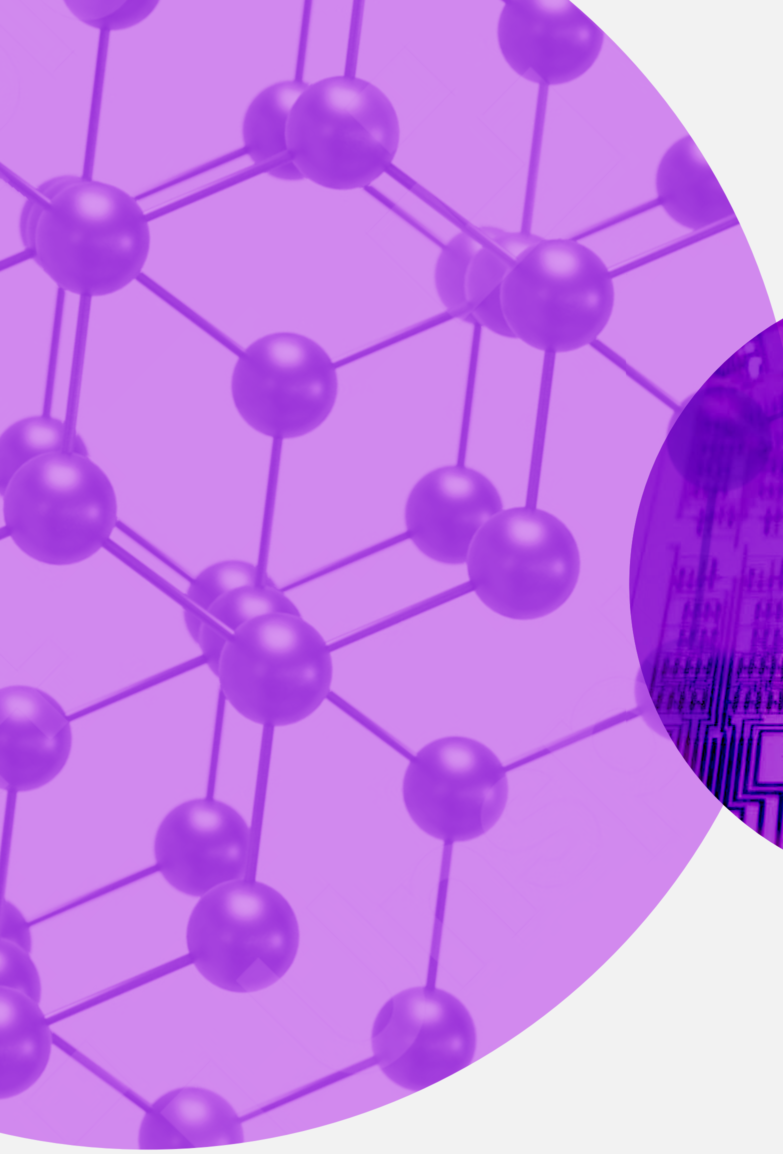

Patent
Landscape
Report

Graphite and its applications

WIPO

Patent
Landscape
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Further information
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Contact: patent.information@wipo.int

Key findings and insights

Named in 1789, the word graphite is derived from the Greek *graphein*, meaning "to draw or write." This stems from its primary use as the "lead" in pencils. From its humble beginning as a means of mark-making and writing, graphite came to prominence in the manufacturing of cannonball molds, because of its excellent refractory properties. Thereafter, graphite, owing to its combination of excellent electrical and thermal conductivity, and good chemical stability and corrosion resistance, became an indispensable material in various industrial applications. This WIPO Patent Landscape Report examines global graphite-related patenting activity in the last decade. The report uses information from individual country policies and market and business information to assess the current state of graphite technologies and identify innovation hot topics, as well as examining both better-studied areas and the emerging applications for graphite.

Innovation in graphite technologies has attracted growing interest in the last decade, but inventions have been concentrated in just a few geographical regions.

Globally, over 60,000 patent families in graphite technologies were filed from 2012 to 2021. Such a large volume of graphite-related inventions underscores the importance of the material across multiple industries.

Interest in graphite is global. Patents were filed by applicants from over 60 countries and regions. However, graphite-related patent families originated predominantly from just a few countries. China was the top contributor with more than 47,000 patent families, accounting for four in every five graphite patent families filed worldwide in the last decade. Among other leading countries were Japan, the Republic of Korea, the United States and the Russian Federation. Together, these top five countries of applicant origin accounted for 95 percent of global patenting output related to graphite.

Flake graphite and artificial graphite were the two preferred primary graphite sources.

Among the different graphite sources, flake graphite has the highest number of patent families, with more than 5,600 filed worldwide from 2012 to 2021. It has strong traction, particularly in China – the primary supplier of flake graphite to the global market. Supported by active research from its commercial entities and research institutions, China is the country most actively exploiting flake graphite and has contributed to 85 percent of global patent filings in this area.

At the same time, innovations exploring new synthesis methods and uses for artificial graphite are gaining interest worldwide, as countries seek to exploit the superior material qualities associated with this man-made substance and reduce reliance on the natural material. Patenting activity is strongly led by commercial entities, particularly world-renowned battery manufacturers and anode material suppliers, with patenting interest focused on battery anode applications.

Exfoliation techniques for bulk graphite processing are well-established.

The exfoliation process, which involves separating the carbon layers within graphite, has been extensively studied. Specifically, ultrasonic and thermal exfoliation have been the two most popular approaches worldwide, with 4,267 and 2,579 patent families, respectively. This is significantly more than for either the chemical or electrochemical alternatives.

Global patenting activity relating to ultrasonic exfoliation has decreased over the years, indicating that this low-cost technique has become well established. It is particularly popular among research institutions as an essential step in processing bulk graphite into graphite nanomaterials and graphene.

Thermal exfoliation is a more recent process. Compared to ultrasonic exfoliation, this fast and solvent-free thermal approach has attracted greater commercial interest.

Battery applications were a key driver, and will continue sustaining global graphite-related innovation.

As the most widespread anode material for lithium-ion batteries, graphite has drawn significant attention worldwide for use in battery applications. With over 8,000 patent families filed from 2012 to 2021, battery applications were a key driver of global graphite-related inventions. China has the most graphite patent families for battery applications, followed by Japan and the Republic of Korea. These top three regions have contributed to over 90 percent of patent families worldwide.

Innovations in this area are led by battery manufacturers or anode suppliers who have amassed sizable patent portfolios focused strongly on battery performance improvements based on graphite anode innovation. Besides industry players, academia and research institutions – Chinese universities, in particular – have been an essential source of innovation in graphite anode technologies.

The need for graphite in batteries is expected to increase further, owing to a rapidly growing demand for energy storage in support of the clean energy sector's explosive market growth over recent years – particularly with respect to electric vehicles and large-scale energy storage. Increasingly, leading innovators are exploring graphite anodes for the next generation of battery technologies, as well as alternative anode solutions with a greater energy density and better performance.

Polymer and ceramic applications are graphite technology innovation hot topics.

Graphite for polymer applications was an innovation hot topic from 2012 to 2021, with over 8,000 patent families recorded worldwide. However, in recent years, in the top countries of applicant origin in this area, including China, Japan and the United States of America (US), patent filings have decreased. A large volume of patent applications followed by a downward trend suggests that it is a well-explored area with substantial technology accumulation. Overall, graphite inventions for polymer composites were strongly commercially driven, with four in every five related patent families having been filed by commercial entities.

Graphite for manufacturing ceramics represents another area of intensive research, with over 6,000 patent families registered in the last decade alone. Specifically, graphite for refractory is the key innovation focus worldwide. It accounted for over one-third of ceramics-related graphite patent families in China and about one-fifth in the rest of the world. Other important graphite applications include high-value ceramic materials such as carbides for specific industries, ranging from electrical and electronics, aerospace and precision engineering to military and nuclear applications.

Graphite applications for carbon brushes have reached saturation point.

Carbon brushes represent a long-explored graphite application area. That it is considered to be a well-established area is evident from related patenting activity worldwide.

There have been few inventions in this area over the last decade, with less than 300 patent families filed from 2012 to 2021. In addition, the majority of patent families originating from China – the top contributing country – were filed in earlier years. Furthermore, graphite for carbon brushes is gaining minimal traction from the rest of the world, with only sporadic patent filings having been made in the last decade. The overall number of patent families originating from the rest of the world filed between 2012 and 2021 is far lower than was filed between 1992–2001 and 2002–2011, respectively, indicating that carbon brush technology has entered the final stage of its technology cycle.

Graphite use for biomedical, sensor and conductive ink applications is emerging.

Biomedical, sensor, and conductive ink are emerging application areas for graphite that have attracted interest from both academia and commercial entities, including renowned universities and multinational corporations.

Typically for an emerging technology area, related patent families were filed by various organizations without any players dominating. As a result, the top applicants have a small number of inventions, unlike in well-explored areas, where they will have strong technology accumulation and large patent portfolios.

The innovation focus of these three emerging areas is highly scattered and can be diverse, even for a single applicant. However, recent inventions are seen to leverage the development of graphite nanomaterials, particularly graphite nanocomposites and graphene.

Introduction

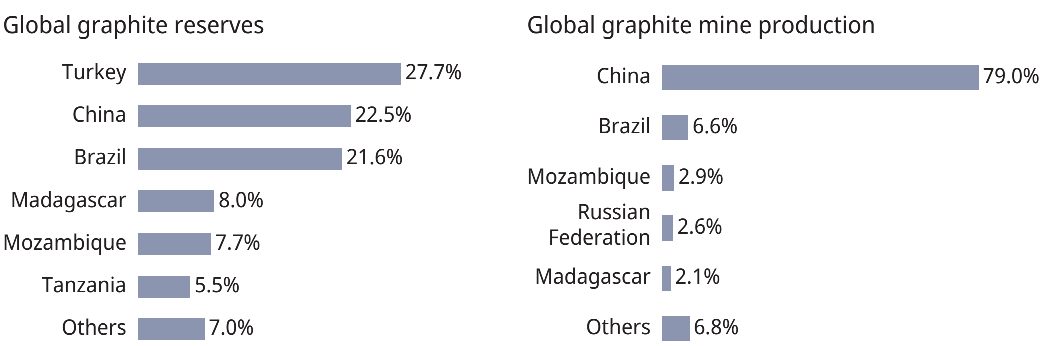
"Lead pencil" is a misnomer: pencils have never contained lead, but are instead made of graphite. Although the true composition of the so-called "lead" in pencils was identified and named graphite in the late 18th century (Uwaterloo, 2022), the term stuck.

The history of graphite dates back to the early 16th century, when an enormous deposit of pure, solid graphite was discovered in Borrowdale, England (Pencils, 2022). Locals used this coal-like mineral for marking sheepskin. When metallurgists encountered the substance, they mistook it for a type of black lead rather than a form of carbon, hence the origin of the term "lead pencil."

Graphite was named in 1789 from the Greek "graphein," meaning "to draw or write," stemming from its primary use in pencils (Uwaterloo, 2022). Graphite's first industrial application was not, however, for marking or writing. Rather, following its discovery, the English Government soon found it to be an excellent refractory material in the making of cannonball molds. The rounder and smoother cannonballs produced from such molds contributed to the English Navy's superiority at the time. Graphite use expanded in the 19th century to include in stove polish, lubricants, paints and foundry facings. But applications exploded in the 20th century, as production and purification methods improved.

However, although the industrial applications and demand for graphite are global, the natural material itself is found in only a few countries. According to the United States Geological Survey, Turkey, China, Brazil, Madagascar and Mozambique are the top five countries with natural graphite deposits (USGS, 2012–2022). Together, they constitute around 80 percent of global graphite reserves (Figure 1). China is the biggest producer of natural graphite. In 2020, that country produced about 80 percent of the world's graphite, followed by Brazil and Mozambique.

Figure 1. World graphite reserves and mine production.
Global graphite mine production is concentrated in just a few countries, because of the uneven geographical distribution of graphite reserves.



Source: United States Geological Survey, Mineral Commodity Summaries 2022.

This report provides an overview of the development of graphite-related technologies and how the material is being used in various industries. The overview is based on patent data, which represents an important and well-structured source of information on scientific and technological advancements, as well as being a lead indicator of commercial adoption.

In addition to patent data, the report also incorporates other information, such as country policies and market and business intelligence, in order to provide a multi-faceted, holistic assessment of today's graphite technologies. The report highlights patent examples to illustrate the current state-of-the-art and novel technological advancements.

Types of graphite

Naturally-occurring graphite is formed from carbon-rich organic matter subjected to a high-temperature, high-pressure geological environment for a long period of time. It can be classified into three categories according to degree of crystallinity: namely, amorphous, flake and vein graphite. In addition, there is graphite that has been artificially synthesized.

- **Amorphous graphite**, also called cryptocrystalline or microcrystalline graphite, consists of very fine graphite flakes. Amorphous graphite is the most abundant natural graphite, but occurs at the lowest grade.
- **Artificial graphite**, or synthetic graphite, is a man-made substance manufactured through the high-temperature processing of other carbon materials, such as petroleum coke. Artificial graphite is often purer than natural graphite, but more expensive, due to the large amount of energy consumed during the synthesis process.
- **Flake graphite** is often distributed in the form of isolated, flat crystalline flakes in metamorphic rocks. It is frequently the preferred form of natural graphite in industry and accounts for the majority of natural graphite production globally.
- **Vein graphite**, also known as lump graphite, occurs as veins between rocks. It has a needle-like macro morphology and often exhibits a very high degree of purity and crystallinity. However, vein graphite deposits are rare, such that Sri Lanka is the only country in the world that produces vein graphite in commercial quantities (Touret *et al*., 2018).

All natural graphite sources contain impurities. These include silica, alumina, other oxides and minerals. As a result, natural graphite ores, once mined, need to be put through a series of crushing, grinding, flotation and purification steps in order to produce raw graphite with a high degree of purity. Further processing transforms purified graphite into its various derivatives, such as graphite powder, expanded graphite, spherical graphite and so on. These graphite derivatives possess properties specifically required by specialized applications across industries.

The diverse range of industrial applications for graphite arise from its crystalline structure. As a form of the element carbon, graphite has a layered configuration wherein carbon atoms are arranged in a hexagonal or honeycomb lattice within each layer. Such a unique crystalline structure gives the material several unique properties, such as excellent electrical and thermal conductivity, plus good chemical stability and corrosion resistance.

Uses of graphite

Graphite is widely used in metallurgy, as well as the machinery, electrical, chemical, textile, national defense and other industrial sectors. One of the most important applications of graphite in recent years is as the anode material in lithium-ion batteries (LIBs), which have been increasingly used for energy storage across different industries, as global efforts to address climate change intensify.

The advent of nanotechnology has opened up an abundance of new opportunities for graphite, with graphite-based nanomaterials attracting attention worldwide. In particular, techniques like exfoliation make it possible for atomic layers of bulk graphite to be separated into sheets or platelets only a few nanometers thick. This results in nanosheets, nanoplatelets and single-layer graphite (also known as graphene). These are all new materials with extraordinary properties and great potential. Considered by many to be the new material of the 21st century, graphene in particular has attracted intense global interest for use in emerging fields, such as flexible wearables, superfast electronics, ultrasensitive sensors, multifunctional composites and more.

Global graphite demand is expected to increase significantly over the coming years, due to a rapid adoption of LIBs in the booming electric vehicle (EV) market and the power sector. Demand for graphite for use in EVs and battery storage is forecast to be somewhere between 10 and 30 times its current level by 2040 (IEA, 2022). Graphite's growing importance and its uneven distribution as a resource have raised global concerns. European countries, China and the United States, together with many other countries and international organizations, have listed graphite as either an essential non-metallic raw material or else a strategic key mineral (MNR, 2016; USDC, 2019; AUS, 2019). Besides placing a stronger emphasis on mining and trading policies, governments around the world are ramping up innovation in an effort to support industry in exploiting this critical material.

Structure of the report and methodology

This report examines the graphite-related patent landscape based on relevant patent applications filed from 2012 to 2021, whose publication information was available as of May 30, 2022 (see Annex A, Methodology, for further details). The patent search was conducted using the Orbit Intelligence patent database from Questel. It incorporated several search iterations using queries combining relevant keywords and patent classification codes (see Annex B, Patent searches, for further details). Specifically, the dataset covers primary graphite sources, including flake graphite, amorphous graphite, vein graphite and artificial graphite; major exfoliation techniques for processing graphite; specific graphite derivatives, such as graphite powder, graphite foil/sheet, expanded graphite, and various graphite products and industrial applications, ranging from conductive ink to battery and biomedical applications (Table 1).

Table 1. Scope of the report.

Main categories were first selected then related areas identified.

Main category	Specific area
Graphite source	Amorphous graphite
	Artificial graphite
	Flake graphite
	Vein graphite
Graphite processing	Chemical and mechanical exfoliation
	Electrochemical exfoliation
	Thermal exfoliation
	Ultrasonic exfoliation
Graphite derivatives	Expanded graphite
	Graphene
	Graphite composites/nanocomposites
	Graphite foil/sheet
	Graphite powder
	Micro/nanographite
	Spherical graphite
Graphite uses and applications	Aerospace
	Air purification
	Automotive
	Battery
	Biomedical
	Capacitor
	Carbon brush
	Carbon nanotubes
	Ceramics
	Coating
	Conductive element
	Conductive ink
	Fuel cell

Main category	Specific area
Graphite uses and applications (contd.)	Heat dissipation
	Heat exchange
	Heating element
	Lubrication
	Metal and alloys
	Packaging
	Polymer
	Railway and marine
	Sealing and gasket
	Sensor
	Solar cell
	Structural materials
	Textile
	Water treatment
	Wind power

Note: The taxonomy of the various categories and sub-categories was co-developed with input from subject-matter experts.

The report first looks at patenting activity according to the origin of inventions, so as to identify the top countries/regions for innovation in the graphite space and their respective areas of interest. How the various graphite sources, exfoliation methods and graphite derivatives have been explored in the last decade is then examined, focusing both on the evolution of related patenting activity over time and the filing activity of leading players in each area. The final part of the report applies a specific analysis technique, the Innovation Maturity Matrix, to provide a good overview of the relative maturity of various graphite uses and applications, before undertaking an in-depth analysis of selected graphite application areas.

InfoBox: What we do, what we count, how we count and why

Several general assumptions and methodologies remain constant throughout the analysis. Without specific mention in the text, the following broad definitions and measures have been applied:

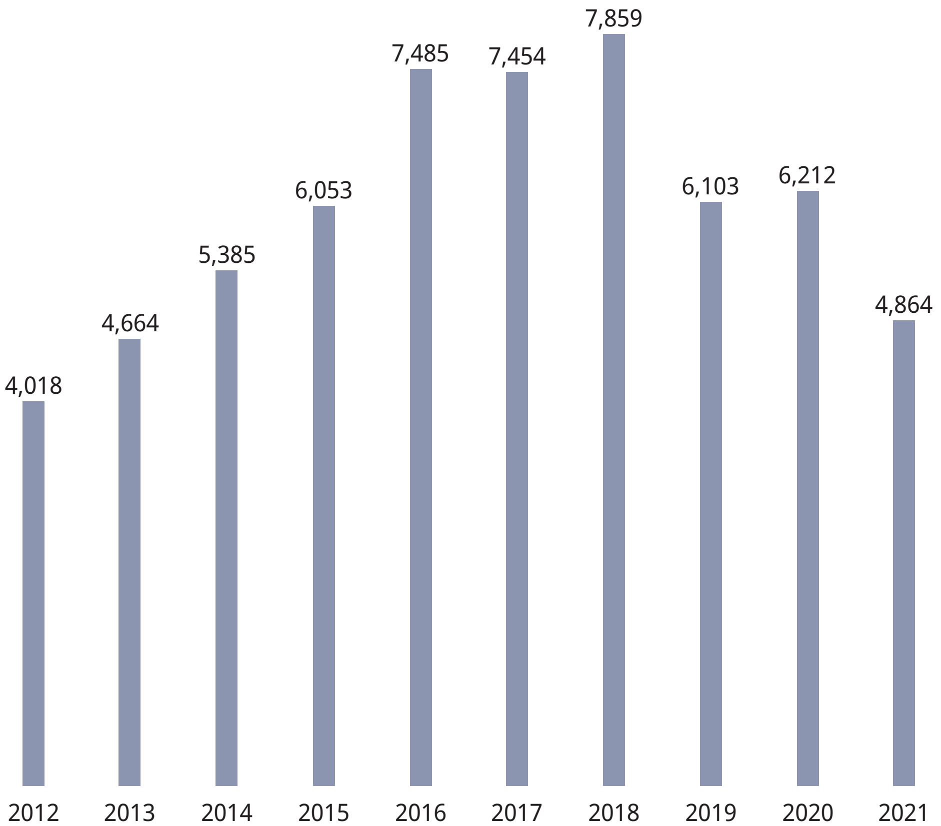
- The number of inventions is measured by counting unique patent families, using the FAMPAT patent families defined in Orbit Intelligence as a proxy. Analyses based on unique patent families more accurately reflect invention output; considering individual patent applications instead will inevitably involve double counting, as a patent family may contain several patent publications, if the applicant files the same invention for patent protection in multiple destinations. See Annex A, Methodology, for FAMPAT family construction rules.
- Most analyses refer to numbers of patent families (through a representative patent family member). In the report, the term “patent filings” is used interchangeably with the terms “patent documents,” “inventions” and “patent families.”
- Patent filings do not include utility models.
- Each patent family is counted only once, and the year in which the first member of a patent family was filed counts as the filing year.
- The country or region of origin of an invention is approximated by the earliest priority country, that is, the country where the first member of a patent family was filed. As a result, analysis of country or region of origin does not include patent families whose first members were filed through the Patent Cooperation Treaty (PCT) or with regional patent offices such as the European Patent Office. The omission of such patent families will have had minimal impact on the analysis, as they account for no more than about 1 percent of the overall dataset.

Global trends

Overall patenting trends

The widespread use of graphite has been brought about through relentless innovation efforts and technology breakthroughs worldwide. Globally, graphite-related innovation has resulted in sustained patent filing, with over 60,000 patent families filed between 2012–2021 (Figure 2). Such a large volume of graphite-related inventions underscores the importance of the material across multiple industries. In particular, graphite-related filings grew continuously from 2012 to 2018. Indeed, with a compound annual growth rate (CAGR) of 11.8 percent, the number of patent families almost doubled during that six-year period, from slightly over 4,000 in 2012 to nearly 8,000 inventions in 2018.

Figure 2. **Graphite-related patent families, by earliest priority year, 2012–2021.**
The high number of patent families filed globally indicates a strong interest in graphite-related innovation worldwide. The CAGR in global patenting between 2012 and 2018 was 11.8 percent.



Note: There is an average 18-month delay between patent filing and publication. 2019 was the last year for which complete data are available, as of May 30, 2022.

Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Interest in graphite is global. Patents were filed by applicants from over 60 countries and regions. Nevertheless, based on total patenting output, graphite-related patent families originated predominantly from just a few countries. Specifically, the top five countries of applicant origin – that is, the location of the applicant and where the invention took place – were China, Japan, the Republic of Korea, the United States and the Russian Federation. Together, they accounted for 95 percent of global patenting output.

China's strong dominance within the global graphite market is clearly reflected in its patenting activity. The world's second biggest economy recorded more than 47,000 patent families in the 10-year period from 2012 to 2021, accounting for four in every five graphite patent families filed worldwide in the last decade. As the single most important contributor, China largely determines the global patenting trend, exhibiting the same strong growth in patenting activity from 2012 to 2018 (Table 2). Chinese research institutions were also more active than their international counterparts, contributing to about 30 percent of graphite patent families in China, which is higher than the 21 percent contributed by the rest of the world (Figure 3).

However, the data also shows a decline in the number of patent families originating from China starting from 2019. This may be connected in part to changes in national policies regarding graphite mining and exploitation, alongside incomplete patent data owing to the average 18-month delay between patent filing and publication. In 2016, crystalline graphite was listed as a strategic mineral in China and mining control and exploitation tightened (MNR, 2016). The Beijing Government later tightened environmental regulations in 2018 (STA, 2018), which, in turn, has placed further restrictions on its domestic mining industry. Consequently, China's annual graphite mine production decreased from 780–800 thousand metric tonnes between 2012–2016 to under 700 thousand tonnes in 2018 and 2019.

In contrast, annual rates of patent families originating from the other top five locations, namely, Japan, the Republic of Korea, the United States and the Russian Federation, remained relatively consistent throughout the surveyed period. Brazil – the second largest graphite producer globally – had over 100 patent filings in the field, though this South American country is just outside the top 10 locations of applicant origin behind France.

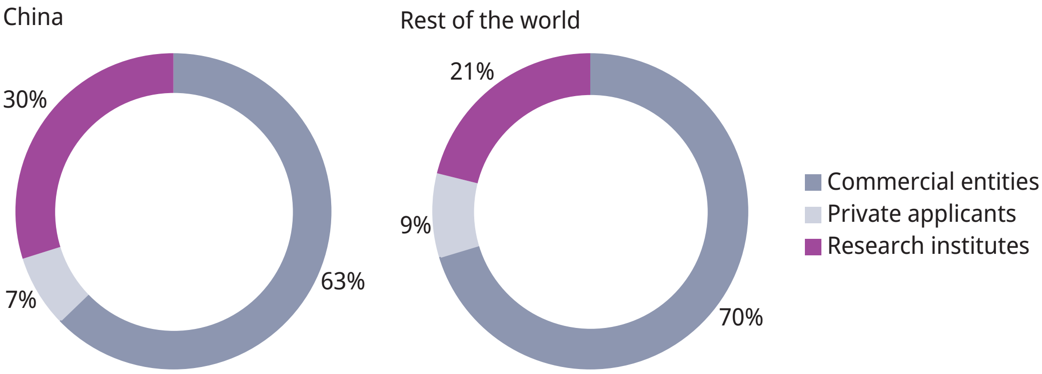
Notably, the majority of graphite patent families originating from China were filed in China alone, with less than 2 percent seeking protection abroad. This shows Chinese applicants focusing strongly on their domestic market. On the other hand, about 35 percent of graphite patent families originating from outside China sought to extend protection beyond their home market. Overall, the number of patent co-applications (patent applications filed by two or more applicants) was minimal for both China and the rest of the world, indicating a low level of collaboration in patenting globally.

Table 2. Patent filing trends for the top 10 origins.
China showed strong patenting growth between 2012–2018, whereas patenting activity by other top origins Japan, the Republic of Korea, the United States and the Russian Federation remained relatively consistent.

Origin	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
China	2,666	3,194	3,951	4,571	6,036	6,123	6,544	4,849	5,079	4,509	47,522
Japan	368	476	447	481	417	404	365	333	265	70	3,626
Republic of Korea	352	323	337	349	347	262	331	296	270	68	2,935
United States	79	193	195	205	178	214	187	185	154	74	1,664
Russian Federation	165	139	134	137	144	117	139	140	146	54	1,315
Germany	113	66	71	49	48	48	36	32	37	5	505
Taiwan Province of China	68	66	48	61	50	42	29	32	39	5	440
India	21	32	27	23	32	34	31	49	35	28	312
UK	19	25	32	24	18	32	26	32	16	2	226
France	31	17	15	14	18	10	12	13	8		138

Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Figure 3. **Applicant profiles for China and the rest of the world.**
Chinese research institutions were more active in patenting graphite-related inventions than their international counterparts and have contributed to a larger proportion of graphite inventions.



Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Regional specialization

To provide further insights into graphite-related patenting activity, this report examines a location's innovation specialization across various specific areas. This is done by using an index measuring the proportion of patent families in a specific area divided by the total number of patent families originating from that location (Table 3). A high specialization index score indicates a stronger emphasis on the area concerned. Therefore the related patenting accounts for a significant proportion of a region's overall number of patent families.

