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Technological prospection of solid waste gasification applications in Brazil

Prospecção tecnológica das aplicações em gaseificação de resíduos sólidos no Brasil

Prospección tecnológica de aplicaciones en gasificación de residuos sólidos en Brasil

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Abstract
Environmental issues weigh heavily on international economic relations with demands for stricter environmental regulations for the deforestation of forest areas and the generation of urban solid waste (USW). These demands drive research in the area of USW to reduce the waste volume and to its use in various fields such as power generation. In 2020, the legal milestone of the National Solid Waste Policy (NSWP) in Brazil was updated, opening space for private initiative in the management of systems related to USW. This work aims to carry out a technological prospection on gasification developed in Brazil using translational research and databases from CAPES, Web of Science, and ESPACENET portals to verify research incentives in universities, public and private, from 1984 to 2022. The search strategy first maps the search for dissertations (master's) and theses (doctoral) documents, called non-patented literature on biomass gasification, and it verifies the relationship with the production of articles in the area, and secondly, it correlates with the production of gasification patent documents. Implementation trends and factors that influenced gasification research were analyzed which generated 357 academic documents (thesis and dissertation), petitioners of patent applications and granted patents in Brazil, and academic research that reached society in the format of 189 articles and one patent.
Keywords: Gasification; Patent; Prospection; Urban Waste; Academic Research.

Resumo
As questões ambientais pesam nas relações econômicas internacionais com demandas por regulações ambientais mais restritas sobre o desmatamento de áreas florestais e geração de resíduo sólido urbano (RSU). Essas demandas impulsionam pesquisas na área de RSU, para a diminuição do volume dos resíduos e para o aproveitamento destes em diversos campos como a geração de energia. Em 2020, foi atualizado o marco da Política Nacional de Resíduos Sólidos (PNRS) no Brasil o que abriu espaço para a iniciativa privada na gestão dos sistemas relacionados ao RSU. Este trabalho tem como objetivo realizar uma prospecção tecnológica sobre a gaseificação desenvolvida no Brasil usando a pesquisa translacional e bases de dados do portal CAPES, do Web of Science e do ESPACENET para verificação de incentivos em pesquisas em instituições de ensino superior, públicas e privadas, de 1984 a 2022. A estratégia de busca primeiro mapeia a pesquisa de documentos dissertações (mestrado), e teses (doutorado), chamada de literatura não patenteada de gaseificação de biomassa, e verificar a relação com a produção de artigos da área para em segundo correlacionar com a produção de documentos de patentes em gaseificação. Foram analisadas as tendências de implantação e fatores que influenciaram a pesquisa em gaseificação que geraram 357 documentos acadêmicos (teses e dissertações), requerentes dos pedidos de patentes e patentes concedidas no Brasil, e pesquisas acadêmicas que alcançaram a sociedade na forma de 189 artigos e uma patente concedida.
Palavras-chave: Gaseificação; Patente; Prospecção; Resíduos Urbanos; Pesquisa Acadêmica.

Resumen
Los temas ambientales pesan mucho en las relaciones económicas internacionales con demandas de regulaciones ambientales más estrictas sobre la deforestación de áreas forestales y la generación de residuos sólidos urbanos (RSU). Estas demandas impulsan la investigación en el área de los RSU, para reducir el volumen de residuos y utilizarlos en diversos campos como la generación de energía. En 2020, se actualizó el marco de la Política Nacional de Residuos Sólidos (PNRS) en Brasil, abriendo espacio para la iniciativa privada en la gestión de los sistemas relacionados con los RSU. Este trabajo objetiva realizar una prospección tecnológica sobre gasificación desarrollada en Brasil utilizando investigaciones traslacionales y bases de datos de los portales CAPES, Web of Science y ESPACENET para verificar incentivos en investigación en instituciones de educación superior, públicas y privadas,

de 1984 a 2022. La estrategia de búsqueda primero mapea la investigación de documentos de disertaciones (maestría) y tesis (doctorado), denominada literatura no patentada sobre gasificación de biomasa, y verifica la relación con la producción de artículos en el área para en segundo lugar correlacionar con la producción de documentos de patente de gasificación. Se analizaron las tendencias de implementación y factores que influyeron en la investigación de gasificación que generaron 357 documentos académicos (tesis y disertaciones), demandantes de solicitudes de patentes y patentes concedidas, y las investigaciones académicas que llegaron a la sociedad en forma de 189 artículos y una patente concedida.
Palabras clave: Gasificación; Patentar; Prospección; Residuos Urbanos; Investigación Académica.

1. Introduction

An important milestone in Brazil's energy development was the inclusion of the use of biomass and biomass residues, since the 1990s, in the strategic guidelines by the Ministry of Science and Technology (MST). Then, the Ministry of Mines and Energy (MME) included in its multi-year and ten-year plans the development of renewable energy sources and clean and efficient renewable technologies. Based on the strategic guidelines of the MST, actions were triggered for education, technological, environmental, and social sectors, for the establishment of facilities, training, and qualification of human resources (MCT, 2008; MME, 2021).

Parallel to the environmental sector development, discussions on waste management also began in Brazil in the 1990s, boosting sustainability discussions in the European Union which resulted in Law nº 12,305 from 2010, which establishes the framework for National Solid Waste Policy (NSWP) in Brazil. This law provides guidelines on the integrated waste management and management of solid waste, including hazardous waste. However, Brazil remained in the implementation stage of these regulatory milestones (Brazil, 2010; Santos & Villac, 2019).

