2D Materials

TOPICAL REVIEW • OPEN ACCESS

Graphene Roadmap Briefs (No. 3): meta-market analysis 2023

To cite this article: Thomas Schmaltz *et al* 2024 *2D Mater.* **11** 022002

IOP Publishing 2D Mater. **11** (2024) 022002 https://doi.org/10.1088/2053-1583/ad1e78

2D Materials

OPEN ACCESS

RECEIVED
31 July 2023

REVISED
10 December 2023

ACCEPTED FOR PUBLICATION
15 January 2024

PUBLISHED
31 January 2024

TOPICAL REVIEW

Graphene Roadmap Briefs (No. 3): meta-market analysis 2023

Thomas Schmaltz, Lorenzo Wormer, Ulrich Schmoch and Henning Döscher*

Competence Center Emerging Technologies, Fraunhofer Institute for Systems and Innovation Research ISI, Karlsruhe, Germany
* Author to whom any correspondence should be addressed.

E-mail: henning.doescher@isi.fraunhofer.de

Keywords: graphene and related materials, market analysis, bibliometrics, patent analysis

Supplementary material for this article is available online

Abstract

Graphene and related materials (GRMs) promise ample application potential throughout numerous industries. A dedicated graphene market gradually forms around emerging suppliers aspiring to satisfy future demands. Its growth critically depends on the interplay of supply stream maturation and initial utilizations to drive the demand. The present issue of Graphene Roadmap Briefs provides quantitative insights into the current state and future development of the emerging graphene market. We aggregate the underlying expectations and projections from commercial market reports and critically discuss the results. Established science and technology metrics complement our analyses and provide deeper insights into the global market landscape and key actors. In particular, we resolve composites, batteries, and electronics as major application areas likely to drive the overall development of the graphene market towards mass production.

About: Graphene Roadmap Briefs

Graphene Roadmap Briefs highlight key innovation areas impacted by graphene and related materials (GRMs) as well as overarching aspects of GRM innovation status and prospects. The series bases on the evolving technology and innovation roadmap process initiated by the European Graphene Flagship. It covers crucial innovation trends beyond fundamental scientific discovery and applied research on GRM utilization opportunities.

List of acronyms

GRM	Graphene and related 2D materials
TIR	Technology and innovation roadmap
3I	Innovation interface investigation
GO	Graphene oxide
rGO	Reduced graphene oxide
EGG	Electronic grade graphene
GNP	Graphene nanoplatelet
REACH	Registration, Evaluation, Authorisation, and Restriction of Chemicals
TRL	Technology readiness level
R&D	Research and development
KPI	Key performance indicator
SME	Small and medium enterprises

The list of abbreviations and acronyms excludes proper names, common use (such as 2D), metric system units, chemical symbols, and isolated introductions (for terms most common as acronym such as CNT).

1. Introduction

The practical isolation of graphene in 2004 [1] sparked enormous expectations in terms of scientific discovery, technological application opportunity, and potential economic value. Properties, which merely existed in theoretical concepts [2] before, suddenly materialized. Long sustained growth in both scientific publication and patent application records (see below) based on GRMs evidence significant momentum often seen as hype [3]. Of course, the translation of a novel material into widespread economic impact takes substantial time spans [4]. Hence, the present market development may appear to lag behind earlier expectations.

Our recent industrialization roadmap [5] shows that the emerging graphene supply industry currently undergoes an extensive consolidation phase. Most producers still remain somewhat in a start-up phase and face an interrelated dual struggle to grow their customer base and to secure funding to scale their production. Others may already succeed in certain niches, some perhaps with little to no public visibility due to strict non-disclosure terms often imposed by customers.

Meanwhile, all actors strive for meaningful market intelligence to inform their executive decisions. This includes observers on the sideline who constitute prospective and potential actors considering if, when and how to enter the market. Key perspectives include:

- Production: Material suppliers seeking for target markets (applications, specification, demand volume, pricing perspectives, etc) and potential customers for business development and scaling perspectives.
- Sourcing: Prospective users seeking competitive advantage (use case, availability and reliability of supply, scalability, cost targets, multi-sourcing opportunities) often prior to engaging in initial practical R&D at all.
- Investment: Executive decision makers and financiers (venture capitalists, banks) seeking to inform and validate their objectives in scaling production lines and corporate infrastructures.

In the present issue of Graphene Roadmap Briefs, we take a closer look at the anticipated graphene market development and the involved key players, by means of a meta-market analysis. To complement the picture, we analyze the international innovation landscape via comprehensive publication and patent analysis down to actor level.

2. Market research

The idea to support decision-making processes by deliberate market research dates back more than a century [6]. Initially, the efforts mainly focused on consumers to understand their behavior and their desires. Market research task soon became a domain of specialists and third party service providers. Today, consumer data became widely available, so that market researchers rather focus on analyzing such datasets and guiding their clients through the gained insights [6]. Beyond provision of specific services to individual clients (to understand their market environment in depth), the creation of market reports for an undetermined broader audience constitutes another business model for market research agencies. These market reports (often also referred to as market studies) aim to provide a general overview of a specific topic and market—and may serve as starting point for in-depth market research conducted by individual companies.

In general, the content of market reports comprises of both primary and secondary research, as well as of analyses and calculations based on the thus obtained information [7–9]. Primary market research typically includes interviews and surveys among relevant (industrial) actors (production, sourcing, investment—section 1) to obtain first-hand information, for instance on production capacities, demand, prices, investments, etc. In contrast, secondary market research rather concentrates on collecting already available information and data, for instance from press releases, news announcements, or quarterly reports of companies. Depending on the topic of the market report, consumer data can also play an important role as well.

Today, trade associations as well as private and public statistics providers publish ample data on all sorts of established markets. In contrast, niche markets and emerging sectors may appear opaque. Their understanding typically requires substantial primary research to gather quantitative information from relevant actors active in that market. Hence, commercial market report providers often concentrate on this segment where they can potentially provide valuable insights to their target audience. Ideally, their reports base on ample interaction with relevant market actors both in public context (trade fairs, conferences, etc) and private settings (deliberate interviews with company representatives). The aggregated information then often is complemented by assumptions, estimates, and extrapolation to allow for a forecast of short- to medium-term market development.

In the present issue of Graphene Roadmap Briefs, we conduct a meta-analysis among market reports covering GRMs (section 3). It focusses on their market forecasts that constitute their highest level of result aggregation and, thus, serves us as a measure of both intercomparison and market expectation harmonization (section 4). Beyond that, we use systematic tracing of claims in individual market actor coverage as a starting point to analyze the graphene market landscapes on both the supply (section 5) and utilization (section 6). We complement the market report data with sophisticated bibliometric and patent analyses drilled down to the actor level for two reasons: (a) to provide a more complete view of the respective market landscapes and (b) to obtain a better judgment of merits and flaws of market reports, both in general (as segment of grey literature) and individual (pre-purchase selection criteria).

3. Meta-market analysis of the graphene market

3.1. Motivation

We can distinguish two fundamental levels of market intelligence: specific insights and global prospects. Both can be of high value to various stakeholders in the wider graphene ecosystem that comprises of both present actors and those potentially entering the market in the future. On the long run, practical operations will primarily benefit from the availability and quality of highly specific market insights to support tactical level decision making. On a sourcing perspective, that will include potential suppliers, intelligence about their product portfolio (material type, quality, purity, etc), their capacity and scaling perspectives. Similarly, on a production perspective, suppliers will strive for specific insights on potential customers to focus and inform their business development activities.

Usually, strategic level decisions precede practical operations and define its scope: whether, when, and how to enter a market, to scale capacity, to provide funding. Internal and external investment perspectives thus often combine high level of impact with a rather low level of information, as experience will often only (further) accumulate once such fundamental decisions have been made. Hence, stakeholders often have strong interest in the overall market development status and prospects, for both primary (inform their own decision) and secondary (convince their partners) purposes.

At the present stage, the graphene industry exemplifies an emerging materials market: First graphene-based products have already entered various markets, but mostly on niche scale so far. Plenty of small-scale graphene producers exist and strive to expand their customer base and scale their production. Meanwhile, many potential graphene users show substantial interest in the material and its properties, but still hesitate with practical engagement due to the strong uncertainty in the market. Of course, the transparency of emerging markets is particularly low. Both interest and expectations may critically depend on hype cycles. And forecasts on novel markets remain particularly speculative as they strongly depend on the decisions on larger market players.

Nevertheless, decision makers strongly desire reliable market assessments and forecasts. In the absence of established alternatives, commercial market reports appear highly attractive. Hence, numerous providers populate the lucrative niche to cover emerging markets, of course including graphene. However, no quality assurance mechanisms (similar to peer-review among scientific publications or formal patent examination processes) exist for market reports. Extensive paywall barriers (access charges on the order of 5000€ for an individual market report are common) further restrict the transparency for this source category.

In this context, our Graphene Roadmap Team assumes a neutral perspective to aggregate, and critically discuss graphene market forecasts available in market reports (including both present and historic issues). Although we have been closely following the development of GRM and their applications for many years, we do not hold any particular stake in the graphene market ourselves. We neither participate on the supply side (producing/selling material), nor on the demand side (developing/marketing products), nor do we have any financial interest in the sale of the intelligence we gather. Our goals include both establishing a balanced expectation of the graphene market development over the coming years and analyzing potential merits and flaws associated with the market report category.

3.2. Methodology

Most market report providers advertise their available reports on their homepage, often including a description of the content and limited preview information. The latter usually contains a disclosure of key market forecasts figures. We systematically searched for graphene market reports (e.g. using the Google search engine) over recent years. In total, we identified 103 English language market reports covering the global graphene market with publication dates ranging from 2013 to 2022 (cut-off: end of 2022). We exclusively consider market reports that claim to provide a global view on the graphene market, i.e. we disregard reports limited to certain geographic regions or companies. Of course, we have no measure to guarantee that our search results are exhaustive, but did implement them systemically and carefully. Hence, we assume having caught the most relevant market reports, in particular over the most recent years (since 2020). Obviously, the utilization of English language goes along with a certain bias (that we will discuss further below).

From all identified market reports we extracted the relevant preview information, in particular quantitative market figures such as revenue estimates and forecasts or forecasts on the compound annual growth rate (CAGR). We limited the systematic analysis of the qualitative content to recording mentions of company names. Due to their advertising character, those excerpts will certainly not disclose the entirety of the market report coverage. However, we still gather a collective impression of which actors on the graphene market the study provider regard that important to advertise their coverage. We complement this actor analysis with comprehensive publication and patent analyses down to actor level employing well-established methodology. Technical implementation details will be provided in that context.

At a first glance, all market reports unanimously agree to report rising interest in the industrial uptake of graphene and, thus, forecast strong and continuous graphene market growth. Of course, these predictions may include some bias of both intentional (sell the report) and unintentional (enthusiasm for the topic) kind. However, the pure existence of the each market report already represents some indication of interest (as the providers at least assume their ability to sell the report). Hence, we can consider the report publication statistics shown in figure 1

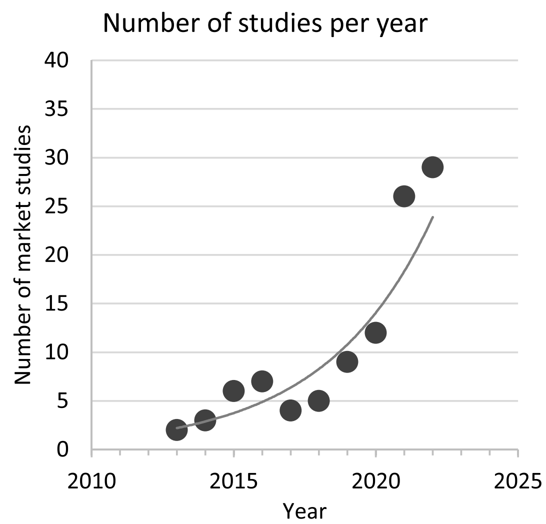

Figure 1. Number of graphene market reports as a function of the publication year. The grey line represents an exponential fit of the historic values as a guide to the eye.

already as an indirect indicator of market interest development.

Figure 1 plots the number of graphene market reports over their publication year. The data clearly shows a substantial increase of the market report coverage of the graphene field. Note that we started our meta-market analysis in this field in 2017, and increased our tracking intensity from 2020 onwards. We employed internet archives to complement our data, but may still face a slightly lower identification rate of market reports published in 2019 and before. However, we recognize strongly growing market report coverage of the graphene sector, particularly over most recent years (2020–2022). With a substantial number of recent data points available, we recognized sufficient breadth in market reports that enables us to conduct an in-depth meta-market analysis. It primarily aims at providing market actors with an initial guidance to navigate the graphene market landscape based on aggregated market expectations. Meanwhile, our analysis also provides some insights into potential merits and flaws of market reports as an information source for market actors.

3.3. Capabilities and limitations

Forecasting of mature markets can usually draw on yearlong experience in that very field. Often, specialized trade associations collect figures and expectation of the relevant players established in the market sector or segment in question. This leads to a high degree of transparency and rather reliable predictions that, thus, often agree very well between various sources.

In contrast, the market situation for emerging technologies or materials such as graphene typically remains quite opaque:

- rather small companies and start-ups are common;
- new players emerge and disappear frequently;
- existing ones grow following unpredictable patterns (strongly dependent on individual customers and investment rounds of start-ups);
- the overall market volume is still rather small, but may grow rapidly;
- value chains are rarely established;
- cost levels may still appear prohibitively high;
- scaling and cost-reduction paths may remain unclear;
- suppliers constantly search for novel application fields and customers;
- corporate strategies differ (e.g. secrecy vs. massive publicity);
- regulatory frameworks remain to be established;
- market acceptance may be limited, often governed by a general reluctance to use novel materials;
- and hype cycle dynamics may create inflated expectations or disillusionment among stakeholders.

