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[1.] Sorina Gabriela SERBAN, [2.] Imre KISS

CLASSICAL AGGLOMERATION TECHNIQUES OF FINE FERROUS WASTES IN STEELMAKING BETWEEN CHALLENGES AND BENEFITS

[1,2.] University POLITEHNICA Timisoara, Faculty of Engineering Hunedoara, Department of Engineering & Management, Hunedoara, ROMANIA

Abstract: Pulverous fine ferrous wastes are fine particulate residues rich in iron and are generated predominantly as by–products from various metallurgical and industrial processes. These wastes typically exist as oxides and fine particles and require specialized recovery processes such as pelletizing and briquetting for reuse in steel production or other iron–utilizing industries. CLASSICAL AGGLOMERATION TECHNIQUES—SINTERING, PELLETIZING, and BRIQUETTING—are essential processes in iron and steelmaking. They convert fine iron–bearing materials, including ore fines and various ferrous wastes, into larger, mechanically strong forms suitable for charging into furnaces. Recovery of these fine wastes not only supports circular economy principles but also mitigates environmental pollution from waste disposal sites, such as regional ponds, by reclaiming storage space and reducing soil and water contamination risks. Agglomeration methods of fine ferrous materials are critically important despite their many challenges because they enable the transformation of fine, often waste or by–product ferrous particles into more manageable, valuable forms suitable for industrial use. These methods play a key role in resource efficiency, environmental management, and economic viability within the steel and metal manufacturing sectors.

Keywords: agglomeration techniques, sintering, pelletizing, briquetting, challenges and benefits

INTRODUCTION

PULVEROUS FINE FERROUS WASTES refers to small, powdery by–products from the iron and steel industry, such as dust and sludge, which can be recycled.[1–6] These wastes are processed through methods like pelletizing, briquetting, and agglomeration to be reused as raw materials for making steel and cast iron. This process is economically and environmentally beneficial because it reduces pollution and conserves natural resources.[1–6]

PULVEROUS FINE FERROUS WASTES are fine particulate residues rich in iron and are generated predominantly as by–products from various metallurgical and industrial processes. These is often in oxide form due to exposure to high temperatures and oxidizing conditions during industrial processes. Pulverous ferrous wastes typically exhibit high iron content (e.g., above 80%) with minor inclusions of other metals such as Cu, Ni, Mn, and trace elements depending on their origin.[1–6] These wastes typically exist as fine particles and require specialized recovery processes such as pelletizing and briquetting for reuse in steel production or other iron–utilizing industries. Recovery of these fine wastes not only supports circular economy principles but also mitigates environmental pollution from waste disposal sites, such as regional ponds, by reclaiming storage space and reducing soil and water contamination risks.

AGGLOMERATION OF FINE FERROUS WASTES is a process by which fine particles of ferrous materials are aggregated into larger, more manageable, and structurally stable lumps or agglomerates (granulates, sinters, briquettes or pellets).[12–23]

The principle of agglomeration involves binding or compacting the fine particles through physical and/or chemical means to improve handling, transport, and further processing. [1–6] Fine ferrous particles are combined using techniques such as pelletizing, briquetting, or granulation. These methods typically involve applying pressure, heat, or binding agents to form larger sized agglomerates. The stable lumps – agglomerates – have improved mechanical strength and uniform particle distribution for enhanced processability.[1–6]

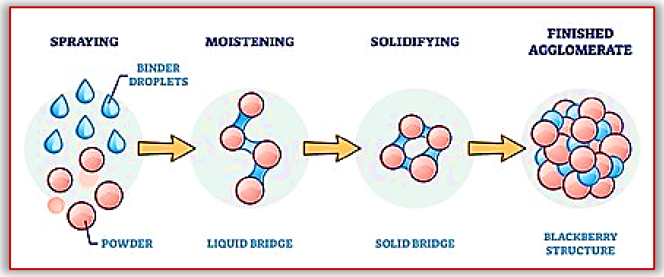

Figure 1. Agglomeration process

PRIMARY SOURCES OF FINE FERROUS WASTES

AGGLOMERATION PROCESSES are used to prepare a wide range of materials for use in metallurgical furnaces, particularly blast furnaces.

- RAW MATERIALS: This includes iron ore fines and concentrates, which are often too small for direct use.
- STEELMAKING WASTE: Agglomeration is a primary method for recycling and reusing iron–rich wastes and by–products generated in integrated steel plants.

