels set to 85dB (A).

The facility has been set up as part of EGAs ongoing commitment to re-using waste and the pre-treated SPL will be ready to use as feedstock by UAE cement companies. Prior to the investment in pre-treatment and crusher facilities, EGA worked with specialist third parties to process SPL. This onsite solution is expected to secure further partnerships with UAE cement companies for the longer term and reduce transportation distances and overall processing costs.

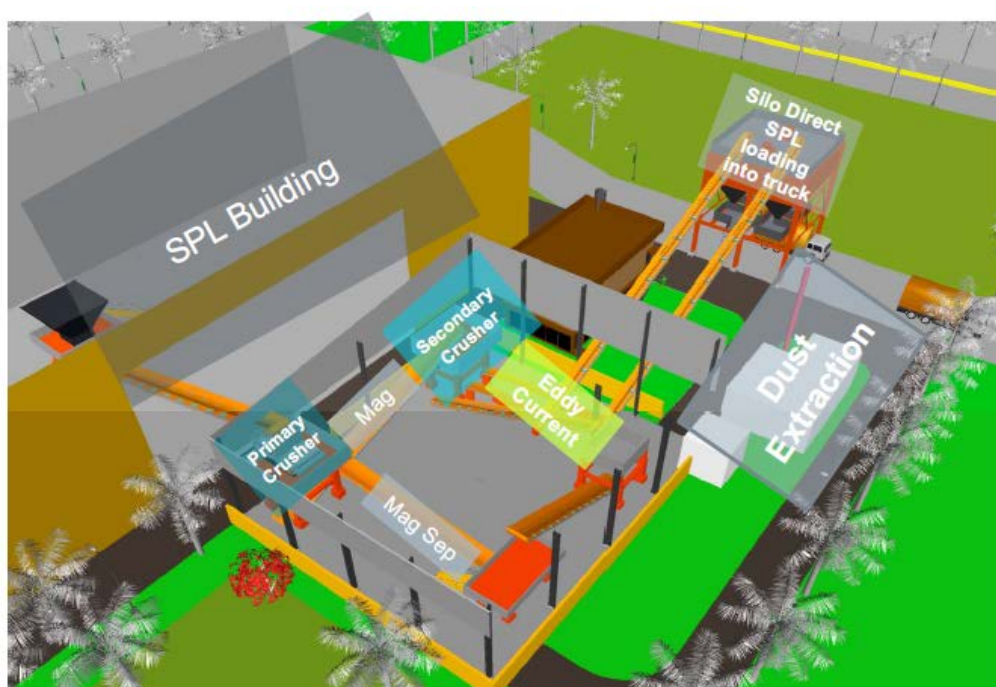


Figure 15: Schematic of pre-treatment facility location and features (EGA)

7.3 Gum Springs Waste Treatment Facility

In January 2020, Alcoa announced that it had agreed to sell the Gum Springs facility to Veolia ES Technical Solutions (VTS). The transaction is expected to close in the first quarter of 2020. Gum Springs is located in Arkansas, USA, and it is one of the largest dedicated SPL processing facilities in the world with a capacity of over 100,000 tonnes per year. The facility, which began ramping up in October 1993, includes a pre-treatment system and a thermal treatment system which operates two waste processing kilns. SPL is mixed with limestone and sand and treated in the kiln for 90 minutes at temperatures of between 500-800°C. The cyanides are thermally destroyed in the process while soluble fluorides form calcium fluoride on reaction with limestone.

Once the SPL has been treated, it is still classified as a hazardous waste due to its caustic nature and it is landfilled on-site in a hazardous waste landfill equipped to collect and treat run-off water from the disposal area. For each tonne of SPL processed, there is an estimated 2.5 tonnes of waste generated. Alcoa is engaged in ongoing work to identify opportunities to utilise the processed SPL in other local industries.

7.4 Low-Caustic Leaching and Liming (LCLL) process, Rio Tinto

In 2008, Rio Tinto inaugurated a new plant in Jonquière (Québec) for the treatment of spent pot lining, based on the “Low-Caustic Leaching and Liming” process (LCLL) developed at the Rio Tinto Arvida Research and Development Centre in the early 1990s. This plant treats 80,000 tonnes of stored and new SPL annually.

The treatment plant is divided in two parts: one dry and one wet sector. The dry sector includes unloading, handling and storage of SPL containers, SPL grinding by an air swept autogenous mill with air classification and screening, and ground SPL storage. The wet sector consists first of a low caustic leaching of fluoride and cyanide. After filtration, calcium additives may be added to the carbonaceous by-product (CBP) to reduce if needed its content in leachable fluorides. Cyanides contained in the leachate are destroyed under high pressure and high temperature hydrolysis. Soluble sodium fluoride in the liquor is then concentrated and crystallized in a multistage evaporation unit. Finally, solid sodium fluoride is reacted with lime to generate inert calcium fluoride and caustic. The caustic solution (causticized liquor) is recycled in the process at leaching, the excess returning to the evaporator to generate a concentrated caustic solution. As a result, the LCLL process generates three by-products:

- A carbonaceous by-product
- A fluoride by-product (in the form of either NaF or CaF_2)
- A concentrated caustic liquor (can be used in other industrial processes e.g. alumina refining)

Since 2008, over 700,000 tonnes of SPL has been treated at the SPL treatment plant in Jonquière. All the CBP production has been valorized as a low-density (1250 kg/m^3) civil engineering construction material for the construction of dams at the Rio Tinto bauxite residue disposal site. The addition of sand and lime to CBP increases the geotechnical properties of this by-product. Both cuts of SPL can be processed individually or mixed using this process. Actual R&D work continues to maximise the valorisation routes of the LCLL by-products. Several thousand tonnes of each cut has been successfully treated at the plant. This has resulted in separate carbon and brick concentrates with a very low fluoride content compared to untreated SPL. Several projects and pilot tests with the cement industry are ongoing for the valorization of these by-products.

The potential recycling of calcium fluoride from the process is also a focus of current R&D efforts. In the Jonquière facilities, the most promising option is to use dry CaF_2 as an alternative raw material (fluorspar) in the nearby aluminium fluoride plant, thus resulting in significant savings. Other valorization options exist, such as fluxing agent in the steel and cement industries, but this option would also require sintering or drying. Currently, a project is underway to install a dryer system at the output of the plant to obtain a CaF_2 humidity content as low as 10%, which will promote some valorization options. This device should be installed by the end of 2021.