Graphite sources

Among the top five origins of graphite-related patent families, China tends to favor flake graphite mined from natural graphite reserves, since it possesses the second largest reserve of natural graphite in the world. A high specialization index of 10.4 percent indicates that one in every 10 patent families from China mentions flake graphite use (see Table 3). On the other hand, despite being the top importer of natural graphite (OEC, 2020), the Republic of Korea places a far greater emphasis on artificial graphite, probably to exploit its superior purity and the tailored quality of synthesized graphite. The United States adopts a balanced approach, placing equal emphasis on flake and artificial graphite.

Processing graphite

Given the long history of graphite exploitation, many conventional processing steps, such as crushing, grinding and purification, are well-established. This report therefore focuses instead on exfoliation, the process of separating carbon layers within graphite. This is a key step in the production of thin graphite nanosheets, including graphene, which consist of a single layer of carbon atoms. Broadly, there are five approaches – mechanical, ultrasonic, thermal, chemical and electrochemical exfoliation. The first relies on mechanical means to physically peel off a sheet of graphite from bulk graphite. In ultrasonic exfoliation, as the name suggests, graphite nanosheets are produced from graphite flakes or particles with the aid of ultrasonic waves that pass through the graphite suspension to separate the layers. Thermal exfoliation involves rapid heating of pre-treated graphite, whereas chemical exfoliation uses strong oxidants and concentrated acids to oxidize the graphite. Lastly, in electrochemical exfoliation, an applied voltage forces ions to intercalate into graphite and form gaseous species that expand and exfoliate individual graphene layers.

Overall, thermal exfoliation has been the preferred method and ranks among the top two exfoliation approaches favored by the top five origins (see Table 3). Specifically, it is the most common method for bulk graphite processing in the Republic of Korea and the United States, though it loses out to its ultrasonic counterpart in China. The United States also places a strong emphasis on both the chemical and mechanical exfoliation techniques.

Graphite derivatives, uses and applications

Graphite derivatives are processed graphite materials with a higher degree of purity and specific properties tailored for specialized applications. Common derivatives are graphite powder, graphite foil/sheet, micro/nanographite and graphite composites. Other specific forms include:

- expanded graphite, which can expand to several hundred times its initial volume under heat;
- spherical graphite – also known as battery-grade graphite – which is used as an anode in batteries; and
- graphene, which is single-layer graphite.

Global patenting activity reveals a diverse patenting focus in the production and subsequent exploitation of graphite derivatives. Graphite powder, for example, represents a significantly larger proportion (22.4 percent) of patent families from China, indicating that it has been essential for graphite products and applications in that country. On the other hand, the United States has exhibited a keen interest in synthesizing graphene from graphite and exploiting such graphite derivatives for different applications, with about one-third of its graphite inventions relating to this area. The Republic of Korea's innovation specialization does not differ significantly from that of the rest of the world; though interestingly, its specialization index is marginally higher across all graphite derivatives in comparison.

From a use and application perspective, this report covers 28 specific areas across different industries. Currently, batteries stands out as the most significant application worldwide. This is particularly the case in Japan, where one in every three patent families filed domestically relates to batteries. Polymers and ceramics are two other major areas where graphite is used and applied globally. In contrast, the majority of other uses and applications for graphite account for a much smaller proportion of patent families, except for a few country-specific cases. For example, graphite use in metal and alloys represents an important area for the Russian Federation, where it constitutes a substantial portion (17.3 percent) of patent families, whereas in the United States biomedical applications have received greater interest than in the rest of the world.

Table 3. **Regional specialization in graphite-related inventions.**
The number refers to a region's specialization index, measured by the proportion of patent families in a specific area divided by the total number of patent families originating from that location. The color key is applied in contrast to the mean value of the rest of the world (RoW), excluding China. A global mean is not used as a reference, because it would largely resemble that of China, given the significantly higher number of patent families recorded by that country.

		China (%)	Japan (%)	Republic of Korea (%)	US (%)	Russian Federation (%)	RoW mean (%)
Graphite source	Amorphous graphite	0.8	3.3	2.5	2.7	0.8	2.6
	Artificial graphite	5.1	4.5	11.2	10.7	2.7	7.4
	Flake graphite	10.0	7.0	4.8	10.9	1.1	6.4
	Vein graphite	0.0	0.1	0.2	0.2	0.0	0.1
Graphite processing	Chemical and mechanical exfoliation	1.9	1.0	2.0	6.0	1.9	2.6
	Electrochemical exfoliation	0.5	0.1	0.4	1.1	0.6	0.8
	Thermal exfoliation	4.1	2.7	8.5	7.3	1.7	5.0
	Ultrasonic exfoliation	8.5	0.6	4.0	1.3	0.1	1.8
Graphite derivatives	Expanded graphite	9.2	11.5	15.0	12.8	6.1	11.5
	Graphene	16.3	8.2	22.0	34.7	4.0	19.1
	Graphite composites	5.1	4.9	6.1	6.8	7.3	5.9
	Graphite foil/sheet	5.9	12.5	11.3	11.2	2.0	10.1
	Graphite powder	22.4	7.3	11.9	7.2	8.2	8.9
	Micro/nanographite	6.8	2.1	7.7	10.9	2.0	6.4
	Spherical graphite	3.6	6.7	5.1	1.6	2.6	4.4

		China (%)	Japan (%)	Republic of Korea (%)	US (%)	Russian Federation (%)	RoW mean (%)
Graphite products and applications	Aerospace	0.1	0.1	0.0	1.8	0.2	0.5
	Air purification	0.1	0.0	0.0	0.1	0.0	0.0
	Automotive	0.5	3.4	1.4	3.4	3.3	2.8
	Battery	12.3	33.0	21.6	18.8	2.1	20.6
	Biomedical	0.6	0.9	1.0	3.0	1.9	1.6
	Capacitor	2.2	2.0	2.5	6.0	1.4	3.1
	Carbon brush	0.5	0.3	0.2	0.1	1.1	0.4
	Carbon nanotubes	2.9	3.5	8.0	8.4	2.1	5.3
	Ceramics	10.4	7.0	9.0	12.1	6.8	8.6
	Coating	5.4	3.0	5.8	5.6	2.4	4.6
	Conductive element	6.3	8.8	8.4	12.3	2.4	8.4
	Conductive ink	0.2	0.2	0.3	1.0	0.1	0.5
	Fuel cell	1.7	4.0	4.3	4.4	0.7	3.7
	Heat dissipation	2.2	9.1	11.3	8.7	0.3	7.4
	Heat exchange	1.2	1.7	1.1	4.9	0.6	2.3
	Heating element	1.9	1.8	3.5	1.5	1.8	2.3
	Lubrication	6.1	4.7	1.5	3.4	8.1	4.2
	Metal and alloys	10.0	8.3	4.4	5.8	17.3	8.0
	Packaging	0.3	0.2	0.7	0.9	0.0	0.4
	Polymer	14.0	14.5	14.0	14.2	3.4	12.7
	Railway and marine	0.1	0.1	0.1	0.1	1.5	0.3
	Sealing and gasket	1.9	2.2	0.7	2.1	3.3	1.7
	Sensor	1.7	0.7	0.9	3.2	3.3	1.9
	Solar cell	0.8	0.3	1.6	1.4	0.3	1.0
	Structural materials	0.7	0.0	0.1	0.7	2.7	0.5
	Textile	1.9	1.4	2.5	3.8	1.8	2.3
	Water treatment	1.2	0.3	1.0	0.4	1.0	0.7
	Wind power	0.2	0.0	0.0	0.1	0.0	0.2

[Purple] Higher than the RoW mean.

[Gray] Lower than the RoW mean.

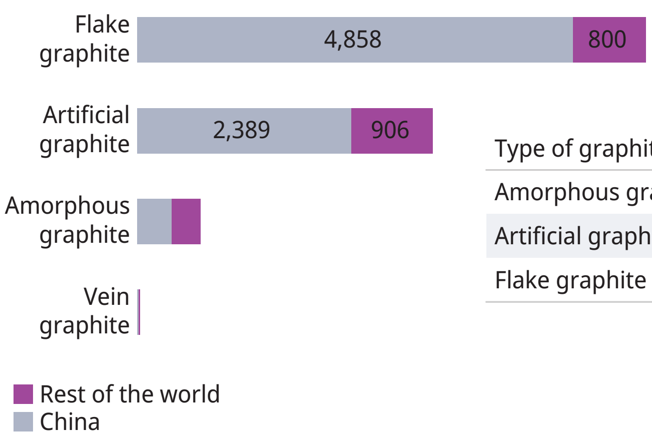
Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Graphite sources, processes and derivatives

Graphite sources

Among graphite sources, flake graphite has the highest number of patent families, with more than 5,600 worldwide (Figures 4 and 5). It has strong traction, particularly in China, with a CAGR of 10 percent. Artificial graphite ranks second with about 3,300 patents worldwide. It is the preferred graphite source in the rest of the world and the only graphite source where the rest of the world shows positive growth, albeit at a low CAGR of 2 percent. In contrast, amorphous and vein graphite have a far smaller number of patent families. Vein graphite, in particular, has recorded only 34 patent families in the last 10 years worldwide. Such a small number of patent filings in vein graphite could be down to its scarcity as a natural resource. This report therefore focuses only on an analysis of flake and artificial graphite.

Figure 4. **Distribution of graphite-related patent families by source type.**
Flake graphite is the most explored graphite source globally, but interest in artificial graphite is growing.



Type of graphite	CAGR China	CAGR RoW
Amorphous graphite	12%	–2%
Artificial graphite	9%	2%
Flake graphite	10%	–2%

Note: CAGR is the compound annual growth rate. Numbers denote the volume of patents published from 2012 to 2021. CAGR is calculated between 2012–2019, as 2019 is the latest year for which patent data was complete. CAGR for vein graphite is not calculated, because of the small number of patent families.

Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Flake graphite

Flake graphite is a common source for various graphite-based derivatives, for example, graphite powder and graphene. It is also used in a range of applications, from pencils to medical dressings, and is an essential raw material for the refractory industry and in dry lubricants.

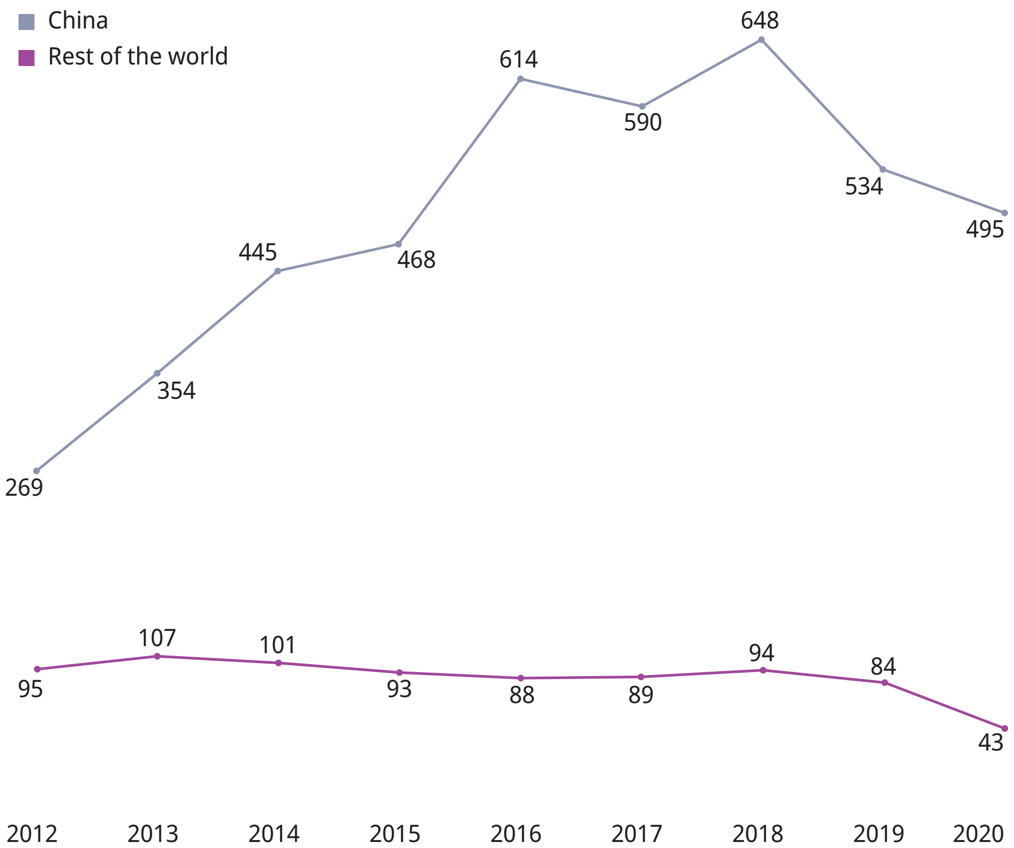
One of the critical uses of flake graphite relates to the manufacture of spherical graphite: that is, where flake graphite concentrate is processed into "rounded" particles of a purity typically greater than 99.95 percent and whose size ranges from 10 to 25 microns (a human hair is about 70 microns in diameter). Ultra-pure spherical graphite is considered battery-grade and a key component in making the anode used in lithium-ion batteries.

China is the primary supplier of flake graphite to the global market. According to USGS data, in 2021, China produced an estimated 79 percent of the total world graphite output, 76 percent of which was flake graphite (USGS, 2022). China is also the most active exploiter of flake graphite. It has dominated patenting activity related to the use of flake graphite and contributed 85 percent of global patent filings in this area from 2012 to 2021 (see Figure 5). Patent families originating from China showed strong growth from 2012 to 2018. Even when there were noticeable declines in 2019 and 2020 – probably owing to an overall slowdown in natural graphite production when the country tightened its environmental and mining policies, as discussed earlier – China's annual patenting output continued to remain significantly higher than the combined total for the rest of the world.

Top applicants in China comprise a balanced mix of commercial entities and research institutions, including the country's leading material suppliers Chengdu New Keli Chemical Science and the Chinese Academy of Sciences, China's national academy for natural sciences (Table 4). In contrast, active patent filers from the rest of the world were predominantly commercial entities.

In addition to the manufacture of various graphite derivatives, such as graphite powder, expanded graphite, graphite composites and graphene, flake graphite has been explored for a broad range of applications. They include lubrication, sealing gaskets, ceramic composites, conductive structures, refractories, battery anode materials and water treatment. Using flake graphite for making graphene and battery anode materials, in particular, constitutes an important research area actively explored by Chinese universities, as well as the Global Graphene Group and LG Chem.

Figure 5. Patent filing trend in flake graphite, 2012–2020.
Patent families originating from China showed strong growth from 2012 to 2018, and have remained significantly higher than the rest of the world combined, despite noticeable declines in 2019 and 2020.



Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Table 4. **Top applicants in the area of flake graphite, China and the rest of the world.** *Flake graphite's diverse applications have attracted strong interest from research institutions and commercial entities worldwide.*

China		Rest of the world	
Chinese Academy of Sciences	154	Global Graphene Group	69
Chengdu New Keli Chemical Science	66	Sekisui Chemical	58
Central South University	45	LG Chem	25
Wuhan University of Science and Technology	40	Kyungpook National University	14
Beijing University of Chemical Technology	35	Showa Denko	14
Jiangyin Carbon Valley Technology	32	Mitsubishi Chemical	12
Harbin Institute of Technology	30	Sumitomo Electric Industries	12
Datong Xincheng New Materials	29	GS Yuasa	11
Sinopec	29	National Chung-Shan Institute of Science and Technology	10
Jiangsu Sidike New Materials Science and Technology	29	POSCO	10

Source: WIPO, based on patent data from Questel Orbit up to May 2022.

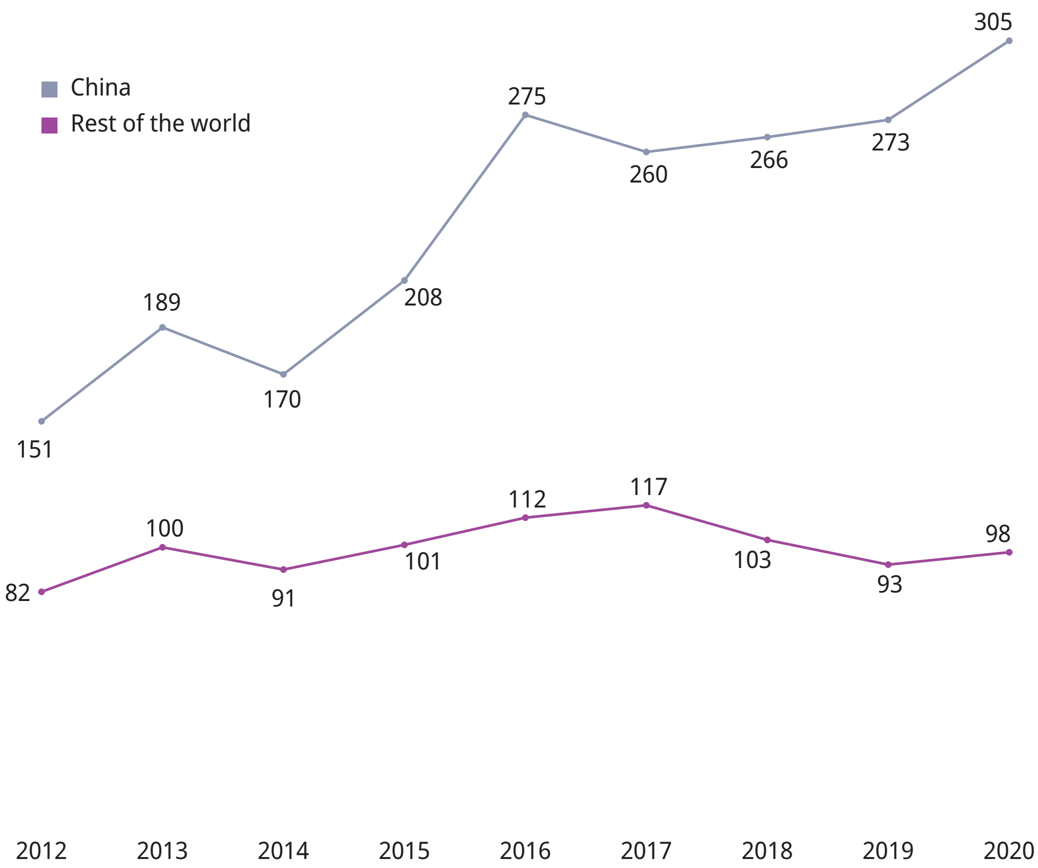
Artificial graphite

Unlike natural graphite, the availability of which is dependent upon the geographical distribution of mine reserves, artificial graphite can be synthesized anywhere in the world from a wide range of carbon sources. Moreover, due to controlled precursors and processes, artificial graphite has a high degree of purity and possesses tailored properties ideal for a wide range of applications. The current mainstream use of artificial graphite is in the metallurgy industry for making refractory materials and crucibles (Mordor Intelligence, 2022). However, battery applications in EVs are a new key driver of both the market and of innovation, as artificial graphite is the preferred anode material in EV batteries for a fast-charge turnaround and a long life cycle (Innovation News Network, 2022).

Innovation exploring new methods of syntheses and uses for artificial graphite are gaining traction worldwide. Interest from China is particularly fast-growing (Figure 6). Despite being home to the second largest reserves of natural graphite, China has been ramping up its synthetic graphite innovation capacity, evident from its high CAGR of 8.8 percent in related patent families. In comparison, patent filings from the rest of the world have grown at a steady but slower pace. Leading countries were Japan, the United States and the Republic of Korea. Their strong interest in artificial graphite could be driven by the lack of a natural graphite reserve, as well as the superior qualities associated with this material.

Commercial entities have played a far more active role (Table 5), with patenting interest focused on battery anode applications. It is notable that the top Chinese commercial companies in this area – Shanshan Technology, BTR New Material, A123 Systems, Hefei Guoxuan High-Tech Power Energy, Contemporary Amperex Technology (CATL) and Guangdong Dongdao New Energy – are either leading battery manufacturers or anode material suppliers. Similarly, nearly all the synthetic graphite-related patent families from the top applicants in the rest of the world focus on battery anodes, although they are from different business backgrounds and include multinational conglomerates operating a broad segment of businesses, such as LG Chem, Samsung and Mitsubishi, as well as steel-maker POSCO and chemical companies Showa Denko and SK Innovation.

Figure 6. Patent filing trend in artificial graphite, 2012–2020.
Despite being home to the second largest reserve of natural graphite, China has been actively exploring artificial graphite.



Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Table 5. Top applicants in artificial graphite, China and the rest of the world.
Top players were primarily either battery anode suppliers or battery-makers. Research is focused on using artificial graphite for battery anode applications.

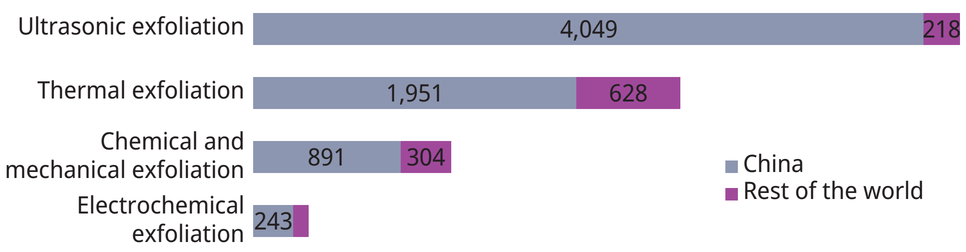
China		Rest of the world	
Shanshan Technology	67	LG Chem	110
Chinese Academy of Sciences	47	Global Graphene Group	84
BTR New Material	33	Samsung Electronics	25
Dongguan Kaijin New Energy	31	POSCO	24
Padnic Thermal Conductive Material	30	Showa Denko	21
A123 Systems	24	SK Innovation	19
Central South University	23	Research Institute of Industrial Science and Technology, Korea	17
Hefei Guoxuan High-Tech Power Energy	23	Mitsubishi Chemical	12
CATL	21	Imertech	11
Guangdong Dongdao New Energy	16	SGL Carbon	11

Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Processing graphite

Based on patent families related to graphite processing, ultrasonic exfoliation is the most basic step commonly utilized by industry (Figure 7). A particularly strong interest is seen in China, which has contributed over 95 percent of global patenting output in this area. Thermal exfoliation ranks second, and chemical/mechanical ranks third, but with a far smaller number of patent families. Compared to ultrasonic exfoliation, these latter two approaches have attracted a more balanced contribution from China and the rest of the world. Electrochemical exfoliation has attracted the least interest, with a far smaller number of patent families. This report focuses only on ultrasonic and thermal exfoliation, given their significantly greater traction worldwide.

Figure 7. **Worldwide patent filing in graphite processes.**
Strong interest in ultrasonic exfoliation is observed in China, but thermal exfoliation is drawing more attention from the rest of the world.



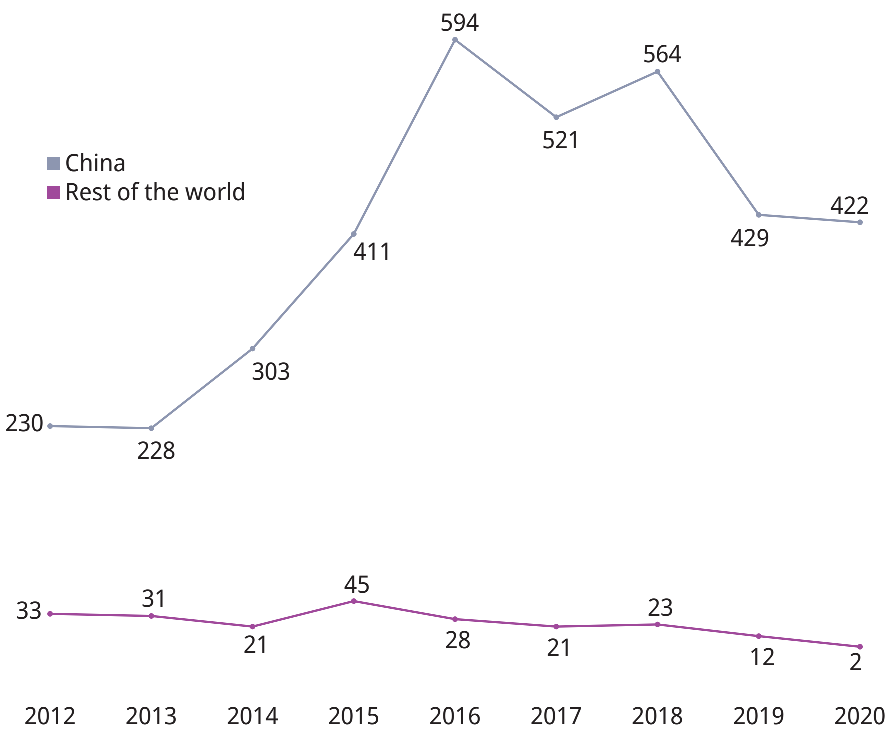
Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Ultrasonic exfoliation

While China dominates patent filings relating to ultrasonic exfoliation, interest in the technique has declined in recent years after an initial exponential growth in 2012–2016 (Figure 8). Chinese research institutions (Table 6), in particular, have thoroughly explored this low-cost technique as an essential step in processing bulk graphite into graphite nanomaterials. For example, two-thirds of patent families related to ultrasonic exfoliation filed by the Chinese Academy of Sciences – the top applicant in China – relate to graphene production.

Patent filings related to ultrasonic exfoliation from the rest of the world were low and have decreased over time. The Republic of Korea is the most active patent filer outside China; six of the top 10 applicants outside China were universities and research institutions in the Republic of Korea. Like their academic counterparts in China, they use ultrasonication mainly for producing graphite nanomaterials, particularly graphene.

Figure 8. **Patent filing trend in ultrasonic exfoliation, 2012–2020.**
Declining interest in ultrasonic exfoliation worldwide indicates that the technique is well-explored.



Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Table 6. **Top applicants in ultrasonic exfoliation, China and the rest of the world.**
Ultrasonic exfoliation is a popular, low-cost technique used by research institutions for processing bulk graphite into graphite nanomaterials.

China		Rest of the world	
Chinese Academy of Sciences	120	Korea Institute of Ceramic Engineering and Technology	10
Harbin Institute of Technology	62	Global Graphene Group	8
Oceans King Lighting	61	Korea Advanced Institute of Science and Technology	6
Shandong University of Technology	54	Arcelormittal	5
South China University of Technology	44	Dong Eui University	5
Central South University	42	Inha Industry Partnership Institute	5
Nanjing University of Science and Technology	35	Kyungpook National University	5
Beijing University of Chemical Technology	33	Sekisui Chemical	5
Jiangsu University	33	Korea Institute of Energy Research	4
Tianjin University	32	POSCO	4

Source: WIPO, based on patent data from Questel Orbit up to May 2022.

