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Beyond Fossil Fuels: Repurposing Legacy Energy Infrastructure for a Sustainable Energy Transition

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ABSTRACT

The reuse of fossil-energy infrastructure could contribute to the energy transition, but scholarship on wells, depleted reservoirs, pipelines, power stations and offshore assets is fragmented across engineering and energy-policy fields. This study distinguishes the scope of a broad bibliometric search from a more specific analysis of physical legacy-asset conversion. A four-block Web of Science topic query produced 4,423 records (2001–2026). An accession-level audit, document-eligibility checks, conservative title–abstract screening and topical review yielded 252 records on legacy infrastructure repurposing (2007–March 2026). The author-provided Biblioshiny figures are retained unchanged as an exploratory map of the original 4,423 records; separate tables and analyses describe the screened 252-publication core. Within the core, output increased from 14 papers in 2007–2014 to 173 in 2021–2025; fossil power stations (107) and wells/fields (70) predominate in the title-based asset coding. The broad-map vocabulary prominently features biomass and conversion, demonstrating why topic-query output should not be equated with the targeted reuse literature. Integrating these distinct evidentiary layers, the review identifies asset integrity, lifecycle emissions, service conversion, finance, governance and community outcomes as key research questions. The PRISMA-adapted diagram reports all screening counts, while the absence of cited-reference fields prevents validated reference co-citation or bibliographic-coupling analysis.

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1. Introduction

Decarbonizing energy systems raises a question that is not resolved by comparing new renewable generating technologies alone: what should happen to the large inventory of wells, pipelines, reservoirs, power stations, offshore platforms, refineries and mining structures built around fossil-fuel production? These resources represent capital, engineering know-how, access rights and physical presence. There may be reasons to keep them, as they may still have useful function; or there may be reasons to decommission them, such as their age, their level of emission, or because they are in a certain location. The problem is thus one of conditional asset conversion instead of assuming that re-use is environmentally good. It includes technology design, liability, local employment, flexibility in the electricity system, and when fossil fuels retire. This diversity is reflected in the underlying literature. Existing oil and gas wells have been explored as heat exchangers for geothermal energy, with previous engineering studies in these wells focusing on the feasibility of producing geothermal energy, while later studies examined the reuse conditions and policy barriers for geothermal production (Bu et al., 2012; Caulk & Tomac, 2017; Davoodi et al., 2024).

Depleted gas reservoirs have been considered for seasonal storage of hydrogen and evaluated for geochemical hazards (Amid et al., 2016; Hemme & van Berk, 2018). The conversion of gas pipelines raises unique material-compatibility and system-planning issues (Morales-España et al., 2024; Telessy et al., 2024). However, other opportunities exist, such as retrofitting coal-fired power plants with carbon capture or thermal storage and evaluating disused mine shafts for gravity storage or offshore platforms for renewable energy use (Fan et al., 2018; Morstyn et al., 2019; Nia & Edalat, 2025). These streams address the same broad reuse problem but employ different assumptions, metrics and disciplinary languages. While there are some studies that focus on particular technologies for repurposing infrastructure, the literature is scattered by asset type, technological use, and analysis. This fragmentation presents challenges for developing an integrated understanding of the contribution of legacy-energy infrastructure to sustainable energy transitions. In addition, large-scale bibliometric searches that include fossil-energy sources, infrastructure, conversion technologies, and sustainability applications might result in the identification of publications that do not necessarily include the concept of adaptive reuse of physical infrastructure but rather general fuel chemistry, biomass conversion, and conventional energy processing. This can therefore impact how publication trends, thematic structures and emerging research priorities are interpreted, as the scope of the research varies. The present study attempts to overcome this shortcoming by separating the general energy-conversion literature from a more specific group of studies that explicitly focus on the re-use of physical fossil-energy resources. Its contribution is to combine bibliometric performance analysis, classification by infrastructure and critical synthesis to determine the evolution of research, key conversion pathways, technological and institutional barriers, and research priorities. The integrated perspective offers a structured basis for comprehending the potential and constraints of repurposing legacy-energy infrastructure in the context of sustainable energy transition strategies.

Bibliometric performance analysis describes the volume, publication outlets and citation patterns of a defined literature; science mapping examines relations among elements such as author keywords (Aria & Cuccurullo, 2017; Donthu et al., 2021). Neither approach directly measures engineering performance or causality. We therefore ask four questions: How has the screened literature developed over time and across publication outlets? Which existing asset families and conversion pathways receive the greatest research attention? What conceptual links emerge from author-keyword co-occurrence? Which underexamined cross-asset questions could form an agenda for engineering, policy and social-science research? The answer integrates descriptive counts, a carefully bounded map and interpretation of representative source studies, rather than presenting citation prominence as proof of a technology's merit.

2. Research Background and Gap

2.1. Subsurface Reuse: Wells, Reservoirs and Pipelines

The subsurface stream distinguishes assets whose original function was to extract or transport hydrocarbons from the new service expected of them. In abandoned wells, downhole heat-exchange design, flow resistance and formation temperature matter to geothermal output. Bu et al. (2012) explored geothermal production using abandoned wells, whereas Caulk and Tomac (2017) considered their reuse in geothermal systems. Davoodi et al. (2024) subsequently reviewed energy recovery from abandoned petroleum wells. Reuse offers a possible role for existing boreholes, but a pre-existing hole is not automatically a serviceable geothermal well: completion design, corrosion, cement condition, heat drawdown and monitoring remain asset-specific constraints. Depleted reservoirs come with a different engineering logic: pore space and containment of the reservoir must be characterized for a fresh injected/stored medium. Amid et al. (2016) investigated the seasonal storage of hydrogen in a depleted natural gas reservoir; Hemme and van Berk (2018) evaluated the hydrogeochemical risks; Zamehrian and Sedaee (2022) investigated the influence of cushion-gas. Hellerschmied et al. (2024) link storage to geo-methanation and Wu et al. (2025) explore carbon utilization and sequestration in depleted hydrocarbon reservoirs. The performance estimate of storage reuse cannot be extrapolated from these studies into a single number

because the nature of hydrogen and carbon dioxide and compressed air and the nature of their end uses; environmental impacts and monitoring needs are different. The well and reservoir problem now becomes a network problem when involving transmission infrastructure. Telessy et al. (2024) explore the constraints and possibilities of converting natural gas pipelines to carry hydrogen, while Morales-España et al. (2024) look at energy-system interactions when hydrogen electrification and natural gas pipeline retrofits are modeled simultaneously. Conversion decisions need to take into account not only a pipe section, but compressors, seals, valves, demand geography and operating rules. A cross-asset assessment is required to determine if the converted pipeline will be used to deliver low emission supply to potential users, or if it will be used to prolong reliance on fossil feedstocks.