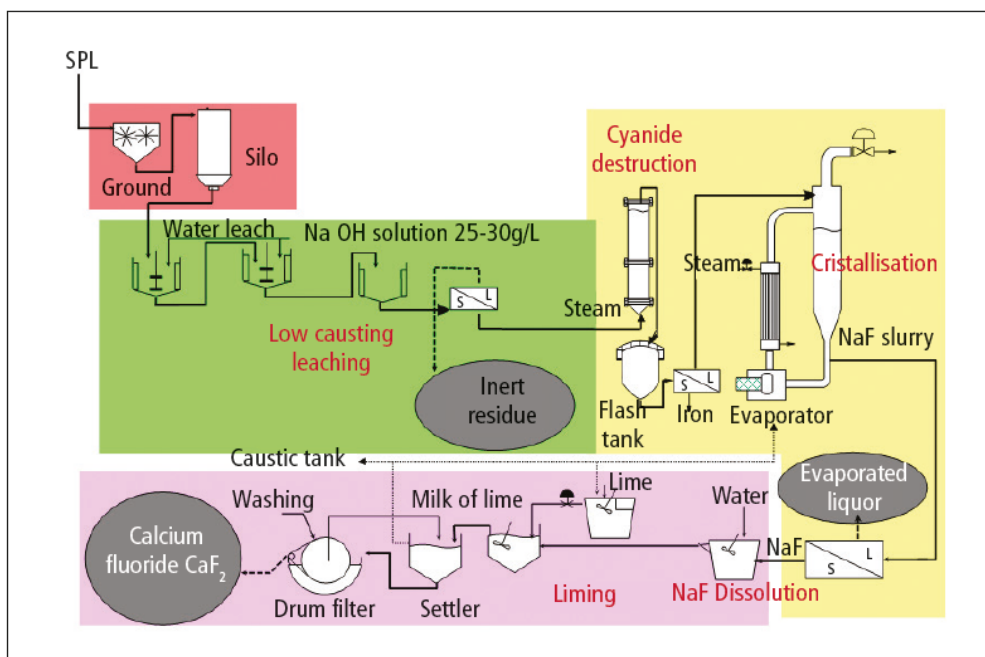


Figure 16: Flow diagram of the LCLL process (Rio Tinto, 2017)

7.5 Befesa

Befesa is based in Spain and operates throughout Europe specialising in the recycling of steel dust, salt slags and aluminium residues. It is a major recycler of salt slags and SPL with a treatment capacity of 630,000 tonnes across five plants. The plants are located in Germany (3), UK (1) and Spain (1).

Through its processing of large volumes of spent salt slags from the secondary aluminium industry, it has expanded its processes to treat SPL as part of a mixed feedstock with salt slags. The SPL and salt slags are co-processed – this involves milling and treatment with chemicals to destroy all cyanides, nitrides and carbides. The addition of crushed SPL reduces the energy requirement for the process. Following these reactions, solids are filtered – a soluble component NaCl/NaF is added to the salt for dross treatment and an insoluble component is collected which is suitable for the use in other industries such as cement, ceramics, bricks and mineral wool. The final output is no longer hazardous and there are no other wastes formed as part of the treatment process.

Befesa recycles SPL for smelters across the globe, with recent shipments from across Europe, Australia and New Zealand. In 2017, it was estimated that over 500,000 tonnes of hazardous wastes from the primary and secondary aluminium industry was treated using the Befesa process. Befesa is authorised to issue certificates of completion under Basel Convention regulations.

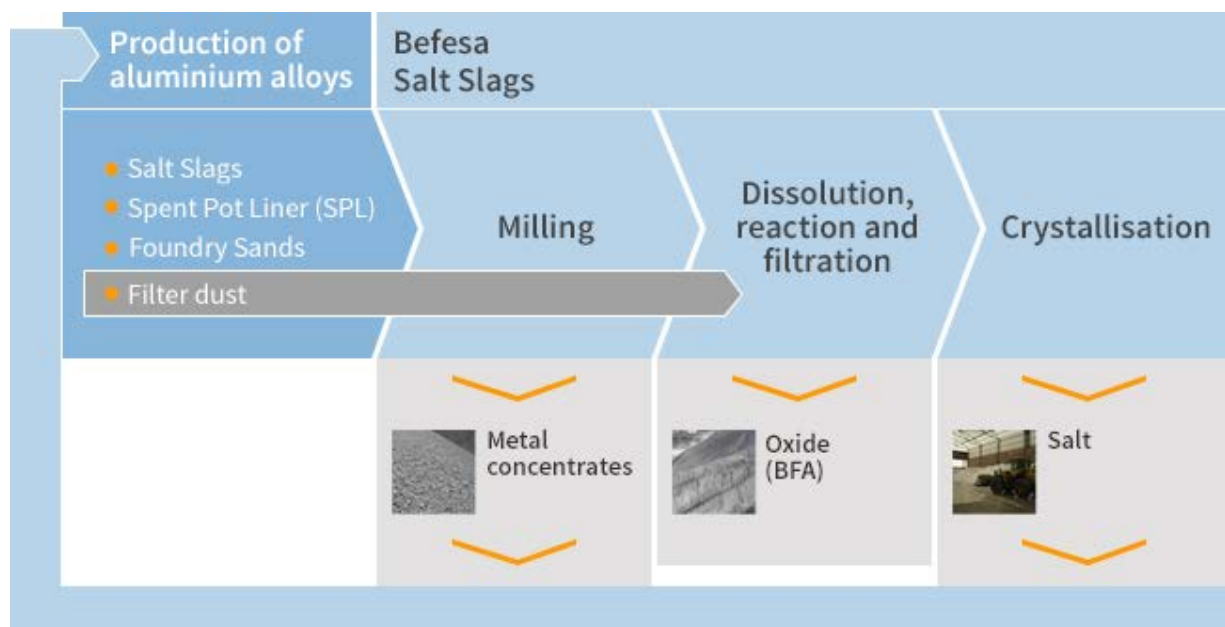


Figure 17: The Befesa Salt Slag and SPL recycling process

7.6 Regain

The Regain SPL Solution provides the process technology to detoxify and refine SPL to simplify its use in other processes such as cement production. The Regain solution relies on an industrial ecosystem approach which includes primary aluminium smelters, SPL processing plants at the smelter site, marketing and logistics specialists, and end users e.g. cement manufacturers. Regain typically builds SPL processing plants at the smelter and the SPL is sorted, physically mixed, quenched to drive off toxic gases and then thermally treated to destroy the cyanides. The Regain process does not destroy the fluorides in the SPL, which can be beneficial in some end-use markets.

