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Thermal Decomposition of Metal Chlorides: Mechanisms, Kinetics, Gas–Solid Coupling, and Metallurgical Process Integration—A Critical Review

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Abstract

Thermal conversion of metal chlorides connects chloride hydrometallurgy, high-temperature metallurgy, oxide manufacture, and reagent recovery, yet the term “decomposition” frequently obscures distinct dehydration, hydrolysis, oxidation, volatilization, and reduction mechanisms. This critical review compares magnesium, iron, aluminum, rare-earth, and selected transition-metal chloride systems using mechanistic, thermodynamic, kinetic, and process-engineering evidence reported between 1980 and 2026. The literature is evaluated by feed identity, reactive atmosphere, phase-resolved products, gaseous chlorine species, and level of experimental validation. Particular attention is given to competing formation of anhydrous chlorides, oxychlorides, and oxides, the limited transferability of apparent activation energies, and the effects of droplet and particle transport in thermal reactors. The study assesses industrial cases through chloride-to-oxide conversion, spray roasting, pyrohydrolysis, and integrated acid regeneration. The synthesis shows that product selectivity is not determined by furnace temperature alone but by coupled water and oxygen potentials, residence-time distributions, and chlorine removal or recycle. We propose a decision framework that links thermodynamic screening, in situ characterization, kinetic discrimination, chlorine mass balance, and process integration. The review identifies priorities for defensible scale-up, including multicomponent feed testing, closed chlorine balances, and reactor models verified against phase- and gas-resolved measurements.

Keywords: Metal chlorides; Thermal decomposition; Pyrohydrolysis; Reaction kinetics; Gas–solid interactions; Chlorine recovery

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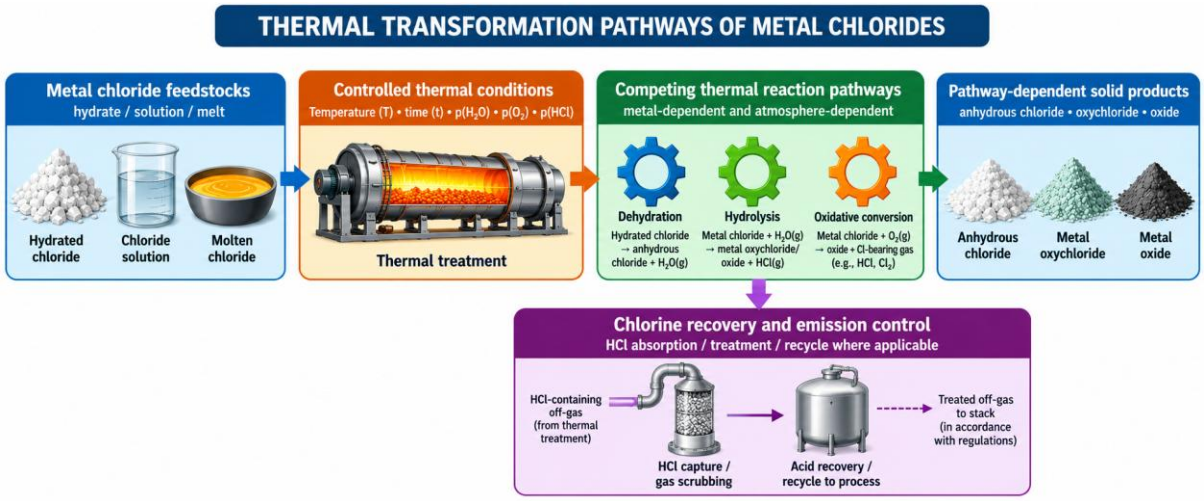
Highlights

- Chloride conversion involves competing dehydration, hydrolysis, and oxidation pathways.
- Reactive-gas potentials govern oxide, oxychloride, and anhydrous-salt selectivity.
- Apparent kinetic parameters require phase-resolved and transport-aware validation.
- Integrated chlorine capture determines the value of industrial chloride processing.

Graphical abstract



1. Introduction

Chloride chemistry offers high dissolution rates, tunable metal speciation, and options for thermal reagent regeneration. Its process advantage is conditional, however, because a chloride-rich liquid, a crystalline hydrate, and a nominally anhydrous salt may enter fundamentally different thermal reaction networks. In practice, dehydration is often inseparable from partial hydrolysis, and an oxide product may emerge through oxychloride intermediates rather than direct cleavage of a dry metal–chlorine bond (Huang et al., 2011; Peek, 2011; Smeets et al., 2013; Van Weert & Peek, 1992).

The technological stakes extend beyond product yield. In steel-pickling regeneration, iron chloride conversion is valuable only when oxide quality and recycled hydrochloric acid meet process requirements; in magnesium production, unintended hydrolysis consumes chloride while contaminating anhydrous feed; in rare-earth processing, oxychloride stability

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may impede oxide formation or offer a deliberate separation route (Ferreira & Mansur, 2011; Kipouros & Sadoway, 2001; Regel-Rosocka, 2010; Yamamoto et al., 2018). Figure 1 introduces the competing-pathway logic, while Tables 1 and 2 distinguish reaction classes and representative chemical systems. Figure 2 addresses evidential requirements for mechanism claims, Figure 3 outlines industrial integration, and Figure 4 consolidates route-selection decisions. Tables 3 and 4 further summarize engineering constraints and research priorities.

This review critically tests five propositions: (i) whether decomposition mechanisms can be generalized across chloride families; (ii) whether thermodynamic endpoints are compatible with measured intermediate phases; (iii) whether reported kinetic constants isolate chemistry from heat and mass transport; (iv) whether chlorine-bearing gases are adequately measured and recovered; and (v) whether laboratory findings support design or scale-up. The intention is not to rank salts by a single nominal decomposition temperature but to establish the conditional evidence needed for a defensible process choice (Cheng et al., 2025; Schiemann et al., 2012; Schiemann et al., 2013; Xu et al., 2025).

2. Review Scope, Literature Selection, and Evidence Grading

2.1. Scope and source selection

The initial bibliography for this review includes 81 documentary entries spanning 1980–2026, assembled using search terms for chloride decomposition, pyrohydrolysis, spray roasting, and rare-earth oxychloride. Because the compilation explicitly identifies incomplete retrospective auditing, this manuscript uses a selected, topic-matched subset rather than representing all 81 entries as independently verified. Preference was given to journal studies with identifiable chemistry, experimental conditions, characterization, or industrial application. Peripheral studies on thermal storage, corrosion, or generalized chloride processing were used only where they directly inform impurity control, atmosphere effects, or reactor interfaces.

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The working bibliography contained 81 documentary records. Following assessment of topical relevance and the available bibliographic details, 51 references were retained for direct citation in the final review, whereas 30 working entries were not included in the final cited bibliography. The original compilation did not preserve a complete record-by-record retrospective search and exclusion ledger; therefore, this numerical difference must not be presented as a systematic screening flow or as evidence that each discarded record failed a particular eligibility criterion. The retained works support the narrative synthesis, with foundational older investigations preserved where chemically indispensable. Search provenance, last-search date, language restrictions, and the extent of citation chaining should be reported only if supported by verifiable records; they cannot be reconstructed reliably from the surviving manuscript alone.

2.2. Critical appraisal framework

Evidence is classified by proximity to the target question: direct conversion experiments on the chloride of interest; analogous chloride or closely related feed studies; and general thermodynamic or engineering evidence. We further evaluate each study for its identification of the incoming hydration state, gas composition, intermediate solids, product-phase identification, and chlorine balance. This distinction matters because reports of final oxide production do not automatically resolve intermediate hydrolysis, and thermogravimetric mass loss cannot, by itself, distinguish escaping H_2O from HCl (Galwey & Laverty, 1989; Huang et al., 2010; Karunadasa et al., 2023; Xue et al., 2017).

The direct/analogous/general evidence hierarchy is an author-developed qualitative appraisal framework specific to this review; it is neither a validated risk-of-bias instrument nor a quantitative certainty-of-evidence scale. Direct evidence addresses a specified chloride feed and operating atmosphere, analogous evidence informs plausibility in related chloride systems, and general evidence supplies thermodynamic or reaction-engineering boundary conditions. Conclusions derived from analogous or general evidence are qualified accordingly.

