

Engineering High-Temperature Superconductors For Future Energy Technologies Of REBCO Materials, Critical Current Density, And Flux Pinning: A Bibliometric Analysis

Risqi Prastianto Setiawan^{1*}, Indras Mahaendrajaya², Heri Sutanto^{2,3}

¹ Master's Program of Environmental Sciences, School of Postgraduate Studies, Universitas Diponegoro, Indonesia

² Department of Physics, Faculty of Sciences and Mathematics, Universitas Diponegoro, Indonesia

³ Smart Materials Research Center (SMARC) Laboratory, Integrated Laboratory, Universitas Diponegoro, Indonesia

*Corresponding Author: Risqi P. Setiawan. E-mail: risqiprassetiawan@gmail.com



Abstract – High-temperature superconductors (HTSs) are promising materials for future energy technologies because they can carry high electrical currents and generate strong magnetic fields under suitable cryogenic conditions. Among the available HTS families, rare-earth barium copper oxide (REBCO) has attracted considerable attention because of its high critical temperature, strong in-field performance, and compatibility with coated-conductor manufacturing. Nevertheless, the practical deployment of REBCO remains constrained by critical-current degradation under magnetic fields, vortex motion, alternating-current losses, mechanical limitations, manufacturing costs, and cooling requirements. This systematic literature review evaluates recent developments in REBCO superconductors, with particular emphasis on critical current density, artificial flux-pinning centers, nanocomposite engineering, conductor fabrication, and potential energy applications. The proposed review follows a transparent literature-search and screening procedure informed by the PRISMA 2020 reporting framework. Relevant evidence is organized into five themes: intrinsic superconducting properties, microstructural engineering, processing–structure–property relationships, application requirements, and technological barriers. The literature indicates that introducing well-designed nanoscale defects can improve vortex pinning and enhance current-carrying performance under magnetic fields. However, improvements depend on defect morphology, orientation, density, and compatibility with the superconducting matrix. Furthermore, higher critical temperature alone does not guarantee superior engineering performance because current density, mechanical integrity, operating temperature, manufacturing yield, and cost must be considered simultaneously. Future research should prioritize scalable nanocomposite fabrication, standardized performance measurements, reduced-cost conductor production, and application-specific optimization. By integrating materials science with engineering requirements, this review establishes a framework for evaluating REBCO development and identifying research directions for future superconducting energy systems.

Keywords: critical current density; high-temperature superconductors; nanocomposite superconductors; REBCO.

I. Introduction

The transition toward more efficient and sustainable energy systems has increased interest in materials that can transport electrical current and generate magnetic fields with reduced electrical dissipation [1], [2]. Conventional metallic conductors, including copper and aluminum, exhibit electrical resistance during operation [3]. Superconducting materials, by contrast, exhibit zero DC electrical resistance below their critical temperature under appropriate magnetic-field and current conditions. They also display characteristic magnetic behavior associated with the Meissner effect [4], [5].

Although superconductivity was discovered more than a century ago, its large-scale implementation has been limited by the requirement for cryogenic cooling, the restricted operating range of individual materials, and the engineering challenges associated with producing long, mechanically reliable conductors [6]. High-temperature superconductors have expanded the potential operating range and enabled new opportunities in power engineering, transportation, medical technologies, and high-field magnets.

Among the available superconducting materials, rare-earth barium copper oxide (REBCO), commonly represented by $\text{REBa}_2\text{Cu}_3\text{O}_{7-\delta}$, has become an important candidate for high-field applications [7], [8], [9], [10], [11], [12]. Here, RE denotes a rare-earth element, such as yttrium in $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (YBCO) [2], [13], [14], [15]. REBCO materials combine relatively high superconducting transition temperatures with favorable in-field performance, making them attractive for coated conductors, superconducting magnets, and selected energy technologies [16], [17], [18].

Recent reviews have highlighted the growing potential of high-temperature superconductors in fusion magnets, power transmission, wind-energy generators, and superconducting electrical machines. However, practical implementation remains dependent on manufacturing cost, cryogenic requirements, alternating-current losses, and conductor performance under realistic operating conditions [14]. One of the most important parameters governing the practical performance of REBCO is the critical current density (J_c) [19], [20]. This parameter describes the maximum current density that a superconductor can sustain before dissipation becomes significant under specified temperature and magnetic-field conditions. In Type-II superconductors, magnetic flux penetrates the material in the form of quantized vortices [21], [22]. When these vortices move under the influence of an applied current, energy is dissipated. Therefore, suppressing vortex motion is essential for maintaining high current-carrying performance [23].

Artificial flux pinning centers have emerged as a promising strategy for addressing this limitation [24], [25]. These centers may consist of nanoscale inclusions, nanoparticles, nanorods, dislocations, stacking faults, or other microstructural features that interact with vortices and restrict their movement [26], [27]. Their effectiveness depends on the size, density, orientation, distribution, and electronic properties of the defects. Despite considerable progress, optimizing REBCO involves a complex trade-off among superconducting properties, microstructural quality, mechanical reliability, and manufacturing cost [11], [28], [29], [30]. A material with a high critical temperature may still exhibit insufficient current density under a strong magnetic field, while an aggressive nanostructuring strategy may introduce defects that adversely affect other superconducting properties.