Regain plants process mixed SPL but have the ability to treat first and second cut SPL separately. The treated product is generally no longer classified as hazardous. There is also no residual material generated as part of the process. Over 370,000 tonnes of SPL have been processed using the Regain solution and over the past two decades, with each plant there have been improvements in cost and technological efficiency.

A Regain SPL processing plant can be constructed anywhere in the world. In December 2019, Alba announced it was partnering with Regain as a technology partner on a new SPL treatment plant in Bahrain. The plant is expected to be operation in 2021 and will have a capacity of approximately 35,000 tonnes.

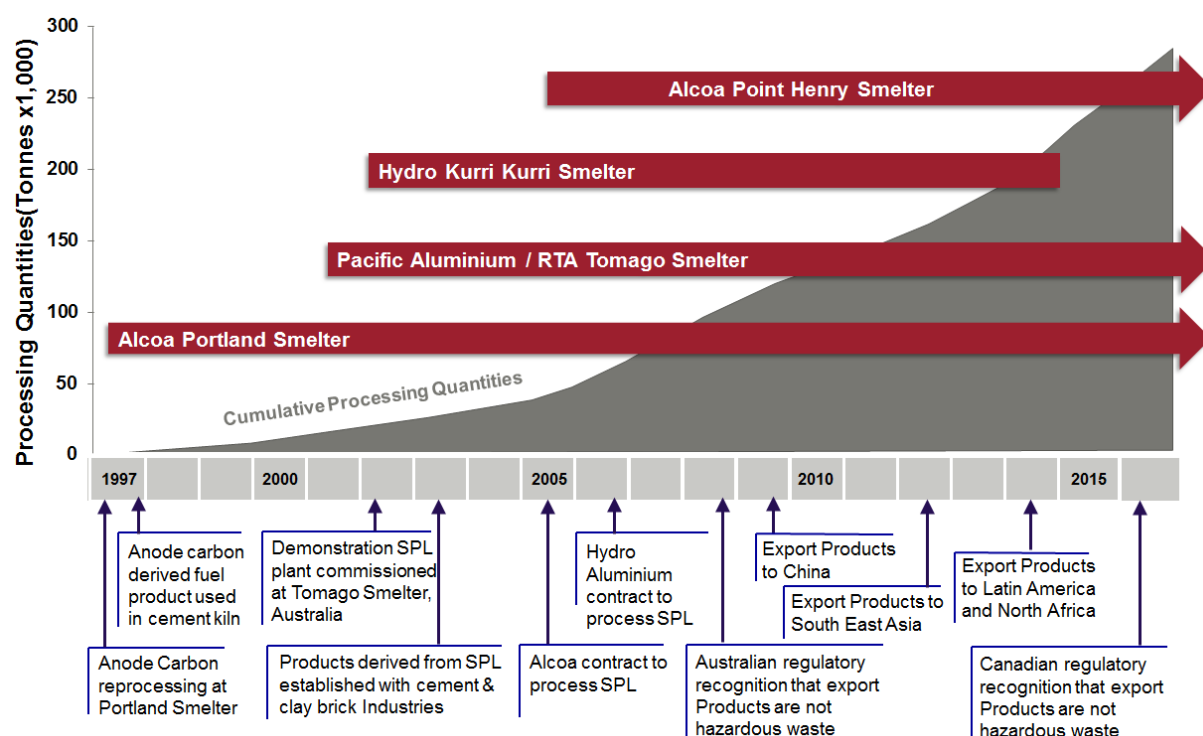


Figure 18: Regain SPL Solution Development and Key Milestones 1997 to 2016 (Regain, 2019)

7.7 Weston Aluminium

Weston Aluminium (Kurri Kurri, Australia) started as a dross recycling operation. It uses rotary furnaces to recover aluminium in a salt-free process originally developed in Japan. Driven by excess production capacity, Weston Aluminium started looking at processing SPL several years ago. It first tested second cut SPL with good success. Currently, Weston Aluminium processes both first and second cut SPL from Hydro Aluminium's Kurri Kurri Smelter and from Portland Aluminium. Weston Aluminium is licensed to process up to a total of 40,000 tonnes per annum of dross and SPL.

The SPL is processed in batches - it is milled and mixed with additives such as glass cullet and iron oxides. The material is fed to the rotary furnace where it is heated at moderate temperatures (<900 °C) to destroy cyanides but to avoid releasing sodium and fluoride. The off gases are cleaned using a lime scrubber followed by a baghouse filter. After a batch is completed the material is cooled in a rotary cooler. The product is crushed and mixed with further additives if required. The process is generally designed to be in line with the end-user requirements. The material, '*Neverflux*', is shipped mainly to brick manufacturers in Asia.

Treatment

Sustainable SPL management should include:

- Consideration of commercial solutions and their suitability based on site-specific issues e.g. SPL characteristics, site location, regulatory regime, local industry opportunities.

CASE STUDY: *IMPLEMENTATION OF REGAIN TECHNOLOGY - TOMAGO SMELTER, TOMAGO, AUSTRALIA*

Tomago Aluminium is located in the Hunter Region in New South Wales, Australia. In 2000, the company was looking for ways to address its stockpiling and indefinite storage of SPL. With limited capacity in the storage shed (34,000 tonnes) and increasingly stringent environmental legislation, in 2001, Tomago began working with Regain to find another approach. Regain's technology and industrial ecology approach to detoxify SPL into a product for use in other industrial processes was the chosen option and a demonstration SPL plant was commissioned onsite. One of the key benefits of the technology was that it produced no further waste residue and both first and second cut SPL could be processed.

Regain identified the cement industry as an ideal off-take partner for the treated Tomago SPL. Through the collaboration, Tomago recognised the benefits of the Regain solution for their SPL management thereby reducing financial liabilities while adopting circular economy principles in its waste management approach. The onsite plant also removed the need to ship SPL to processors in Europe while delivering a preferred outcome based on the waste management hierarchy.



Figure 19: Tomago aluminium smelter (Tomago Aluminium 2019)

Since the initiation of the demonstration plant in 2001, Tomago has processed 135,000 tonnes of SPL and other similar waste material via the Regain process. The collaborative approach has delivered a solution that improved SPL management both environmentally and financially. Continued improvements over the years have also impacted process efficiencies and cost with Regain's technology becoming more established and used by others in the industry, increasing practical experience, technological expertise and benefitting from economies of scale.

