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Artículo de investigación

Trends in the development of metallic and bimetallic nanoparticles: a patents landscape analysis

Tendencias en el desarrollo de nanopartículas metálicas y bimetálicas: un análisis del panorama de patentes

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Abstract

The upward development of nanotechnology in the last 30 years, especially in the development of nanoparticles for applications in medicine, agriculture, energy, among others, it has substantially impacted the development of scientific articles and patents. This has stimulated the knowledge economy by improving university-industry integration, which benefits everyone in this area of research. The increasing development of patents leads us to analyze, within a period of 10 years, the emerging technologies in developing metallic and bimetallic nanoparticles. Additionally, the incidence that the production of patents has had on developing this technology in leading countries such as the United States, China, Australia, and India is shown. This article shows a scientometric analysis of the development of patents the metallic and bimetallic nanoparticles. Aspects such as patents by country, types of patents, inventors, applicants, and most developed technologies were evaluated. Scopus databases, Espacenet software, and different computer tools were used for the analysis.

Resumen

El desarrollo ascendente de la nanotecnología en los últimos 30 años, especialmente en el desarrollo de nanopartículas para aplicaciones en medicina, agricultura, energía, entre otros, ha impactado sustancialmente el desarrollo de artículos científicos y patentes. Esto ha estimulado la economía del conocimiento al mejorar la integración universidad-industria, lo que beneficia a todos en esta área de investigación. El creciente desarrollo de patentes nos lleva a hacer un análisis dentro de un período de 10 años, de las tecnologías emergentes en el desarrollo de nanopartículas metálicas y bimetálicas, además de mostrar la incidencia que la producción de patentes ha tenido, en el desarrollo de esta tecnología, en países lideres como Estados Unidos, China, Australia e India. Este artículo muestra un análisis cienciométrico del desarrollo de patentes relacionadas al desarrollo de nanopartículas metálicas y bimetálicas, evaluando aspectos como, patentes por país, tipos de patentes, inventores, solicitantes y tecnologías más desarrolladas. Para el análisis fueron utilizadas las bases de datos Scopus, Software Espacenet, y diferentes herramientas informáticas. Los resultados mostraron a Estados y China con un 53,3% de producción de patentes respecto al total; las patentes son desarrolladas principalmente por Estados Unidos y los principales entes solicitantes son Universidades con un 63% e industria con un 37%.

Keywords:
Nanoparticle/metal; Bimetallic nanoparticles; Patents; Trends, Inventors, Scientometric

Palabras clave:
Nanopartículas metálicas; Nanopartículas bimetálicas; Patentes, Tendencias, Inventores, Cienciometría.

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Contribution

Why was it done?

The accelerated growth of nanotechnology products and the implications they have, especially on human health and the environment, requires a patent protection system, analyzing intellectual property issues and regulations that not only promote innovation and scientific research but can also contribute to a country's economic development.