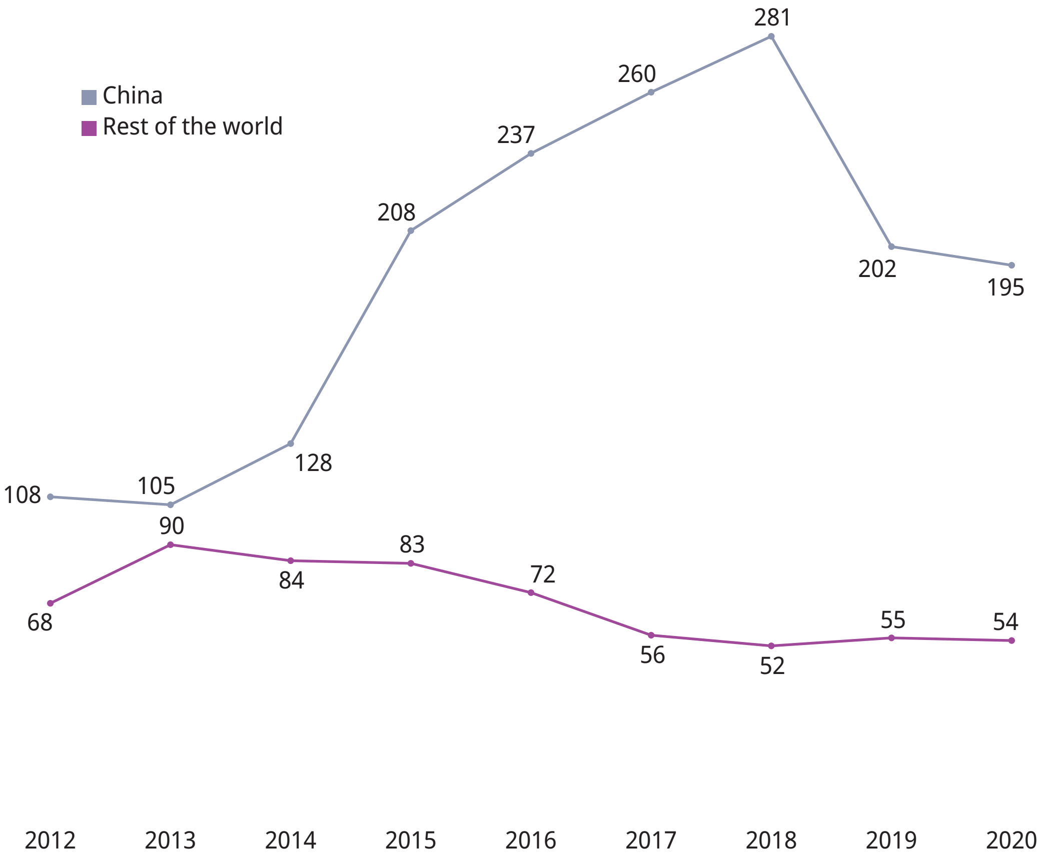
Thermal exfoliation

Thermal exfoliation is another well-explored technique. It offers high throughput, with exfoliation occurring within seconds at high-temperature processing. Furthermore, most thermal exfoliation methods produce graphene in a gaseous environment without the need for a liquid solvent.

Thermal exfoliation is a more recent technique than its ultrasonic counterpart. Patent families originating from China peaked only in 2018, two years after ultrasonic exfoliation reached peak patenting activity in 2016 (Figure 9). There has also been stronger interest from the rest of the world, with a higher number of related patent families recorded than for ultrasonic exfoliation.

Compared to ultrasonic exfoliation, this fast and solvent-free thermal approach has also attracted more interest from commercial entities. Among the top Chinese applicants were Oceans King Lighting, a lighting specialist that has invested heavily in graphene research, and two established graphite manufacturers – Datong Xincheng New Materials and Hunan Guosheng Graphite Technology (Table 7). Datong Xincheng New Materials is located in Shanxi Province, home to one of China's biggest reserves of flake graphite (Guo *et al.*, 2018). Founded in 2007, the company manufactures basic graphite materials such as graphite powders and blocks, as well as advanced products such as graphitic electrodes. It has amassed a substantial portfolio of 21 patent families relating to thermal exfoliation for graphene production. Similarly, the top applicants from the rest of the world show a strong presence of commercial entities. With 55 patent families, Global Graphene Group is the top player outside China. As a leading manufacturer of graphene and graphene-based products, this US-based company focuses strongly on thermal exfoliation for graphene production.

Figure 9. **Patent filing trend in thermal exfoliation, by earliest priority year, 2012–2020.**
Thermal exfoliation is a more recent technique; related patent families originating from China peaked as recently as 2018, two years after ultrasonic exfoliation had reached peak patenting activity in 2016.



Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Table 7. **Top applicants in thermal exfoliation, China and the rest of the world.**
Compared to ultrasonic exfoliation, thermal exfoliation has attracted more patenting interest from commercial entities.

China		Rest of the world	
Chinese Academy of Sciences	67	Global Graphene Group	55
Oceans King Lighting	33	University of Seoul	13
Tsinghua University	28	Korea Advanced Institute of Science and Technology	11
Datong Xincheng New Materials	21	National Chung-Shan Institute of Science and Technology	10
South China University of Technology	21	NEC	10
Shanghai Jiao Tong University	18	POSCO	9
Central South University	17	Showa Denko	9
Hunan Guosheng Graphite Technology	15	Kaneka	8
Beijing University of Chemical Technology	15	Korea Institute of Science and Technology	8
Zhejiang University	13	Sekisui Chemical	8

Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Graphite derivatives

Graphite powder is the most common form of processed graphite among graphite derivatives and can be produced from either natural or artificial graphite. It has diverse applications, including as a dry lubricant, a polymer additive, a coating material or a pigment. With such a wide range of commercial applications, it is not surprising that graphite powder accounted for the highest number of patent families filed in the last decade, with more than 10,000 originating from China and 1,100 from the rest of the world (Figure 10).

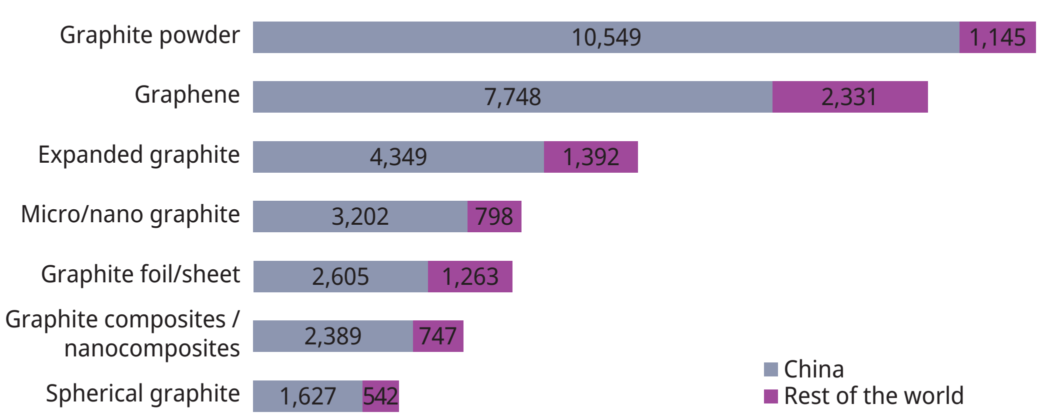
Using graphite to manufacture graphene has drawn strong innovation interest. Notably, it is the best explored graphite derivative outside China, with over 2,300 patent families, significantly higher than any other graphite derivative. However, despite the large volume of patent families, patenting activity in the rest of the world exploring graphite for graphene synthesis has declined substantially in recent years (Figure 11).

Note: because this report focuses on graphite, the graphene data included does not give a complete picture of global graphene invention, as it does not encompass graphene synthesized from non-graphite sources nor graphene applications. In addition, the report does not include an in-depth analysis of graphene, although it is a popular graphite derivative, graphene technologies having been extensively covered in several patent landscape reports published by organizations other than WIPO (IPOS International, 2021; Patseer Pro, 2017; UKIPO, 2015).

Expanded graphite, as its name suggests, can expand to several hundred times its initial volume under heat and thus function as a sealing material for fire control. In addition, its porous structure makes it a promising adsorbent, especially for organic compounds such as oils, and thus an ideal candidate for water treatment. Having other applications in the electrical and chemical industries, expanded graphite has gathered substantial interest and registered a combined global total of more than 5,700 patent families within the last 10 years.

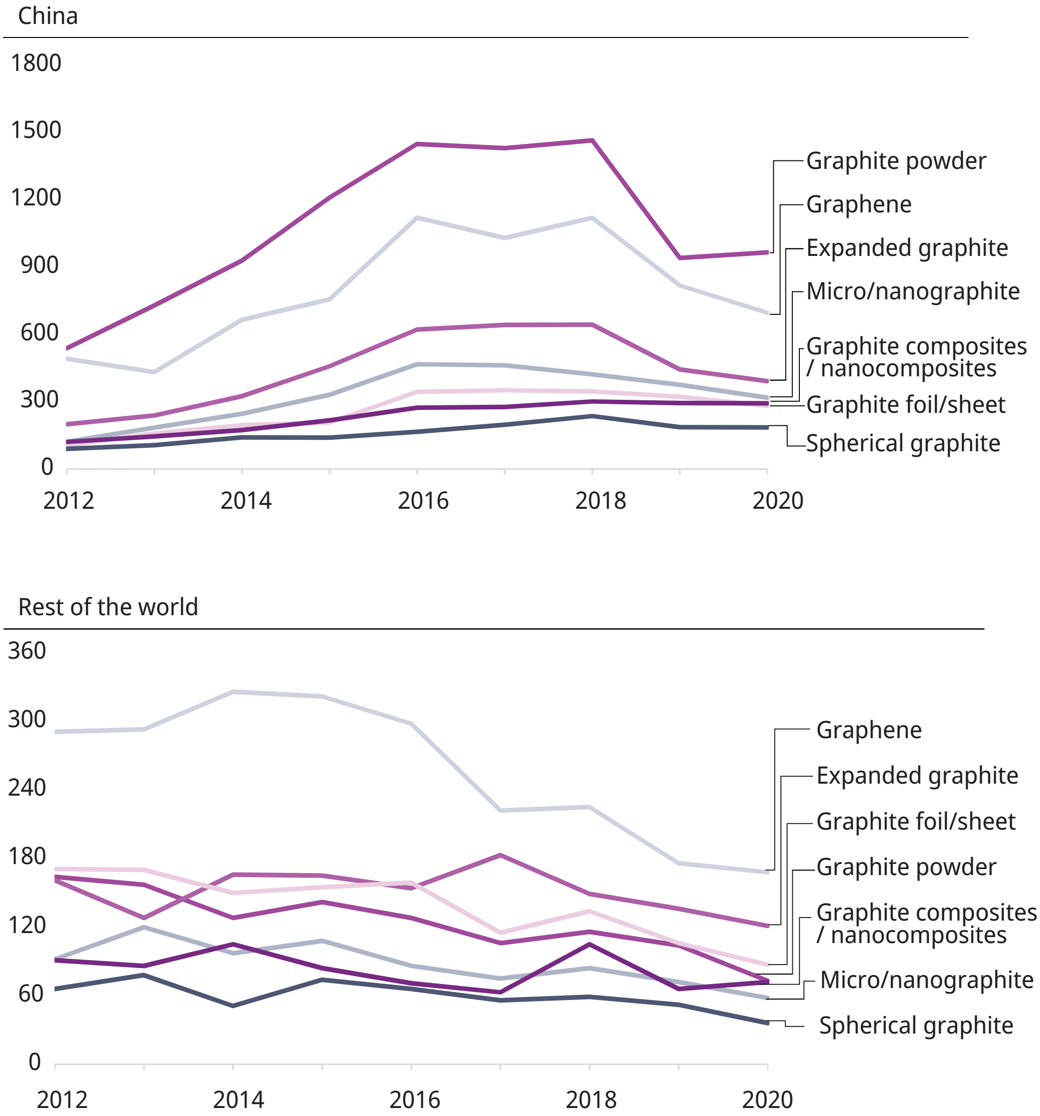
Similarly, about 3,000–4,000 patent families were filed globally for micro and nanographite, graphite foils and sheets, and graphite composites and nanocomposites. Among the different graphite derivatives, spherical graphite is the one that has attracted least interest, with just over 2,100 patent families.

Figure 10. **Distribution of patent families by graphite derivative type.**
Graphite powder, graphene and expanded graphite were the three best-explored graphite derivatives.



Source: WIPO, based on patent data from Questel Orbit up to May 2022.

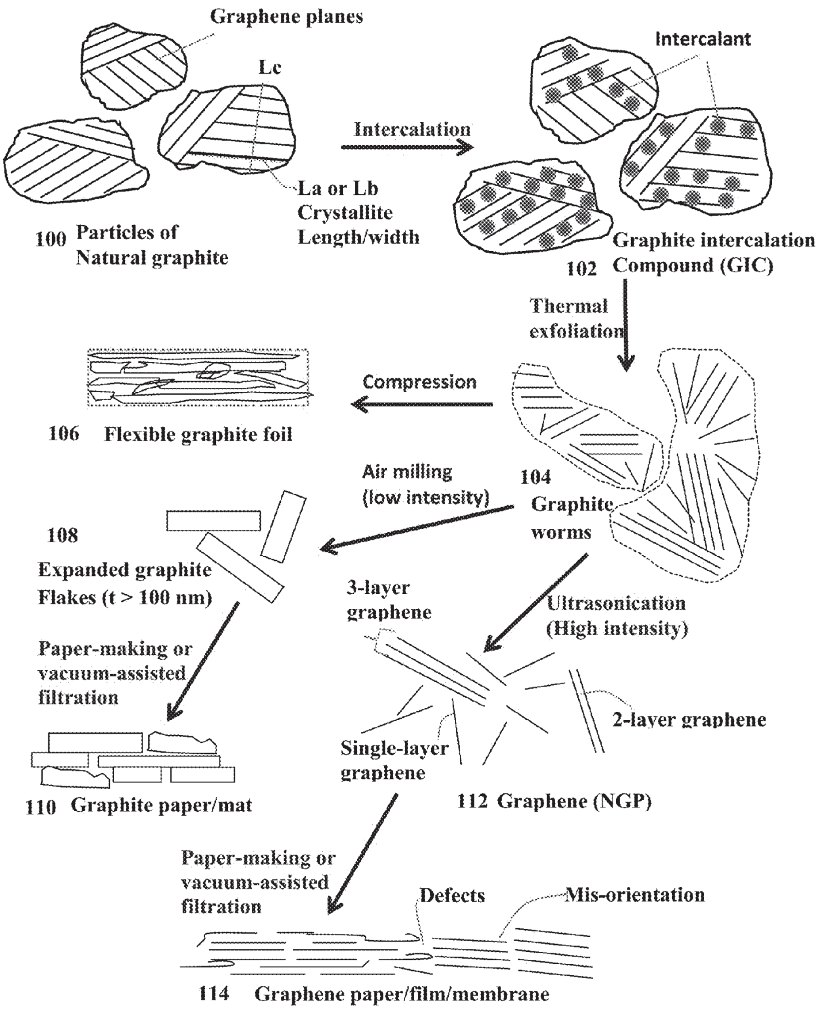
Figure 11. **Worldwide filing trend in graphite derivatives, China and the rest of the world, 2012–2020.**
Using graphite for the manufacture of graphene has drawn strong patenting interest worldwide; China has focused strongly on the synthesis and exploitation of graphite powder.



Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Figure 12. **An example of processing methods to obtain graphene derivatives.**
Processing methods for use by the Global Graphene Group for obtaining different graphene derivatives from natural graphite particles (US2018/0135200A1).

Figure 12 shows an example of different processing methods used to obtain various graphene derivatives from graphite.



Source: Patent application US2018/0135200A1.

Natural graphite particles are first immersed in a strong acid and/or an oxidizing agent, for example, a mixture of sulfuric acid, nitric acid and another oxidizing agent (e.g., potassium permanganate or sodium chlorate). The resulting graphite intercalation compound is actually graphite oxide particles, which are then repeatedly washed and rinsed in water to remove excess acids, resulting in a graphite oxide suspension or dispersion. Water is then removed from the suspension to obtain "expandable graphite," followed by a thermal exfoliation step that exposes the expandable graphite to a temperature in the range typically of 800–1,050°C. The rapid thermal expansion results in graphite worms – exfoliated graphite or networks of interconnected/non-separated graphite flakes. These graphite worms can be re-compressed to obtain flexible graphite sheets or foils that typically have a thickness in the range of 0.125 mm. One may also choose to use a low-intensity air mill or shearing machine to break up the graphite worms to produce so-called "expanded graphite flakes," which contain mostly graphite flakes or platelets thicker than 100 nm. The graphite worms may be subjected to ultrasonication to form separated, isolated or discrete graphene oxide sheets, which can then be chemically or thermally reduced to obtain reduced graphene oxides. These single-layer graphene oxide and multi-layer graphene oxide sheets are often collectively called nanographene platelets. They can be packed into a film or paper sheet of non-woven aggregates for further processing.

Graphite powder

The diversity of applications for graphite powder has attracted strong interest from research institutions and commercial entities worldwide. In addition to China, countries such as the Republic of Korea, Japan, the Russian Federation and the United States have recorded a sizeable number of patent families (Annex Table C1).

The top applicant in China is graphite manufacturer Datong Xincheng New Materials (Table 8). Its inventions relate to a wide range of graphite powder applications that includes carbon brushes, carbon–copper composite pantograph slide plates, expanded graphite and others. Graphite powder has also been widely explored as a starting material for producing graphene by several renowned Chinese universities and research institutions, including the Chinese Academy of Sciences, Harbin Institute of Technology and Tsinghua University.

Japanese companies were the leading innovators apart from China and occupy seven of the top 10 positions. Showa Denko tops the list with 18 patent families. Its carbon division is one of the world's largest suppliers of ultra-high-powered graphite electrodes, and the majority of its patents in graphite powder relate to electrode preparation.

It is notable that the Pacific National University, one of the biggest higher education institutions in the far east of the Russian Federation, also has a substantial patent portfolio in this field, focusing on graphite powder applications in refractory materials and lubricants.

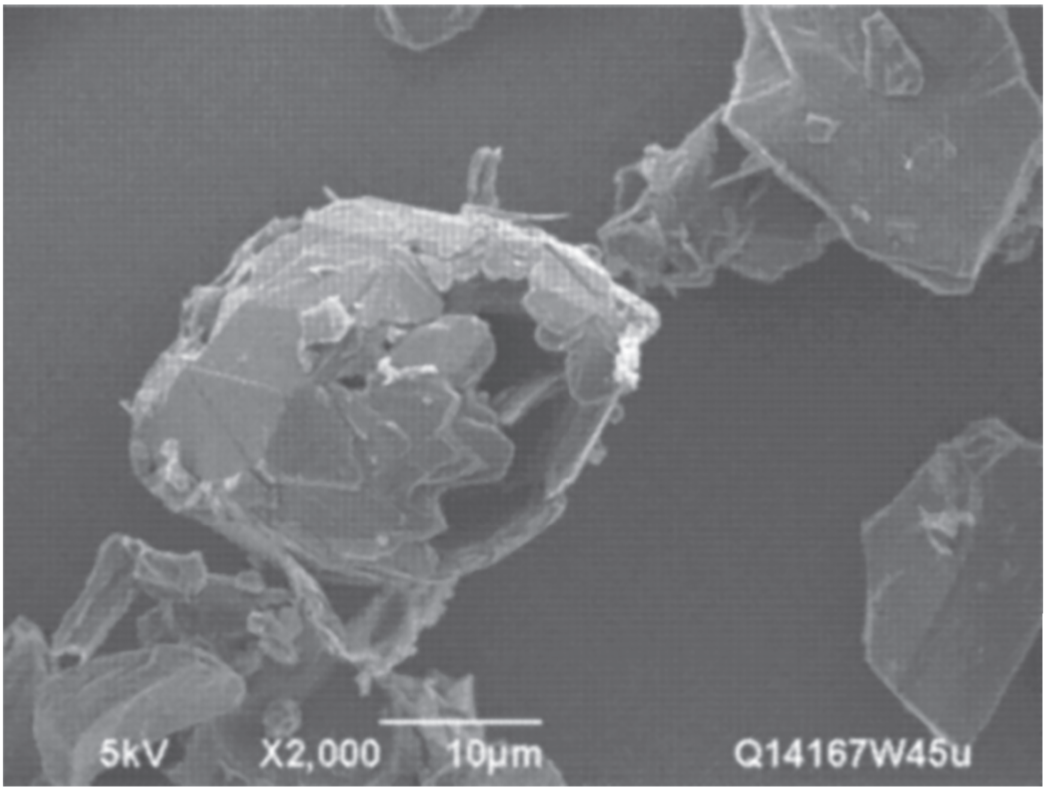
Table 8. Top applicants in graphite powder, China and the rest of the world.
Graphite powder has attracted strong interest from research institutions and commercial entities worldwide, because of its diverse applications.

China		Rest of the world	
Datong Xincheng New Materials	99	Showa Denko	18
Central South University	82	Toyota Motor	17
Chinese Academy of Sciences	70	JFE Holdings	16
Harbin Institute of Technology	66	NTN Corporation	13
Chengdu New Keli Chemical	50	Hitachi Chemical	12
South China University of Technology	44	Pacific National University	11
Tsinghua University	43	POSCO	11
University of Science and Technology Beijing	38	Panasonic	10
Jiangsu University	34	Tokai Carbon	10
Qingdao Jizhi Energy Saving Environmental Protection	34	National Chung-Shan Institute of Science and Technology	9

Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Micro graphite powder is a battery anode material disclosed in a patent application (US2018/0069260A1) filed by Showa Denko, Japan (Figure 13).

Figure 13. An example of micro graphite powder use in battery applications
A patent filed by Showa Denko of Japan discloses a battery anode material that uses micro graphite powder.



Source: Patent application US2018/0069260A1.

The micro graphite powder is manufactured at low-cost by graphitizing a mixture of a carbon raw material powder and a silicon carbide powder. It has a high degree of crystallinity and is suitable as a battery anode material due to its high density and capacity.

Expanded graphite

In the area of expanded graphite, Chinese research institutions dominate the top applicants, with the Chinese Academy of Sciences ranking 1st, with 120 patents (Table 9). This is in stark contrast to the rest of the world, where the top applicants were predominantly commercial entities led by Sekisui Chemical, Global Graphene Group and Nippon Pillar.

Sekisui Chemical has a variety of business segments, among which its Urban Infrastructure and Environmental Products business is renowned for its expertise in piping and infrastructure and building materials. The company has been actively exploring the fire-resistant property of expanded graphite. Its patent families extend to the use of expanded graphite in fire-resistant piping, fittings and windows, as well as doors in buildings.

Global Graphene Group's patent families focus mainly on expanded graphite for producing graphene through exfoliation and other processes, the company's key business being graphene and graphene-based products.

Nippon Pillar is a fluid control equipment manufacturer specializing in mechanical seals, gland packings, gaskets and so on. This Japanese company developed its first expanded graphite packing in 1987. Based on its 37 patent families, the company has made a continuous innovation effort in expanded graphite products, including expanded-graphite sliding members and gaskets with enhanced mechanical properties and lower slide resistance suitable for high-temperature and high-pressure fluid applications.

Table 9. Top applicants in expanded graphite, China and the rest of the world.
The top applicants in China were primarily academic players, whereas those in the rest of the world were principally commercial entities.

China		Rest of the world	
Chinese Academy of Sciences	120	Sekisui Chemical	110
Chengdu New Keli Chemical	63	Global Graphene Group	79
South China University of Technology	36	Nippon Pillar	37
Sinopec	33	Toyota Motor	16
Beijing University of Chemical Technology	30	Baker Hughes	15
Tsinghua University	30	SGL Carbon	15
Harbin Institute of Technology	26	Zeon	14
Henan Zhilian Huanyu IP Operation	25	Firestone	12
University Yanshan	23	Hitachi Chemical	12
Shanghai Jiao Tong University	22	Korea Institute of Construction Technology	12

Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Graphite-based nanocomposites

About 600 of the 3,100 graphite-based composite patent families filed globally relate specifically to graphite-based nanocomposites. A comparatively recent area, it has attracted intense interest from academic research worldwide.

The top applicants were predominantly universities and research institutes (Table 10), all with small patent portfolios and a scattered innovation focus. The exception is Sinopec, one of the biggest petrol companies in the world. This Beijing-based oil and gas enterprise has amassed 64 graphite nanocomposite patent families, 61 of which relate to graphite-coated transition metal catalysts for chemical engineering processes.

Academic research on graphite nanocomposites focuses on combining graphite-based nanomaterials with a variety of materials, including metal, silicon, ceramics and organic or polymeric materials for diverse applications. One example is a patent filed by Amity University in India disclosing graphite nanocomposites as chemical sensors using functionalized graphite nanoparticles and grafted polymers (IN806/DEL/2012). Another is Arizona State University's patent US2014/0131192A1, which employs a reduced graphite oxide/TiO_2 nanocomposite as a photocatalyst in the conversion of CO_2 to CH_4. In patent CN111266114A, the Beijing University of Chemical Technology showcases an iron/zinc oxide/carbon ternary nanocomposite with superior photocatalytic performance in the visible light catalytic degradation of organic pollutants.

Table 10. Top applicants in graphite nanocomposites, China and the rest of the world.
A more recent technology area, graphite nanocomposites are attracting strong interest from academic researchers worldwide.

China		Rest of the world	
Sinopec	64	Amity University	6
Nanjing University of Science and Technology	19	Indian Institute of Technology Madras	4
Jiangsu University	15	Centro de Investigación en Química Aplicada	4
Chinese Academy of Sciences	10	Northwestern University	3
Beijing University of Chemical Technology	10	University of Houston System	3
South China University of Technology	8	University of Valencia	3
Changzhou University	8	Inha University	2
Harbin Institute of Technology	6	Korea Institute of Industrial Technology	2
Peking University	6	Solvay	2
Ningbo University of Technology	6	Council of Scientific and Industrial Research	2

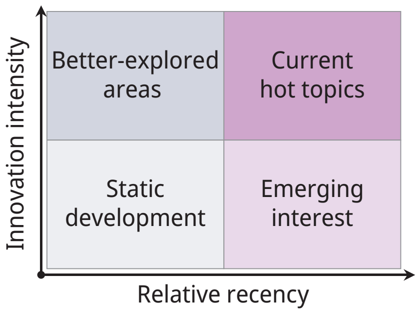
Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Graphite uses and products

The current graphite technology landscape is focused predominantly on graphite uses and products. Of the 60,000 graphite patent families captured in the overall dataset, over 45,000 involve graphite use in a wide range of products and industrial applications.

By categorizing these graphite patent families according to specific products or application areas and their respective recency – a measure of how recently the related graphite patent applications were filed – this report assesses the relative technology maturity of each graphite use and product through the analysis of an Innovation Maturity Matrix (Figure 14).[1]

Figure 14. Innovation Maturity Matrix.
This Innovation Maturity Matrix depicts innovation intensity against the relative recency of innovation for each graphite use and product, based on graphite patent applications filed worldwide.



Innovation intensity is measured by number of patent families.

Recency: A quantitative indicator on how recently the technologies were developed and published (see Annex A, Methodology). **Relative recency** in this report refers to a normalized recency, where the recency of the overall dataset is 1.

