p-ISSN: 2301-6663, e-ISSN: 2477-250X
URL: http://ojs.ummetro.ac.id/index.php/turbo

FERROUS OXALATE FROM METAL WASTE FOR ADVANCED MATERIALS: A REVIEW

Yasa Sanusi[1*], and Deni Shidqi Khaerudini[2]

[1,2]Master of Mechanical Engineering Study Program, Faculty of Engineering, Mercu Buana University Jakarta
Jl. Meruya Selatan No.1, Kembangan, West Jakarta City, DKI Jakarta 11650
[2]National Reseach and Innovation Agency (BRIN)
BJ Habibie Science and Technology Area, Serpong, South Tangerang, Banten, 15314, Indonesia
**Corresponding author*: yasa.sanusi@gmail.com

Abstract

The rapid development of the manufacturing industry, particularly in the machinery sector, produces large amounts of metal waste, much of which ends up as scrap metal without any added value. This situation not only creates environmental problems and risks of contamination but also leaves economic potential untapped. Various studies have shown that iron-rich metal waste can be converted into ferrous oxalate through various synthesis and characterization methods, thus potentially becoming a high-value material. Therefore, a comprehensive study is needed to identify, analyze, and evaluate research developments on the utilization of ferrous oxalate from metal waste. The novelty of this study lies in the preparation of a comprehensive map that integrates metal waste sources, synthesis technologies, characterization methods, applications as advanced materials, and the potential for economic value creation. This study used a scoping review method of 30 scientific publications published between 2020 and 2025. The results show that various iron-rich wastes can be processed into high-purity ferrous oxalate, and prospects for applications in energy storage, wastewater treatment, pigments, sustainable cement, electrorheological fluids, and gas sensors. This finding strengthens the opportunity to utilize metal waste as a source of advanced materials that support a circular economy and have high economic value.
Keywords: *Ferrous oxalate, metal materials, precipitation process, sustainable advance materials, economic value.*

1. Introduction

The rapid development of the manufacturing industry, especially in machining processes, produces large amounts of metal waste [3][4] that contributes to environmental problems, including global warming. Global crude steel production reached approximately 1.885 billion tons in 2024, approximately 30–32% of which supplies industrial raw material needs, contributing approximately 7–11% of carbon dioxide (CO_2) emissions [2]. In Indonesia, it has reached almost 17 million tons and is projected to increase to 60 million tons per year by 2060 [1]. Most of this waste is still utilized as low-value scrap metal without adequate valorization processes [5][6][7], thus creating waste management challenges, contamination risks, and potential pollution [8][9][10]. Nevertheless, metal waste is now seen as a high-value resource that has not been optimally utilized [11][12]. This paradigm shift encourages the development of sustainability-based waste management strategies and a circular economy that not only reduce environmental impacts but also create new economic opportunities [13][14].

Figure 1 shows the conventional metal processing process. In Figure 1(a), the machining process produces waste in the form of scrap or iron flakes.

DOI: https://doi.org/10.24127/trb.v15i1.4640.
Received 24 October 2025; Received in revised form 8 July 2026; Accepted 13 July 2026
Available online July 2026

Figure 1. Iron Scrap Processing Process (Before utilizing iron waste);

a) Machining Process [15], b) Machining Waste Scrap[16], c) Waste Recycling with Casting Process[17].

Furthermore, Figure 1(b) shows that this waste is collected as scrap metal, which is generally not optimally utilized. In Figure 1(c), the iron waste is then melted through a casting process to produce new iron products. This situation indicates that the potential of iron waste from the machining process as a raw material for high-value materials remains underutilized.

In the concept of sustainable advanced materials, converting iron waste into value-added materials is a strategy that supports waste reduction and environmental impact reduction. With good mechanical and magnetic properties [18], iron waste has great potential for recycling into functional materials, such as ferrous oxalate, which has higher economic value [19].

Ferrous oxalate is an inorganic compound that can be synthesized from iron in metal waste and serves as an important precursor in the development of advanced materials[20]. This compound, known as iron(II) oxalate dihydrate ($FeC_2O_4{\cdot}2H_2O$), contains Fe^{2+} and $C_2O_4^{2-}$ ions, is pale yellow, and is slightly soluble in water[21]. Due to its high purity and ease of decomposition, ferrous oxalate is widely used as a precursor in the synthesis of lithium iron phosphate (LFP) battery cathodes, iron oxides for catalysts and photocatalysts, pigments, and gas sensors, thus offering potential as a sustainable iron-based advanced material.

In line with this, the increasing demand for high-performance advanced materials is driving extensive research in various sectors, especially energy storage and environmental protection[22]. Various studies have shown that metal waste can be converted into ferrous oxalate through various synthesis methods, thus having the potential to be a high-value material. Therefore, this review systematically examines the characteristics, raw material sources, synthesis technologies, characterization methods, applications, and potential economic value of ferrous oxalate. Unlike previous reviews that generally only discuss specific syntheses or applications, this study integrates all these aspects within a single scoping review framework to provide a more comprehensive perspective on the development of sustainable advanced materials.

2. Research Methods

2.1 Methods

The method used in the review paper is a Scoping Review in the form of a study review or literature review, which aims to comprehensively map and group the literature that examines potential ferrous oxalate sourced from iron waste.

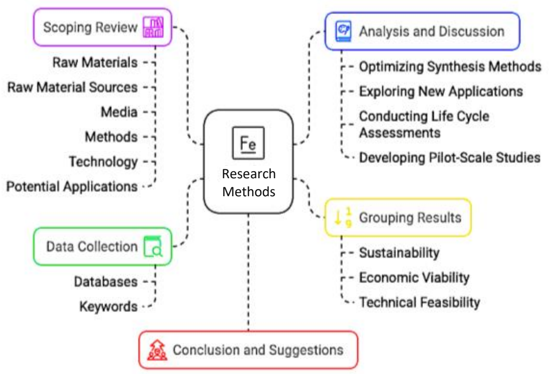


Figure 2. Research Methods

1. Data Collection
   Data collection was carried out by sorting literature on ferrous oxalate derived from iron waste.
2. Scoping Review
   Conduct identification and categorization based on scientific publications published from 2020 to 2025, indexed Q4 to Q1 from

Google Scolar and publish or perish.

3. Grouping Result
   Grouping based on raw materials, raw material sources, media, methods, and technology, as well as potential ferrous oxalate.
4. Analysis and Discussion
   Potential analysis of ferrous oxalate from metal waste to become sustainable advanced materials that have high economic value.
5. Conclusion and Suggestions
   Summarizing the potential ferrous oxalate from metal waste to become a sustainable advanced material that has high economic value, and provides implications and suggestions for further research.

2.2 Material

The materials used for review include literature relevant to the potential of ferrous oxalate from metal waste to become sustainable advanced materials with economic value. This literature consists of 30 scientific publications (journals, articles, conferences,) and other information sources published from 2020 to 2025, indexed Scopus Q4 to Q1 from google scolar and publish or perish by grouping the theme about ferrous oxalate.