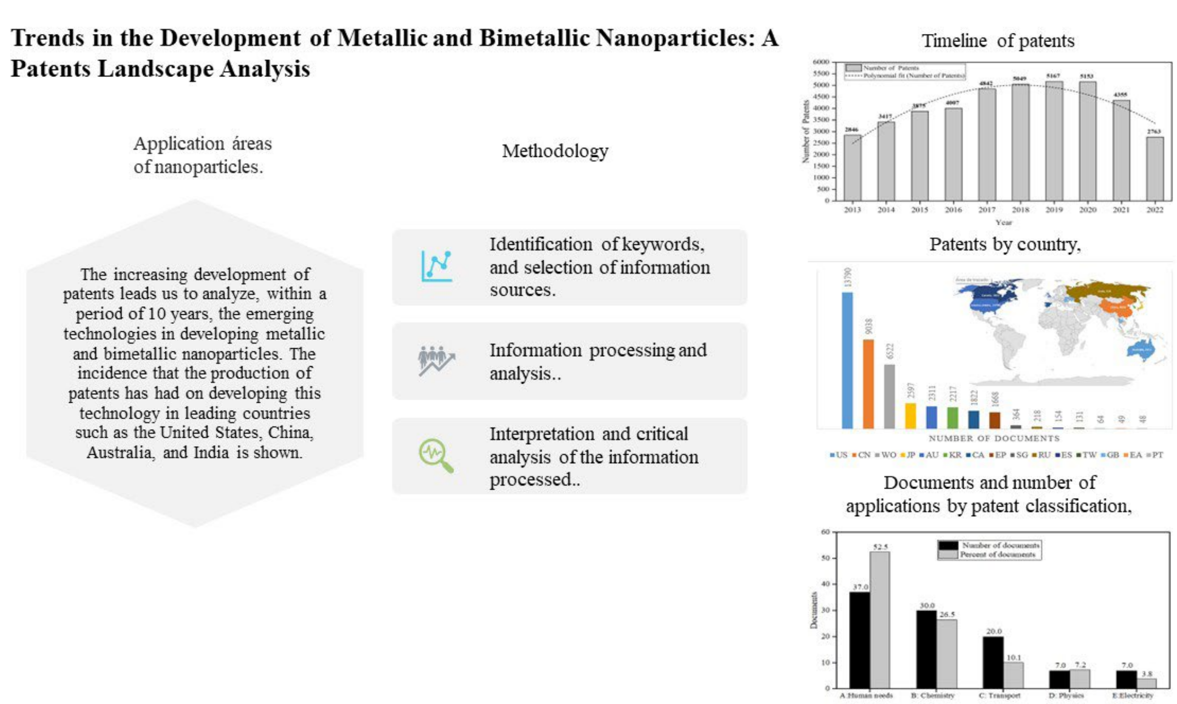
What were the most relevant findings?

The results showed a scientometric analysis where the incidence of patent production in the development of metallic and bimetallic nanoparticles was determined, based on a timeline, most influential countries, application areas, most representative applicants and inventors.

What do these results provide?

The results showed an upward growth in the generation of patents in the development of metallic and bimetallic nanoparticles worldwide in the study period (2012-2021). It was found that the United States and China had the highest production, attributed to significant investments in public and private research and development (R&D). The areas of greatest interest in the development of patents are located in human needs, especially in the area of health. In addition, the scientometric analysis made it possible to identify trends and influential aspects in this area worldwide.

Graphical Abstract



Introduction

Nanotechnology is a complex technology that seeks to change and analyze the properties of materials at the nanometric level, exploring multidisciplinary fields such as biology, physics, chemistry, and others. The growth related to nanotechnology and the implications that nanomaterials present due to their characteristics make necessary a protection system under the patent model that facilitates the knowledge and distribution of these types of products, their applications, and their incidence in the economy of a country. On the other hand, generating nanomaterials where different multidisciplinary areas are involved generates problems at the time of patenting(1).

Industrial Applications of Nanoparticles

One of the crucial aspects of nanotechnology has been the progress and research in agriculture, closing gaps to ensure food resources and meet the Sustainable Development Goals (SDGs) such as overcoming poverty, zero hunger, fight against climate change, among others (2); In this sense, the development of nanotechnology in this area has consolidated several actions for more sustainable processes, lower environmental impact, and development in the agricultural economy (3). Thus, in pursuing these objectives, we face a series of challenges such as nutrient deficiencies, stagnation of crop yields, climate change, and reduction of labor, not to mention uncontrolled fertilization that lowers the level of crops. Therefore, nanotechnology is used to evaluate aspects such as detection, recording, handling, storage, and control of soils and environmental conditions such as climate, water, soil condition, and consumer needs that improve agricultural performance (4) (5).

The rational use of nanoparticles can facilitate the growth of plants in their germination and growth process. In the case of the application of nano-fertilizers, these can improve conditions by reducing losses of mobile nutrients with slow-release processes. At the same time, nanosensors allow monitoring and data collection of soil and plant health for early detection in making quick decisions with proper management of pesticides, fertilizers, water, and soil, among others (6) (7).