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The analysis is narrative and critical, not a systematic meta-analysis. No pooled activation energies or numerical treatment efficiencies are calculated because temperature programs, vapor pressures, heating rates, feed geometries, and conversion definitions are not consistently normalized. The evidence categories used below should therefore be interpreted as a transparent appraisal of reported mechanisms, not as a formal risk-of-bias scoring instrument.

3. Thermodynamic Foundations and Chemical Boundaries

3.1. Dehydration, hydrolysis, and oxidation are distinct

Hydrate dehydration can be written schematically as $MCl_x \cdot nH_2O(s) \rightleftharpoons MCl_x \cdot (n-m)H_2O(s) + mH_2O(g)$, provided a stable lower hydrate exists. A competing hydrolysis pathway consumes coordinated water and produces metal–oxygen bonds while evolving HCl, while an oxidizing pathway may convert chloride to an oxide, producing chlorine-containing gas products. The validity of each idealized equation depends on the metal oxidation state, species activities, and the actual phases present (Huang et al., 2011; Smeets et al., 2013; Yang et al., 2021).

For divalent magnesium chloride, a useful limiting description is $MgCl_2(s) + H_2O(g) \rightleftharpoons MgOHCl(s) + HCl(g)$, followed, under appropriate conditions, by $MgOHCl(s) \rightleftharpoons MgO(s) + HCl(g)$. These schematic relations highlight that lowering the HCl partial pressure or increasing water availability can shift product selectivity; they do not prescribe a universal temperature for conversion. Equilibrium calculations should explicitly accommodate hydrates and oxychlorides rather than forcing a two-species chloride/oxide assumption (Galwey & Laverty, 1989; Huang et al., 2010; Kipouros & Sadoway, 2001; Pathak et al., 2016).

3.2. Gas chemical potentials and phase fields

The equilibrium driving force depends on $\Delta G = \Delta G^\circ + RT \ln Q$. For gas-forming steps, Q includes activities or fugacities of H_2O, HCl, oxygen, and potentially Cl_2. Consequently, the

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same solid feed may appear stable in HCl-rich atmospheres but convert readily when chloride is stripped by sweeping or absorption. Apparent disagreements among published thermal endpoints may therefore arise from differing purge rates, open versus closed sample pans, gas humidity, and residence time (Hartman et al., 2005; Smeets et al., 2013; Yang et al., 2022; Yang et al., 2021).

Strictly, the reaction quotient Q is dimensionless: each gaseous species contributes a fugacity ratio f_i/f° (or an appropriately justified activity), and condensed species contribute activities relative to defined standard states. Partial pressures provide useful approximate operating descriptors under ideal-gas conditions; nonideal HCl–H_2O–O_2–Cl_2 mixtures require fugacity corrections or a suitable thermodynamic model. The reference pressure, standard state, gas composition, and assumptions used for any calculated equilibrium boundary must be declared.

Oxygen must not be treated as an interchangeable substitute for steam. Oxidative chlorination and hydrolysis have different gas products, and Cl_2 should not be assumed as the primary gaseous chlorine form when conversion is dominated by water-driven HCl evolution. The direct identification of gases is essential, especially in multivalent transition-metal systems and any process integrating hot off-gas with downstream capture (Jóźwiak & Maniecki, 2005; Suleiman et al., 2011; Zhou et al., 2021).

Table 1 organizes these distinctions into process-relevant reaction families.

Table 1. Reaction families and their diagnostic signatures

Pathway	Main control	Typical indication	Critical ambiguity
Dehydration	Water vapor pressure; heating program	Water loss; lower hydrate / dry salt	Simultaneous HCl release
Hydrolysis	H_2O/HCl potentials	Oxychloride/hydroxyl chloride; HCl	Intermediate phase may be transient
Oxidation	O_2 potential and metal valence	Oxide; chlorine-bearing gas	Mixed oxidative–hydrolytic pathways
Volatilization	Vapor pressure; gas removal	Feed loss without solid oxide	Condensation elsewhere in train

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Pathway	Main control	Typical indication	Critical ambiguity
Reduction/dechlorination	Reductant potential	Lower chloride/metal	Reductant and by-product balance

Note. This review synthesizes pathways and operating requirements from the cited studies; they depend on the feed, atmosphere, and reactor.

The classification makes clear why mass loss is an insufficient mechanism label. At minimum, a defensible assignment combines evolved-gas evidence with phase-resolved solid characterization.

4. Mechanistic Pathways and Intermediate Phases

4.1. Hydrate reaction sequences

Magnesium chloride hydrates provide a particularly informative example of branching pathways. Differential thermal methods and mechanistic studies show that the dehydration sequence cannot be interpreted independently of hydrolysis and the resulting production of basic chlorides or magnesium oxide. Recent in situ diffraction work strengthens intermediate-phase identification but still requires comparison with the actual gas composition experienced during heating (Galwey & Laverty, 1989; Huang et al., 2011; Huang et al., 2010; Karunadasa et al., 2023).

Additive-assisted dehydration strategies, including salt mixtures and alternative coordination environments, aim to limit unwanted oxychloride formation. Nevertheless, lowering an observed transformation temperature is not necessarily equivalent to improving yield of sufficiently pure anhydrous $MgCl_2$: additives may alter phase equilibria, generate secondary salt streams, or introduce impurity species to an electrolysis feed (Kipouros & Sadoway, 2001; Li et al., 2025a, 2025b; Pruttskov et al., 2024; Zhang et al., 2014; Zhang et al., 2019).

Figure 1 summarizes the conceptual competition among pathways, including gas recovery.

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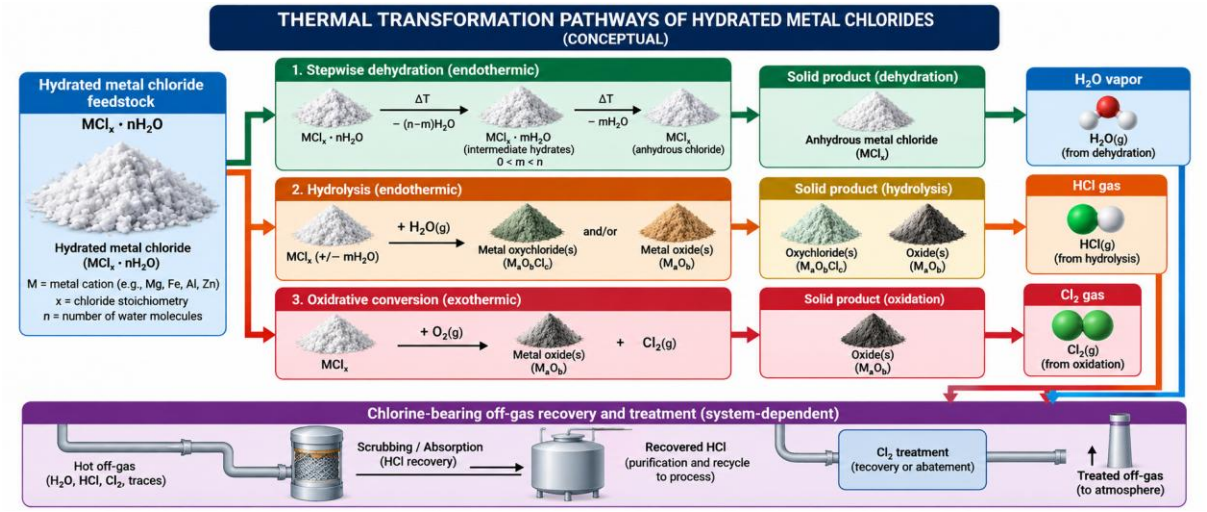

Figure 1. Competing dehydration, hydrolysis, and oxidative conversion pathways for generic metal chloride hydrates.
Note. Original conceptual diagram developed for this review, informed by mechanistic themes in the cited literature; not adapted from a single published figure.