Table 1. Ferrous oxalate Research

No	Researcher / Years / Publisher	Journal Theme	Methods and Material	Application	Findings
1	Carla S. Valdivieso-Ramírez et al. (2024) [23] – MDPI Minerals (Q2)	Catalysis and Environmental Remediation	Metods: Synthesis, and Reaction kinetics analyzed. Materials: iron and titanium	Photocatalist for Waste Water Decontamination	The synthesized ferrous oxalate is suitable for photocatalysis.
2	Salomé Galeas et al. (2024) [24] - MDPI Molecules (Q1)	Catalysis and Environmental Remediation	Methods: Hydrothermal Materials: Ferrotitaniferous black sand, Granular activated carbon	Phenol Remover (Adsorptive-Photocatalytic Composite)	The study developed a low-cost dual-function AC/α-FOD composite with strong performance.
3	Chitiphon Chuaicham et al. (2023) [25] - MDPI Separation (Q1)	Catalysis and Environmental Remediation	Methods: Photo-reduction Materials: slag, Oxalic acid	Degradation of Rhodamine B	Performance of industrial waste-derived photocatalysts.
4	Lu Fu et al. (2022) [26] - MDPI Polymers (Q1)	Catalysis and Environmental Remediation	Methods: Dye degradation ex Materials: ferrous oxalate, and aramid nanofibers,	Degradation of Methylene Blue	Effective heterogeneous Fenton catalyst for dye degradation.
5	Chitiphon Chuaicham et al. (2023) [27] - MDPI Separation (Q1)	Catalysis and Environmental Remediation	Methods: photoreduction Materials: Iron ore	Degradation of Methylene Blue	Iron oxalate dihydrate effectively degrades RhB under light.
6	Elizaveta A. Fedorova et al. (2025) [28] – Chemistry European Journal (Q1)	Catalysis and Environmental Remediation	Methods: X-ray absorption spectroscopy (XAS), Materials: Alkali metal promoters, Gases.	Degradation of Methylene Blue (Fenton Catalyst)	Combined spectroscopy and kinetic modeling elucidate FeC_2O_4 decomposition.
7	Marcelinus S. Christwardana et al. (2023) [14] – Analytical and Bioanalytical Electrochemistry (Q3)	Energy Storage, Environmental Remediation,	Methods: calcinationand coating via electrophoretic deposition Materials: mill scale, calcium carbonate ($CaCO_3$)	Degradation of Methylene Blue (Fenton Catalyst)	Calcination time has a significant effect on increasing the purity of hematite produced from mill scale,
8	P.B. Dahivade et al. (2023) [29] – Engeneered Science Publisher (Q1)	Structural, Energy Storage, Environmental Remediation,	Methods: cathodic potentiodynamic electrodeposition Materials: stainless steel substrates	Degradation of Methylene Blue (Fenton Catalyst)	Cathodic electrodeposition produces high-performance nanostructured hematite electrodes.
9	Geng Gao et al. (2022) [30] – Progress in Chemistry Publisher (Q3)	Energy Storage, Environmental Remediation	Methods: various synthesis methods Materials: ferrous oxalate (FeC_2O_4)	Iron Oxalate Anode for Ion Battery	Ferrous oxalate is a promising candidate for use as an anode material.
10	Vasilii Gromov et al. (2023) [22] – MDPI Condensed Matter (Q3)	Energy Storage, Environmental Remediation	Methods: conversion mechanism in transition metal oxalates, Materials: metal oxalates,	Anhydrous Iron Oxalate Anode for Na-Ion Battery	Anhydrous ferrous (II) oxalate has promising electrochemical properties for batteries

No	Researcher / Years / Publisher	Journal Theme	Methods and Material	Application	Findings
11	Lubomir Teoharov et al. (2022) [31] - De Gruyter Brill Publisher (Q3)	Synthesis of Energy Storage, Environmental Remediation	Methods: Drying and Firing Materials: Sodium ferrioxalate ($Na_3Fe(C_2O_4)_3$)	NASICON Cathode for Na-Ion Batteries	NASICON-type $Na_3Fe_2(PO_4)_3$ was synthesized from ferrous oxalate.
12	Atin Pramani et al. (2021) [32] - Journal of Physics: Materials (Q1)	Energy Storage, Environmental Remediation,	Methods: Electrochemical, Characterization techniques Materials: $Na_2Fe(C_2O_4)(HPO_4)$	Oxalate Phosphate Cathode for Li/Na Ion Battery	Stable crystal structure and Fe^{2+} magnetic behavior were confirmed.
13	Yongjia Li et al. (2021) [33] - IOP Conference Series: Earth and Environment	Energy Storage, Environmental Remediation	Methods: thermal decomposition Materials: ferrous oxalate nanowires	Iron Oxalate Composite Anode for Li-ion Battery	Ferrous oxalate nanowires enabled porous α-Fe_2O_3 nanowires with superior gas sensing.
14	Joyce S. Yeoh et al. (2020) [34] - Royal Society of Chemistry (Q1)	Energy Storage, Environmental Remediation	Methods: Electrochemical testing Materials: scrap iron, carbon dioxide	Energy Storage Precursor	The synthesized ferrous oxalate successfully converted CO_2 and scrap iron
15	Chao Hu et al. (2022) [19] – SRRN by Elsevier (Q3)	Energy Storage, Environmental Remediation, Fundamental	Methods: photochemical reduction under Materials: phosphoric acid, oxalate ions	Battery Precursor (High Purity Ferrous Oxalate)	The study achieved a purity of 99.62% ferrous oxalate with less than 120 ppm impurities.
16	Fatemeh Keshavarz et al. (2023) [35] – MDPI Condensed Matter (Q3)	Energy Storage, Environmental Remediation	Methods: electrochemical, Materials: Ferrous oxalate dihydrate	Anode for Li-Ion Batteries	Dehydrated ferrous oxalate shows lower voltage and higher capacity
17	Keyu Zhang et al. (2021) [36] –Chemical Engineering Journal by Elsevier (Q1)	Energy Storage, Environmental Remediation	Methods: Electrochemical tests Materials: iron oxalate (FeC_2O_4),	Iron Oxalate Anode Interface Chemistry	Reversible interface and intermediates enable excellent lithium storage.
18	Vítězslav Heger et al. (2022) [37] - Springer International Publishing AG – Chemical Papers (Q2)	Energy Storage, Environmental Remediation	Methods: and SEM Materials: hydrated polymorphs of iron(II) oxalate dihydrate	Polymorph Study for Li-ion Battery Anode	Heating induces polymorphic changes in anhydrous iron(II) oxalate.
19	Zhijun Luo et al. (2020) [38] – Chemosphere by Elsevier (Q1)	Environmental Remediation and Resource Recovery	Methods: Photoreduction Materials: ferrous oxalate powder, oxalic acid, ferrous sulfate	Phenanthrene Degradation in Contaminated Soil	Ferrous oxalate can effectively degrade phenanthrene in soil via photochemical
20	Abdul Wafi et al. (2023) [39] - Journal of Sustainable Metallurgy (Q1)	Environmental Remediation and Resource Recovery	Methods: leaching, photoreduction, and hydrothermal Materials: Steel waste	Fe(II) Oxalate from Steel Waste for Batteries, Photocatalysts, Pigments	The study successfully developed a sustainable method for the synthesis of Fe(II) oxalate from steel industry waste
21	Yunhui Hua, Zuotai Zhang (2024) [40] - Waste Management by Elsevier (Q1)	Environmental Remediation and Resource Recovery, Fundamental Material Science	Methods: ferrioxalate photolysis Materials: lithium iron phosphate ($LiFePO_4$ or LFP)	Recovery of Li, Fe, P from Used LFP Batteries	Ferrous oxalate (FeC_2O_4) has significant potential in producing materials of economic value
22	Xingying Zhang et al. (2025) [41] IOP Science – Journal of Physic	Environmental Remediation and Resource Recovery	Methods: dealkalization of red mud via drying, grinding, and HCl leaching. Materials: red mud.	Ferrous Oxalate from Red Mud for Batteries	Red mud was valorized into ferrous oxalate and ferric hydroxide.
23	Emiliano Salucci et al. (2024) [42] - MDPI Materials (Q2)	Environmental Remediation and Resource Recovery	Methods: Thermogravimetric Analysis Materials: $FeC_2O_4 \cdot 2H_2O$,	Magnetite Production from Preservation Waste	Iron(II) oxalate dihydrate was converted into crystalline magnetite.
24	Qiang Zeng et al. (2021) [43] – Environmental Research by Elsevier (Q1)	Environmental Remediation and Resource Recovery	Methods: morphology and microstructure Materials: ferrous oxalate, SiO2 and silver ions	Ag+ Remover/ Recovery (SiO_2-supported Ferrous Oxalate)	The composite effectively removed Ag+ ions, with size control of nano silver particles influenced by pH.
25	Irina Makarova et al. (2020) [44] - Separation and Purification Technology by Elsevier (Q1)	Environmental Remediation and Resource Recovery	Methods: Electrochemical leachingMaterials: Spent NdFeB magnets,	Recovery of REE Oxalate (Iron Oxalate as a related compound)	Electro-leaching with oxalic acid significantly increased neodymium leaching