Data recorded over a decade in the implementation of the NSWP served as the basis for the elaboration of a new framework for basic sanitation in the country as approved by Law nº 14,026 in 2020. This law updates the existing guidelines for solid waste management, enabling ambitious goals for the sanitation of residential and industrial waste by 2033 with the treatment of 99% water and 91.2% solid waste and sewage.

Within this new law, the zero-methane program was included which aims to reduce methane emissions and reconcile measures to encourage the use of biomethane and biogas with sustainable development by 2030. These updates to sanitation opened the area to the private sector, which is more likely to absorb new models and technologies in waste treatment and to maintain interest in the energetic use of waste, which could expand the diversification of renewable energy sources in the country (Brazil, 2020).

The prospect of energy matrix diversification combined with waste treatment rekindles attentiveness to gasification technology in Brazil. The relevance of gasification in waste treatment lies in the process' characteristic of consuming the waste to obtain a significant reduction of solid waste volume at the end of the process, passivation of waste, elimination of additional steps in final disposal with the possibility of obtaining energy (Watson et al., 2018; Souza et al., 2022; Barros et al., 2022).

The equipment used in gasification is robust, consisting of a feeding system, a reactor, and a system to make use of byproducts (gasses and heat). Reactors are mainly classified into two groups - fixed bed and fluidized bed - and have several subclassifications regarding the type of bed and direction of fuel flow. The main ones are fixed bed downdraft or updraft (descending and ascending), crossflow fluidized bed (CFB), bubbling fluidized bed (BFB), circulating fluidized bed (CFB), or entrained fluidized bed (EFB) (Miranda et al., 2020).

The gasification process under real operating conditions is a complex set of reactions. They are not subject to specific process optimization, including the reform of tar, the main liquid byproduct, due to the presence of toluene and naphthalene (Basu, 2010; Cortazar et al., 2019). The exploratory studies addressed in most of the analysis discuss economic viability of the process: stabilization of energy demand to provide uniform temperatures in the process; equipment maintenance and minimization of byproducts that cause equipment corrosion, and proposals of catalytic methods based on nickel, magnesium, and aluminum for biomass gasification (Borges, 2020). Focus remains on working with individual reactions and interactions in the gasification process for syngas generation, but most of these studies do not use gasifiers but process subsystems or similar operations and techniques, such as thermogravimetric analysis.

Despite advantages, the gasification process still lacks studies regarding raw materials and technology implementation. In this scenario, the private sector could be the driving force in the search for solutions for the gasification process, based on data generated in decades of technological survey research carried out both in the industrial and academic environments to identify possible opportunities or challenges that need further studies and investments (Hossain, & Charpentier, 2015).

This article proposes translational research of technological applications for waste gasification in Brazil. Based on patents and related academic works through prospecting tools, this paper researched the relationship between public policy incentives and the opportunities that emerged with the approval in 2020 of the new sanitation mark, with implementation by 2033, opening the area to the private sector.

2. Solid Waste

The definition of waste is every material that can be removed because it is of no use to the owner. It can be related to three questions: the source that originated the waste (urban or rural), the type of waste, and waste composition, which is also responsible for heterogeneity in terms of sizes and shapes (Diaz et al., 2019; Ghosh et al., 2020).

In Brazil, urban solid waste (USW) is non-radioactive material from industrial, domestic, hospital, commercial, agricultural, and public cleaning services. The Brazilian standard NBR 10004 of 2014 includes sludge from water treatment systems and pollution control facilities as USW. From this standard, solid urban waste (residential and commercial) includes all items of rural waste (agriculture) and almost all components of industrial waste. Table 1 presents a classification for USW by source, type, and components.

Table 1 - Sources, types, and components commonly related to USW.

Source	Waste type	Waste components
Residential and Commercial	Organic/Inorganic	Food waste, paper, cardboard, plastics, textiles, leather, garden waste, wood, glass, cans, aluminum, other metals, ash, street leaves.
Industrial	Organic/Inorganic	Paper, cardboard, plastics, wood, food waste, glass, metal waste, ash, textiles, rubber.
Agriculture	Organic	Food waste, forestry waste, garden waste.

Source: Ghosh et al. (2020).

3. Classification for USW management

Management of USW values systematizing the collection, processing, and disposal of waste efficiently to preserve human health and the environment (Allesch & Brunner, 2014). There are other approaches in parallel to minimize waste generation, encouraging citizens to segregate organic and inorganic waste for recycling and reuse, to add value to the waste,