Market report providers attempt to navigate these opaque conditions with varying degrees of insight and dedication. Some may cover a wide variety of emerging markets with systematic methodology, but limited depth. Others may just focus selected market segments for in-depth coverage. All face strict limitations of theirs resources bound to maintain commercially viable operation. Thus, quality and content of market reports with similar scope may differ substantially. Still, even the best sources may only gather partial insights into such highly opaque markets. Hence, any individual market report can only paint a limited—and possibly distorted—picture of the actual market conditions and developments.

The meta-market analysis approach developed by Fraunhofer ISI rather regards the ensemble of market reports on an emerging market segment, exemplified by graphene here. Our meta-analysis systematically aggregates the overarching conclusions of each available market report as expressed in their market predictions (revenue, growth rate, etc; converted by us to a unified metric where necessary). Thus, it balances the different viewpoints expressed in individual market reports and consolidates an aggregated picture on the overall market situation including a forecast range for the most likely market development.

Of course, our results critically depend on both, the source data available to us and our ability to express it on a unified metric. We recognize substantial limitations on this path as the underlying specification market projection typically remain rather intransparent. For instance, market size usually refers to the global revenue generation in the investigated market segment, but figure statements often lack clear definitions ('market size of 1 billion US$'). Simultaneously, similar labels (such as 'the graphene market') may not necessarily encompass identical market segment definitions. Market reports may deviate in their accounting of subsequent value-addition steps and their consideration of certain sub-markets, but providers usually do not detail the utilized specifications. Physical quantities (on production, capacity, demand) or price figures usually require further context (that not all market reports always clearly indicate), particularly in the case of 'graphene'. That label usually spans a wide variety of production methods [10] and product types (e.g. monolayer graphene, graphene nanoplatelates, GO) with very different properties.

Hence, our meta-market analysis of the graphene sector cannot resolve much detail, but rather provides a balanced overview of current market expectations. It clearly indicates a corridor for the most likely market development path, identifies extreme expectations (highly optimistic/pessimistic scenarios), and provides some insight to the average level of uncertainty in the market. Still, it remains subject to systematic errors, for instance due to overall market sentiment (when all market reports may be influenced by optimism or pessimism throughout the community), due to intentional and unintentional biases among individual providers, or due to market reports also considering competing reports into account.

4. Graphene market projections

4.1. Graphene market expansion

We analyzed 103 market reports [11–113] on the global graphene market and aggregated the results to obtain an overview of the range of predictions and the average revenue values (figure 2). The global graphene market has been continuously growing over the last years to reach an average estimated global annual revenue of 380 million US$ in 2022 (forecast range between 50 million and 1.1 billion US$). This is still significantly smaller than e.g. the graphite market (22.5 billion US$ in 2022) [114] or the carbon black market (17 billion US$ in 2021) [115], but considering the short time since it is discovery for practical use it is already quite impressive.

Significant market growth over the next years will lead to a predicted market size of 1.5 billion US$ in 2027 (forecast range between 0.34 and 5.5 billion US$). Considering that many industries are rather conservative in using novel materials, this rapid anticipated growth is impressive and reflects the excellent physical properties (mechanical, electrical, etc) of graphene that can enhance products in various ways.

The analyzed market reports exhibit a large variation between their forecast figures with more than a factor of ten between lowest and highest forecast value. The spectrum between these extreme forecasts is continuous, when looking at the individual market predictions (figure 3). Only one exception of particularly high forecast values stands out. We attribute these large variations and this wide range of predictions to the novelty and immaturity of the market that is still characterized by various small companies and start-ups and large market dynamics. In such a novel market it seems difficult to make good predictions, because of the large number of active players, the little amount of secured information that can be obtain from them (as compared to large established companies that often publish relevant information) and the general uncertainty about the maturity of the technology.

The semi-logarithmic plot (figure 3) furthermore indicates the CAGRs as slope in the plot. Although variations in the absolute numbers of the market size

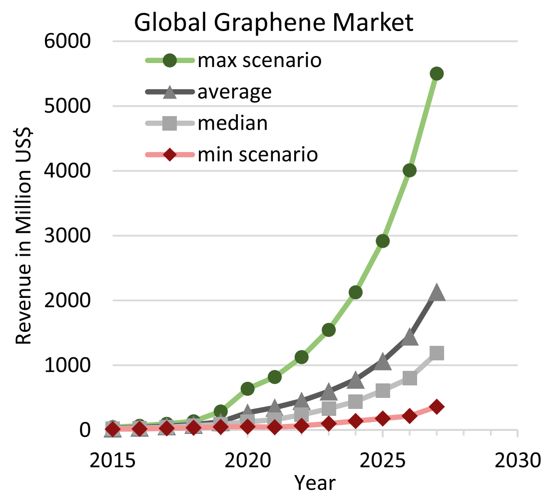

Figure 2. Predicted global graphene market revenue between 2015 and 2027, resulting from our meta-analysis. The true market development is likely to be between the extreme (min/max) predictions, possibly close to the mean or median curve.

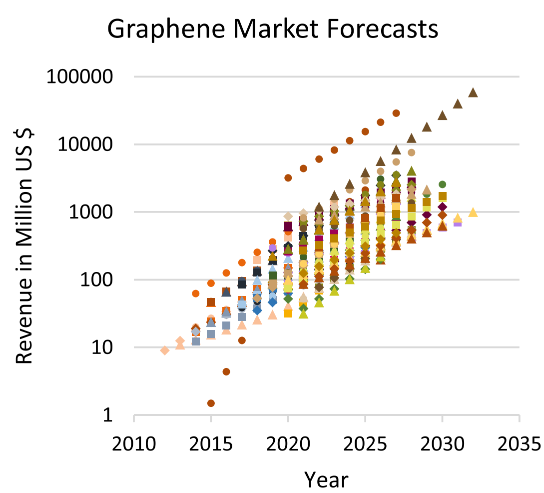

Figure 3. Data from all 103 analyzed market report previews [11–113] on the global graphene market between 2010 and 2035 (enlarged diagram with references in the SI, figure S1). The spectrum between highest and lowest prediction is continuous, with the exception of one high estimate outlier. All market reports predict a significant market growth in their forecast period, indicated by the slope in the semi-logarithmic plot.

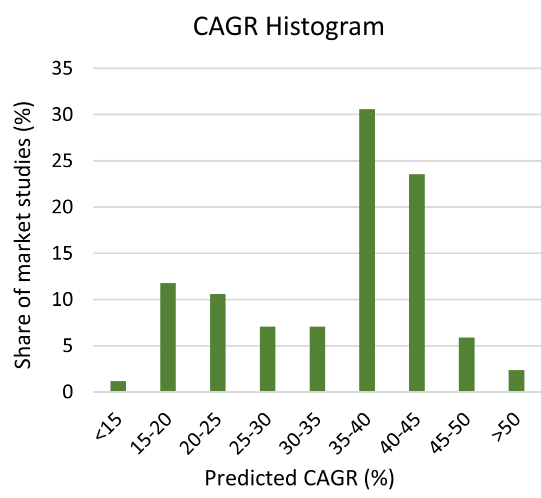

Figure 4. Distribution of CAGR forecasts in the analyzed 103 market reports. Most market reports predict a CAGR between 35% and 45% in their forecast period.

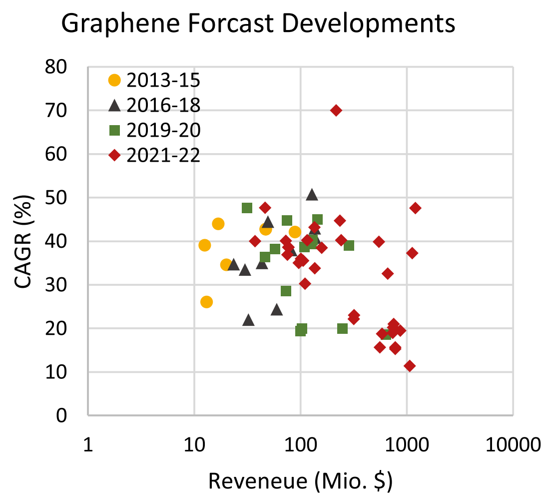

Figure 5. Revenue and CAGR forecasts for the global graphene market by publishing year of the study (identical to forecast year).

exist, all market reports agree on a significant growth of the graphene market over their forecast period. To further analyze the forecasted growth rates, we plotted the CAGR values according to their occurrence in the market reports in a histogram (figure 4). Only one of the analyzed market reports expects a CAGR below 15% and only 12% predict a CAGR between 15% and 20%. That means that more than 85% of the market reports forecast growth rates of more than 20%, almost 70% of the market reports even expect a CAGR of more than 30%. More than half of the study providers predict a CAGR between 35% and 45%, and 8% of the studies forecast a CAGR of more than 45%. In summary, most market reports expect a strong growth of more than 30% of the graphene market in the near- to medium-term future. These are enormous growth rates that require the graphene producers to scale up their production capacity on average by 35% each year. In order to achieve this growth, new markets and applications have to be established for graphene and the current markets have to grow.

4.2. Dynamics in forecastings

The analyzed market reports were published between 2013 and 2022, which allows for the analysis of forecast trends over time (figure 5). As the market grew, the revenue figures increased, while the CAGR remained on a similar level. The individual studies from the years 2013 to 2015 mostly form clusters with only few studies predicting deviating figures. Market reports from 2016 to 2018 cluster already less and diverge more and more in their predictions. A trend that continues further for the studies from 2019 to 2020. In the most recent studies from 2021 to 2022 the formation of sub-clusters can be observed, i.e. clusters of studies that published very similar predictions diverging significantly from other forecast figures. This effect could be attributed to the increasing overall number on market reports on the topic (figure 1), to an increasing uncertainty on how the market develops, or possibly to some market report providers adopting trends and forecasts from other reports.

Looking more closely at the predicted growth rate predictions for the graphene market as a function of the publishing year of the study (SI, figure S2), a trend towards slowly decreasing market growth rates can be observed. While in 2013 an average CAGR of 43% was predicted, the forecast figures decreased to 33% in 2021 and 2022. This deceleration of market growth is common for growing markets where the revenue figures increase.

4.3. Graphene price and production volume developments

For both companies that produce graphene materials and companies that use graphene in their products, the price of graphene is more important than the overall market size. The price of graphene materials, however, is even more difficult to determine and to forecast, as many different varieties and qualities are being produced [116] and sold at a wide range of prices. In order to assess the price developments of graphene we collected price estimations from different sources [78, 117–119] estimating graphene prices between 50 and 1000 $ kg^{-1} (SI, figure S3). These estimations refer to GNPs and similar top-down graphene materials (i.e.GO and rGO).

Hence, above estimates do not include EGG such as high-quality monolayer or epitaxial graphene used for e.g. microelectronics applications. Such materials usually require bottom up synthesis, typically by chemical vapor deposition (CVD) processes. Thus, their costly substantially exceeds powdered forms of GRM. Requirements differ as well, with emphasis on low thickness (often only a single monolayer) and low defect density. Specifications and pricing will rather base on areal (m^2) than gravimetric (kg) unit. Thus, comparison to powdered forms of GRM hardly makes sense.

Hence, our analysis exclusively focusses GRM powders, i.e. GNPs, GO and rGO, all of which are already being produced in the (multi-)ton scale. In general, the fabrication of rGO requires the highest number of processing steps, followed by GO and GNPs, which will influence production costs (along many other parameters). However, our analyses below require harsh simplification regarding pricing, basically reflecting typical levels for average powered material from high volume production.

Typically, prices decrease during upscaling of production (or more precisely with the cumulative production) according to the so-called price learning curve hypothesis [120]. To determine the slope of the learning curve, i.e. the price reduction rate with cumulative production, we used forecast figures from a commercial market study.

In particular, we derive an expected annual price reduction rate of 12% based on the volume demand and revenue forecasts for graphene powder/platelet material of IDTechEx [29]. Combining this with the wide range of current market price estimations, we may calculate price scenarios for the coming years (figure 6). These forecast scenarios, the graphene prices range from 26 to 680 $\$$ kg^{-1} in 2022, with median price of 85 $\$$ kg^{-1}. A price decrease to prices as low as 12 $\$$ kg^{-1} in 2028 might happen, which is along the lines with the estimations of NanoXplore that graphene prices of 10 $\$$ kg^{-1} are achievable [118]. The major part of graphene materials will be sold at higher price, though, according to our scenarios at a median price of 40 $\$$ kg^{-1}in 2028. It is also possible that some producers are asking for graphene prices higher than 680 $\$$ kg^{-1}or lower than 26 $\$$ kg^{-1}.

The actual price development will, of course, depend on the speed of scale-up of graphene production and on corporate pricing schemes. Initially, new materials are often put on the market to prices below production costs to attract customers and gain advantage over competitors. The general trend of decreasing prices, however, is very clear due to the upscaling of graphene production from many graphene producers.

From the price development scenarios and the revenue forecasts (section 4.1), we calculated the graphene volume demand (figure 7). We assumed that currently and in the near future 90% of the revenue can be attributed to top-down graphene materials that are represented in our price forecast scenarios. The remaining 10% are attributed to high-quality monolayer or epitaxial graphene that are typically used in microelectronics applications. Further, we used the median graphene price scenario and the min, max, mean and median scenario of the revenue forecasts (figure 2).