8. Disposal and Landfill

Landfills are excavated or engineered sites where non-liquid hazardous waste is deposited and covered for final disposal. Disposal of SPL in landfill is generally considered the least preferable management practice based on the waste management hierarchy. However, for some sites and situations, recycling, reuse or recovery is not a feasible option and landfill is a necessary part of the waste management plan. In such cases, it is important for disposal and landfiling to be conducted in a responsible manner. It is good practice to treat SPL prior to final disposal to reduce or eliminate potentially hazardous compounds. In some cases, the treatment of the SPL can also take place at the hazardous waste site. In Norway, the waste management company, NOAH, for example, mixes gypsum and lime with SPL to stabilise it and fixate some of the fluorides prior to its use as backfilling material as part of old mine rehabilitation.



Figure 20: Hazardous waste depot NOAH at Langøya, Vestfold, Norway (Source: NOAH website)

Every country has landfill facilities for municipal waste and for hazardous wastes and in each jurisdiction the rules and regulation may demand specific features for the design and management of the landfill. It is important to consult with relevant stakeholders including site owners, regulatory authorities and local communities when disposing of SPL. In all cases, disposal of SPL should be carried out in compliance with all regulatory requirements and all necessary permitting should be obtained.

A comprehensive risk assessment should be conducted and systems to mitigate and monitor key risks should be put in place and regularly reviewed to assess suitability of this management practice. During the planning stages, specific consideration should be given to the design and operation of

the landfill site including assessment of specific SPL chemical and physical properties, suitability of the proposed site, hazardous waste cell design, cell liner material suitability and monitoring systems for environmental contaminants. Generally, it is good practice to dispose of SPL in cells with engineered barrier-liner systems. Run-off water that has been in contact with the waste material (leachate) should be collected and treated to minimise contamination from the landfill site. It should be noted that the suitability of landfill and disposal systems will vary significantly across different jurisdictions and should be evaluated on a site-specific basis.

In some instances, seawater is used in the treatment of SPL before final disposal. This involves filling a coastal basin with SPL and during high tide, allowing the SPL to be exposed to seawater. The seawater acts to neutralize the SPL prior to deposition in landfill. Adding layers of limestone in the basin can promote the neutralization process. Seawater basin neutralisation was historically practiced in Norway and Iceland but is currently now only used in Iceland and is practiced in line with operational licencing requirements.

Disposal and Landfill

Sustainable SPL management should include:

- A risk assessment to identify all potential environmental, social, economic, health and safety risks associated with disposal or landfilling and systems in place to monitor and mitigate these risks;
- Consultation with relevant stakeholders including site owners, regulatory authorities and local communities to minimise impacts on the environment and human health;
- Compliance with all relevant laws and permitting.

CASE STUDY: HAZARDOUS WASTE LANDFILL CONSIDERATIONS – UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (USEPA)

In the US, landfills are located, designed, operated and monitored to ensure compliance with federal regulations. They are also designed to protect the environment from contaminants, which may be present in the waste stream. Landfills cannot be built in environmentally sensitive areas, and they are placed with on-site environmental monitoring systems. These monitoring systems check for any sign of groundwater contamination and for landfill gas, as well as providing additional safeguards. Today's landfills must meet stringent design, operation and closure requirements established under the Resource Conservation and Recovery Act (RCRA).

Hazardous wastes are regulated under Subtitle C in the RCRA Act. This Subtitle establishes a federal program to manage hazardous wastes from cradle to grave. The objective of the Subtitle C program is to ensure that hazardous waste is handled in a manner that protects human health and the environment. To this end, there are Subtitle C regulations for the generation, transportation and treatment, storage or disposal of hazardous wastes including SPL.

Landfills are selected and designed to minimize the chance of release of hazardous waste into the environment. In the US, design standards for hazardous waste landfills require:

- Double liner
- Double leachate collection and removal systems
- Leak detection system
- Run on, runoff, and wind dispersal controls
- Construction quality assurance program

Operators must also comply with inspection, monitoring, and release response requirements. Since landfills are permanent disposal sites and are closed with waste in place, they are subject to closure and post-closure care requirements including:

- Installing and maintaining a final cover
- Continuing operation of the leachate collection and removal system until leachate is no longer detected
- Maintaining and monitoring the leak detection system
- Maintaining ground water monitoring
- Preventing storm water run on and runoff
- Installing and protecting surveyed benchmarks

The following illustration shows the design of a hazardous material landfill in accordance with the USEPA RCRA regulations. It is provided as an example of the requirements in one jurisdiction, regulatory requirements will differ across jurisdictions.

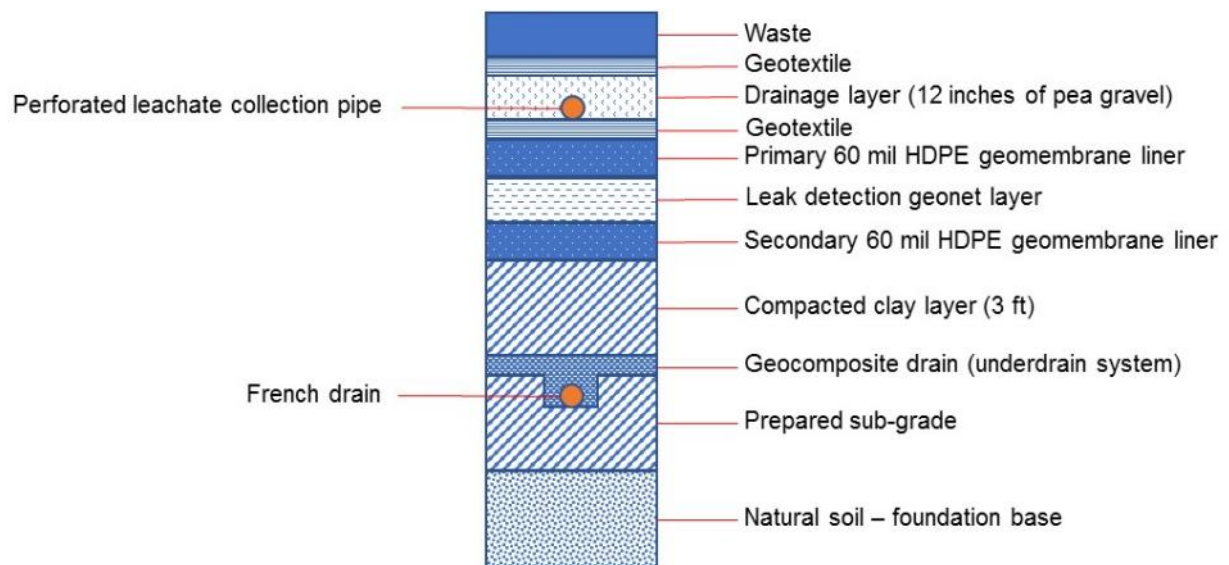


Figure 21: Engineered barrier-liner system for hazardous waste according to RCRA regulations (for illustration purposes only)