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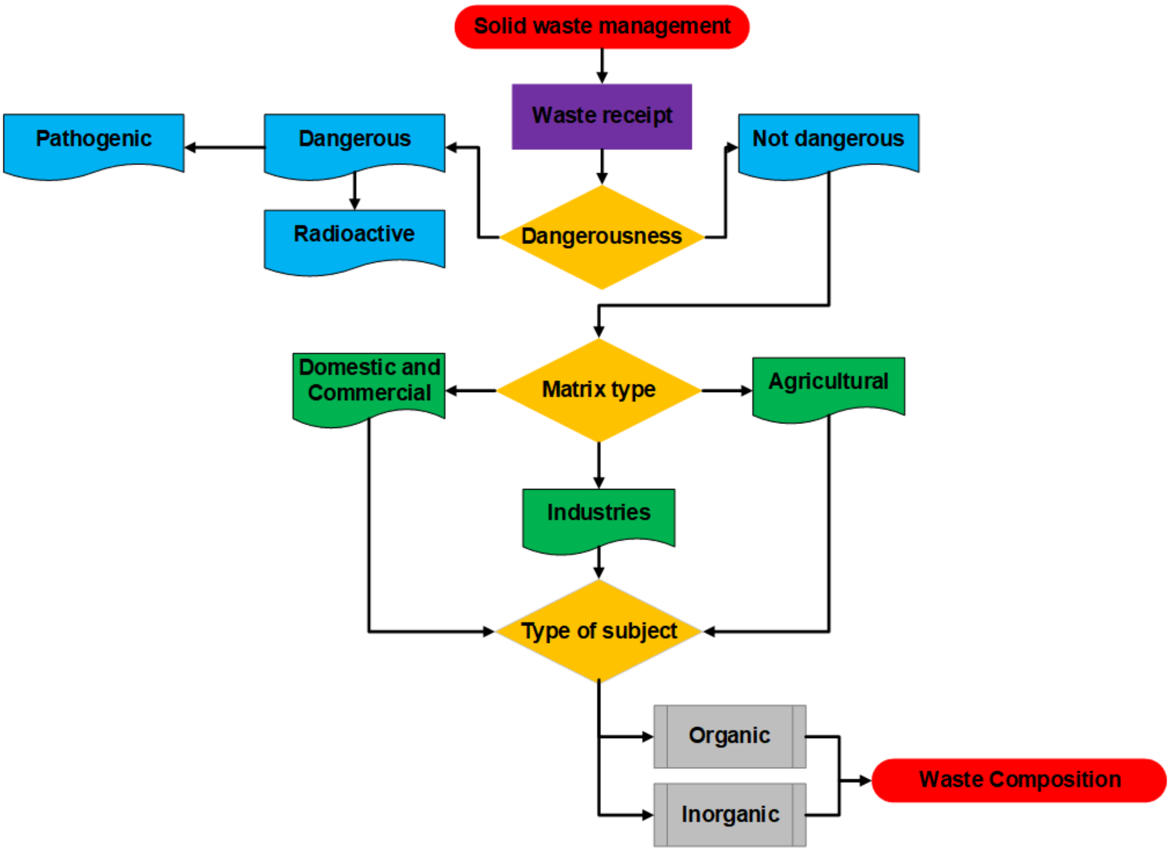
which gives sustainability to the process and proper treatment to the final waste (Munasinghe, 1993; Tchobanoglous & Kreith, 2002).

The waste generated and treated as USW undergoes classification to define the best procedure and treatment steps according to local legislation. With a comprehensive start, it classifies the waste according to dangerousness, type of matrix, type of matter, and lastly by specific composition, as represented in Figure 1 (Millati et al., 2019; Brazil, 2010).

Figure 1 - USW classification flowchart in Brazil.



Source: Brazil (2010).

Classification of waste composition follows validated guidelines such as ASTM D5231 (Standard Test Method for Determining the Composition of Unprocessed Urban Solid Waste) and allows adaptations to meet specificities (EPA, 2018; European Commission, 2020).

The result of proper waste classification enables management to go through a sustainability-oriented hierarchy: waste prevention > reuse > recycling > recovery (energy, chemicals) > burial (Cucchiella et al., 2014).

4. The classic treatment of USW

Technologies employed in the USW treatment in Brazil are traditionally based on simple and low-cost implementation methods such as sanitary landfills and dumps. However, these methods have serious disadvantages: there is an accumulation of municipal USW; they generate harmful byproducts with the leaching and release of methane (CH_4); they do not generate resources for the maintenance of the process; and there is pressure for adequacy in the strictest international environmental standard as a requirement to the country be accepted as OECD member (OECD, 2022).

The formulation of the NSWP, which ran from 2010 to 2021, focused on USW integrated with waste management and the creation of low-hazardous solid waste management mechanisms to encourage reuse and recycling. In this policy, the private sector has low participation, which turns out to be a contradiction, as the private sector is more likely to absorb new technologies in waste treatment, to be interested in the energy of waste, and to expand the diversification of renewable energies (Brazil, 2020).

5. Thermal Processes

Thermochemical processes are an alternative to traditional waste treatment methods. Those are composed of combustion, pyrolysis, and gasification. They can be integrated with aerobic and anaerobic wastewater biomechanical processes, maximizing volume reduction, waste passivation, and water treatment (Watson et al., 2018; Youcai & Ran, 2021; Yu et al., 2016).

Combustion is an efficient treatment method for USW, destroying the residue by thermal decomposition via oxidation of carbonaceous matter where the major products are carbon dioxide, water, ash, and heat. It presents the lowest requirements regarding equipment and waste pretreatment for implementation for waste energy recovery (Waste-to-Energy - WtE). It can also be applied in the oxidation of harmful gaseous components originated in the formation of leachate in landfills, and in the direct burning of gas (Jeswani & Azapagic, 2016). Even though it is efficient when compared to other methods such as gasification, the cost of cleaning the gas resulting from combustion increases the operation cost (Kumar & Samadder, 2017).

Combustion technology in USW enables the recovery of combined heat and energy by using the heated gases generated by burning the waste in electric generators. The type and operational capacity of the combustion plant will reflect on the amount of energy recovered.