The four-quadrant matrix helps identify:

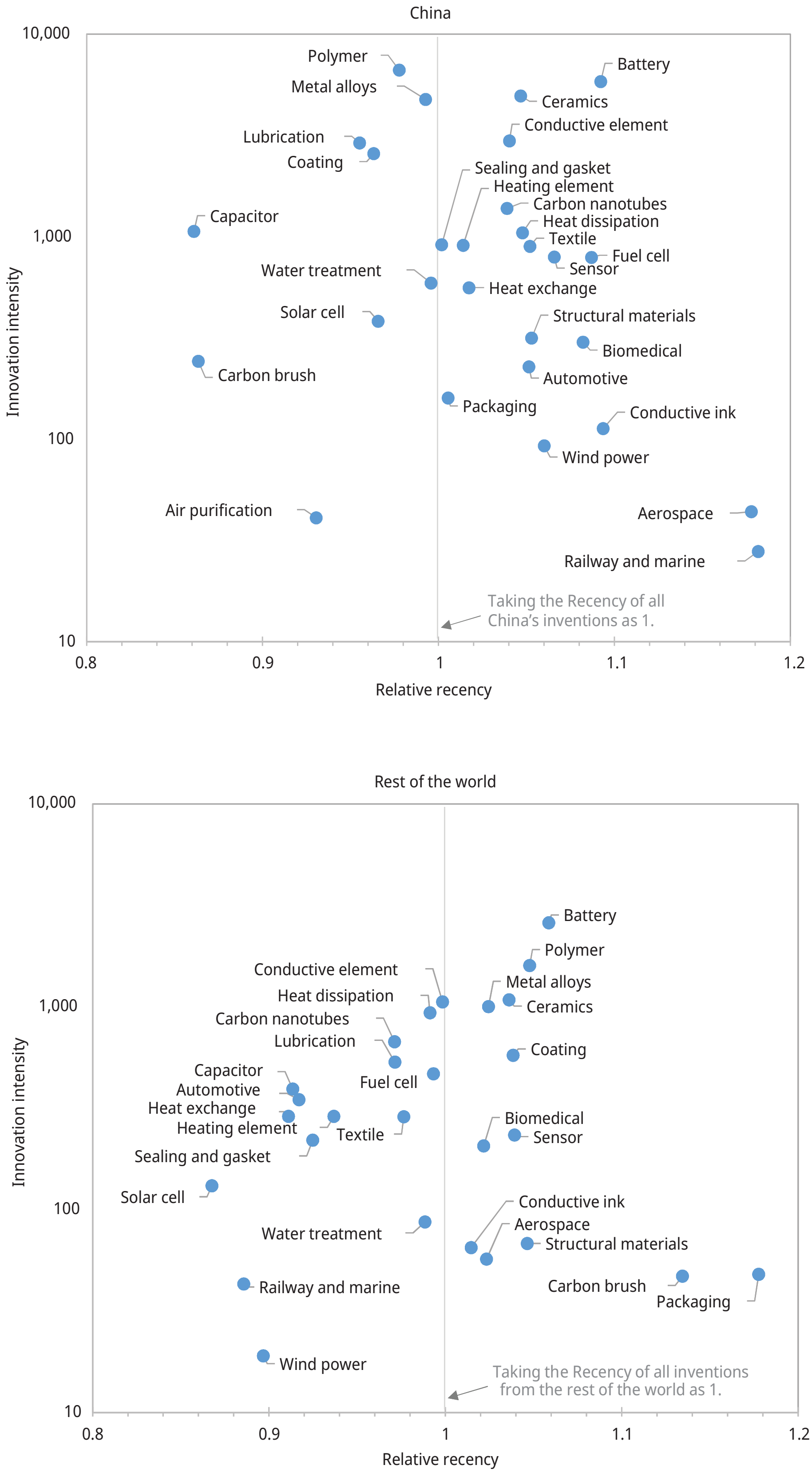
1. *Emerging interest* – areas with related patent families that have the most recent priority year but are not yet large in volume. Such areas are emerging and gaining rapid industry traction.
2. *Current hot topics* – research areas that are the current industry focus and have a high number of accumulated patent families.
3. *Better-explored areas* – areas with a high number of patent families but are no longer the current key focus, as most patent families were published in the relative past.
4. *Static technology development* – areas that are not of recent focus and have a small number of filings. These could already have arrived at the final stage of the technology cycle, that is, at the decline stage; or else areas that have been explored for a (relatively) long period of time but not gained traction at the time of the patent analytics report.

The Innovation Maturity Matrix analysis was carried out for China separately from the rest of the world in order to prevent the significantly higher number of patent families originating from Chinese graphite innovators from obscuring the analysis of innovation trends for the rest of the world (Figure 15).

That said, interestingly, China and the rest of the world show fairly similar innovation trends. For example, graphite applications in batteries and ceramics were intense innovation hot topics for both. Graphite use in polymers and for heat dissipation and lubrication have also attracted strong interest from China together with the rest of the world, albeit with slight differences in innovation recency values. In comparison, the number of patent families related to graphite applications for biomedical purposes, sensors and conductive inks is smaller worldwide, including China, but interest has been growing rapidly recently. This is in stark contrast to graphite use in nanocomposites and water treatment, neither of which is any longer a current research focus, as evidenced by their respective low recency values. Graphite for carbon brushes represents an interesting case, however. Chinese innovators consider it a well-explored area from which they are moving away at the same time as interest from the rest of the world is growing.

Figure 15. **Innovation Maturity Matrix of graphite-related patent families, China and the rest of the world.**

The Innovation Maturity Matrix helps identify current research hot topics and emerging areas.



Note: Categories are not mutually exclusive, some graphite patent applications may encompass more than one type of product or application. For example, an invention may include graphite in a metal alloy for biomedical applications, in which case it is grouped under both metal alloys and biomedical applications.

Source: WIPO, based on patent data from Questel Orbit up to May 2022. See Annex A, Methodology, for the methods of computing recency and relative recency. Annex Tables C2 and C3 summarize the innovation intensity, recency and relative recency of each graphite use and product illustrated.

Current innovation hot topics

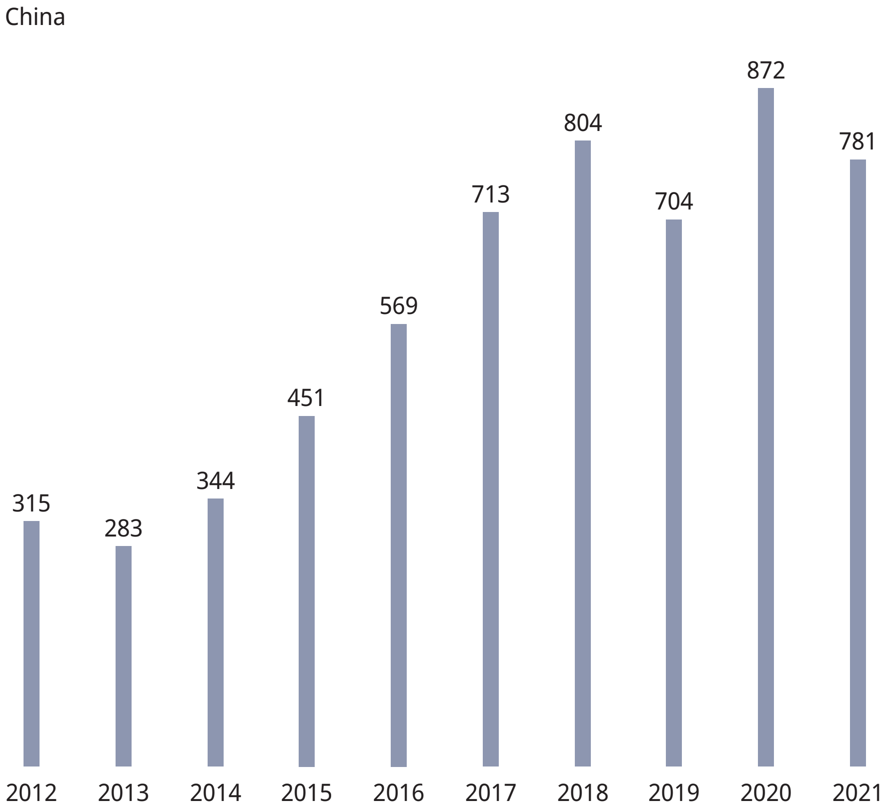
Battery applications

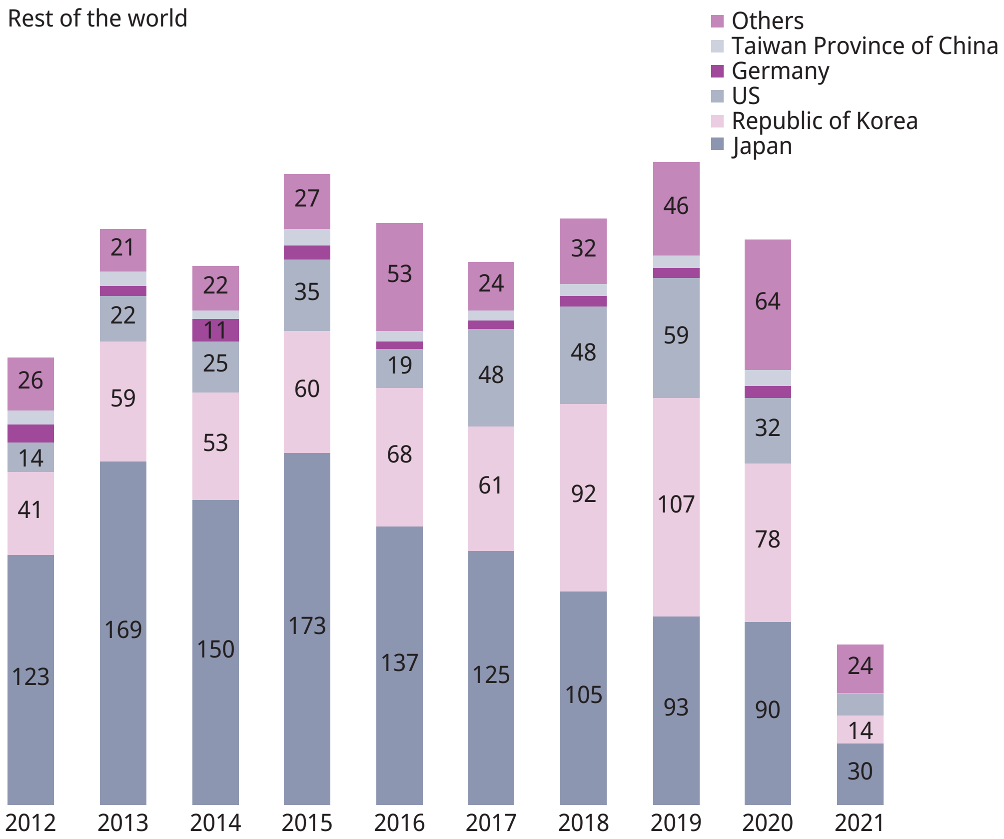
For over a hundred years, carbon has been a key component of batteries. It is found in zinc-carbon primary cells or nickel-cadmium rechargeable batteries. Graphite, in particular, plays a crucial role in lithium-ion batteries (LIBs), the most popular choice of energy storage for consumable electronics, EVs and stationary energy storage. Graphite's layered structure can host a high number of lithium ions in the form of the compound LiC_6 thus exhibiting outstanding energy density. Such a unique feature, together with good electrical conductivity and chemical inertness, makes graphite an excellent anode material with few viable alternatives. By weight, graphite is the most prominent component in LIBs.

Graphite for battery energy storage accounts for 10–15 percent of global graphite production. Yet, what is already a large proportion is expected to grow even further, because of the demand for energy storage from the clean energy sector, which has exploded over recent years – particularly for EVs and large-scale energy storage. The International Energy Agency (IEA) has forecast that the electric mobility and low-carbon energy sectors are likely to require 25 times more graphite annually by 2040 than is needed today (IEA, 2022). As a result, the European Union and the United States have designated graphite a supply-critical mineral.

Global efforts directed toward electrification and the utilization of green and renewable energy have created an insatiable need for battery technologies that has made batteries an innovation hot topic (Figure 16). As a key component of state-of-the-art LIBs, graphite has drawn significant innovation attention. Among all graphite uses and products, patent application filing related to graphite use in battery applications has been the most intensive, with over 8,000 patent families filed in the last decade alone.

Figure 16. Number of graphite patent families related to battery applications, by year of filing, China and the rest of the world, 2012–2020.
Battery applications have gained strong traction globally and remain a top graphite application.





Source: WIPO, based on patent data from Questel Orbit up to May 2022.

China has the highest number of graphite patent families for battery applications, accounting for about 70 percent of global invention output with around 5,800 inventions, followed by Japan and the Republic of Korea. These three Asian countries lead in LIB technologies. Together, they supply 90 percent of LIB packs to the global market (Tsiropoulos *et al.*, 2018). China's dominance is even more pronounced in regard to LIB anode material, being responsible for 90 percent of graphite anode production globally (PR Newswire, 2021), along with a significantly greater number of patent families than any other country.

Currently, natural and synthetic graphite are used in making LIB anodes, usually as a mixture in different ratios. Some battery-makers prefer synthetic graphite, because of its higher material consistency, low impurity, ease of specification control and better performance, despite the higher cost associated with the energy-intensive, high-temperature synthesis process (DW, 2022).

Table 11. Top applicants for graphite in battery applications, China and the rest of the world.
The top applicants in this area were mainly either battery manufacturers or anode suppliers that had accumulated sizeable patent portfolios.

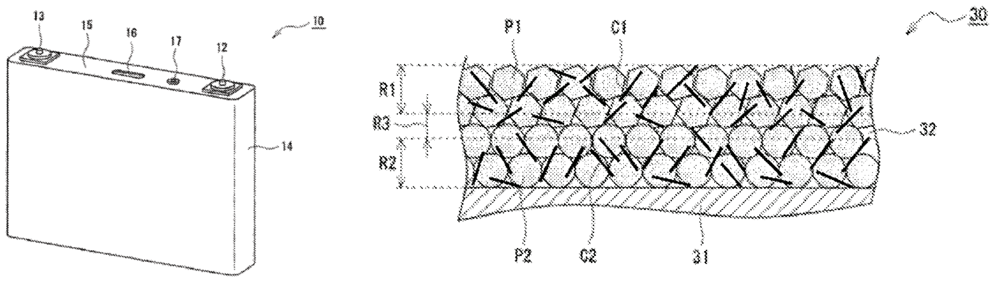
China		Rest of the world	
Shanshan Technology	181	Toyota Motor	162
CATL	129	Panasonic	143
Dongguan Kaijin New Energy	100	Showa Denko	135
Hefei Guoxuan High-Tech Power Energy	96	LG Energy Solutions	96
Central South University	94	LG Chem	88
BTR New Material	78	Mitsubishi Chemical	77
Zhuhai Cosmx Battery	46	GS Yuasa	76
South China University of Technology	44	Global Graphene Group	71
Hunan Guosheng Graphite Technology	42	JFE Holdings	56
Datong Xincheng New Materials	34	POSCO	56

Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Inventions related to graphite for battery applications largely originate from commercial entities, which contributed more than 70 percent of global invention output (Table 11). The top applicants in this area were mainly either battery manufacturers or anode suppliers. In particular, Panasonic, LG Chem, CATL and Hefei Guoxuan High-Tech Power Energy are leading global battery-makers, whereas Shanshan Technology, Dongguan Kaijin New Energy, BTR New Material and Showa Denko are top anode suppliers.

These global leaders focus strongly on battery performance improvement, based on graphite anode innovation. For example, CATL disclosed a graphite anode manufacturing method for improving the low-temperature and cyclic performance of LIBs in patent application CN103367714A. They have also identified graphite anodes for the next generation of battery technologies, for instance solid-state LIBs. In a recent patent application (US20210202932A1), Panasonic combined graphite with carbon fibers in an anode in order to inhibit the decrease in capacity during charging/discharging in a solid-state LIB (Figure 17).

Figure 17. Graphite anode for nonaqueous electrolyte secondary batteries disclosed in a patent application (US2021/0202932A1) filed by Panasonic.
The battery anode (reference no. 13) in this invention comprises a mixed layer (reference no. 32) formed using graphite (reference no. P1, P2) and carbon fiber (reference no. C1, C2), with different specific surface area values to inhibit the decrease in capacity during a charging and discharging cycle.



Source: Patent application US2021/0202932A1.

In addition, the industry is also actively exploring alternative anode solutions that have greater energy density and better performance, the best commercial graphite anodes having already reached 365 mAh/g (Deloitte, 2022), very close to the theoretical energy density ceiling of about 372 mAh/g. For example, BTR New Material, a leading Chinese anode supplier, has been innovating on a silicon-graphite composite anode for better LIB performance (see patent CN102651476A, for example).

Besides industry players, academia has been an important source of innovation in battery technologies, accounting for about 30 percent of related invention. Among the top applicants were two Chinese universities with sizable patent portfolios comparable to their commercial counterparts. The Central South University has published 94 patent families. Its recent inventions aim to address the fast-growing demand for graphite as a raw material, focusing strongly on the re-use and recycling of graphite anodes exemplified in the stepped utilization method of graphite LIB anodes proposed in patent CN110176647A, and a waste treatment procedure for LIB carbon slags recently disclosed in patent CN112142044A.

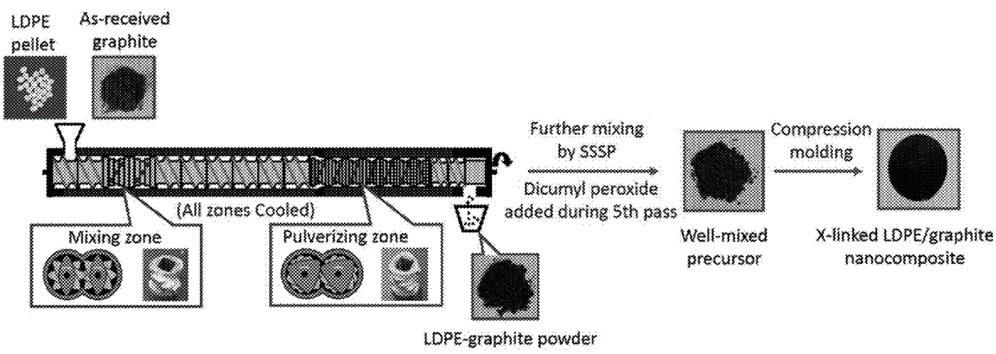
Polymer composites

Polymers are materials comprising large molecules. Besides natural products such as wool, silk, cellulose and natural rubber, there are synthetic polymers derived from petroleum that include nylon, Teflon, polyvinyl chloride (also known as PVC) and epoxy. Synthetic polymers are ubiquitous in various industries and can be found in products ranging from CDs, toys and containers to foams, fabrics, films, coatings, automobile parts and machines.

Polymer materials owe their success to being elastic, having a high chemical resistance and a low melting point, and being easy to manufacture. However, typically, polymer materials have poor thermal and electrical conductivity. This makes them good for insulation and thermal isolation, but can be disadvantageous for some other applications. In this regard, graphite powders are ideal fillers in making conductive polymers with better thermal or electrical properties. Compared to metal fillers, graphite is lighter in weight, cheaper in price and compatible with most polymer systems.

For example, DuPont, one of the leading chemicals and polymers manufacturers, has added graphite powder to polyimide film for higher thermal conductivity, as disclosed in patent US2013/0240777A1. Graphite can also improve the tribological properties of polymer composites. As described in patent US2022/0017704A1, researchers from Northwestern University have produced crosslinked polyolefin with a high wear resistance by incorporating unmodified graphite (Figure 18). Interestingly, by treating graphite in acids and introducing sulfur or nitrogen compounds as intercalation agents, the layered material is transformed into expandable graphite. Owing to its high expansion rate at high temperatures, expandable graphite is an excellent fire-retardant material widely used in fire-proof packages or fire-resistant polymer boards.

Figure 18. Graphite incorporated in the synthesis of crosslinked polyolefin nanocomposites, as described in a patent application (US2022/0017704A1) filed by Northwestern University.
The crosslinked polyolefin nanocomposites are formed by dispersing exfoliated, unmodified graphite and unreacted peroxide crosslinker throughout the polyolefin. The resulting polyolefin nanocomposites exhibit improved wear resistance.

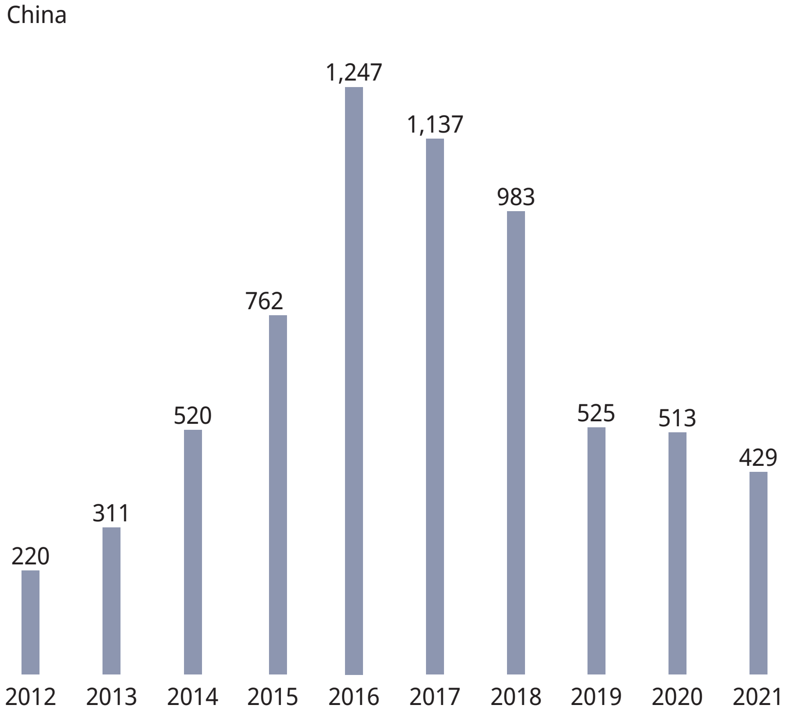


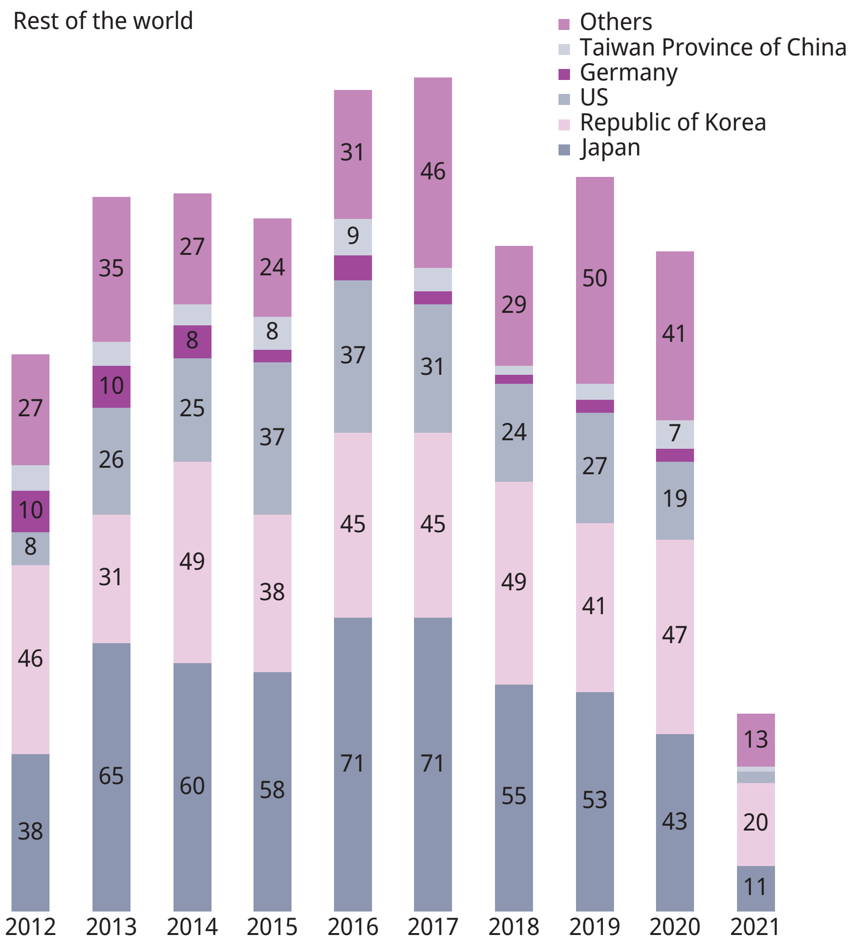
Note: LDPE is low-density polyethylene; SSSP is solid-state sheer pulverization.
Source: Patent application US2022/0017704A1.

With over 8,000 patent families filed from 2012 to 2021 (Figure 19), graphite for making different polymer composites has attracted strong patenting interest globally. However, unlike for battery applications which have been on a rising trend, patent filings related to graphite applications for polymers have been decreasing over the last five years. This downward patenting trend is particularly prominent in China, resulting in a low relative recency value (see Figure 15). In addition, slight declines in related patenting activities were observed in Japan and the United States.

Overall, the large volumes of patent applications and the downward patenting trend suggests that graphite for polymer applications is a better-studied area with a substantial accumulation of technology.

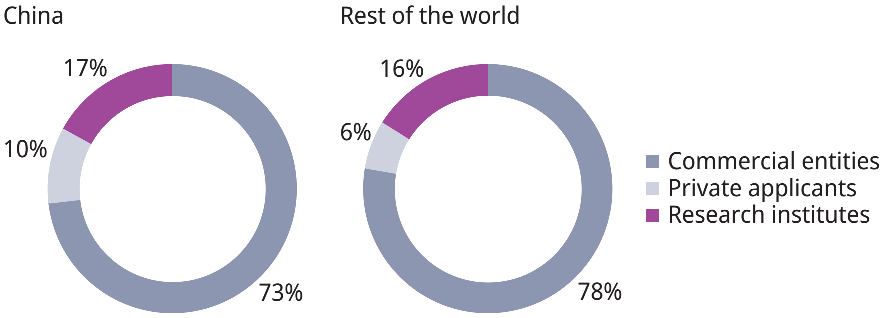
Figure 19. **Number of graphite patent families related to polymer composites, by year of filing, China and the rest of the world, 2012–2021.**
The large volume of patent applications and the downward patenting trend in top regions like China, Japan, and the United States suggest that graphite for polymer applications is a well-researched area with substantial technology accumulation.





Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Figure 20. **Patent applicant profiles for graphite-related patent families in polymer composites, China and the rest of the world.**
Graphite inventions for polymer composites were strongly commercially driven, with three in every four patent families filed by commercial entities.



Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Overall, graphite inventions for polymer composites were seen to be strongly commercially driven, with three in every four related patent families filed by commercial entities (Figure 20). In contrast, public research institutes accounted for between 16–17 percent of global patenting output, significantly lower than their contribution to overall graphite patent families (see Figure 3).

The strong dominance of commercial entities is also apparent from the absence of public research or academic players in the contribution by the rest of the world. The top applicant list for the rest of the world is entirely populated by world-renowned chemical or plastics manufacturers, such as Sekisui Chemical from Japan, LG Chem from the Republic of Korea and BASF based in Germany (Table 12). More particularly, nearly half of the 112 patent families filed by the top player – Sekisui – were directed toward expandable graphite for fire-resistant resin compositions or flame-resistant sheet products.

Similarly to the rest of the world, commercial entities were the dominant players in China. However, the patent landscape in China is slightly different in that numerous companies with relatively small portfolios contributed to graphite patent families for polymer applications. State Grid Corporation of China – China's top applicant – filed 56 patent families, focused mainly on using graphite for making insulating cables (CN106380826A), electricity distribution boxes (CN105885152A) or other protective materials in power towers and substations (CN113250517A). As a result of the fragmented patent landscape in China, there were few Chinese public research institutes with a sizable portfolio among the top applicants. Compared to their commercial counterparts, the innovation focus of these organizations on advanced polymer materials is greater, ranging from 3D-printable nylon powders (CN103980484A, filed by the Institute of Chemistry, Chinese Academy of Sciences) to resin/graphite microchip composite for aerospace applications (CN103435975A, filed by Harbin Institute of Technology).

Table 12. **Top applicants for graphite in polymer composites, China and the rest of the world.**
Graphite inventions for polymer composites were strongly commercially driven, led by world-renowned chemicals or plastics manufacturers.

China		Rest of the world	
State Grid Corporation of China	56	Sekisui Chemical	112
Jiangsu Sidike New Materials Science and Technology	37	Kaneka	36
Chinese Academy of Sciences	36	PI Advanced Materials	24
Sinopec	27	Showa Denko	19
Harbin Institute of Technology	27	LG Chem	19
Beijing University of Chemical Technology	27	Denka	16
South China University of Technology	23	Amogreentech	14
Chengdu New Keli Chemical	23	Zeon	14
Anhui Weiwei Rubber	21	BASF	13
Nanjing University of Science and Technology	21	Panasonic	13

Source: WIPO, based on patent data from Questel Orbit up to May 2022.