The primary sources of pulverous fine ferrous wastes are: [12–23]

- STEELMAKING INDUSTRY, which generates:
  - Steel dust and sludge, generated from gas and industrial water filtration systems used to capture airborne and waterborne particulates in steel plants.
  - Blast furnace dust and sludge, fine particles collected from the blast furnace gas.
  - Converter dust, from basic oxygen furnaces (BOF), also contribute significantly to pulverous ferrous waste streams.
  - Electrofilter dust, from electric steel mills, is a notable contributor, consisting of very fine metal oxides.
  - Mill scale, iron oxide layers that form on steel surfaces during rolling.
  - Slags, in fact processed and sized metallurgical slag
- AGGLOMERATION AND PELLETIZING PROCESSES: Dust collected from pelletizing and agglomeration processes where iron ores are treated often results in fine ferrous sludges or dust. These wastes contain iron–rich particles that can be reprocessed into pellets for reuse in electric arc furnaces, enhancing resource efficiency and reducing waste landfill.
- MINING AND MINERAL PROCESSING: Alongside the metallurgical sector, mining and minerals processing generate ferrous–containing wastes such as pyritic ash from mineral extraction and ore processing activities.
- OTHER INDUSTRIAL PROCESSES: Certain chemical industries, energy generation sectors, and other metal processing plants produce fine iron–rich residues, often as sludge or dust from filters and waste treatment systems.

BENEFITS OF AGGLOMERATION

By recycling these materials, steel plants can reduce disposal costs and environmental impact, turning a waste product into a valuable resource.[7–11] This process is essential in iron and steel production for utilizing fines and dust that otherwise cause handling problems and material loss. It supports circular economy goals by enabling reuse and value recovery from fine ferrous wastes. Benefits of agglomeration of fine ferrous wastes can be summarized as follow:

- Technically, the agglomeration converts various fine waste into a marketable product (granulates, sinters, briquettes or pellets), reducing waste disposal needs.
- Practically, improves handling and transport efficiencies by reducing dust and fines.
- Technologically, enhances process flow and efficiency in subsequent metallurgical operations like smelting and sintering.
- Environmental benefits include reduced landfill use and improved recycling capabilities.
- Economic benefits include lower transportation and material handling costs and recovery of valuable materials.

AGGLOMERATION offers significant benefits for steelmaking efficiency, economics, and environmental sustainability.[7–13]

- Improved material properties: Agglomerates (sinter, pellets, and briquettes) have a precise particle size, uniform composition, and high mechanical strength. This improves the permeability of the burden in the blast furnace, allowing for better gas flow and more efficient reduction reactions.
- Enhanced process efficiency: The uniform size and composition lead to a more stable and predictable furnace operation. This improves productivity and reduces fuel consumption.
- Impurity Removal: High–temperature agglomeration processes, like sintering and pelletizing, are highly effective at removing harmful elements such as sulfur and zinc, which would otherwise “poison” the blast furnace.
- Waste recycling and environmental benefits: Agglomeration allows for the recycling of iron–rich wastes, reducing the amount of material sent to landfills. This directly lowers disposal costs and minimizes the environmental footprint of steel production. Newer processes, like cold briquetting, also help reduce greenhouse gas emissions by eliminating the need for a high–temperature heat treatment stage.

CLASSICAL AGGLOMERATION TECHNIQUES

CLASSICAL AGGLOMERATION TECHNIQUES in steelmaking convert fine, powdery materials—like iron ore fines, dust, and other wastes—into larger, durable forms for use in furnaces.[12–23] These processes, including SINTERING, PELLETIZING, and BRIQUETTING, improve the physical and chemical properties of the materials, enhancing furnace operations and promoting resource recycling.

PELLETIZING and BRIQUETTING are the primary methods for processing these wastes to recover metal value. Binding agents such as bentonite and slag additives are used to produce pellets with sufficient mechanical strength suitable for steel furnace inputs.[12–23]

AGGLOMERATION TECHNIQUES AND METHODS

Different agglomeration techniques have distinct effects on ferrous waste recycling, primarily influencing material handling, process efficiency, and the quality of the recycled products.

— BRIQUETTING (MECHANICAL or PRESSURE AGGLOMERATION) enhances recycling by consolidating fines into uniform shapes that improve process feeding and reduce material loss. Involves compressing fine ferrous waste particles into dense, solid briquettes using high pressure, sometimes with binders. Produces strong lumps that can be reused directly in smelting or steelmaking.[12–23] Challenges include binder selection and control of moisture to ensure briquette strength, but benefits include improved handling and transport by reducing dust and fines.