Another area of great application of nanoparticles is related to the area of medicine. Here we find essential developments in drug delivery (8–10) and cancer treatment (11) in the diagnosis and treatment of diseases such as neurodegenerative diseases like Alzheimer's, which is a public health problem in the world. In this case, nanotechnology offers alternatives of great interest (12).

From the environmental point of view, nanoparticles have generated an important option for removing pollutants, especially in the case of arsenic removal, a significant problem in India and China (13,14). Similarly, in wastewater treatment for the elimination of emerging contaminants that are present in minimum concentrations and are treated with adsorption and photocatalysis processes (15); However, we cannot ignore the impact that these materials generate due to their release into the environment, nanotoxicity and their impact on aquatic ecosystems (16).

The environmental crisis generated by producing energy through non-renewable fossil fuels and other exploitation techniques has made it necessary to search for alternatives that respond to the energy demand with a minimum environmental impact. One of these alternatives is the use of nanotechnology, where vital research is being carried out in the development of solar cells, Li-ion batteries, catalytic hydrogen evolution, etc., as well as in the development of new technologies for the production of energy (17,18), in energy storage systems (19), in fuel cells, sensors and structures that enhance energy efficiency (18,20,21).

The development of patents in the knowledge economy

A Patent is an exclusive right granted to an invention; it is a deal between an inventor and a government, where the inventor agrees to disclose his invention to the public, who will benefit from it. This privilege consists of the right to exclusively exploit the invention for a determined period, generally 20 years (22).

Scientific activity plays an essential role in industrial innovation and increasingly generates more confidence in different fields. Thus the knowledge economy is becoming an element recognized by professionals in the university-industry relationship, where it is becoming more critical and helpful daily. The upward growth in the development of patents by institutions has become remarkable due to the need not only to innovate but also to protect their products and generate some profitability in the process; without affecting the generation of scientific research (23). Countries such as India, with great potential in the development of nanotechnology, show a great interest in the development of patents in this area, analyzing not only the conditions for development but also intellectual property and regulatory issues that allow the commercial success of this technology (24). China generated a strong technological revolution almost 40 years ago with the economic reform of Deng Xiaoping. This reform provided economic support for learning-by-doing and mass-developing products and services. This methodology generated the need to protect these products and ideas with the development of patents and intellectual property management (25). In addition, if we compare the level of nanotechnology development, we find in the first place the United States, which since 2000 has had significant growth in scientific publications. However, China has been rising due to increased government funding, infrastructure, and research with a strong alliance in the nanotechnology industry (26). According to Cely et al, in a previous study it was evidenced that the production of patents in the area of metallic and bimetallic nanoparticles grew by 10.0% in the last decade (Scopus). This fact sets a precedent for the significant impact generated by patents in this area (27).

This article offers a scientometric analysis related to the development of patents in metallic and bimetallic nanoparticles, promoting the discussion towards the production of patents, leading countries in this technology, and industry-university relationship among other basic elements to observe the future of nanoparticles in different areas of the industry.

Materials and method

The methodology was developed from a scientometric analysis of patents. This analysis is a method that allows visualizing interdisciplinary connections, development, and emerging areas in nanoparticle research.

A patent analysis was developed using the Scopus database and Esp@cenet software; it was based on a combination of keywords using logical operators AND, OR, NOT and including title, abstract, and keywords. Keywords such as metal nanoparticles, oxide-metal nanoparticles, bimetallic nanoparticles, Nano-Au-Nano-Ag, etc. were used, where about 41210 patents were found during (2013-2022). The data were collected on October 11th, 2022 using Espacenet software.

