Business Plan for the Harmless Disposal of Aluminum Ash and its Low-Carbon, High-Value-Added Circular Application Project Using an Intelligent Three-Ring Kiln

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1. Introduction

1.1 Project Overview

This project aims to apply the large-scale patented "Intelligent Three-Ring Kiln" equipment, developed by Shandong Hening Shun Kiln Industry Co., Ltd. with independent intellectual property rights, to provide an industrialized solution for the complete harmless treatment and full-component, high-value utilization of secondary aluminum ash—a hazardous solid waste that is currently extremely difficult to dispose of. Through an original four-step closed-loop process, secondary aluminum ash is "exhaustively utilized," efficiently co-producing 4N-grade high-purity alumina and industrial-grade cryolite, achieving an "alchemical" transformation from hazardous solid waste to high-end strategic new materials.

1.2 Market Pain Points and Opportunities

Secondary aluminum ash, especially high-fluorine aluminum ash, is a recognized environmental challenge and a severe problem for the electrolytic aluminum industry. Its components, such as aluminum nitride and fluorides, readily produce toxic gases upon contact with water, contaminating soil and water sources. Traditional landfill methods pose significant secondary environmental risks, while existing technologies like hydrolysis and conventional pyrometallurgy suffer from low denitrogenation rates, poor thermal efficiency, and difficulty in controlling pollutants. With increasingly strict national environmental regulations, the global consensus on low-carbon development, and the promotion of "waste-free cities," the market urgently needs an advanced technology that can achieve fundamental harmlessness while simultaneously recovering resources.

Notably, the European Union's Carbon Border Adjustment Mechanism (CBAM, or "carbon tariff"), set to be fully implemented in 2026, will place heavy cost pressures and trade barriers on aluminum companies using high-energy, high-carbon traditional

disposal methods. This project precisely targets this market gap, presenting a tremendous opportunity.

1.3 Solution and Core Advantages

Our proposed solution centers on the Intelligent Three-Ring Kiln, implementing a four-step closed-loop process for the full-component, high-value utilization of secondary aluminum ash: ① Enhanced pretreatment via ash briquetting → ② Gradient calcination and activation in the Intelligent Three-Ring Kiln → ③ Selective leaching and separation using a sulfuric acid system → ④ Co-production and purification of alumina/cryolite.

Disruptive Technology: The Intelligent Three-Ring Kiln can directly process lump materials. Through its three-temperature-zone gradient activation and "smoldering homogenization" technology, it achieves precise material activation and complete reactions, with the product's loss on ignition (LOI) stably below 1%.

Economic Efficiency:

Shorter Process: The process flow is 50% shorter than traditional methods.

Lower Energy Consumption, Fewer Carbon Emissions: A unique four-stage waste heat closed-loop circulation system achieves a comprehensive thermal efficiency of over 85%, reducing fuel costs by approximately 40%. This directly corresponds to significant carbon reduction, providing a solid foundation for companies to address carbon tariffs and participate in carbon trading.

Higher Value: The output of high-purity alumina and cryolite increases the value per ton of aluminum ash by 2.3 times.

Environmental Thoroughness: The recovery rates for key components like fluorine, sodium, and aluminum all exceed 98%. The recovery rate of waste gas (HF) is greater than 99%. Waste gas, wastewater, and solid waste generated during production are internally digested and recycled, ultimately achieving "zero waste discharge."

1.4 Financial Highlights and Investment Value

This project establishes a "four-fold revenue" economic model, comprising "product profits + hazardous waste disposal fees + policy subsidies + carbon trading income." Thanks to extremely low raw material costs and disruptive technological advantages, the project demonstrates extraordinary profitability. Financial assessments of similar projects show that the gross profit margin can reach as high as 70%, with a static investment payback period far shorter than conventional industrial projects, at approximately 10 months. This project features high technical barriers, substantial economic returns, and perfectly aligns with the national "new quality productive forces" strategy and global green, low-carbon circular economy trends. It is a key measure to help related enterprises effectively cope with the EU carbon tariff and enhance international competitiveness, possessing extremely high investment value and commercial potential.