No	Researcher / Years / Publisher	Journal Theme	Methods and Material	Appli cation	Findings
26	Emmanuel De Gregorio et al. (2023) [45] - Chemical Engineering Research and Design by Elsevier (Q2)	Environmental Remediation and Resource Recovery	Methods: Electrochemical, leaching Materials: Red mud's	Iron Oxalate Production from Red Mud	The study successfully produced ferrous oxalate from red mud with good purity.
27	Marina S. Zelenskaya et al. (2021) [46] – MDPI Crystals (Q2)	Environmental Remediation and Resource Recovery	Methods: Cultivation, Analysis of mineral and crystal composition Materials: Siderite ($FeCO_3$) and pyrrhotite ($Fe_{1-x}S$)	Biomineralization, Bioleaching, Environmental Remediation	The study demonstrates that *A. niger* can induce biomineralization of iron and calcium oxalates on mineral surfaces
28	Su In Lee et al. (2022) [20] – MDPI Processes (Q2)	Environmental Remediation and Resource Recovery	Methods: spectrometry or titration Materials: ferrous ammonium sulfate, oxalic acid,	Kinetics of Iron Oxalate Precipitation	Ferrous oxalate formation is primarily dependent on the ferrous ammonium sulfate
29	Jae Kwan Park et al. (2022) [47] - Korean Nuclear Society (Q2)	Environmental Remediation and Resource Recovery	Methods: experimental methods Materials: magnetite, oxalic acid, and ferrous ions	Precipitation Kinetics for Nuclear Power Plant	Higher supersaturation accelerated ferrous oxalate precipitation.
30	Paula Vehmaanperä et al. (2021) [48] Clays and Clay Minerals Journals by Springer (Q2)	Environmental Remediation and Resource Recovery	Methods: DFT simulations Materials: hematite (α-Fe2O3) as the iron oxide source	Humboldtine Formation (Photo-Fenton Oxidation)	Humboldtine precipitates during hematite dissolution in oxalic acid.

Table 1 shows that ferrous oxalate (FeC_2O_4) research for the 2020–2025 period is dominated by its use as a precursor for advanced materials, especially for energy storage, such as Li-ion and Na-ion battery anodes, NASICON cathodes, phosphate oxalate cathodes, and the synthesis of hematite (α-Fe_2O_3). In the environmental field, FeC_2O_4 is widely used as a photocatalytic and Fenton catalyst for pollutant degradation and waste remediation. Sustainability aspects are also increasingly prominent through the synthesis of FeC_2O_4 from various industrial wastes, such as steel waste, red mud, and pickling waste, as well as metal recovery from used LFP batteries. In addition, FeC_2O_4 is used for the synthesis of Fe_5C_2, iron oxalate cement, gas sensors, electrorheological fluids, and material property studies. Overall, the study confirms that ferrous oxalate is a multifunctional precursor that has the potential to support the development of sustainable materials in the energy and environmental fields.

3. Result and Discussion

3.1 Review Result and Discussion Based on Research Theme

Table 2. Ferrous oxalate Research Review Based on Research Theme Category

Research Theme / Researcher	Implementation	The Role of Ferrous oxalate	Uses / Indicators
Catalysts and Adsorbents [23], [24], [25], [26], [27], and [28]	Photocatalysts, Natural Synthesis, and Adsorbent Applications	Photocatalyst ferrous oxalate dihydrate, Nanomaterials Fe_3O_4 layered *Ferrous oxalate,* And Magnetically purifiable catalyst.	Excellent photocatalytic properties, effective for methylene degradation under UV light, Methane synthesis, and can remove heavy metals in water
Energy Storage [14], [29], [30], [22], [31], [32], [33], [34], [19], [35], [36], and [37] .	Lithium-ion Battery (LIB), Sodium-ion Battery (NIB), and Supercapacitor batteries with reduction and oxidation reaction flow	Anhydrous ferrous oxalate (AFO) anode material, cathode material precursor, anode material, and electrode material as well as stabilizer additives	High power storage in LIB batteries with low reaction potential, Iron core source for batteries *Lithium Ferro Phosphate*, and explored for high capacity and stability
Environmental Remediation, Basic Materials [39], [38], [40], [41], [42], [43], [44], [45], [46], [20], [48], [49], [47], [50], and [10]	Environmental remediation, precursor for other materials	Precursor for dielectric, magnetic, and other metal materials	As an intermediary for material synthesis and precursor for iron oxide nanoparticles.
Other Applications [51], [52], [53], [54], [55], [56], [57], and [58]	Pigments and dyes, and Electrorheological (ER) fluids	Building block materials, dyes, and fillers (*ferrous oxalate* rod-shaped)	Used for natural dyes in the textile industry, paint, ink, and good color fastness / stability, and with the changing religiosity properties under electric fields can

Research Theme / Researcher	Implementation	The Role of Ferrous oxalate	Uses / Indicators
			improve ER performance

Table 2 presents the results of a synthesis of previous research on the potential of ferrous oxalate as a sustainable advanced material. Data are grouped by raw material, raw material source, media, methods, and testing technology to analyze research developments from various perspectives. In general, the research includes material synthesis and characterization, electrochemical applications, catalysis, environmental, and thermal studies. The results of the study indicate that ferrous oxalate plays an important role as a photocatalyst, Fenton catalyst, adsorbent, and precursor for the synthesis of magnetic materials, including Fe_3O_4 and α-Fe_2O_3. In the field of energy storage, FeC_2O_4 is used as an anode material and cathode precursor in Li-ion, Na-ion batteries, supercapacitors, and Lithium Iron Phosphate (LFP). In addition, ferrous oxalate is also used as a precursor for dielectric materials, magnetic materials, gas sensors, iron oxalate cement, and electrorheological fluids, and has potential as a pigment and dye. These findings confirm that ferrous oxalate is a multifunctional precursor that supports the development of sustainable materials in various energy, environmental, and industrial sectors.

