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Review

Tracing the Research Pulse: A Bibliometric Analysis and Systematic Review of Hydrogen Production Through Gasification

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Abstract: Clean hydrogen is expected to play a crucial role in the future decarbonized energy mix. This places gasification of biomass as a critical conversion pathway for hydrogen production owing to its carbon neutrality. Yet there is limited research on the direction of the body of literature on the subject matter. Utilising the Bibliometrix package R, this paper conducted a systematic review and bibliometric analysis of the literature on gasification-derived hydrogen production over the past three decades. The results show a decade-wise spike in hydrogen research, mostly contributed by China, the United States, and Europe whereas the scientific contribution of Africa on the topic is limited. The current trend of the research is geared towards alignment with the Paris Agreement through feedstock diversification to include renewable sources such as biomass and municipal solid waste and decarbonising the gasification process through carbon capture technologies. The review reveals a gap in the experimental evaluation of heterogenous organic Municipal Solid Waste for hydrogen production through gasification within the Africa context. The study provides an incentive for policy actors and researchers to advance the green hydrogen economy in Africa.

Keywords: Thermochemical conversion; Municipal Solid Waste; Hydrogen; Biomass; Gasification

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1. Introduction

Amidst concerted global efforts to mitigate the climate crisis, the energy landscape is undergoing a profound transformation. Global energy demand continues to grow, influenced mainly by demand growth in emerging economies [1]. Hydrogen is theoretically expected to play a critical role in meeting this growing energy demand with the potential of supplying 18% of global energy demand by mid-century, exceeding projected fossil fuel demand in the heavy industry sector as well as in the shipping and aviation industries, and unlocking a multi-trillion dollar while mitigating CO2 emissions [2].

The strategic advantages of hydrogen are multi-faceted. The gas is abundantly available in nature and possesses the highest gravimetric energy density compared to any known fuel, thus positioning it as a promising choice for energy storage and for applications in energy-intensive industries [3]. Perhaps the most significant attraction of hydrogen in the transition economy is its low-carbon footprints. Hydrogen releases only water vapor when combusted, making it a plausible addition to the net-zero energy mix [4].

Various technological pathways have been developed and explored for hydrogen production, including water splitting, mainly through electrolysis; thermochemical conversion through pyrolysis and gasification; and biological processes photolysis [3]. The environmental friendliness of hydrogen is largely hinged on its method of production and feedstocks from which it is derived, thus giving rise to what is popularly termed the hydrogen rainbow [5]. Table 1. Illustrates the different types of hydrogen by their colour codes.

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Table 1. The hydrogen rainbow.

Energy Source Material	Hydrogen Production Technology	Hydrogen Type Produced
Biomass	Conversion (Thermochemical/Biochemical)	Green Hydrogen
Direct Solar	Electricity for Electrolysis	Green Hydrogen
	Direct Water Splitting	Green Hydrogen
	Electricity for Electrolysis	Green Hydrogen
Solar PV	Electricity for Electrolysis	Green Hydrogen
Hydro	Electricity for Electrolysis	Green Hydrogen
Wind	Electricity for Electrolysis	Green Hydrogen
Geo-thermal	Electricity for Electrolysis	Green Hydrogen
Nuclear Energy	Electricity for Electrolysis	Pink Hydrogen
Aluminium (Metals)	Chemical Reaction	Grey Hydrogen
Coal	Gasification	Grey or Black Hydrogen
Natural Gas	Electricity for Electrolysis (indirect)	Grey Hydrogen
	Steam Reformation	Grey Hydrogen
Petroleum/Oil	Steam Reformation + Carbon Sequestration	Blue Hydrogen
	Electricity for Electrolysis (indirect)	Grey Hydrogen
	Cracking	Grey Hydrogen
	Cracking + Carbon Sequestration	Blue Hydrogen

Source: Authour's construct (based on [6–8]).

Even though water electrolysis using renewable-generated energy has gained prominence in the literature because of its environmental benefits (denoted green as shown in Table 1), electrolysis is constraint by economic and infrastructure concerns. For instance, while hydrogen generated from electrolysis is estimated to cost about 4 – 6 USD/kg, biomass gasification is estimated to generate hydrogen at a cost of about USD 2.68/kg of hydrogen [9].

The literature is, therefore, increasingly replete with biomass gasification as a viable alternative to conventional means of hydrogen production. Through a thermo-chemical process, gasification converts biogenous feedstocks into hydrogen-rich synthetic gas. Gasification offers a circular economy pathway for valorizing biogenous resources and some plastics into energy fuel [10,11]. The diversity of feed stocks available for gasification and the limited electricity supply in Sub-Saharan

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Africa makes the region an ideal geography for biomass gasification [9]. Gasification is also distinguished by its flexibility, efficiency and carbon-neutrality, with a potential for significant emission reduction through carbon capture techniques and reliance on sustainable sources of biomass [11,12]. For instance, [13] reported a carbon saving of 2.3 kgCO2eq for pyrolysis of waste as compared to landfilling.

With emerging techniques such as supercritical water gasification (SCWG), biomass is conveniently converted without the need for intensive drying thus further lowering the cost curve of the gasification-driven hydrogen economy [14]. However, the commercial deployment of gasification as a sustainable pathway for hydrogen production remains constraint by limited policy incentives and high feedstock costs [2]. This notwithstanding, the positive drivers of gasification research include the climate imperative to decarbonize the global energy mix and growing affordability of gasification technologies [15,16].

Even though the literature demonstrates a growing consensus on biomass gasification as a viable pathway for clean or green hydrogen production, the knowledge remains fragmented thus necessitating synthesis of the existing literature on gasification-derived hydrogen and its evolution. In this regard, some attempts have been made. Many of these reviews have either been skewed towards the gasification of biomass feedstock or do not target research with a focus on hydrogen production [17,18] Other reviews such as that of [19], have sought to conduct a comparative analysis of food-waste-to-energy thermochemical conversion pathways. Their study identified incineration, pyrolysis, and gasification as inefficient technologies based on their energy yields. However, in view of the improvement in technology efficiency over time, it is worth exercising caution in lending contemporary relevance to this decade-old study. Their findings for instance, sharply contrasts those of [16] and [20], who, barely a year later, reported gasification as the most efficient thermochemical process, and increasingly, the most cost-effective [16].

This context points to a gap in synthesized knowledge on hydrogen production through gasification across scales, feedstock diversity, and bibliometric trends. The objectives of the study are therefore set as follows:

- To map the evolution of thermochemical pathways for hydrogen production through gasification for the past three (3) decades.
- To examine regional and institutional distribution of hydrogen-focused gasification research output.
- To provide future research directions for policymakers, researchers, and industry actors interested in advancing low-carbon hydrogen production through gasification.