Note that combustion works with temperature ranges on average, below 2,000°C, being used in countries with land restrictions for landfills and limitations on energy sources, such as European countries. The most used modalities are the fluidized bed reactor, rotary kiln, grate kiln, fireplace, and liquid injection reactor (Duan et al., 2021; EPA, 1998; Nixon et al., 2013).

Pyrolysis and gasification processes are advanced thermochemical methods compared to USW combustion. Combustion of waste releases energy in the form of heat that can be used directly or in subsequent steps. In pyrolysis and gasification processes, residue goes through preparation stages such as the removal of moisture, glass, metal, cardboard, and elements that may have resale value, as well as crushing to homogenize the size of the residue. It proceeds with the conversion into secondary energy, with the formation of liquid, solid fuel, or synthesis gas. There is also the possibility of recovering chemical components and subsequently recycling secondary energy to feed other systems (Bosmans & Helsen, 2010).

Pyrolysis is understood as the thermal degradation of a substance in the absence of oxygen or another oxidant, requiring an external supply of heat to maintain the temperature between 300 and 800°C, producing gas with a net calorific value between 10 and 20 MJ/Nm^3, an oily liquid phase and a char as solid phase (DEFRA, 2013). A waste pyrolysis plant configuration can use several models of reactors: fixed bed reactors, batch or semi-batch reactors, rotary kilns, and bubbling or circulating fluidized bed reactors. The “Burgau” industrial plant in Germany, with more than 30 years of operation, is an example of municipal and industrial waste pyrolysis technology (Czajczyńska et al., 2017).

Gasification is understood as a process of thermal degradation fed by a sub-stoichiometric amount of oxygen to promote the autothermal partial oxidation of the feed, operating at temperatures above 750°C (Vieira et al., 2021). The main product is a synthesis gas and other gaseous components with a calorific value between 4 and 10 MJ/Nm^3. The configuration of the gasification plant can vary according to the type of bed: fixed bed, fluidized bed, entrained flow, and plasma (Saleem, 2018).

A gasification plant can be inserted in the recovery step according to the classification for USW management. After the pretreatment and material treatment stages, gasification process recovers energy and chemical products. A successful example is an industrial plant in Güssing, Austria, with gasification of wood chips with water content of 20 to 30%, with more than 20 years in operation (Werle & Sobek, 2019).

6. Methodology

Scientifical and technological prospection searches were performed according to bibliometric methodologies (Borschiver & Silva. 2016).

Documents such as patent applications and granted ones were obtained from ESPACENET database (https://worldwide.espacenet.com); academic articles from Web of Science database (https://apps-webofknowledge.ez35.periodicos.capes.gov.br); and technical reports, theses and dissertations from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) database (http://catalogodeteses.capes.gov.br/catalogo-teses/). Reviews were not considered because they are documents whose scope does not involve actual work on gasification, but rather address other works on the subject. Search restricted to submissions in Brazil. The time range used starts from the starting point of the databases until November 2022.

Initially, searches in CAPES database used the keywords “gasification” and “urban waste” performed with keywords in Portuguese. Searches in prospection in ESPACENET database, keywords used were (1) “urban waste”, in the sub keywords in the search terms “residue” or “refuse”, (2) “gasific*” with sub keywords “syngas” or “fuel”. The Boolean operator “AND” was used to concatenate the results between the keywords (1) and (2). The “OR” operator concatenates the additional terms to cover the possible synonyms assigned in the English translation the keywords (1) and (2). The truncation operator “*” defines a keyword stem for the search (Fernandes et al, 2018).

Secondly, searches in Web of Science database was used to refine the search and to differentiate documents that are restricted to citing keywords from those that effectively discuss the processes that represent the keywords “gasification” and “urban waste” at the universities that generated the documents theses and dissertations. And highlight the dissertations and theses documents that were not translated into articles.

Lastly, all results were treated by reading titles and abstracts of documents to refine and exclude repetitions. Patents and articles were analyzed by publication year. Articles were studied to collect various information like: publishing institution for the articles, focus of the work developed, type and model of gasifiers used in each technical report, dissertation and thesis, and by institutions. Patents were analyzed and described with title, dates and applicants. Patents were also analyzed by countries that have applications submitted in the Brazilian Patent Office – INPI. Further correlations were stablished with technology exploitation in Brazil.