In general, the results in Table 2 indicate that iron-rich metal waste from various sources, such as mill scale, industrial process sludge, used LFP batteries, red mud, and steel processing waste, have high potential as raw materials for ferrous oxalate synthesis. Despite using different raw materials and synthesis methods, most studies successfully produced ferrous oxalate with high purity and crystal characteristics suitable for various advanced material applications. These findings indicate that the success of the synthesis is influenced not only by the type of waste, but also by the selection of the synthesis method and the control of process parameters, such as reagent concentration, temperature, reaction time, pH, and photoreduction or hydrothermal conditions. Thus, metal waste is no longer viewed as industrial process residue, but as a secondary resource with the potential to produce high-value-added materials, while supporting the concept of waste valorization and a circular economy.

3.2 Review Result and Discussion Based on Raw Material Categories

Table 3. Ferrous oxalate Research Review Based on Raw Material Categories

Source of Raw Materials	Raw material	Sustainability Aspects and Products Produced	Researchers
Steel factory waste	Mill scale	Green synthesis without waste with high economic value, Utilization of waste for battery electrodes, and purity improvement process. The resulting products are Ferrous oxalate Fe(II) and Hematite (Fe_2O_3) with high purity.	[10], [39], [14], [59].
Electronic Waste	LFP Batteries Waste	Waste purification by producing environmentally friendly products, FeC_2O_4, $2H_2O$ and LiH_2PO_4	[40]
Alumina Production Waste	Red mud	Utilization of industrial waste with sustainable processing, produces ferrous oxalate high quality	[45]
Steel Processing Waste	Residue Pickling Process	Utilizing waste into materials with economic value and sustainable industry. Producing magnetite crystals (Fe_3O_4)	[42]
Natural Resources	Mineral sand *Ferrotitaniferous* and Iron ore	A low-cost and environmentally friendly by-product of TiO_2 is Monoclinic α-ferrous oxalate dihydrate. Then the processing of iron ore produces a simple and cost-effective catalyst with abundant and sustainable raw materials.	[23]
Steel Production by-Products	Connverter Slag	Sustainable photocatalyst from steel industry waste produces ferrous oxalate terdoping Mg-Mn	[25] [27]
Copper Industry Waste	Copper Slag	A construction material made from waste that is highly durable and easy to manage. The product produced from this waste processing is Ferrous Oxalate Hydrate Cement (FOC)	[53]
Traditional Iron Waste	CO_2 and Scrap Metal	Sustainable synthesis in dealing with iron-based waste green chemical produce precursor products ferrous oxalate.	[34]

Research on raw material sources for Ferrous Oxalate (FeC_2O_4) synthesis demonstrates a shift toward sustainability and a circular economy, with industrial waste as the primary raw material source. Steel waste, particularly mill scale, is widely utilized to produce FeC_2O_4, hematite, and Fe metal through oxalic acid leaching, photoreduction, hydrothermal, calcination, and carbothermic reduction. Calcination increases the purity of hematite and produces electrode layers suitable for batteries [14], while oxalic acid leaching followed by photoreduction or hydrothermal treatment produces high-purity FeC_2O_4 with different crystal structures and morphologies [39]. Mill scale roasting at 900 °C also produced high purity hematite [59], while carbothermic reduction using coconut fiber-based carbon produced Fe metal in excess of 80 wt% with good corrosion resistance [10].

In addition, red mud from the alumina industry was successfully converted to ferrous oxalate through oxalic acid leaching and ascorbic acid reduction with yields up to 85%[41], as well as through selective leaching and precipitation[45]. Steel pickling waste was utilized to produce FeC_2O_4 and magnetite (Fe_3O_4) of economic value [42], while spent LFP battery waste enabled the recovery of Li, Fe, and P through oxalic acid leaching and ferrioxalate photolysis with very minimal waste [40]. Other studies also utilize converter slag as a photocatalyst precursor[25][27], copper slag for the synthesis of ferrous oxalate (FOC) cement[53], and iron ore and ferrotitaniferous sand as low-cost natural sources for the synthesis of ferrous oxalate while producing TiO_2 as a by-product[23]. Overall, these results confirm that industrial waste and low-cost resources have the potential to become high-value FeC_2O_4 raw materials through a green chemistry approach and support the implementation of a circular economy [34].

Overall, Table 3 shows that no single characterization method can provide complete information about the properties of ferrous oxalate. Therefore, most studies combine several characterization techniques to obtain more comprehensive results. XRD is used to identify the crystal phase and degree of crystallinity, SEM-EDS to evaluate the morphology and elemental composition, while FTIR, XPS, and Mössbauer spectroscopy play a role in confirming the chemical bonding, iron oxidation state, and surface structure of the material. The combination of these techniques improves the reliability of the characterization, allowing for a more accurate evaluation of the relationship between the synthesis method, material structure, and its potential applications.

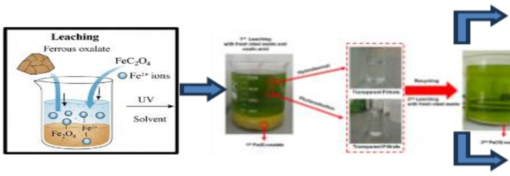
3.3 Review Result and Discussion Based on Media and Method Categories

Tabel 4. Ferrous oxalate Research Review Based on Media and Method Categories

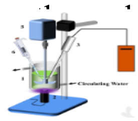
Raw material	Media / Sourc of Oxalic Acid	Methods	Parameters and Result	Researchers
Mill scale dari limbah industry baja	Oxalic Acid	Leaching, Photochemical Reduction, Hydrothermal	By using a sample of 50 mg/mL of steel waste soaked in oxalic acid solution for 3 hours at a temperature of 200^{0}C (hydrothermal), produces Fe(II) Oxalate in the form of rods (4-10 micronmeters), with high purity	[10], [39], [14], and [59].
Baterai LFP Bekas	Oxalic Acid, H_2O_2	Leaching, Fotolysis Ferrioxalate	With the process leaching 0.01 – 0.2 M Fe was soaked in oxalic acid at room temperature with UV for 5 – 120 minutes, producing a high purity with decomposition > 95%.	[40]
phosphor Acid Wet Process (Fe^{3+})	Oxalic Ion	Crystallization, Photochemical Reduction	By adjusting pH, temperature, and light intensity, it produces $FeC_2O_4·2H_2O$ with high purity and quality for batteries.	[41], [45]
Mineral sand *Ferrotitanium iron* and Iron ore	Origin of Oxalic	Use of Pressurized and Hot Liquid Oxalic Acid	By using liquid oxalic acid under pressure and a temperature of 115^{0}C and 135^{0}C, the raw material is soaked for 2 – 12 hours, resulting in monoclinic α-$FeC_2O_4·2H_2O$	[42]
Ferrous Powder	Oxalic Acid	Precipitation and Dehydration	Through heating with heating rates of 1, 2, 10, and 20^{0}C/ min in N_2, yielding an oxalate ferric hydrate (α-$FeC_2O_4·2H_2O$, β-$FeC_2O_4·2H_2O$).	[23]
Hydrated ferric nitrate ($Fe(NO_3)_3·9H_2O$)	Oxalic acid dehydrate	Calcination and Synthesis Solvoterma	Ferric nitrate dehydrate was synthesized for 15 hours at 100^{0}C produces iron oxalate FeC_2O_4 with a size of 150-200 nm.	[25][27]
Red mud	Oxalic Acid and	Leaching, Photocatal	Leaching HCl or oxalic acid is carried out in two	[53] [34]

Raw material	Media / Sourc of Oxalic Acid	Methods	Parameters and Result	Researchers
	Chloride Origin	ysis with two stages of redox reaction	stages, where Fe powder is soaked in ascorbic acid to produce high quality FeC_2O_4 reaching 85%.	