2. Materials and Methods

The systematic literature review approach followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) as shown in Figure 1. The search terms, and the bibliometric database used for the search as well as the inclusion and exclusion strategies for the sourced literature are discussed subsequently. The data analysis and visualisation tools are also discussed.

2.1. Search Querry

The literature search was conducted on May 01, 2025, using the Scopus database. Scopus is considered one of the most comprehensive and credible indexing for peer-reviewed scientific papers [21,22]. The search term (gasification AND "bio-hydrogen") OR (gasification AND "clean hydrogen") OR (gasification AND "green hydrogen”) OR (gasification AND hydrogen) was used.

2.2. Inclusion and Exclusion Criteria

The initial search using the search terms described earlier yielded 11,743 documents from the Scopus database. The documents were filtered for documents published from 1995 to 2025; to

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consider the evolution of literature over the past 30 years and a decade post the Paris Agreement, which marked the world's greatest diplomatic success on climate change [23]. Document types were limited to finalised publications comprising articles, conference papers, reviews, books, and book chapters and further limited to only documents published in English Language. The documents were further filtered to include only literature from Energy, Environmental Science, Chemical Engineering, Engineering, Physics, Chemistry, Mathematics, Materials Science, Agricultural and Biological Sciences, Computer Science, Decision Science, and Economics and Econometrics subject areas.

The resulting documents from the foregoing inclusion and exclusion criteria were screened through manual reading of titles and abstracts to exclude documents that did not directly address or focus on gasification and hydrogen production. This resulted in a total of 8440 studies considered in this review. The PRISMA-compliant approach [24] is summarised in Figure 1.

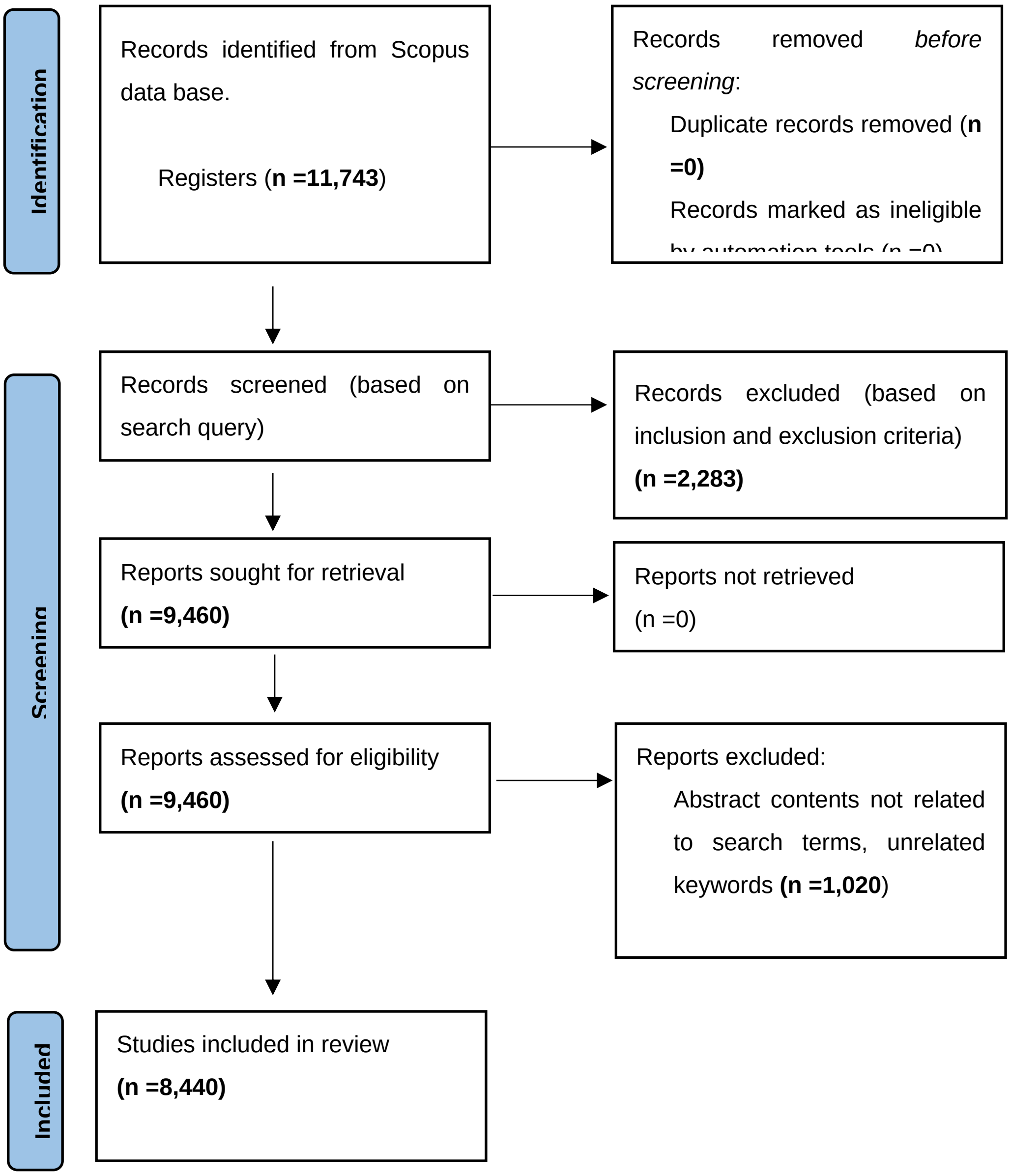

Figure 1. 2020 PRISMA flow chart.

2.3. Analysis and Visualization Tools

The Scopus-extracted data was exported in BibTeX format and analysed using the R package, Bibliometrix and its graphic user interface, Biblioshiny. Bibliometrix is the most popular R package for systematic review and visualisation of large volumes of literature [25], which, coupled with the

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biblioshiny package provides a user-friendly, web-based interface to identify and graphically-present the main themes of the literature [26].