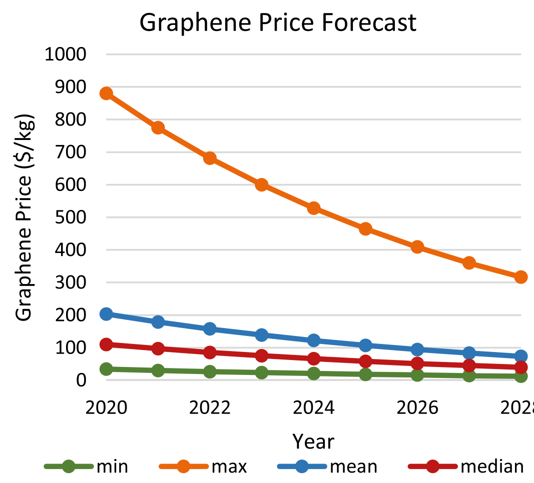

Figure 6. Graphene price development scenarios based on recent price estimates and the assumption of an annual price reduction rate of 12%.

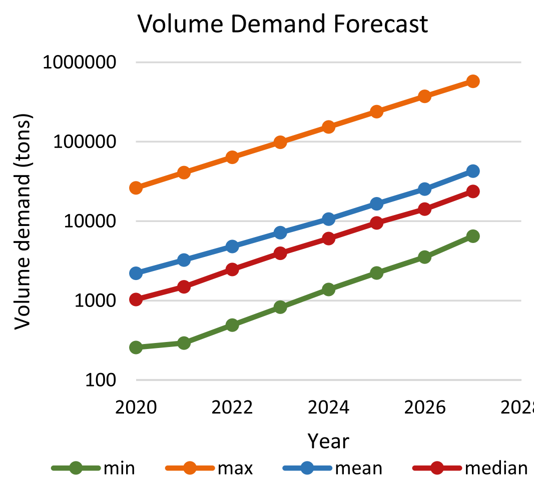

Figure 7. Graphene volume demand scenarios, based on the graphene price development (median scenario, figure 6) and revenue forecast scenarios (figure 2).

According to these forecast scenarios (figure 7), the global graphene demand was in the range of 500–12 000 tons per year (median 2500 t) in 2022. An increase in demand to 9000–170 000 tons per year in 2028 are forecast, with a median of 30 000 tons.

These numbers aim to give a rough estimation of the demand development of graphene in the next years. The actual demand development will, of course, depend on the performance of graphene materials in application cases, the actual price developments, corporate decisions and the thus resulting market adoption. Fast advances in volume applications such as composites can strongly influence the demand.

5. Market landscape: supply side

The emerging graphene market primarily consists of dedicated suppliers of various origins with start-up character that usually focus on growing their customer base and scaling their production. Common backgrounds include university spin-outs that try to capitalize specific process know-how and graphite miners that seek to add value to their products. Hence, we begin our analysis of market actors on the supply side.

5.1. Data from market reports

Beyond the forecast figures, market reports often provide information on companies that they consider relevant in the context of the topic. In the full text of good market reports, detailed profiles of various companies can be found, with background information on e.g. the origin of the company (e.g. spin-out from University), patents, production volumes, type of graphene, production methods and their focus on certain applications sectors and many more. Without having access to all full texts of the market reports, we had to rely on freely available information.

Many market report providers include information on some (or sometimes all) of the companies that are considered in the studies on their homepages for advertising purposes and we systematically collected such mentioned company names and adjusted the slightly different spellings (e.g. addition of company type in the name). Although in the free preview of the studies not always all companies considered in the study are mentioned, generally we assume that the ones, considered most relevant, are named. We extracted these mentions of the companies and analyzed, which companies appear most frequently (Figure 8). This list not necessarily reflects, which companies are most important or even leading in terms of production volumes or revenues in the graphene field. It merely shows, how often these companies were considered relevant by the market report providers.

This analysis, as all analyses in this paper, has the limitation of considering only English language market reports. Therefore, only companies with publically available information in English will have a significant number of mentions, as most market report providers will not extent their search beyond the English language. Furthermore, the recipient or customer sphere of the market reports will also focus on the English speaking market regions, so that some more regional companies, e.g. in Asia, will certainly be underrepresented. As a result, the top 10 list of company mentions contains only companies from North America and Europe, with a dominance of the UK and USA. Judging from publication and patent data (sections 5.4 and 5.5), also strong commercial activities should be expected in Asia and especially China, which is reflected here much less. An explanation for the lower appearance of Asian companies could be the language barrier of the market report providers, combined with the immaturity of the graphene market with many rather small companies that are even harder to detect, when no foreign language skills exist in that company.

An extended list with all companies mentioned at least once since 2020 and at least three times in total can be found in the supporting information (table S1). It also contains some rather interesting entries such as 'Vorbrck Materials' (SI, table S1). This may be quickly considered the result of a rather apparent typo when slightly misspelling the renowned graphene supplier 'Vorbeck Materials Corp.' (rank 13 in figure 8). However, while the original company itself received 23 recent market report mentions, the suspected typo variant collected 9 recent mentions as well. Beyond the question whether to aggregate potential typo variants of a certain company name under their main label might improve our statistics, the origin and proliferation of such a very specific, but yet surprisingly common type deserves some attention as well (SI, table S2).

Rank	Organization name		National origin	Mentions since 2020	Mentions (total)
1	Haydale		United Kingdom	55	73
2	Graphenea		Spain	54	76
3	ACS Material, LLC		United States	53	64
4	XG Sciences, Inc.		United States	50	72
5	NanoXplore Inc.		Canada	41	53
6	CVD Equipment Corporation		United States	39	48
7	Graphene NanoChem Plc		United Kingdom	38	48
8	Thomas Swan & Co. Ltd.		United Kingdom	34	48
9	Grafoid Inc.		Canada	32	50
10	Angstron Materials Inc.		United States	27	44
11	Applied Graphene Materials plc		United Kingdom	26	41
12	Directa Plus S.p.A		Italy	24	32
13	G6 Materials Corp.		United States	23	23
13	Vorbeck Materials Corp.		United States	23	38
15	Global Graphene Group		United States	21	25
16	BGT Materials Limited, Ltd.		United Kingdom	18	25
16	The Sixth Element [Changzhou] Materials Technology Co.,Ltd		China	18	28
18	2D Carbon Graphene Material Co., Ltd.		China	17	22
19	Graphene Laboratories, Inc.		United States	16	32
20	2-DTech Ltd [Versarien PLC]		United Kingdom	13	14
20	Xiamen Knano Graphene Technology Co., Ltd.		China	13	22
22	Bluestone Global Tech, Ltd.		United States	12	19
23	AMO GmbH		Germany	11	15
23	Nanjing XFNANO Materials Tech Co.,Ltd.		China	11	23
23	Perpetuus Advanced Materials PLC		United Kingdom	11	18
26	Ningbo Moxi Technology Co. Ltd.		China	10	12
26	Deyang Carbonene Technology Co., Ltd		China	10	14
26	Ningbo Morsh Technology Co. Ltd.		China	10	14
26	Versarien plc		United Kingdom	10	13

Figure 8. Companies that are most frequently mentioned (more than 10 times since 2020) in the analyzed graphene market reports ordered by their number of recent mentions.

Both common sense and trademark laws largely rule out the actual existence of 'Vorbrck' as an actual rip-off company, and internet searches mainly point to the various market reports as primary evidence of their existence. Our systematic meta-market analysis and its breakdown for this entity (SI, table S2) shows its very first appearance in 2016 (in two independent market reports). And then remained dormant for several years, until starting to reappear in 2020 with increased frequency ever since. Of course, we cannot rule out the fully independent reproduction of the identical typo by different market report providers, but its overall frequency rather points to alternate explanations. In analogy, we also found a total of seven mentions of 'Granphenea' by six independent market report providers since 2019. Of course, this name closely resembles 'Graphenea' (rank 2 in figure 8), just deviating by a single, very specific typo (SI, table S3). Hopefully, the proliferation of these typos will eventually fade out soon, but they still maintain a certain presence in most recent (2023) market reports. In general, we can attribute the effect as evidence of a certain level of rather uncritical copy-and-paste practices among some market report providers, which does not build trust in their methodology. Of course, more sophisticated providers do exist and they do produce highly valuable market reports. However, due the lack of any independent quality assurance mechanism, the market report category as an element of grey literature maintains a rather flawed reputation.

Beyond analyzing the frequency of market report mentions for individual actors, we may also analyze they ensemble. In particular, we can break down the national origin each company that was mentioned in the market report previews (figure 9). As expected due to the language bias of our analysis (see above), a large dominance of English-speaking countries, such as the USA, the UK and Canada is apparent. However, it remains hard to differentiate between pure language bias and actual industrial dominance as influence factors without considering secondary indicators. Hence, we attempt to break down other monitoring techniques down to actor level as well (see below), also to enable some qualified comparison.

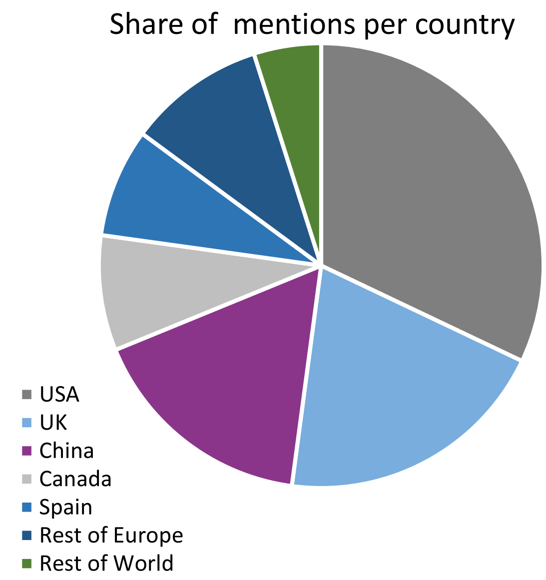

Figure 9. Countries with the largest number of company mentions (only companies with at least 3 mentions were counted) in the analyzed market reports and the corresponding shares of mentions.

5.2. Complementary market data

Other freely available sources of graphene companies exist, such as the SIO Graphene Supplier list [121], which even provides information on the production capacities. Comparing the companies on this list with production capacity of more than ten tons per year (2D fab, 2D Materials, AVANZARE Innovacion Tecnologica, GrapheneCR, Nanografi Nanotechnology, Saint Jean Carbon, Xiamen Knano Graphene Technology, The Sixth Element (Changzhou) Materials (even $>100\ \mathrm{t\ yr^{-1}}$)), it seems surprising that these companies with significant production capacities were considered only by few market report provider, or at least were not considered to be very important (with the exception of Xiamen Knano Graphene Technology and The Sixth Element that are both present in the top20).

The Graphene Council [122] and Graphene Info [123] also provide public information of graphene companies. Finally, another source of relevant company information in the graphene sector is the list of companies that registered their products under the European Union REACH regulation [124]. Although some company names that appear in this list seem to be service providers rather than graphene producers, some background search (e.g. [125] www.graphene-info.com/new-eu-consortium-launched-handle-reach-graphene-registrations) will reveal that Advanced Graphene Products, Avanzare innovacion Tecnologica, Directa Plus, Flexegraph, Global Graphene Group, Talga Advanced Materials, The Sixth Element (Changzhou) Materials, NanoXplore and Applied Graphene Materials have registered to manufacture or import between 10 and 100 tons of graphene per year and can thus be considered relevant players.

5.3. Indirect indicators for industrial activity

In contrast to the rather opaque information available on market status and progress, innovation researchers utilize much better access to the foundational stages of the innovation process [126]. Scientific discovery and research usually is well documented by journal publications that undergo rigorous quality assurance by peer-review processes. Similarly, development of novel technology is usually protected by patents that

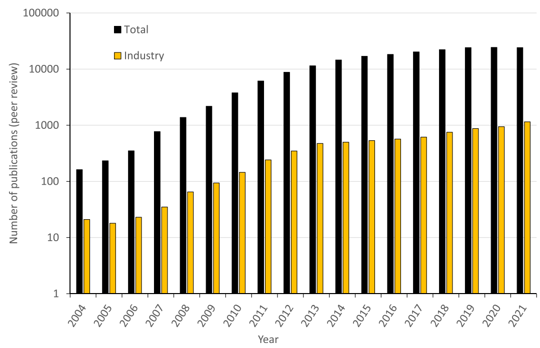

Figure 10. Development of graphene-related publications in peer-review journals over time: total number (black) vs. those with industrial contributions (yellow).

undergo well-structured quality assurance and publication processes as well [127]. Typical tasks of both bibliometric and patent analyses cover the temporal development of R&D activities and their regional distribution, as provided by us for the field of graphene and related materials (GRMs) [126]. Please refer to figure A1 in the supplemental material for an updated version including most current data. Here, we specifically focus on resolving further evidence on industrial activity from such data.

5.4. Industrial publication activity

Among scientific publications on GRM, we can identify a small percentage of articles with co-authors having an affiliation with an industrial entity (figure 10).

In particular, figure 10 shows the total number of GRM peer-review publications for each publication year (black bars) as identified via SciSearch (STN international, by simple key word search) on a logarithmic scale. Note that we employ SciSearch here for its particular strengths for certain tasks, while we require different databases for different research tasks (see below). In this case, we attempt to trace authorship with industrial affiliations. This requires a systematic search for common incorporation identifiers (such as Co., Corp., Inc., GmbH, plc, etc) and careful correction of common atypical entries (such as public research centers incorporated as such legal entities). As a result, we can separate the number of publications that include at least one co-author with an industrial affiliation (figure 10, yellow bars). Our results show both the general trend of growing publication numbers in the field and a relatively stable share of industrial publication on the order of about 4% for each year. We further utilized this data to identify the top industrial actors who have been publishing in the graphene field (figure 11).