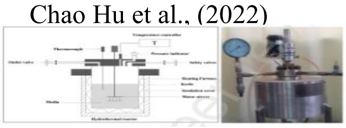
Table 4 and Figure 3 show that the synthesis of ferrous oxalate (FeC_2O_4) from iron-rich waste is carried out using various complementary methods to control the morphology, purity, and crystal phase of the product.



A. Wafi et al. (2023)



Chao Hu et al., (2022)



Zongkui Ruan et al. (2022)

Fugure 3. Leaching, Photoreduction, and Hydrothermal Methods

Oxalic acid acts as both a leaching agent and a precipitating agent, while a combination of leaching, photoreduction, and hydrothermal treatment is the most widely used approach due to its greater sustainability. The differences in methods indicate that synthesis conditions must be tailored to the desired material characteristics.

Leaching is the initial step in dissolving iron using oxalic acid, followed by precipitation of FeC_2O_4 through direct precipitation or reduction of the Fe(III)-oxalate complex to Fe(II). Photoreduction under UV irradiation produces high-purity FeC_2O_4 and has proven effective in the recycling of LFP batteries and phosphate industry waste, with a decomposition efficiency of >95% and a product purity of 99.62%, as the selective reduction of Fe^{3+} minimizes the formation of byproducts. Hydrothermal methods utilize high temperatures and pressures to control crystal nucleation and growth. In mill-scale synthesis, a process at 200°C for 3 hours produces rod-shaped α- and β-$FeC_2O_4 \cdot 2H_2O$ phases (4–10 μm) with high crystallinity. Compared with precipitation methods, hydrothermal processes produce more uniform, purer crystals with fewer defects.

Other methods include thermal conversion/decomposition to produce hematite, magnetite, or carbides, such as the conversion of Fe(II) oxalate from pickling waste into crystalline magnetite and the decomposition of FeC_2O_4 nanowires into porous α-Fe_2O_3 for gas sensors. Coprecipitation is used to form magnesium iron oxalate as a precursor for ferropericlase, while electroleaching, electrodeposition, and s[...] synthesis extend process ([...]othermal synthesis using ferric [...] °C for 15 hours successfully produced FeC_2O_4 nanowires with uniform size of 150–200 nm.

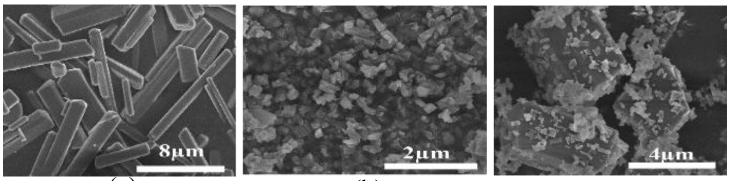
Overall, each synthesis method has different characteristics and advantages according to its intended application. The hydrothermal method is more suitable for producing ferrous oxalate crystals with high morphology and crystallinity, the precipitation method is simpler and more economical for large-scale production, while the photoreduction method is superior in increasing product purity through a more environmentally friendly process. Therefore, the choice of synthesis method is not only determined by process efficiency, but also by the desired material characteristics and the type of metal waste used as raw material.

3.4 Review Result and Discussion Based on Testing Technology Categories

Table 5. Ferrous oxalate Research Review Based on

Testing Technology Categories

Shape	Testing Techniques an	Morphology	Impact	Reasercher
α-FeC_2O_4·$2H_2O$ Humboldtine	XRD, SEM, TEM, Mossbauer, DFT	Shaped like a stable monoclinic prism like a rod with a wider distance between layers.	Improved Lithium diffusion process, has a stable and good cycle, creates photocatalytic activity	[37], [49], [48]
β-FeC_2O_4 $2H_2O$	XRD, SEM, TEM, Mossbauer,	The form of orthorhombic sheets or unstable nano-sized rods	The impact on the small particle size results in the Lithium diffusion process being less stable.	[37]
α@β FeC_2O_4 Mixtute	XRD, SEM, TEM, BET, XPS, DFT	The distribution is more homogeneous with a mixed structure.	High reversible capacity with Lithium movement can be increased, and more stable	
Anhydrous FeC_2O_4 (AFO)	DFT, OCV, Theoretical capacity calculation	Dehydrated form and has high capacity with low voltage	Anode performance. Very high in Lithium batteries, with stable electronic stability.	[22] [22]
Iron Oxalate Nano wires	XRD, SEM, TEM, FTIR, XPS	Homogeneous shape with high ratio	Has high sensitivity, so that gas monitoring is carried out accurately.	Jia et al. (2021, 2020) [12][52]
Doped HAp Fe (From Ferrous Oxalate)	XRD, SEM, TEM, FTIR, BET, EPR, DFT	Shaped like a needle or rod with a smaller and wider size	Can be applied in the medical field as biomedical	Goldberg et al. (2021) [51]
Rod-Shaped Iron(II) Oxalate Particles	SEM, XRD, Mikroskop Optik	Rod-like shape but polarized	With controllable viscosity, it can result in improved electrorheological performance.	[54]
Ferrioxalate complex ($Fe(C_2O_4)_3^{3-}$)	XRD, XPS, SEM, EDX	The material dissolves quickly in water and is sensitive to light.	Used in green recycling with iron precipitation under light	[40]



(a) (b) (c)

Figure 4. SEM Result
(a) α-FeC_2O_4·$2H_2O$ (Humboldtine), (b) β-FeC_2O_4·$2H_2O$, (c) α@β FeC_2O_4 Mixture
Heger et al., (2022)

Table 5 and Figure 4 show that the characterization of ferrous oxalate (FeC_2O_4) was performed using various analytical techniques to ensure the purity, crystal structure, morphology, and functional properties of the material. XRD was the primary technique for phase and crystallinity identification, supported by SEM/FE-SEM and EDS for morphology and elemental distribution analysis, FTIR and Raman for functional group identification, and XRF for elemental composition verification. Thermal, electrochemical, and photocatalytic properties were evaluated using TGA/DSC, EIS, and UV-DRS/PL, while XPS and Mössbauer spectroscopy were used to study the oxidation state, electronic environment, and local bonding of iron. All experimental results were often combined with Density Functional Theory (DFT) calculations to elucidate atomic-scale mechanisms and optimize the design of FeC_2O_4 materials for energy and environmental applications.