Therefore, a systematic assessment of the relationship between microstructure, critical-current performance, fabrication methods, and practical applications is needed. This review aims to synthesize the literature on REBCO superconductors and evaluate the potential of microstructural engineering to improve their performance. Specifically, the review addresses five research questions presented in Table 1.

Table 1. Research Questions Defined to Determine the Topic in This Study and Its Justification

No.	Research Question	Justification
RQ1.	What material properties determine the practical performance of REBCO superconductors?	To identify the intrinsic physical parameters (such as T_c , J_c , and critical fields) that establish the baseline operational limits of REBCO performance in real-world applications.
RQ2	How do artificial flux pinning centers influence critical current density under applied magnetic fields?	To evaluate how nanoscale structural engineering (artificial pinning centers) traps magnetic flux to maintain high critical current density under strong magnetic fields.
RQ3.	How do fabrication methods affect defect formation, microstructure, and superconducting performance?	To connect manufacturing and deposition methods directly to microstructural defect formation and their ultimate impact on superconducting transport properties.
RQ4.	What trade-offs limit the translation of laboratory-scale improvements into commercial conductors?	To analyze the technical, mechanical, and economic bottlenecks that hinder the transition of successful laboratory-scale improvements into industrial commercial production.

By addressing these questions, the review seeks to connect fundamental materials science with the engineering requirements of next-generation superconducting technologies.

II. MATERIALS AND METHODOLOGY

1. Research Design

The study of REBCO and YBCO as superconducting materials employs a Systematic Literature Review (SLR) combined with bibliometric analysis, an intentional methodological pairing where bibliometric analysis maps the structural evolution, publication trends, citation patterns, research collaboration, and emerging themes of the field as described by Donthu et al. (2021), while the systematic review examines what the literature actually states regarding the substantive problem [31]. To operationalize this dual approach, the bibliometric analysis uses RStudio Bibliometrix as an open-source, R-based workflow for science mapping, while the systematic-review component strictly follows the reporting principles and updated flow diagrams of PRISMA 2020 [32], [33].

2. Database

Scopus (<https://www.scopus.com/home.uri>) was used as the bibliographic database, and the search targeted records containing terms related to REBCO and YBCO superconductors, superconducting performance, critical current density, flux pinning, artificial pinning centers, nanocomposites, nanorods, nanoparticles, microstructure, magnetic fields, and applications.

3. Research Strategy

To establish a rigorous search and selection framework, this study adopted the PRISMA 2020 guidelines, which are systematically illustrated in the flow diagram presented in Figure 1. The initial database query was executed within Scopus using the exact search string targeting article titles, below.

("REBCO" OR "rare-earth barium copper oxide" OR "YBCO" OR "coated conductor" OR "high-temperature superconductor" AND "critical current density" OR "flux pinning" OR "artificial pinning center" OR "nanocomposite" OR "nanorod" OR "nanoparticle" AND "microstructure" OR "magnetic field" OR "application")

The initial search retrieved 9,208 documents. Restricting the publication period to 2016–2026 reduced the dataset to 2,775 documents. Subsequently, the subject-area filter was applied to retain publications classified under Materials Science, Physics and Astronomy, Engineering, Energy, Chemistry, and Chemical Engineering, resulting in 2,716 documents. A further keyword-based refinement was conducted using thematic groups covering core REBCO and YBCO materials, superconductivity and performance metrics, magnetic-field characteristics, engineering and application formats, and advanced microstructural features, reducing the dataset to 2,569 documents. Finally, document-type and language filters were applied to retain only publications classified as Articles and written in English, yielding a final dataset of 2,221 documents. The entire screening and selection process, including the specific search parameters and thematic mapping applied at each stage, is illustrated in Figure 1.