Figure 11 lists industrial entities ranked by the number of co-authored graphene publications found in the SciSearch database (see above). We show complete results for entities with at least 15 SciSearch hits and selective entries with at least 5 SciSearch hits. Our selection criteria intend to highlight entities frequently mentioned in market reports studies (see figure 8; yellow name field) and European actors (blue flag field).

As an additional indicator, we calculated the graphene fraction among the overall publication activity of all relevant entities. However, due to the different strengths of databases, we need to employ Web of Science (WoS) to analyze these records (see below for a discussion of details and discrepancies). Figure 11 species these results for each entity shown. In addition, field coloring highlights both remarkably high (>80%; green) and low (<2%; red) values for visual guidance.

Industrial authorship of graphene publications

Rank	SciSearch entries	Affiliation (by term in database)	National Origin	WoS entries (total)	WoS entries (on graphene)	Graphene fraction
1	89	AMO GMBH	Germany	289	128	44.3%
1	89	NTT CORP	Japan	7395	159	2.2%
3	43	INTEL CORP	Canada	7825	68	0.9%
3	43	TOYOTA CENT RES & DEV LABS INC	Japan	4379	57	1.3%
5	37	IBM CORP	United States	48412	161	0.3%
6	34	GRAPHENEA SA	Spain	51	50	98.0%
7	32	BASF SE	Germany	3211	39	1.2%
8	28	JEOL LTD	Japan	2788	50	1.8%
9	23	SAMSUNG ELECT CO LTD	South Korea	4099	64	1.6%
10	22	SHT SMART HIGH TECH AB	Sweden	66	25	37.9%
11	20	KINTECH LAB LTD	Russia	84	35	41.7%
11	20	UES INC	United States	1710	31	1.8%
13	19	HITACHI EUROPE LTD	Japan	154	20	13.0%
13	19	NEC CORP LTD	Japan	7031	76	1.1%
13	19	SUZHOU NANOWIN SCI & TECHNOL CO LTD	China	77	24	31.2%
16	17	HITACHI LTD	Japan	16887	70	0.4%
17	15	IBM TJ WATSON RES CTR	United States	2200	129	5.9%
18	14	CANATU LTD	Finland	44	17	38.6%
18	14	INFINEON TECHNOL AG	Germany	1116	20	1.8%
18	14	NANOFORCE TECHNOL LTD	United Kingdom	83	30	36.1%
27	12	NANOXPLORE INC	Canada	22	15	68.2%
30	11	PRECIOUS TYRONE NEW MAT CO LTD	China	8	8	100.0%
30	11	SIXTH ELEMENT CHANGZHOU MAT TECHNOL CO LTD	China	13	13	100.0%
30	11	SPECS SURFACE NANO ANAL GMBH	Germany	58	19	32.8%
35	10	SICHUAN CHANGHONG BATTERY CO LTD	China	11	11	100.0%
40	9	APAR IND LTD	India	17	15	88.2%
40	9	NANOMAT INNOVAT LTD	Germany	76	20	26.3%
52	8	GRAPHENE SQ INC	South Korea	10	10	100.0%
52	8	IBM RES ZURICH	Switzerland	998	41	4.1%
52	8	M SOLV LTD	United Kingdom	17	7	41.2%
52	8	TALGA TECHNOL LTD	United Kingdom	6	6	100.0%
52	8	TECH INSPECT & CONSULTING ENGINEERS CO	Iran	8	7	87.5%
75	7	BEDIMENS SPA	Italy	34	33	97.1%
75	7	NANESA SRL	Italy	8	8	100.0%
102	6	GRAPHENE XT SRL	Italy	7	7	100.0%
102	6	HEFEI CARBON ART TECHNOL CO LTD	China	9	9	100.0%
102	6	SHANGHAI XIYIN NEW MAT CORP	China	7	6	85.7%
102	6	SICHUAN KONKASNOW NEW MAT CO LTD	China	6	6	100.0%
102	6	SIXTH ELEMENT MAT TECHNOL CO LTD	China	6	6	100.0%
130	5	ADV GRAPHENE PROD SP ZOO	Poland	6	6	100.0%
130	5	GRAFOID INC	Canada	5	5	100.0%
130	5	GRAPHENEA	Spain	26	25	96.2%
130	5	HAYDALE LTD	United Kingdom	6	6	100.0%
130	5	VORBECK MAT CORP	United States	17	16	94.1%

Figure 11. Industrial entities with publication activities in graphene context ranked by SciSearch entries (only selective entities shown for less than 15 SciSearch entries).

We recognize a tendency for such extreme values determining two basic actor types: large multinational corporations (such as NTT, Intel, Toyota, IBM, BASF, Samsung, etc) with broad research and publication activities typically show rather low graphene intensity on one end of the spectrum. And well-known players from the emerging graphene industry (such as Graphenea, Nanoexplore, Sixth Element, etc) typically with only modest publication numbers that particularly focus graphene on the other end. Note that companies frequently mentioned in market studies so far usually fall in the latter category.

Regarding the activities of larger entities, the statistics shown in figure 11 alone may not distinguish between dedicated graphene research efforts or coincidental character of the underlying records. The sheer breadth of research activities within a multinational corporation would likely dilute down the publication numbers related to any dedicated graphene research program within such an enormous organization. However, graphene utilization may also only constitute a plausible material option (among other micro- and nano-carbons) in diverse application contexts. Prominent mentions of such options may likely trigger an inclusion in key word search results in publication databases as well. A proper resolution of these effects will require either advanced bibliometric studies, in-depth content analysis of the underlying publications, or ideally a combination of both.

Prior to more sophisticated bibliometric analysis of the results, also our general approach may deserve some further attention as it already pushes the boundaries of common publication databases. First of all, the straight-forward identification of industrial affiliations is typically not supported by literature databases. Our approach discussed above leads to fairly decent results, but still containing substantial flaws. It requires substantial experience and manual data cleaning (i.e. removal of false hits), while also a significant miss ratio (e.g. through absent or not included corporation acronyms) appears likely. Meanwhile, also the utilized database collections may not only influence the scale, but also the order of the results. For instance, the WoS representation[1] utilized here obviously produces more extensive search results for 'graphene'. In principle, these deviations are consistent with the underlying database structures. SciSearch represents the core collection of the Science Citation Index, which also constitutes the foundation of WoS, but expanded versions exist. For instance, SciSearch claimed to cover 78% of the extended WoS version in 2021. However, deviations for individual entities shown in figure 11 fluctuate between identical and nearly identical hit numbers (many cases), moderate increases (∼50%; many cases as well), and stark amplifications (by multiples; only few cases). The effect probably relates to institutional publication preferences (e.g. journal articles vs. conference proceedings) and their inclusion in either database. Finally, affiliation search terms appear to lack unification throughout databases, leading to the entries of each company potentially being split between several search terms, compromising the significance of an unadjusted ranking either way. Of course, it may make sense to distinguish between subsidies of larger multinationals (e.g. IBM appearing on ranks 5, 17, and 52 with distinct legal entities), but multiple entries for the exact legal entity frequently occur. One prominent example is Graphenea appearing on ranks 6 and 130 with and without their corporation acronym. Publications under each entry do not intersect. Close inspection of full text articles did not result any trace of author influence (identical spelling of affiliation and address on full text publication records from both groups). Hence, we consider that internal database protocols (e.g. when merging partial record collections) carry responsibility.

In conclusion, our results shown in figure 11 certainly highlight some industrial entities with substantial scientific publication activity in the graphene sector, but inclusion and order of actors remain somewhat arbitrary (in particular due to split records). Nevertheless, we recognize many players that also market reports frequently mention, but not necessarily in the same order. Moreover, publication analysis also reveals further actors with a profile similar to known graphene producers (smaller overall publication footprint, but a high fraction of those on graphene). Most graphene suppliers currently fall in that category, in turn that profile likely identifies further graphene suppliers. Comparing that group (>5 SciSearch hits, >80% graphene fraction; highlighted green in figure 11) with players frequently mentioned in market reports (figure 8), we recognize a much higher diversity of national origin. Of course, scientific publication activity does not represent a good measure of market relevance (in particular, as players may deliberately decide to not engage), but our approach constitutes a valuable complement to overcome that apparent language bias of market reports (for players active in English speaking regions).

5.5. Global patenting activity

In contrast to general scientific discovery discussed in peer-review publications, the development of novel technology and protection of the resulting intellectual property constitutes a key activity among many industrial entities. Structured processes for patent submission and examination primarily exist on national level. Despite strong similarities, both the required effort and the incentives to engage in patenting may strongly vary between countries. However, a single patent may well be expanded to protection in various jurisdictions, giving rise to

[1] Note that Web of Science search results depend on the license environment, as institutions may subscribe to various extent of the underlying literature database.

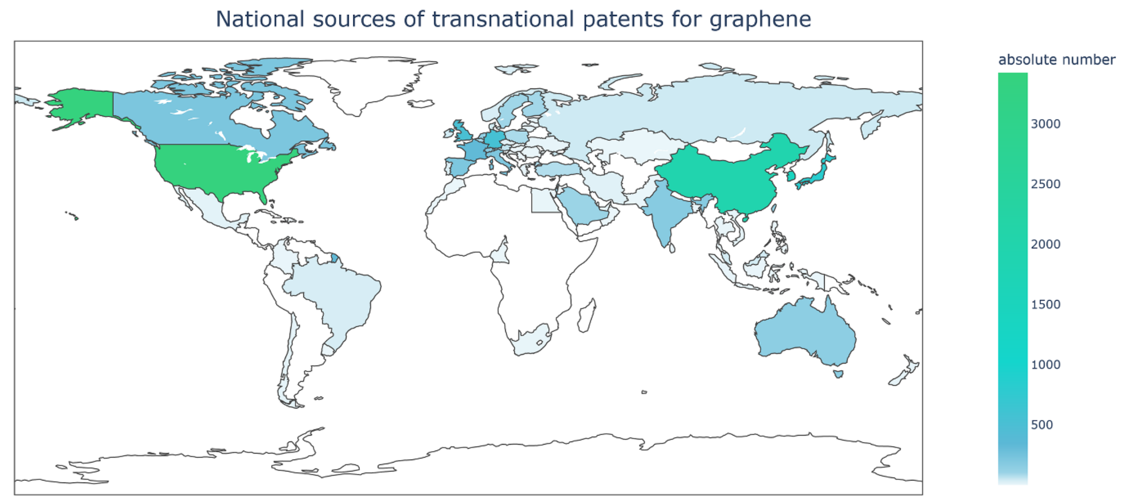

Figure 12. World map resolving transnational patenting activity for the overall graphene field by national origin of inventors.

patent families consisting of numerous national patent records with analogous technical coverage. Of course, cost and effort scale with the number of markets to be covered, which strongly discourages secondary patenting motivations (prestige, career building, research funding etc) other than commercial exploitation through technical application.

Good practice in patent analysis requires the consideration of (only) transnational patents (that cover several national markets). Here, only patent families are considered with applications at the European Patent Office or PCT applications at the World Intellectual Property Organisation, as these applications aim at several foreign markets and hence involve high application costs. The searches for transnational patents have proved to provide rational country comparisons in terms of technical performance. The searches are performed in the database World Patents Index, as this database is organized in patent families and is very effective in keyword searches. This is due to the fact that all documents have special technology-oriented titles and abstracts provided by technical experts.

Figure 12 provides an overview of the global distribution of transnational intellectual property generation in the graphene field based on the nationality of inventors for patent families with priority dates from 2000 to 2020. Note that the simple keyword search (for 'graphene' in patent titles and/or abstracts) should identify graphene related patent records in the broadest conceivable way, but does not consider the specificity of their practical content. It ranges from practical procedures to generate certain types of graphene and applications relying on very specific graphene properties to the general utilization of carbon particles among which graphene may just be named as one example among multiple others.

A thorough resolution of graphene specificity among this pool of patents would require the inspection of the full text patent records by experts capable of resolving the technical core of each single potentially masked by the legal nature of those documents. In particular, applicants usually try to maximize the breadth of their claims by their least specific and inclusive formulation, often deliberately at the expense of clarity and transparency. Hence, we consider the search above as a superset of all potentially relevant transnational patents related to graphene, among which we conduct further analyses. These results show no major indications for regional biases in the specificity or focus of those patents (see below), so that we consider relative intensity of the graphene IP generation as depicted in figure 12 fairly representative. We recognize the USA and China as the two most active inventor nations in this field in absolute terms.

Many European countries (such as Germany, France, Great Britain, etc) show substantial activity as well. Combined, the EU-27 countries as a global entity with comparable economic weight ranks roughly at par with the USA and China in graphene IP generation (also compare figure 17).

5.6. Industrial patenting activity

In this chapter, we strive for the resolution of industrial activity, particularly considering the supply side. Depending on their origin, typical graphene suppliers may be centered on an attractive process routes or access to suitable feedstock for graphene production. In either case, successful suppliers will likely develop and protect process IP for the isolation or synthesis of graphene, which are covered by highly specific patent classes within the 'nanosized carbon materials' (C01B 32/15) category of the IPC scheme.

In particular, we consider the IPC codes from C01B 32/182 to C01B 32/198 where the preparation of graphene by different techniques is listed. Typical examples include classifications for exfoliation and post-treatment, CVD and epitaxial growth. Of course, these codes only cover a limited part of all graphene-related patent applications, while the majority of graphene patents are mostly classified towards specific application areas such as batteries, microelectronics or plastics (see below). Of course, this restriction substantially reduces the absolute number of patents identified through the restricted search compared to figure 12, but the relative global distribution of the IP over nationality of inventors remains largely comparable (Please refer to figure S2 in the supplemental material to compare visualizations.).