The search equation is composed of words such as: emerging AND (nanoparticle/metal OR nano-metal-oxide OR “*bimetallic nanoparticles*” OR “*metallic nanoparticles*” OR *nano-Ag* OR *nano-Au* OR *nano-Cu* OR *nano-Al* OR *nano-Fe* OR *nano-Ti* OR *nano-Zn* OR *nano-CdSe* OR *nano-ZnS* OR *nano-CdTe* OR *nano-*TiO_2 OR *nano-*Al_2O_3 OR *nano-*Fe_2O_3 OR *nano-ZnO* OR *nano-CuO* OR *nanoparticle**), analyzed in the 2013-2022 period.

Databases such as Scopus and Espacenet software were used, as well as software such as OpenRefine and advanced Excel. The analysis made it possible to determine the incidence of patent production, timeline, most representative countries, application areas, applicants, and most representative inventors.

Results and discussion

Patents analysis

Patent analysis was developed from databases using Espacenet software, using a keyword list of metallic, bimetallic, and oxide nanoparticles. The equation used was as follows: *“emerging” AND “nanoparticle/metal”, “nano-metal-oxide”, “bimetallic nanoparticles”, “metallic nanoparticles”, “nano-Ag”, “nano-Au”, “nano-Cu”, “nano-Al”, “nano-Fe”, “nano-Ti”, “nano-Zn”, “nano-CdSe”, “nano-ZnS”, “nano-CdTe”, “nano-*TiO_2*”, “nano-*Al_2O_3*”, “nano-*Fe_2O_3*”, “nano-ZnO”, “nano-CuO”,* in the 2013-2022 period, where 41210 patents were found.

Figure 1 shows the timeline of patents in the research of nanoparticles in the last decade. It is evident, as found from the analysis of the Scopus database, the upward growth of patent production. In this case, under the analysis with Espacenet, the average annual growth rate was 25.3%, with more than 2000 patents per year in the thematic. The highest peak was presented in 2019, with 5167 patents.

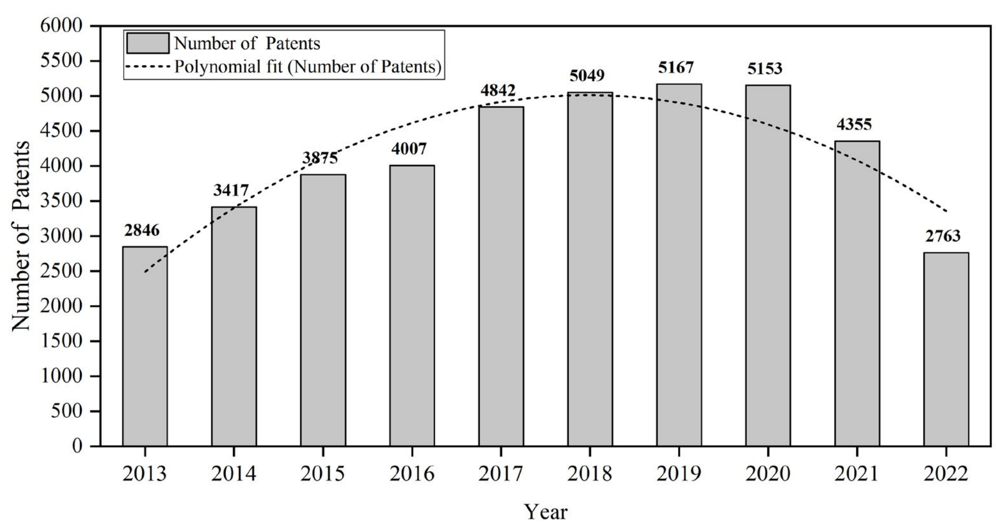


Figure 1. Timeline of patents found in the area of metallic and bimetallic nanoparticles in the period 2013-2022.

Patents by Country

An interest in obtaining patent protection has accompanied the rapid growth of nanotechnology. Due to experiences such as in the case of the United States and China, universities are increasingly proactive in commercializing their research results and converting them into products for industry in general as a knowledge transfer (1,23). Figure 2 shows the number of patents for the United States (33.4%), China (21.9%), WIPO (15.8%), Japan (6.3%), and Australia (5.6%), i.e., the first five countries or entities account for 83.1% of the total. No patents from Latin American countries were found under the search equation.