The waste needs to be capped to avoid or minimize water to get into contact with the waste materials. The next illustration shows how the cap is formulated:

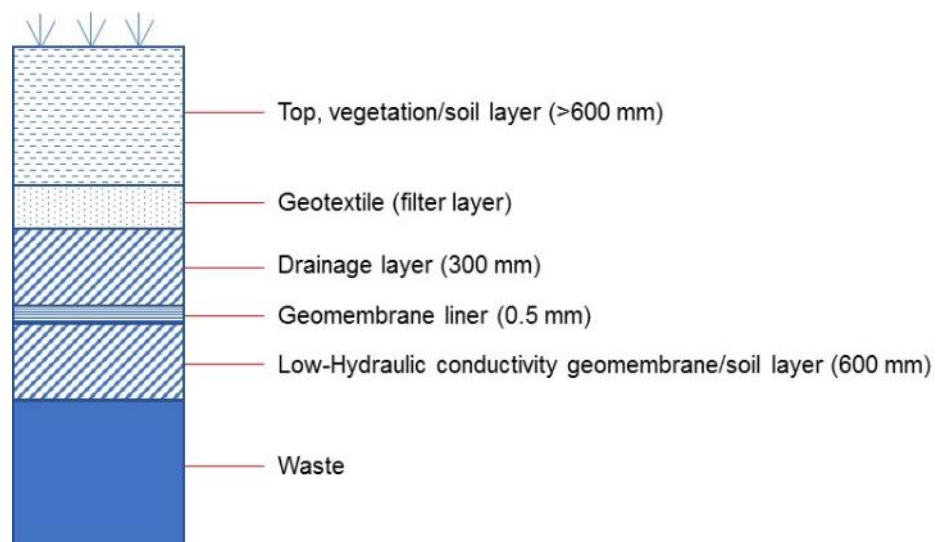


Figure 22: Engineered cap barrier-liner system for hazardous waste according to RCRA regulations (for illustration purposes only)

9. Utilisation of SPL

9.1 Utilisation of SPL in other industries

SPL can be used as a material in other industrial processes. Many companies are actively pursuing opportunities for utilisation of SPL in other industries as part of wider circular economy and resource efficiency efforts. There are a number of different industries currently using SPL as an energy source or feedstock raw material in their production processes. The most widely used utilisation options are outlined in this chapter. Key features of each option are summarised in Table 6 below.

Industrial Use	First cut/ Second cut/ Both	Pre-treatment	Use/Impact	Fluorides	Cyanides
Cement	Both	Crushing	Energy & Raw Material	Fluxing effect	Destroyed
Steel	First Cut	Crushing	Energy	Fluxing effect	Destroyed
Mineral Wool	First Cut	Crushing and screening	Energy	Captured in mineral wool and in gas cleaning	Destroyed

Table 6: Summary of SPL utilisation options and key features

9.2 Cement

SPL can be utilised in the cement production process and its composition is complementary to the process. It can be added to the clinker production process (clinker is the precursor to cement) as an alternative fuel or raw material bringing economic and environmental benefits. Traditionally, coal is used as fuel in the cement kiln and calciner, but the carbon contained in the SPL can be used as a fuel for the process. In addition, the fluorides act as a fluxing agent, enhance mineralisation and lower the required kiln temperature. The temperature in the kiln (~1450°C) is very high and destroys the hazardous cyanide compounds in the SPL, eliminating the need for detoxifying pre-treatment processes. Both the first cut and second cut can be used in cement production.

	SPL Content	Role/Impact on cement production
First Cut Carbon Layer	Carbon	Lowers fuel requirement – combustion releases heat
	Silicon	Replaces standard raw materials in clinker
	Aluminium	
Second Cut Refractory Layer	Fe ₂ O ₃ , CaO, MgO	
	Alkali	Balances SO ₃ off-gas in other raw materials
	Fluoride	Flux effect – incorporated into clinker
	Sulfur	Relatively low S content
	Cyanide	Potential scrubber for NO _x

Table 7: SPL composition and its role in the cement manufacturing process
(adapted from EGA, 2019)

There are also challenges with the addition of SPL to the clinker production process – notably, the alkali nature of SPL and the large amount of sodium (Na) that it contains. In concrete production, sodium levels are restricted as it can have detrimental effects to the quality of the product. This restricts the utilisation of SPL in cement plants that operate with high alkalinity in their raw materials. It is estimated that plants with low alkalinity can add up to 0.75 wt.% to the raw meal. Normal levels are more in range of 0.25 to 0.5 wt%.

Early trials of using SPL in cement were conducted in the USA back in 1986. Currently, the utilisation of SPL in cement production has been one of the most widely explored, large-scale options for SPL utilisation by aluminium smelters globally. The presence of a suitable local cement manufacturer and regional transportation and logistics play a key role in determining the viability of the cement industry as an SPL consumer. Large-scale co-processing of SPL and cement has been utilised in a number of countries including: Brazil, South Africa, USA, Australia, Oman, UAE, Qatar and India. Cement production continues to be one of the largest volume SPL consuming processes.

CASE STUDY: *EMIRATES GLOBAL ALUMINIUM, UNITED ARAB EMIRATES*

Since 2010, EGA has worked with a number of cement companies based in the UAE exploring the potential for the use of SPL in the cement manufacturing process. It has successfully provided SPL to a number of different UAE cement companies for use in their production and in 2018, supplied over 41,000 tonnes of its SPL stockpile to UAE cement producers. As part of EGA's strategy to develop relationships with local cement producers and increase SPL utilisation, in 2019, they embarked on a comprehensive study to quantify the environmental benefits of SPL addition to the cement manufacturing process.

The study, intended to support dialogue between aluminium smelters and cement manufacturers, investigated the environmental benefits of using SPL as feedstock into a local cement plant's production process. Star Cement is located in Ras Al Khaimah – a short distance from EGA's operations. The study focused on three key areas of environmental concern:

- NO_x and SO_x emissions;
- Energy savings and CO₂ reductions; and
- Raw material repurposing and toxic substance destruction.