Beyond national origin, we utilize the process IP portfolio as characterized above to identify key actors in the field based on the applicant data filed with each patent. Inventors may file patent applications themselves (in private interest, as a natural person), but usually commercial and other legal entities will assume this role. We recognize strong legal and financial drivers: First of all, employers usually claim rights to their employee's invention in case resulting from work activities. Meanwhile, both the patenting process itself and the commercial exploitation of the protected IP usually requires substantial financial resources, which strongly incentivizes the utilization of legal entities (perhaps even founded for that specific purpose).

Given the low maturity of the graphene supply industry, universities and other research organizations hold a substantial share of graphene supply related patents. Also, the extensive IP portfolios of large multi-national companies may coincidentally contain some patents classified in the categories described above. Meanwhile, emerging graphene suppliers may command only few, but crucial patents. Hence, we abstain from simply ranking applicants by the number of relevant patents. Instead, we rather attempt to prescind our empirical experience in a systematic calculation of a specialist score. Its design intends to balance the following factors regarding their IP portfolio:

- n_s: number of patents specifically classified among the graphene supply categories (as described above)
- n_g: number of graphene-related patents (including n_s: simple key word search as used for figure 12)
- n_a: number of all patents filed by the entity.

The basic idea and only function of our fully empirical specialist score is to deliberately highlight small industrial actors with only few, but often highly relevant patents. A profile that matches well with start-ups, university spin-outs, and other emerging graphene suppliers common on the market today. In contrast, we seek to discount both singular applicants (often private persons) and larger entities with much wider IP portfolios that contain some graphene patents, but usually are currently not actively engaging in the commercialization of that specific technology. The latter group particularly includes universities and other research institutions that may engage in graphene research, but usually follow no specific exploitation strategy other than licensing. Also, large multi-national corporations in technology intense business fields usually gather extensive IP portfolios where graphene utilization options may at least be covered in a certain fraction.

In several iterations, in which we benchmarked calculation concepts with our empirical knowledge of the field. Eventually, we settled for combining two concepts:

- We consider graphene application patents as partially relevant, thus define an indicator for relevant patents as: $n_r = n_s + \frac{1}{f} \cdot (n_g - n_s)$ where our choice of the factor $f = 4$ clearly emphasizes genuine graphene supply patents.
- We assign applicants with a relevancy ratio that relates their relevant patents to their entire patent portfolio: $r_r = \frac{n_r}{n_a + b}$, where the deliberate choice of the bias value of $b = 3$ intends to quench the influence of very small patent portfolios.
- Now, we can assign any given applicant with our empirical specialist score (v_s) when evaluating their relevant patents (n_r) with the square of their relevancy ratio (r_r).
- In total, we obtain: $v_s = n_r \cdot {r_r}^2 = n_r \cdot (\frac{n_r}{n_a + b})^2$.

Here, squaring r_r strengthens the influence of our deliberate biases that discriminates against both larger, yet less specific IP portfolios (particularly affected by their high n_a) and really small ones (particularly affected by $b = 3$). Note that slight adjustments of the constants b and f as well as the exponent may prove useful in other contexts. However, we found that our choices worked reasonably well for both our immediate purpose (of highlighting companies that specialize in graphene production) and the translation of the concept to certain graphene applications (see below).

In summary, we like to stress that the resulting value of the specialist score v_s conveys no particular meaning. It just serves as an arbitrary measure to rank and, thus, highlight certain patent applicants amongst numerous others following our criteria specified above. The development of the empirical indicated based on testing its ability to highlight small-scale graphene suppliers already known to us. Hence, it shall also identify further entities with a similar profile. A high position in the ranking of patent applicants according to their specialist score simply suggests a high probability of the respective entity to be a graphene supplier.

Probable niche suppliers of graphene materials

Rank	v_s	Affiliation (by term in database)	National origin	Graphene production patents	General graphene patents	Total patents (PATSTAT)	Fraction of total patents
1	14.79	NANOTEK INSTRUMENTS INC	United States	47	130	142	33.1%
2	5.61	PARAGRAF LTD	United Kingdom	11	14	14	78.6%
3	3.34	GLOBAL GRAPHENE GROUP INC	United States	13	25	32	40.6%
4	2.82	HANGZHOU GAOXI TECH CO LTD	China	9	16	18	50.0%
5	2.03	APPLIED GRAPHENE MATERIALS UK LTD	United Kingdom	6	10	10	60.0%
6	1.88	XG SCIENCES INC	United States	6	12	12	50.0%
7	1.50	GRAPHENEA SA	Spain	5	9	9	55.6%
8	1.40	SHT SMART HIGH TECH AB	Sweden	6	8	11	54.5%
8	1.40	GRAPHENE SQUARE INC	South Korea	5	11	11	45.5%
10	1.37	LYTEN INC	United States	9	13	24	37.5%
17	0.70	GRAPHENSIC AB	Sweden	3	4	4	75.0%
21	0.56	INSTYTUT NISKICH TEMPERATUR I BADAŃ...	Poland	4	8	12	33.3%
22	0.55	THE INSTITUTE OF PHOTONIC SCIENCES	Spain	3	3	4	75.0%
25	0.42	PERPETUUS R&D LTD	United Kingdom	3	3	5	60.0%
26	0.38	DIRECTA PLUS SPA	Italy	4	14	24	16.7%
27	0.32	GRAPHITENE LTD	United Kingdom	2	4	4	50.0%
44	0.17	THE UNIVERSITY OF MANCHESTER	United Kingdom	19	51	337	5.6%
113	0.01	SEOUL NATIONAL UNIV R&DB FOUND	South Korea	19	52	1491	1.3%
151	0.00	SEKISUI CHEM CO LTD	Japan	19	51	2239	0.8%
169	0.00	MASSACHUSETTS INSTITUTE OF TECH	United States	19	108	5056	0.4%
182	0.00	LG CHEM LTD	South Korea	28	136	10266	0.3%
225	0.00	THE REGENTS OF THE UNIVERSITY OF CA...	United States	30	138	15566	0.2%
390	0.00	SAMSUNG ELECT CO LTD	South Korea	21	149	49445	0.0%

Figure 13. Specialist scores of transnational graphene production IP applicants: top-10 ranks in global (bold font) and European (blue highlight) comparison, complemented by top-8 in absolute terms (green highlight). Yellow highlights indicate entries renowned from market reports.

Still, the achieved rank at best constitutes a weak measure of the relative strength of an entity's IP portfolio (only based on numbers, not on content) and certainly does not measure their absolute position in the market. In particular, legitimate executive decisions may prevent inclusion of an important graphene supplier at all, in case they chose to

- protect their IP as trade secrets (instead of patenting),
- license IP from third parties (e.g. the university they spun out of),
- file their patents only in their domestic (or any other single national) market, or
- operate with standard processes (without developing specific IP, seeking competitive advantage through other measures).

Thus, the results shown in figure 13 highlight likely graphene suppliers, but a substantial share of relevant graphene suppliers will probably never be listed there. They only constitute a complementary perspective among several others that may jointly produce a more complete picture.

In detail, figure 13 lists a selection of applicants that filed transnational patents in the graphene production category ranked according to our empirically deduced specialist score. The table combines several selection criteria, showing all entities among the top-10 both in global (bold font) and in European (blue highlight) comparison as well as the top-8 entities with regard to the absolute number of graphene patent applications (green highlight) as reference. The latter group illustrates the motivation to establish the specialist score, as it exemplifies applicants that largely dominate conventional patent statistics in this field. Among these eight, we recognize four universities (such as MIT, UCal) and three large corporations (such as Samsung, LG Chem), but only a single graphene supplier (Nanotek) due to its outstanding IP portfolio. Other emerging suppliers pale in that comparison.

In contrast, the ranking according our specialist score as shown in figure 13 highlights emerging graphene suppliers that filed relevant IP. Well-known players frequently mentioned in market reports already claim six out of the top-10 ranks. Also the entirety of the remainder consists of companies dedicated to graphene commercialization. Notably, European players claim a substantial share of the top positions: Four among global top-10, while the tenth best ranked European still claims rank 27 in a global comparison.

Generally speaking, the specialist score concept largely fulfills its intended purpose of highlighting probable industrial specialists for an emerging technology. Of course, non-industrial parties may show up as well in case they carry a similar IP profile. For instance, ranks 21 and 22 in figure 13 are claimed by smaller scale research institutes with a rather narrow activity profile. In contrast, larger entities with a highly diversified IP portfolio receive much lower ranks. Of course, such entities may eventually pursue an active business strategy in the field as well, but in most cases we can assume a high probability of a rather passive stance at present. In general, universities and research organization rather target licensing income and/or spin out strategies instead of actively marketing products. Large technology conglomerates usually acquired broad, comprehensive IP portfolios mainly to secure their freedom to operate for future technology generations.

Of course, no single approach can provide the full picture by itself, we rather advocate for combining several perspectives. With regard to patent-based actor analysis, we recognize a particular strength of our novel specialist score approach over conventional ranking (based on the absolute number of relevant patents) when considering emerging fields of technology. We may add a third perspective (figure 14) that requires the identification of the industrial sector or domain the emerging technology attempts to enter. For graphene suppliers, we may assume that many entities aspire to become a relevant actor of

Top intellectual property holders for carbon materials

Rank	Affiliation (by term in database)		National origin	Carbon materials patents (PATSTAT)	Graphene production patents (WPI)	Indicative fraction (WPI / PATSTAT)
1	LG CHEM LTD		South Korea	132	28	21.21%
2	ZEON CORP		Japan	70	2	2.86%
3	SUMITOMO ELECT IND LTD		Japan	59	3	5.08%
4	SEKISUI CHEM CO LTD		Japan	52	19	36.54%
5	CEA		France	50	11	22.00%
6	BASF SE		Germany	49	6	12.24%
7	NATIONAL INSTITUTE OF ADVANCED IND ...		Japan	48	12	25.00%
8	TORAY IND INC		Japan	44	16	36.36%
9	NEC CORP		Japan	43	13	30.23%
10	CO LTD TOSHIBA		Japan	41	4	9.76%
11	SHELL INTE RESEARCH MAATSCHAPPIJ BV		Netherlands	39	1	2.56%
13	CNRS		France	36	13	36.11%
21	SABIC GLOBAL TECH BV		Netherlands	24	8	33.33%
25	SIEMENS AG		Germany	22	1	4.55%
27	NANOTEK INSTRUMENTS INC		United States	19	47	247.37%
27	CONSEJO SUPERIOR DE INVESTIGACIONES...		Spain	19	10	52.63%
27	BAYER MATERIALSCIENCE AG		Germany	19	1	5.26%
43	THE UNIVERSITY OF MANCHESTER		United Kingdom	13	19	146.15%
50	ARCELORMITTAL		Luxembourg	12	13	108.33%
87	RUTGERS THE STATE UNIVERSITY OF NEW...		United States	7	10	142.86%
87	SEMICONDUCTOR ENERGY LAB CO LTD		Japan	7	16	228.57%
108	LYTEN INC		United States	6	9	150.00%

Figure 14. Frequent patent applicants in the carbon materials category (top-10 on global and European scale) and their relevant graphene IP. Top-5 regarding their graphene intensity included as well. Refer to the main text for a discussion of obvious database discrepancies.

the general micro- and nano-carbon supply industry. Material classes such as carbon black or activated carbon already enjoy mass utilization as additives in various contexts (such as the polymer industry, battery electrodes, concrete, etc). Hence, we may attempt to analyze that carbon supply industry based on their relevant transnational IP activity (figure 14).

In particular, figure 14 shows both the global and the European top-10 applicants for carbon supply IP. We immediately recognize a dominance of Japanese companies in this sector, who claim 7 positions among the global top-10. LG Chem from Korea, however, claims an unrivalled at top rank. The top-10 European actors appear scattered within the global ranking, but two actually occur among the global leaders. In general, public research centers such as CEA (rank 5) and AIST (rank 7) appear frequently between industrial entries.

We calculate an indicative graphene fraction among the relevant IP of each entity. Here, we seek to combine the strength of two databases (WPI and PatStat), but need accept dealing with not fully commensurate data in turn. WPI actively maintains and augments its database in many way, resulting in a substantial improvement in the identification of relevant patent records (∼30% more hits in average). However, PatStat provides better access to actual patent records and their meta-data, also enabling systematic large scale searches (e.g. to quantify an entities IP portfolio). In this dilemma, we prioritized the quality of core data (i.e. best possible identification of graphene related transnational patent families) over fully consistent of an auxiliary indicator. Hence, we have to suspect slightly inflated values for all indicative graphene fractions (as shown in (figures 14, 19, 21, and 23)) of about 30% in average—and way beyond in special cases. For instance, PatStat does only show those patents records originally filed by Nanotek Instruments, while using WPI all records associated with related subsidies appear under the same label. The calculated values, thus, only represents some indication for the relevance of graphene within any given entity.

Taking the limitations of the indicative graphene fractions shown in figure 14 into account, we still recognize that many established carbon materials producers already carry a substantial amount of relevant graphene production IP in their portfolio (∼20%). Actually, only few among the leading carbon suppliers show much lower values (∼5%). Extreme values exist, but rather point to relevant universities (Manchester, Rutgers) than to operative graphene suppliers. However, the typical magnitude of carbon supply IP among established players (∼50 transnational patents) does not fully outclass emerging graphene suppliers, which may eventually establish themselves in the broader regime of the carbon material industry.