3. Results

3.1. Analysis of Scientific Research Output

The results (Figure 2) show an increasing trend of production output of research on gasification focused on hydrogen production over the past three decade with over 60% of the research published between 2051 and 2025, peaking in 2024 with over 880 documents published on the topic. The trend also shows spikes in 2006, 2017 and 2024. This trend, though anecdotal, points to a 10-year cycle of increasing interest in hydrogen research. In fact, the International Energy Agency (IEA)'s 2024 Global Hydrogen Review shows that most hydrogen projects are expected to be delivered in 2027 [27], demonstrating a possible surge in hydrogen research from 2027 through 2030. The Covid-19 may have influenced the marginal spike observed in 2019 as overall global research output increased due to increased remote worktimes under lock-down orders [28,29]

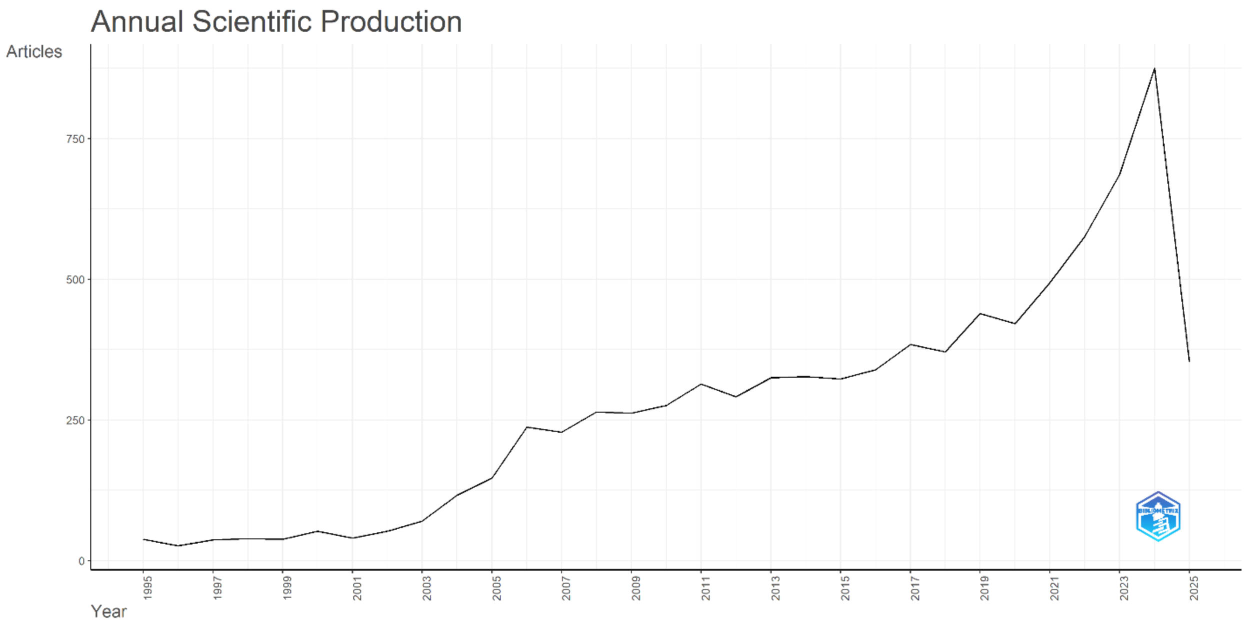

Figure 2. Annual production of literature.

Figures 3 and 4 illustrate the most globally cited documents and relevant authors respectively.

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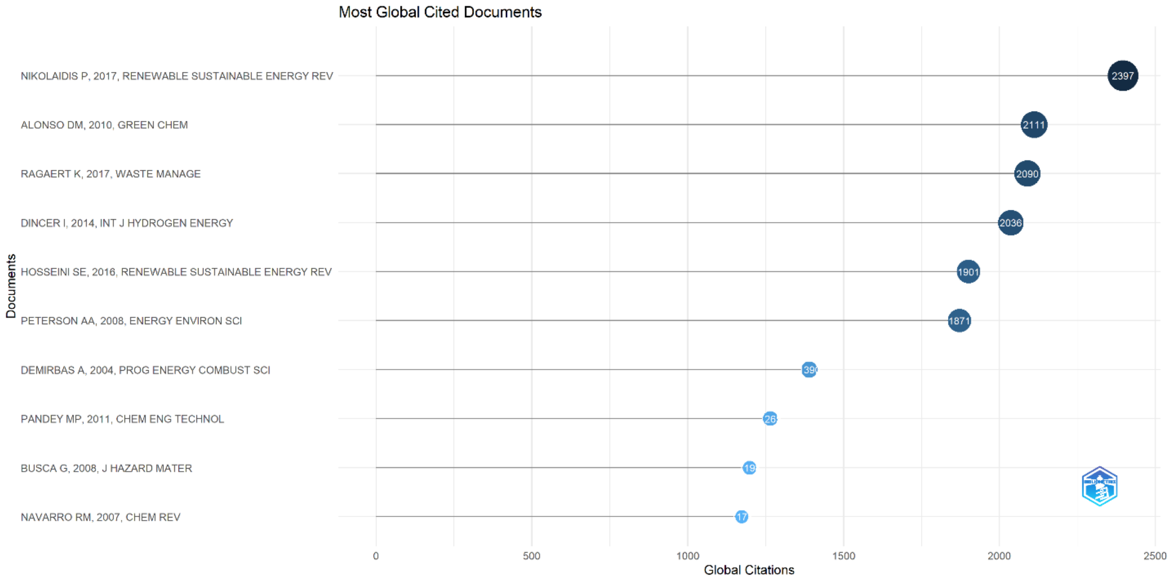

Figure 3. Most globally cited documents.

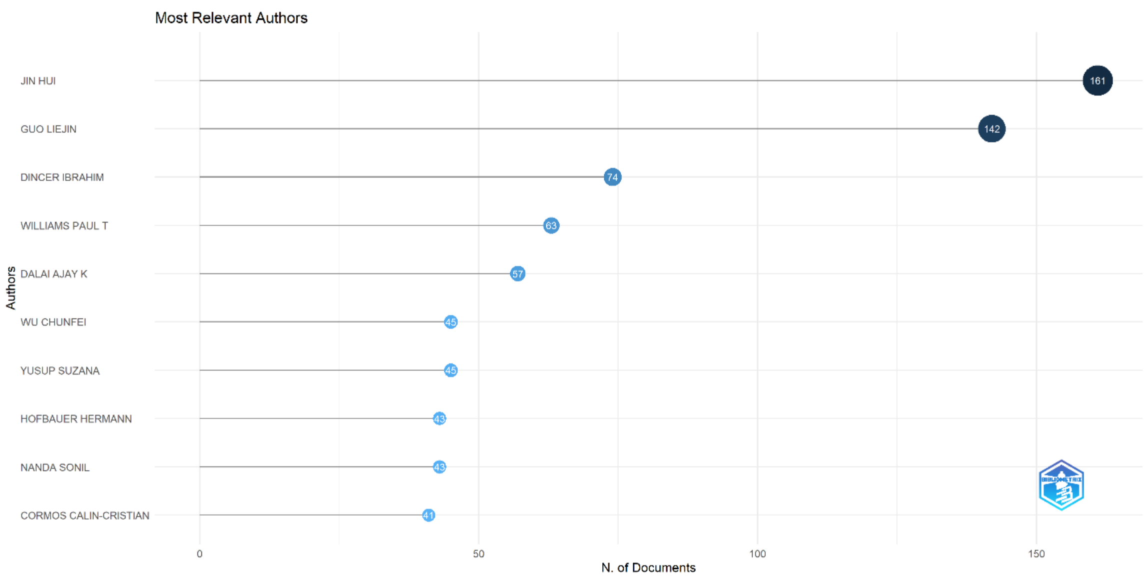

Figure 4. Most relevant authors.