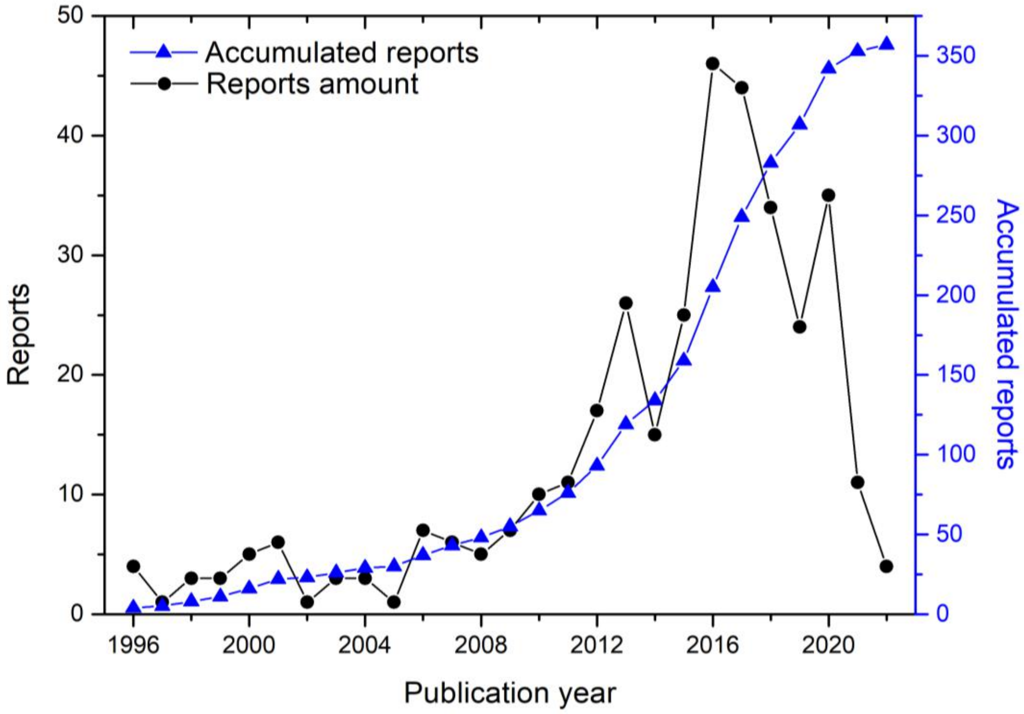
7. Results and Discussion

7.1 Academic production on gasification in solid waste

The graph represented in Figure 2 demonstrates the evolution of academic papers publications on gasification. It can be used to testify the specialized academic training in gasification produced in Brazil, in view of the data contained in the CAPES bank, in the period between 1996 and 2020, obtaining records from 58 different universities.

Academic documents on gasification are from publications such as dissertations and theses, which together make up a record of 357 reports. There are 26 related to USW, 46 are about modeling and computational simulation of thermochemical processes, and 285 documents are about biomass residues.

Figure 2 - Monitoring of academic production in gasification between 1996 – 2022.



Source: Research data.

In the research of published technical reports represented in Figure 2, three behaviors can be observed, the first being from the beginning until 2008, in which less than ten annual reports were published, which corresponds to training less than ten qualified professionals per year in the area. From 2008 to 2016, there was an increase in the number of reports, reflecting the influence of the MST's strategic guidelines. Within the multi-annual and ten-year plans for the MME and Ministry of Education (MEC), there was funding for research, education, and training of human resources in research involving biomass in various fields, such as renewable energy, with a focus on those with the greatest potential for applicability in the country, such as hydraulics, biomass, biogas, wind and solar (MME, 2021). The last change in behavior occurs after 2016: a sharp decrease reflecting the decrease in funding for research projects, given that in 2015 the estimated budget availability was $1.39billion, while in 2016 it passed to BRL 819million via the Financing Agency of Studies and Projects (FINEP from Portuguese), a body subordinated to MEC (Finep, 2022; Oliveira, 2016).

The 26 academic reports obtained on gasification in USW describe a perspective of the effort to work in conditions close to real life, with *in natura* material of heterogeneous composition. And distance themselves from exploratory research and technological application. There was no proposal to use catalysts in USW gasification. The studies with catalysts were carried out using only residues of homogeneous composition. This approach allows the processing of different types of organic and inorganic residues that can compose USW, facilitating the understanding of WtE process. These studies are closer to actual conditions and, therefore, the closest to obtaining a technological application process and product with market potential.

Of the 58 universities that managed projects in the gasification area, eight are private educational institutions, and the rest is maintained with government resources. In the ranking of the ten institutions with the highest production, observed in Table 2, all are maintained with public resources; the private institution with the best qualification appears in the twenty-sixth position.

Table 2 - Ranking of top ten institutions in gasification academic research in Brazil.

Institution	Number of technical reports	Published articles
Universidade Federal de Itajubá (UNIFEI)	40	25
Universidade Estadual de Campinas (UNICAMP)	39	49
Universidade Federal do Rio de Janeiro (UFRJ)	29	18
Universidade de São Paulo (USP)	19	16
Universidade Estadual Paulista (UNESP)	17	31
Universidade Federal do Rio Grande do Sul (UFRGS)	17	25
Universidade Federal de Santa Catarina (UFSC)	15	9
Universidade de Pernambuco (UPE)	15	3
Universidade de Brasília (UNB)	14	5
Universidade Federal de Viçosa (UFV)	12	8

Source: Research data.

Of the institutions listed in Table 2, the top six have the highest number of articles publications. From the seventh position down, a sharp decrease in the number of articles was observed, and these results are even smaller than the number of technical reports from these same institutions.

Analyzing the works' abstracts, it was possible to obtain the scope of the desired results in four areas of gasification. Catalysts for gasification; parameter optimization (equivalence ratio, amount of raw material, temperature, tar); instrumentation for gasifier implementation; and studies on raw materials to be gasified for the generation of synthesis gas (H_2, CO, and other gases) as a chemical intermediate or in the form of energy, as represented in Table 3.

Table 3 - Focus of academic works.

Document focus/ Total amount	189
Parameter optimization	92
Feedstock	55
Recycle gasification gas outlet	19
Production of synthesis gas	15
Catalyst development	8

Source: Research data.