2. Market Background and Industry Pain Points

2.1 The Severe Challenge of Aluminum Ash Disposal

Classified as hazardous waste, the disposal of secondary aluminum ash is a "pain point" for the electrolytic aluminum industry.

Chemical Toxicity and Environmental Hazards: Aluminum nitride (AlN) in the ash reacts with water or moisture to produce toxic ammonia gas (NH_3). Meanwhile, fluorides and chlorides have strong leaching toxicity, posing a serious and long-term threat to the atmosphere, water bodies, and soil.

Limitations of Traditional Disposal Methods:

Landfill: Common practices like off-site transportation and sealed landfills not only waste valuable land resources but also fail to eradicate pollution, always carrying the risk of leakage and other secondary environmental hazards.

Wet Processes: The denitrogenation rate of hydrolysis processes is only 30-40%, making it inefficient and difficult for tail gas to meet standards.

Traditional Pyrometallurgy: Using conventional equipment like rotary kilns for treatment generally suffers from low thermal efficiency, uneven material heating (leading to "under-burning" or "over-burning"), and difficulty in controlling pollutants (such as fluorine-containing gases).

2.2 Market Opportunities: Triple Drivers of Environmental Protection, Low Carbon, and Trade Barriers

Domestic Environmental Pressure: With increasingly strict environmental regulations and the comprehensive promotion of "waste-free cities," aluminum processing enterprises face immense pressure for environmental compliance. Seeking advanced technologies that can fundamentally render aluminum ash harmless while simultaneously recovering resources has become an urgent need and consensus across the industry.

Global Low-Carbon Transition Trend: Under the framework of the Paris Agreement, major global economies have set clear carbon neutrality goals. Energy conservation and carbon reduction in the industrial sector are core paths to achieving these goals, and high-energy-consumption traditional solid waste disposal technologies are no longer in line with development trends.

Direct Impact of the EU Carbon Tariff: Starting in 2026, the EU will impose a carbon tariff on certain goods imported into its member states, including aluminum products. This means that aluminum companies will not only have to pay for the direct carbon emissions from their production processes but also for the indirect emissions from their supply chain (including solid waste treatment). The large amount of carbon emissions from traditional pyrometallurgical disposal of aluminum ash will directly translate into costs for exported products, severely weakening their competitiveness in

the international market. This project, relying on the disruptive technology of the Intelligent Three-Ring Kiln, provides a perfect industrialized solution to these three challenges.

3. Core Technology Platform and Customized Process Solution

3.1 Core Technology Platform: The Disruptive Advantages of the Intelligent Three-Ring Kiln

The Intelligent Three-Ring Kiln is the cornerstone of this project's success. Through a series of disruptive innovations, it systematically solves the core pain points of high energy consumption, heavy pollution, and inconsistent quality in the calcination of lump materials.

Disruptive Direct Firing of Lump Material and Precise Activation:

1. Directly process aluminum ash briquettes (Φ30-50mm) after pretreatment.

2. Internally designed with three temperature zones: a **Preheating Zone** (400–600°C), a **Decomposition Zone** (650–850°C), and an **Activation Zone** (900–1100°C) for gradient activation of the material, overcoming the industry-wide problem of uneven heating.

3. The kiln bottom features a "smoldering homogenization" slow cooling section lasting **24 to 36 hours**, allowing residual reactions within the briquettes to complete thoroughly, ensuring the product's loss on ignition (LOI) is stably below 1% (compared to 3–8% in traditional processes), completely solving the "under-burning" problem.

Revolutionary Energy Closed-Loop and Ultimate Energy Savings: A four-stage waste heat closed-loop circulation system uses high-temperature flue gas to preheat the briquettes and low-temperature waste gas to drive a boiler for power generation, with the

final exhaust temperature below 130°C. The comprehensive thermal efficiency exceeds 70% and can be further optimized to **over 85%** in this project's plan, significantly reducing fuel costs by about 40%.

Fully Intelligent Control and Unmanned Operation: Equipped with an AI digital twin control system and infrared sensor robots for 24-hour unmanned discharge. The processing efficiency is **3–5 times** that of traditional kilns, and dust spillage is eliminated at the source.