Overall, Table 5 and Figure 4 show that the performance of ferrous oxalate is strongly influenced by the relationship between crystal structure, morphology, and the characterization techniques used. The α-FeC_2O_4·$2H_2O$ phase with a rod-shaped morphology and high crystallinity tends to provide better lithium ion diffusion, high cycling stability, and more optimal photocatalytic activity compared to the β-FeC_2O_4·$2H_2O$ phase which has smaller and less stable crystals. Meanwhile, mixed structures (α@β), nanowires, and doped materials can increase the active surface area, homogeneity, and electron and ion transport, thus providing better performance in battery, gas sensor, photocatalyst, and biomaterial applications. These findings indicate that a combination of characterization techniques, such as XRD, SEM, FTIR, XPS, and DFT, is essential to understand the relationship between material structure and its functional properties, thus providing a basis for designing ferrous oxalate according to application needs.

3.5 Review Result and Discussion Based on Ferrous Oxalate Potential Categories

Tabel 6. Ferrous oxalate Review Result Based on Ferrous Oxalate Potential Categories

Implementation	Material	Findings	Researchers
Anoda baterai Lithium-Ion	Hematite (mill scsle), α-FeC_2O_4 and β-FeC_2O_4 Mixture, Anhydrous Fe(II) Oxalate (AFO), FeC_2O_4 Composite	Better charge/discharge capacity, cycle stability, lower charge transfer resistance. Sustainable battery electrodes from industrial waste.	[14], [22], [33], [60],[22]
Common Na-Ion and Ion Battery Cathodes	$Na_2Fe(C_2O_4)(HPO_4)$ and ferrous oxalate	Large-scale, environmentally friendly, and cost-effective energy storage. Promising for ion batteries, efficient, and sustainable.	[32] [30]
LFP Cathode Precursor, Hematite Electrode, CO_2made of iron	Ferrous oxalate	Precursor for synthesizing $LiFePO_4$Efficient and cost-effective energy storage material.	[41], [29], [34]
Catalyst	Ferrous oxalate, AC/α-FOD Composites, Mg-Mn Doped Iron Oxalate, Nano Ferrous Oxalate	Environmentally friendly and sustainable photocatalysts from low-cost natural/waste resources. Used in water treatment, photoreaction, environmental remediation.	[23], [24], [25], [27] [26], [28]
Pigment	Ferrous Oxalate	As a precursor for hematite which produces hydrophobic material for corrosion resistance, and environmentally friendly pigment.	[14], [39], [61]
Cement	Ferrous Oxalate	Sustainable construction materials with high strength oxalate cement	[53]
Proton Conductor	Ferrous Oxalate	Forms a hydrogen bond network in the solid state which is used for humidity sensors.	[50]

Table 6 shows Ferrous Oxalate (FeC_2O_4) covers an extensive range of applications, making it a very valuable precursor material in various industrial sectors. Its main applications are centered on energy storage, where FeC_2O_4 is used as an anode material and precursor for Lithium Ion Batteries (LIBs), providing significant findings in the form of better charge/discharge capacity, high cycle stability, and lower charge transfer resistance. Furthermore, FeC_2O_4 is an essential precursor for the cathode of Sodium-Ion Batteries, which is promising in large-scale energy storage that is environmentally friendly and cost-effective. In addition to energy, the compound ferrous oxalate acts as an ecologically friendly photocatalyst, often synthesized from inexpensive waste resources for water treatment, photoreactions, and environmental remediation. In other sectors, FeC_2O_4 serves as a precursor for environmentally friendly pigments that produce hydrophobic hematite materials for corrosion resistance, sustainable construction materials such as high-strength oxalate cement, and solid proton conductors that form hydrogen bonding networks for humidity sensor applications. Overall, the role of FeC_2O_4 goes beyond simple precursors; it is a fundamental material supporting innovation in energy transition, environmental protection, and sustainable construction materials.

.

4. Conclusion

The findings show that various iron-rich wastes can be effectively converted into ferrous oxalate with high purity through environmentally friendly processes, including leaching, photoreduction, and hydrothermal processes. Ferrous oxalates show tremendous potential in energy storage, heavy metal removal from wastewater, pigments, sustainable cement, electrorheological fluids, and gas sensors. Methods used in the synthesis of ferrous oxalate include Leaching, Photochemical Reduction, Hydrothermal, Solvothermal Calcination and Synthesis, with XRD, SEM, EDX, TEM, Mossbauer, DFT, BET, XPS, EPR, Optical Microscope, and other relevant testing technologies. This review is expected to open new perspectives in the utilization of ferrous oxalate waste or by-products as value-added materials with high economic value. The novelty of this review lies in its scoping review, which integrates metal waste sources, applications, and the economic value of ferrous oxalate into a single framework. However, this review only covers 30 publications from 2020–2025 and does not include quantitative analysis.

Reference

[1] A. Hasanbeigi *et al.*, “Roadmap Net-Zero untuk Industri Baja Indonesia,” May 2025. Accessed: Oct. 28, 2025. [Online]. Available: https://aseanenergy.org

[2] Omer Amar, “Steel’s Sustainability: Metal’s Environment Impact Calculated,” Jul. 2025.

[3] A. M. Predescu *et al.*, “An innovative method of converting ferrous mill scale wastes into superparamagnetic nanoadsorbents for water decontamination,” *Materials*, vol. 14, no. 10, May 2021, doi: 10.3390/ma14102539.

[4] F. Ling Wen Xia *et al.*, “Turning waste into value: Extraction and effective valorization strategies of seafood by-products,” Sep. 01, 2024, *Elsevier B.V.* doi: 10.1016/j.wmb.2024.06.008.

[5] Department of Energy USA, “Steel Industry Technology Roarmapa Chapter 3 Iron Unit Recycling,” Jul. 2025. Accessed: Jul. 28, 2025. [Online]. Available: https://energy.gov/sites/prod/files/2013/11/f4/roadmap_chap3.pdf

[6] Association for Iron and Steel Technology (AIST), “Roadmap for Iron and Steel Manufacturing: Revolutionizing U.S. Global Leadership for a Sustainable Industrial Supply Chain,” 2022.

[7] I. Energy Agency, “Iron and Steel Technology Roadmap Towards more sustainable steelmaking Part of the Energy Technology Perspectives series,” 2025. [Online]. Available: www.iea.org/t&c/

[8] J. Briffa, E. Sinagra, and R. Blundell, “Heavy metal pollution in the environment and their toxicological effects on humans,” Sep. 01, 2020, *Elsevier Ltd*. doi: 10.1016/j.heliyon.2020.e04691.

[9] V. Kumar, S. K. Tyagi, K. Kumar, S. Kumar Tyagi, and R. Singh Parmar, “Heavy Metal-Induced Pollution in the Environment through Waste Disposal,” 2023. [Online]. Available: www.ijrpr.com

[10] D. S. Khaerudini, I. Chanif, D. R. Insiyanda, F. Destyorini, S. Alva, and A. Pramono, “Preparation and Characterization of Mill Scale Industrial Waste Reduced by Biomass-Based Carbon,” *Journal of Sustainable Metallurgy*, vol. 5, no. 4, pp. 510–518, Dec. 2019, doi: 10.1007/s40831-019-00241-x.