Figure 2. Briquettes from fine ferrous wastes

— PELLETIZING (PHYSICAL–THERMAL or NON–PRESSURE AGGLOMERATION) enables recovery of ultra–fine wastes by converting them into valuable feedstock for ironmaking. Fine ferrous particles are formed into pellets by layering and binding, usually followed by thermal treatment to increase strength.[12–23] Therefore, requires thermal processing which adds energy consumption and costs. The pellets are suitable for direct use in blast furnaces, offering good metallurgical performance.

Figure 3. Pellets from fine ferrous wastes

— SINTERING (THERMAL AGGLOMERATION or POST–AGGLOMERATION) is crucial for efficient recycling of fine wastes with better metallurgical performance. Adds process complexity and energy needs but results in higher quality materials, producing durable, heat–resistant products ideal for blast furnaces. Agglomerates like briquettes or pellets undergo high–temperature treatment to fuse particles. [12–23]

Figure 4. Sinter from fine ferrous wastes

— GRANULATION (PRE–AGGLOMERATION) is often a pre–step to further processing like SINTERING or BRIQUETTING. Is a relatively simple and low energy but may produce weaker agglomerates compared to briquettes or pellets. In this method the fine particles are aggregated into granules using moisture and mechanical forces. The resulted granules have good flowability and are useful in processes requiring uniform particle sizes.

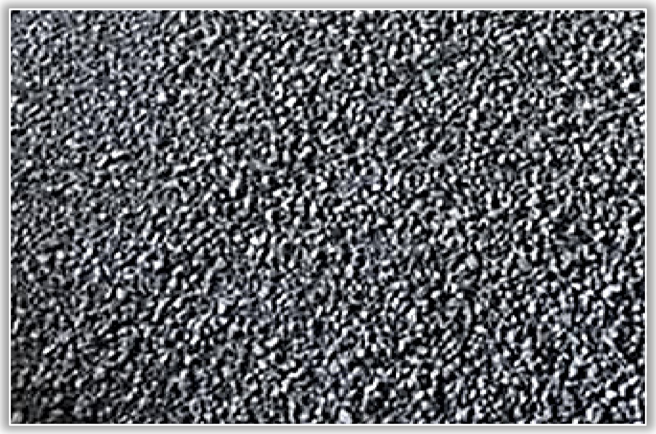

Figure 5. Granules from fine ferrous wastes

Table 1. Summary on ferrous waste recycling by agglomeration methods

Agglomeration Technique	Impact on Recycling Process	Product Quality	Operational Considerations
Briquetting	Improves handling, reduces dust	High density, strong briquettes	Requires binders and moisture control
Pelletizing	Converts fines into furnace-ready feedstock	Uniform pellets	Requires thermal treatment, energy intensive
Granulation	Simplifies particle handling	Loose granules, moderate strength	Low energy, often precursor to other steps
Sintering	Enhances strength and durability	Solid, fused high-strength product	High energy, adds process complexity

These recovery methods by agglomeration valorize fine ferrous wastes, minimizing disposal and optimizing resource reuse in steel and iron production, with benefits for economic and environmental sustainability.[12–23] Overall, agglomeration technologies enable efficient recycling of fine ferrous wastes by improving material transport and feeding properties and producing value–added feedstock for steelmaking. The choice of method depends on the specific waste characteristics, cost constraints, and desired end–product quality.

CHALLENGES OF AGGLOMERATION

Challenges of agglomeration refer to the negative effects and difficulties that arise when firms, people, or activities concentrate geographically in clusters or dense urban areas. While agglomeration can create economic benefits such as reduced production costs, increased specialization, innovation, and improved access to suppliers and customers, it also leads to significant challenges. Key challenges include: [12–23]

- Technical challenges, ensuring consistent agglomerate strength and size to avoid disintegration during handling. In addition, require additional processing steps and equipment, adding to operational costs. Also, variability in feedstock properties (moisture, particle size, chemical composition) affecting agglomeration quality.
- Management challenges, managing the fine raw materials selection and use, binder selection and addition, optimization to balance cost, performance, and environmental compliance.
- Environmental problems or potential emissions during process stages like drying or heating such as pollution (air, water, land degradation) and increased energy consumption due to dense industrial and population concentrations.