Most of the work described in Table 3 focused on the implementation of the gasifier and mastery of the process, by studies of equipment and process parameters and raw materials. A natural consequence of the target on operation and optimization is the smaller number of documents directed to products of gasification. What draws attention are the studies on catalysts, as the number of catalysts tested in real gasification conditions was restricted.

7.2 Gasifiers used in academic publication

Examination on the types of gasifiers applied in each of the 189 articles indicated the use of 11 model types of gasifiers, listed in Table 4 with the corresponding citation amount.

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Table 4 - Types of gasifiers described in articles.

Gasifier type	Articles
Fixed Downdraft Bed (FDB)	45
Fluidized Bed (FB)	31
Circulating Fluidized Bed (CFB)	28
Theoretical Simulation of Gasification (TSG)	16
Supercritical Water Gasification (SWG)	14
TGA gasification simulation (TGA-GS)	14
Entrained Flow Bed (EFB)	10
Bubbling Fluidized Bed (BFB)	9
Fixed Updraft Bed (FUB)	6
Commercial Gasification Simulation Module (CGSM)	5
Thermal Plasma Bed (TPB)	3

Source: Research data.

For the same institution, the operation with different models of gasifiers was observed, as shown in Table 5. This occurred in institutions with at least a decade of research in the area of gasification, pushed by incentives from the MME and MEC for studies on renewable energies and biomass or research maturation.

Table 5 - Gasifier models by institution

Institution	Gasifier model
UNICAMP	FDB, CFB, BFB, FB, EFB, SWG, TSG
UNIFEI	FDB, BFB, FB, SWG
UFRJ	BFB, EFB, SWG
USP	FDB, FUB, CFB, FB, EFB, TGA-GS, SWG, CGS
UNESP	FDB, CFB, BFB, EFB, SWG, CGS
UFRGS	FDB, CFB, FB, EFB, TGA-GS, SWG, CGS
UFSC	FDB, FB, TGA-GS, CGS
UPE	FDB, FUB
UNB	FDB, FUB
UFV	FDB, EFB, SWG, CGS

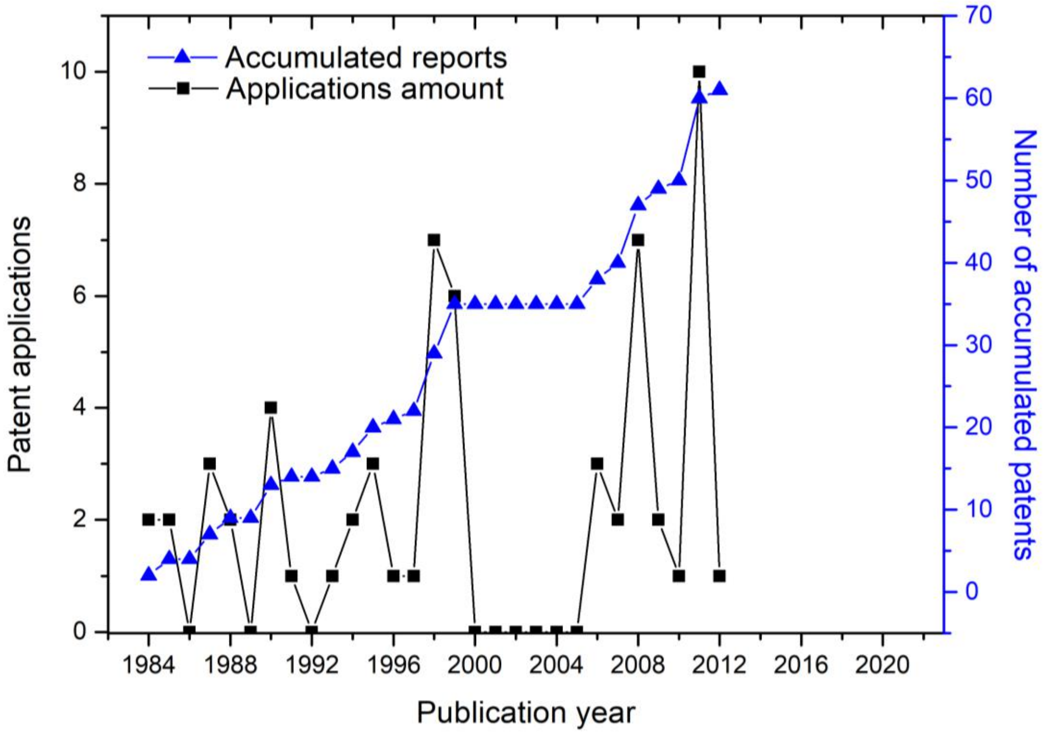
Source: Research data.

A pattern was not observed among institutions for the implementation of different gasifiers. However, it was observed that there was a tendency in most institutions for the initial selection of models that present an extensive amount of data as a fixed bed (downdraft and updraft) and circulating fluidized bed. Such behavior is understandable, as there is more data on the characteristics of the equipment, implementation parameters, and fuel (material to be gasified) for these gasifier models, allowing for fewer errors in implementation (Puig-Arnavat et al, 2010; Valderrama et al, 2018).