It should be noted that although the composition of EGA's SPL for this study was not a "typical" composition as outlined on page 9, the type of analysis conducted, relationship building with cement producers and objective to demonstrate the potential benefits of SPL use in cement, is widely applicable.

Star Cement, which currently follows the BS EN cement standards for its products, set a limit of 0.75% SPL (by weight) in raw meal based on market demands. The study focused on using 0.6% SPL in the feedstock, and concluded that as a result of this addition, fuel consumption and emissions were reduced notably:

- Coal consumption was estimated to reduce by 3.5%;
- Reductions in CO₂ emissions and NO_x emissions were 0.74% and 3.75%;
- Toxic materials such as cyanide and fluorides were reduced to below detection limits.

The findings of this study supported EGA's strategy to increase utilisation of SPL in cement production and concluded that further research into the use of other aluminium smelting wastes in cement production should be carried out. There are two notable recommendations from the study:

1. Further cross-industry collaboration is needed to promote the benefits of using SPL on the environmental performance of cement facilities; and
2. Further research is needed into the impacts of SPL addition on the microstructure cement products.

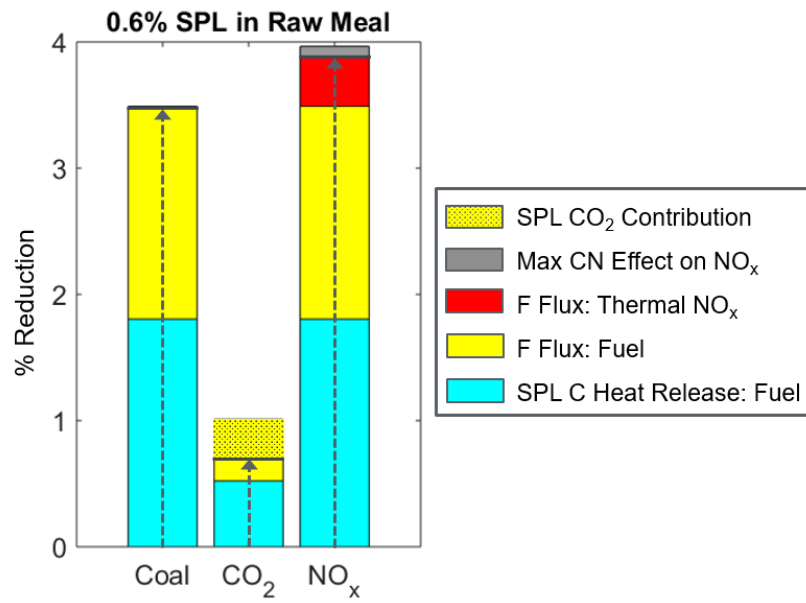


Figure 23: A summary of the effect of 0.6% SPL on coal consumption, CO₂ and NOX emissions from cement production (EGA, 2019)

9.3 Steelmaking

Steel production via basic oxygen furnace (BOF) and electric arc furnace (EAF) uses a variety of carbon-rich materials. Typically, metallurgical coke or pulverised carbon injection is used in the process, but steelmakers have been open to incorporating alternative carbonaceous materials where these raw materials are in short supply. The first cut of SPL, owing to its high carbon content, can be used as a secondary fuel source or as a reducing agent in the furnace. SPL also has a low sulphur content which can be beneficial for steelmakers as excess sulphur can impact the brittleness and weldability of the steel.



Figure 24: Hot metal in basic oxygen furnace (BOF) during steel production process (worldsteel, 2019)

The addition of SPL can also bring other benefits: improved thermal insulation which enables better slag formation and increased the fluidity of the slag. SPL can also reduce the melting point in the furnace due to the fluxing characteristics of the fluorides. The presence of fluorides has also been found to increase the efficiency of lime in the desulphurisation process.

The presence of a suitable local steel manufacturer plays a key role in determining the viability of the steel industry as an SPL consumer. SPL utilisation in the steel production process has been adopted in: Brazil, Russia, Oman and Qatar.

CASE STUDY: *SOHAR ALUMINIUM AND JINDAL STEEL, ELECTRIC ARC FURNACE, OMAN*

As part of Sohar Aluminium's sustainable waste management strategy, it has partnered with a neighbouring steel plant, Jindal Steel, to explore opportunities for use of SPL as a carbonaceous raw material in the electric arc furnace (EAF). This followed the successful utilisation of over 5000 tonnes of waste carbonaceous material in Qatar Steel's EAF process. EAF's produce steel using a high current electric arc which melts scrap or reduces pellets of iron ore or pig iron. Coarse carbon is typically used in the process but there is potential for this to be replaced, at least in part, with first cut SPL. Jindal uses direct reduced iron and needs the carbon to correct the final carbon content of its steel. Jindal Steel is the largest integrated steel plant in Oman and the collaboration with Sohar Aluminium began in 2016 with a trial phase to test the potential for addition of first cut SPL from Sohar's operations in its steelmaking process.

Following a successful trial period, in 2017, Jindal Steel began taking first cut SPL from Sohar Aluminium. Before the SPL is fed to the EAF furnace it is crushed to a finer size (50 to 80 mm). This pre-treatment allows for ease of use once at the steelmaker, but it results in a residual fine fraction of the first cut. The collaboration between Sohar Aluminium and Jindal Steel has reduced the need for virgin raw materials and brought cost and environmental benefits for both Sohar Aluminium and Jindal Steel.

CASE STUDY: *UC RUSAL, RUSSIA AND WEST SIBERIAN METALLURGICAL PLANT RUSSIAN FEDERATION*

UC RUSAL's overall waste management strategy is aimed at:

- Increasing the share of recycling and reuse of waste; and
- Ensuring the safe storage and disposal of wastes.

Since 2011, UC RUSAL has engaged in research and activities with local research institutes to increase the market for the use of waste produced from its aluminium production processes. In 2014, SPL from RUSAL's smelters was sold to the West Siberian metallurgical plant, located in the Kemerovo Region, for use in its basic oxygen furnace. The SPL was used as a partial replacement of fluorspar which enabled the liquefaction of the slag in the furnace and facilitated the slag removal process.

Currently, RUSAL's Bratsk Aluminium Smelter supplies the West Siberian metallurgical plant with approximately 10-20% of the total SPL generated annually at the smelter. This ongoing relationship

has contributed to the continued increase in the overall share of recycled SPL across RUSAL's smelters over the past few years (Figure 25).