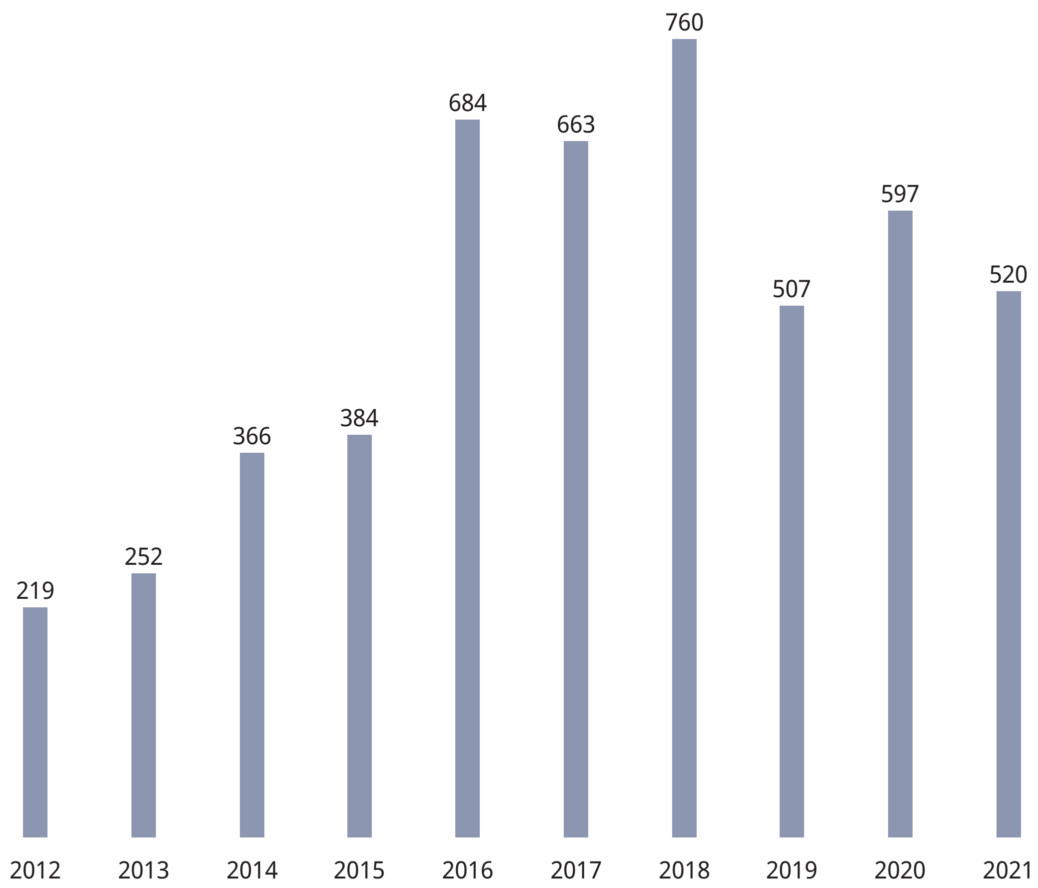
Ceramics

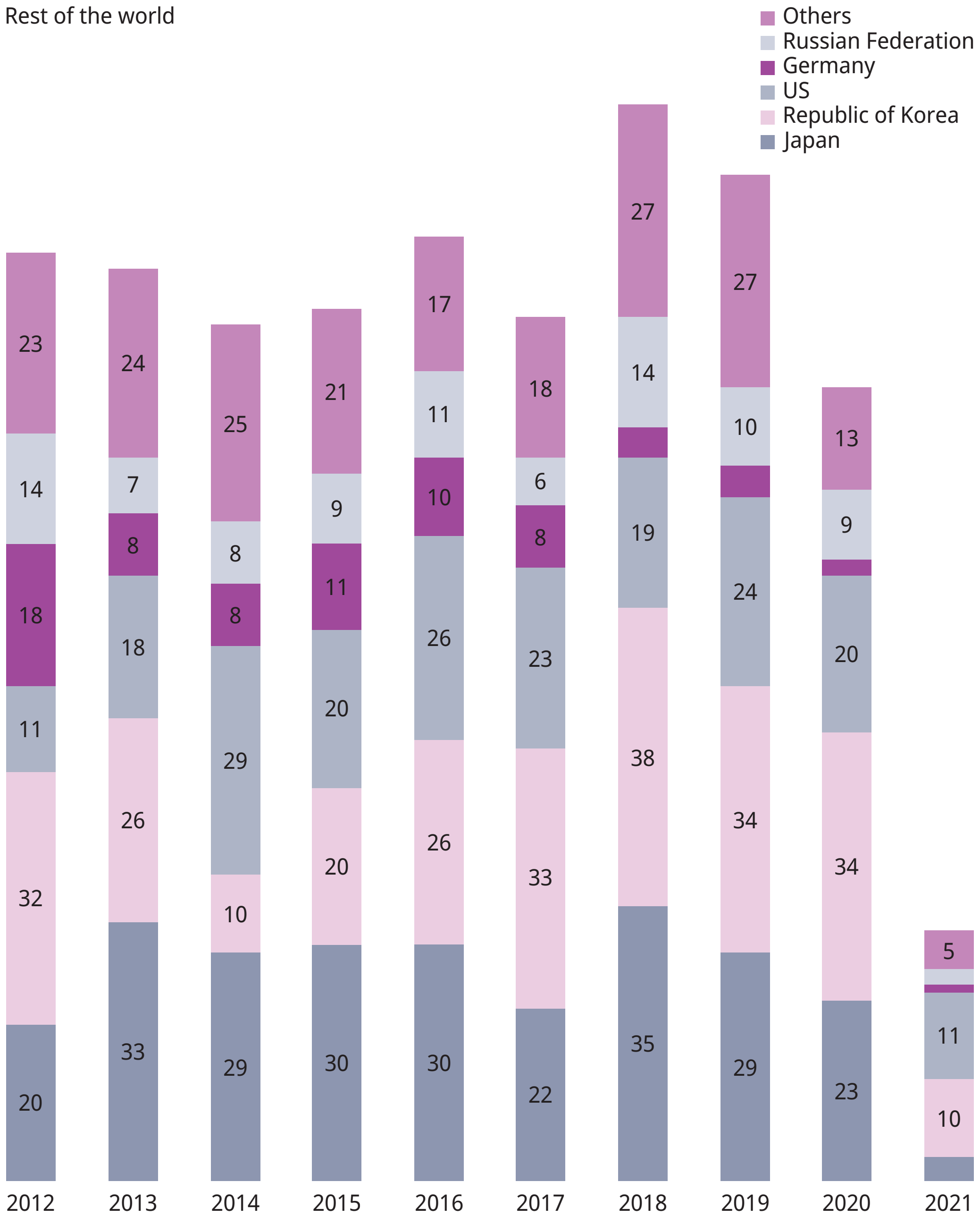
Ceramics are common in everyday life and have a wide range of industrial applications, owing to their excellent heat- and corrosion-resistant properties. Their thermal and chemical stability is further enhanced through the addition of, or coating with, graphite, which is ideal as a refractory material for crucibles, mag-carbon bricks, kiln linings, incinerators, furnaces and reactors. Moreover, the reducing property of graphite makes it a protective agent for steel ingots, silicon crystals and precious metals. Consequently, graphite has been widely used in foundry casting and molding in the metallurgical industry.

Graphite applications for ceramics have attracted strong interest worldwide, with over 6,000 patent families published in the last decade. In addition to China, which contributes about 80 percent of global patent filings, strong patenting output was also observed in the Republic of Korea, Japan and the United States (Figure 21).

Figure 21. **Number of graphite patent families related to ceramic applications, by year of filing, China and the rest of the world, 2012–2021.**
Graphite for ceramics has drawn consistent interest worldwide in recent years.

China

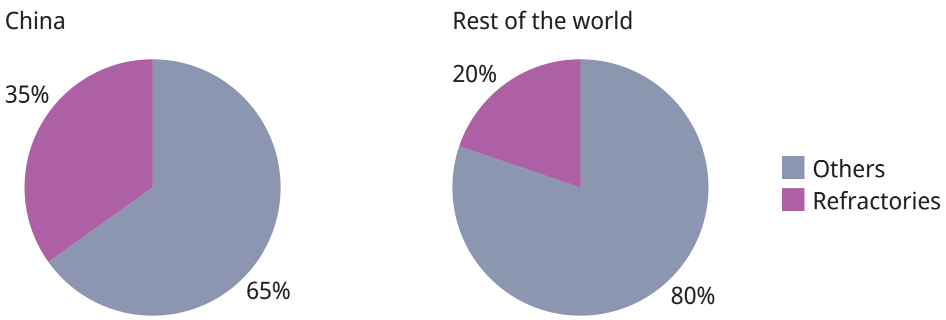




Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Figure 22. Patent families related to graphite for ceramics according to use, China and the rest of the world .

Strong innovation focus on refractory applications was observed in both China and the rest of the world.



Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Among the many uses for graphite in ceramics, refractory applications were a key innovation focus worldwide. Specifically, they account for over one-third of ceramics-related graphite patent families in China and about one-fifth in the rest of the world (Figure 22). Such a high level of interest is to be expected, as graphite used for refractories constitutes the largest share (43.4 percent) of the global graphite market (Fortune Business Insights, 2021).

Chinese commercial companies were particularly active innovators. Besides carbon crucibles and molds, graphite is also used in the making of the mag-carbon and alumina-carbon bricks prevalent in China's refractory market. These companies' intensive patenting output has been crucial in supporting the enormous steel, metallurgy, glass and ceramics industries of the world's largest manufacturing economy. For example, Datong Xincheng New Materials – one of China's leading graphite suppliers – has over 100 patent families in this area (Table 13). Its research focus includes graphite in molds for train wheels (CN104496498A), metal furnace lining (CN106565253A) and specific metal molds for isostatic pressing (CN108218430A).

Led by Shandong University of Technology and Wuhan University of Science and Technology, Chinese academic players were also strong contributors. They account for around 30 percent of ceramics-related graphite patent families originating from China. In addition to refractory applications, these families cover novel ceramic materials and composites for a broad range of uses. For example, Shandong University of Technology is seen to focus strongly on carbon fiber-based friction materials for automotive and power machinery applications. By adding different carbides, such as silicon carbide, boron carbide, zirconium carbide and titanium carbide, graphitized carbon fibers have been created that have enhanced mechanical strength, tenacity (toughness) and friction performance.

Table 13. **Top applicants for graphite in ceramics, China and the rest of the world.**
Overall, graphite inventions for ceramics were led mainly by commercial companies, but Chinese academic players were also strong innovators.

China		Rest of the world	
Shandong University of Technology	134	Ibiden	39
Datong Xincheng New Materials	104	POSCO	27
Wuhan University of Science and Technology	98	Krosaki Harima	25
Harbin Institute of Technology	55	PI Advanced Materials	22
Central South University	40	SGL Carbon SE	20
Wuhan University of Technology	39	Sumitomo Electric Industries	19
Beijing Lier High Temperature Materials	37	Korea Institute of Ceramic Engineering and Technology	15
Wuhan Iron and Steel	37	Global Graphene Group	13
Institute of Metal Research	28	Kaneka	11
Haicheng Lier Maige Xita Materials	27	Denka	10

Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Outside of China, academia plays a less active role, with patenting activity led principally by commercial entities. Among the top players were world-leading graphite ceramics supplier Ibiden (Japan), renowned steel-maker POSCO (Republic of Korea), and well-known firebricks manufacturer Krosaki Harima (Japan). Notable inventions include Ibiden's ceramic-coated graphite crucible for melting silicon with superior anti-silicon adhesion disclosed in patent JP2019156653A, POSCO's corrosion-resistant refractory composition comprising magnesia and flake graphite for steel casting described in patent WO2017090929A1 and Krosaki Harima's blast furnace hearth brick with improved molten pig iron and slag resistance discussed in patent EP3564201A1.

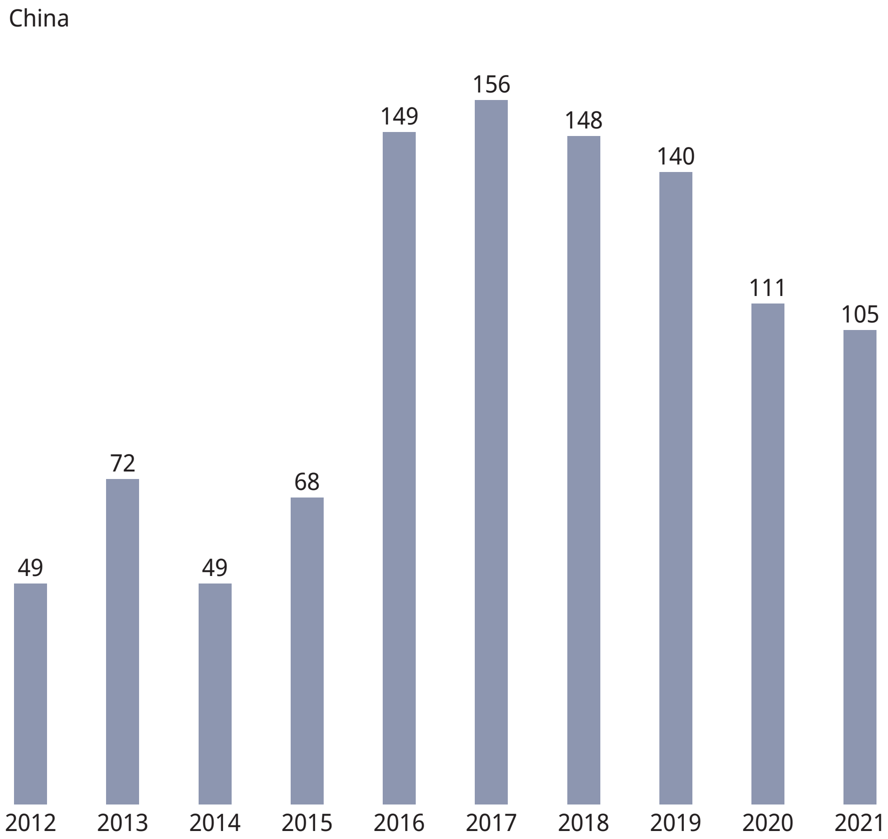
In addition to refractory applications, graphite is a critical raw material in the making of silicon carbide, boron carbide, tungsten carbide, zirconium carbide, carbon nitride, carbon fiber and so on. These high-value ceramic materials are essential for specific industrial applications, ranging from aerospace and precision engineering to military and nuclear applications. Additionally, graphite can be incorporated at the nanoscale to produce high-quality carbide materials suitable for electrical and electronics applications. As exemplified by the Korea Institute of Ceramic Engineering and Technology invention described in patent KR101385570B1, high-quality silicon carbide nanofibers with high electrical conductivity can be manufactured at low cost by inserting amorphous silica between expanded graphite layers followed by the carbothermal reduction of a mixed powder consisting of expanded graphite and silica.

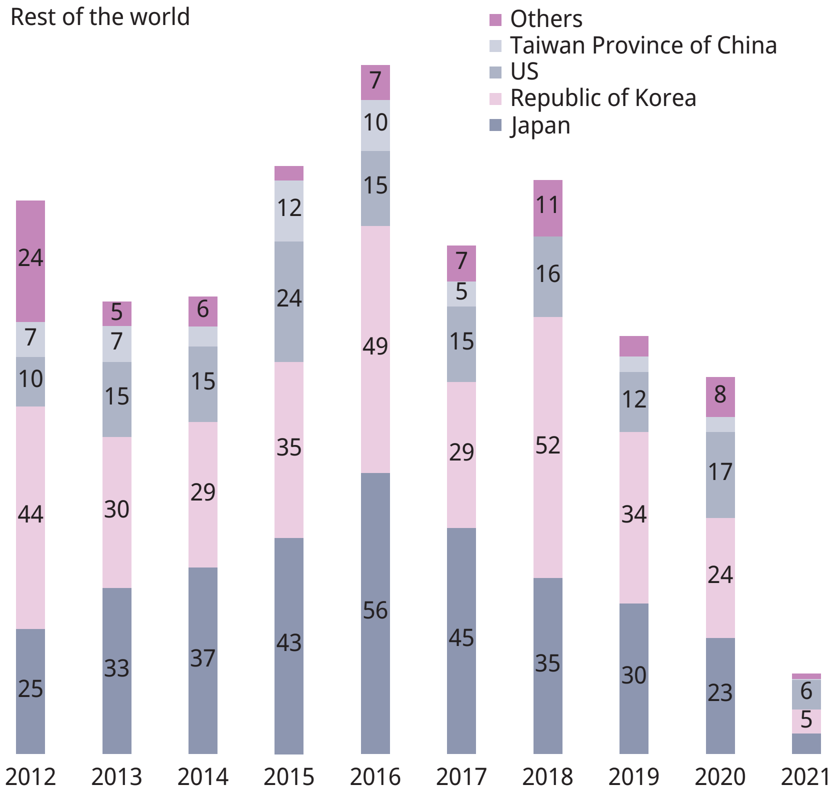
Heat dissipation

Electronic devices usually generate heat. This is becoming an issue, because of the burgeoning computing power, high-resolution displays, massive data streaming and so on, as the high heat generated can adversely affect both device performance and user experience. However, traditional heat dissipation devices like metal heat sinks are incompatible with consumer electronics favoring delicate designs and small form factors. Graphite paste and graphite films have become mainstream heat dissipation solutions for electronic devices, thanks to their superior thermal conductivity and light weight. For example, by attaching a graphite sheet to a battery module or circuit board inside a smartphone, it can act as a heat sink spreading heat away from the source, thereby efficiently preventing issues such as battery thermal runaway and improving phone performance. Indeed, the increasing demand for graphite heat sinks from the electronics industry has been a key driver of the growing graphite sheet market (DataIntelo, 2021).

As revealed by global patenting activity, graphite for heat dissipation is one of the few areas where the patenting output of the rest of the world is comparable to that of China, with a strong contribution coming from Japan, the Republic of Korea, the United States and Taiwan Province of China (Figure 23). Patents in this area were predominantly filed by commercial entities headed by world-leading graphite sheet suppliers, such as Jiangsu Sidike New Materials Science and Technology , Panasonic, Kaneka, GrafTech International and Jones Technology (Table 14). Only a small proportion of related patent filings originated from research organizations – 16 percent for China and 8 percent for the rest of the world (Figure 24).

Figure 23. Number of graphite patent families related to heat dissipation, by year of filing, China and the rest of the world, 2012–2021.
Heat dissipation is one of the few graphite application areas where the rest of the world has a patenting output comparable to that of China.

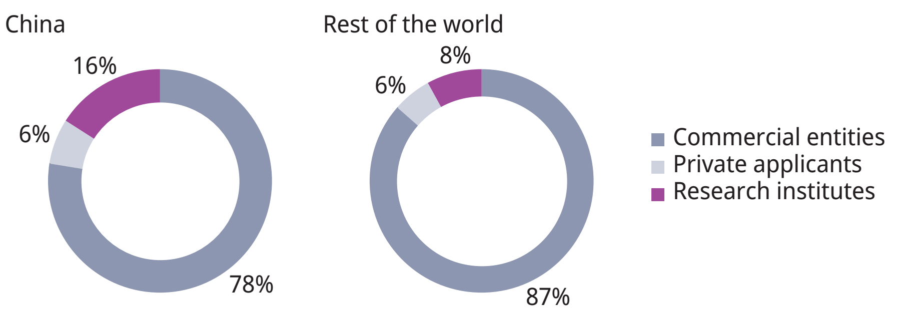




Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Figure 24. Patent applicant profiles for graphite in heat dissipation, China and the rest of the world.

Overall, commercial entities lead for graphite inventions for heat dissipation.



Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Table 14. Top applicants in using graphite for heat dissipation, China and the rest of the world

Commercial players have a strong patent portfolios in graphite for heat dissipation applications.

China		Rest of the world	
Jiangsu Sidike New Materials Science and Technology	47	Panasonic	52
Padnic Thermal Conductive Material	21	Kaneka	45
Guangdong Oppo Mobile	13	SKC	20
Jones Technology	11	GrafTech International	18
Chinese Academy of Sciences	10	Showa Denko	17
State Grid Corporation China	9	Toyota Motor	17
Lenovo	8	Global Graphene Group	16
Qihua Optronics	8	Amogreentech	15
University of Science and Technology Beijing	6	Zeon	12
Huawei Technologies	5	Shin Etsu Chemical	11

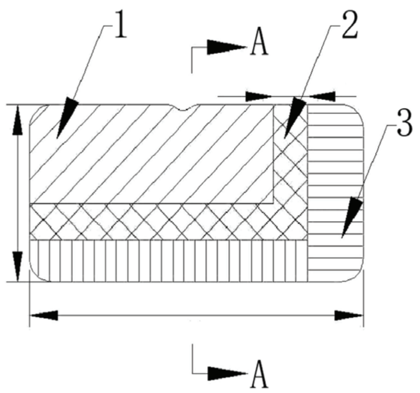
Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Panasonic has been an industry leader in advanced graphite-based heat dissipation solutions for electronic devices, in-vehicle inverters and base station applications. In its recent patent application (WO2020162117A1), Panasonic disclosed an easy-to-apply graphite heat-conducting sheet capable of absorbing the unevenness of a heat-generating component to ensure close contact with the heat source and stable heat spreading. This could be part of the company's innovation effort to develop a new graphite thermal interface material with an excellent thermal dissipation performance (Panasonic, 2017).

The continual improvement in electronics, particularly in semiconductor chips, has resulted in high-performance portable computing devices, which, in turn, has led to the proliferation of high-power applications, increased functionality associated with the internet and high-speed interconnectivity enabled by fifth-generation (5G) communications. As a result, the power dissipation levels of mobile devices are expected to increase further, and current graphite-based heat dissipation approaches may no longer be sufficient. Innovators are exploring novel graphite-based compositions and microstructures, for example, graphene and graphene oxide, and configurations of graphite-based materials, such as combining a graphite sheet with a heat pipe or vapor chamber for better heat dissipation performance.

Jiangsu Sidike New Materials Science and Technology, the top applicant, has been actively patenting innovations related to graphite sheets, films, tapes and heat dissipation devices, together with the corresponding fabrication processes. In a recent invention (CN113896535A), the Chinese heat dissipation material supplier illustrates a graphene heat-conducting film with high thermal conductivity. Specifically for 5G applications, Jones Technology, a leading supplier of thermal insulation, heat dissipation and shielding materials, has revealed a novel layered structure comprising a composite low-dielectric layer together with one or more graphite sheet layers (patent CN112590323A, Figure 25). According to the Beijing-based company, this new layered structure ensures superior heat dissipation for a high-powered 5G antenna, while leaving signal transmission unaffected.

Figure 25. Graphite sheet for use in a heat dissipation device disclosed in a patent application (CN112590323A) filed by Jones Technology.
The invention incorporates a graphite sheet for high heat conductivity with minimal impact on the signal transmission for a mobile phone antenna and suitable for high-power-consuming 5G applications.



1. Graphite sheet layer
2. Bonding layer
3. Low dielectric heat sink layer

Source: Patent application CN112590323A.

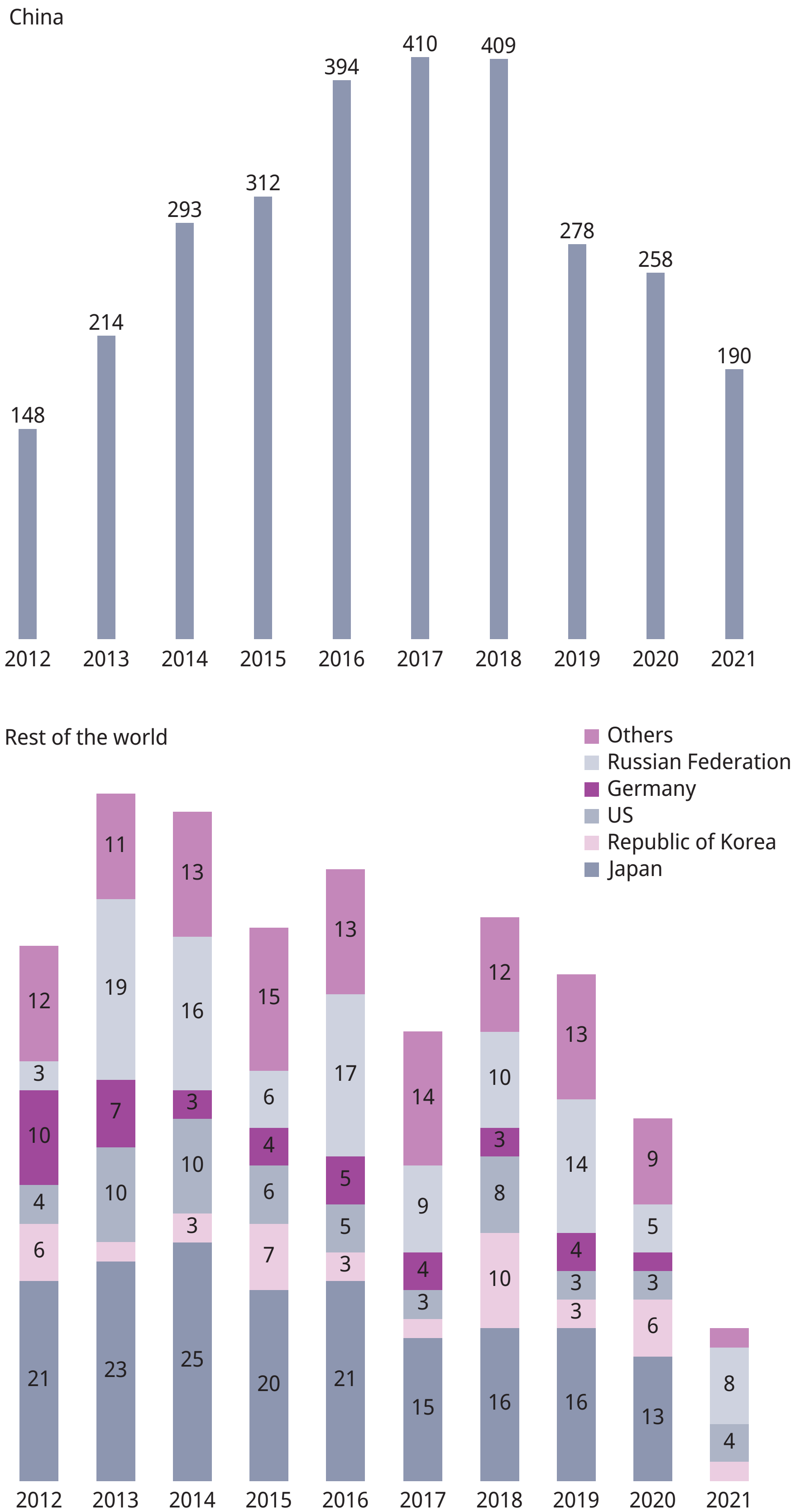
Lubrication

Graphite is widely used as a high-performance lubricant for high-temperature and pressure applications, such as compressors, combustors and turbine rotors, when common lubrication oils and greases are unsuitable. Unlike oils or greases, graphite leaves no sticky residue that may attract dust. A key graphite application area, the global graphite lubricant market was estimated at USD 1.62 billion in 2022 and is forecast to exceed USD 2.45 billion in 2032 (Fact.MR, 2022).

Graphite as a lubricant is a top graphite patenting area, with nearly 3,500 patent families published worldwide during 2012–2021 (Figure 26). Notably, strong patenting output was observed in the Russian Federation, which ranked 3rd behind China and Japan, with 107 patent families.

Figure 26. **Number of graphite patent families related to lubrication, by year of filing, China and the rest of the world, 2012–2021.**

Graphite for lubricant applications is well-explored, as evidenced by the pronounced decline in patenting activity in China and the rest of the world starting in 2019.



Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Overall, graphite for lubricant applications is considered to be well-explored, patenting activity having undergone a pronounced decline in recent years in both China and the rest of the world. The drop in China is particularly noticeable – down from more than 400 patent families in 2018 to under 300 in 2020.