Figure 1 should be read as a branching schematic rather than a universal kinetic sequence. Metal-specific phase diagrams, oxygen potential, and evolved-gas measurements are necessary before assigning any depicted route to an industrial feed.

4.2. Rare-earth chloride-to-oxychloride conversion

Rare-earth trichlorides frequently pass through oxychloride-bearing states when heated in environments containing oxygen or moisture. Experimental dehydration schemes for Nd, Tb, and Dy and studies on cerium chloride establish why “oxide production” can require multiple controlled stages. Conversion to REOCl is not always a failure: its stability can supply a chemically useful separation variable when the target product or flowsheet is defined appropriately (Sundström & Van Hong, 1997; Van Hong & Sundström, 1997; Xue et al., 2017; Yamamoto et al., 2018; Yang et al., 2022).

For cerium, oxidation state changes and aerosol geometry further complicate the route from chloride precursor to CeO_2. Spray-pyrolysis demonstrations show a viable, short preparation route, but their reported product attributes must be interpreted alongside chloride

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removal, droplet residence times, and downstream calcination. La hydroxychloride and mixed rare-earth hydroxychloride studies similarly show that precursor identity strongly affects the thermal solid phase attained (Teplonogova et al., 2024; Tian et al., 2024; Wei et al., 2025; Wu et al., 2021).

4.3. Iron, aluminum, and transition-metal chlorides

Iron chlorides represent both a volatile chloride chemistry problem and an established acid-regeneration opportunity. Spray-roasting conversion depends on liquid atomization, iron oxidation state, and the spatial distribution of H_2O, O_2, and HCl. Aluminum chloride chemistry is equally feed-state sensitive: anhydrous chloride volatility must be separated from the thermal decomposition of aluminum chloride hexahydrate, which follows hydrate-mediated processes with distinct phase products (Hartman et al., 2005; Park et al., 2000; Pereira, 2026b; Schiemann et al., 2012; Schiemann et al., 2013; Yang et al., 2021; Zhang et al., 2018).

Transition-metal compounds cannot be collapsed into one canonical oxide-forming equation. Noble-metal chloride decomposition varies with atmosphere, copper chlorides participate in reversible redox/chlorine chemistry, and FeOCl may be deliberately stabilized as a functional material rather than fully converted to an oxide (Jóźwiak & Maniecki, 2005; Suleiman et al., 2011; Yu et al., 2023).

5. Comparative Behaviour of Representative Chloride Systems

The qualitative comparisons in Table 2 emphasize observed mechanistic tendencies instead of artificial universal decomposition temperatures. Temperature alone is not a meaningful design descriptor unless hydration state, atmosphere, and measurement method are specified (Hartman et al., 2005; Kipouros & Sadoway, 2001; Xue et al., 2017; Yang et al., 2021).

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Table 2. Representative chloride systems: desired routes and competing outcomes

System	Useful outcome	Main competing pathway	Required evidence
$MgCl_2 \cdot 6H_2O$	Low-oxide anhydrous $MgCl_2$	MgOHCl and MgO via hydrolysis	XRD; residual O/Cl; HCl/H_2O
$FeCl_2$ / $FeCl_3$ liquors	Fe_2O_3 plus regenerated HCl	Incomplete oxidation or chloride carry-over	Iron oxide phase; acid strength; total Cl
$AlCl_3 \cdot 6H_2O$	Al-containing oxide / controlled precursor	Complex hydrate and chloride volatility	Solid phases; gas speciation
$RECl_3 \cdot nH_2O$	REOCl or RE_2O_3 (target-dependent)	Persistent oxychloride; chloride losses	REOCl/oxide ratio; chloride closure
$CeCl_3$ solution droplets	CeO_2 particles	Incomplete conversion; residual chloride	Particle morphology; residual Cl
Selected Cu/Fe oxychlorides	Functional phase or full conversion	Atmosphere-sensitive redox steps	In situ phase + gas evidence

Note. We developed the synthesis for this review from the cited studies; pathways and operating requirements depend on the feed, atmosphere, and reactor.

As Table 2 illustrates, magnesium and oxide-production routes may demand opposite operating strategies: the former seeks to suppress hydrolysis, whereas a chloride-to-oxide process typically exploits it while capturing generated HCl.

The comparison also cautions against transferring rare-earth observations directly between elements. Valence preferences, hydroxychloride stability, and precursor composition can change the dominant sequence. Similarly, anhydrous chloride synthesis and chloride decomposition are inverse operations only in a simplified thermodynamic sense; industrial irreversibilities, separation steps, and impurity partitioning make them operationally distinct (Shah et al., 2024; Tian et al., 2024; Yamamoto et al., 2018; Yang et al., 2022).

6. Reaction Kinetics and Measurement Quality

6.1. Rate laws and conversion definitions

A common empirical description is $d\alpha/dt = k(T)f(\alpha)$, with $k(T) = A \exp(-E_a/RT)$, where α is an explicitly defined conversion fraction, A is the apparent pre-exponential factor, E_a is an apparent activation energy, and $f(\alpha)$ represents a proposed conversion function. For multistep

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chloride hydrates, α inferred from total weight loss may combine water release, HCl production, and chloride volatility, so an apparently precise activation energy may have limited mechanistic meaning (Huang et al., 2010; Janković et al., 2023; Xu et al., 2021).

The meaning of α must be specified separately for the event under investigation (e.g., dehydration extent, HCl-evolution extent, chloride conversion, or oxide-formation extent), preferably from a chemically selective analytical signal and a defined initial/final basis. For a linear temperature program, $\beta = dT/dt$ and $d\alpha/dT = (A/\beta) \exp[-E_a/(RT)] f(\alpha)$, provided that the proposed single-step apparent model is appropriate. This relation does not remove ambiguities created by overlapping dehydration, hydrolysis, and volatilization.

Model selection should test whether the reaction is isothermal, whether its onset is controlled by nucleation, whether a product crust blocks diffusion, and whether internal temperature differs from furnace temperature. Results from a milligram-scale thermogravimetric sample should not be used directly to size a heated particle bed without explicitly addressing temperature gradients and vapor removal (Galwey & Laverty, 1989; Karunadasa et al., 2023; Schiemann et al., 2012; Xu et al., 2025).

6.2. Apparent activation energy and identifiability

Isoconversional analyses may reveal changes of apparent E_a with α, signaling overlapping steps, changing transport regimes, or a nonuniform solid reaction. However, neither a high linear-regression coefficient nor agreement with a named solid-state model proves a molecular mechanism. Mechanistic attribution requires independent phase observations and, ideally, varied sample mass, heating rate, purge flow, and vapor partial pressure (Huang et al., 2011; Huang et al., 2010; Janković et al., 2023; Korzun et al., 2018).

Reports of E_a should specify its confidence interval or another uncertainty measure, the conversion interval, the number and range of heating rates, the estimation procedure, and model assumptions. Small differences in fitted E_a cannot be assigned chemical significance without

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uncertainty analysis. At minimum, tests varying sample mass, purge rate, particle size, and heating rate should probe transfer limitations; Biot-type heat-transfer criteria and internal/external mass-transfer assessments can be used where geometry and property data permit.

Figure 2 presents an experimental triangulation scheme. Its central principle is that kinetic model fitting becomes persuasive only when gas identity, solid phase, and material balance are mutually consistent.