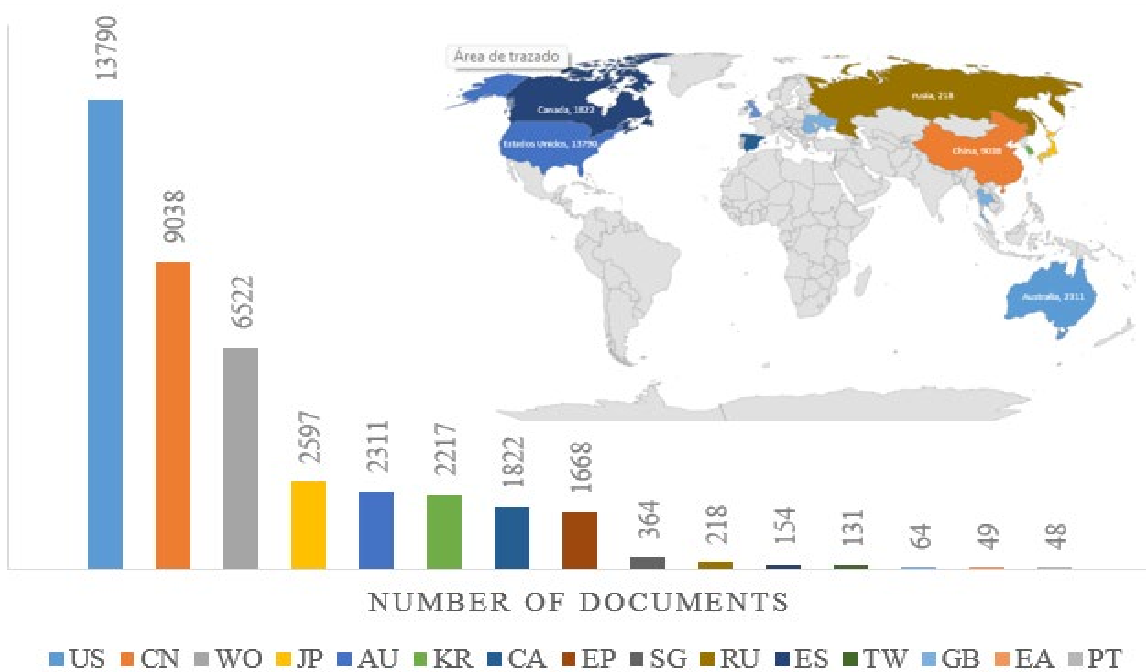


Figure 2. Number of patents by country, in the area of metallic and bimetallic nanoparticles in the period 2013-2022. According to Esp@cenet, countries are designated by the following nomenclatures: US=United States, CN=China, WO=WIPO, JP=Japan, AU=Australia, KR=Korea, CA=Canada, EP=European Patent Office, SG=Singapore, RU=Russia, ES=Spain, TW=China Tipei, GB=United Kingdom, EA=Eurasian Patent Organization, PT=Portugal.

It should be noted that countries such as India, Germany, and the United Kingdom, which have a high production of scientific articles on the subject, do not show this strength in the generation of patents.

In general, the growth of patents in this area of nanoparticles has been significant, with the United States and China leading the process. This growth has been generated not only by investment policies of the great powers in the area of innovation and technology but also from the concept itself of size reduction, which generates a different material susceptible of being patented, either for its properties or the solution to certain problems of the environment (28)

On the other hand, Wu *et al*. (29) found that since 2011 the growth of patents in China has been ascending, surpassing countries such as the United States, Korea, and Germany, making it the country with the highest production of patents. When analyzing and comparing what happens with that patent development and according to Maxwell *et al* (30), who developed a comparison of patent production between China and Australia it can be evidenced that there are factors in that growth model. It is the case of Australia, which developed its first patent in 1904 and since then has had a successful development for its national market. The patent right prevents others from exploiting that technology in Australia. However, due to international policies, foreign entities can also own Australian patent rights for the commercialization of those technologies, as in the case of China, which under government incentive policies, concessions, and tax deductions, has acquired a large part of those patent rights.