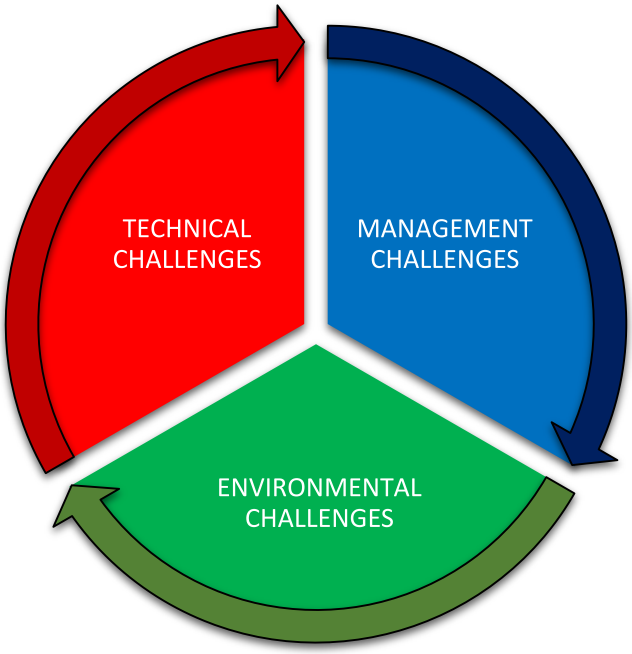

Figure 6. Key challenges

Addressing these challenges requires careful industrial and urban planning, investment in infrastructure, environmental protection measures, and policies that balance growth with sustainability. [12–23] These challenges are often referred to as “diseconomies of agglomeration” and represent the tradeoffs as cities or industrial clusters grow too large or dense, requiring careful planning and policies to mitigate adverse effects while maximizing benefits. Diseconomies of agglomeration refer to the economic inefficiencies and negative effects that arise when firms, people, or activities cluster too densely in a particular area. While agglomeration can bring advantages like cost savings, innovation, and easier access to markets, diseconomies occur when these benefits are outweighed by drawbacks as the scale or density grows excessively.

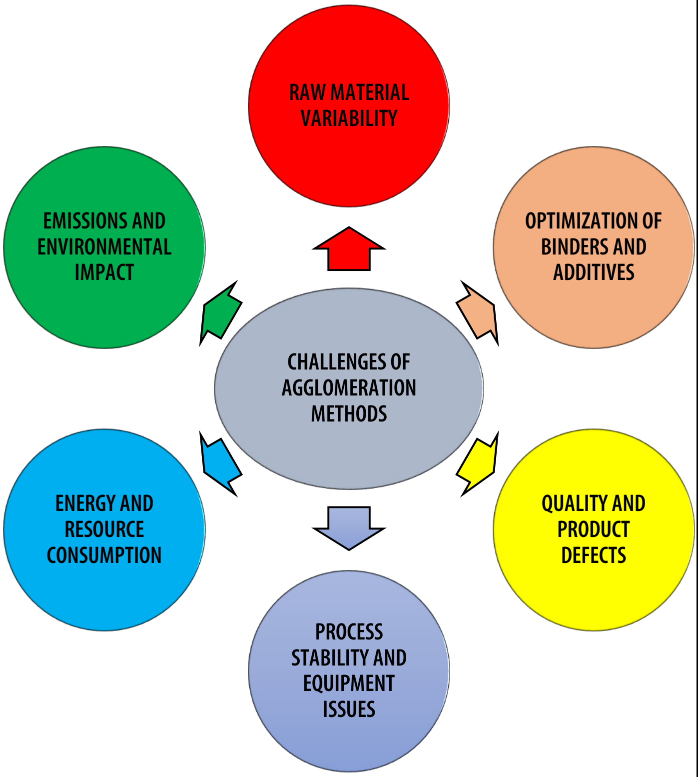

Figure 7. Common challenges of agglomeration

More precisely, the common challenges in iron ore agglomeration processes include: [12–23]