2.2. Power Generation, Industrial Sites and Offshore Structures

Studies on coal-fired plants involve pathways that have widely divergent transition implications. Fan et al. (2018) discuss the potential of carbon-capture retrofit, with an explicit focus on technology lock-in. Debiagi et al. (2022) discuss the feasibility of using iron as energy carrier for coal station retrofits, and Yong et al. (2022) assess thermal-storage coupling for flexible grid operation. The flexibility or direct emissions reduction that could come from adaptation at an operating station could be countered by other emissions from early retirement and replacement generation and lifecycle emissions. A bibliometric count of retrofit papers does not allow determining which policy choice has the lowest social cost. The re-use possibilities outside of the typically defined generating units are also heterogeneous. Sedlar et al. (2019) explore blue energy conversion using offshore gas infrastructure, Alias and Go (2023) explore solar conversion at sea, and Nia and Edalat (2025) explore platform-to-wind decisions. Each asset is limited in its suitability by structural fatigue and environmental and offshore maintenance requirements. Morstyn et al. (2019) explore the use of suspended weight gravity for storage in abandoned mines, while Colas et al. (2023) cover pumped storage in coal mines. The integration options in the pathways for biofuels and refinery applications are distinct: Integration of biofuel supply chains with existing refineries is explored by Tong et al. (2014), while carbon-capture and electrification retrofits in oil refineries are discussed by Chattopadhyay et al. (2025). The examples are all intended to indicate a wide conceptual range but do not, necessarily, indicate technical interchangeability.

2.3. The Unresolved Bibliometric Problem

Most of the engineering articles and reviews focus on a particular asset class, conversion medium or case-study geography. That specialization is necessary for technical depth but hides the fact that there are overlaps in research streams: a well can be a heat exchange asset, a reservoir can be used for seasonal storage, and a pipeline could be used to transport the seasonal storage to end users. The financing and ownership can be split between different parties. In the case of transition-oriented decisions, the question needs to be asked whether these complementary assets are examined jointly, how risks are being categorized and if environmental statements consider lifecycle and decommissioning counterfactuals. The present study attempts to fill this gap in mapping with the help of an asset specific corpus, comparative theme coding and a cross-asset research matrix. It is not the first study of bibliometrics on energy transitions, nor does it assume that there are unmeasured empirical relationships.

3. Materials and Methods

3.1. Data Source, Search Construction and Time Window

The primary data source was the researcher-supplied Web of Science plain-text export comprising 4,423 records downloaded. The topic query required four OR-based conceptual groups connected by AND: a fossil-energy source; a physical infrastructure term; a reuse or conversion action; and a low-carbon or energy-transition application. Appendix A reproduces the full search string. The unfiltered export spans publication years 2001–2026 and is the analytical population represented by all the original Biblioshiny images supplied with the study. No Scopus records were added, and the supplied figures were neither redrawn nor recalculated. A second, deliberately narrower, screening exercise retrospectively restricted

eligible publications to 31 March 2026 and identified research explicitly addressing conversion of physical fossil-energy assets. This screened corpus spans 2007–March 2026 and is the population for Tables 2–5 and the corresponding textual calculations. English-language journal articles and reviews were eligible for the narrower analysis; retracted publications were excluded. The separate coverage periods and populations must be preserved when interpreting the results.

3.2. Record Screening and Transparent Flow

WoS accession numbers were used as primary duplicate identifiers, with no duplicates detected. Exclusions were sequential: 49 non-English items and seven retracted records left 4,367 metadata-eligible items. A deterministic title–abstract screening rule required a title reference to a physical legacy fossil-energy asset and evidence of repurposing or a transition application in the title or abstract. This conservative lexical screen excluded 4,082 records and retained 285 candidates. A further candidate-level review of titles and available abstracts excluded 33 records primarily concerned with conventional fossil processing, general chemistry, remediation without an energy-reuse pathway or no physical asset conversion. The final corpus consists of 252 publications. A record-level audit contains accession number, title, metadata and the applicable disposition. Figure 1 visualizes this sequence using a PRISMA-adapted flow. To increase transparency and traceability in the selection of bibliometric records, the screening procedure was adapted from PRISMA 2020 (Page et al., 2021) reporting principles. The eligibility assessment was based on two main criteria: identification of existing physical fossil-energy infrastructure and explicit link to infrastructure repurposing, conversion or low-carbon energy applications. Studies that focused on traditional fossil-fuel processing, general chemical conversion or environmental remediation but did not have an application for energy-reuse were excluded. The screening was performed in two stages: the first by title and the second by topical relevance of the records selected for the first stage. This process focused on the identification of publications that have been directly related to the re-use of physical infrastructure, and not necessarily general research on energy-conversion. However, the title-based screening process may have missed relevant studies that mentioned infrastructure repurposing in the abstract and/or full text but did not explicitly state it in the title. In addition, the screening was not done on an independent dual-reviewer basis, with a full-text eligibility assessment, or with a formal risk-of-bias assessment. As such, the final set of 252 publications may be considered as a well-defined and specific bibliometric set rather than a comprehensive list of all the research focused on fossil-energy infrastructure repurposing. The methodological limitations are recognized in the interpretation of findings and are important for future studies.

3.3. Analytical Variables and Reproducibility

The analysis uses two explicitly different units. First, 4,423 exported records underpin the author-provided Biblioshiny outputs, including source and author productivity, affiliations, geographic distributions, citation patterns, word frequencies, trend topics, thematic mapping and conceptual-structure graphics. These are exploratory maps of the original four-block search, not results for the 252 relevant studies, and all original image files are inserted without alteration. Second, the 252 screened records were parsed into publication year (PY), source (SO), document type (DT), authors (AU), author keywords (DE), Times Cited (TC), DOI (DI), title (TI) and abstract (AB). Focused measures include annual publication counts, journal counts, citation totals, asset classifications and keyword pairs. For this narrower corpus, keywords were normalized for case and a few direct synonyms (for example CCS/carbon capture and storage); distinct term pairs were counted per publication, but no additional co-occurrence chart was manufactured. Missing DE fields were not imputed. An ordered title-based coding scheme assigned one primary asset family per record, and a separate, non-exclusive screen identified six technological or governance themes. The author-supplied exploratory visualizations were not retrospectively relabeled or interpreted as screened-corpus outputs. The broad corpus includes many general conversion and biomass papers that did not pass the asset-repurposing screen. This contrast is at the heart of the interpretation and boundaries of the paper. There is no cited-reference (CR) field in the WoS

file, therefore there is no figure for either bibliographic coupling or reference co-citation. The terminology used for performance versus science-mapping is based on the works of Aria and Cuccurullo (2017) and Donthu et al. (2021).