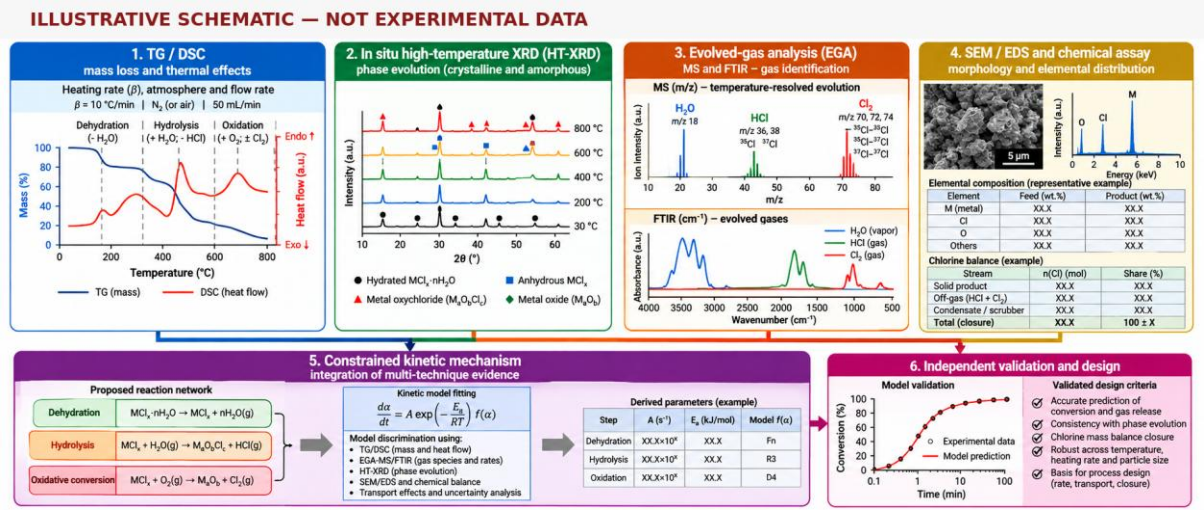

Figure 2. Evidence triangulation required for reliable kinetic and mechanistic attribution.
Note. Original conceptual figure developed for this review; inspired by thermal-analysis and in situ characterization approaches in the cited studies, with no direct graphic reproduction. Illustrative schematic—not experimental data. All curves, numerical-looking axes, diffraction patterns, spectra, images, and fit panels are schematic placeholders, not a single measured dataset.

The diagram distinguishes complementary diagnostics. Thermogravimetric analysis supplies a mass trajectory, not unique chemical speciation; gas spectroscopy and diffraction provide the additional constraints needed to distinguish coincident pathways.

6.3. Transport-coupled conversion

Mechanistic validation requires linked sample identity, calibrated temperature and gas flow, measured gas humidity, appropriate blank corrections, and phase- and chlorine-resolved

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analytical cross-checks. The illustrative datasets in Figure 2 should not be interpreted as results from a single experimental campaign.

Within a droplet or porous particle, the latent heat of evaporation, thermal conduction, diffusion of chloride-bearing gases, and evolving pore structure operate simultaneously. Numerical investigations of bischofite droplets and industrial iron chloride spray roasting reinforce the point that measured conversion may depend on atomization and reactor hydrodynamics as strongly as intrinsic reaction chemistry (Schiemann et al., 2012; Schiemann et al., 2013; Xu et al., 2025).

A practical hierarchy separates intrinsic reaction parameters, particle- or droplet-scale heat and mass transfer, and reactor-scale residence-time distributions. Validation at one scale cannot substitute for the next. For instance, a computational fluid dynamics model may predict average outlet gas temperature while still missing the distribution of residual chloride in individual oxide particles (Cheng et al., 2025; Schiemann et al., 2013; Wang et al., 2024a).

7. Gas–Solid, Gas–Liquid, and Multicomponent Interactions

7.1. Evolved chlorine species and local equilibrium

The preferred chlorine sink can vary from HCl in steam-driven pyrohydrolysis to Cl_2 in particular oxidative chloride chemistries, while unchanged chloride may volatilize and later condense. Sampling close to the reactor outlet should discriminate HCl, molecular chlorine where relevant, entrained chloride aerosol, and condensable metal chlorides. A bulk “total chloride” value at the stack cannot resolve the elementary gas pathway (Suleiman et al., 2011; Van Weert & Peek, 1992; Zhou et al., 2021).

Local accumulation of HCl can impede hydrolysis even when the nominal sweep atmosphere is favorable. Conversely, unplanned ingress of moist air can initiate hydrolysis of anhydrous process salts. Thus, both equilibrium and transient transfer phenomena must be

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considered when designing sealed systems, staged contactors, or recycle-gas configurations (Kipouros & Sadoway, 2001; Smeets et al., 2013; Zhao & Gomez-Vidal, 2020).

Measurement protocols should distinguish molecular HCl and Cl_2 from entrained chloride aerosols, condensed metal chlorides, and chloride-bearing oxide particulates. Cooling, condensation, wall adsorption, and reactions within sampling lines can change measured speciation; heated lines, phase-resolved particle capture, preservation tests, and sampling-train blanks should therefore be selected and documented as appropriate to the gas matrix.

7.2. Impurities, double salts, and coexisting phases

Commercial feeds contain alkali salts, alkaline-earth chlorides, sulfates, and oxides that modify water activity, melting behavior, pore structure, and metal selectivity. Mixtures containing potassium, ammonium, or aluminum salts can modify dehydration trajectories, but a process-level evaluation must account for additive inventory and any downstream impurity penalties (Li et al., 2025a, 2025b; Pruttskov et al., 2024; Zhang et al., 2014; Zhang et al., 2019).

Residual MgO and MgOHCl in high-temperature chloride media highlight the need to analytically distinguish among dissolved, suspended, and reacted impurities. Complementary chemical methods are needed because low impurity concentrations may still materially affect corrosion, electrolysis, or oxide quality (Klammer et al., 2020; Zhao & Gomez-Vidal, 2020).

8. Industrial Applications and Integrated Process Configurations

Industrial spray-roasting performance depends on the evolution of droplet-size distributions rather than on a nominal diameter alone. Reactor validation therefore requires measured or independently constrained residence-time distributions, residual-chlorine distributions in the product, and agreement between predicted and measured phase fractions over a representative operating envelope.

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8.1. Magnesium chloride dehydration

Anhydrous magnesium chloride production is a selectivity challenge: the route must remove coordinated water while minimizing formation of MgOHCl and MgO. Thermochemical analysis, molecular modeling, and improved dehydration schemes all indicate the need to couple atmosphere control with staged thermal treatment. A seemingly higher percentage of water removal is not a sufficient success metric; residual oxygenated impurities and chloride yield are decisive (Kipouros & Sadoway, 2001; Pathak et al., 2016; Pruttskov et al., 2024; Zhang et al., 2019).

8.2. Iron chloride spray roasting and acid regeneration

Spent steel-pickling liquors illustrate a more integrated objective: convert iron chloride to a usable iron oxide and regenerate hydrochloric acid for return to pickling. Bench and reactor-model studies emphasize coupled atomization, droplet heating, chloride conversion, separation of entrained oxide, and acid absorption. Plant performance must be evaluated by recycled acid quality and iron oxide attributes, not merely by nominal chloride decomposition (Bascone et al., 2016; Ferreira & Mansur, 2011; Gao et al., 2021; Regel-Rosocka, 2010; Schiemann et al., 2012; Schiemann et al., 2013).

Figure 3 locates the principal recovery interfaces in a schematic integrated route.