7.3 Gasification patents in Brazil

Analysis of the ESPACENET database resulted in 61 patent applications filed in the period from 1984 to 2022, as shown in Figure 3. There was no record of patent deposits between 2013 to 2022; from 2019 above there is the condition of secrecy of three years from the deposit that can help explain this lack of data. There are peaks in patent deposits in periods between 1998 to 1999 and 2008 to 2011. It is also observed that no deposit occurred between the peaks that coincide with the approval period of the NSWP regulatory milestone. The lack of patent deposits after approval of the regulatory mark can be attributed to a breach of expectations in the use of technology in waste treatment.

Figure 3 - Monitoring the deposit of gasification patent applications in Brazil between 1984-2022



Source: Research data.

Of the 61 requests for patents, accumulated total, only eight were granted, of which three were requests from Brazilian applicants and the other five were from foreigners who requested correspondence from the deposit in Brazil, as shown in Table 6.

Table 6 - Brazilian granted patentes.

Patent Number	Title	Filing Date	Publication Date	Grant Date	Applicant
BRPI0418977B	Process for converting carbonaceous material into energy gases, processes for producing synthetic gas and liquid fuel; Apparatus for producing a synthetic gas and liquid fuel in a substantially self-sustaining process	04/08/2004	29/01/2008	11/02/2014	University of California
BRPI0414839B	Process for the valorization of metal values in a waste carrying Zn, Fe and Pb and single-chamber fusion and gasification reactor for treating waste carrying Zn	30/08/2004	21/11/2006	07/05/2013	Umicore
BRPI0416197B	Gasification	03/11/2004	16/01/2007	09/12/2014	ITI Limited
BRPI0607812B	Process for treating waste and apparatus for carrying out the process	29/06/2006	23/03/2010	18/12/2018	Tetronics Limited
BRPI0700732B1	Process of using biogas as a thermochemical gasifying reagent	27/02/2007	14/10/2008	28/06/2016	Universidade Federal de Minas Gerais (UFMG)
BRPI0700631B	Process of producing one or more alcohols, and alcohol(s)	02/03/2007	21/10/2008	17/05/2016	Braskem S.A.
BRPI0711275B	Integrated system and method for producing and vaporizing liquid hydrocarbon fuels for combustion	01/05/2007	08/11/2011	24/01/2017	LPP Combustion LLC
BRPI1000573B1	Industrial fuel production process from urban solid waste	10/02/2010	27/09/2011	15/05/2018	Evandro Jose Lopes; Marcos Aurelio Wipprich; Maximiliano Bernardi

Source: Research data.

The waiting time between filing and the fastest publication was 19 months; on the other hand, the slowest release took 45 months. This variation is attributed to backlog, procedure changes and queuing system. In a recent process of documents digitalization of the Brazilian National Institute of Industrial Property (INPI Brazil), applications initiated on paper and which did not undergo examinations were reintroduced in the system, competing with the applications currently being submitted. In 2019, there was the formulation of measures to reduce former applications, INPI/PR nº 241/19, with plans and goals for, in two years, to decide 80% of late applications in the system with a closing deadline in 2021. In this plan, from 2023 each application will be analyzed within 24 months, inserting Brazil into the world standard for patent examination (INPI, 2019).

Back to Table 6 results, applicants University of California, Umicore, ITI Limited, LPP Combustion LLC, and Tetronics Limited, are listed because, as a way of ensuring the rights to exploit their technologies in different territorialities, each depositor filed corresponding patent application in the territories of interest. These procedures are accepted by countries members of the World Intellectual Property Organization (WIPO) and Patent Cooperation Treaty (PCT), like United States Patent and Trademark Office (USPTO) and European Patent Office (EPO).

The total number of 61 applications filed reflects the number of people interested in commercializing this technology, however, the difference in the number of applications granted, eight, depends on several factors ranging from the withdrawal of the application to the challenge of implementation. Patents research is an analysis in technological innovation, being, therefore, the final stage of the development of a product with technological application potential. In patents examination, if applications do not meet requirements of novelty and inventiveness, they cannot be patented.

Patents in the area of gasification, observed in Table 6, as in other energy technologies, have priority focus is the optimization of equipment conditions to increase efficiency, improve equipment components resistance, reduce generation of liabilities that require treatments and get economic viability. In other words, obtaining new means of producing inputs with high added value and the benefit of reducing the volume of waste would be an alternative to traditional means of treatment such as incineration and landfills.

Among the analyzed institutions, the only one to which a patent was granted was UFMG. In comparison with technical reports (dissertations and theses), among the top institutions ranked in Table 2, UNICAMP has 37 reports and no granted patent, UFMG is in the 22th position and has five technical reports and five articles published. This result gives a significant indication of the difference between carrying out research as the final objective and reconciling research with the production of products that benefit society.