3.2 Customized Process Solution: A Four-Step Method for High-Value Utilization of Secondary Aluminum Ash

Targeting the complex characteristics of aluminum ash, this project has designed a complete closed-loop process centered on "targeted impurity removal and precise separation."

Step 1: Enhanced Pretreatment via Aluminum Ash Briquetting

Objective: Increase reaction activity and prepare for targeted defluorination in the subsequent high-temperature calcination.

Optimized Formula: An exclusive formula of "secondary aluminum ash + calcium aluminate cement (binder) + aluminum sulfate (fluorine-fixing agent)" is used.

Innovative Mechanism: The added aluminum sulfate ($Al_2(SO_4)_3$) decomposes at high temperatures to produce highly active Al_2O_3, while promoting the temporary fixation of fluorine as AlF_3, which is easier to volatilize later.

Step 2: Gradient Calcination and Activation in the Intelligent Three-Ring Kiln

Gradient Calcination: The aluminum ash briquettes are fed into the Intelligent Three-Ring Kiln for activation under multi-temperature zones and intelligent atmosphere control.

Dehydration Zone (300-600°C): Gently removes physical and crystalline water to prevent briquette explosion.

Defluorination Zone (900°C): 1.2 m³/t of water vapor is introduced to promote the targeted volatilization of fluorine as AlF↑ ($2NaF + Al_2O_3 + H_2O \rightarrow Na_2O + 2AlF\uparrow$), facilitating subsequent unified collection.

Crystallization Zone (1200°C): In a weak reducing atmosphere, residual sodium is deeply removed ($Na_2O + C \rightarrow 2Na\uparrow + CO\uparrow$). After 2.5 hours of calcination, the residual sodium rate is below 0.5%.

Outcome: Achieves targeted gasification of fluorine with a collection rate of **over 98%**, laying the foundation for the subsequent co-production of cryolite.

Step 3: Selective Leaching and Separation in a Sulfuric Acid System

Innovative Process: A "controlled-acid leaching" method is used to achieve synergistic recovery of fluorine and aluminum.

Precise Conditions: The calcined clinker is stirred for 90 minutes in a 10% dilute sulfuric acid solution at 80°C with a liquid-to-solid ratio of 4:1. Critically, the pH value is strictly controlled between **1.5-2.0**.

Separation Effect: At this pH, the dissolution rate of the target product α-Al_2O_3 is less than 3%. After filtration, the following are obtained:

Filtrate: Rich in Al^{3+}, F^-, and Na^+ ions, used for cryolite synthesis.

Filter Residue: High-purity α-Al_2O_3 with a purity greater than 99.2% and Na_2O content below 0.3%.

Step 4: Product Co-production and Purification System

Cryolite Synthesis: The pH of the filtrate is adjusted to 5.0 with Na_2CO_3 to crystallize and synthesize high-purity cryolite (Na_3AlF_6). The product purity is ≥98%, compliant with the YS/T 273-2020 standard.

Alumina Refining: The filter residue is further purified through the mature "alkaline dissolution → carbonation → calcination" process to finally obtain a 4N-grade (Na_2O < 0.1%) high-end alumina product.

3.3 Full System Closed-Loop and "Zero Waste Emission"

Full Component Utilization: The conversion rates for fluorine, sodium, aluminum, and silicon are as high as 99.7%, 99.5%, 98.9%, and 100%, respectively.

Waste Gas Utilization: Combustible waste gases such as hydrogen and methane produced during production can be directly fed into the kiln for combustion. Trace fluorides in the tail gas are treated by a "Venturi scrubber + two-stage alkaline washing tower" and can be recovered to produce high-purity cryolite, with a removal rate of 99.9%.

Wastewater Utilization: Production wastewater is recycled as a mother liquor and can eventually be purified to produce industrial by-products like sodium sulfate powder (also known as thenardite) (Na_2SO_4) for external sale.