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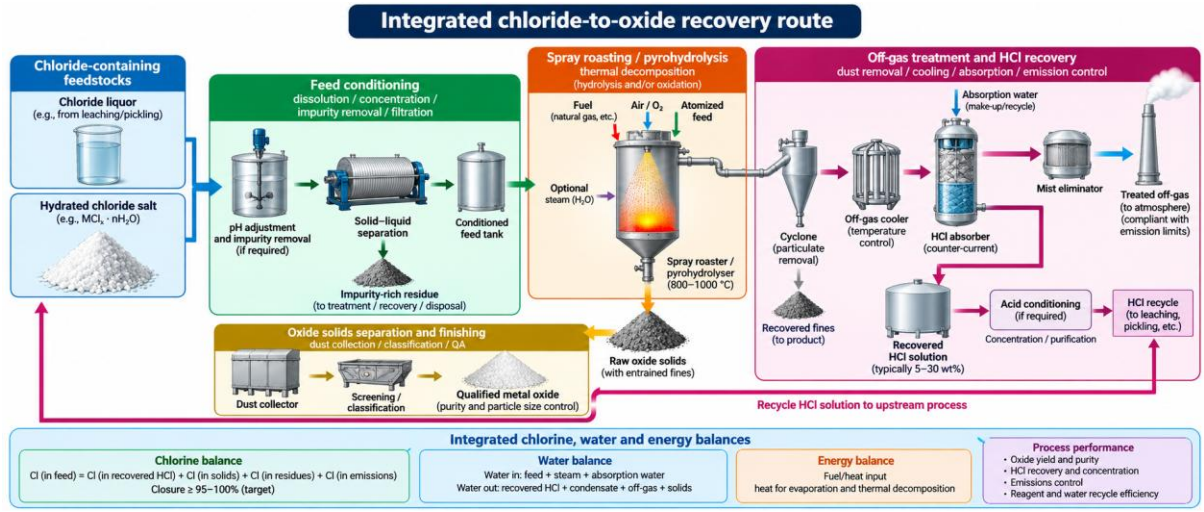

Figure 3. Conceptual process integration for chloride-to-oxide conversion and hydrochloric acid recovery.
Note. Original simplified process flow diagram developed for this review from general process principles discussed in spray-roasting and acid-regeneration studies; not adapted from a particular plant flowsheet.

The solids circuit and gas-recovery circuit must be evaluated together. Dissolved chloride in oxide, particulate carry-over to the absorber, and acid concentration determine whether the process actually closes its reagent loop.

8.3. Rare-earth oxides and specialty materials

Short-route spray pyrolysis from rare-earth chloride solutions can combine drying, intermediate formation, and oxide generation in one intensively heated apparatus. However, a high-quality oxide requires control of particle size, morphology, residual chloride, and the fate of liquid or gaseous impurities. Current rare-earth process reviews underscore the potential for integrated chloride wastewater recycling but do not justify universal predictions about each rare-earth species (Cheng et al., 2025; Wang et al., 2024a; Wang et al., 2024b; Wei et al., 2025; Wu et al., 2021).

Deliberate preparation of FeOCl, La hydroxychloride, or other oxychlorides serves the opposite objective: intermediate stabilization may be desirable. The appropriate criterion is

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therefore product-specific selectivity, not maximum chloride destruction regardless of the intended application (Tian et al., 2024; Yu et al., 2023).

9. Reactor Design, Scale-Up, and Operational Control

Fixed beds, moving beds, fluidized beds, spray roasters, and aerosol reactors impose distinct transport and solids-handling constraints. Fixed and packed solids develop internal steam and HCl gradients; fluidization can improve contact but demands control of fines and agglomeration; spray roasting shortens characteristic diffusion distances but introduces wide droplet-size and residence-time distributions. Select an industrial reactor based on feed rheology and phase evolution, not solely on the stoichiometric reaction equation (Bascone et al., 2016; Schiemann et al., 2012; Schiemann et al., 2013; Sundström & Van Hong, 1997; Xu et al., 2025).

Table 3 summarizes engineering decisions that should precede scale-up.

Table 3. Scale-up controls and minimum evidence requirements

Design issue	Measurement or model	Decision consequence
Feed variability	Hydration, metals, acid, impurities	Pre-treatment and safety margin
Atmosphere	H_2O/O_2/HCl profiles; leak tightness	Phase selectivity and materials
Heat transfer	Particle/droplet temperature, enthalpy	Energy demand and reactor dimensions
Residence time	Distribution rather than mean alone	Incomplete conversion and carry-over
Off-gas management	HCl, aerosols, Cl_2 if applicable	Absorber and corrosion design
Product qualification	Phase composition; chlorine and morphology	Value and recycle acceptance

Note. This review synthesizes information from the cited studies; pathways and operating requirements depend on feed, atmosphere, and reactor.

Table 3 demonstrates why nominal furnace temperature is an incomplete design basis. Each scale-up variable influences either the chemical environment encountered by reacting material or the downstream ability to recover value.

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Technological readiness levels are informative only for a defined process configuration with independently demonstrated operation. The maturity of conventional industrial acid-regeneration equipment does not automatically transfer to a new feed containing rare-earth chlorides, highly variable impurities, or unprecedented recycling requirements. For these cases, verified pilot mass balances and extended campaigns are more useful than assigning an unsupported numerical TRL (Regel-Rosocka, 2010; Van Weert & Peek, 1992; Wang et al., 2024b).

10. Environmental, Energy, and Circularity Assessment

10.1. Chlorine mass balance

A complete accounting separates chlorine in feed solution, retained product solids, captured oxide dust, absorber liquor, washed residues, condensates, purge streams, and atmospheric releases. “Acid recovered” and “chlorine recovered” are different claims when losses occur as aerosol or when a concentrated absorber liquor cannot be reused directly. System boundaries should therefore include any make-up hydrochloric acid, off-gas treatment chemicals, wash water, and purge obligations (Binnemans & Jones, 2023; Regel-Rosocka, 2010; Van Weert & Peek, 1992; Wang et al., 2024b).

For a declared boundary and reporting period, chlorine closure (%) = 100 × [Σ_j m(Cl)$_j$,out]/m(Cl)in, where all quantities refer to elemental chlorine mass and the outlet sum spans final product, unconverted salts, captured dust, absorber liquor, condensate, washes, purge, and measured gaseous and particulate emissions; changes in internal inventory must be included for non-steady operation. A result close to 100% indicates inventory reconciliation, not necessarily successful reagent regeneration. Define recovered-chlorine fraction RCl = m(Cl)recovered/m(Cl)feed and recovered-HCl fraction RHCl = m(HCl)captured as HCl-equivalent/m(HCl)theoretical, each with an explicit boundary and basis. Reusable-acid yield must additionally report the mass of HCl meeting the specified recycle concentration and

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impurity limits relative to the theoretically recoverable HCl, and must be distinguished from total absorber chloride.

10.2. Energy and materials burden

Energy use encompasses sensible heating, solvent evaporation, chemical reaction enthalpies, air or oxygen conditioning, gas cooling, acid absorption, and solids handling. Spray roasters are especially sensitive to feed dilution and gas-volume demand. Robust comparisons with alternative precipitation or solvent-based recovery require a common functional unit, equivalent product specifications, and demonstrated heat integration rather than an isolated furnace duty (Bascone et al., 2016; Ferreira & Mansur, 2011; Gao et al., 2021; Wang et al., 2024b).

Energy comparisons should state the functional unit, such as MJ per kilogram of on-specification oxide, MJ per kilogram of chloride feed converted, or MJ per kilogram of reusable HCl recovered. When oxide and acid are coproducts, the allocation or system-expansion procedure must be transparent. Report evaporation, sensible heating, reaction duty, gas conditioning, cooling, absorption, solids handling, and recoverable heat separately, at equivalent feed and product specifications.

10.3. Emissions, corrosion, and safety

HCl-bearing hot gases pose corrosion risks; chlorine-containing atmospheres may also create more aggressive conditions, depending on materials and oxygen potential. In addition, chlorinated organic contaminants in complex wastes require a feed-specific environmental assessment rather than assuming that chloride feed alone determines pollutant formation. Process design should prioritize dry/wet-zone segregation, emergency scrubbing, containment, and verifiable discharge limits (Pereira, 2026a; Suleiman et al., 2011; Zhou et al., 2021).

Corrosion assessment should be resolved by equipment temperature zone: hot dry-chloride exposure, cooling and condensation interfaces, acid dew-point regions, hygroscopic

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deposited salts, and wet absorption equipment can present different controlling mechanisms. Dew-point excursions, shutdowns, and transient moisture ingress deserve specific evaluation alongside containment and emergency scrubbing.

11. Critical Synthesis, Research Gaps, and Decision Framework

11.1. Evidence gaps

Three recurrent weaknesses constrain cross-study comparison. First, authors underspecify the initial feed when they report “metal chloride” without water content, coordination state, or impurity balance. Second, end-point powder diffraction often misses transient oxychlorides, while kinetic analysis based solely on total mass loss can conflate water and HCl evolution. Third, studies sometimes report reactor conversion without a chlorine distribution across oxide, absorbers, dust, and wastewater. These weaknesses compromise both mechanism assignment and process economics (Karunadasa et al., 2023; Schiemann et al., 2012; Smeets et al., 2013; Zakiryanova et al., 2024).