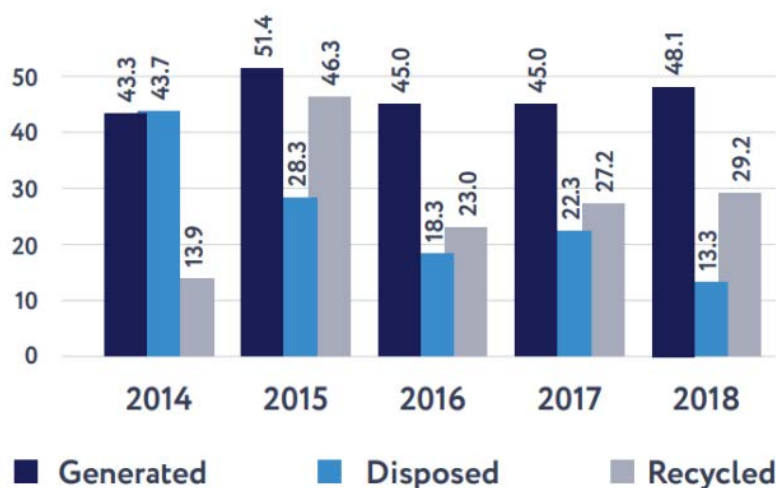


Figure 25: UC RUSAL SPL generation, disposal and recycling ('000 tonnes) 2014-2018 (UC RUSAL, 2018)

9.4 Mineral Wool

Mineral wool is an insulation material that is produced from molten rock and minerals. There are a number of different mineral wool producers globally. ROCKWOOL is a major mineral wool producer and has used SPL in its process since 1999. It has processed SPL from smelters in Norway, Canada, New Zealand and Germany. The mineral wool production process uses first cut SPL as a replacement for more expensive coke that is otherwise used in the furnaces. The furnace, a cupola, uses carbon materials as fuel in the process and this material can partly be replaced by first cut SPL. The cupola process uses a blast of hot air that rises through the bed of raw materials inside the furnace. Based on the difference in heating value, in the process 2 to 3 tonnes of first cut SPL replaces 1.3 to 2 tonnes of coke.

As a certain porosity inside the bed of the furnace must be maintained to have the air pass through, there are often specific requirements for the size of SPL feedstock. A nominal size of 100-250 mm for coke is targeted. Finer fractions (<50mm) cannot be used and are separated pre-processing and sent to third party users. Refractory materials are not compatible with the process so the first cut SPL must be as clean as possible.

During mineral wool processing, the cyanides are fully destroyed, and sodium and fluorides are mostly included in the stone wool melt. In order to process a hazardous waste material, ROCKWOOL

has a special permit which requires strict emission limits. As some fluorides are released in a gaseous phase, flue gas cleaning is required in process.

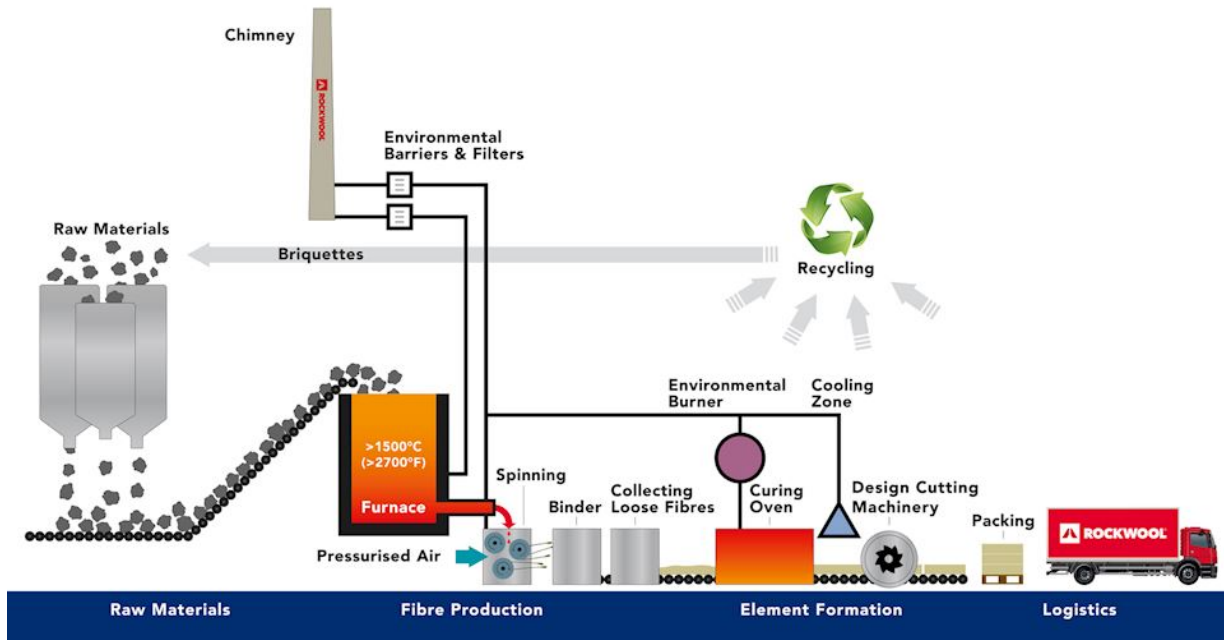


Figure 26: Schematic presenting the mineral wool process (Source: ROCKWOOL)

CASE STUDY: SPL IN MINERAL WOOL - UC RUSAL, RUSSIA

As part of a wider initiative to reuse SPL in other industries, UC Rusal has explored the use of SPL in mineral wool production. In this process, first cut SPL can be used as a burning additive which results in the partial replacement of foundry coke for melting the raw charge (rocks of gabbro-basalt group, dolomite, phenol formaldehyde resin, modifiers). Foundry coke and natural gas are typically used as the main energy components during combustion in cupola furnaces.

UC Rusal has worked closely with the mineral wool producer during an industrial testing phase to establish optimal process parameters. These parameters were set to provide a stable combustion process with the simultaneous addition of foundry coke, butts of spent baked anodes and first cut SPL. The testing phase results showed that the consumption of foundry coke was reduced to 30% when feeding butts and first cut SPL to cupola furnaces at the ratio of 1.2/1. UC Rusal and the mineral wool producer have continued to work closely together to optimize the use of first cut SPL in mineral wool production.

Utilisation of SPL

Sustainable SPL management should include:

- Consideration of the various utilisation options for SPL and their suitability based on site-specific issues e.g. SPL characteristics, site location, regulatory regime, local industry opportunities.
- Opportunities to utilise SPL in other industrial applications should be maximised where possible.