With a citation of over 2382, the paper by [16] is by far the most cited document on the topic under review. Their paper provided a comprehensive overview of hydrogen production processes including thermochemical methods such as gasification. They concluded that gasification was among the most cost-competitive and efficient means of producing hydrogen (at a production cost of between $1.34 and $2.27/kg). [30], whose paper emerged as the second most cited in the literature, evaluated the conversion of biomass to biofuels through catalysis and provided early support for the conversion of sugars to renewable hydrogen. The third most widely cited document, though focused on thermochemical conversion techniques, was a slide deviation from the heavy emphasis of the literature on biomass but rather assessed the feasibility of hydrogen generation from solid plastics gasification [31].

The next most cited paper conducted a comprehensive assessment of hydrogen production methods, concluding that gasification and other thermochemical processes were preferred as long as efficiency is a priority [32]. [14] corroborated the cost-competitiveness of gasification for hydrogen production, with a distinct endorsement of biomass feedstocks and highlighted the prospects of super critical water gasification (SCWG) to further enhance efficiency.

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In a state of the arts overview of biomass technology, [33], with 804 citations, reported that biomass gasification was a cost-effective means of producing hydrogen but concluded that a comprehensive review of the literature was missing. Other widely cited papers in the literature have reviewed the gasification technology either with respect to different feedstocks, environmental impacts, or the state of the technology [34–42].

The top destinations for documents pertaining to the topic were published in the International Journal of Hydrogen Energy and Energy, accounting for 1107 publications (representing nearly 13% of the literature) as shown in Figure 5. The distribution of publication on the subject matter supports Bradford’s law of scattering, which states that, “if scientific journals are arranged in order of decreasing productivity of articles on a given subject, they may be divided into a nucleus of periodicals more particularly devoted to the subject and several groups or zones containing the same articles as the nucleus, when the number of periodicals in the nucleus and succeeding zones will be as 1: n: n2, where “n” is a multiplier” [43] This law effectively posits that articles are majorly published in a concentrated few journals and the rest distributed over a large number of journals (See table 2).

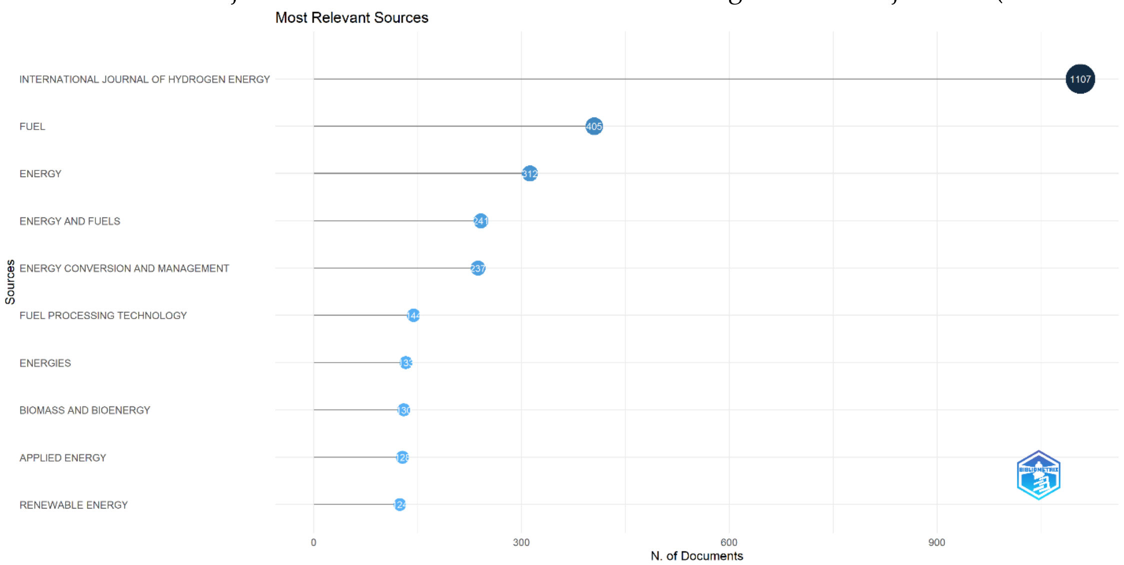

Figure 5. Most relevant sources.

Table 2. Main sources of literature obey Bradford's Law.

Source	Rank	Frequency	Cumulative Frequency	Zone
INTERNATIONAL JOURNAL OF HYDROGEN ENERGY	1	1107	1107	Zone 1
FUEL	2	405	1512	Zone 1
ENERGY	3	312	1824	Zone 1
ENERGY AND FUELS	4	241	2065	Zone 1
ENERGY CONVERSION AND MANAGEMENT	5	237	2302	Zone 1
FUEL PROCESSING TECHNOLOGY	6	144	2446	Zone 1
ENERGIES	7	133	2579	Zone 1
BIOMASS AND BIOENERGY	8	130	2709	Zone 1
APPLIED ENERGY	9	128	2837	Zone 1
RENEWABLE ENERGY	10	124	2961	Zone 2

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INDUSTRIAL AND ENGINEERING CHEMISTRY RESEARCH	11	112	3073	Zone 2
CHEMICAL ENGINEERING JOURNAL	12	106	3179	Zone 2
JOURNAL OF CLEANER PRODUCTION	13	99	3278	Zone 2
CHEMICAL ENGINEERING TRANSACTIONS	14	83	3361	Zone 2
ENERGY PROCEDIA	15	83	3444	Zone 2
JOURNAL OF THE ENERGY INSTITUTE	16	83	3527	Zone 2
BIOMASS CONVERSION AND BIOREFINERY	17	75	3602	Zone 2
EUROPEAN BIOMASS CONFERENCE AND EXHIBITION PROCEEDINGS	18	71	3673	Zone 2
ACS NATIONAL MEETING BOOK OF ABSTRACTS	19	70	3743	Zone 2
RENEWABLE AND SUSTAINABLE ENERGY REVIEWS	20	68	3811	Zone 2
JOURNAL OF SUPERCRITICAL FLUIDS	21	67	3878	Zone 2
ENERGY SOURCES, PART A: RECOVERY, UTILIZATION AND ENVIRONMENTAL EFFECTS	22	62	3940	Zone 2
PROCEEDINGS OF THE ASME TURBO EXPO	23	62	4002	Zone 2
AICHE ANNUAL MEETING, CONFERENCE PROCEEDINGS	24	58	4060	Zone 2
PROCESS SAFETY AND ENVIRONMENTAL PROTECTION	25	58	4118	Zone 2

3.2. Keywords Tree Map

Figure 6 shows the prevalence of the keywords in the literature, demonstrating that the words 'gasification', 'hydrogen production', 'hydrogen' and 'biomass' emerged as the most prevalent keywords with gasification comprising 12%, and the next top three prevalent keywords making up 7% of the keywords in the literature respectively. The next most occurring keywords are 'carbon dioxide' (5%), 'synthetic gas' (4%), and 'biomass gasification' (3%). Apart from the fact that these dominant keywords may be attributed to their use in the direct search terms, the dominance of 'gasification' and 'hydrogen production' in the literature is also due to the positive prospects of biomass gasification as an efficient means of producing green hydrogen [44,45].