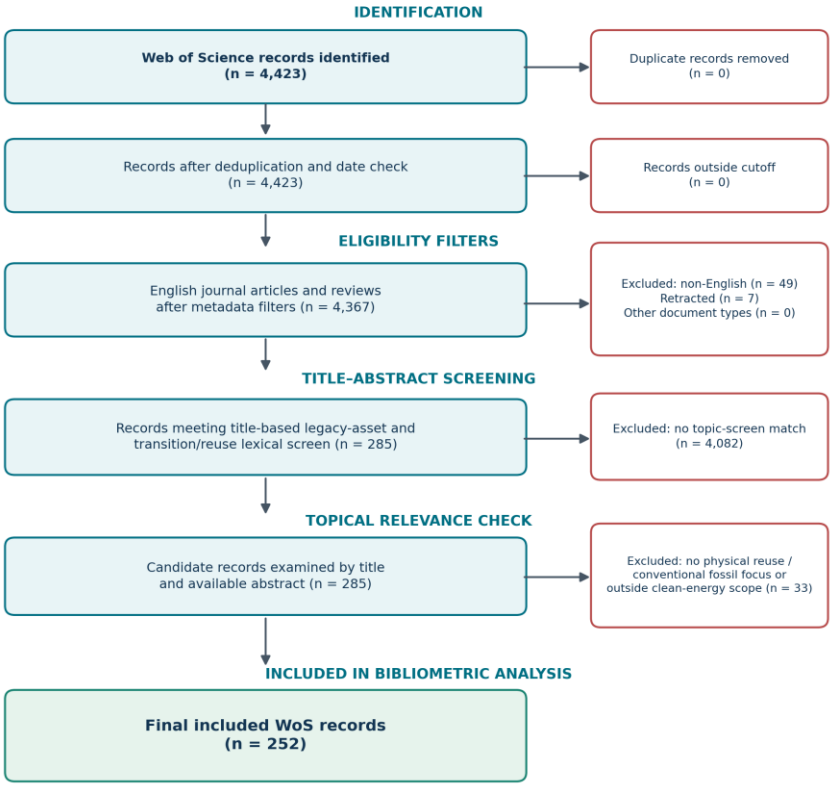


Figure 1:PRISMA Diagram

Table 1
Database, Eligibility Criteria and Analytical Decisions

Dimension	Recorded decision or operational definition
Source	Web of Science; supplied Full Record-like export; retrieved 2026.
Search logic	Four AND blocks: fossil-energy source × infrastructure × reuse action × low-carbon application.
Time boundary	Exploratory Biblioshiny export: 2001–2026 (4,423 records); focused study: 2007–31 March 2026 (252)
Document eligibility	English-language journal articles and reviews; retractions removed.
Relevance criterion	Physical legacy fossil-energy asset plus explicit conversion/transition context in screened metadata.
Deduplication	Exact WoS accession-number comparison; zero duplicate records.
Performance measures	Focused n = 252: annual volume, journal counts, asset classes, document type and source-record Times Cited. Broad n = 4,423: supplied original figures only.
Science map	Original Biblioshiny maps: broad n = 4,423 (unaltered). Focused n = 252: text-only, normalized keyword-pair counts; no replacement figures generated.
Unavailable analysis	No cited-reference lists: no valid bibliographic coupling or co-citation analysis.
Figure population	Figure 1: screening flow from 4,423 to 252; Figures 2–16: author-supplied Biblioshiny maps for all 4,423 exported records. Never pool or compare their frequencies with the 252-record tables.

4. Results

4.1. Corpus Characteristics And Publication Development

The bibliometric analysis separates the population of publications from the original Web of Science query from the final set of publications about physical legacy-energy infrastructure repurposing. The first search resulted in 4,423 publications on a wide variety

of applications of fossil energy conversion, infrastructure and sustainability, as shown in Figure 1. After going through the eligibility and relevance screening process, 252 publications were retained (around 5.7% of the initial publications of the search). A methodologically significant distinction is that the general energy conversion, fuel chemistry and biomass processing studies encompass those not specifically focused on the adaptive reuse of fossil fuel energy assets. So, the main descriptive results are based on the 252-publication corpus, while the original Biblioshiny visualizations, based on 4,423 records, are kept only to provide a glimpse of the overall research field. The focused dataset comprises 235 research articles and 17 review papers from 114 journals (Table 2). Of these publications, 251 have digital object identifiers, while 228 contain author keywords. The data represents 1,162 author occurrences in publications, not 1,162 different researchers. Cumulative Web of Science citations are 6,945 and the average number of citations per publication is 27.6 while the median is 13. These indicators describe the research activity in the screened corpus and are not necessarily the same as the publication, citation and thematic characteristics of the whole 4,423 record set.

Within the focused 252 records, annual output is small in the earlier period (14 publications in 2007–2014), reaches 46 during 2015–2020 and totals 173 in the five complete years 2021–2025. The latter yearly counts are 14 (2021), 26 (2022), 24 (2023), 49 (2024) and 60 (2025); another 19 records are associated with January–March 2026. These figures reflect the specified metadata screen and do not estimate project commissioning, emissions avoided or future annual production. No author-supplied annual-production figure was available for the 252-record sample, so the observed annual counts are reported as text rather than as a newly constructed graph.

Table 2
Descriptive Profile of the Screened Bibliometric Dataset

Characteristic	Observed value
Records included	252
Publication window	2007–31 March 2026
Document types	Articles: 235; reviews: 17
Source journals	114
Records with DOI	251 of 252
Records with author keywords	228 of 252 (24 missing)
Author appearances across records	1,162 (not unique authors)
WoS Times Cited	6,945 in total; mean 27.6; median 13

Citation-age differences are illustrated separately using the originally supplied broad-export graphic in Figure 2. Its year-based average citation measurements concern all 4,423 search results, including papers later excluded for lacking a specific legacy-asset conversion focus. Peaks in earlier years and the lower values for very recent years cannot be used to judge the comparative quality of specific technologies. Citation counts are observed in 2026, while 2026 is an incomplete publication year. The figure provides context for the fact that it is important not to compare the number of citations by source record without considering the age and subject mix.

Figure 2 shows the user's average-article-citations-per-year output for the broad search (2001-2026). The curve is age sensitive and as such, mixes different research objects and therefore cannot be used as a time series for the focused sample, but rather as a descriptive citation context only.

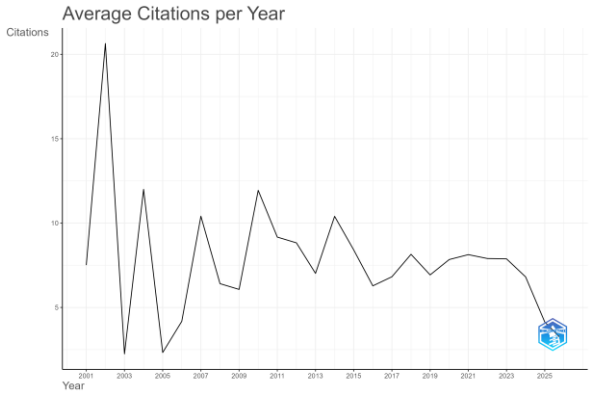


Figure 2: Average Article Citations Per Publication Year

4.2. Publication Outlets and Highly Cited Studies

Table 3 records the most frequent sources within the screened 252-publication core: International Journal of Greenhouse Gas Control (17), Energies and Applied Energy (16 each), Energy (15), International Journal of Hydrogen Energy (14), and Journal of Energy Storage and Renewable Energy (nine each). The seven outlets contribute 96 records (38.1%); the remaining 156 papers appear in 107 other journals. The author's original Biblioshiny graphics answer a different question. Figure 3 shows source productivity across the broad 4,423-record search, in which International Journal of Hydrogen Energy, Energies and Energy have particularly large counts. Figure 4 reports local h-index values within that broad search; Renewable & Sustainable Energy Reviews and Applied Energy display high values on this measure. Source frequency and local h-index are different metrics and should not be treated as a journal-quality ranking. Above all, neither chart should be read as though it were calculated from Table 3's 252 records.

Table 3
Most Frequent Journals In The Screened Corpus

Journal	Publications (n)
International Journal of Greenhouse Gas Control	17
Energies	16
Applied Energy	16
Energy	15
International Journal Of Hydrogen Energy	14
Journal Of Energy Storage	9
Renewable Energy	9
Other 107 journals	156
Total	252

The scope difference is especially evident in source productivity. Figure 3 reflects journals publishing general fossil-energy and conversion studies, whereas Table 3 restricts the count to papers that passed the physical-asset screen. The figure therefore highlights International Journal of Hydrogen Energy, Energies, Energy and Applied Energy in the full export without overturning the narrower outlet profile.