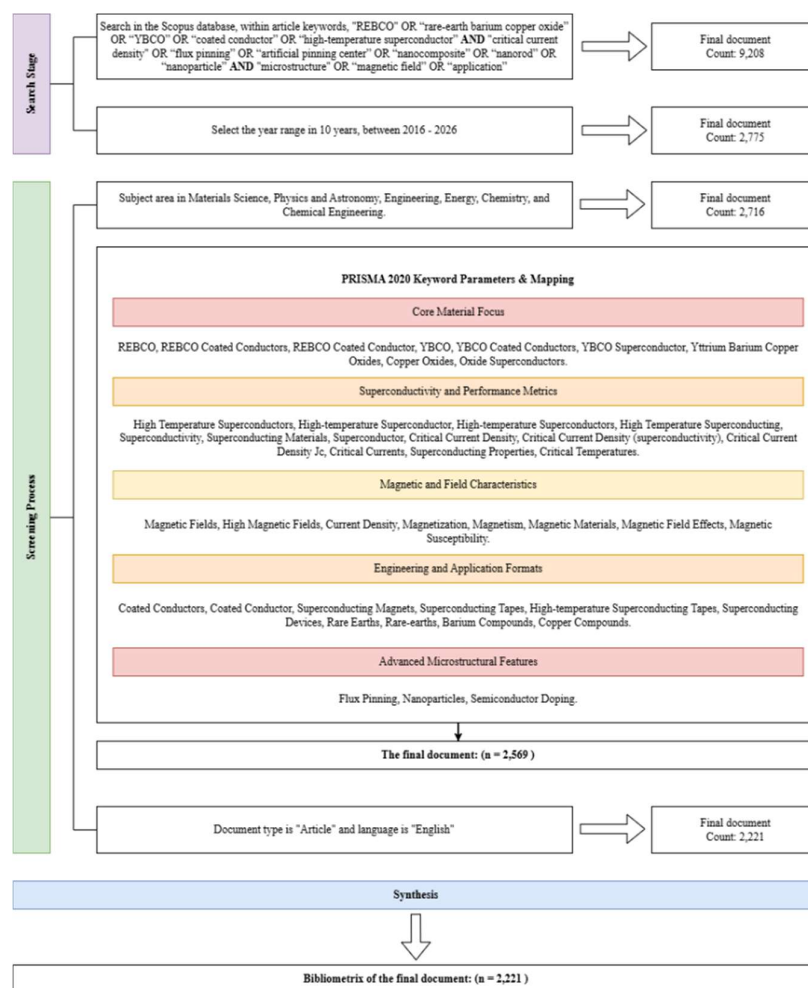


Figure 1. PRISMA 2020 flow diagram illustrating the literature search, screening, filtering, and synthesis process leading to the final dataset of bibliometric analysis.

The bibliographic references for this study were retrieved from the Scopus database (<https://www.scopus.com/home.uri>), which provides broad and internationally recognized coverage of scientific publications. Scopus was selected as the primary database because of its extensive coverage and suitability for bibliometric and systematic literature analyses. The temporal scope of the study was defined from 2016 to 2026, with 2026 treated as a partial publication year because the search was conducted before the end of the year. The database, search date, and exported metadata should be reported explicitly in the final version to

make the analysis reproducible. Table 2 presents the research strategy used to query the Scopus database for studies on superconductor materials.

Table 2. Search Strategy Applied to Scopus Database

Data Type	Research Strategy	Total Documents
Search keywords chain	"REBCO" OR "rare-earth barium copper oxide" OR "YBCO" OR "coated conductor" OR "high-temperature superconductor" AND "critical current density" OR "flux pinning" OR "artificial pinning center" OR "nanocomposite" OR "nanorod" OR "nanoparticle" AND "microstructure" OR "magnetic field" OR "application"	9,208
Research code line	(TITLE-ABS-KEY (REBCO) OR TITLE-ABS-KEY (rare-earth barium copper oxide) OR TITLE-ABS-KEY (YBCO) OR TITLE-ABS-KEY (coated conductor) OR TITLE-ABS-KEY (high-temperature superconductor) AND TITLE-ABS-KEY (critical current density) OR TITLE-ABS-KEY (flux pinning) OR TITLE-ABS-KEY (artificial pinning center) OR TITLE-ABS-KEY (nanocomposite) OR TITLE-ABS-KEY (nanorod) OR TITLE-ABS-KEY (nanoparticle) AND TITLE-ABS-KEY (microstructure) OR TITLE-ABS-KEY (magnetic field) OR TITLE-ABS-KEY (application)) AND (LIMIT-TO (SUBJAREA , "MATE") OR LIMIT-TO (SUBJAREA , "PHYS") OR LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "CHEM") OR LIMIT-TO (SUBJAREA , "ENER") OR LIMIT-TO (SUBJAREA , "CENG")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (EXACTKEYWORD , "Critical Current Density (superconductivity)") OR LIMIT-TO (EXACTKEYWORD , "High Temperature Superconductors") OR LIMIT-TO (EXACTKEYWORD , "Yttrium Barium Copper Oxides") OR LIMIT-TO (EXACTKEYWORD , "Magnetic Fields") OR LIMIT-TO (EXACTKEYWORD , "Barium Compounds") OR LIMIT-TO (EXACTKEYWORD , "Coated Conductors") OR LIMIT-TO (EXACTKEYWORD , "Superconducting Magnets") OR LIMIT-TO (EXACTKEYWORD , "Copper Compounds") OR LIMIT-TO (EXACTKEYWORD , "Superconducting Tapes") OR LIMIT-TO (EXACTKEYWORD , "Critical Currents") OR LIMIT-TO (EXACTKEYWORD , "Flux Pinning") OR LIMIT-TO (EXACTKEYWORD , "High-temperature Superconductor") OR LIMIT-TO (EXACTKEYWORD , "Superconducting Materials") OR LIMIT-TO (EXACTKEYWORD , "High Temperature Superconducting") OR LIMIT-TO (EXACTKEYWORD , "Critical Current Density") OR LIMIT-TO (EXACTKEYWORD , "Critical Current") OR LIMIT-TO (EXACTKEYWORD , "Copper Oxides") OR LIMIT-TO (EXACTKEYWORD , "Magnetization") OR LIMIT-TO (EXACTKEYWORD , "Superconducting Properties") OR LIMIT-TO (EXACTKEYWORD , "Rebco") OR LIMIT-TO (EXACTKEYWORD , "Magnetism") OR LIMIT-TO (EXACTKEYWORD , "Rare Earths") OR LIMIT-TO (EXACTKEYWORD , "Rebco Coated Conductors") OR LIMIT-TO (EXACTKEYWORD , "Coated Conductor") OR LIMIT-TO (EXACTKEYWORD , "Superconducting Devices") OR LIMIT-TO (EXACTKEYWORD , "Ybco") OR LIMIT-TO (EXACTKEYWORD , "High Magnetic Fields") OR LIMIT-TO (EXACTKEYWORD , "Current Density") OR LIMIT-TO (EXACTKEYWORD , "Rare-earths") OR LIMIT-TO (EXACTKEYWORD , "High-temperature Superconductors") OR LIMIT-TO (EXACTKEYWORD , "Nanoparticles") OR LIMIT-TO (EXACTKEYWORD , "Critical Temperatures") OR LIMIT-TO (EXACTKEYWORD , "Semiconductor Doping") OR LIMIT-TO (EXACTKEYWORD , "High Temperature Superconductor") OR LIMIT-TO (	2,221