The most valuable next experiments combine controlled water and oxygen potentials with simultaneous evolved-gas measurement, in situ phase analysis, and quantitative assays of product chlorine. Reactor research should then connect such measurements to droplet/particle submodels validated over feed concentrations and throughput. Studies of changing chloride hydrates and spray-pyrolysis systems provide a basis but not yet a universally portable parameter library (Cheng et al., 2025; Xue et al., 2017; Xu et al., 2025; Zakiryanova et al., 2024).

For product qualification, residual chlorine should be apportioned where possible among surface-adsorbed chloride, occluded or washable salts, unconverted chloride, and structural oxychloride using sequential washing, phase analysis, and complementary surface/bulk measurements. Proposed minimum quality descriptors are water, MgOHCl, MgO, and contaminants for anhydrous $MgCl_2$; oxide phase, particle morphology, and residual

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chlorine for iron-oxide products; and $REOCl/RE_2O_3$ phase fractions, morphology, and residual chlorine for rare-earth oxide or oxychloride products. These are reporting categories, not universal numerical acceptance limits.

Table 4 ranks the necessary research tasks by the decisions they can resolve, rather than assigning unsupported universal TRLs.

Table 4. Research priorities, evidence types, and expected process decisions

Priority	Critical evidence	Decision enabled
Mechanistic discrimination	Gas-resolved TGA + in situ XRD	True dehydration vs hydrolysis
Multi-salt phase behavior	Measured feed-speciation/phase maps	Selectivity under industrial impurities
Intrinsic vs transport kinetics	Mass, heating-rate, and flow variation	Transferable reactor submodels
Chlorine closure	Independent Cl analyses in all streams	Actual reagent recovery
Extended integrated trials	Product specs + emissions + energy	Robust scale-up and economics

Note. This review synthesizes information from the cited studies; pathways and operating requirements depend on the feed, atmosphere, and reactor.

These priorities respond directly to the observed distinction between reported chemical conversion and a reproducible, environmentally credible industrial process. In particular, chlorine closure should be treated as a primary performance metric.

11.2. Integrated decision logic

Figure 4 consolidates the proposed route-selection sequence. It begins with the target product—dry chloride, oxide, oxychloride, or metal—because the same hydrolysis step may be undesirable in one circuit and indispensable in another. The sequence then requires feed characterization, specification of $H_2O/O_2/HCl$ potentials, phase- and gas-resolved experiments, and independent verification of balances before engineering commitment.

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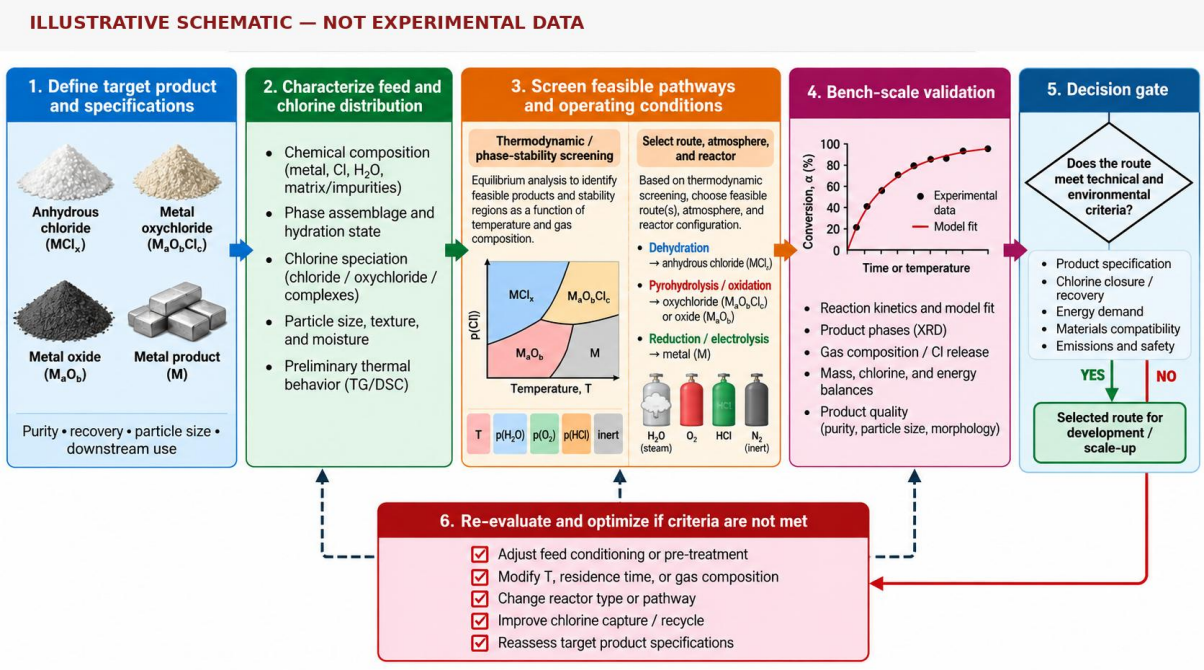

Figure 4. Evidence-based decision framework for chloride thermal processing route selection.
Note. Original conceptual framework developed for this review; no published diagram has been reproduced or adapted. Illustrative schematic—not experimental data; the embedded data/model comparison is conceptual.

The iterative arrow emphasizes that a promising laboratory conversion remains provisional if gas capture, product purity, or heat demand cannot be reconciled at the integrated-process level.

The framework's strongest implication is methodological: comparing chloride technologies through a single decomposition temperature or activation energy is often scientifically invalid. The meaningful comparison is conditional—same inlet speciation, imposed atmosphere, product definition, conversion measure, and scope of the chlorine and energy balance.

12. Conclusion

Thermal conversion of metal chlorides is best understood as a set of coupled, atmosphere-sensitive reaction networks rather than a single universal decomposition

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phenomenon. Hydrate dehydration, oxychloride formation, oxidation, and volatilization compete according to the incoming chemical state and the evolving water, oxygen, and chlorine potentials. Magnesium chloride processing illustrates the need to suppress hydrolysis for dry-salt production, whereas iron chloride regeneration and selected rare-earth oxide routes deliberately use conversion chemistry to recover products and reagents.

This review's main analytical contribution is an evidence-based comparison linking thermodynamic conditions, transient phase identification, evolved-gas measurement, transport-aware kinetic interpretation, and complete chlorine accounting. Future experimental and scale-up work should prioritize controlled atmospheres, phase- and gas-resolved measurements, multicomponent feed variability, and quantitative linkage between oxide quality and hydrochloric acid recovery. Any apparent process advantage remains provisional until these measurements are reconciled with energy demand, emissions, and long-duration operability.

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Author Contributions

Author contributions: Conceptualization, literature synthesis, critical analysis, and manuscript preparation (subject to author confirmation).