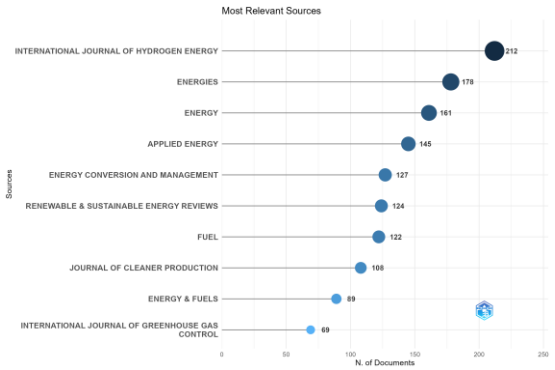


Figure 3: Most Relevant Sources By Publication Count

Figure 4 shows source-local h-index values within the same unfiltered export. Renewable & Sustainable Energy Reviews have a displayed local h-index of 68 and Applied Energy 57; such measures describe citations within the retrieved set and reflect document mix, citation opportunity and database scope. The figure does not establish journal standing or a preferred outlet for research on repurposing.

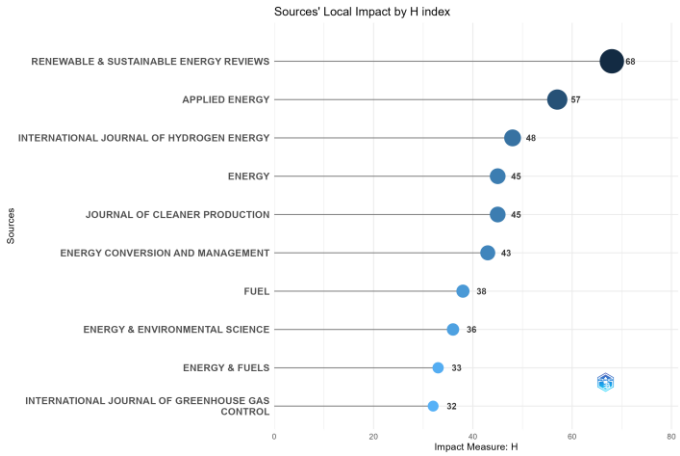


Figure 4: Local H-Index By Source

Citation visibility inside the screened sample differs from the broad journal-level metrics. Table 4 presents the six included records with the highest raw WoS Times Cited values in the 2026, including work on subsurface hydrogen storage, well-to-geothermal conversion and coal-plant transformation. Amid et al. (2016) record 325 citations and Hemme and van Berk (2018) 302; Bu et al. (2012) have 229. These figures remain source-record counts for the 252-publication sample, not local h-indices or country citation totals from Figures 4 and 9. Publication date, methodological reach and disciplinary size can strongly influence each measure. None establishes the environmental superiority of a reuse pathway.

Table 4
Six Highly Cited Source Records

Study	Year	Study focus	TC
Amid et al.	2016	Seasonal storage of hydrogen in a depleted natural gas reservoir	325
Hemme & van Berk	2018	Hydrogeochemical Modeling to Identify Potential Risks of Underground Hydrogen Stora…	302
Bu et al.	2012	Geothermal energy production utilizing abandoned oil and gas wells	229
Caulk & Tomac	2017	Reuse of abandoned oil and gas wells for geothermal energy production	159
Fan et al.	2018	Carbon capture and storage (CCS) retrofit potential of coal-fired power plants in C…	147
Debiagi et al.	2022	Iron as a sustainable chemical carrier of renewable energy: Analysis of opportunity…	147

Note: *TC = Times Cited as recorded in the supplied 2026 export; no field or age normalization was applied. Full bibliographic details appear in References.*

4.3. Authors, Institutional Contributions and Geographical Patterns

The original figures give a different perspective of who is involved in the larger four-block search, not the subset of 252 papers. The authors who published the most works are listed in Figure 5, and there are a high number of authors with names like Zhang X or Wang Y. These are strings of names used in the database, which may match different researchers with the same first letter(s) if the authors are not disambiguated. They should not be used to identify a uniquely dominant contributor to physical asset repurpose.

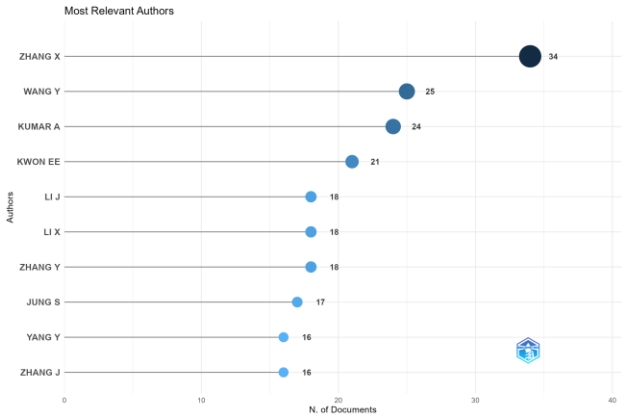


Figure 5: Author Publication Frequencies Within the Broad Export

The institutional contribution of the original search records is shown in Figure 6, with the United States Department of Energy and the Chinese Academy of Sciences having a significant contribution at the institutional level. These frequencies may be impacted by WoS affiliation standardization and multi-affiliation articles, and do not represent unique institutional ownership of the cited article. This broader research activity creates potential contacts for more focused collaboration analyses once the exact 252-record dataset is rerun through Biblioshiny.

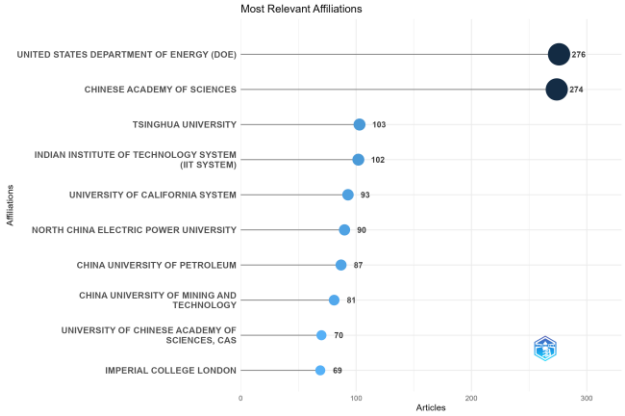


Figure 6: Affiliations With the Largest Record Counts

Geographical charts require equally careful differentiation. Figure 7 classifies corresponding-author countries and separates single-country publications from multi-country publications; China and the United States occupy large shares of this wider search. Figure 8 maps scientific production geographically, using a different counting basis from corresponding-author location. A country may appear through any contributing affiliation in the production map even when its scholar is not the corresponding author. The patterns therefore describe global participation in the search field, not where infrastructure reuse projects have been constructed.