1. Challenges regarding the RAW MATERIAL VARIABILITY, meaning:
   - variations in iron ore particle size, mineralogy, and chemical composition affect agglomeration performance.
   - poor granulation characteristics, even with chemically suitable ores, can lead to low productivity and poor sinter quality.
   - blending optimization is required to balance these raw material factors.
2. Challenges regarding the OPTIMIZATION OF BINDERS AND ADDITIVES, meaning:
   - selection and dosage of binders like burnt lime must be carefully controlled to optimize particle bonding and permeability.
   - over– or under–dosing binders may reduce agglomerate quality or cause permeability issues in the sintering bed.
3. Challenges regarding the PROCESS STABILITY AND EQUIPMENT ISSUES, which means the followings:
   - maintaining the uniform mixing of various fine raw materials and a consistent processing parameters is challenging, avoiding the equipment blockages and degradation (reducing operational reliability).
   - granulation and mixing efficiency affect particle growth and agglomerate strength, with factors like drum speed and mixing time needing optimization.
4. Challenges regarding the QUALITY AND PRODUCT DEFECTS include:
   - issues such as weak or friable agglomerates, irregular shapes, and excessive fines result from improper moisture control, inadequate binder action, or uneven heating.
   - contamination and impurity segregation can degrade product quality, impacting downstream metallurgical processes.
   - achieving consistent mechanical strength, porosity, and reducibility in agglomerates (granulates, sinters, briquettes or pellets) is difficult.
5. Challenges regarding the ENERGY AND RESOURCE CONSUMPTION:
   - agglomeration processes, especially thermal treatments like sintering and pelletizing, are energy–intensive.
   - high consumption of coke, coal, and electricity leads to elevated operational costs.
   - water usage in pelletizing and briquetting requires recycling and efficient management.
6. Challenges regarding the EMISSIONS AND ENVIRONMENTAL IMPACT:
   - agglomeration generates emissions such as CO2, SOx, NOx, particulate matter, and trace element releases.
   - dust collection, wastewater treatment, and emission control systems are mandatory but add complexity and cost.
   - compliance with increasingly stringent environmental regulations pressures plants to innovate in emission reduction.

Overall, these challenges underscore the need for precise control of process parameters, raw material quality, and equipment maintenance to achieve efficient and environmentally compliant iron ore agglomeration.

Agglomeration creates both positive and negative externalities. [12–23] While it can boost productivity, innovation, and economic growth through clustering, it also generates significant social, environmental, and economic challenges that need addressing.

Recognizing and managing agglomeration challenges is essential for creating sustainable, equitable urban and regional development that leverages clustering advantages without causing excessive harm. [12–23]

DISCUSSIONS: CHALLENGES VS BENEFITS

Agglomeration methods of fine ferrous materials from primary sources of siderurgy are critically important despite their many challenges because they enable the transformation of fine, often waste or by–product ferrous particles into more manageable, valuable forms suitable for industrial use. [12–23] These methods play a key role in resource efficiency, environmental management, and economic viability within the steel and metal manufacturing sectors.

PULVEROUS FINE FERROUS WASTE MANAGEMENT plays an important role in advancing circular economy goals in the iron and steel sector. These fine iron–rich wastes, such as steel dust and sludge, when recovered and reused efficiently, contribute to sustainable resource utilization and pollution reduction. Key aspects of pulverous ferrous waste management for circular economy include:

— RESOURCE RECOVERY and WASTE MINIMIZATION: Fine ferrous materials, such as dusts, sludges, and powders generated during metal processing, are often difficult to handle directly. Pulverous ferrous wastes can be converted into solid pellets or briquettes by mixing fines with binders and applying thermal or mechanical processing. These products can be reused as feedstock in electric arc furnaces or blast furnaces, thus closing the loop by returning valuable iron content into the steel production cycle. This approach minimizes raw material extraction and reduces landfill dependency. AGGLOMERATION (e.g., PELLETIZING, BRIQUETTING) consolidates these fines into larger, uniform particles that can be reintroduced into steelmaking processes, reducing raw material waste and supporting circular economy principles.

— ENHANCED PROCESS EFFICIENCY: Uniform pellet size improves feeding consistency and combustion or smelting efficiency in furnaces or blast furnaces. Agglomerates (granulates, sinters, briquettes or pellets) have better permeability and heat transfer characteristics compared to irregular fines.

— IMPROVED HANDLING AND TRANSPORT: Agglomerated forms are easier to store, transport, and feed into furnaces compared to loose fines, minimizing dust–related environmental hazards and operational inefficiencies. Agglomeration transforms fine, dusty particles into larger, uniform pellets or granules, making the material easier, safer, and cleaner to handle, store, and transport. This reduces dust–related losses and health hazards.