4. Product Planning and Market Application

4.1 Core Products

4N-Grade High-Purity Alumina: Purity of 99.99%, Na_2O content below 0.1%. It is a core raw material for manufacturing LED sapphire substrates, lithium battery separators, specialty ceramics, aerospace, and other fields.

High-Purity Cryolite: Purity greater than 98%. Can be directly returned to the electrolytic aluminum process as a flux.

4.2 By-products

Industrial-Grade Sodium Sulfate (Thenardite): Obtained from the evaporation and crystallization of the acid leaching solution.

CO_2 Dry Ice: Captured CO_2 can be made into dry ice for sale.

Vitreous Slag: Can be used as a high-quality building material.

5. Investment Value and Benefit Outlook

5.1 Innovative "Four-Fold Revenue" Business Model

The project breaks the traditional industrial model of relying on single-product profits, building a more robust and diversified value creation system.

Diversified Product Revenue: Main income is derived from the sale of high-value-added products like high-purity alumina and cryolite.

Hazardous Waste Disposal Revenue / Cost Advantage: The acquisition cost of the core raw material, aluminum ash, is extremely low, and may even generate income from hazardous waste disposal fees.

Potential Policy Benefits: As a nationally encouraged project for the comprehensive utilization of bulk hazardous waste, it is expected to receive financial subsidies.

Clear Carbon Asset Revenue: This is the project's greatest potential growth point. Firstly, by adopting our low-carbon disposal solution, it can help aluminum companies significantly reduce the overall carbon footprint of their products, gaining a huge cost advantage in dealing with the 2026 EU carbon tariff, which is in itself a form of "hidden income." Secondly, the certified emission reductions generated by its significant energy-

saving and emission-reduction effects can be sold in domestic and international carbon trading markets in the future, generating considerable direct "carbon revenue."

5.2 Excellent Profitability and Investment Returns

Significant Cost Advantage: The high thermal utilization rate of over 85% in the Intelligent Three-Ring Kiln allows its fuel costs to be significantly reduced by about 40% compared to traditional kilns. This cost-reduction effect will become more prominent as energy and carbon prices continue to rise.

Huge Value Creation: Transforms low-value, high-hazard solid waste into high-value-added industrial raw materials, achieving an "alchemical" leap in value.

Rapid Investment Return: The combination of low-cost input and high-value output gives the project extraordinary profitability and strong cash flow generation capabilities. Financial assessments of similar projects show that its gross profit margin is as high as 70%, and the static investment payback period is far shorter than conventional industrial projects, typically completed within one year (about 10 months), fully demonstrating its excellent investment efficiency and extremely low risk.

5.3 Significant Social and Environmental Benefits

Environmental Benefits: Fundamentally solves the environmental pollution problem caused by the hazardous solid waste of aluminum ash, serving as a model for achieving "waste-free cities" and a green circular economy.

Social Benefits: The construction and operation of the project will directly create jobs and drive the development of downstream supporting industries, playing a positive role in promoting the local economy.

Strategic Benefits for Climate Change: This project is a concrete practice of energy conservation, emission reduction, and low-carbon transformation in the industrial sector. It not only reduces its own operational carbon emissions but also, through

resource recycling, lowers the energy consumption of primary resource extraction and processing, contributing to national and even global carbon neutrality goals.

6. Conclusion

This project, relying on the activation and calcination technology of the Intelligent Three-Ring Kiln and a process route tailor-made for secondary aluminum ash, successfully transforms the environmentally hazardous waste of aluminum ash into high-value-added industrial raw materials, constructing a complete circular economy industrial chain. The project has high technical barriers, a mature and reliable process route, abundant economic returns, an extremely short investment payback period, and can generate significant social and environmental benefits.

In the macro context of the global low-carbon transition and the imminent EU carbon tariff, the strategic value of this project is further magnified. It is not only an environmental protection project to solve solid waste pollution but also a "green shield" that empowers the aluminum industry chain to cope with new international trade regulations. It not only provides a "Chinese solution" for the global high-temperature calcination industry that is both economical, environmentally friendly, and strategic, but it is also a high-quality industrial project with high investment value and explosive commercial potential.