[11] D. Andriani, D. R. Suhendra, S. Sutriyatna, R. D. Yani, T. Pratomo, and N. Sa’adah, “Manufacturing of Organic Waste Shredding Machine,” *Turbo : Jurnal Program Studi Teknik Mesin*, vol. 14, no. 1, Jul. 2025, doi: 10.24127/trb.v14i1.4107.

[12] X. Peng *et al.*, “Recycling municipal, agricultural and industrial waste into energy, fertilizers, food and construction materials, and economic feasibility: a review,” Apr. 01, 2023, *Springer Science and Business Media Deutschland GmbH*. doi: 10.1007/s10311-022-01551-5.

[13] G. Office for Science, “From waste to resource productivity: evidence and case studies.”

[14] M. Christwardana, Z. Kurniawan, and D. S. Khaerudini, “From Mill Scale to Hematite: Processing and Electrophoresis Deposition Coating for Sustainable Secondary Battery Electrodes,” *Analytical and Bioanalytical Electrochemistry*, vol. 15, no. 8, pp. 622–636, Aug. 2023, doi: 10.22034/abec.2023.707323.

[15] Anebon Precision Metal Pabrication, “Strategi Daur Ulang Material Berkelanjutan Dalam Pemesinan CNC,” Donguan, China, May 29, 2025.

[16] Acre Metals Ltd, “Stailess Steel Turning Scrap,” Chicago USA, Jul. 30, 2025.

[17] L. Fujian Xinyanchuang Technology Co., “Steel Making Product Foaudry Molten Iron Steel Casting Ladle,” Jul. 30, 2025.

[18] M. Forsyth, “Materials & skills for historic building conservation.”

[19] C. Hu, Y. Wang, and L. Yang, “Preparation of ferrous oxalate as a lithium-ion battery precursor: photochemical reduction-crystallization,” 2022. [Online]. Available: https://ssrn.com/abstract=4388902

[20] S. I. Lee *et al.*, “Precipitation of Ferrous Oxalate from Ferrous Ammonium Sulfate in Oxalic Acid Solution,” *Processes*, vol. 10, no. 11, Nov. 2022, doi: 10.3390/pr10112420.

[21] A. Verma, A. M. Allgeier, A. M. Scurto, D. R. Corbin, and D. A. Fowle, “Sustainable Processes for Critical Metal Recovery using Oxalate Chemistry,” 2021.

[22] V. Gromov, A. Noubir, F. Keshavarz, E. Laakso, B. Barbiellini, and A. Bansil, “Anodic Potential and Conversion Chemistry of Anhydrous Iron (II) Oxalate in Na-Ion Batteries,” *Condens. Matter*, vol. 8, no. 2, Jun. 2023, doi: 10.3390/condmat8020038.

[23] C. S. Valdivieso-Ramírez *et al.*, “Synthesis of Alpha Ferrous Oxalate Dihydrate from Ferrotitaniferous Mineral Sands via Hot Pressurized Aqueous Oxalic Acid: Kinetics and Characterization,” *Minerals*, vol. 14, no. 9, Sep. 2024, doi: 10.3390/min14090891.

[24] S. Galeas *et al.*, “Adsorptive–Photocatalytic Composites of α-Ferrous Oxalate Supported on Activated Carbon for the Removal of Phenol under Visible Irradiation,” *Molecules*, vol. 29, no. 15, Aug. 2024, doi: 10.3390/molecules29153690.

[25] C. Chuaicham *et al.*, “Enhancement of Photocatalytic Rhodamine B Degradation over Magnesium–Manganese Baring Extracted Iron Oxalate from Converter Slag,” *Separations*, vol. 10, no. 8, Aug. 2023, doi: 10.3390/separations10080440.

[26] L. Fu *et al.*, “Ferrous-Oxalate-Modified Aramid Nanofibers Heterogeneous Fenton Catalyst for Methylene Blue Degradation,” *Polymers (Basel)*., vol. 14, no. 17, Sep. 2022, doi: 10.3390/polym14173491.

[27] C. Chuaicham *et al.*, “Preparation of Iron Oxalate from Iron Ore and Its Application in Photocatalytic Rhodamine B Degradation,” *Separations*, vol. 10, no. 7, Jul. 2023, doi: 10.3390/separations10070378.

[28] E. A. Fedorova *et al.*, “Revealing the Mechanism and Kinetics of Fe5C2 Formation From Ferrous Oxalate under CO2 Fischer-Tropsch Conditions Using Time-Resolved In Situ X-Ray Absorption Spectroscopy,” *Chemistry-Methods*, 2025, doi: 10.1002/cmtd.202400058.

[29] P. B. Dahivade, S. N. Pawar, and B. J. Lokhande, "Structural, Morphological, and Electrochemical Analysis of Electrodeposited Iron Oxide Electrodes," *ES Energy and Environment*, vol. 20, Jun. 2023, doi: 10.30919/esee909.

[30] K. Z. Q. W. L. Z. D. C. Y. Y. Geng Gao, "Metal Oxalate-Based Anode Materials: A New Choice for Energy Storage Minerlas Applied in Metal Ion Batteries," 2022.

[31] L. Teoharov, P. Penev, M. Härmas, and A. Jänes, "Synthesis of Na3Fe2(PO4)3 with NASICON-type structure from ferrous oxalate precursor in the presence of colloidal silicon dioxide," *International Journal of Materials Research*, vol. 114, no. 1, pp. 1–6, Jan. 2023, doi: 10.1515/ijmr-2022-0243.

[32] A. Pramanik, A. J. Bradford, S. L. Lee, P. Lightfoot, and A. R. Armstrong, "Na2Fe(C2O4)(HPO4): A promising new oxalate-phosphate based mixed polyanionic cathode for Li/Na ion batteries," *JPhys Materials*, vol. 4, no. 2, Apr. 2021, doi: 10.1088/2515-7639/abe5f9.

[33] Y. Li, G. Gao, Q. Wang, K. Zhang, and Y. Yao, "Synthesis and Electrochemical Performances of Iron Oxalate-Multiwalled Carbon Nanotubes Composite Anode for Lithium-ion batteries," in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing Ltd, Mar. 2021. doi: 10.1088/1755-1315/692/2/022073.

[34] J. S. Yeoh, I. Di Bernardo, N. G. White, V. Otieno-Alego, T. Tsuzuki, and A. Lowe, "Iron-based energy storage materials from carbon dioxide and scrap metal," *Mater. Adv.*, vol. 2, no. 1, pp. 292–302, 2021, doi: 10.1039/d0ma00588f.

[35] F. Keshavarz, M. Kadek, B. Barbiellini, and A. Bansil, "Anodic Activity of Hydrated and Anhydrous Iron (II) Oxalate in Li-Ion Batteries," *Condens. Matter*, vol. 7, no. 1, Mar. 2022, doi: 10.3390/condmat7010008.

[36] K. Zhang *et al.*, "Insights into the interfacial chemistry and conversion mechanism of iron oxalate toward the reduction by lithium," *Chemical Engineering Journal*, vol. 426, Dec. 2021, doi: 10.1016/j.cej.2021.131446.

[37] V. Heger, J. Kopp, V. Procházka, and P. Novák, "Polymorphism of anhydrous iron(II) oxalate," *Chemical Papers*, vol. 78, no. 1, pp. 13–22, Jan. 2024, doi: 10.1007/s11696-023-03122-6.