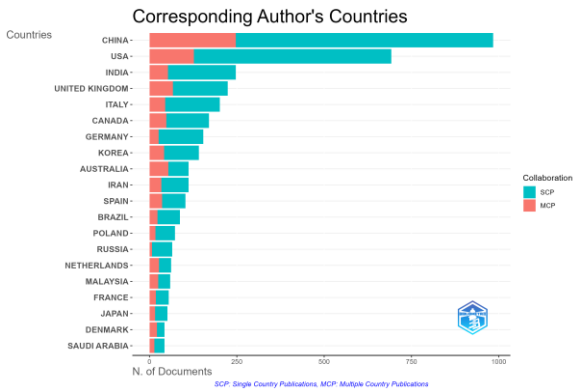


Figure 7: Corresponding-Author Countries and Single-Multiple-Country Publication Types

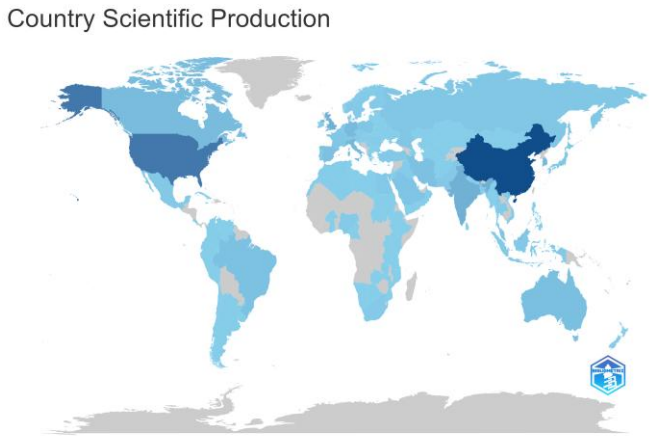


Figure 8: Geographical Distribution Of Scientific Production

Figure 9 presents the most-cited countries in the original Biblioshiny results, with the United States and China showing high aggregate totals. Citation totals combine numerous articles of different ages, subfields and international coauthorship patterns; they cannot be interpreted as national technology performance. Figures 7–9 are not national statistics for the 252 focused asset-repurposing papers. They are useful for locating the broad scientific context and for motivating a later, subset-specific collaboration analysis.

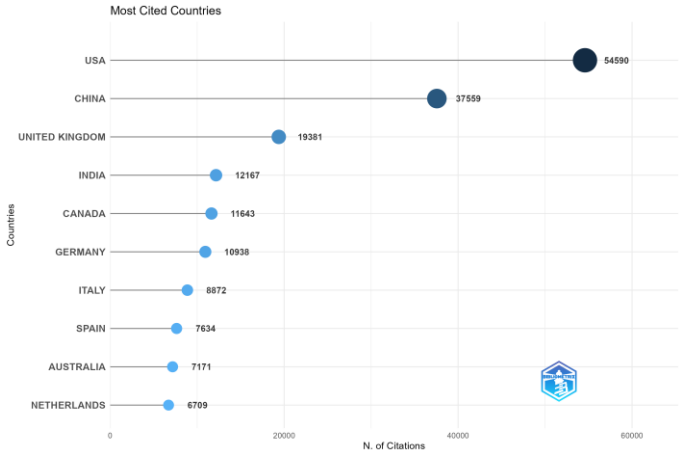


Figure 9: Country-Level Citation Totals

4.4. Legacy-Asset Families In the Focused Corpus

Asset-based coding makes the narrower research object visible. Table 5 shows that fossil power stations account for 107 screened records (42.5%), wells/fields for 70 (27.8%), depleted reservoirs for 27 (10.7%), gas/CO_2 networks for 16 (6.3%), offshore platforms and coal mines for 12 each (4.8% each), refinery/industrial assets for three (1.2%), and cross-cutting or other records for five (2.0%). Each publication was assigned one primary asset based on ordered title rules; a multi-asset paper may therefore contribute to only one row. These counts are a focused asset taxonomy, not figures inferred from the broad Biblioshiny country or keyword maps. Table 5 is more informative than an asset bar chart generated by the new asset addition, as the counts and caveat on the classification are already written.

The sizeable power-station group comprises multiple strategies, including carbon capture, alternative fuels, thermal storage and repowering. Well-based geothermal studies require the temperature, completions and well integrity (Bu et al., 2012; Caulk & Tomac, 2017); for depleted-reservoir studies, the fluid and geochemical response are required (Amid et al., 2016; Hemme & van Berk, 2018). While the numbers of publications is an indicator of the size of the bibliometric streams, the size of the physical opportunities in the screened

sample is far smaller in the offshore and former-mine opportunities. The biomass and conversion priority of the graphics in the broad search should not be counted as evidence for the main asset counts in Table 5.

Table 5
Legacy Energy-Infrastructure Asset Families

Primary asset family	Records	Share (%)
Fossil power stations	107	42.5
Wells / fields	70	27.8
Depleted reservoirs	27	10.7
Gas / CO2 networks	16	6.3
Offshore platforms	12	4.8
Coal-mine assets	12	4.8
Cross-cutting / other	5	2.0
Refineries / industrial	3	1.2
Total	252	100.0

4.5. Keyword Structure and Thematic Development

A separate lexical analysis of the screened titles results in 62 mentions of carbon capture/storage, 61 of geothermal reuse, 61 of governance/appraisal, 46 of renewable integration/repowering, 37 of hydrogen networks/storage and 21 of grid/thermal storage. The categories are non-exclusive, so that a record may reference the physical retrofit and the economic and/or regulatory context. Governance/appraisal is a general term-matching group, and not an indication that every record is a thorough appraisal. To maintain the visual materials provided by the user, the counts are presented in text, not converted to an additional figure.

Author keywords in the focused corpus identify carbon capture and storage and geothermal energy (32 occurrences each), followed by coal-fired power plant (18), abandoned wells (14), geothermal (11), hydrogen storage (nine) and depleted reservoirs (eight). These counts are for the 228/252 records that have DE fields; lexical variants are not automatically interchangeable. The original Biblioshiny images in Figures 10–16 map the much broader 4,423-record search. They are retained in their original form to record the vocabulary and evolution of the search field, but they are not used to validate or to replace these narrower keyword frequencies.

The screened author-keyword pairs offer a qualitative connection between asset and technology keywords: carbon capture and storage co-occur with coal-fired power plant in six documents and with biomass co-firing in five; abandoned wells co-occur with geothermal energy in six documents; depleted reservoirs co-occur with hydrogen storage in four documents. These are labels that are shared with metadata, not causal or technologically compatible. No new keyword network is offered, as the directions are to apply the original Biblioshiny figures; the number of pairs can be viewed in the audit. The broad-export keyword diagrams below refer to a different population and are not intended to be read as a reproduction of this pairing analysis that is focused on export.

4.5.1.Vocabulary Concentration and Search-Field Breadth

The most frequent words are biomass (509), conversion (494), energy (413), hydrogen (396), performance (328) and optimization (301) as reported in figure 10. It can also be seen renewable energy, natural gas, storage and capture of CO_2. These labels illustrate the "big picture" of the four-block query. Biomass/generic conversion is not in itself an indicator of a paper that examines a reused legacy structure but is used as part of the rationale for screening to make asset-specific conclusions.

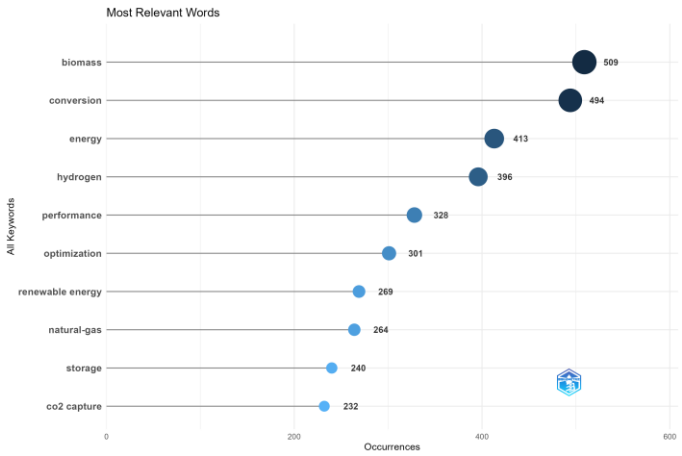


Figure 10: Most relevant words

The provided word cloud (Figure 11) and keyword treemap (Figure 12) provide a similar big picture graphic of the vocabulary supplied. The cloud represents the relative visual dominance of the conversion, biomass, hydrogen and related energy terms, while the treemap clusters common labels by the size of the rectangles. These displays are kept as part of the original output of the researcher but do not provide an independent sample or structural relationships between topics. The numeric occurrence chart in Figure 10 still serves as the benchmark for comparing the frequency of keywords.