While commercial entities filed more than 70 percent of patent families from China, the top Chinese applicants were academic players (Table 15). Notably, Lanzhou Institute of Chemical Physics – a Chinese Academy of Science research institute – tops the list with 43 patent families. It is home to China's State Key Laboratory of Solid Lubrication, whose breadth of research on graphite-based lubricant materials ranges from a copper/graphite composite lubricating sealing material (as described in patent CN110976852A) to a high-strength solid lubricating coating for aircraft engines (CN112251135A).

In contrast, the top applicants from the rest of the world were commercial entities. Japanese companies were strong leaders, represented by renowned bearing manufacturers NTN Corporation, Daido Metal, Taiho Kogyo, Oiles Corporation and NSK. Their graphite inventions are strongly focused on the automotive industry. A typical example is the use of graphite and molybdenum disulfide in the manufacture of a special wheel rolling bearing unit disclosed in a patent (JP2016150362A) by NSK.

Table 15. Top applicants for graphite in lubricants, China and the rest of the world.
Graphite lubricant inventions in China came largely from academic players, whereas the top applicants from the rest of the world were mainly Japanese companies.

China		Rest of the world	
Lanzhou Institute of Chemical Physics	43	NTN Corporation	19
Suzhou Donon Carbon Products	27	Daido Metal	16
Chengdu New Keli Chemical	20	Taiho Kogyo	12
Sinopec	18	Oiles Corporation	12
University of Science and Technology Beijing	16	NSK	9
Tsinghua University	15	Nisshinbo	9
Jiangsu University	15	Toyota Motor	8
Central South University	15	Showa Denko	7
Xi'an University of Technology	14	Schaeffler Technologies AG	6
Xi'an Jiaotong University	13	Diamet Corporation	5

Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Areas with declining technology development and niche applications

Carbon brushes

Graphite has long been used in the making of carbon brushes. These are essential functional components establishing electrical contact between the stationary and rotating parts of an electric motor. They are widely used in automotive applications, vacuum cleaners, home appliances and many industrial tools. Future Market Insights valued the global carbon brush market at about USD 2.5 billion in 2021 and it is expected to continue growing, driven by increasing demand from the automotive sector (Future Market Insights, 2022).

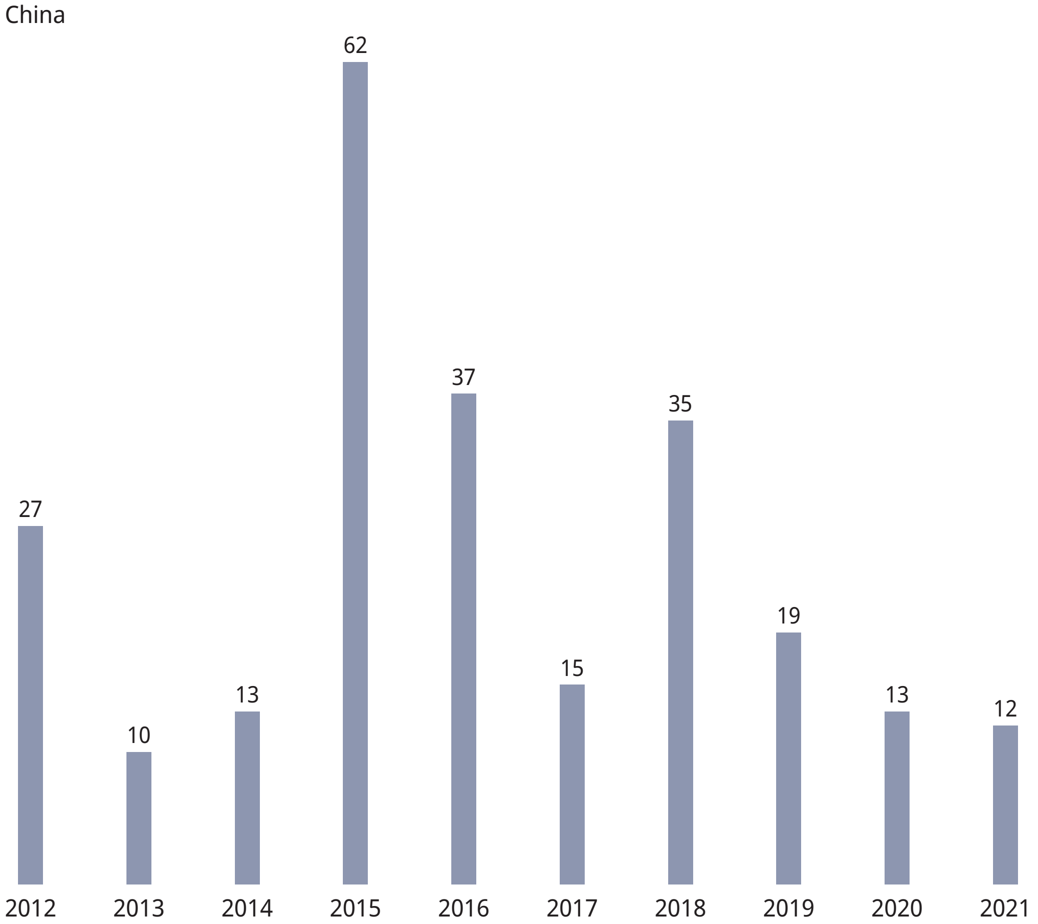
Despite this, compared to many other graphite applications, there have been few inventions in this area in the last decade, with less than 300 patent families registered between 2012–2021 (Figure 27). Overall, carbon brushes can be considered to be a well-established area, given its comparatively smaller volume of patenting output worldwide.

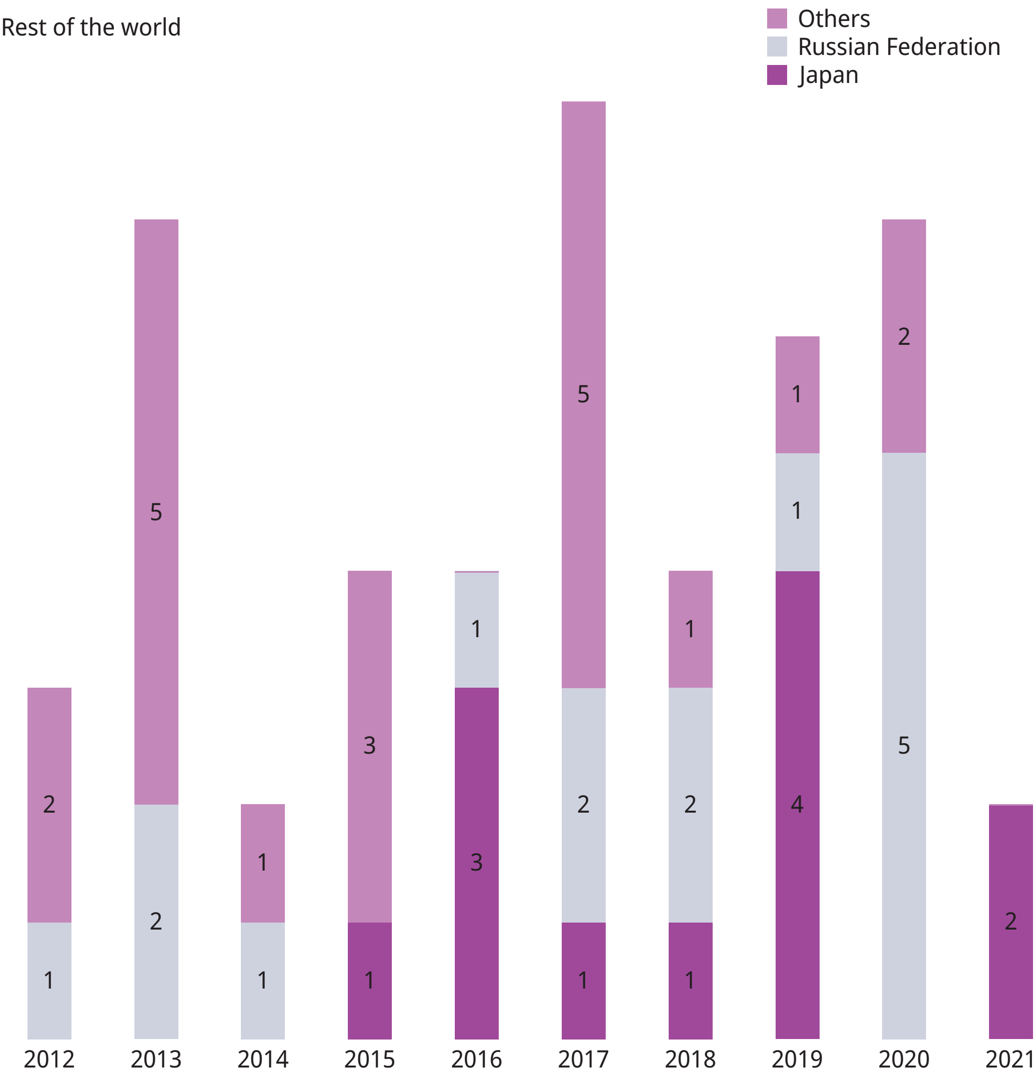
The relative recency of inventions originating from China is low, with the majority of patent families having been filed in earlier years. Unlike other graphite application areas, where public research organizations have a strong presence, the top 10 carbon brush applicants in China were all commercial entities (Table 16). Top Chinese applicants include Suzhou Donon Carbon Products, a carbon brush supplier, and Datong Xincheng New Materials.

Graphite for carbon brushes is gaining minimal traction from the rest of the world, with only a handful of patent families filed between 2012–2021. The Russian Federation and Japan were the main innovators, though their patent filings have been sporadic over the last decade. The overall small number of patent families and the small increases from Japan and Russia in 2019 and 2020, respectively, have resulted in a high relative recency value. However, this should not be interpreted as meaning that graphite inventions for carbon brushes are a recent phenomenon. The overall number of patent families from the rest of the world filed between 2012–2021 is much lower than was filed between 1992–2001 and 2002–2011, respectively (Annex Figure C1), indicating that carbon brush technology has entered the final stage of its technology cycle and is in decline.

The top patenting entities outside of China were mainly global suppliers of either carbon brushes or automotive parts (Table 16). For example, top applicant Eesavyasa Technologies is an India-based supplier of industrial products. Its recent inventions include graphite abrasive brushes for ultra-low energy, direct-current motors for blowers and agricultural equipment described in patents IN0067/CHE/2013 and IN0070/CHE/2013. South Ural State University – one of the top Russian Federation universities – is also among the top applicants, with four patent families. One of its recent inventions relates to a graphite-plastic powder composition for improving the working surface hardness of carbon brushes (RU2682985C1).

Figure 27. **Number of graphite patent families related to carbon brushes, by year of filing, China and the rest of the world, 2012–2021.**
Patent families relating to graphite for carbon brushes have been sporadic in the last decade globally, indicating that the technology has reached the decline stage of development.





Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Table 16. Top applicants for carbon in carbon brushes, China and the rest of the world.
Interest in graphite for carbon brushes was observed in a few players only.

China		Rest of the world	
Suzhou Donon Carbon Products	22	Eesavyasa Technologies	4
Suzhou Donsun Carbonware	16	South Ural State University	4
Datong Xincheng New Materials	12	Showa Denko	3
Hefei Lanke New Materials	10	Schunk Carbon Technology	3
Anhui Tianyu Electromechanical	10	Mitsuba Corporation	2
Chongqing Hehai Carbon Products	9	TRIS, Inc.	2

Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Water treatment

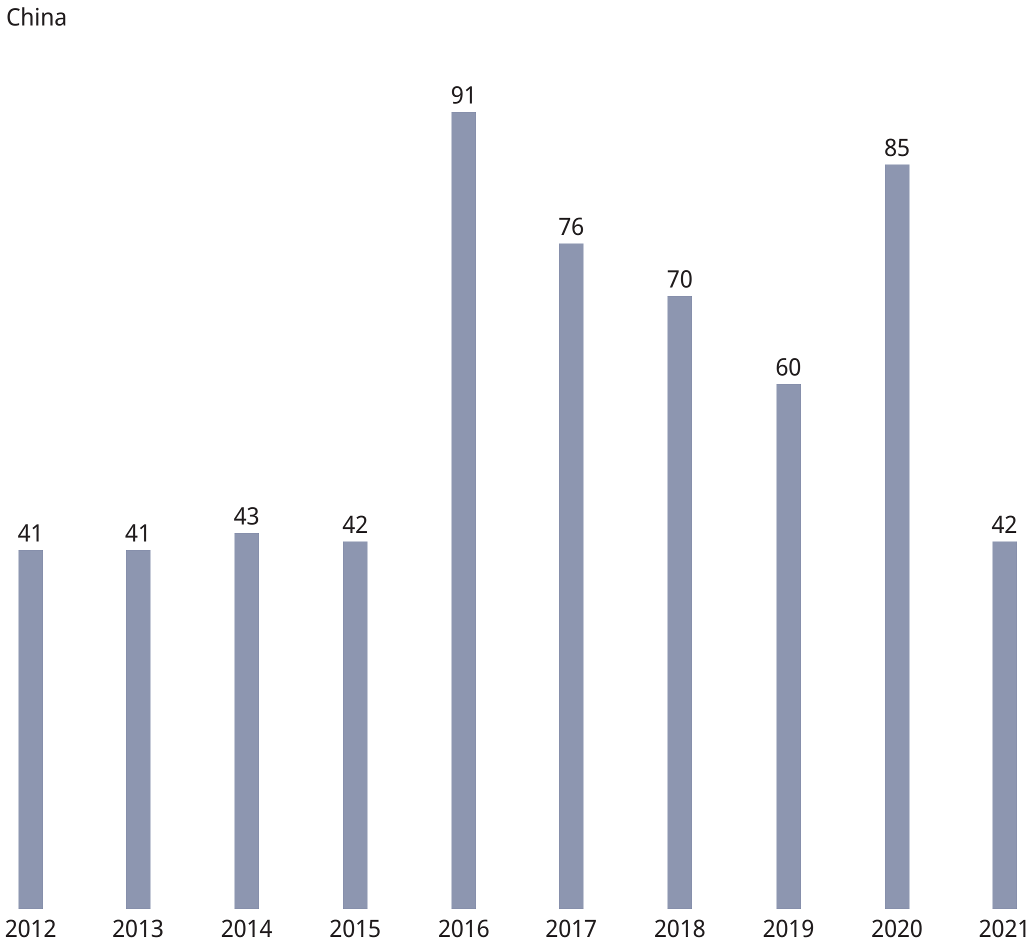
Graphite has excellent adsorption properties. This is particularly the case for expanded graphite, whose rich pore structure is an ideal microbial carrier. In liquid phase adsorption, graphite materials have a better adsorption effect than does activated carbon. Owing to its non-polarity, graphite is lipophilic and hydrophobic in liquid and thus ideal for water treatment, especially for water contaminated by oil or organic macromolecules. In 1997, when there was an offshore oil spill near Fukuoka, Japan, expanded graphite was used to remove oil pollution from the seawater and achieved good results.

Graphite-based nanomaterials, such as graphene, are also excellent candidates for filtration and separation, owing to their large specific surface area, controllable functional groups and engineerable porous microstructure affording channels for the selective transport of water, ions or gas molecules. For example, UT Battelle, a non-profit company based in Tennessee, that manages and operates the Oak Ridge National Laboratory for the United States Department of Energy, has developed a distillation membrane made of a porous graphitic foam with a superhydrophobic coating for highly efficient solar-thermal desalination (US10946340B2).

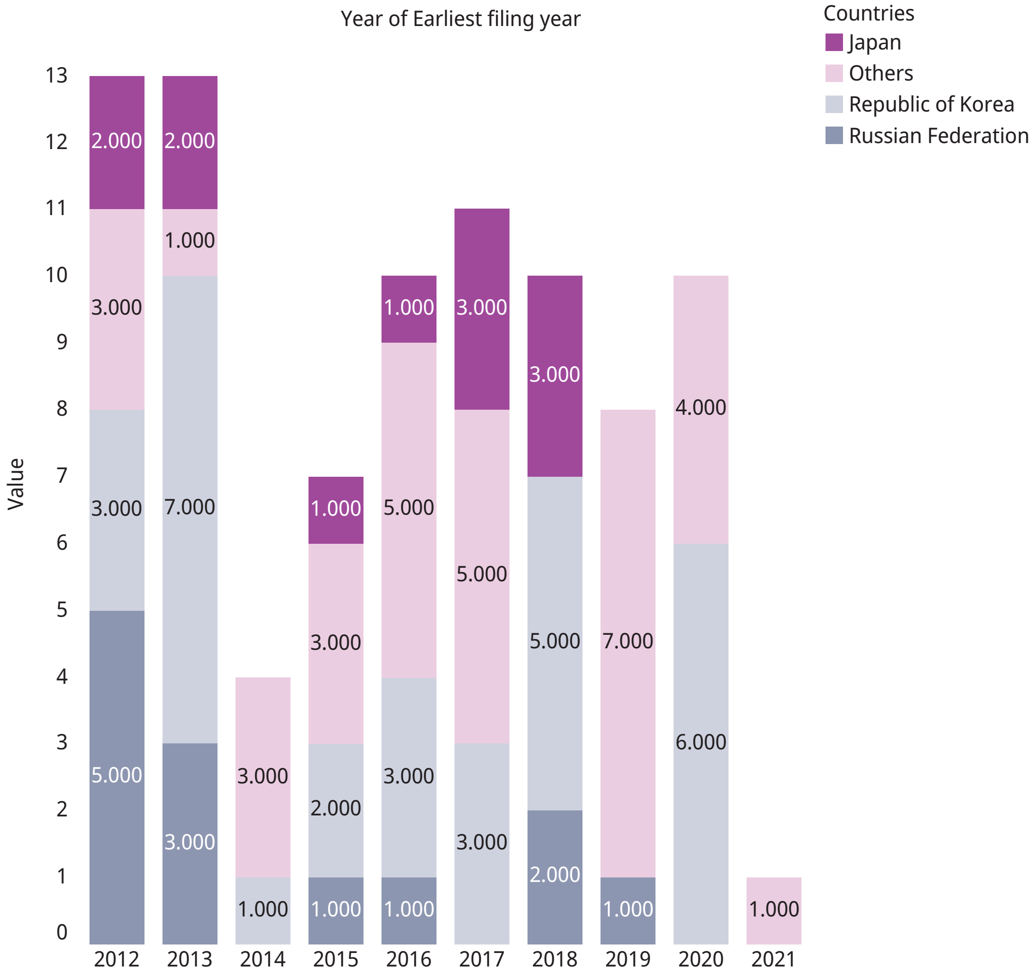
Globally, almost 700 patent families related to graphite for water treatment were filed from 2012 to 2021. While the overall number is modest, such a niche application has gained consistent innovation traction worldwide (Figure 28). However, graphite for water treatment constitutes only a small part of the highly competitive water treatment industry, where sorption technologies for treating liquid pollutants alone registered more than 35,000 inventions during the same period (IPOS International, 2022).

Notably, universities and research organizations from China, the Republic of Korea and the Russian Federation were among the top applicants (Table 17). Their research relates strongly to novel applications, such as graphene-based filtration or desalination, both of which are relatively new areas at the initial research and development stage.

Figure 28. **Number of graphite patent families related to water treatment, by year of filing, China and the rest of the world, 2012–2021.**
Water treatment is a niche application area attracting consistent innovation interest worldwide.



Rest of the World



Japan, Others, Republic of Korea and Russian Federation for each Earliest filing year Year. Color shows details about Japan, Others, Republic of Korea and Russian Federation. The marks are labeled by Japan, Others, Republic of Korea and Russian Federation. Details are shown for Japan, Others, Republic of Korea and Russian Federation.

Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Table 17. Top applicants in graphite for water treatment, China and the rest of the world. *Universities and research organizations from China, the Republic of Korea and the Russian Federation were among the top applicants.*

China		Rest of the world	
Beijing University of Technology	12	Jukam Co. KR	4
Beijing University of Chemical Technology	12	Korea Institute of Energy Research	2
Hohai University	11	Korea Maritime and Ocean University	2
Beijing Yiqingyuan Environmental Protection Technology	10	Chelyabinsk State University	2
Qingdao Guoqiang Environmental Protection Technology	10	Showa Denko	2
Tongji University	10	General Electric	2

Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Biomedical

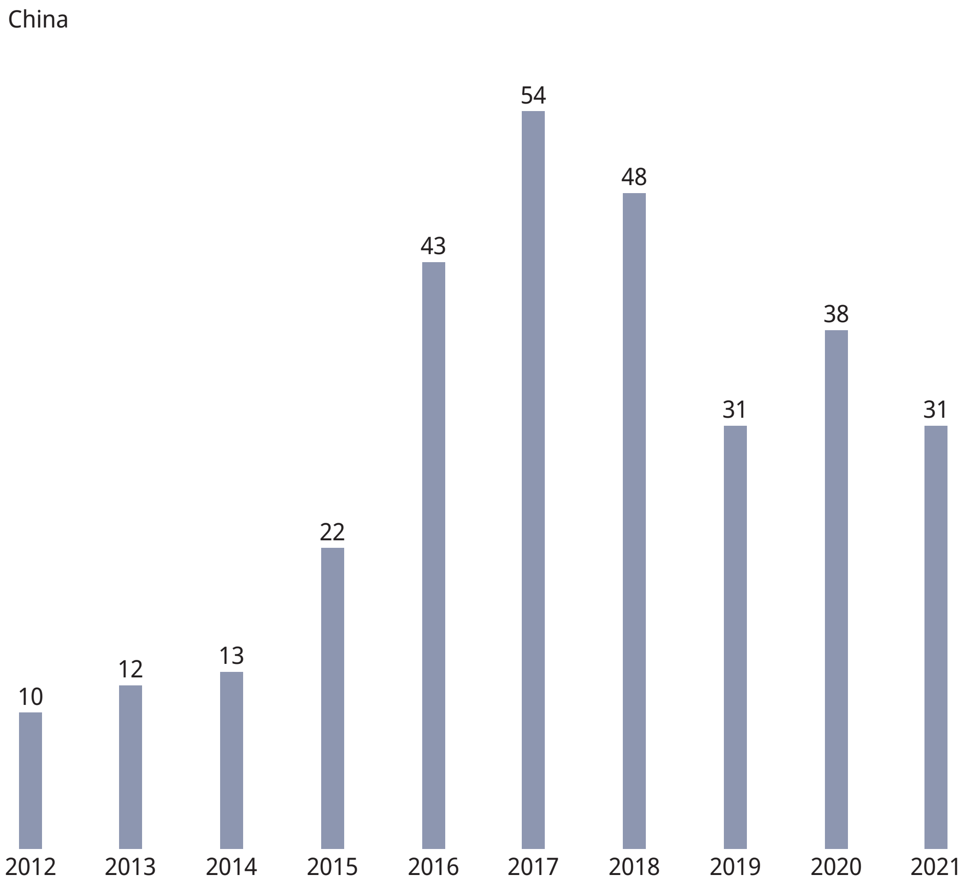
Graphite has a wide range of biomedical applications, owing to its non-toxicity and good adsorption of organic and biological macromolecules. For example, expanded graphite used as a medical dressing instead of gauze has proven to be non-toxic, non-irritating to the wound surface and free of side effects, and can promote wound healing. This is exemplified by the high-performance medical dressing made of expanded graphite (CN109200327A) filed by Suzhou Gaide Fine Material, a fine chemicals supplier based in China. In addition, graphite is used for other biomedical applications, including in radiation therapy, physical therapy, prostheses, medication and for specific steel compositions for surgical implements.

Graphite for biomedical purposes represents an emerging application area, with about 500 patent families having been filed globally from 2012 to 2021 (Figure 29). High relative recency values (see Figure 15) indicate that inventions in this area are, on average, more recent worldwide. In particular, graphite nanomaterials – for example, graphene – are being increasingly explored for biomedical applications and account for one-quarter of patent families in this area. For example, in patent publication US20140248214A1, filed by Northwestern University in the United States, graphene-based aqueous dispersions are used as a drug delivery or imaging contrast agent *in vivo*. Researchers from Zhejiang Sci-Tech University have meanwhile used graphite to make graphene oxide for the preparation of nanomedicine carriers with better biocompatibility and targeted delivery (CN107010616A).

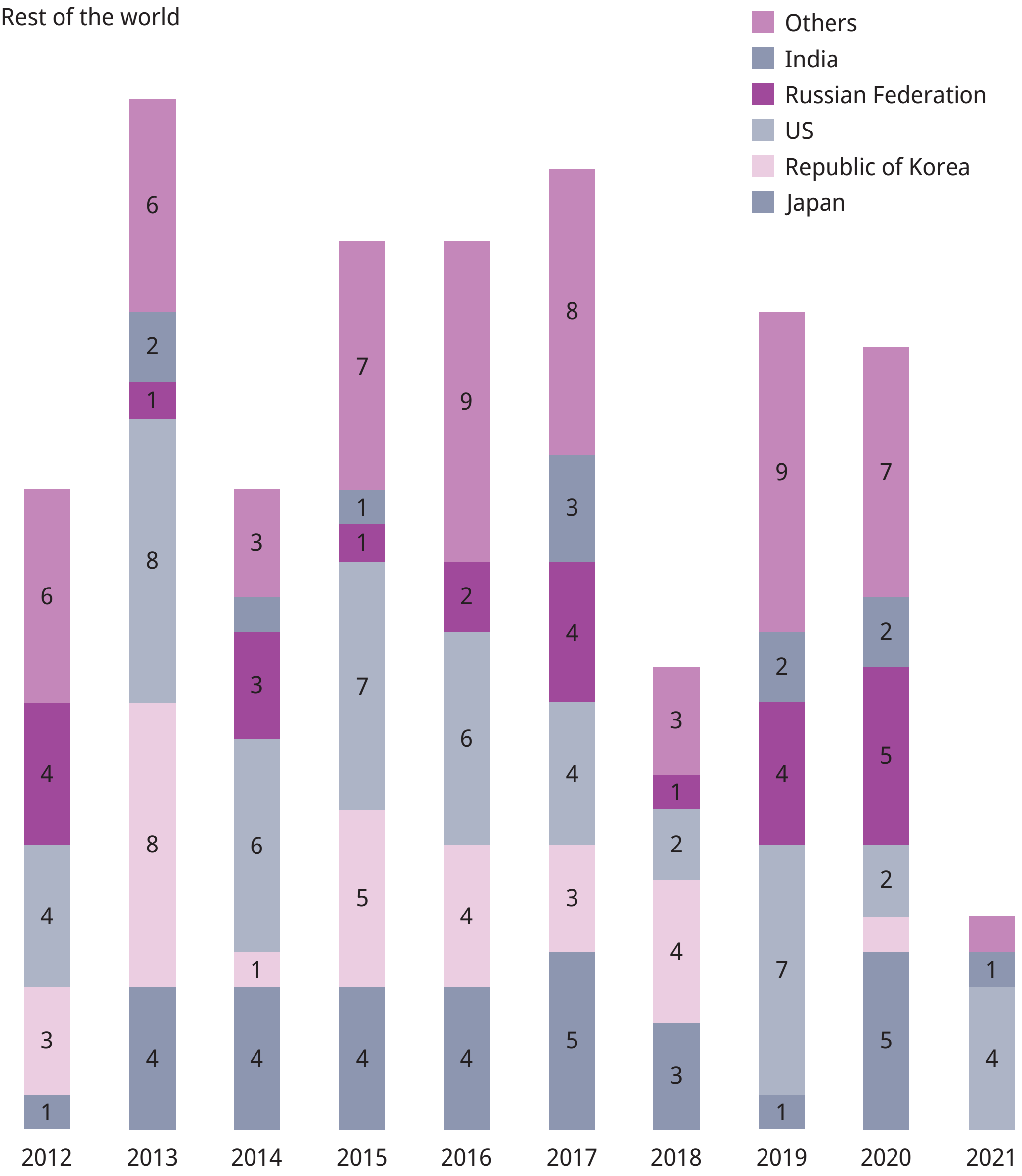
Top applicants were almost equally divided between commercial entities and academic players all with a small number of patent families (Table 18). This is typical of an emerging area, where related patent families are filed by various organizations exploring graphite-based materials for diverse biomedical applications. In an invention filed by two applicants, Hefei CAS Ion Medical and Technical Devices and the Institute of Plasma Physics, Chinese Academy of Sciences (CN109224321A), graphite is used as an energy degrader in a synchrocyclotron-based, proton heavy particle therapy system. In another invention (BR102013034036A2, see Figure 30), filed by Empresa Brasileira de Pesquisa Agropecuaria – Embrapa and the Federal University of São Carlos , both from from Brazil, discloses a process for obtaining magnetic biohybrid films using magnetic graphite nanoparticles and alginate biopolymer for controlled drug release.