— ENVIRONMENTAL BENEFITS: Recovery technologies mitigate environmental pollution risks from dust dispersion, soil contamination, and water pollution associated with storing pulverous wastes in ponds or landfills. Reducing deposited waste volume frees up valuable land and lowers hazards to public health and ecosystems, supporting sustainable industrial development. By recycling fine ferrous materials through agglomeration, the industry reduces landfill disposal, mitigates heavy metal contamination risks, and lowers overall environmental footprint. Reducing dust emissions and landfill waste contributes to better air quality and lower contamination risks. Agglomeration can also facilitate more efficient downstream processing reducing energy consumption.

— ECONOMIC ADVANTAGES: By converting fines into a saleable product, agglomeration reduces raw material costs, waste disposal expenses, and improves overall operational cost–effectiveness. Reusing pulverous ferrous wastes translates into cost savings by decreasing disposal expenses and by substituting expensive raw iron materials. This supports more economically viable and competitive steel production while contributing to circular material flows. In fact, agglomeration methods recover value from what would otherwise be waste, improving raw material cost efficiency and generating additional revenue streams.

— INTEGRATION IN INDUSTRIAL PROCESSES: Pulverous ferrous wastes are increasingly being reincorporated into agglomeration feed charges (2–3% addition) to optimize resource efficiency. This integration enhances yield while maintaining steel quality and lowers total waste generation.

These recovery methods enable valorisation of otherwise challenging pulverous ferrous wastes, enhancing resource efficiency, reducing environmental impact by mitigating landfill disposal, and supporting circular metallurgical production cycles. Although challenges such as energy consumption, binder selection, process optimization, and equipment costs exist, the benefits in waste minimization, sustainable resource use, and improved production logistics underscore why agglomeration methods remain essential. Innovating to overcome these challenges yields significant returns in environmental compliance, cost savings, and circular resource management.

Thus, the importance of agglomeration methods for fine ferrous materials lies in enabling sustainable, economically viable recycling and reuse of valuable metal fines despite operational difficulties. In fact, valorisation of pulverous fine ferrous wastes enables environmental sustainability, economic savings, industrial efficiency, and regulatory compliance, making it a vital practice for modern steel production and circular economy implementation.

CONCLUSIONS

In conclusion, pulverous fine ferrous waste management embodies circular economy principles by turning industrial by–products into valuable secondary raw materials, reducing environmental impact, and strengthening economic competitiveness of steelmaking. Continued advancement of pelletizing, briquetting, and thermal reduction technologies will further unlock these wastes' full resource potential and contribute significantly to sustainable iron and steel industry transformation.

This management approach aligns ecological preservation with industrial economic interests, formulates a circular industrial material flow, and fosters responsible resource stewardship in metallurgy.

If more focused insights on technology or policy frameworks for circular economy in ferrous waste management are desired, those can be provided as well. Pulverous fine ferrous waste management is a key element in advancing circular economy principles within the iron and steel industry. These fine iron–rich wastes, primarily originating from steelmaking dusts and sludge, can be recovered and reintegrated into metallurgical processes, thus reducing reliance on virgin raw materials and minimizing environmental impacts.

Recovery methods such as pelletizing and briquetting transform these wastes into solid forms usable as secondary raw materials in electric arc furnaces or blast furnaces. This process closes material loops by returning iron values into production cycles, which lessens the quantities sent to landfill and reduces associated pollution from dust and leachate. Integrating pulverous ferrous wastes back into agglomeration feed or furnace charges enhances resource efficiency and process sustainability.

Environmentally, this approach diminishes contamination risks to air, soil, and water in the vicinity of waste disposal sites, improving public health and preserving ecosystems. Economically, it lowers disposal costs and offsets the need for costly primary iron ores, boosting operational competitiveness.

Thus, managing pulverous fine ferrous wastes through optimized recovery and reuse epitomizes circular economy strategies—maximizing resource valorisation, minimizing environmental footprint, and fostering sustainable metallurgical industry growth. Continued innovation in recovery technologies and supportive industrial policies will further solidify this contribution to sustainable steel production and responsible resource stewardship.

Policy responses must balance maximizing agglomeration benefits and minimizing diseconomies. This requires targeted investment in affordable housing, infrastructure, inclusive labor markets, and environmental protections. Agglomeration enables recycling of fine ferrous wastes that would otherwise be discarded or landfilled. This supports circular economy goals by recovering valuable iron content and reducing environmental impact.

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