Patents Groups

The groups of patents are classified by area as follows: a) Human Needs; b) Transportation; c) Chemical; d) Textiles and Paper; e) Construction; f) Mechanical Engineering; g) Physics; h) Electricity, and i) General.

Figure 3 shows the number of documents according to patent classification. For the case study, the area of Human Needs is where most documents are found (52.5%), followed by the area of Chemistry (26.5%), Transportation (10.0%), Physics (7.19%), and Electricity (3.8%), the other areas do not present documents in analysis.

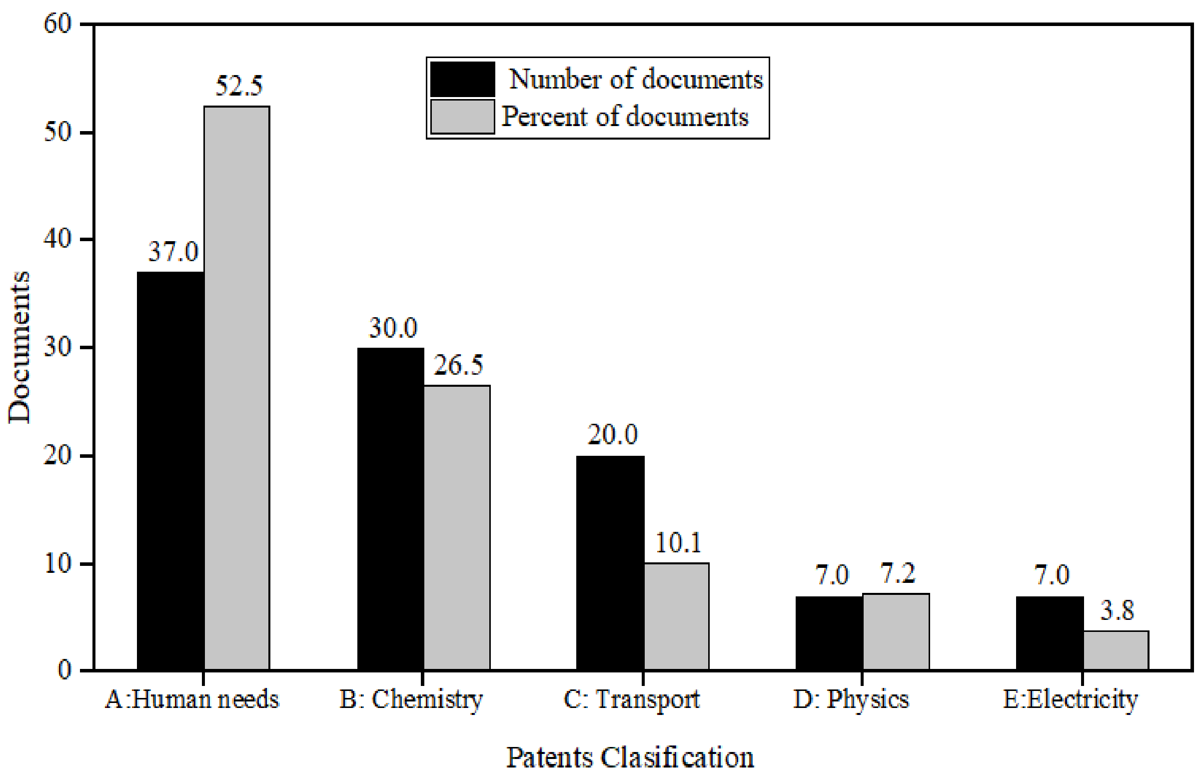


Figure 3. Percentage of documents and number of applications by patent classification, in the area of metallic and bimetallic nanoparticles in the period 2013-2022

Patent groups can be classified into main and subgroups; in this case, Table 1 shows the top 10 main patent groups and areas of work.