Among leading commercial players in this area were Denka, one Japan's top graphite suppliers, and Medtronic, a world-leading medical device company based in the United States. In addition, Kunshan YuanKe Hongsen Metal and Shenzhen Tanmei Medical are also pioneers in this area. These two Chinese companies specialize in graphite-steel compositions for surgical implements and carbon-based materials for infrared physiotherapy, respectively.

Figure 29. **Number of graphite patent families related to biomedical applications, by year of filing, China and the rest of the world, 2012–2021.**
The emerging use of graphite for biomedical applications has attracted consistent interest worldwide, albeit the number of patent families is small.



Rest of the world



Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Table 18. **Top applicants in graphite for biomedical applications, China and the rest of the world.**

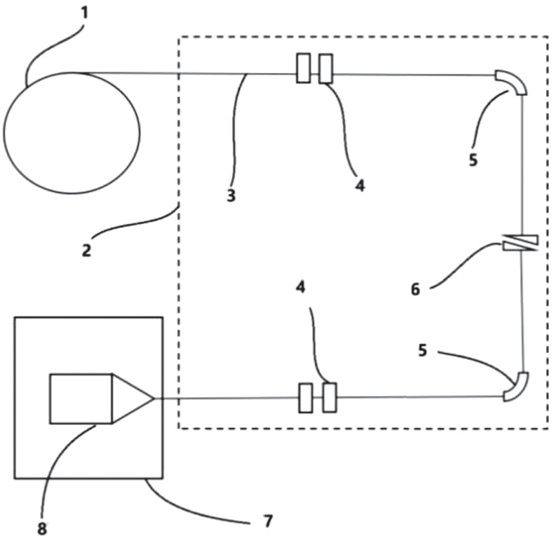
Graphite inventions for biomedical applications have been filed by applicants from different backgrounds, including by medical companies, graphite suppliers and academic players.

China		Rest of the world	
Kunshan Yuanke Hongsen Metal	10	Denka	6
Chinese Academy of Sciences	7	Kaneka	5
Shenzhen Tanmei Medical	7	Medtronic	3
Zhejiang Sci-Tech University	7	Federal University of São Carlos	3
Central South University	5	Chelyabinsk State University	2

Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Figure 30. **Graphite degrader used in a radiotherapy system, as described in a patent application (CN109224321A).**

The invention describes a proton heavy-particle therapy system that uses a synchrocyclotron to accelerate protons or heavy ions to the energy level required for treatment. Beam energy output is continuously adjustable through an arranged graphite energy reducer.



1 – Synchrocyclotron main body
2 – High-energy transit
3 – Drift section
4 – Four-level magnet
5 – Two-level magnet
6 – Graphite-based energy selector
7 – Mono-therapeutic room
8 – Rotary frame

Source: Patent application CN109224321A.

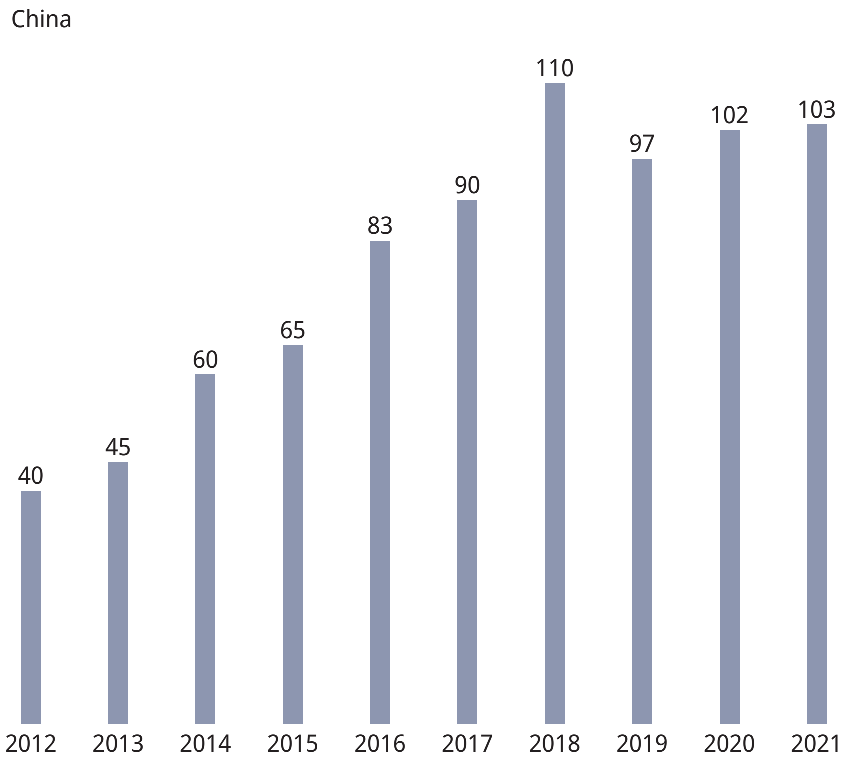
Sensors

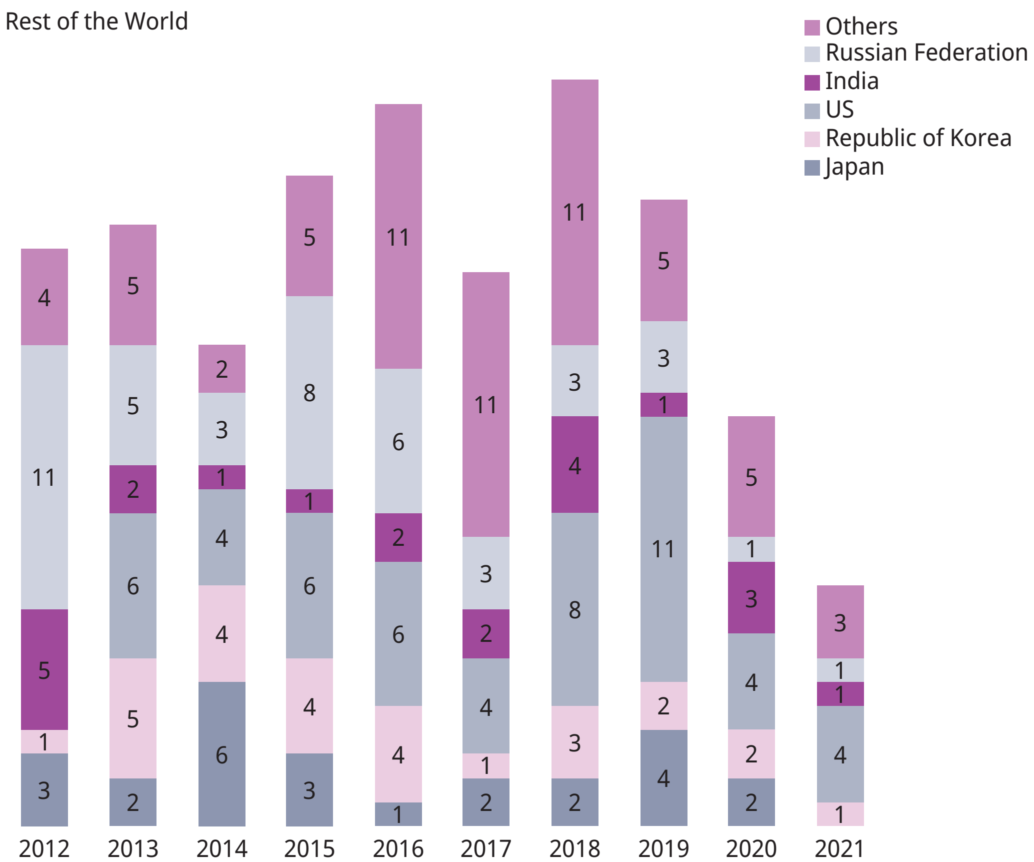
Like biomedical applications,graphite for sensors is an emerging area (see Figure 15), with patenting momentum strong worldwide. Globally, over 1,000 patent families were filed in the area of graphite-based sensors between 2012–2021. Patenting activity in China and the rest of the world points to a consistent interest in using graphite for sensors (Figure 31). In particular, about a hundred related patent applications were filed in China annually from 2018 to 2021, which is about two times the annual patenting output in 2012 and 2013.

Overall, graphite for sensor applications is developing, with universities and research institutes having contributed to over half of patent families (Figure 32). As a result, top applicants were mainly from academia, except for ABB (Table 19). Compared to commercial entities, universities and institutes typically engage in basic research, thereby leveraging their expertise in material science and applied physics.

Based on the patent information, the innovation focus is highly scattered and mostly stems from opportunistic rather than systematic research. For example, graphite-based materials or electrodes have been used for pH sensing, as illustrated in the joint patent application by ABB and the University of Idaho US2020/0284747A1 **(**Figure 33**)**, or to detect precious metals, such as gold, platinum and rhodium in aqueous solutions, as described by Tomsk Polytechnic University in patents RU2494385C1, RU2013152248A and RU2624789C1. Other sensor inventions include the use of graphite in combination with other materials, including for an amperometric nitrate sensor based on a cobalt-coated graphite electrode invented by the King Fahd University of Petroleum and Minerals (US2015/0276647A1), as well as for a ZrN/graphite electrochemical sensor disclosed by the University of Jinan (CN108645901A).

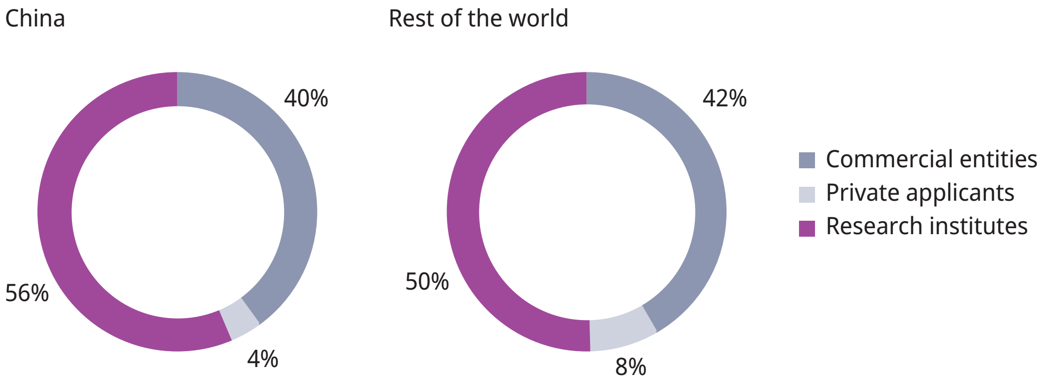
Figure 31. Number of graphite patent families related to sensor applications, by year of filing, China and the rest of the world, 2012–2021.
Graphite for sensor applications is an emerging area, with strong patenting momentum observable, particularly in China.





Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Figure 32. **Patent applicant profiles for graphite sensor applications, China and the rest of the world.**
Graphite for sensor applications is at the developing stage, with universities and research institutes contributing more than half of patent families.



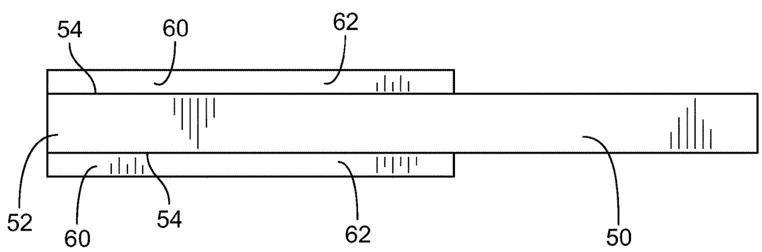
Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Table 19. **Top applicants in graphite for sensor applications, China and the rest of the world.**
The top applicants in both China and the rest of the world were mainly academic players.

China		Rest of the world	
Chinese Academy of Sciences	17	Tomsk Polytechnic University	17
University of Jinan	17	King Fahd University of Petroleum and Minerals	11
Zhejiang University	12	ABB	6
Huainan Normal University	11	Amity University	5
Xi'an Polytechnic University	10	Universidade Federal de Uberlândia	4

Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Figure 33. **Pseudo-graphite used in the making of a chemical oxygen-demand sensor disclosed in a patent application (US2020/0284747A1) filed by ABB and the University of Idaho.**
The invention relates to a novel chemical oxygen-demand sensor by coating a pseudo-graphite material (reference no. 54) onto the surface (reference no. 52) of an electrode substrate (reference no. 50). The pseudo-graphite may be modified with an electrochemically sensitive material (reference no. 62), in order to alter the sensing property of the electrode in aid of enhanced organic species detection.



Source: Patent application US2020/0284747A1.

Conductive ink

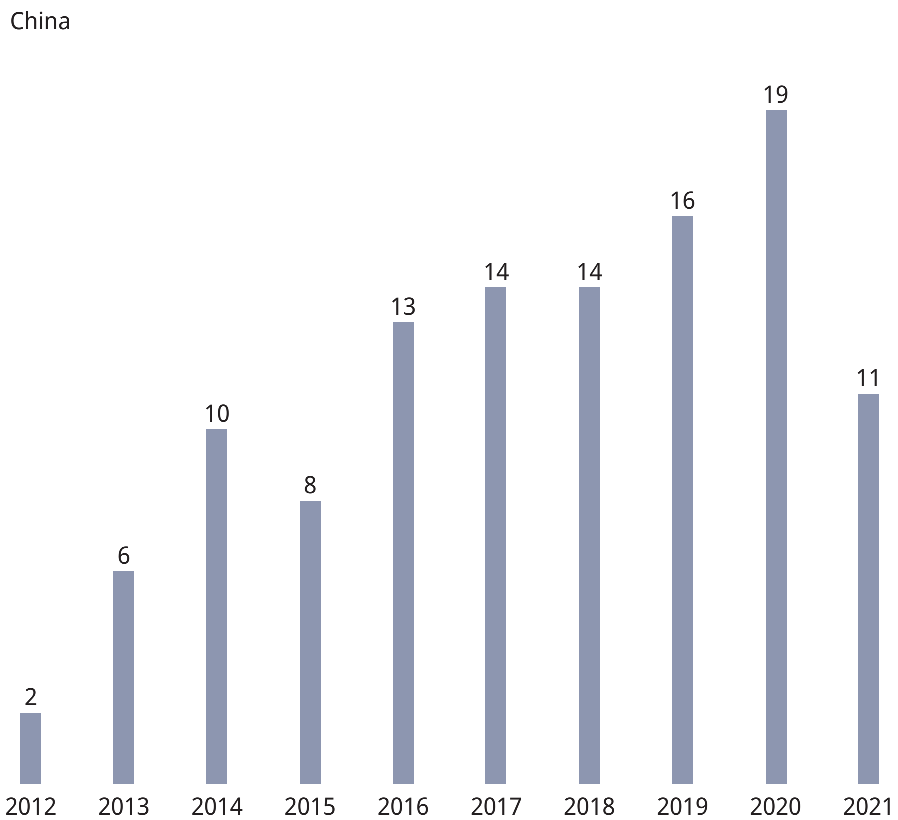
Conductive inks are composed of metallic or conductive particles suspended in solvents and can be printed directly onto various materials to conduct electricity. Unlike the conventional method of making printed circuit boards in which copper layers are etched away in a subtractive process, conductive inks can be printed in a straightforwardly additive manner. They have been applied in the manufacturing of photovoltaic cells, touch screens, radiofrequency identification, wearable or textile electronics, flexible devices and even 3D-printed electronics.

Silver conductive ink is the current mainstream product, because of its high degree of conductivity and oxidation resistance; graphite and other carbon-based materials are among the alternatives. Graphite for conductive ink applications is a less explored area, with under 200 patent families filed in the survey period. However, it has recently gained traction fast, particularly in China (Figure 34). An upward trend in patenting is especially noticeable between 2015–2020, though the overall number of patent families remains small. Similar to the scenario in China, graphite-related inventions for ink applications in the rest of the world are relatively new and register a higher recency score in the Innovation Maturity Matrix (see Figure 15).

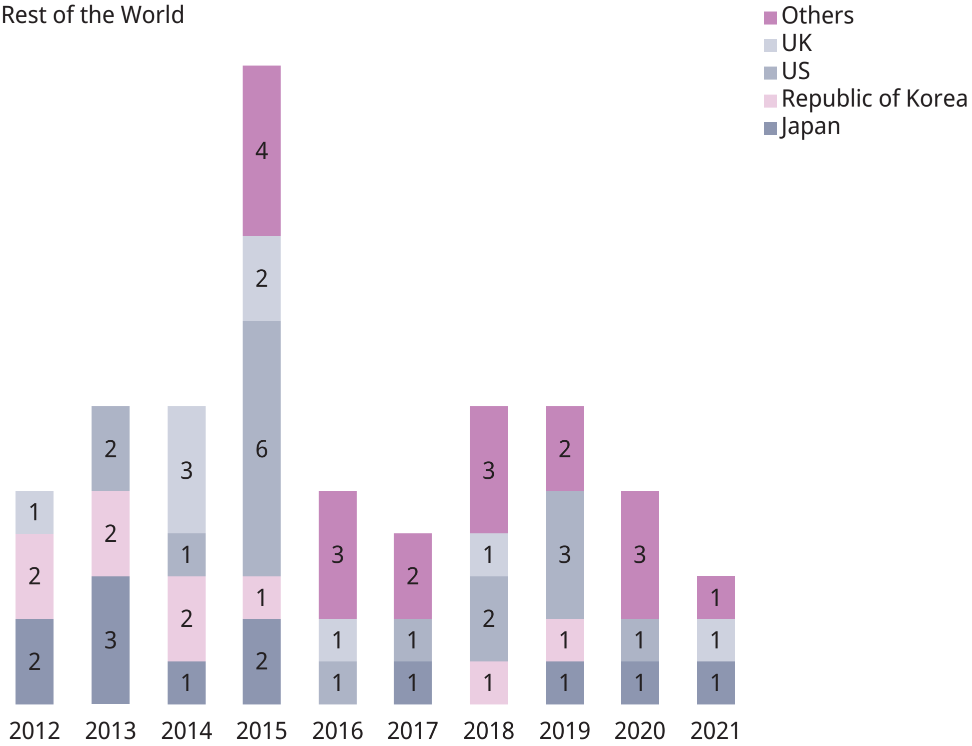
Recent inventions leverage the development of graphene materials. Specifically, about half of the patent families relate to graphene dispersants as a conductive ink composition. Graphene has excellent mechanical strength and constitutes a conductive ink with better flexibility and extensibility. In addition, it is transparent and has high electrical conductivity. Together, these unique features have made graphene-based conductive inks the preferred choice over their metallic counterparts for flexible and wearable electronic devices. For example, in one frequently cited patent application (US2015/0337145A1), researchers from Cambridge University (applicant is Cambridge Enterprise, a part of Cambridge University) disclose a method of dispersing graphene derived from pristine graphite in the making of conductive functional inks (Figure 35).

Overall, graphite application in conductive inks is an emerging area that has attracted interest from both academia and commercial entities, including renowned multinational corporations like Samsung Electronics and LG Chem. It is presently at the initial stage of development, where even top players have only a small number of patent families (Table 20). It will be interesting to see whether this area goes onto gain more traction, particularly from the research community.

Figure 34. Number of graphite patent families related to conductive ink, by year of filing, China and the rest of the world, 2012–2021.
Graphite for conductive ink applications has fast gained traction, particularly in China.



Rest of the World



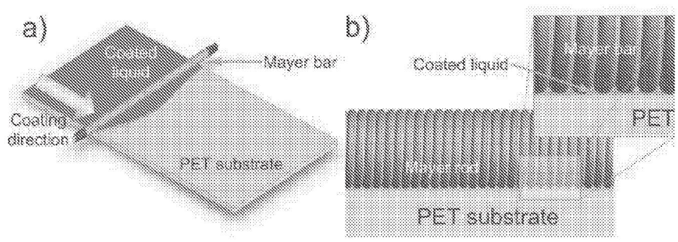
Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Table 20. **Top applicants for graphite in conductive ink, China and the rest of the world.**
Graphite applications as conductive ink is an emerging area that has attracted interest from both academia and commercial entities.

China		Rest of the world	
Shanghai Baoyin Electronic Materials	4	Toyo Ink	6
Guangdong Kangxi Technology	3	Graphene Platform	3
Huarui Moshi Danyang	2	Cambridge Enterprise	2
Qilu University of Technology	2	LG Chem	2
Shenzhen Guochuang Jiawei Graphene Technology	2	Samsung Electronics	2

Source: WIPO, based on patent data from Questel Orbit up to May 2022.

Figure 35. **Pristine graphite as the source material for making conductive inks, as described in a patent application (US2015/0337145A1) filed by Cambridge Enterprise, part of Cambridge University .**
Graphene dispersion prepared by graphite exfoliation is applied to produce an electrically conductive and optically transmissive printed layer. The conductive ink can also be tailored for different printing processes.



Source: Patent application US2015/0337145A1.

Endnote

1 The Innovation Maturity Matrix is a proprietary method developed by the patent analytics team of the Intellectual Property Office of Singapore.

Conclusion

Graphite has become a valuable and important mineral in the advancement of science and technology, since the discovery of a large deposit back in the 16th century. It is encountered everywhere in our daily lives, from pencils and batteries to dry lubricants and car brakes. It is also essential in steelmaking, metal casting and many other industrial sectors. Increasingly, graphite is being explored for use in novel applications, including in the manufacture of graphite nanocomposites and graphene, and for new applications, for example, in the biomedical area and sensors.

The wide range of graphite applications has stemmed from an intensive research and development effort worldwide. Patent filings for graphite-related technologies have originated from over 60 countries across every region. However, although this suggests graphite innovation is global, it is actually the case that graphite-related patent families originate predominantly from just a few countries. Specifically, the top five applicant origins are China, Japan, the Republic of Korea, the United States and the Russian Federation. Together, they account for the vast majority (95 percent) of global patenting output.

China is dominant among the top five applicant origins, responsible for four in every five graphite patent families filed worldwide in the last decade. It is most active in the exploitation of flake graphite, being home to the world's second-largest reserve of natural graphite and the primary supplier of flake graphite to the global market. Artificial graphite, on the other hand, is a well-explored alternative to natural graphite, especially in countries without a rich natural reserve, such the Republic of Korea.

Battery applications were the key driver of graphite technologies, accounting for 10–15 percent of global graphite production. Among all graphite uses and products, graphite for battery applications is the one that has attracted the most intensive patent filing, with over 8,000 patent applications filed from 2012 to 2021. Such a high level of patenting activity is expected to continue, as the global effort to fight climate change intensifies. In particular, the explosive market growth of EVs and large-scale energy storage will demand more graphite innovations; for example, novel graphite-based anode solutions with greater energy density and better performance.

The two other application areas that recorded intense patent activity were ceramics and heat dissipation. Ceramic applications have remained an active patenting field, attributable to their indispensable role in refractory applications. In addition, novel graphite-filled ceramic materials and composites have been explored for a broad range of uses, including in automotive and power machinery applications. Graphite for heat dissipation is one of the few areas where the rest of the world has shown a comparable patenting output to China, with substantial contributions coming from Japan, the Republic of Korea, the United States and Taiwan Province of China. As the level of power dissipation has increased owing to a continual performance improvement in electronics, research has shifted toward novel graphite-based compositions and microstructures for better heat dissipation performance.

Unlike current application hot topics, namely, batteries, ceramics and heat dissipation, where vigorous patenting activity can be expected to continue, graphite for polymers and lubrication is considered well-explored. Despite each having a high number of patent families, patenting activity in both areas has undergone a pronounced decline over recent years. Another well-studied area is graphite application in carbon brushes, which is likely to have already reached the end of its technological development, having gained minimal traction globally, with less than 300 patent families registered from 2012 to 2021.

Graphite for biomedical purposes represents an emerging application area. Typically for an emerging area, it has gained traction from both commercial entities and research institutions, though neither grouping has yet accumulated a strong patent portfolio. The biomedical research focus is wide, ranging from radiation therapy, physical therapy and medication to prostheses and specific steel compositions for surgical implements.

Graphite for sensor applications is likewise at the developing stage, with universities and research institutes contributing to over half of patent families. Based on patenting information, the innovation focus is highly scattered and mostly stems from opportunistic rather than systematic research.

Lastly, novel graphite applications have leveraged the development of graphite nanomaterials, particularly graphite nanocomposites and graphene. Emerging interest in applying these nanomaterials to water treatment and for use in conductive ink has become apparent in the last decade.

Annex A: Methodology

Dataset

The final dataset of graphite-related inventions was retrieved on May 30, 2022. The dataset consists of patent applications published worldwide from 2012 to 2021, retrieved from the Questel Orbit database.

Search string

To ensure the optimal recall and accuracy of the dataset retrieved, the search strings used in this report were formulated incorporating keywords, their synonyms and variants, relevant patent classification codes and indexing, for example, International Patent Classification (IPC) and Cooperative Patent Classification (CPC). Detailed lists of main keywords and the patent classification codes used are presented in Annex B.

Grouping by the FAMPAT patent family

In this report, the number of unique inventions is measured using the Orbit Intelligence FAMPAT patent family counts.

A FAMPAT family groups together all publications for patents of a single invention, and is constructed using the following rules:

- Patents sharing the exact same priority number(s) are grouped in the same FAMPAT family.
- Any national phase of a PCT application (WO) is included in the family of its PCT parent.
- Any national phase of a European patent (EP) is included in the family of its EP parent.
- Japanese applications that, when combined together, are equivalent to a European or North American application, are grouped in the same family.
- Non-US applications claiming priority to a US provisional application are grouped with the respective US application(s). Without a US publication, this US provisional is ignored.
- Any EP divisional application will be grouped with its parent EP.

Source: Orbit Intelligence, FAMPAT family construction rules.

Data cleaning

Systematic data cleaning and manual review were carried out in order to:

1. remove non-patent specification, for example, utility models; and
2. ensure the relevance of the dataset prior to carrying out the analyses.

Grouping of technology domain and areas

Grouping of patent families belonging to the retrieved dataset into the respective technology domains and areas was carried out based on patent classifications codes, text-mining and the semantic analysis of patent specifications, in particular, the titles, abstracts and patent claims, as well as a manual review of the individual patent applications.

Compound annual growth rate

Compound annual growth rate (CAGR) is used in this report to measure the annual growth rate of patenting activities over a period of time.

Formula

$$CAGR = \left(\frac{N_{last}}{N_{first}}\right)^{\frac{1}{y}} - 1$$

where

N_{first} and N_{last} are the numbers of patent applications in the first and last year, respectively, and y is the duration of the survey period in years.

Regional specialization index

The regional specialization index (S_{is}) in this report is used to investigate the top countries of patent origin and their invention focus across different technology areas. It is calculated by the percentage of inventions related to a specific technology area over the total number of inventions filed by applicants in the countries.

Formula

$$S_{is} = \frac{w_{is}}{w_i}$$

where

w_{is} is the number of inventions related to a specific technology area originating from the country or region *i*,
W_i is the total number of graphite-related inventions filed by applicants in the region *i*.

Recency

Recency in this report measures quantitatively how recently technologies were first filed for patent protection (developed). It is calculated by a weighted average of inventions, whereby a higher weighting is given to inventions filed in more recent years.