EXACTKEYWORD , "Ybco Coated Conductors") OR LIMIT-TO (EXACTKEYWORD , "Superconductivity") OR LIMIT-TO (EXACTKEYWORD , "Rebco Coated Conductor") OR LIMIT-TO (EXACTKEYWORD , "Critical Current Density Jc") OR LIMIT-TO (EXACTKEYWORD , "Oxide Superconductors") OR LIMIT-TO (EXACTKEYWORD , "Superconductor") OR LIMIT-TO (EXACTKEYWORD , "Magnetic Materials") OR LIMIT-TO (EXACTKEYWORD , "High-temperature Superconducting Tapes") OR LIMIT-TO (EXACTKEYWORD , "Magnetic Field Effects") OR LIMIT-TO (EXACTKEYWORD , "Magnetic Susceptibility") OR LIMIT-TO (EXACTKEYWORD , "Ybco Superconductor")) AND PUBYEAR > 2015 AND PUBYEAR < 2027.

Table 3 below details the study's inclusion and exclusion criteria based on the 2016–2026 timeframe, document type, subject area, thematic keywords, and language. The accompanying academic narrative summarizes the essence of these criteria for use in the methodology chapter, avoiding the need to repeat the entire list of keywords. For further drafting guidance, please refer to the provided methodology draft.

Table 3. Eligibility Criteria for the Bibliometric Systematic Literature Review

No.	Bibliometric Metadata	Inclusion Criteria	Exclusion Criteria
1.	Timespan	2016 - 2026	Beyond the 2016–2026 period
2.	Document type	Articles	Conference paper, review, book chapter, note, erratum, conference review, book, short survey, retracted, data paper.
3.	Subject area	Materials Science, Physics and Astronomy, Engineering, Energy, Chemistry, Chemical Engineering.	Mathematics, Computer Science, Multidisciplinary, Biochemistry, Genetics and Molecular Biology, Environmental Science, Social Sciences, Earth and Planetary Sciences, Medicine, Neuroscience, Decision Sciences, Immunology and Microbiology, Pharmacology, Toxicology and Pharmaceutics, Business, Management and Accounting, Agricultural and Biological Sciences.
4.	Keywords	Critical Current Density (superconductivity), High Temperature Superconductors, Yttrium Barium Copper Oxides, Magnetic Fields, Barium Compounds, Coated Conductors, Superconducting Magnets, Copper Compounds, Superconducting Tapes, Critical Currents, Flux Pinning, High-temperature Superconductor, Superconducting Materials, High Temperature Superconducting, Critical Current Density, Critical Current, Copper Oxides, Magnetization, Superconducting Properties, Rebco, Magnetism, Rare Earths, Rebco Coated Conductors, Coated Conductor, Superconducting Devices, Ybco, High Magnetic	Superconducting Coils, Superconducting Films, 'current, High Temperature Applications, Magnetic-field, Magnets, Temperature, Ac Loss, Rhenium Compounds, Finite Element Method, Superconducting Cables, Thin Films, Microstructure, Vortex Flow, Scanning Electron Microscopy, Magnetic Levitation, Pulsed Laser Deposition, Winding, Gadolinium Compounds, Superconducting Wire, Cables, Superconducting Transition Temperature, Substrates, Copper, Organometallics, Applied Magnetic Fields, Bismuth Compounds, Binary Alloys, Textures, Defects, Calcium Compounds, Squids, Accelerator Magnets,

Fields, Current Density, Rare-earths, High-temperature Superconductors, Nanoparticles, Critical Temperatures, Semiconductor Doping, High Temperature Superconductor, Ybco Coated Conductors, Superconductivity, Recco Coated Conductor, Critical Current Density J_c , Oxide Superconductors, Superconductor, Magnetic Materials, High-temperature Superconducting Tapes, Magnetic Field Effects, Magnetic Susceptibility, Ybco Superconductor.