10. Research Initiatives & Other Developments

The treatment and utilisation options outlined in preceding chapters have taken many years to develop into implementable, commercial SPL solutions. At present, there is no clear option to eliminate SPL generation from the primary aluminium production process and so the focus of ongoing research remains on the innovation and development of novel processing options for SPL. In keeping with the circularity and resource efficiency ambitions associated with current sustainable waste management practices, many initiatives aim to find methods to turn SPL from a waste into a valuable raw material.

In this section we provide a summary of some current developments in SPL processing technologies. These are not yet commercially available but provide some indication of other potential solutions under development. Please note that many of these processes have yet to be proven on an industrial scale so there is no guarantee any will make it to a commercially available solution. We have also included some information about SPL management in China.

10.1 China

The hazardous waste classification of SPL in China restricts disposal options for smelters but as of yet no clear solution for large-scale management of SPL has been identified. Anecdotal information from China Non-Ferrous Metals Industry Association indicates that most research is focused on fluoride destruction as this would eliminate the hazardous waste classification. As of yet, much of this has yet to be explored beyond lab scale. New regulations around storage of hazardous waste material has also seen warehouse/storage building limits of 12 months.

Chalco has however had a detoxification process for its SPL in operation since 2005. It has two SPL treatment plants in operation and the process involves SPL being crushed, mixed with limestone and additives and fed to a kiln at temperatures of 900-1050°C. The final product is aluminium fluoride

(which can be recycled in the reduction cells) and a solid residue which can be utilised in cement production.

10.2 Vacuum treatment

Research on vacuum treatment of SPL is related to the first cut carbon lining only. The process involves applying a high temperature and vacuum to evaporate species such as fluoride and sodium from the carbon materials. The process leaves a reusable material while the fluoride can be condensed and recovered. A number of researchers are working on vacuum treatment options including research at the University of Toronto and Norwegian University of Science and Technology. At the Swerim Metals Research Institute in Sweden, a small-scale pilot project to test the concept has been developed through a collaboration between Alcoa Mosjøen Norway and Hydro Aluminium. The process has the potential to produce high purity carbon which could be reused in other applications.

10.3 The Oriens Process

The Oriens process evolved from the original Calsifrit process which recycles SPL to produce an additive that can strengthen cement and improve porosity. Several improvements have been made with the Oriens process, for example it is no longer conducted in a kiln but in rotary furnaces which gives it a distinct advantage of control over the quality of the product. The process produces no residues and the product is an alternative pozzolanic cement additive called *Adcim*. Oriens operated a semi-commercial plant in Bécancour, Canada, and has historically processed SPL from smelters in Quebec. The plant remains closed but the Oriens technology could become available for future processing of SPL.

10.4 Plasma vitrification

Tetronics and Harsco built a SPL processing plant using the Tetronics plasma technology. This technology involves a treatment of SPL and additives in a furnace where it is subjected to a plasma torch of temperatures approaching 10,000°C. The resulting material is an inert glass. One plant was built but processing costs are relatively high, and deployment is still at pilot scale level.

10.5 Engitec, Italy

Engitec was one of the original developers of the spent salt slag recycling (STE) process. It started with the development of a process to treat SPL and to recover the fluoride and sodium as products that potentially can be reused in the bath. The carbon and refractory materials are detoxified and then discarded from the process.

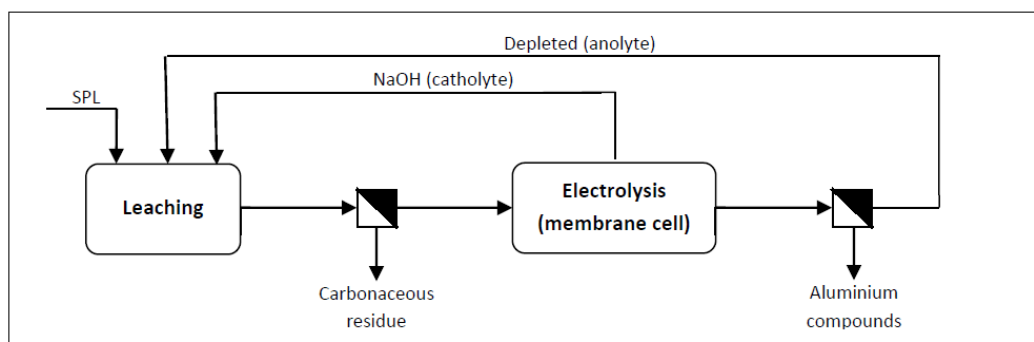


Figure 27: Process diagram of the new process for treating SPL under development by Engitec

The novelty of the Engitec process is the use of a special membrane to regenerate caustic soda that leaches the SPL (Figure 28). Engitec is collaborating with the University of Milan in the development - it has built a 15 kg/hr pilot and is seeking to test the process. It is worth noting that this SPL process could be integrated with the STE process.

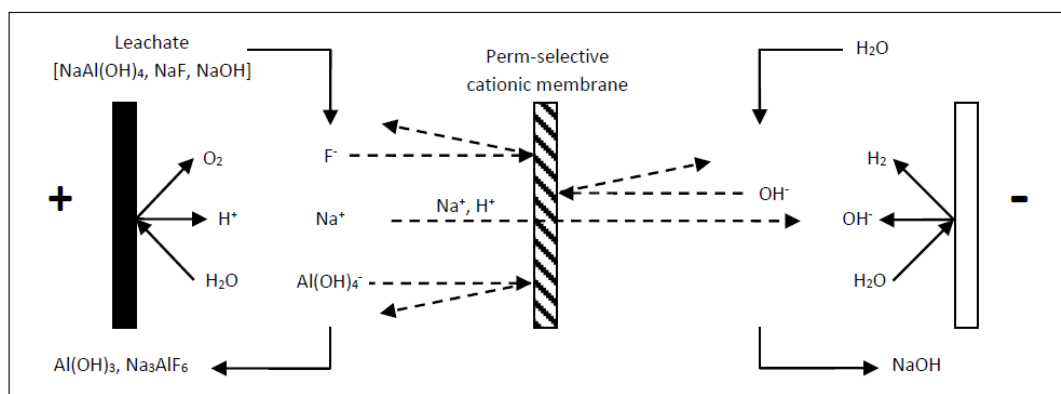


Figure 28: Principles of the working of the membrane in the Engitec SPL process

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13. Appendix A: Safety Data Sheet Examples



Rio Tinto MSDS SPL CA.pdf



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