In essence, this section establishes a comprehensive approach for actor analysis based on public available structured data for the emerging graphene supply industry. In its infancy, actors often combine materials and application development. Hence, we try to apply relevant parts of the approach to analyze the graphene utilization actor landscape in a similar fashion.

6. Market landscape: utilization side

So far, the emergence and development of graphene as an advanced material for diverse applications is largely driven by the materials supply side [5]. The plethora of conceivable utilization options, their specific benefits in each proposed application fields, and the complexity of the potentially arising value chains is in the center of our graphene roadmap work [126]. However, in the present Roadmap Brief, we specifically regard broader generalization that we can derive from market reports by our meta-market analysis approach and further evaluate in the light of complementary data.

Of course, individual market reports will provide much more details and insights for specific applications and actors, but we pay specific attention to aspects that enable at least a certain level of comparability across multiple sources. Many market reports do not only specify and predict figures for the overall graphene market, but also distinguish certain segments. In particular, the segments of graphene composites, graphene electronics, and graphene batteries appear most frequently. Note that the nature and breadth of the above fields largely differs. Also, the market report providers may apply non-coherent definitions to differentiate those market segments, which could potentially further add to the scatter between market predictions. However, a certain consensus on highlighting these application areas (compared to other not or less frequently considered) indicate substantial commercial interest in these fields as providers particularly seek to sell their market reports to interested industrial customers.

We collected market report preview information on these three graphene sub-markets (graphene composites [128–156], graphene electronics [157–185], and graphene batteries [186–218]) and compared them to the overall graphene market (figure 15). The estimations for the current market revenue (approx. 100 million US$ in 2022) and the expected growth (CAGR between 20% and 30%) for the graphene battery market are rather consentaneous. This is not the case for the graphene electronics market, where the predictions for revenue values reach from below 100 million US$ to more than 1 billion $ and for growth rates reach from below 20% to almost 40%. Interestingly some revenue estimations exceed those of the overall graphene market, which could partially be explained with the definition of the electronics market (some market report providers include the battery market into the electronics market, others not). Even more drastic are the variations in the graphene composite market estimations, reaching from revenue values of below 20 million $ to almost 12 billion $ in 2022 and growth rates between 3.5% and 40%. Obviously, the market report providers were considering very different aspects and products (e.g. from only the graphene material costs to the product values achieved with graphene composite products). It is hence very difficult to gain very meaningful insights out of this analysis, other than that these segments are apparently quite important markets for the graphene industry.

Beyond overall graphene market segment volume and growth predictions, publicly available portions of market reports rarely specify the most relevant actors for each application field. Across the board, our 3I into prospective value chains [126] clearly indicate that at present graphene suppliers often still drive application development, usually in close collaboration with selected prospective customers [5]. This practice certainly also constitutes a mitigation measure to overcome the hesitance among most downstream players on the market who largely remain in an observant posture. Of course, some market reports may provide useful intelligence for either of the above market segment. In contrast, we rely on

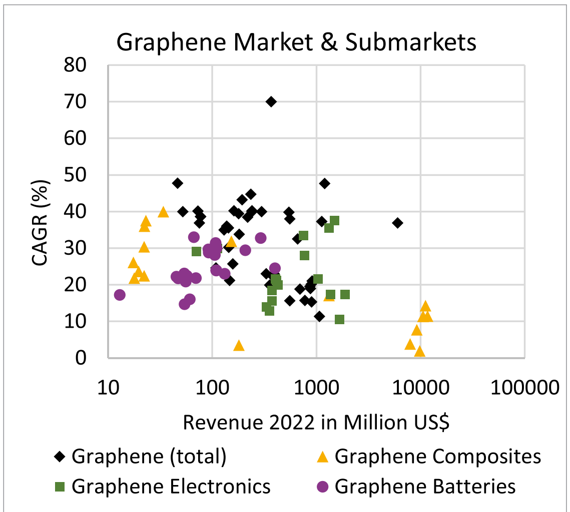

Figure 15. Revenue and CAGR figures of various market reports for the global graphene market (market reports from 2021/22) and its submarkets graphene composites, graphene electronics and graphene batteries.

complementary analyses to provide a comprehensive of the current market landscape in these three application fields.

We begin with a global overview comparing these graphene utilization fields on the basis of transnational patenting statistics (a) to each other, (b) their development over time, and (c) their regional distribution (section 6.1). We further analyze each sector to resolve present and potentially relevant actors in each field of graphene utilization (sections 6.2–6.4). Typically for emerging niche technologies, public research institutions still largely dominate the respective IP landscapes, while the incumbent players on the general market for each application field often maintain a passive, possibly rather observant posture (see above). Hence, we follow a dual approach to map the industrial landscapes. First we employ our ranking strategy (as described in section 5.6) to highlight emerging industrial actors dedicated to graphene utilization among transnational patent applicants. Then, we also employ patent statistics over the entirety of each application field (i.e. without considering graphene utilization) to resolve major industrial players—and analyze in what extent their present IP portfolio already considers graphene utilization today.

6.1. Global comparison of application sectors

In analogy to section 5.3, we utilize transnational patenting as a strong indicator for commercial exploitation intent. Among the pool of general graphene patent applications as shown in figure 12 above (identified by a WPI-based key word search), we rely on the IPC classification scheme to identify those records specifically relevant for certain application areas. In particular, we consider graphene use in electronics, batteries, and plastic composites, roughly in line with

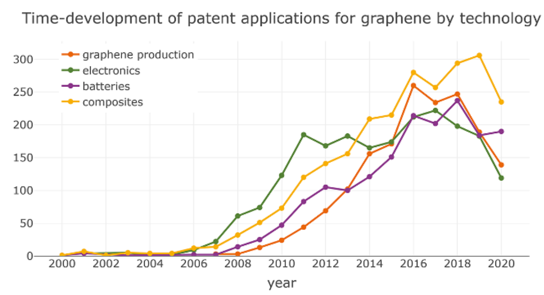

Figure 16. Development of transnational patenting activity in graphene electronics (green), composites (yellow), and battery (blue) applications and in the material supply field (orange) over time.

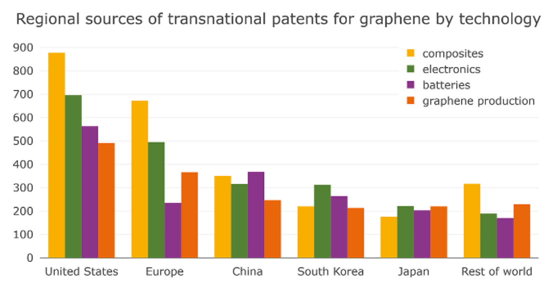

Figure 17. Global distribution of transnational patenting activity for electronics (green), composites (yellow), and battery (blue) applications and material supply (orange) over regional/national origin of inventors.

major application areas specified in multiple market reports (as shown in figure 15). Beyond our superset definition by keyword (see above), we defined subsets relevant for each application context by:

- IPC-code H01L as the core classification for semiconductor devices for the electronics field;
- IPC-code H01M in combination with keyword 'batteries' or 'battery' (to distinguish from fuel cell patents assigned to the same subclass) for the battery field; and
- IPC-codes B29C or C08 for (plastic) composites, where B29C comprises of shaping or joining of plastics, while C08 comprises of organic macromolecular compounds, i.e. different types of polymers.

Of course, these subfield definitions maybe debatable at detail level, but sufficiently recognize the vast majority of relevant transnational patent records in either field. At first, we analyze the temporal development (figure 16) and regional distribution (figure 17) of the application-specific graphene IP in all three application fields as well as for graphene production as defined above.

Figure 16 depicts the distribution of the graphene IP pool segments assigned to each of the application fields as defined above, along with the material supply category (as described in section 5.3), over the first priority years assigned to either application. We recognize that substantial patenting activity did not start before 2008, just a couple of years after the first practical isolation of graphene (in 2004) and well before its recognition with the Nobel Prize (in 2010). All curves roughly resemble a similar shape consisting of minor onsets (prior to 2007), followed by a rather steep growth in yearly numbers, which eventually transitions into slower expansion of patenting activity thereafter. In detail, we recognize a few significant differences though: at first, graphene applications in electronics (green line) and composites (yellow line) led the IP statistics in nearly linear ramp from 2007 through 2011 to almost 200 transnational patent applications. While the yearly count for graphene electronics fluctuates around this level ever since, graphene composites continued to grow to a level of about 300 records per year today. In contrast, IP generation related to the very supply of graphene (a key requisite for any industrial utilization) follow a more restrained ramp-up trajectory. Still in 2011 less than 50 transnational patents were filed in this category, but the expansion rather occurred in an exponential fashion and already reached over 250 in 2016. Finally, the battery sector represents a way more specific field with a much narrower definition. The entire battery field experienced unprecedented growth as key factor in e-mobility context. Meanwhile, graphene receives at least some attention as a possible additive for upcoming battery anode generations. Hence, we recognize substantial transnational patenting activity in this rather narrow field. At a rate of about 200 applications in recent years, graphene battery IP reaches a similar level as the much broader electronics and composites categories, providing some justification for the specific attention to graphene batteries in market reports.

Figure 17 compares the regional distribution of IP creation based on the national origin of the inventors for all four categories described above. We recognize that the three world regions of North America, East Asia, and Europe largely dominate global graphene IP generation at nearly comparable shares so far. Basically, the situation in every application field as displayed in partly aggregated fashion in figure 17 resembles the overall global graphene IP distribution as resolved in figure 12. Of course, we recognize some regional trends, such as a specific focus on graphene utilization in batteries in East Asia consistent with their current industrial leadership in overall battery technology. The sectoral distribution of IP creation in the US and Europe roughly represents the global distribution (with highest numbers accumulated in the composites sector). The relative strength of the rest of the world with regard to graphene supply mainly traces back to Canadian and Australian contributions. The two countries feature a traditional focus on the mining sector, where graphene production essentially may be considered as possible value-addition through betterment of graphite feedstock.

Please refer to figures S4–S7 in the supplemental material for a full resolution of the national IP distribution in either category in analogy to figure 12. In the following, we present patent-data-based actor analyses for each of the major graphene application sectors as described above.

6.2. Graphene electronics

Among the three main graphene application sectors we can distinguish based on market reports, the electronics industry stands-out for its distinction in high-value. Here, a single layer of graphene (and other materials) and its particular quality may be critical for the function of an entire device. Thus, entirely different KPIs may apply to both quality (electron mobility vs. average flake dimensions) and quantity (area in cm^2 vs. mass in kg) of EGG as primarily used for high-end micro-integration. Of course, bulk applications of graphene exist in the electronics sector, too (e.g. heat spreaders, switches, etc). First, we try to identify probable niche players that specialize on graphene utilization in the electronics sector applying the specialist score concept introduced above (figure 18).

Probable niche suppliers of graphene electronics

Rank	v_s	Affiliation (by term in database)		National origin	Graphene electronics patents	General graphene patents	Total patents (PATSTAT)	Fraction of total patents
1	8.05	PARAGRAF LTD		United Kingdom	13	14	14	92.9%
2	3.73	SOLAN LLC		United States	9	14	14	64.3%
3	2.27	NANOTEK INSTRUMENTS INC		United States	5	130	142	3.5%
4	1.95	NANOMEDICAL DIAGNOSTICS INC		United States	5	5	5	100.0%
5	1.87	EMBERION LTD		Finland	10	11	21	47.6%
6	1.79	CARBEN SEMICON LTD		Cyprus	5	6	6	83.3%
7	1.00	CRAYONANO AS		Norway	4	4	5	80.0%
8	0.97	GRAPHENE SQUARE INC		South Korea	4	11	11	36.4%
8	0.97	SHT SMART HIGH TECH AB		Sweden	5	8	11	45.5%
10	0.75	BEIJING HUATAN TECH CO LTD		China	3	3	3	100.0%
10	0.75	TERA BARRIER FILMS PTE LTD		Singapore	3	3	3	100.0%
10	0.75	NEUTRINO DEUTSCHLAND GMBH		Germany	3	3	3	100.0%
13	0.70	GRAPHENSIC AB		Sweden	3	4	4	75.0%
14	0.63	GRAPHENEA SA		Spain	3	9	9	33.3%
16	0.34	AMO GMBH		Germany	4	5	12	33.3%
18	0.32	GRAPHITENE LTD		United Kingdom	2	4	4	50.0%
19	0.31	INSTYTUT TECHNOLOGII MATERIALOW ELE...		Poland	4	14	27	14.8%
109	0.01	MASSACHUSETTS INSTITUTE OF TECH		United States	37	108	5056	0.7%
200	0.00	NOKIA TECH LTD		Finland	34	64	7351	0.5%
249	0.00	BOE TECH GROUP CO LTD		China	41	82	14287	0.3%
303	0.00	SAMSUNG ELECT CO LTD		South Korea	75	149	49445	0.2%
368	0.00	INTEL CORP		United States	38	43	19606	0.2%

Figure 18. Specialist scores of transnational graphene electronics IP applicants: top-10 ranks in global (bold font) and European (blue highlight) comparison, complemented by top-5 in absolute terms (green highlight). Yellow highlights indicate entries renowned from market reports.

Actually, figure 18 shows numerous interesting entities, including some graphene suppliers specializing in the provision of EGG such as Graphene Square (rank 5) and Graphenea (rank 14). Several companies strive for the commercialization of graphene-based electronics in substantial breadth (such as Paragraf, rank 1) or in more specific contexts (such as SHT, rank 8, thermal management; Emberion; rank 5; image sensors). Also some lesser known entities show up on high ranks and, thus, can be prioritized for further consideration when analyzing graphene electronics in depth. Of course, also some smaller-scale but well focused research organizations (such as AMO) made the list as will for their similar IP portfolio.