Performance, Magnetic Field Measurement, Artificial Pinning Centers, Nanorods, Numerical Methods, Grain Boundaries, Bulk Superconductors, Single Crystals, Temperature Distribution, Property, Organic Superconducting Materials, Iron-based Superconductors, Deposition, Wire, Vortex Pinning, Permanent Magnets, Hts, X Ray Diffraction, Magnetic Flux, Numerical Models, Solid State Reactions, High Resolution Transmission Electron Microscopy, High Critical Current Densities, Electric Windings, Conductor, Anisotropy, Screening Current, Thin-films, Liquefied Gases, Temperature Measurement, Strontium Compounds, High Field Magnets, Strain, External Magnetic Field, Lanthanum Compounds, Superconducting Electric Lines, Ion Beams, Fabrication, Surface Discharges, Film Growth, Transport Currents, Superconducting Layer, Buffer Layers, Pinning, Electromagnetic Fields, Superconducting Fault Current Limiters, Magnetic Storage, Magnetic Resonance Imaging, Magnetic Levitation Vehicles, Ion Bombardment, Barium Zirconate, Transmission Electron Microscopy, Temperature Dependence, Pulsed Lasers, Nanomagnetism, Magnetic Moments, Iron Compounds, Electric Current Measurement, Power Cables, Hafnium Compounds, Ac Losses, Trapped Field, Sintering, Nuclear Magnetic Resonance, Morphology, Magnetic Shielding, Film Preparation, High-field, Levitation Force, Electric Fields, Dynamic Resistance, Boron Compounds, Oxygen, No Insulations, Magnetization Loss, Magnetic Field, Magnesium Compounds, Stacked Tape, Nanocomposites, Epitaxial Growth, Electric Current Carrying Capacity (cables), Angular Dependence.

5. Language English

Chinese, Korean, Japanese, and Russian.

III. RESULTS ANALYSIS

1. Annual Scientific Production

As depicted in Figure 2, the publication output exhibits a fluctuating trend over the decade. Following a relatively stable period with a minor peak in 2019 (around 204 articles), the publication volume experienced a downward trend, reaching its lowest point between 2020 and 2021 with roughly 165 articles published annually. However, a significant and sharp surge is observed starting in 2023, escalating rapidly to reach a peak production of nearly 270 articles in 2025. This dramatic upward trajectory highlights a renewed and intensifying global research interest in advanced superconductor materials in recent years.

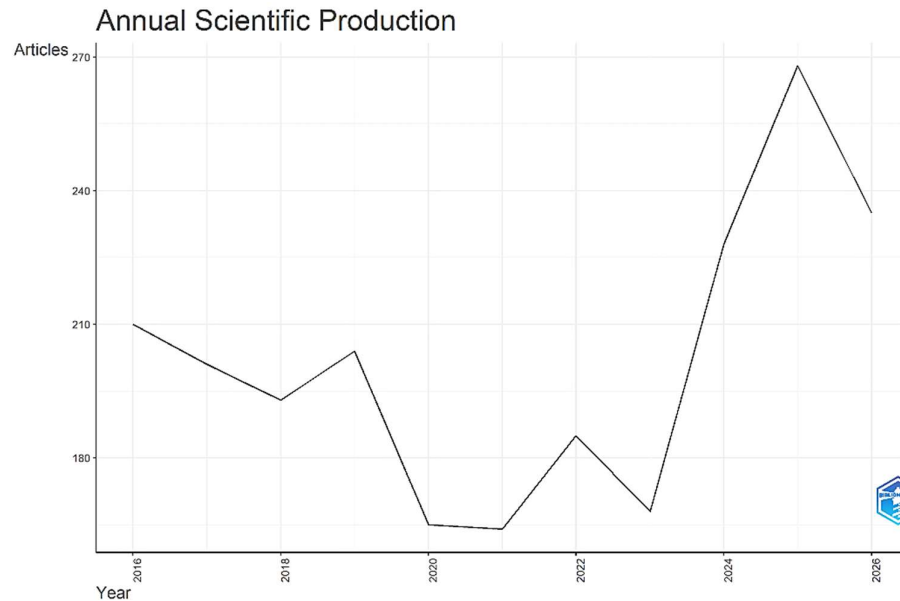
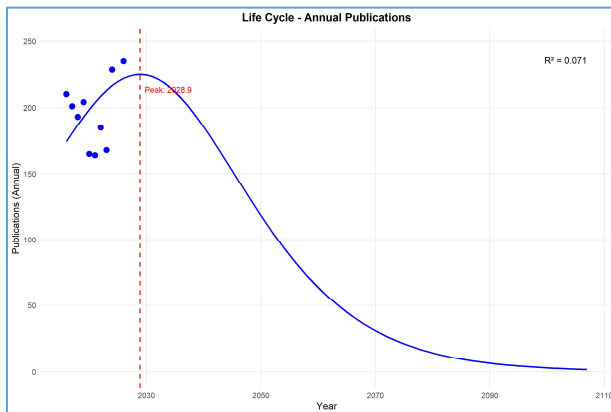


Figure 2. Annual scientific production of publications on REBCO and related high-temperature superconductors, 2016–2026.

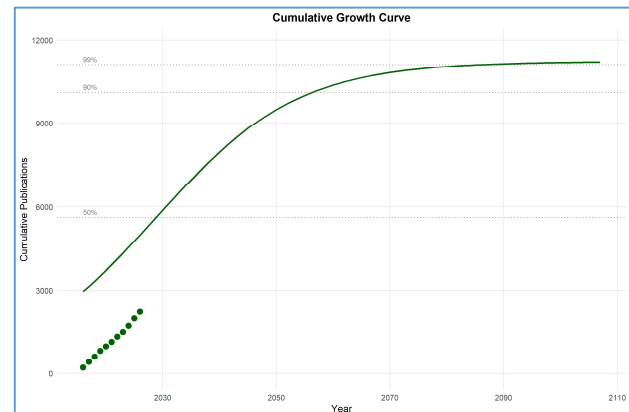
The annual-production plot indicates that publication output fluctuated over the observation period rather than increasing each year uniformly. The plotted series shows a marked rise toward the end of the period, with the highest visible point in 2025, followed by a lower value for 2026. Because 2026 is incomplete, its count should not be compared directly with full-year counts. Exact annual values should be reported from the Scopus export or Bibliometrix output rather than estimated from the figure.