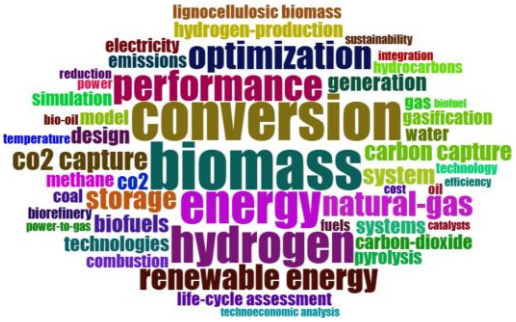


Figure 11: Word Cloud

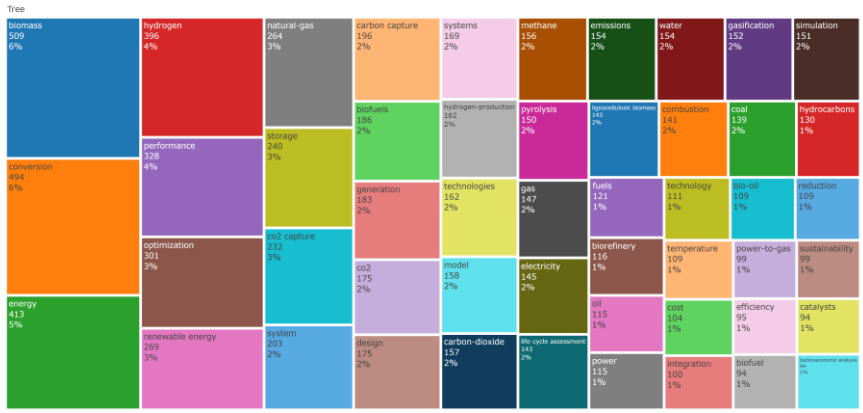


Figure 12: Term-frequency Treemap

4.5.2.Temporal and thematic configurations

The trend-topic display (Figure 13) indicates a shift in the generic search term that was used in the earlier fuel and refinery terms to hydrogen and geothermal energy, and then to embrittlement and sensitivity, toward the right side of the plot. The circles represent the term frequency while the horizontal spans represent the periods of the term(s) observed by the author based on the settings in Biblioshiny. These positions are not to be interpreted as the date when a particular technology was introduced or what will happen with the technology in the future, but rather where terms were found in the broader set.

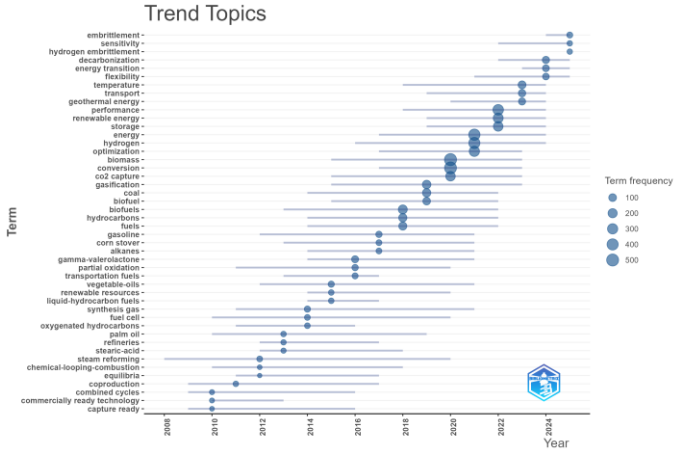


Figure 13: Trend Topics And Observed Term Windows

Figure 14's thematic map plots clusters against network centrality and density. The niche-theme areas of biomass, conversion and biofuels are relatively developed, but peripheral; energy, performance and optimization seem closer to the edge of the well-connected basic and developed niche-theme areas. Hydrogen, CO_2 and hydrogen production lie near the lower central part of the display. The quadrant labels are characteristics of this mapping configuration, NOT independent estimates of maturity, technical readiness or economic return. The map reinforces the need to separate the energy-conversion literature from the specific infrastructure-repurposing question.

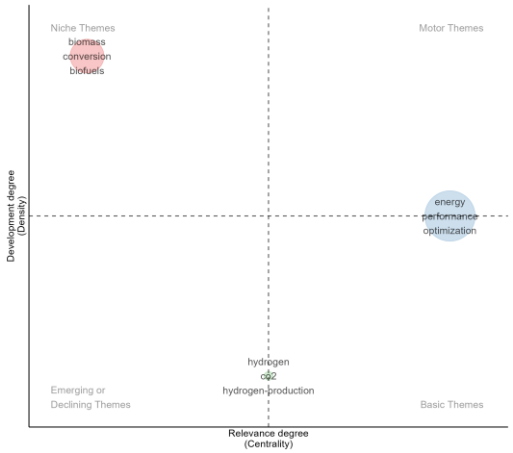


Figure 14: Original Thematic Map By Centrality And Density

The factorial conceptual map (Figure 15) and accompanying dendrogram (Figure 16) reproduce the user's original conceptual-structure outputs. The map positions terms according to statistical proximity in the selected bibliometric representation, while the dendrogram presents hierarchical grouping from the same broad vocabulary. Small labels, term selection and distance choices restrict what can be inferred from the images alone; without raw plotting settings, cluster identities and exact coordinate values should not be invented. Both figures are reported as exploratory illustrations, not as co-citation or bibliographic-coupling networks and not as a clustering of only the 252 screened documents.