The five reference cases in figure 18 (who lead conventional graphene electronics patent rankings for absolute number of relevant applications) show similar profiles as discussed above. In particular, they include some microelectronics giants (Samsung, Intel) that at least already secure a substantial foothold in graphene electronics to secure their freedom to operate in the future. (And might be interested to keep a rather stealthy profile whenever starting an active engagement in graphene scaling.) Also a renowned research actor in the field (MIT) made that list with numerous patents in this sector, while Nokia Tech also represents the foundation of as successful spin-out (Emberion) now recognized as a specialist in the graphene electronics integration field. It can be of interest to compare the role of the above actors with leading IP applicants in the overall electronics sector figure 19 and determine their relative emphasis put on graphene technology.

Figure 19 compares the magnitude of the general electronics IP of established applicants (global and European top-10) with their specific filings for graphene electronics. Of course, it includes some reference cases (such as Intel, rank 6; Samsung, rank 9) shown in figure 18, at least for those cases where their IP portfolio in centered on the electronics sector. However, for all top actors, the ratio of electronics patents that relate to graphene almost negligible, often below 1%. In this regard, Samsung almost stands out by reaching about 3%, which still constitute only a tiny fraction of their patent portfolio. Note that we derive this indicative fraction from not fully compatible data bases (see above). Figure 19 includes 8 entities with highest values in this regard for reference, confirming the hurdle to easily recognize potential specialists in conventional patent statistics.

6.3. Graphene composites

We conducted an analogue analysis for graphene (polymer) composites as defined by our search

Top intellectual property holders for electronics

Rank	Affiliation (by term in database)	National origin	Electronics patents (PATSTAT)	Graphene electronics patents (WPI)	Indicative fraction (WPI / PATSTAT)
1	MATSUSHITA ELECT IND CO LTD	Japan	4716	5	0.11%
2	APPLIED MATERIALS INC	United States	4707	7	0.15%
3	BOE TECH GROUP CO LTD	China	4492	41	0.91%
4	SHARP CO LTD	Japan	3762	3	0.08%
5	TOKYO ELECTRON LTD	Japan	3745	12	0.32%
6	INTEL CORP	United States	3287	38	1.16%
7	SONY CORP	Japan	3165	15	0.47%
8	FUJIFILM CORP	Japan	2589	8	0.31%
9	SAMSUNG ELECT CO LTD	South Korea	2416	75	3.10%
10	OSRAM OPTO SEMICONDUCTORS GMBH	Germany	2401	3	0.12%
11	KON PHILIPS ELECT NV	Netherlands	2245	6	0.27%
13	CEA	France	2062	27	1.31%
26	ROBERT BOSCH GMBH	Germany	1167	5	0.43%
35	MERCK PATENT GMBH	Germany	959	9	0.94%
54	SOITEC	France	581	2	0.34%
55	FRAUNHOFER GESELLSCHAFT ZUR FORDERU...	Germany	576	5	0.87%
56	IBM UK LTD	United Kingdom	555	8	1.44%
58	CNRS	France	543	24	4.42%
60	ASML NETHERLANDS BV	Netherlands	523	6	1.15%
447	PARAGRAF LTD	United Kingdom	8	13	162.50%
465	SOLAN LLC	United States	7	9	128.57%
518	INSTYTUT TECHNOLOGII MATERIALOW ELE...	Poland	5	4	80.00%
518	SAMSUNG TECHWIN CO LTD	South Korea	5	4	80.00%
518	NANOMEDICAL DIAGNOSTICS INC	United States	5	5	100.00%
518	CRAYONANO AS	Norway	5	4	80.00%
518	CARBEN SEMICON LTD	Cyprus	5	5	100.00%
518	AMO GMBH	Germany	5	4	80.00%

Figure 19. Frequent patent applicants in the electronics sector (top-10 on both global and European scale) and their relevant graphene IP. Top-8 regarding their graphene intensity included as well (see above regarding database discrepancies).

Probable niche suppliers of graphene composites

Rank	v_S	Affiliation (by term in database)	National origin	Graphene composites patents	General graphene patents	Total patents (PATSTAT)	Fraction of total patents
1	6.13	NANOTEK INSTRUMENTS INC	United States	24	130	142	16.9%
2	3.24	XG SCIENCES INC	United States	8	12	12	66.7%
3	2.67	BEYOND LOTUS LLC	United States	6	6	6	100.0%
4	2.03	APPLIED GRAPHENE MATERIALS UK LTD	United Kingdom	6	10	10	60.0%
5	1.72	VORBECK MATERIALS CORP	United States	8	17	22	36.4%
6	1.61	GARMOR INC	United States	7	10	14	50.0%
7	1.39	HANGZHOU GAOXI TECH CO LTD	China	6	16	18	33.3%
8	1.16	GUANGDONG NANOLUTION SCIENCE & TECH...	China	6	13	17	35.3%
9	1.00	ALFAISAL UNIVERSITY	Saudi Arabia	5	6	9	55.6%
10	0.92	DIRECTA PLUS SPA	Italy	7	14	24	29.2%
13	0.42	PERPETUUS R&D LTD	United Kingdom	3	3	5	60.0%
17	0.37	GRAPHENEA SA	Spain	2	9	9	22.2%
19	0.34	INSTYTUT NISKICH TEMPERATUR I BADAŃ...	Poland	3	8	12	25.0%
22	0.32	GRAPHITENE LTD	United Kingdom	2	4	4	50.0%
25	0.28	GT ELEKTROTECHNISCHE PRODUKTE GMBH	Germany	4	4	12	33.3%
28	0.27	PARAGRAF LTD	United Kingdom	1	14	14	7.1%
31	0.22	SHT SMART HIGH TECH AB	Sweden	2	8	11	18.2%
35	0.16	AVANZARE INNOVACION TENCOLOGICA SL	Spain	2	2	4	50.0%
128	0.01	ARKEMA FR	France	37	47	2053	1.8%
238	0.00	SABIC GLOBAL TECH BV	Netherlands	29	53	3418	0.8%
380	0.00	THE REGENTS OF THE UNIVERSITY OF CA...	United States	26	138	15566	0.2%
470	0.00	BASF SE	Germany	24	63	12250	0.2%

Figure 20. Specialist scores of transnational graphene composites IP applicants: top-10 ranks in global (bold font) and European (blue highlight) comparison, complemented by top-5 in absolute terms (green highlight). Yellow highlights indicate entries renowned from market reports.

strategy discussed above. In this context, GRMs will usually serve as a functional additive. The typical application scenario is replacing some incumbent additive with a lower degree of effectivity or more undesirable side effects (e.g. toxicity). Of course, the advanced performance of graphene eventually promise to unlock applications simply inconceivable before. Figure 20 shows probable niche players in this field.

Actually, figure 20 shows that half of the global top-10 specialist scores in the graphene composites field went to fairly established graphene suppliers well known in market reports. Companies with a similar business model also dominate the top European entities, but with a lower recognition rate among market reports. Again, a few public research entities (such as Alfaisal University, rank 9) may show comparable IP portfolios. However, larger entities with a broader scope (such as UC or BASF) may hold substantial numbers of relevant graphene patents that still pale in relation to their entire portfolio. We benchmark that observation with top applicants of general composites patents (figure 21).

In particular, figure 21 compares the magnitude of the general composites IP of global and European top-10 applicants with their graphene composites patents. Again, the list includes some of the earlier reference cases (such as BASF, rank 1; Sabic, rank 9) from above. Among the entire top groups, the indicative graphene fraction ranges well-below the 1% mark and often reflects only few individual patents. In contrast, the reference group (with the highest ratio) only reaches ranks beyond the 500 mark in conventional patent statistics, even though it contains several graphene suppliers well-known for their activities in the composite sector.

6.4. Graphene batteries

Finally, we apply the analogue logic to the graphene battery field. In contrast to the above, this represents a much narrower application range, which still draws substantial economic and scientific attention due to its relevance for e-mobility and beyond. Graphene may primarily serve as an additive to electrode materials in this sector, but many other utilizations also appear relevant (e.g. heat dissipation, sensors, etc). We begin with a look on probable niche players (figure 22).

Figure 22 shows the global top-11 group (due to a split rank) regarding specialist scores for graphene

Top intellectual property holders for composites

Rank	Affiliation (by term in database)	National origin	Composites patents (PATSTAT)	Graphene composites patents (WPI)	Indicative fraction (WPI / PATSTAT)
1	BASF SE	Germany	4091	24	0.59%
2	DOW GLOBAL TECH LLC	United States	3786	20	0.53%
3	3M INNOVATIVE PROPERTIES CO	United States	2901	20	0.69%
4	FUJIFILM CORP	Japan	2639	6	0.23%
5	LG CHEM LTD	South Korea	2552	21	0.82%
6	E I DU PONT DE NEMOURS & CO	United States	2160	3	0.14%
7	MITSUBISHI CHEM CORP	Japan	2151	1	0.05%
8	GENERAL ELECT CO	United States	1916	3	0.16%
9	SABIC GLOBAL TECH BV	Netherlands	1900	29	1.53%
10	BRIDGESTONE CORP	Japan	1666	1	0.06%
16	BAYER MATERIALSCIENCE AG	Germany	1206	6	0.50%
18	CIE GEN DES ETS MICHELIN	France	1115	8	0.72%
19	BOREALIS AG	Austria	1075	2	0.19%
20	ARKEMA FR	France	1072	37	3.45%
21	COVESTRO DEUTSCHLAND AG	Germany	1064	6	0.56%
26	STE DE TECH MICHELIN	France	1014	4	0.39%
27	HENKEL AG&CO KGAA	Germany	1002	7	0.70%
28	SIEMENS AG	Germany	1001	3	0.30%
516	NANOTEK INSTRUMENTS INC	United States	11	24	218.18%
570	XG SCIENCES INC	United States	8	8	100.00%
624	BEYOND LOTUS LLC	United States	6	6	100.00%
624	GUANGDONG NANOLUTION SCIENCE & TECH...	China	6	6	100.00%
624	APPLIED GRAPHENE MATERIALS UK LTD	United Kingdom	6	6	100.00%
663	QINGDAO UNIV OF TECH	China	5	8	160.00%

Figure 21. Frequent patent applicants in the (polymer) composites sector (top-10 on both global and European scale) and their relevant graphene IP. Top-6 regarding their graphene intensity included as well (see above regarding database discrepancy).

Probable niche suppliers of graphene batteries

Rank	v_s	Affiliation (by term in database)	National origin	Graphene batteries patents	General graphene patents	Total patents (PATSTAT)	Fraction of total patents
1	47.56	NANOTEK INSTRUMENTS INC	United States	90	130	142	63.4%
2	6.29	GLOBAL GRAPHENE GROUP INC	United States	18	25	32	56.2%
3	2.98	XIFENG 2D FUJIAN MATERIAL TECH CO L...	China	8	11	12	66.7%
4	1.42	GRST INT LTD	China	8	8	16	50.0%
5	0.86	INCUBATION ALLIANCE INC	Japan	5	6	10	50.0%
6	0.75	BEIJING TUNGHSU CARBON ADVANCED MAT...	China	3	3	3	100.0%
7	0.64	XG SCIENCES INC	United States	3	12	12	25.0%
8	0.55	HANGZHOU GAOXI TECH CO LTD	China	3	16	18	16.7%
9	0.55	SINODE SYSTEMS INC	United States	3	3	4	75.0%
9	0.55	KRATOS LLC	United States	3	3	4	75.0%
9	0.55	FORD CHEER INT LTD	British Virgin Islands	3	3	4	75.0%
26	0.16	IMERYS GRAPHITE & CARBON SWITZERLAN...	Switzerland	4	7	23	17.4%
39	0.11	VARTA MICRO INNOVATION GMBH	Austria	3	3	13	23.1%
45	0.09	INSTYTUT TECHNOLOGII MATERIALOW ELE...	Poland	1	14	27	3.7%
46	0.08	BELENOS CLEAN POWER HOLDING AG	Switzerland	7	8	65	10.8%
48	0.07	THE PROVOST FELLOWS SCHOLARS & OTHE...	Ireland	3	6	24	12.5%
49	0.07	CONTEMPORARY AMPEREX TECH CO LTD	China	47	47	1213	3.9%
57	0.04	DST INNOVATIONS LTD	United Kingdom	2	3	15	13.3%
65	0.03	THE UNIVERSITY OF MANCHESTER	United Kingdom	2	51	337	0.6%
67	0.02	CLARIOS GERMANY GMBH & CO KGAA	Germany	2	2	16	12.5%
68	0.02	ZAPGO LTD	United Kingdom	1	4	13	7.7%
69	0.02	ALBEMARLE GERMANY GMBH	Germany	3	3	33	9.1%
96	0.01	LG CHEM LTD	South Korea	89	136	10266	0.9%
100	0.01	SEMICONDUCTOR ENERGY LAB CO LTD	Japan	43	46	3272	1.3%
290	0.00	SAMSUNG ELECT CO LTD	South Korea	42	149	49445	0.1%

Figure 22. Specialist scores of transnational graphene battery IP applicants: top-10 ranks in global (bold font) and European (blue highlight) comparison, complemented by top-5 in absolute terms (green highlight). Yellow highlights indicate entries renowned from market reports.

batteries. It includes three renowned graphene suppliers (with frequent mentions in market reports). Most other entries seem to aspire to a very similar business model as well (with more or less focus on battery applications), many of the headquartered in East Asia. The absence of European actors in the top-10 further extents to lower ranks, with first European entry only occurring at rank 26. In addition, the top-10 placed European actors include roughly a third of public research entities. However, we also recognize some renowned specialists such as Varta (for microbatteries) and Imerys (for electrode additives) that claim some graphene battery IP.