2. Life Cycle of Scientific Production

A publication life-cycle curve was fitted to explore whether the annual publication pattern follows a simple growth-and-decline trajectory. Figure 3 shows the fitted curve, and this model is exploratory and should not be interpreted as a forecast without validation against the underlying annual counts and comparison with alternative models.



(a)



(b)

Figure 3. Life cycle of scientific production based on (a) annual publications and (b) cumulative growth curve.

The cumulative-growth plot in Figure 3(b) suggests that the accumulated number of records rises rapidly during the observed period and then approaches a plateau in the fitted curve. However, the figure also extrapolates beyond the 2016–2026 observation window; the extrapolated portion should be described as a model projection, not as observed publication activity. The fit statistic shown in Figure 3 appears low, so interpret the life-cycle model cautiously and check the underlying data and model specification.

3. Bibliometric Science Mapping

3.1. Network Analysis of the Co-Occurrence of Authors' Keywords

A co-occurrence analysis of author keywords was used to identify terms that appear together across the selected records, and the resulting network is shown in Figure 4. In the network, node size represents term frequency and links represent co-occurrence relationships; cluster colours indicate groups of terms that are more strongly connected within the network.



Figure 4. Author-keyword co-occurrence network for REBCO and high-temperature superconductivity research based on (a) co-occurrence network and (b) Word Cloud from RStudio.

The network places critical-current-density and high-temperature-superconductor terminology near the centre of the mapped field, consistent with the study's focus on current-carrying performance. Connected terms also include magnetic fields, superconducting materials, coated conductors, flux pinning, and related engineering concepts. Cluster membership should be interpreted as a mapping result, not as proof that the terms represent independent research subfields. The analysis settings—especially the minimum keyword frequency, counting method, and thesaurus cleaning—must be stated in the final manuscript.

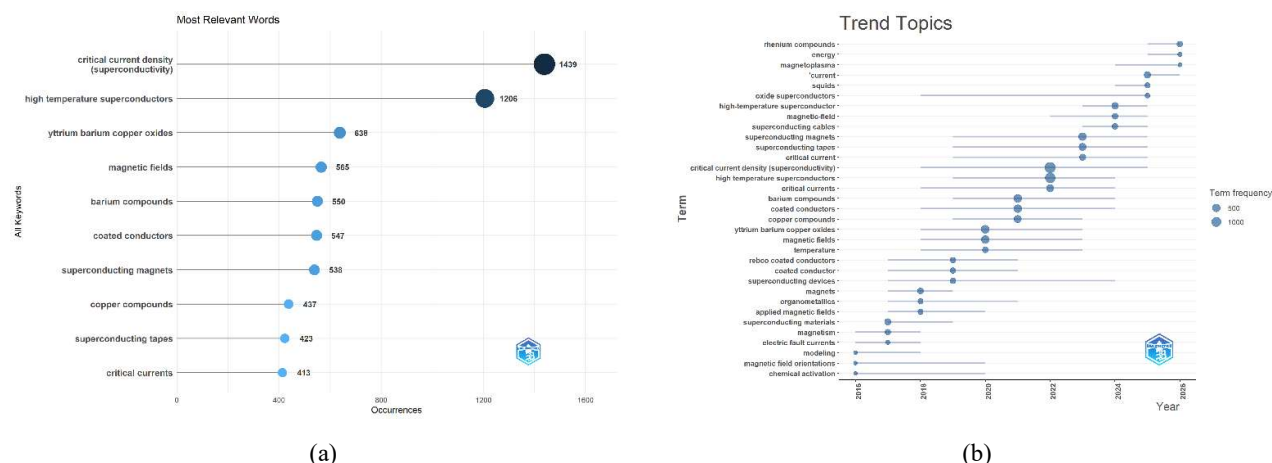


Figure 5. Connected terms based on (a) the most relevant words and (b) trend topics of semiconductor materials.

[illegible]

Based on Figure 6, the Treemap analysis delineates the overarching thematic architecture of the REBCO and YBCO literature by scaling keywords according to their frequency. Critical current density (superconductivity) emerges as the most prominent node, representing 11% of the weighted terms, alongside high-temperature superconductors at 9%. Essential chemical and physical parameters—such as yttrium barium copper oxides (5%), magnetic fields (4%), barium compounds (4%), and coated conductors (4%)—further shape the landscape. Together, these clusters validate the scientific community's continuous dedication to resolving electromagnetic constraints and advancing high-temperature superconductor technologies.

The thematic map generated from author keywords is presented in Figure 7. The distribution illustrates how different research topics cluster according to their relevance and internal maturity. Core performance and material keywords, including critical current density and high-temperature superconductors, show high centrality, linking various auxiliary technological aspects. Concurrently, specific oxide formulations form distinct groupings that highlight the chemical and structural focus areas underlying REBCO and YBCO advancements.