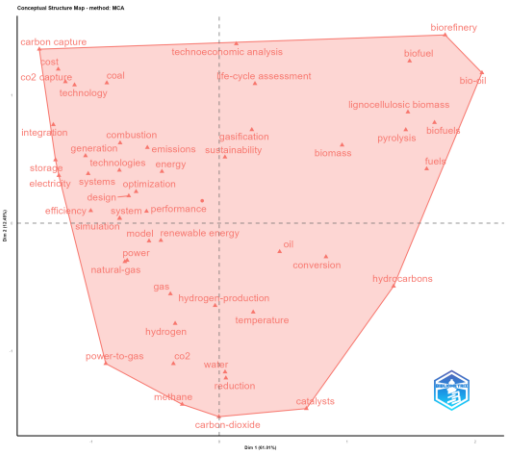


Figure 15: Factorial Conceptual Structure

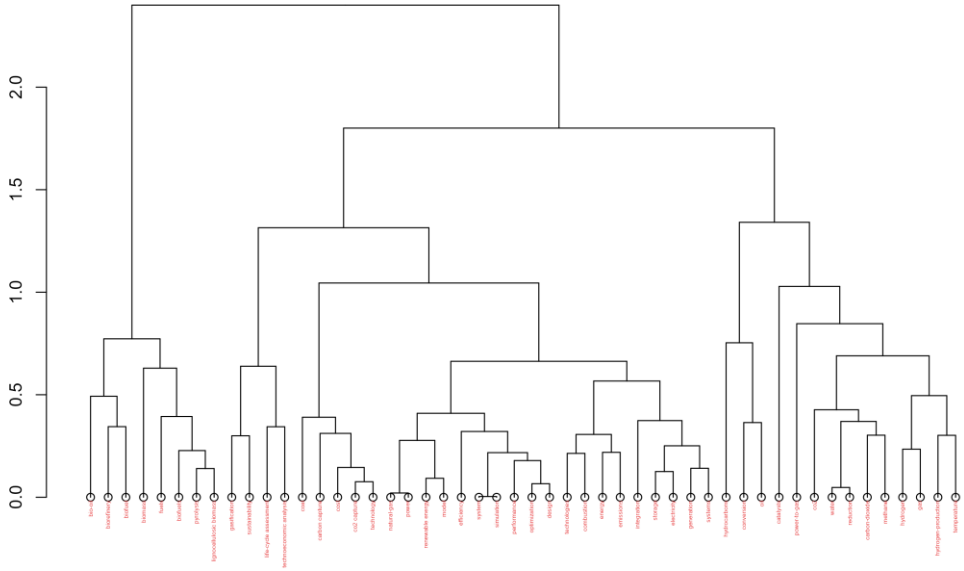


Figure 16: Hierarchical Dendrogram Accompanying the Factorial Analysis

4.6. Integrative Evidence By Conversion Pathway

When reading, the focus is not on performance but on the results of the keywords, which is to be expected. As is expected, the focus of reading is not on the performance itself but on the results of the keywords. The primary concern with geothermal well re-use is whether an existing borehole can be used to deliver heat for a useful life. Bu et al. (2012) discuss energy production from abandoned wells, Davoodi et al. (2024) reviews the literature on the subject and Higgins and Pratson (2026) discuss the subject with a focus on horizontally drilled wells. This may be a better alternative than a newly drilled alternative, depending on site conditions and the evidence of well integrity. In addition, it would be misleading to consider both the geothermal direct heat and geothermal power generation under a single measure since this would not represent the demand and seasonality of geothermal applications. There are relationships between underground storage and gas transport; however, they do need separate risk models. Amid et al. (2016) and Zamehrian and Sedaee (2022) focus on hydrogen storage in depleted hydrocarbon systems, and Hemme and van Berk (2018) on geochemical risk. Telessy et al. (2024), Sayani et al. (2025) and Khaing et al. (2026) focus on pipeline conversion, from a technological or economic point of view. A complete reuse chain needs to be established, which includes compatible subsurface storage,

wellbores, compressors, pipelines and market demand. While a cost improvement in the individual component is no guarantee of economic superiority for the whole system, and the results of engineering tests performed in natural-gas service are not necessarily applicable to hydrogen or CO_2 service.The transition alignment becomes an issue with power-station research. Fan et al. (2018) consider the potential for lock-in due to capture-technology choices, Yong et al. (2022) discuss thermal storage associated with coal units and Yang et al. (2026) explore unit-level transition paths. These methods have varying impacts on fuel use, use of capacity and future decommissioning costs. The offshore studies also move away from platform re-use concepts towards asset specific decision methods (Alias & Go, 2023; Nia & Edalat, 2025; Sedlar et al., 2019). Gravity- and pumped-hydro based storage studies are added, depending on the topology and safety, for mines (Colas et al., 2023; Morstyn et al., 2019). The cross-technology evidence is therefore in support of conditional assessment, not the general principle of re-use over retirement.

5. Discussion

5.1. From Technology Clusters to A Whole-Asset Transition Lens

The results reveal significant variations between the research landscape of fossil-energy conversion and the literature especially focused on reusing existing physical energy infrastructures. As presented in Table 5, fossil power stations represent the largest proportion of the screened publications (42.5%), followed by wells and fields (27.8%) and depleted reservoirs (10.7%). The results show that the research focus is mainly on infrastructure categories that are related to power generation, subsurface energy recovery, and storage application. The general bibliometric visualization in the Figures 10–16, on the other hand, highlight the areas of biomass, energy conversion, hydrogen, and optimization, which corresponds to the more general search strategy. This difference illustrates the impact of the definition of the analytical population on the identification of dominant research areas and thematic relationships. But, publication rate and co-occurrence of keywords should not be taken as direct measures of technological feasibility, environmental effectiveness, and economic superiority. Infrastructure repurposing for sustainable energy transitions is subject to a number of interlinked factors, such as asset integrity, technological compatibility, infrastructure adaptation costs, lifecycle GHG emissions, regulatory considerations and long-term operational performance. Furthermore, the assessment of individual conversion technologies should be integrated in broader energy systems. For instance, the storage of hydrogen in depleted reservoirs would depend on suitable end-use demand, transportation systems, surface processing plants, and compatible wells. Likewise, the transition from conventional power stations to lower carbon energy stations must take into account other energy generation methods, the retiral of the infrastructure and the possibility of carbon lock-in. Future research should therefore take an integrated approach to the infrastructure assessment, comparing the technical, economic and environmental consequences of using the existing infrastructure, with the consequences of retiring, remediating and replacing it.

5.2. Distinguishing Emissions Reduction from Asset Life Extension

The label 'sustainable reuse' requires a stronger test than the existence of an adapted asset. Technical papers may report a reduction in direct stack emissions, a new capacity for storing electricity or avoidance of some construction expenditure. To judge transition value, comparable studies should also account for construction and retrofit emissions, continued fossil throughput, upstream leakage, operational energy use, project lifetime, eventual decommissioning and the alternative energy-system configuration. For CCS retrofit studies, avoided emissions depend partly on capture performance and the fate of transported carbon, but also on whether operation displaces lower-emission generation. For hydrogen systems, outcomes depend on hydrogen production pathways and methane leakage where relevant. The bibliometric record counts cannot measure any of these system-level outcomes directly. The existing literature contains resources for assessing such trade-offs but does not make one uniform decision across sites. Patel et al. (2025) have considered the levelized cost of repurposing oil and gas infrastructure and Fan et al. (2018) have explicitly considered viewpoint of technology-lock-in for CCS in coal-plants. These views suggest that the status quo of legacy assets can either help or hurt in the development or perpetuation of structural

dependence, depending on the project and the counterfactual (Hunt, 2025). The study does not treat either interpretation as universally correct; it identifies emissions accounting and institutional context as empirical questions that need to accompany engineering appraisal.

5.3. Research Gaps and An Operational Agenda

Table 6 translates the focused source synthesis and the broad literature's thematic context into an operational research agenda. It identifies the missing comparisons linking well integrity with heat delivery; reservoirs with surface networks; component tests with network readiness; power-station conversion with fossil-retirement alternatives; and offshore or mine reuse with end-of-life and place-based obligations. The themes derive from interpretive synthesis, not an arithmetic ranking of keywords or a claim that the broad thematic map contains 252 screened publications. Research should disclose the physical asset inventory, technical stage, emissions boundary, ownership and counterfactual before generalizing project-level conclusions.