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DOI: 10.66104/kp64h285
Pages: 1-29

References

Bascone, D., Cipollina, A., Morreale, M., Randazzo, S., Santoro, F., & Micale, G. (2016). Simulation of a regeneration plant for spent pickling solutions via spray roasting. Desalination and Water Treatment, 57(48–49), 23405–23419. https://doi.org/10.1080/19443994.2015.1137146

Binnemans, K., & Jones, P. T. (2023). The twelve principles of circular hydrometallurgy. Journal of Sustainable Metallurgy, 9, 1–25. https://doi.org/10.1007/s40831-022-00636-3

Cheng, Z., Huang, X., Feng, Z., Long, J., Yu, H., Wang, M., Yang, J., & Hao, H. (2025). Progress in study of spray pyrolysis technology for chloride salt solutions in rare earth extraction and separation processes. Journal of Rare Earths, 43(10), 2053–2064. https://doi.org/10.1016/j.jre.2024.12.013

Ferreira, A. S., & Mansur, M. B. (2011). Statistical analysis of the spray roasting operation for the production of high quality Fe_2O_3 from steel pickling liquors. Process Safety and Environmental Protection, 89(3), 172–178. https://doi.org/10.1016/j.psep.2010.11.005

Galwey, A. K., & Laverty, G. M. (1989). The thermal decomposition of magnesium chloride dihydrate. Thermochimica Acta, 138(1), 115–127. https://doi.org/10.1016/0040-6031(89)87246-6

Gao, Y., Yue, T., Sun, W., He, D., Lu, C., & Fu, X. (2021). Acid recovering and iron recycling from pickling waste acid by extraction and spray pyrolysis techniques. Journal of Cleaner Production, 312, Article 127747. https://doi.org/10.1016/j.jclepro.2021.127747

Hartman, M., Trnka, O., & Šolcová, O. (2005). Thermal decomposition of aluminum chloride hexahydrate. Industrial & Engineering Chemistry Research, 44(17), 6591–6598. https://doi.org/10.1021/ie058005y

Huang, Q., Lu, G., Wang, J., & Yu, J. (2011). Thermal decomposition mechanisms of $MgCl_2 \cdot 6H_2O$ and $MgCl_2 \cdot H_2O$. Journal of Analytical and Applied Pyrolysis, 91(1), 159–164. https://doi.org/10.1016/j.jaap.2011.02.005

Huang, Q.-Z., Lu, G.-M., Wang, J., & Yu, J.-G. (2010). Mechanism and kinetics of thermal decomposition of $MgCl_2 \times 6H_2O$. Metallurgical and Materials Transactions B, 41, 1059–1066. https://doi.org/10.1007/s11663-010-9390-4

Janković, B., Manić, N., Perović, I., Vujković, M., & Zdolšek, N. (2023). Thermal decomposition kinetics of deep eutectic solvent (DES) based on choline chloride and magnesium chloride hexahydrate: New details on the reaction mechanism and

Nexus Science Review
INTERNATIONAL JOURNAL OF INTERDISCIPLINARY RESEARCH

Received: 21/09/2026 - **Accepted:** 12/10/2026
Vol: 01.05
DOI: 10.66104/kp64h285
Pages: 1-29

enthalpy–entropy compensation (EEC). Journal of Molecular Liquids, 374, Article 121274. https://doi.org/10.1016/j.molliq.2023.121274

Jóźwiak, W. K., & Maniecki, T. P. (2005). Influence of atmosphere kind on temperature programmed decomposition of noble metal chlorides. Thermochimica Acta, 435(2), 151–161. https://doi.org/10.1016/j.tca.2005.05.006

Karunadasa, K. S. P., Rajapakse, R. M. G., Pitawala, H. M. T. G. A., & Manoratne, C. H. (2023). Microstructural insight into the thermal decomposition of $MgCl_2 \cdot 6H_2O$ examined by in situ high-temperature X-ray powder diffraction. Journal of Solid State Chemistry, 322, Article 123965. https://doi.org/10.1016/j.jssc.2023.123965

Kipouros, G. J., & Sadoway, D. R. (2001). A thermochemical analysis of the production of anhydrous $MgCl_2$. Journal of Light Metals, 1(2), 111–117. https://doi.org/10.1016/S1471-5317(01)00004-9

Klammer, N., Engtrakul, C., Zhao, Y., Wu, Y., & Vidal, J. (2020). Method to determine MgO and MgOHCl in chloride molten salts. Analytical Chemistry, 92(5), 3598–3604. https://doi.org/10.1021/acs.analchem.9b04301

Korzun, I. V., Nikolaeva, E. V., & Zakir'yanova, I. D. (2018). Mechanism and caloric effects of the thermal dehydration of $GdCl_3 \cdot 6H_2O$ crystalline hydrate. Russian Metallurgy (Metally), 2018(8), 722–727. https://doi.org/10.1134/S0036029518080104

Li, K., Dong, M., Han, L., Li, M., Zhang, H., Ye, X., Liu, H., Zhang, S., Li, Q., Liu, H., Shi, G., & Wu, Z. (2025a). Significant reduction in the dehydration temperature of magnesium chloride hexahydrate through the addition of AlCl3 and NH4Cl. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 708, Article 136019. https://doi.org/10.1016/j.colsurfa.2024.136019

Li, K., Zhang, H., Dong, M., Song, Z., Li, M., Wang, C., Liu, H., Ye, X., Shi, G., & Wu, Z. (2025b). Acceleration of the pyrolysis of magnesium chloride hexahydrate by graphene. Journal of Solid State Chemistry, 346, Article 125287. https://doi.org/10.1016/j.jssc.2025.125287

Park, K. Y., Park, Y.-W., Youn, S.-H., & Choi, S.-Y. (2000). Bench-scale decomposition of aluminum chloride hexahydrate to produce poly(aluminum chloride). Industrial & Engineering Chemistry Research, 39(11), 4173–4177. https://doi.org/10.1021/ie000029b

Pathak, A. D., Nedea, S., van Duin, A. C. T., Zondag, H., Rindt, C., & Smeulders, D. (2016). Reactive force field development for magnesium chloride hydrates and its application for seasonal heat storage. Physical Chemistry Chemical Physics, 18, 15838–15847. https://doi.org/10.1039/C6CP02762H

Nexus Science Review
INTERNATIONAL JOURNAL OF INTERDISCIPLINARY RESEARCH

Received: 21/09/2026 - **Accepted:** 12/10/2026
Vol: 01.05
DOI: 10.66104/kp64h285
Pages: 1-29

Peek, E. (2011). Chloride metallurgy: Process technology development. In S. N. Monteiro, D. E. Verhulst, P. N. Anyalebechi, & J. A. Pomykala (Eds.), EPD Congress 2011. Wiley. https://doi.org/10.1002/9781118495285.ch56

Pereira, A. C. (2026a). Avoiding PCDD/F formation in metal chloride-based chlorination-calcination processes: Mechanisms, risk factors and best available practices. Revista Multidisciplinar do Nordeste Mineiro, 2(2), 1–47. https://doi.org/10.66104/72db6485

Pereira, A. C. (2026b). Thermal decomposition of iron chlorides in chloride-based metallurgy: Mechanisms, kinetics, gas–solid coupling, and process implications—A critical review. Nexus Science Review, 1(5). https://doi.org/10.66104/a1p8y062

Pruttskov, D., Krivoruchko, N., & Kirichenko, A. (2024). Improving the dehydration technology of MgCl2·6H2O and KCl·MgCl2·6H2O. JOM, 76(11), 6589–6599. https://doi.org/10.1007/s11837-024-06848-0

Regel-Rosocka, M. (2010). A review on methods of regeneration of spent pickling solutions from steel processing. Journal of Hazardous Materials, 177(1–3), 57–69. https://doi.org/10.1016/j.jhazmat.2009.12.043

Schiemann, M., Wirtz, S., Scherer, V., & Bärhold, F. (2012). Spray roasting of iron chloride $FeCl_2$: Laboratory-scale experiments and a model for numerical simulation. Powder Technology, 228, 301–308. https://doi.org/10.1016/j.powtec.2012.05.037

Schiemann, M., Wirtz, S., Scherer, V., & Bärhold, F. (2013). Spray roasting of iron chloride $FeCl_2$: Numerical modeling of industrial-scale reactors. Powder Technology, 245, 70–79. https://doi.org/10.1016/j.powtec.2013.04.034

Shah, S., Pietsch, T., & Ruck, M. (2024). Facile synthesis of anhydrous rare-earth trichlorides from their oxides in chloridoaluminate ionic liquids. Angewandte Chemie International Edition, 63(4), Article e202317480. https://doi.org/10.1002/anie.202317480

Smeets, B., Iype, E., Nedea, S. V., Zondag, H. A., & Rindt, C. C. M. (2013). A DFT based equilibrium study on the hydrolysis and the dehydration reactions of $MgCl_2$ hydrates. The Journal of Chemical Physics, 139(12), Article 124312. https://doi.org/10.1063/1.4822001