On the other hand, 'coal combustion', 'feedstocks', 'water gas shift gasification', 'hydrogen fuels', 'fuel cells', 'super critical water', 'gas emissions' are among the least prevalent keywords in the literature, accounting for 1% each of the keywords. This depicts either a decline or the emergence of literature on these terms. For instance, while the low prevalence of 'coal combustion' in the literature may be attributed to a declining interest in coal as a feedstock post-Paris Agreement [46], the low prevalence of 'feedstocks' could be attributed to the recent interest in exploring renewable feedstocks as alternatives to fossil fuels for gasification-derived bio-hydrogen [47,48].

It is observed that, even though bio-hydrogen is gaining momentum as a sustainable and competitive alternative to fossil-derived hydrogen [49,50], the term does not occur in the tree map in Figure 6. This is because the search string for this study focuses on hydrogen derived from gasification (a thermochemical process) whereas bio-hydrogen is a term often associated with hydrogen derived from biological processes such as anaerobic microbial digestion or fermentation [51,52].

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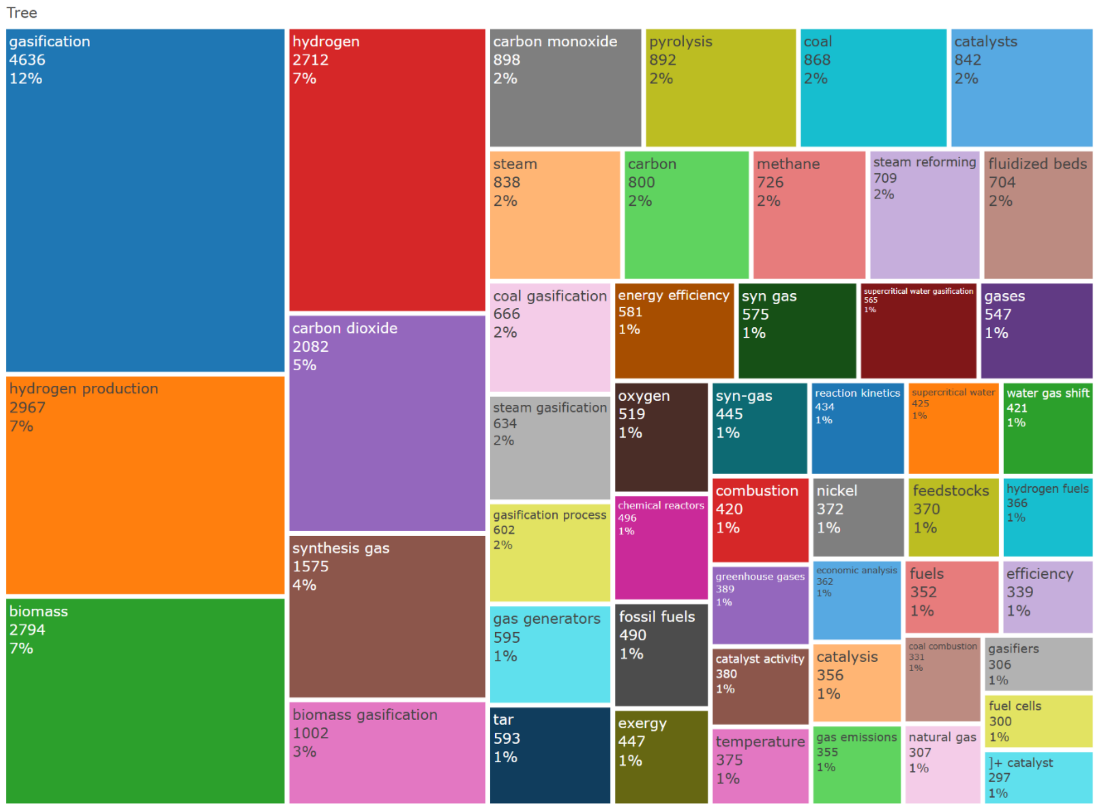

Figure 6. Tree Map of Keywords.

3.3. Co-occurance Analysis

A co-occurrence network analysis (Figure 7) reveals four main clusters: Green, purple, red and blue clusters. The green cluster shows the co-occurrence of keywords such as 'biomass gasification', 'hydrogen production', 'biomass', 'steam gasification', 'chemical reactions' and 'syngas' reflecting a focus on process-oriented literature and revealing the strong interlinkage between gasification processes and hydrogen production in the literature. Some works with this focus on feedstock have assessed the feasibility of Athabasca bitumen as a feedstock for hydrogen generation through super critical water gasification, reporting significant hydrogen yields [53]. Similarly, [54] reported the viability of biomass as an alternative feedstock for hydrogen production through gasification.

The purple cluster is replete with keywords such as 'carbon dioxide', 'hydrogen', carbon monoxide', 'methane', and 'synthetic gas', 'oxygen', 'gases', 'gas generators'. This clearly illustrates a strong focus on the diverse products and bio-products of gasification processes. It is observed that there is a strong research link between the green and purple clusters, given that fundamental thermos-chemical processing techniques are often discussed in-tandem with the accompanying products and bi-products.

The blue cluster emphasises process optimisation techniques for improved efficiency and product ,'catalysts', 'catalysts activity', 'supercritical water' and 'nickel'. Research with these keywords have sought to investigate the utility of various catalysts to improve biofuel yields and process efficiency. For instance, [55] reported increased hydrogen yield (90%) under optimised conditions of (360 °C, 0.5 g Ni-La catalyst loading, 0.5 g biomass and 10 min), emphasising the importance of Ni-L catalyst in the gasification process. Other studies have focused on assessing the effect of various catalysts on optimising the gasification process for improved hydrogen yield [56,57].

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The red cluster focuses on environmental assessment and cost-benefit analyses featuring keywords such as ‘energy efficiency’, ‘economic analysis’, and ‘exergy’. Works in this cluster have evaluated the cost-competitiveness of using various feedstocks to produce hydrogen through gasification [58–60]. Understandably, keywords on greenhouse gas emission analysis co-occur with keywords such as ‘coal gasification’ and ‘natural gas’ as the literature here seeks to evaluate the emission profiles of fossil fuel feedstocks.