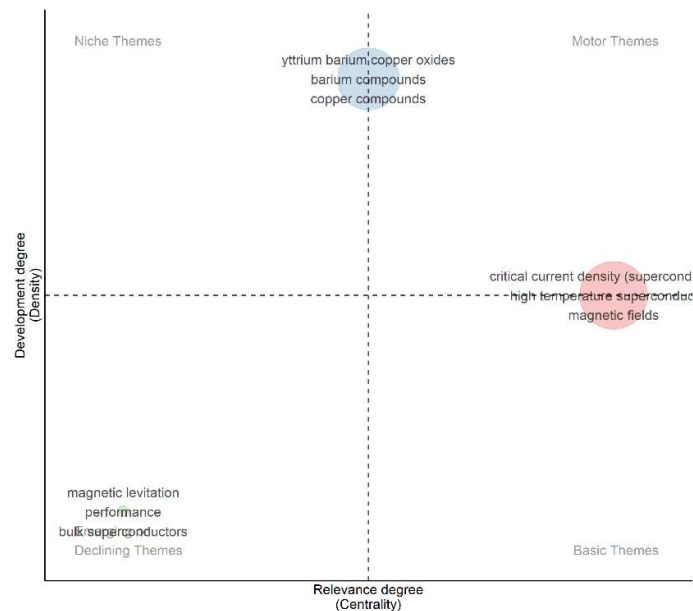


Figure 7. Thematic map classifying research topics based on their degree of relevance (centrality) and degree of development (density).

The thematic map positions critical-current-density and high-temperature-superconductor terms among the more central topics in the mapped dataset. Other terms appear in different quadrants, indicating differences in their connectedness to the wider field and their internal development. The interpretation of individual quadrants should follow the axes and labels shown in the figure; topics should not be labelled as emerging or declining solely from their position without considering frequency and time trends. In the conventional thematic-map interpretation, motor themes have relatively high centrality and density; basic themes have high centrality but lower density; niche themes have lower centrality but high density; and emerging or declining themes have low centrality and low density. The labels in this figure should be checked against these definitions and the underlying Bibliometrix output before publication.

3.3. Thematic Structure Analysis through Factorial Mapping and Dendrograms

Multiple correspondence analysis (MCA) was employed to explore the conceptual relationships and similarities among terms in the bibliographic metadata. The resulting factorial map and hierarchical clustering dendrogram are presented in Figure 8, providing complementary visualizations of the conceptual structure of the research field.

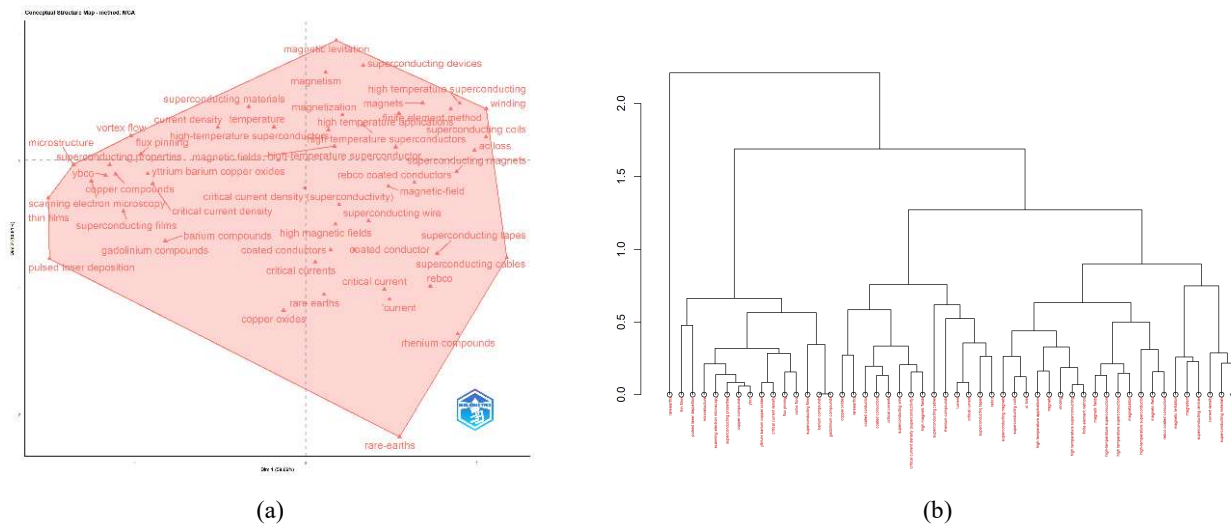


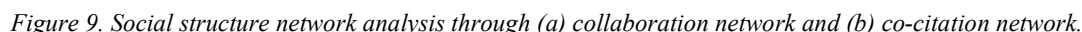
Figure 8. Thematic structure analysis through (a) factorial mapping and (b) dendrograms within the topics of semiconductor materials.

To uncover the underlying conceptual architecture of the literature, multiple correspondence analysis (MCA) and hierarchical cluster dendrograms were constructed, as illustrated in Figure 8. The conceptual structure map in Figure 8(a) (Factorial Map) demonstrates how research terms are spatially distributed across two primary dimensions, explaining 59.66% and 13.81% of the variance (Dim 1 and Dim 2, respectively). The map clearly partitions the field into distinct thematic domains: the left hemisphere is heavily concentrated on structural and material characterization—featuring terms such as microstructure, scanning electron microscopy, pulsed laser deposition, vortex flow, and flux pinning—while the right hemisphere clusters macro-level engineering and device applications, including superconducting magnets, coils, cables, AC loss, and finite element methods.