Formula

$$\bar{R} = \frac{\sum_{i=1}^{n}(w_i \times i)}{n \times \sum_{i=1}^{n} w_i}$$

where

i = 1 for the first year of the survey period, and *i* increases by 1 for every subsequent year in chronological order;
n is the total number of years of the survey period; and
w_i is the number of inventions filed in the year.

Relative recency

Refers to normalized recency by taking the recency of the entire graphite-related technology dataset to be 1.

Annex B: Patent searches

Overall dataset

A main query comprising two sub-queries was first established to retrieve an overall dataset for all graphite-related patent applications, with the following search characteristics:

- patent coverage: worldwide patent applications in the Orbit Intelligence patent database;
- time frame: 2012–2021 (based on a patent family's the earliest application year);
- combination of two searches, as shown in Table A1:

    1. patent specifications with the keyword "graphit+" in either the Title or Abstract. Note that the search excluded the specific combination of "graphite alkene," which is used in some countries for graphene instead of graphite;
    2. search combining the keyword "graphit+" in either the Title, Abstract or Claims AND a patent classification code related to graphite technologies.

This main dataset was the basis for all the analyses, once utility models were removed (which accounted for about 30 percent of the dataset, resulting in about 62,000 patents).

Table A1. Search queries for the overall dataset.

Query No.	Orbit Search Query	Results * (FAMPAT families)
#1	(GRAPHIT+ NOT (GRAPHITE W ALKENE))/TI/AB AND EPRD=2012:2021	86,438
#2	(A61F-2310/00173 OR A61F-2310/00586 OR B01J-2203/061 OR B01J-2219/0227 OR B01J-2219/0272 OR C01B-031/04 OR C01B-032/192 OR C01B-032/20 OR C01B-032/205 OR C01B-032/21 OR C01B-032/215 OR C01B-032/22 OR C01B-032/225 OR C01B-032/23 OR C04B-014/024 OR C04B-2235/425 OR C04B-035/522 OR C04B-035/536 OR C09C-001/46 OR C21C-001/10 OR C21D-2211/006 OR C22C-037/04 OR F16C-2202/52 OR F16C-033/16 OR F16K-017/1633 OR F16N-015/02 OR F27D-2009/0059 OR H01J-2201/30461 OR H01J-2329/0449 OR Y10S-148/068)/IPC/CPC AND (GRAPHIT+)/TI/AB/CLMS AND EPRD=2012:2021	12,280

*Results as of May 30, 2022.

Grouping of technology areas

Main keywords used

- flake graphite; amorphous / cryptocrystalline graphite; vein / lump graphite; synthetic/ artificial / man-made graphite
- mechanical / chemical / mechanochemical **and** exfoliate / strip / peel / shear / treatment; ultrasonic / supersonic **and** exfoliate / strip / peel / shear / treatment; electrochemical exfoliate / strip / peel / shear / treatment; thermal / heat / high-temperature **and** exfoliate / strip / peel / shear
- micro / nano graphite; spherical graphite; expanded / expandable graphite; graphite powder; graphite foil / sheet / film; graphite composite/nanocomposite; graphene
- battery, secondary cell, energy storage, fuel cell, capacitor, supercapacitor; automotive, automobile, aeroplane, aircraft, drone; sensor, sensing detector; conductive ink; carbon brush; lubrication; photovoltaic, photo energy, solar cell; wind energy / power / electricity; armor, Kevlar, structural materials; paint, coating; mold, molding, casting, die; heat dissipation, thermal / heat conductivity, heat / thermal exchange; bio, medical, treatment, patient, surgery, medicine, drug; water / waste water / sewage **and** treatment / purification / filtration; sealing, gasket, washer, carbon ring.

Main IPC/CPC used

- A61F 2310/00173, A61F 2310/00586, A61L 28/0084, A61L 29/103, A61L 31/122, A61L 2300/108, A61L 2420/00, A61L 2430/00
- B01J 2203/061, B01J 2219/0227, B01J 2219/0272, B32B 2264/00, B32B 2264/10, B32B 2264/12, B32B 2264/30, B32B 2264/40, B32B 2264/50, B43K 19/02
- C01B 31/04, C01B 32/192, C01B 32/20, C01B 032/205, C01B 032/21, C01B 32/215, C01B 032/22, C01B 032/225, C01B 032/23, C03B 2205/63, C03B 2205/64, C03B 2215/24, C03C 25/44, C04B 14/024, C04B 2235/425, C04B 35/522, C04B 35/536, C04B 38/068, C04B 41/5005, C09C 1/0045, C09C 1/46, C09C 2200/10, C10M 103/02, C10M 113/02, C10M 125/02, C10M 2201/041, C10M 2201/042, C21C 1/10, C21D 2211/006, C22C 32/0084, C22C 33/0228, C22 C37/04
- F16C 2202/52, F16C 33/16, F16K 17/1633, F16N 15/02, F27D 2009/0059,
- H01J 2201/30461, H01J 2329/0449, H01L 2224/00, H01L 2924/00, H01M 4/625, H01M 8/0234
- Y10S 148/068, Y10S 277/938, Y10S 516/901

Table A2. Search queries for graphite sources, processes, derivatives, uses and products.

Step	*Query*	Remark
1	(GRAPHIT+ NOT (GRAPHITE W ALKENE))/TI/AB AND EPRD>=2012	Overall dataset – Query 1
2	(A61F-2310/00173 OR A61F-2310/00586 OR B01J-2203/061 OR B01J-2219/0227 OR B01J-2219/0272 OR C01B-031/04 OR C01B-032/192 OR C01B-032/20 OR C01B-032/205 OR C01B-032/21 OR C01B-032/215 OR C01B-032/22 OR C01B-032/225 OR C01B-032/23 OR C04B-014/024 OR C04B-2235/425 OR C04B-035/522 OR C04B-035/536 OR C09C-001/46 OR C21C-001/10 OR C21D-2211/006 OR C22C-037/04 OR F16C-2202/52 OR F16C-033/16 OR F16K-017/1633 OR F16N-015/02 OR F27D-2009/0059 OR H01J-2201/30461 OR H01J-2329/0449 OR Y10S-148/068)/IPC/CPC AND (GRAPHIT+)/TI/AB/CLMS AND EPRD>=2012	Overall dataset – Query 2
3	(1: 2)	Overall graphite dataset
4	3 AND ((BATTERY OR BATTERIES) NOT (FLOW_BATTER+))/TI	Battery
5	3 AND ((BATTERY OR BATTERIES) NOT (FLOW_BATTER+))/TI/AB/CLMS	Battery
6	3 AND (H01M-002+ OR H01M-006+ OR H01M-050+)/IPC/CPC	Battery
7	3 AND (BATTERY OR BATTERIES)/KEYW AND (H01M-004+ OR H01M-010+ OR Y02E-060/10)/IPC/CPC	Battery
8	3 AND (FUEL_CELL? OR FLOW_BATTER+ OR REDOX_BATTER+)/TI	Fuel cell
9	3 AND (FUEL_CELL? OR FLOW_BATTER+ OR REDOX_BATTER+)/TI/AB/CLMS	Fuel cell
10	3 AND (FUEL_CELL? OR FLOW_BATTER+ OR REDOX_BATTER+)/KEYW AND (H01M-008+ OR H01M-2250+ OR Y02E-060/50)/IPC/CPC	Fuel cell
11	3 AND (+CAPACITOR+)/TI	Capacitor
12	3 AND (+CAPACITOR+)/TI/AB/CLMS	Capacitor
13	3 AND (Y02E-060/13)/IPC/CPC	Capacitor
14	(8: 10)	Fuel Cell
15	(4 NOT 14) OR (5: 7 NOT (11 OR 14))	Battery
16	11 OR ((12: 13) NOT (4 OR 8))	Capacitor
17	3 AND (H01M OR Y02E-060+)/IPC/CPC	
18	(14: 17)	All energy storage
19	3 AND (B60+ OR Y02T-010+)/IPC/CPC	Automotive
20	3 AND (B64+ OR Y02T-050+)/IPC/CPC	Aerospace
21	3 AND (B61+ OR Y02T-030+ OR B63+ OR Y02T-070+)/IPC/CPC	Rail and marine transport
22	(19: 21)	All transport
23	3 AND (G01N-027+ OR B82Y-015+)/IPC/CPC	Sensors
24	3 AND (+SENSOR? OR +SENSING+ OR DETECT+)/TI	Sensors
25	(23: 24)	Sensors
26	3 AND ((INK OR INKS)/TI OR C09D-011+/IPC/CPC)	Inks
27	3 AND ((CONDUCTIVE 3W (INK OR INKS))/TI/AB OR (C09D-011/52+)/IPC/CPC)	Conductive ink
28	3 AND D0+/IPC/CPC	Textiles
29	3 AND (((BRUSH???)/TI/AB AND (H02K OR H01R)/IPC/CPC) OR ((CARBON OR GRAPHITE) 2W BRUSH???)/TI/AB)	Brush
30	3 AND (((CARBON 2W NANO_TUBE?) OR CNT OR CNTS)/TI/AB OR (C01B-032/158 : C01B-032/178)/IPC/CPC)	Nanotubes
31	3 AND (NANO_FLUID? OR MICRO_FLUID?)/TI/AB	Nanofluids
32	3 AND ((LUBRICA+)/TI/AB OR (C10M+ OR C10N+ OR F16C-2202/52 OR F16N+)/IPC/CPC)	Lubrication
33	3 AND (NANO_COMPOSITE?)/TI/AB	Nanocomposite
34	3 AND (C08+)/IPC/CPC	Polymers
35	3 AND (C22+ OR C21+)/IPC/CPC	Metal/alloys

Step	*Query*	Remark
36	3 AND (C04B+)/IPC/CPC	Ceramics
37	3 AND ((Y02E-010/5+)/CPC OR (PHOTOVOLTAIC OR PHOTO_ENERGY OR SOLAR_ CELL? OR SOLAR_PANEL?)/TI/AB)	Solar cell
38	3 AND ((WIND 3D (ENERG+ OR POWER OR ELECTRICITY))/TI/AB OR (Y02E-010/7+)/CPC)	Wind power
39	3 AND ((Y02E-010/+)/CPC OR (PHOTOVOLTAIC OR PHOTO_ENERGY OR SOLAR_ CELL? OR SOLAR_PANEL? OR (WIND 3D (ENERG+ OR POWER OR ELECTRICITY)))/ TI/AB)	Overall renewable energy
40	(3 AND (ARMOR? OR ARMOUR? OR KEVLAR OR ((STRUCTURAL+) 2W (MATERIAL? OR COMPOSITE? OR STRENGTH+ OR REINFORC+)) OR (WEAR W RESISTAN+ W (MATERIAL? OR COMPOSITE? OR STRUCT+)))/TI/AB)	Structural material
41	3 AND ((C09D)/IPC/CPC OR (GRAPHITE W (PAINT? OR COATING?))/TI/AB)	Coating
42	(3 AND (((GRAPHITE? OR GRAPHITIC) 3D (MO?LD OR MO?LDING OR CASTING OR DIE OR REFRACTOR+ OR MOTAR? OR CRUCIBLE?))/TI/AB OR (B22C OR B22D OR B28B OR B28C OR C04B-033+ OR C04B-035/66+)/IPC/CPC)) NOT (B22C-003+ OR C22+)/IPC/CPC	Refractories and casting
43	3 AND ((H05K-007/20+ OR H01L-033/64+ OR H01L-023/34:H01L-023/4735)/IPC/ CPC OR (((HEAT OR THERMAL) W (SINK OR DISSIPAT+ OR CONDUCT+))/TI/AB AND (H01+ OR H02+ OR H05+ OR F21+)/IPC/CPC))	Heat dissipation
44	3 AND ((ELECTRIC+ W CONDUCT+) OR (ELECTRIC+ 1W (THERMAL OR HEAT) 1W CONDUCT+) OR ((CONDUCTIVE OR CONDUCTIVITY) NOT ((HEAT OR THERMAL) W CONDUCT+)))/TI/AB AND (H01+ OR H02+ OR H05+ OR F21+)/IPC/CPC	Conductive element
45	3 AND (PACKAGE? OR PACKAGING)/TI/AB AND ((H01+ OR H02+ OR H05+ OR F21+) NOT (H01M OR Y02E))/IPC/CPC	Packaging
46	((3 NOT (18 OR 39)) AND (H01+ OR H02+ OR H05+ OR F21+)/IPC/CPC) OR (43: 45)	Overall electronics
47	3 AND (FOOD 2D (PACKING OR PACKAGE? OR PACKAGING))/TI/AB	Food packaging
48	3 AND ((FOOD 2D (PACKING OR PACKAGE? OR PACKAGING))/TI/AB OR ((PACKING OR PACKAGE? OR PACKAGING)/TI/AB AND (B65D)/IPC/CPC))	Overall packing
49	3 AND (A61+)/IPC/CPC	Biomedical
50	3 AND (GRAPHENE OR 石墨烯)/TI/AB AND (C02F+ OR Y02W-010+ OR Y02A-020/124 : Y02A-020/131)/IPC/CPC	Graphene – Water treatment
51	3 AND (GRAPHENE OR 石墨烯)/TI/AB AND ((AIR OR GAS OR GASES OR GAS?OUS) 2D (PURIFI+ OR FILTRAT+))/TI/AB	Graphene – Air purification
52	3 AND ((((WATER OR WASTEWATER OR SEWAGE) 3D (TREAT+ OR PURIFICATION OR PURIFY+ OR FILTRAT+)) OR +WATER_TREAT+ OR +WATER_PURIF+ OR DESALIN+ OR (GRAPHITE 1D (SORBENT OR ADSORB+OR ABSORP+ OR FELT OR FILTER OR FILTRAT+)))/TI/AB OR (C02F+ OR Y02W-010+)/ICM/CPCM OR (C02F-2103/08 OR Y02A-020/124 : Y02A-020/131)/IPC/CPC)	Water treatment
53	3 AND ((AIR OR GAS OR GASES OR GAS?OUS) 2D (PURIFI+ OR FILTRAT+))/TI/AB	Air purification
54	3 AND (((HEAT OR THERMAL) 3W EXCHANG+)/TI/AB OR (F28+)/IPC/CPC)	Heat exchanger
55	3 AND (((GRAPHITE? OR GRAPHITIC) 3W (HEATER OR HEATING))/TI/AB OR (H05B-003 OR H05B-2203)/IPC/CPC)	Heating element
56	3 AND ((GRAPHITE? 2W (SEALING OR GASKET? OR WASHER? OR RING?))/TI/AB OR (F16J-015+)/IPC/CPC)	Sealing ring and gasket
57	3 and ((NATURAL 3D LUMP 3D GRAPHIT+)/TI/AB/CLMS OR ((((VEIN OR CEYLON OR SRI_LANKA+) 7D GRAPHIT+)/TI/AB/CLMS NOT (VEIN_QUARTZ OR POLYMERIC_ VEIN OR ORGANISM OR (VEIN 2D (LIQUID OR WATER))))/TI/AB/CLMS))	Vein graphite
58	3 and (AMORPH+ 3D GRAPHIT+)/TI/AB/CLMS	Amorphous graphite
59	3 and (FLAK+ 3D GRAPHIT+)/TI/AB/CLMS	Flake graphite
60	3 and ((SYNTHE+ OR ARTIFICIAL+ OR MAN_MADE) 3D GRAPHIT+)/TI/AB/CLMS	Artificial graphite
61	3 and ((MECHANICAL+ OR CHEMICAL+ OR MECHANO_CHEMICAL+) 3D (STRIP+ OR GRIND+ OR EXFOLIAT+ OR PEEL+ OR SHEAR+ OR TREAT+))/TI/AB/CLMS	Chemical and mechanical exfoliation
62	3 and ((ULTRA_SONIC+) 3D (STRIP+ OR GRIND+ OR EXFOLIAT+ OR PEEL+ OR SHEAR+ OR TREAT+))/TI/AB/CLMS	Ultrasonic exfoliation
63	3 and ((THERMAL+ OR HEAT OR HIGH_TEMPERATURE) 3D (STRIP+ OR GRIND+ OR EXFOLIAT+ OR PEEL+ OR SHEAR+ OR TREAT+))/TI/AB/CLMS	Thermal exfoliation
64	3 and ((ELECTRO_CHEMICAL+) 3D (STRIP+ OR GRIND+ OR EXFOLIAT+ OR PEEL+ OR SHEAR+ OR TREAT+))/TI/AB/CLMS	Electrochemical exfoliation
65	3 and ((((MICRO+ OR NANO+) 1D GRAPHIT+)/TI/AB/CLMS) NOT ((MICROWAVE OR MICROB+)/TI/AB/CLMS))	Micro/nanographite
66	3 and ((SPHER+ 1D GRAPHIT+)/TI/AB/CLMS OR (C22C-037/04 OR F05C-2201/0442)/IPC/CPC)	Spherical graphite
67	3 and (EXPAND+ 1W GRAPHIT+)/TI/AB/CLMS	Expanded graphite
68	3 and (GRAPHIT+ 1D POWDER+)/TI/AB/CLMS	Graphite powder
69	3 and ((GRAPHENE+)/TI/AB OR (C01B-032/182 OR C01B-032/184 OR C01B-032/186 OR C01B-032/188 OR C01B-032/19 OR C01B-032/192 OR C01B-032/194 OR C01B-032/196 OR C01B-032/198)/IPC/CPC)	Graphene
70	3 and (GRAPHIT+ 1D (FOIL+ OR SHEET+ OR FILM))/TI/AB/CLMS	Graphite foil/sheet
71	3 and (GRAPHIT+ 2D (COMPOSITE+ OR NANO_COMPOSITE+))/TI/AB/CLMS	Graphite composites / nanocomposites

Annex C: Additional information

Table C1. Top 10 applicant origins (non-China) for graphite powder patents.

Jurisdiction	Patent families
Republic of Korea	356
Japan	263
Russian Federation	131
United States	117
Taiwan Province of China	79
India	44
Germany	28
Ukraine	14
France	10
Australia	8

Table C2. Application trend for patent families related to various graphite uses and products originated in China.

	Earliest application year										Total	Recency	Relative recency
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021			
China overall	2,666	3,194	3,951	4,571	6,036	6,123	6,544	4,849	5,079	4,509	47,522	0.59	1.00
Aerospace	2	2	5	2	3	3	2	4	11	10	44	0.70	1.18
Air purification	2	2	3	5	6	8	11	1	2	1	41	0.55	0.93
Automotive	6	8	8	28	38	31	42	26	26	15	228	0.62	1.05
Battery	315	283	344	451	569	713	804	704	872	781	5,836	0.65	1.09
Biomedical	10	12	13	22	43	54	48	31	38	31	302	0.64	1.08
Capacitor	123	103	117	106	165	114	103	77	83	73	1,064	0.51	0.86
Carbon brush	27	10	13	62	37	15	35	19	13	12	243	0.51	0.86
Carbon nanotubes	66	65	82	123	222	176	192	166	159	129	1,380	0.62	1.04
Ceramics	219	252	366	384	684	663	760	507	597	520	4,952	0.62	1.05
Coating	95	165	255	227	449	433	366	221	211	151	2,573	0.57	0.96
Conductive element	176	171	253	240	337	335	381	364	369	352	2,978	0.62	1.04
Conductive ink	2	6	10	8	13	14	14	16	19	11	113	0.65	1.09
Fuel cell	61	56	58	47	40	72	98	116	118	125	791	0.64	1.09
Heat dissipation	49	72	49	68	149	156	148	140	111	105	1,047	0.62	1.05
Heat exchange	28	34	46	66	68	67	70	51	63	67	560	0.60	1.02
Heating element	73	74	63	68	113	96	85	98	124	113	907	0.60	1.01
Lubrication	148	214	293	312	394	410	409	278	258	190	2,906	0.57	0.96
Metal alloys	267	333	438	435	567	630	668	528	484	418	4,768	0.59	0.99
Packaging	8	10	6	22	32	14	17	17	20	14	160	0.60	1.01
Polymer	220	311	520	762	1,247	1,137	983	525	513	429	6,647	0.58	0.98
Railway and marine		1	3	1	5	3	1	1	7	6	28	0.70	1.18
Sealing and gasket	72	61	79	88	85	106	120	86	114	102	913	0.59	1.00
Sensor	40	45	60	65	83	90	110	97	102	103	795	0.63	1.07
Solar cell	32	26	29	30	53	47	71	32	30	33	383	0.57	0.97
Structural materials	16	18	20	42	21	32	44	53	38	32	316	0.62	1.05
Textile	30	48	48	96	134	112	127	113	93	97	898	0.62	1.05

	Earliest application year										Total	Recency	Relative recency
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021			
Water treatment	41	41	43	42	91	76	70	60	85	42	591	0.59	1.00
Wind power	5	10	6	5	2	12	16	15	13	9	93	0.63	1.06

Table C3. Patent families related to various graphite uses and products originated in the rest of the world (RoW).

	Earliest application year										Total	Recency	Relative recency
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021			
RoW overall	1,352	1,470	1,434	1,482	1,449	1,331	1,315	1,254	1,133	355	12,575	0.50	1.00
Aerospace	5	7	5	9	5	9	5	4	5	3	57	0.51	1.02
Air purification				1			1		2		4	0.73	1.45
Automotive	41	41	47	50	42	39	45	22	17	4	348	0.46	0.92
Battery	220	283	265	310	286	267	288	316	278	79	2,592	0.53	1.06
Biomedical	18	29	18	25	25	27	13	23	22	6	206	0.51	1.02
Capacitor	47	56	45	52	57	41	41	22	25	7	393	0.46	0.91
Carbon brush	3	7	2	4	4	8	4	6	7	2	47	0.57	1.13
Carbon nanotubes	55	88	87	100	83	69	67	59	46	18	672	0.48	0.97
Ceramics	118	116	109	111	120	110	137	128	101	32	1,082	0.52	1.04
Coating	42	72	58	80	72	66	39	69	57	21	576	0.52	1.04
Conductive element	118	120	113	136	119	100	125	114	73	38	1,056	0.50	1.00
Conductive ink	5	7	7	15	5	4	7	7	5	3	65	0.51	1.01
Fuel cell	59	60	48	55	49	32	50	55	46	13	467	0.50	0.99
Heat dissipation	110	90	91	117	137	101	114	83	75	16	934	0.49	0.99
Heat exchange	49	34	33	37	26	29	31	21	24	4	288	0.45	0.91
Heating element	37	30	35	39	43	33	25	20	20	6	288	0.47	0.94
Lubrication	56	72	70	58	64	47	59	53	38	16	533	0.48	0.97
Metal alloys	102	117	113	94	110	113	134	99	88	32	1,002	0.51	1.02
Packaging	5	2	3	5	3	3	12	8	7		48	0.59	1.18
Polymer	135	173	174	168	199	202	161	178	160	48	1,598	0.52	1.05
Railway and marine	4	10	8	3	4	1	4	6	2	1	43	0.44	0.89
Sealing and gasket	20	25	47	27	24	18	27	14	13	5	220	0.46	0.92
Sensor	24	25	20	27	30	23	31	26	17	10	233	0.52	1.04
Solar cell	19	28	11	15	13	14	9	13	7	2	131	0.43	0.87
Structural materials	6	8	11	8	2	6	7	9	9	2	68	0.52	1.05
Textile	37	32	26	41	30	38	23	28	28	4	287	0.49	0.98
Water treatment	13	13	4	7	10	11	10	8	10	1	87	0.49	0.99
Wind power	2	3	3	3	1	1	3	3			19	0.45	0.90

Figure C1. **Application trend for patent families related to graphite for carbon brushes originating from the rest of the world (i.e., non-China), 1972–2021.**

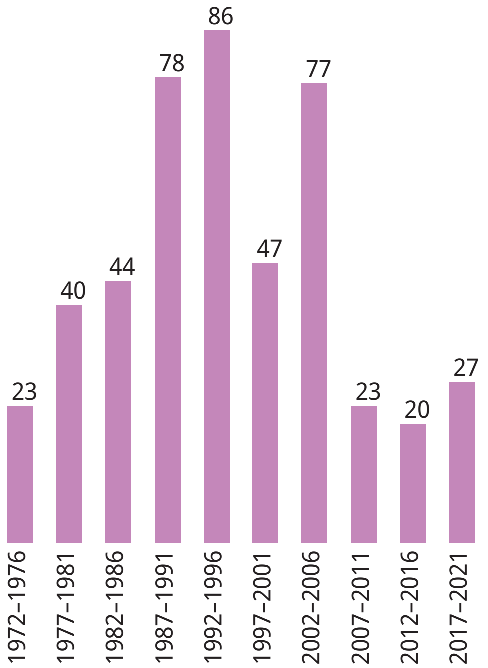


Figure C2. **Applicant profiles for graphite applications related to water treatment, China and the rest of the world.**

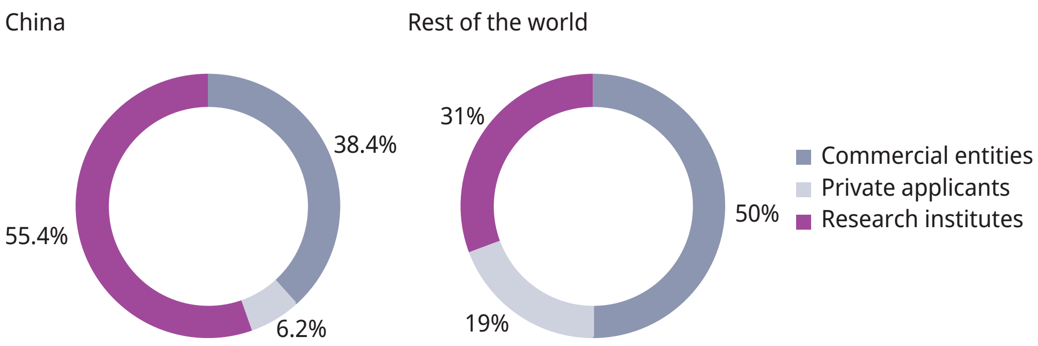
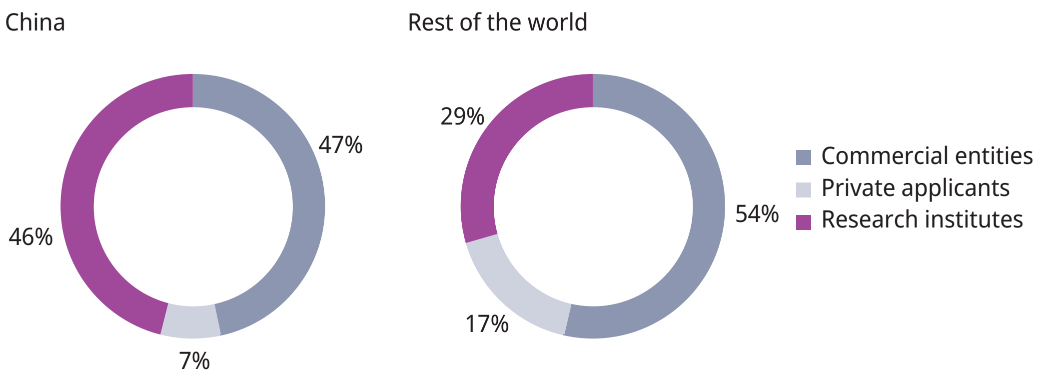


Figure C3. **Patent applicant profiles for graphite in biomedical applications, China and the rest of the world.**



Patents referred to in the report can be found using any patent database, for example PATENTSCOPE, Espacenet, Google patents, or others.

Acronyms

CAGR	compound annual growth rate
CATL	Contemporary Amperex Technology Co. Limited
CPC	Cooperative Patent Classification
EV(s)	electric vehicle(s)
IPC	International Patent Classification
IPOS	Intellectual Property Office of Singapore
LIB	lithium-ion battery
PCT	Patent Cooperation Treaty
UK	United Kingdom
US	United States of America
USD	United States dollar
USGS	United States Geological Survey
WIPO	World Intellectual Property Organization

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