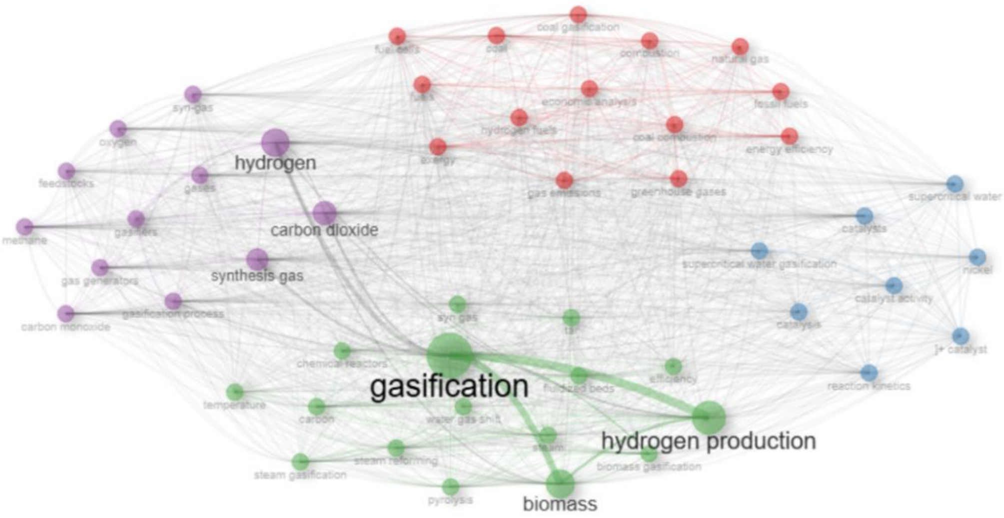

Figure 7. Co-occurrence map.

The co-occurrence analysis therefore reveals four clusters of literature on the subject matter: Fundamentals of the gasification process for hydrogen production and the feasible feedstocks as seen in [61–68]; evaluation of products and bio-products of the gasification process as reported by [62,69]; thermochemical process optimisation for hydrogen production, as reported by [70–74]; and emission and economic evaluation of the gasification process [75–79].

3.4. Most Relevant Affiliations

The bibliometric analysis (Figure 8) reveals that the top 10 affiliations are Xi’an Jiaotong University (China), Huazhong University of Science and Technology (China), King Fahd University of Petroleum and Minerals (Saudi Arabia), Universiti Teknologic Petronas (Malaysia), Chulalongkorn University (Thailand), National Energy Technology Laboratory (United States of America), University of Tehran (Iran), Southeast University (China), Tsinghua University (China), Zhejiang University (China). This trend points to a concentration of researcher affiliations with institutions in Asia and the Middle East, with only one of the top 10 institutions with the most author affiliations located outside Asia and the Middle East, i.e. The National Energy Technology Laboratory of the U.S.A. The proliferation of countries that may be characterised as petro-states such as Saudi Arabia and Iran in the top list of most affiliated institutions can be explained in terms of the fact that petro-states have an increased incentive and are actually making efforts in research and development to diversify away from petroleum, and thus views hydrogen as a convenient alternative in the long-term [80,81].

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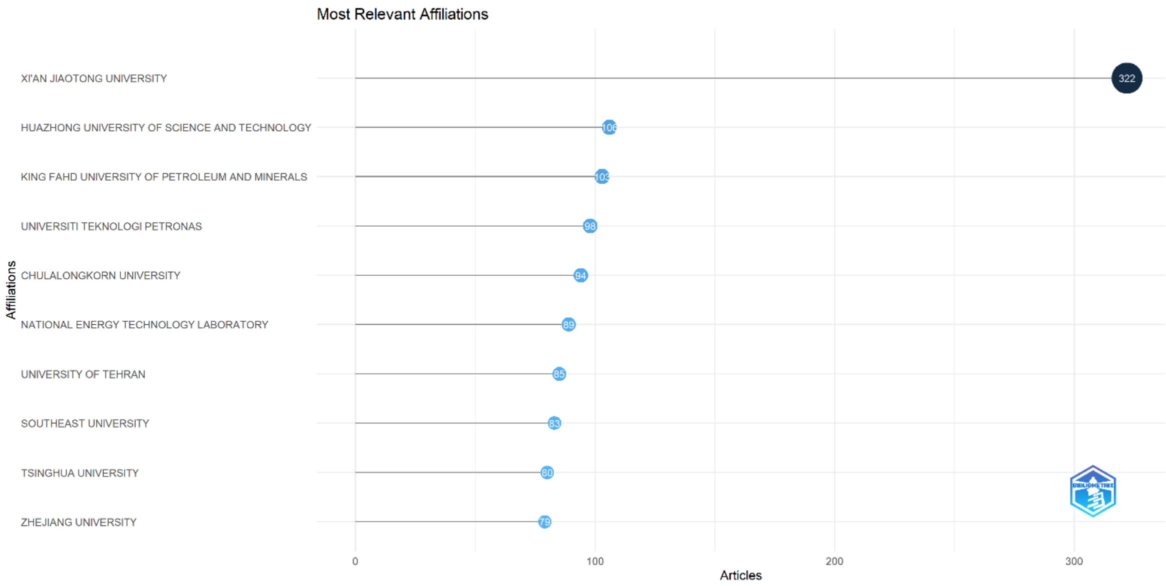

Figure 8. Most relevant affiliations.

3.5. Country Scientific Production and Collaboration

Figure 9 illustrates the comparative scientific research output on hydrogen production through gasification. The map shows that research output on the subject matter are concentrated within a few countries, illustrated by the dark shades. Thus China, the United States of America, Germany, India and the United Kingdom register substantial research outputs. The map conversely shows large parts of Africa, Central Asia and some portions of Latin America in grey, pointing to limited research activity on the subject matter. African countries with marginal research output include South Africa, Egypt, and Nigeria.

The concertation of research outputs in China and Europe is reflected in their hydrogen infrastructure maturity as the two regions collectively hosts over 70% of global hydrogen capacity [82].