Complementing the analysis, the hierarchical cluster dendrogram in Figure 8(b) categorizes these semantic relationships into distinct branches. The clustering confirms a logical progression from microscopic material synthesis and foundational parameters (YBCO, yttrium barium copper oxides, barium compounds) to complex electromagnetic performance metrics (critical current density, magnetic fields) and practical high-temperature superconducting devices. This dual mapping validates that contemporary research in REBCO and high-temperature superconductors operates as a cohesive bridge connecting fundamental materials science with advanced power and energy applications.

3.4. Social Structure

The collaboration network was examined to characterize the social structure of the research field. Figure 9 presents the network visualization included in the source file. Before submission, the caption and text should specify whether the nodes represent authors, institutions, or countries, and whether link weights represent co-authorship or another collaboration measure.



Concurrently, the co-citation network in Figure 9(b) highlights the foundational literature clusters and intellectual linkages connecting key scientific milestones in superconductor research. The distinct modular groups indicate that scholarly works are anchored around specific theoretical and experimental paradigms—such as critical-current behavior, vortex dynamics, and material synthesis—where heavily cited references act as core intellectual bridges across different subfields.

The bibliometric findings indicate that critical current density (J_c), high-temperature superconductivity, magnetic fields, coated conductors, and flux pinning are important themes in REBCO research. These topics reflect the challenge of maintaining superconducting performance under practical operating conditions. In Type-II superconductors, magnetic vortices can move under an applied current and cause energy dissipation. Artificial pinning centres, including nanoparticles, nanorods, and other microstructural defects, can help suppress vortex motion and improve current-carrying performance. However, their effectiveness depends on defect morphology, size, density, orientation, and distribution within the superconducting matrix. Therefore, the prominence of these terms in the bibliometric network indicates research interest rather than proving the superiority of a particular pinning strategy.

The keyword co-occurrence network, thematic map, and conceptual structure analysis provide complementary perspectives on the intellectual organization of REBCO research. Keyword co-occurrence identifies relationships between frequently associated terms, while thematic mapping distinguishes topics according to their centrality and density. Multiple correspondence analysis further illustrates similarities within the analysed metadata. However, the positions and connections of keywords do not independently demonstrate causal relationships, technological maturity, or scientific impact. The interpretation of these

visualizations therefore depends on appropriate keyword cleaning, counting methods, occurrence thresholds, and the treatment of synonymous terms such as REBCO and YBCO.

The annual scientific production analysis provides an overview of publication activity from 2016 to 2026. Nevertheless, the incomplete 2026 observation period limits comparisons with previous full years. Similarly, the fitted publication life-cycle curve should be interpreted cautiously because its reliability depends on the underlying annual publication counts and goodness of fit. The collaboration network can help identify connections among researchers or institutions, but quantitative publication and citation data are needed to establish their relative productivity and influence. These considerations emphasize the importance of distinguishing observed bibliometric patterns from model-based interpretations.

From an engineering perspective, the development of REBCO conductors requires balancing superconducting performance with mechanical reliability, alternating-current losses, thermal stability, cryogenic requirements, manufacturing scalability, and cost. High critical current density alone does not guarantee suitability for applications such as high-field magnets, power transmission, and superconducting electrical machines. Future research should therefore integrate bibliometric mapping with a systematic comparison of experimental results under comparable operating conditions. This approach would help identify promising flux-pinning strategies while assessing their reproducibility and practical applicability. The findings should also be interpreted in light of the study's limitations, particularly its reliance on Scopus, the reproducibility of the search strategy, and the incomplete 2026 dataset.

VI. CONCLUSION

This study combines systematic literature-review principles with bibliometric mapping to characterize research on REBCO and related high-temperature superconductors during 2016–2026. The records and visualizations indicate that critical current density, high-temperature superconductivity, magnetic fields, coated conductors, and flux-pinning-related terms are prominent components of the mapped literature. These themes reflect the importance of maintaining current-carrying performance under applied magnetic fields while developing conductors suitable for practical engineering applications.

The broader literature identifies artificial pinning centres and microstructural engineering as strategies for mitigating vortex motion and improving in-field performance. However, the effectiveness of these approaches depends on defect size, density, morphology, orientation, distribution, and compatibility with the superconducting matrix. Practical translation also requires attention to mechanical integrity, alternating-current losses, cryogenic operation, manufacturing scalability, and cost.

The contribution of this study is a bibliometric overview of the intellectual and thematic structure of the selected Scopus records, rather than a direct experimental ranking of REBCO materials or pinning strategies. The findings should therefore be interpreted in light of the search strategy, database coverage, keyword cleaning, and the incomplete 2026 publication year.

Future work should report exact annual counts and the full reproducible Scopus query, validate the life-cycle model against the underlying data, provide quantitative tables for the leading authors/sources/countries/keywords, and conduct a focused full-text synthesis of comparable measurements of critical current density under specified temperature and magnetic-field conditions. Such steps would strengthen the connection between bibliometric patterns and engineering recommendations for superconducting energy technologies.

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