These ten groups correspond to 37.6% of the total documents per patent group. The topics with the highest production are focused on the health part (8 of 10 large groups), with the analysis of devices or methods, generation of peptides, analysis of antibodies and control topics, and analysis of physical and chemical properties.

Table 1. Main Groups of patents, in the area of metallic and bimetallic nanoparticles in the period 2013-2022

IPC Main Groups	Patents	Area
A61K31	3162	Health: devices or methods for medical or dental purposes
A61P35	2595	Health: Chemical components or medicinal preparation
A61K47	2344	Health: Devices or methods for medical or dental purposes - non-active ingredients (transporters)
C12N15	2330	Health: Devices or methods for medical or dental purposes
G01N33	2122	Physics: Analysis of materials for the determination of physical or chemical properties.
A61K9	2108	Health: Devices or methods for medical or dental purposes
A61K39	2085	Health: devices or methods for medical or dental purposes - antibodies
A61K38	1711	Health: Devices or methods for medical or dental purposes
C12Q1	1521	Chemistry: testing and measuring processes of microorganisms, enzymes, and nucleic acids.
A61K45	1488	Health: Devices or methods for medical or dental purposes
C07K14	1472	Chemistry, metallurgy: Peptides-amino acids.

Applicant Entities

Every patenting process involves two types of actors: the inventors or creators and the applicants- companies, universities, organizations, or individual users. As previously mentioned, and according to Jain & Rangan(24), the generation of patents is increasing due to the commitment and activity developed by universities and research institutes with a dynamic of intellectual property protection. The percentage of type of applicant entities, being representative the participation of universities with 63% (2884 documents) and companies with 37% (1628 documents); independent users were not found in the analysis. Table 2 shows the ten entities with the most patents applied.

Table 2. Entities applying for patents in the area of metallic and bimetallic nanoparticles in the period 2013-2022

Applicants	Number of Patents
Univ California	338
Massachusetts Inst Technology	285
Broad Inst Inc	183
Harvard College	160
Univ Texas	138
Univ Leland Stanford Junior	102
Univ Johns Hopkins	90
Massachusetts Gen Hospital	85
Hoffmann La Roche	82
Univ Northwestern	81

Seven of the ten entities are universities, and the principal applicant countries are the United States, Korea, Germany, the United Kingdom, and Canada.

Inventors

The percentage of documents related to inventors by country. The first five countries account for 75.6% of the total number of documents. The United States has the largest number of documents (77%), followed by Germany (7%) and the United Kingdom (6%). Table 3 shows the inventors with the highest number of documents.

Table 3. Most representative inventors in the area of metallic and bimetallic nanoparticles in the period 2013-2022

Inventors	Number of Patents
Zhang Feng	79
Regev Aviv	54
Chen Jian	33
Jang Bor Z	25
Wang Chao	25
Miller David	23
Wang Meng	23
Weiner David	23
Wang Wei	21
Zhang Wei	21

Despite the impact generated by the Covid-19 pandemic, around 3.3 million patent applications were filed worldwide in 2020, representing an increase of 1.6% over 2019, especially the participation of China, the Republic of Korea, Hong Kong, and India. In this patent growth, it is notable to see Asian economies leading a global recovery with 1.6% in patent applications for 2020. The long-term trend in patent applications worldwide tends to rise so that applications have increased from 1 million in 1995 to 3 million in 2016 (22).

Conclusion

The generation of patents has been a way of encouraging the knowledge economy, giving value to the development of innovations, and generating a more significant link with industry, showing that the requesting entities with the greatest impact were universities with 63% compared to the industry with 37%.

The scientometric analysis allows finding trends related to metallic and bimetallic nanoparticles in their applications in different areas of the industry; thus, the area with the greatest impact was that of human needs (52.4%) in applications for the health area.

The development of patents shows an upward trend, with the United States and China, with 55.3% of the total, being the countries with the highest production in the area of research; on the other hand, worldwide, the overall production of patents for 2019 and 2020 reached more than 3 million applications.

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