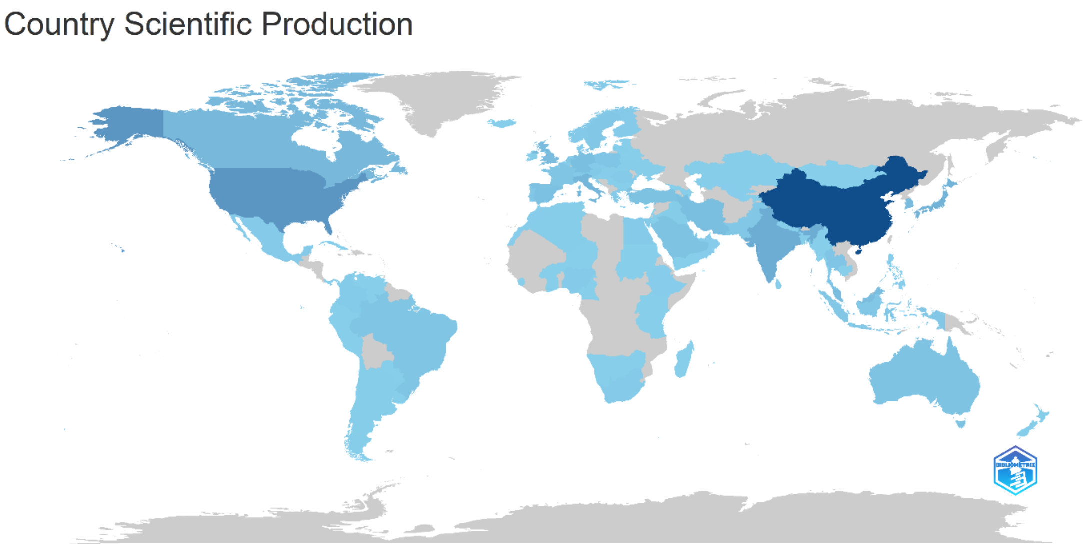

Figure 9. Country scientific production.

The country collaborative map (Figure 10) shows that countries with the most density of research outputs tend to also exhibit the most collaborative link across the globe. So that China, the United

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States and countries in Europe hosts the densest research links whereas the Global South demonstrates limited research collaborations, both inwardly and outwardly.

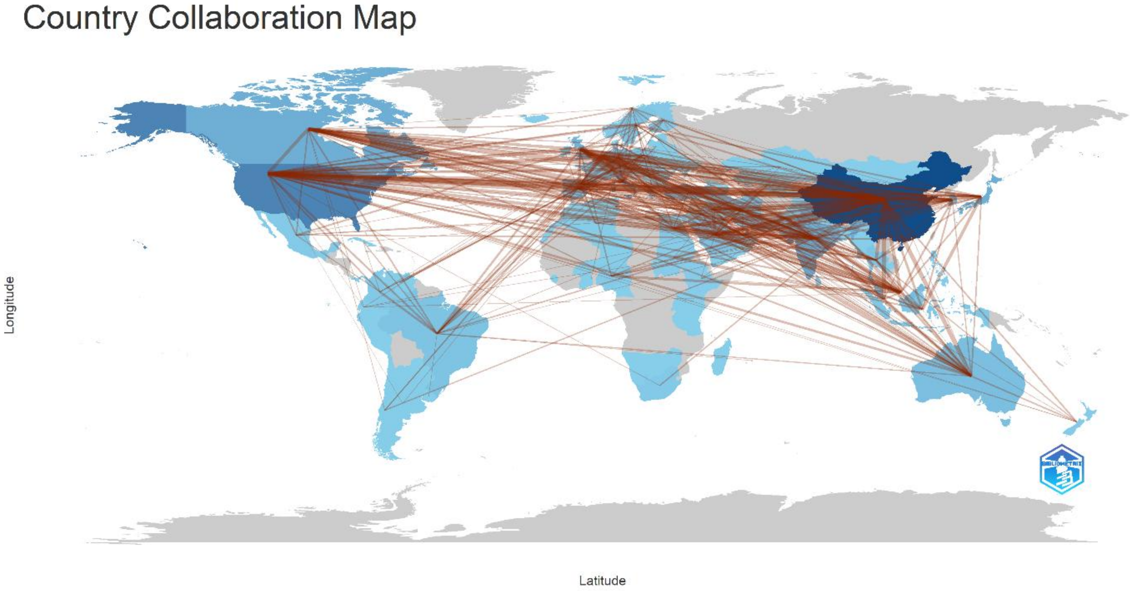

Figure 10. Research collaborative map.

3.6. Trend of the Research

Figure 10 illustrates the evolution of the research from 1995 to 2025. Four thematic timelines emerge in the literature, discussed below:

Fundamentals of thermochemical processes (1995 – 2002)

The literature within this period is characterised by keyword such as 'sulphidation', 'pressure drop', 'combustion', 'high temperature effects' and 'gasifiers'. This emphasises a focus on technical feasibility and unravelling the science behind thermochemical processes. For instance, [83] developed a reduced nitrogen oxides model for industrial coal-firing boilers. Their study reported that the latter stages of the gasification process (such as gasification) were important for the formation of hydro-carbon radicals from left over char. Also, [84] reported that the ammonia content in the resulting producer gas from a gasification process were most sensitive to the nitrogen content of the gasification fuel. Similar studies within this period assessed hydro-carbon yield from pyrolysis and gasification processes [85] while other literature assessed the effects of various gasifying agents on the gasification process [86,87].

Notwithstanding the focus of literature within the period on the thermodynamic fundamentals of gasification technology, the earliest appearance of the word 'hydrogen' in the published literature within the period was in 1995 when [88] discussed the emergence of carbon as a hydrogen carrier and advanced optimism about the generation of hydrogen from fossil fuels.

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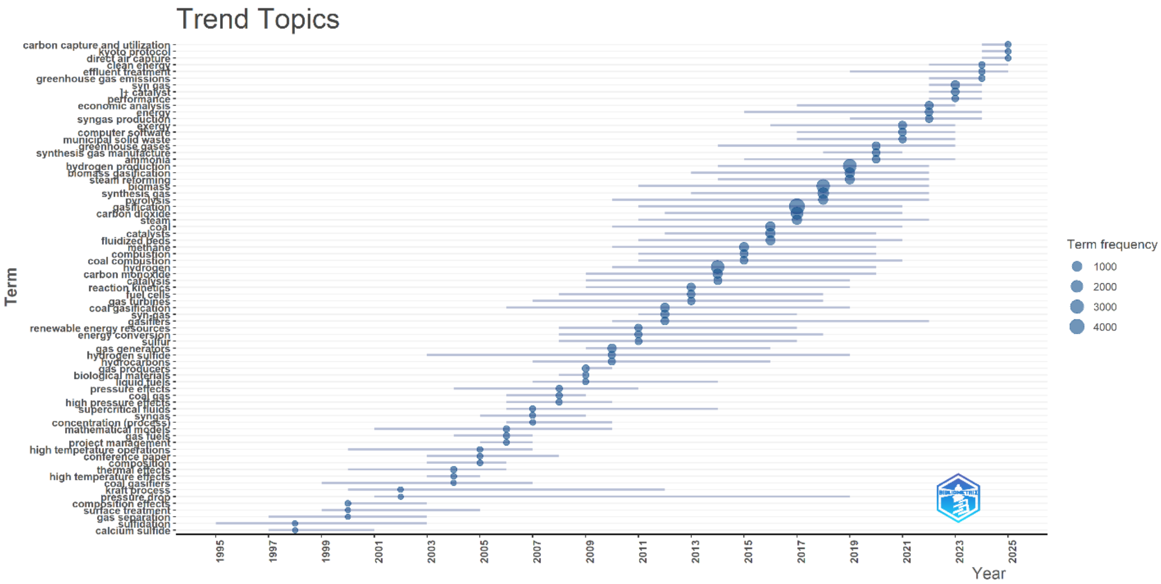

Figure 11. Research trend.