Table 6
Research Agenda Derived from the Bibliometric Map and Source Synthesis

Observed stream	Unresolved cross-cutting issue	Suggested design / indicator
Well-to-geothermal reuse	Uncertain integrity, thermal decline and alternative-drilling benchmark	Asset-specific lifecycle comparison with integrity, temperature and retirement scenarios.
Reservoir hydrogen/CO_2 storage	Sparse links to surface networks and different medium-specific risks	Integrated well–reservoir–pipeline simulation; leakage, cushion gas and monitoring requirements.
Pipeline conversion	Component material tests may omit end-to-end network readiness	Service-qualification inventory, compressor upgrades, routing and demand sensitivity.
Power-station retrofits	Transition lock-in and incomplete fossil-retirement counterfactuals	Lifecycle emissions and system dispatch compared with retirement/replacement.
Offshore platform conversion	Structural longevity and marine obligations vary by platform	Site-specific fatigue assessment and full decommissioning counterfactual.
Mine and industrial site reuse	Uneven attention to place-based benefits and liabilities	Comparable costs, jobs, land, remediation, safety and stakeholder participation.

The result of a synthesis is an integrated decision sequence – it does not need to be illustrated; it is self-generated. Discuss the concept of the nature of the legacy asset and environmental obligations and useful life (initially). Secondly, evaluate the new service and necessary wells, compressors, grid and storage areas/ports as a system. Third, make the same comparisons for conversion/closure and remediation and replacement for lifecycle emissions, cost, safety, regulation and impacted communities. Finally, differentiate between demonstrated results, simulation, pilot projects and general proposals. This is a decision sequence which was originally presented as a graphic and has been reproduced here in text format as it was not provided in the bibliometric outputs in graphic form.

5.4. Implications for Research and Infrastructure Planning

For researchers the map is a symbol of designs that relate the performance of one converted asset to upstream supply and downstream demand and a counterfactual investment in infrastructure. Joint investigations of reservoirs, wells and pipeline service qualification are particularly relevant to hydrogen and CO_2 chains, joint work of power engineers and environmental economists is relevant to retrofits, geotechnical, offshore and community expertise is relevant to mine and platform conversion. Reports should include whether a benefit is estimated, simulated or piloted/observed in the marketplace. That separation will assist future reviews to distinguish the good ideas from the tried and tested operations. The main point for infrastructure operators/public agencies is methodological and not prescriptive. Inventories can be developed by transparent appraisal to describe the

remaining service life, integrity, site constraints and decommissioning liability and compared to reuse versus retirement, remediation and greenfield alternatives under common assumptions. The need to clearly define the certification criteria, the monitoring and ownership after conversion. Instead of using a high cited article or popular technology term and extrapolating to the site, site level evidence can be used. This is in line with the main difference the paper draws between the research attention received and the social or environmental benefit that was demonstrated.

6. Limitations and Future Research

The evidence is limited to the supplied WoS export and associated author-provided Biblioshiny images. Coverage may exclude papers, reports, patents and non-English sources outside the indexed record set. The four-block query is deliberately broad, and the original 4,423-record thematic, country, source, author and keyword graphics include general biomass conversion and other studies that do not establish physical fossil-infrastructure reuse. They are retained unchanged as exploratory context, not relabeled as figures for the 252-screened sample. A high-specificity title-focused relevance screen may omit papers whose asset-reuse content appears only deeper in the abstract or full text. Candidate exclusions were audited from available metadata, but no independent dual-reviewer or full-text screening took place, so the PRISMA-style diagram does not claim full systematic-review compliance. Keyword maps depend on author term selection, normalization and the original Biblioshiny settings, which cannot be reconstructed fully from PNG images alone. Source and country citation figures are aggregate descriptors with age, coverage and field biases. There are no cited-reference fields, so no co-citation or bibliographic coupling results are claimed. Other activities include exporting complete reference lists, using Biblioshiny on the 252 records included sensitivity to other definitions of assets, and systematically evaluating the lifecycle, engineering and society outcomes with full text.

7. Conclusion

This study examined the evolution, themes, and research priorities emerging for repurposing legacy fossil-energy infrastructure for sustainable energy transitions. The analysis was based on an initial data set from the Web of Science of 4,423 publications and a more focused data set of 252 relevant publications from 2007 to March 2026, revealing key distinctions between the general literature on energy conversion and the specific research on the adaptive reuse of existing physical infrastructure. The results show that the most common infrastructure types in the dataset screened are fossil power stations, wells and fields, and depleted reservoirs. The literature reviewed suggests that there are a number of potential pathways for repurposing these wells: geothermal energy recovery from abandoned wells, hydrogen storage in depleted reservoirs, pipeline conversion, carbon-capture retrofitting, and integration with renewable energy. The analysis differentiates general research on energy conversion from research on physical infrastructure reuse, thereby giving a more targeted view of advances in research and highlighting technological, environmental and institutional challenges for further exploration.

The study advances the energy-transition literature by highlighting that repurposing infrastructure needs to be evaluated in an integrated technological, economic, environmental and governance framework. While publication frequencies, citation indicators, and thematic relationships can help to identify opportunities for lower carbon energy applications and re-use of existing fossil-energy assets, the contribution of fossil energy assets to sustainability cannot be determined solely based on these measures. The environmental and economic impacts rely on the integrity of the assets, technological compatibility, life cycle GHGs emissions, infrastructure modification needs, regulatory requirements and long-term operational performance. Comparative evaluations of repurposing, decommissioning, remediation and replacement options should therefore be used to support decisions on infrastructure conversion. Future studies should combine bibliometric evidence with lifecycle assessment, techno-economic analyses and infrastructure risk analyses, as well as empirical studies on environmental and social impacts. These interdisciplinary approaches would provide policymakers, energy-sector stakeholders, and researchers with greater evidence to

support the creation of sustainable and economically viable approaches to legacy-energy infrastructure in the transition to low-carbon energy systems.

Authors Contribution
Muhammad Azhar Bhatti: Write and revised the complete draft.

Conflict of Interests/Disclosures
The authors declared no potential conflicts of interest w.r.t the research, authorship and/or publication of this article.

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Appendix A: Web of Science Search Strategy

The following reproduces the four-concept logic of the exact supplied topic query. Within each parenthesis, synonyms were joined by OR; the four groups were joined by AND. The supplied full literal string (including wildcard variants) is retained in the attached project materials and can be supplied to the journal as a supplemental search file.

```
TS=(
(
"oil and gas"
OR "oil & gas"
OR "natural gas"
OR petroleum
OR oilfield*
OR "oil field*"
OR "gas field*"
OR hydrocarbon*
OR "fossil fuel*"
OR "coal-fired"
OR "coal fired"
OR "coal power"
OR "coal mine*"
OR "coal mining"
)
AND
(
infrastructure
OR "abandoned well*"
OR "depleted reservoir*"
OR "depleted field*"
OR wellbore*
OR "oil well*"
OR "gas well*"
OR pipeline*
OR "gas network*"
OR reservoir*
OR platform*
OR refiner*
OR "power plant*"
OR "power station*"
OR "mine shaft*"
OR "coal mine*"
)
AND
(
repurpos*
OR reus*
OR retrofit*
OR convert*
OR conversion
OR reconvert*
OR redevelop*
OR reutiliz*
OR reutilis*
OR "second life"
OR "adaptive reuse"
)
AND
```

```
(
geothermal
OR hydrogen
OR "carbon capture"
OR "carbon storage"
OR "carbon sequestration"
OR "carbon dioxide storage"
OR "CO2 storage"
OR "energy storage"
OR "compressed air energy storage"
OR "pumped hydro*"
OR renewable*
OR "offshore wind"
OR "solar energy"
OR "solar power"
OR biofuel*
OR biorefin*
OR "clean energy"
OR "low carbon"
OR "low-carbon"
OR decarboni*
OR "energy transition"
OR "net zero"
OR "circular economy"
)
)
```