Suleiman, I. A., Mackie, J. C., Kennedy, E. M., Radny, M. W., & Dlugogorski, B. Z. (2011). Quantum chemical study of copper(II) chloride and the Deacon reaction. Chemical Physics Letters, 501(4–6), 215–220. https://doi.org/10.1016/j.cplett.2010.11.030

Sundström, J., & Van Hong, V. (1997). Investigation of the kinetics of the fluidized bed process for the dehydration of $NdCl_3·6H_2O$, $TbCl_3·6H_2O$ and $DyCl_3·6H_2O$. Thermochimica Acta, 306(1–2), 13–21. https://doi.org/10.1016/S0040-6031(97)00293-1

Nexus Science Review
INTERNATIONAL JOURNAL OF INTERDISCIPLINARY RESEARCH

Received: 21/09/2026 - **Accepted:** 12/10/2026
Vol: 01.05
DOI: 10.66104/kp64h285
Pages: 1-29

Teplonogova, M. A., Kozlova, A. A., Yapryntsev, A. D., Baranchikov, A. E., & Ivanov, V. K. (2024). Synthesis and thermal decomposition of high-entropy layered rare earth hydroxychlorides. Molecules, 29(7), Article 1634. https://doi.org/10.3390/molecules29071634

Tian, H., Guo, J., Pei, Y., Hou, S., Wang, Y., & Xia, Y. (2024). A synthetic method for lanthanum hydroxychloride suitable for industrialization and its thermal decomposition properties. RSC Advances, 14, 29282–29287. https://doi.org/10.1039/D4RA03987D

Van Hong, V., & Sundström, J. (1997). The dehydration schemes of rare-earth chlorides. Thermochimica Acta, 307(1), 37–43. https://doi.org/10.1016/S0040-6031(97)00296-7

Van Weert, G., & Peek, E. M. L. (1992). Reagent recovery in chloride hydrometallurgy—Some missing links. Hydrometallurgy, 29(1–3), 513–526. https://doi.org/10.1016/0304-386X(92)90030-4

Wang, Q., Hao, H., Wu, Z., Wang, M., Feng, Z., Zhang, Y., Xue, X., & Huang, X. (2024a). Mechanism study on the effect of H_2O_2 on spray pyrolysis of $MgCl_2$ wastewater in rare earth extraction and separation process. Journal of Water Process Engineering, 60, Article 105089. https://doi.org/10.1016/j.jwpe.2024.105089

Wang, Q., Song, C., Hao, H., Wang, M., Feng, Z., Zhang, Y., Xue, X., & Huang, X. (2024b). Full recycling of $MgCl_2$ wastewater generated in rare earth extraction and separation process by spray pyrolysis. Process Safety and Environmental Protection, 183, 544–554. https://doi.org/10.1016/j.psep.2024.01.019

Wei, J., Bian, X., Zhu, X., Huang, H., Ye, C., Sun, S., Zhong, L., & Tu, G. (2025). Review of oxides prepared by a short process using rare-earth chlorides. Materials, 18(20), Article 4669. https://doi.org/10.3390/ma18204669

Wu, Y., Li, H., Bian, X., Wu, W., Wang, Z., & Liu, Y. (2021). Green and short preparation of CeO_2 nanoparticles with large specific surface area by spray pyrolysis. Materials, 14(17), 4963. https://doi.org/10.3390/ma14174963

Xu, H., Cheng, D., Zhao, L., Dong, H., & Liu, B. (2025). Numerical study of bischofite precursor droplet evaporation and thermal decomposition for spray pyrolysis systems. Chemical Engineering Science, 301, Article 120680. https://doi.org/10.1016/j.ces.2024.120680

Xu, J., Li, T., Yan, T., Chao, J., & Wang, R. (2021). Dehydration kinetics and thermodynamics of magnesium chloride hexahydrate for thermal energy storage. Solar Energy Materials and Solar Cells, 219, Article 110819. https://doi.org/10.1016/j.solmat.2020.110819

Nexus Science Review
INTERNATIONAL JOURNAL OF INTERDISCIPLINARY RESEARCH

Received: 21/09/2026 - **Accepted:** 12/10/2026
Vol: 01.05
DOI: 10.66104/kp64h285
Pages: 1-29

Xue, S., Wu, W., Bian, X., & Wu, Y. (2017). Dehydration, hydrolysis and oxidation of cerium chloride heptahydrate in air atmosphere. Journal of Rare Earths, 35(11), 1156–1163. https://doi.org/10.1016/j.jre.2017.06.001

Yamamoto, H., Furusawa, K., & Uda, T. (2018). Hidden nature of the conversion reaction from rare earth chloride to oxychloride and the application to novel separation. ChemistrySelect, 3(11), 2998–3002. https://doi.org/10.1002/slct.201702581

Yang, S., Anderko, A., Riman, R. E., & Navrotsky, A. (2022). Thermochemistry of 3D and 2D rare earth oxychlorides (REOCls). Inorganic Chemistry, 61(19), 7590–7596. https://doi.org/10.1021/acs.inorgchem.2c00763

Yang, Y., Wang, N., Pang, X., Yasinskiy, A., Tan, Y., Yu, J., Wang, Z., & Shi, Z. (2021). Thermodynamics of the decomposition of aluminum chloride hexahydrate to prepare alumina. Journal of Materials Research and Technology, 15, 6640–6646. https://doi.org/10.1016/j.jmrt.2021.11.099

Yu, T., Xing, A., Wang, S., Zhao, D., & Liang, S. (2023). Growth of FeOCl nanoparticles via thermal decomposition under reduced pressure and rotation. Journal of Crystal Growth, 609, Article 127147. https://doi.org/10.1016/j.jcrysgro.2023.127147

Zakiryanova, I., Korzun, I., Vovkotrub, E., & Antonov, B. (2024). A comprehensive study of the thermal behavior of rare earth chloride hydrates: Resolving contradictions. Electrochemical Materials and Technologies, 3(1). https://doi.org/10.15826/elmattech.2024.3.028

Zhang, N., Yang, Y., Wang, Z., Shi, Z., Gao, B., Hu, X., Tao, W., Liu, F., & Yu, J. (2018). Study on the thermal decomposition of aluminium chloride hexahydrate. Canadian Metallurgical Quarterly, 57(2), 235–244. https://doi.org/10.1080/00084433.2017.1412556

Zhang, Z., Lu, X., Wang, T., Yan, Y., & Pan, F. (2014). The dehydration of $MgCl_2 \cdot 6H_2O$ in $MgCl_2 \cdot 6H_2O$–KCl–NH_4Cl system. Journal of Analytical and Applied Pyrolysis, 110, 248–253. https://doi.org/10.1016/j.jaap.2014.09.009

Zhang, Z., Lu, X., Yan, Y., & Wang, T. (2019). The dehydration of $MgCl_2 \cdot 6H_2O$ by inhibition of hydrolysis and conversion of hydrolysate. Journal of Analytical and Applied Pyrolysis, 138, 114–119. https://doi.org/10.1016/j.jaap.2018.12.014

Zhao, Y., & Gomez-Vidal, J. (2020). Potential scalability of a cost-effective purification method for $MgCl_2$-containing salts for next-generation concentrating solar power technologies. Solar Energy Materials and Solar Cells, 215, Article 110663. https://doi.org/10.1016/j.solmat.2020.110663

Zhou, S., Etschmann, B., Qian, B., Liu, C., & Zhang, L. (2021). Synchrotron X-ray absorption spectroscopy study of the evolution of chlorine during the pyro-hydrolysis

Nexus Science Review
INTERNATIONAL JOURNAL OF INTERDISCIPLINARY RESEARCH

Received: 21/09/2026 - **Accepted:** 12/10/2026
Vol: 01.05
DOI: 10.66104/kp64h285
Pages: 1-29

of calcium and magnesium chloride waste. Waste Management, 120, 608–615. https://doi.org/10.1016/j.wasman.2020.10.026