Process Optimisation and Feedstock Diversification (2003 – 2015)

This period represents the longest run where the trend shows a growing popularity of keyword such as 'catalysts', 'concentration', 'thermal effects', 'mathematical modelling', 'biological materials', 'renewable energy resources', and 'reaction kinetics'. These keywords represent an evolution of the literature towards technical process optimisation and feedstock diversification beyond fossil fuel resources. Mathematical models and experimental set-ups have been designed to assess the effects of different operating conditions on the chemical properties of the resulting producer gas [89–92]. Some of these studies have established a positive correlation between temperature and hydrogen output from gasification processes with CaO also reported to increase hydrogen yield by over 16% [89]. Under high-pressure conditions, hydrogen yield is also reportedly increased through the use of $Ca(OH)_2$ as a CO2 absorbent [93].

This period also demonstrates that the interest in diversifying the feedstock away from fossil fuels precedes the Paris Agreement, given the early, albeit limited, emergence of literature seeking to assess the viability of renewable resources for hydrogen production via gasification [92,93].

Post Paris Agreement Alignment (2016 – 2022)

The literature post-Paris agreement sees a strong emergence of keywords such as 'biomass gasification', 'municipal solid waste' (MSW), 'hydrogen production', and 'economic analysis'. Improvements in gasification technology and incentive to transition to a low-carbon economy makes municipal solid waste increasingly suitable and attractive for use in the thermos-chemical conversion of heterogenous waste such as Municipal Solid Waste to hydrogen-rich syngas [96,97], with the possibility of reaching an energy efficiency of 57% [96]. For instance, [97] reported that the organic component of Municipal Solid Waste in parts of Western Norway is able to generate 2700 tonnes of hydrogen via gasification. Similarly, [98] found that waste generation in a typical city in Ghana (Cape Coast) has the potential of generating over 780,000 kg of bio-hydrogen, with the waste generated projected to increase by over 70% in the next 29 years.

Despite this enormous potential of MSW for hydrogen production, unsustainable waste management practices pose a major barrier [98]. Lessons may be derived from a four-staged strategy proposal for the management of crop residue encompassing stakeholder engagement, education and capacity building and the development of integrated systems for the collection, storage and transportation of biomass resources for hydrogen production [99].

As established in the case of gasification of other biomass feedstocks, higher gasification temperatures tend to improve hydrogen yield from MSW gasification. [100] found that the gasification of Municipal Solid Waste at higher temperatures (600℃ – 800℃) increases the hydrogen

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yield by 30 - 40 percent. An oxygen-steam gasifying agent rather than pure oxygen is advised for hydrogen-rich syngas production from MSW gasification [100,101]. Similarly, metal and calcite-based catalysts such as marbles have proven effective in improving hydrogen yield from MSW gasification [100,102].

Decarbonisation (2023 – 2025)

This period marks a deep decarbonisation focus on the evolution of the literature on hydrogen production from gasification. The keywords prevalent here include 'carbon capture and utilisation' (CCU), 'direct capture', Kyoto protocol', 'clean energy', and 'greenhouse gas emissions'. Whilst the earliest emergence of the literature on CCU-coupled hydrogen production from gasification on within the period of 1995 – 2025 was recorded in 2011 [103], the period 2023 to 2025 is particularly replete with literature on the use of CCU as a carbon abating approach in the thermochemical production of hydrogen from biomass. Thus, several studies have been done on the lifecycle assessment (LCA) of bioenergy carbon capture and storage (BECCS) [104–108]. A key finding from this emerging theme is the need for a standardised approach to LCA of bioenergy production with CCS [108].

3.7. Research Gaps

The review of the literature on hydrogen production through gasification reveals a scarcity of research on the specific context of Africa. This is demonstrated by light colourisation of the region as shown in Figure 9 and Figure 10. This is particularly relevant because the MSW generated in most African cities is composed of over 60% organic component [109], whereas only about 44 - 60% of this waste is collected [110] with only 1% of this waste recovered [98]. Comparatively, over 96% of MSW is reportedly collected advanced countries [111]. This gap provides an incentive for increased research to advance the hydrogen economy in emerging economies such as Africa.

Furthermore, while literature features some studies on the evaluation of MSW gasification, the vast of the studies have treated MSW as a homogeneous resource, often overlooking the heterogeneity of MSW. For instance, some studies have focused on food waste [98,112] while others have focused on livestock manure [113,114] and crop residues [99] as raw materials for hydrogen production via gasification. This calls for expansive studies to broaden the body of knowledge on the thermodynamic, chemical and operational enablers of increased hydrogen production from municipal solid waste gasification.

4. Conclusions

The Post-Paris Agreement energy landscape is increasingly defined by an urgent demand for decarbonized energy systems. Hydrogen has emerged as a plausible alternative to carbon-intensive fossil fuels. As a result, thermochemical processes such as gasification have gained traction as competitive pathways for hydrogen production, particularly utilizing biomass and other biogenous substances as feedstock.

This study systematically mapped the evolution of thermochemical pathways for hydrogen production through gasification for the past three decades (from 1995 to 2025). The review revealed an increasing trend in research output on the subject matter, with spikes occurring in about every ten (10) years, demonstrating that we are living through the decade of hydrogen research and development. An institutional and geographical analysis of the research field reveals that the top contributing researchers are affiliated to institutions in Asia and the Middle East, predominantly in China, Saudi Arabia and Iran. This demonstrates a peculiar incentive of petro-states to diversify their economies from fossil fuels with hydrogen as a prospective alternative. The study also showed that the most extensive collaboration links are observed from China to the rest of the world. The United States also demonstrates strong research collaboration links. However, research collaborations among and with African researchers on the subject matter have been modest.

A trend analysis of the literature shows a most recent shift towards research focused on climate change mitigation in hydrogen production through thermochemical processes using carbon capture

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techniques. The most consistent research of interest, however, has been on the use of renewable biomass for hydrogen production through gasification.

Importantly, the study identifies a research gap on the sparsity of knowledge resource on the subject matter in the African context and the techno-economic feasibility of hydrogen production from heterogenous municipal solid waste gasification.

Abbreviations

IEA	International Energy Agency
PV	Photo Voltaic
USD	United States Dollars
SCWG	Super Critical Water Gasification
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
MSW	Municipal Solid Waste
CCU	Carbon Capture and Utilisation
CCS	Carbon Capture and Storage

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