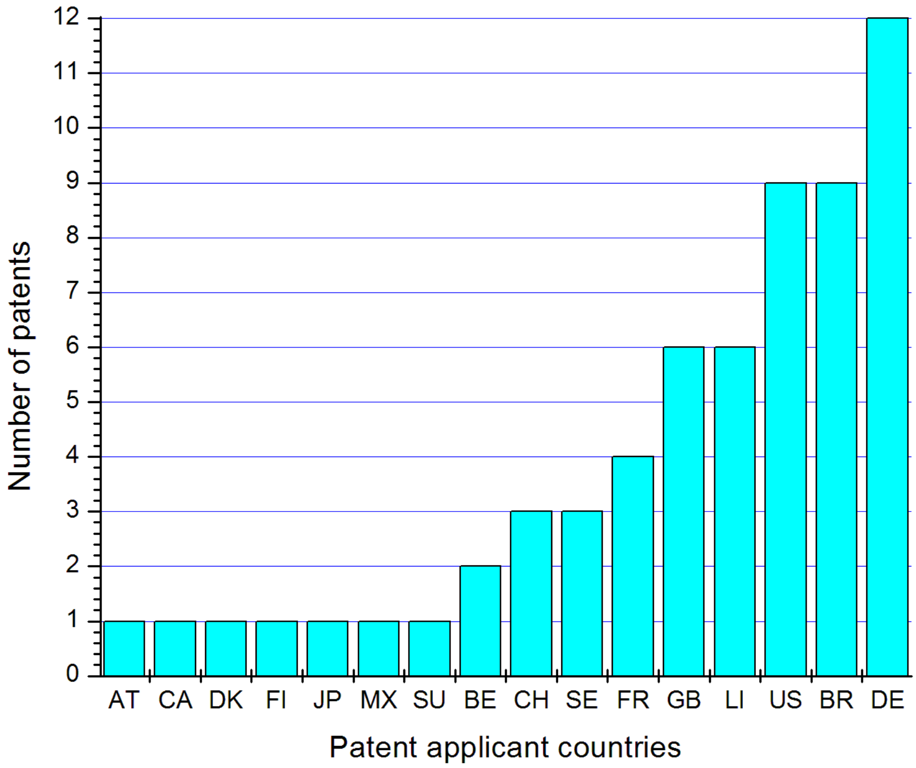
Research projects in Brazilian universities are not intended to obtain products or technology for the market, but rather to focus on basic research and training of human resources. This behavior has been shown to limit development in the technological areas in Brazilian educational institutions. The search for solutions that meet market demands can be the breaking point in this behavior, generating the thrust of the technology.

It is observed in Table 6 that, from total granted patents, seven are for processes that improve production of gasified product and one is for gasification equipment. Both types of applications can be obtained as academic research results. Although there are specifications in the patents for a particular type of waste to be applied, they can also be tested for other types of solid waste.

7.4 Patent applicants in Brazil

The analysis of depositor's country for patent applications in Brazil from ESPACENET database pointed out that Brazilian applications are in second place, in number, together with north-Americans, with nine applications. The main depositors are from Germany with 12 applications, as shown in Figure 4.

Figure 4 - Monitoring the origin of patent applicants in Brazil



Source: Research data.

The diversity observed in the origin of patent applicants can be associated with the low number of national companies in the sector and large foreign interest in the Brazilian market. Additionally, applicant is not obliged to carry out research in the jurisdiction that is interested in filing the patent, so foreign companies seek to reduce product research and development costs by ensuring the rights to exclusive commercialization in several countries.

Countries guarantee the right to exploit the patented technology to attract companies with consolidated know-how to the industrial park that will train human resources; it is no different with the Brazilian government. This behavior was observed in the data represented in Table 7. Of the top 10 companies that explore gasification technologies that have patents deposited in Brazil, all are foreign companies with representation in the country.

Table 7 - Companies exploring gasification technology deposited in Brazil.

Applicants	Number of documents
Thermoselect ag	6
Voest Alpine Ind Anlagen	3
Braskem SA	2
Chemrec AB	2
Diehl Joerg	2
Kraftwerk Union AG	2
Kvaerner Pulping Tech	2
Advanced Plasma Power LTD	1
Aerts Jonathan	1
Ahlstrom Machinery INC	1

Source: Research data.

8. Conclusion

The gasification research carried out in Brazilian educational institutions is the result of public policy incentives, which created a demand for training human resources, with results presented in the publication of technical reports and articles. However, there is no return of academic research to the market in the form of products, as observed in the production of the ten most active institutions in the area of Brazilian gasification, as they have no patent applications. The institution in the eighteenth position in terms of publication of reports, was the only one to have a granted patent, referring to the process of improvement of biogas as a reagent.

Public policies to strengthen research are essential tools for boosting scientific and technological development. However, dependence on government resources also limits research, a behavior observed in the monitoring of technical reports on gasification, which showed a reduction corresponding to budget cuts. Research in the country should change focus, turning to practical solutions and more immediate technological applications. Basic, academic and technological studies are fundamental and form human resources that contribute to science. However, the exploratory study has greater potential to generate products with direct applications that help support industrial and commercial demand.

The new sanitation legal milestone approved in 2020 may be an opportunity to change this behavior in Brazilian research for the gasification of biomass residues and USW. Especially the zero-dump program, which aims to treat 91.2% of organic solid waste by 2033, and the zero-methane program, which aims to reduce methane emissions with the consumption of biomethane and biogas with sustainable development. The adoption of climate standards specifications for Brazil entry into the OECD, up to the time of this November 2022 analysis, has already obtained factual results. Nine of the 27 units that make up the Brazilian federation, which are Alagoas, Espírito Santo, Mato Grosso do Sul, Amapá, Rio de Janeiro, Ceará, and Goiás, have already handed over the administration of all or part of the water and sewage treatment systems to the private sector.

This healthy scenario for research focused on the private sector's demand for applied processes and supplements for USR, allows for the promotion of partnerships between the private sector and the government via MME and MEC. In view of the open opportunity for research on gasification in MSW and the paradigm shift in academic research on gasification, monitoring this scientific, technological, and human development is recommended.

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