[38] Z. Luo, Y. Min, L. Qu, Y. Song, and Y. Hong, "Remediation of phenanthrene contaminated soil by ferrous oxalate and its phytotoxicity evaluation," *Chemosphere*, vol. 265, Feb. 2021, doi: 10.1016/j.chemosphere.2020.129070.

[39] A. Wafi *et al.*, "Sustainable Recovery of Fe(II) Oxalate from Steel Industry Waste Using Leaching, Hydrothermal, and Photo-Reduction Routes," *Journal of Sustainable Metallurgy*, vol. 9, no. 3, pp. 1114–1125, Sep. 2023, doi: 10.1007/s40831-023-00714-0.

[40] Y. Hua and Z. Zhang, "Ferrioxalate photolysis-assisted green recovery of valuable resources from spent lithium iron phosphate batteries," *Waste Management*, vol. 183, pp. 199–208, Jun. 2024, doi: 10.1016/j.wasman.2024.05.010.

[41] X. Zhang, W. Chen, S. Fu, and H. Liu, "Experimental Study on the Directional and Graded Conversion of Ferrous Oxalate and Ferric Hydroxide from Red Mud," in *Journal of Physics: Conference Series*, Institute of Physics, 2025. doi: 10.1088/1742-6596/2941/1/012018.

[42] E. Salucci *et al.*, "Valorization of Iron (II) Oxalate Dihydrate Coming from Pickling Processes through Thermal Conversion," *Materials*, vol. 17, no. 18, Sep. 2024, doi: 10.3390/ma17184630.

[43] Q. Zeng, W. Sun, H. Zhong, and Z. He, "Efficient and selective removal of Ag+ as nano silver particles by the composite of SiO2 supported nano ferrous oxalate," *Environ. Res.*, vol. 202, Nov. 2021, doi: 10.1016/j.envres.2021.111696.

[44] I. Makarova *et al.*, "One-step recovery of REE oxalates in electro-leaching of spent NdFeB magnets," *Sep. Purif. Technol.*, vol. 251, Nov. 2020, doi: 10.1016/j.seppur.2020.117362.

[45] E. De Gregorio, A. Occhicone, F. Montagnaro, G. Roviello, L. Ricciotti, and C. Ferone, "A novel method of iron oxalate production through the valorization of red mud," *Chemical Engineering Research and Design*, vol. 194, pp. 95–104, Jun. 2023, doi: 10.1016/j.cherd.2023.04.036.

[46] M. S. Zelenskaya, A. R. Izatulina, O. V. Frank-Kamenetskaya, and D. Y. Vlasov, "Iron oxalate humboldtine crystallization by fungus aspergillus niger," *Crystals (Basel).*, vol. 11, no. 12, Dec. 2021, doi: 10.3390/cryst11121591.

[47] J. Kwan Park *et al.*, "Precipitation Kinetics of Ferrous Oxalate in Oxalic Acid Depending on Hydrogen Peroxide and Iron Catalyst for NPP Chemical Decontamination," 2022.

[48] P. Vehmaanperä, B. Gong, P. H. L. Sit, R. Salmimies, B. Barbiellini, and A. Häkkinen, "Formation Of Humboldtine During The Dissolution Of Hematite In Oxalic Acid – Density Functional Theory (Dft) Calculations And Experimental Verification," *Clays Clay Miner.*, vol. 69, no. 6, pp. 655–662, Dec. 2021, doi: 10.1007/s42860-021-00146-5.

[49] H. Müller, L. Bourcet, and M. Hanfland, "minerals Iron(II)oxalate Dihydrate-Humboldtine: Synthesis, Spectroscopic and Structural Properties of a Versatile Precursor for High Pressure Research," 2021, doi: 10.3390/min.

[50] A. Lozančić, S. Burazer, S. Renka, K. Molčanov, L. Molčanov, and M. Jurić, "Proton transport in oxalate compounds of iron(iii) containing (alkyl)ammonium cations: the influence of the density of hydrogen bonds on conductivity," *CrystEngComm*, 2024, doi: 10.1039/d3ce01267k.

[51] M. A. Goldberg *et al.*, "Mesoporous iron(Iii)-doped hydroxyapatite nanopowders obtained via iron oxalate," *Nanomaterials*, vol. 11, no. 3, pp. 1–21, Mar. 2021, doi: 10.3390/nano11030811.

[52] Y. Jia, J. Ni, and F. Fang, "Thermal decomposition of ferrous oxalate nanowires to porous nanowire-like α-Fe2O3 with a good gas-sensing properties," *Mater. Sci. Semicond. Process.*, vol. 125, Apr. 2021, doi: 10.1016/j.mssp.2020.105650.

[53] Z. Luo *et al.*, "Preparation and characterization of ferrous oxalate cement—A novel acid-base cement," *Journal of the American Ceramic Society*, vol. 104, no. 2, pp. 1120–1131, Feb. 2021, doi: 10.1111/jace.17511.

[54] E. Kutalkova, A. Ronzova, J. Osicka, D. Skoda, and M. Sedlacik, "The influence of synthesis conditions on the electrorheological performance of iron(II) oxalate rod-like particles," *Journal of Industrial and Engineering Chemistry*, vol. 100, pp. 280–287, Aug. 2021, doi: 10.1016/j.jiec.2021.05.011.

[55] Y. Xiao, T. Sun, and Y. H. Zhao, "Experimental study on preparation of ferropericlase by oxalate

coprecipitation," *Minerals*, vol. 10, no. 2, Feb. 2020, doi: 10.3390/min10020179.
[56] L. V. Lutkus, A. Krytenberg, J. Taylor, A. Bhattacharjee, B. A. Steinkamp, and T. M. McCormick, "Simplification of the potassium ferrioxalate actinometer through carbon dioxide monitoring," *Can. J. Chem.*, vol. 101, no. 3, pp. 171–176, Sep. 2022, doi: 10.1139/CJC-2022-0188.
[57] Y. Zhao *et al.*, "Acid leaching of vivianite separated from sewage sludge for recovering phosphorus and iron," *Water Res.*, vol. 266, Nov. 2024, doi: 10.1016/j.watres.2024.122361.
[58] K. de Fátima Ulbrich and C. E. M. de Campos, "Obtaining of hematite from industrial steel waste using dry-milling and high temperature," *Clean. Eng. Technol.*, vol. 5, Dec. 2021, doi: 10.1016/j.clet.2021.100327.
[59] M. T. Aldiramadan, J. Nabilah, M. Ridwan, and D. S. Khaerudini, "Numerical simulation and experimental study on hematite production by oxidation of mill scale," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1195, no. 1, p. 012044, Oct. 2021, doi: 10.1088/1757-899x/1195/1/012044.
[60] Z. Fang, L. Zhang, W. Huang, F. Cheng, W. Liu, and K. Yang, "Prepared Fe 3 O 4 /rSCCO-700 by ball milling-roasting method from spent carbon cathode as anode for lithium ion batteries," 2023. [Online]. Available: https://ssrn.com/abstract=4963299
[61] R. M. Iqbal *et al.*, "Surface Modification of Hematite using Stearic Acid as Hydrophobic Inorganic Pigment Materials," vol. 26, p. 2025, 2025, doi: 10.55981/jsmi.8982.