The results in figure 22 somewhat reflects the high degree of concentration of the vibrant battery business in East Asia, but also the latent implied bias of market reports against actors from the regions (see above). A look at the top general battery IP applicants and their relative graphene intensity (figure 23) augments the picture.

In particular, figure 23 show both global and European top-10 of applicants for general battery IP, which partially paints a different picture. Of course, it also confirms the dominance of Asian players that claim nearly all top-10 positions. But it also includes one remarkable European entry (Bosch, rank 5), while many others follow rather close behind. Europe currently largely lacks global battery IP leaders, but already excels in the second tier (∼100 relevant patents) with highly frequent entries starting around rank 20.

The indicative graphene fraction among global battery IP leaders shown in figure 23 ranges at a negligible level (∼1%) for most entries. In this comparison, CATL already stands out for almost 6% of their battery IP involving graphene. Only due to the much narrower definition of the battery sector (compared to the broader categories shown in figures 19 and 21 above), dedicated specialists (with small, but dedicated graphene battery IP portfolios) show up at nominally more favorable ranks (∼200 instead of ∼500) in conventional patent statistics.

Top intellectual property holders for batteries

Rank	Affiliation (by term in database)		National origin	Batteries patents (PATSTAT)	Graphene batteries patents (WPI)	Indicative fraction (WPI / PATSTAT)
1	LG CHEM LTD		South Korea	3427	89	2.60%
2	SAMSUNG ELECT CO LTD		South Korea	2134	42	1.97%
3	MATSUSHITA ELECT IND CO LTD		Japan	2016	3	0.15%
4	LG ENERGY SOLUTION LTD		South Korea	1487	22	1.48%
5	ROBERT BOSCH GMBH		Germany	1224	20	1.63%
6	TOYOTA JIDOSHA CO LTD		Japan	1188	3	0.25%
7	CONTEMPORARY AMPEREX TECH CO LTD		China	807	47	5.82%
8	MURATA MANUFACTURING CO LTD		Japan	714	5	0.70%
9	CO LTD TOSHIBA		Japan	498	2	0.40%
10	SONY CORP		Japan	435	4	0.92%
12	CEA		France	406	12	2.96%
19	BAYERISCHE MOTOREN WERKE AG		Germany	253	3	1.19%
22	BASF SE		Germany	200	10	5.00%
23	LI TEC BATTERY GMBH		Germany	182	3	1.65%
24	DAIMLER AG		Germany	147	1	0.68%
25	CNRS		France	143	5	3.50%
28	SIEMENS AG		Germany	128	1	0.78%
32	LITHIUM ENERGY & POWER GMBH & CO KG		Germany	104	1	0.96%
33	UMICORE		Belgium	101	1	0.99%
33	VARTA MICROBATTERY GMBH		Germany	101	3	2.97%
48	NANOTEK INSTRUMENTS INC		United States	71	90	126.76%
153	PPG IND OHIO INC		United States	14	12	85.71%
205	OCEANS KING LIGHTING SCIENCE & TECH...		China	7	7	100.00%
205	WILLIAM MARSH RICE UNIVERSITY		United States	7	12	171.43%
244	IMERYS GRAPHITE & CARBON SWITZERLAN...		Switzerland	5	4	80.00%

Figure 23. Frequent patent applicants in the battery field (top-10 on both global and European scale) and their relevant graphene IP. Top-5 regarding their graphene intensity included as well (see above regarding database discrepancies).

7. Conclusions

7.1. Graphene market

Our analyses confirm the still emerging character of the graphene market. The consensus estimate of the current global market volume indicates an annual revenue of $380 million for 2022. The relatively small size, however, goes along with strong growth in upcoming years with forecasted growth rates ranging between 20% and 50% per annum. In contrast to early prediction during the initial hype phase, graphene cannot immediately convert all its initial promises to overwhelming market success. The diffusion of this novel class of two-dimensional materials takes time. Early actors continue to face severe challenges, but also steadily achieve substantial progress overcoming hurdles one after the other.

Our previous analyses [5, 126] evidence the severity of direct and indirect production scaling challenges to the emerging graphene supply industry and the graphene sector in its entirety. In the past, aspiring early adopters in various industries often faced critical setbacks in their graphene application development programs related to both quality and quantity of their material supply streams. Early commercial suppliers mainly comprised of university spin-offs and similar start-ups that lacked consistent production capabilities. Throughout the community, such disillusionments lead many players to phase out initial activities, while others recognized confirmation for their continued hesitance to engage at all.

Still today, dedicated specialists hold a major share of graphene production IP, but their supply streams mature. Production volumes increase. Most suppliers plan out industrial scaling steps and eagerly await implementation opportunities. Now, the pace of demand growth (and growth expectations) and capital investment requirements largely limit the expansion of production capacity. Graphene-based niche products enter multiple application markets, but limited adoption rates, in particular for mass products, still restrict overall market growth. Hence, suppliers increasingly engage in both close co-development activities with potential customers [5] and community level trust building activities such as standardization or REACH registration.

In the coming years, supply stream quality and availability of graphene will continue to increase steadily. Following hype and disillusionment, a more realistic view on graphene capabilities throughout various application fields starts to settle in, setting the stage for a phase of sustained market growth.

7.2. Market reports

Market reports address a widespread desire for in-depth market intelligence, particular in emerging fields where little experience is available and potential actors seek to position themselves. Commercial providers largely control the creation of market reports and finance themselves by extensive access fees that create a particularly high paywall barrier. No external quality control mechanisms apply whatsoever, hence market reports form a specific niche segment among grey literature.

Potential actors considering to engage in an emerging field of technology in various roles (from materials supply over application development and systems integration to investors) require market insights to inform their decision making process. Despite substantial access fees, the purchase of a market report may appear a cost sensitive solution compared to conduction own market research initiatives or outsourcing those to a third-party service provider. Hence, market reports clearly advertise to fulfill this need and, thus to offer ample insight into specific market segments or fields of technology development.

In our observation, not all market reports on specific segment (exemplified by graphene) appear suitable to deliver on such expectations equally well. While many market reports seem professional and offer profund data and forecasts, we also found ample clues that indicate inferior quality among several commercially available sources. For instance, some market report previews kindly express forecasts in terms of both market revenue and growth rates. The numbers, however, are not always consistent with each, which can be attributed to basic calculation errors within those market projections. Other market reports stand out for extreme market revenue predictions, roughly exceeding median projections by a factor of 1000. Readers may guess whether superior market knowledge or an undetected mix up (such as millions for billions) may explain such findings.

We also found surprising degrees of agreement between certain market projections from nominally independent reports from different providers (i.e. identical series of numbers) way beyond statistical coincidence. Of course, we can never entirely rule out that two parties simply arrived at identical conclusions. Still a suspicion remains that not all market report providers always rely on their own original research activities to inform their market forecasts. Tracking of coincidental typo provides further evidence towards a certain copy-and-paste attitude among some market report providers. In particular, the proliferation of prominent misspellings among company names (such as 'Vorbrck' or 'Granphenea') between various market reports is likely not coincidence.

Despite detecting frequent and basic shortcomings in some market reports, we also found flawless records and inspected a small and non-representative selection of full-text sources. Better market reports provide ample intelligence on the graphene sector, in-depth analyses of application trends, and validated information on numerous market actors. We feel unable to highlight the most valuable sources as we lack equal access to all relevant sources and, thus, might be biased. Instead, we try to point out criteria that prospective buyers of market reports may consider prior to their purchase:

- Track-record: Do previous versions exist? Has the market report provider been active in the particular field of interested for an extended period of time?
- Web presence: Is the homepage designed professionally? Does it provide all necessary information in a professional way?
- Methodology: Ideally, providers combine a wide range of methods to gather and validate the information provided. We suggest particular attention towards interviews with industrial experts.
- Content: We suggest a few categories of desirable expertise summaries and types of analyses to look out for (as spelled out applicable for graphene, but transferrable to other topics and technologies):
  - Discussion of material types
  - Discussion of production methods
  - Analysis of competing materials
  - Analysis on application sectors
  - Analysis of regional activities
  - Discussion of the general market environment and framework conditions
  - Forecasts on production volumes, revenues and prices
  - Intelligence on industrial actors in the field.

7.3. Meta-market analysis

We established a systematic approach to investigate the distinct, yet rarely analyzed grey literature category comprised of market studies. It equally serves two unique objectives that go along with very different perspectives. It enables:

(A) a systematic aggregation of market expectations for a certain market segment, in this study exemplified by the emerging graphene sector; and
(B) an approach for the scientific analysis of commercial market reports to shed more light on this influential, yet rather inaccessible grey literature segment.

Both perspectives highly benefit from the availability of complementary results by other quantitative innovation research methods. In this regard, we chose bibliometrics and patent analysis in order to combine the primarily economic perspective of market reports with the scientific domain (bibliometrics) and applied technology development (patents). Beyond addressing complementary segments of the technology innovation system for graphene, we specifically focused each technique towards the identification and evaluation of relevant industrial actors as a common denominator.

Regarding market expectations (A), any given market report shows an individual perspective. The emergence of markets based on novel technologies goes along with substantial levels of uncertainty. Hence, market forecasts usually scatter tremendously between sources. Our meta-market approach balances individual estimation errors and biases. It provides access to harmonized market expectations and consolidated market development scenarios (best/worst case expectations). Of course, collective biases among the ensemble of market studies on a given technology segment cannot be excluded entirely.

Regarding the merits and flaws of market reports (B), we recognize a wide quality range spanning from serious reports providing ample intelligence and in-depth analyses to studies likely filled by negligent copy&paste techniques partially containing blatant errors. We highly recommend potential buyers to apply due diligence prior to their purchase as no external quality assurance mechanisms exist at all. In general, we suspect certain conscious (high numbers promise to sell more reports) and unconscious (tendency to cover markets that are perceived promising) biases among market report providers expedited by their commercial intent. Only systematic benchmark tests over a long period of time may substantiate and quantify this suspicion. However, according to our experience, some high-quality market reports with honest analyses without obvious flaws do co-exist with others of rather dubious quality.

Finally, we recognize substantial language and information biases in both our study and its subject. We only considered English language market reports, which are primarily written by English speakers (both native and second language) and primarily for an English speaking audience. Hence, both intent and access barriers may prioritize content from English speaking countries (and the Western World at large). Our complementary bibliometric and patent analyses enable less biased means for actor identification and evaluation, that clearly confirm a strong preference of market reports for US and UK companies, while players from EU countries and China may be less well covered. Hence, such market reports tend to provide a certain and incomplete perspective, which may also affect their conclusions.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Acknowledgments

This project has received funding from the European Union's Horizon 2020 and Horizon Europe research and innovation programmes under Grant Agreement Nos. 785219 (GrapheneCore2), 881603 (GrapheneCore3), and 101119461 (GrapheneEU). The authors thank all other members of the Fraunhofer Graphene Roadmap. We particularly express our gratitude to Marianne Kronsbein and Paul Städter for their instrumental role in the processing of market reports.

ORCID iDs

Thomas Schmaltz https://orcid.org/0000-0003-2069-4436
Ulrich Schmoch https://orcid.org/0000-0001-8615-5115
Henning Döscher https://orcid.org/0000-0001-9352-4644

References

[1] Novoselov K S, Geim A K, Morozov S V, Jiang D, Zhang Y, Dubonos S V, Grigorieva I V and Firsov A A 2004 Electric field effect in atomically thin carbon films *Science* **306** 666–9
[2] Wallace P R 1947 The band theory of graphite *Phys. Rev.* **71** 622–34
[3] Barkan T 2019 Graphene: the hype versus commercial reality *Nat. Nanotechnol.* **14** 904–6
[4] Reiss T, Hjelt K and Ferrari A C 2019 Graphene is on track to deliver on its promises *Nat. Nanotechnol.* **14** 907–10
[5] Döscher H, Schmaltz T, Neef C, Thielmann A and Reiss T 2021 Graphene roadmap briefs (No. 2): industrialization status and prospects 2020 *2D Mater.* **8** 22005
[6] Diaz Ruiz C A 2022 The insights industry: towards a performativity turn in market research *Int. J. Market Res.* **64** 169–86
[7] www.verifiedmarketresearch.com/ *Report Research Methodology* (available at: www.verifiedmarketresearch.com/research-methodology/) (Accessed 27 July 2023)
[8] www.mymarketresearchmethods.com/ 2020 *An Overview of Market Research Methods* (available at: www.mymarketresearchmethods.com/an-overview-of-market-research-methods/) (Accessed 27 July 2023)
[9] www.marketsandmarkets.com/ 2021 *Graphene Market—Methodology Tab* (available at: www.marketsandmarkets.com/Market-Reports/graphene-market-83933068.html) (Accessed 27 July 2023)
[10] Backes C *et al* 2020 *Production and Processing of Graphene and Related Materials—IOP Science* (available at: https://iopscience.iop.org/article/10.1088/2053-1583/ab1e0a) (Accessed 17 July 2020)
[11] Market Research Future 2021 *Graphene Market Research Report- Forecast to 2027* (Market Research Future)
[12] Market Research.com 2022 *Global Graphene Market: Analysis by Material (Graphene Oxide, Reduced Graphene Oxide, Graphene Nanoplatelets, and Others), by Application (Composites, Electronics, Energy and Others), by Region Size and Trends with Impact of COVID-19 and Forecast up to 2027* (Market Research.com)
[13] market.us 2022 *Global Graphene Market by Material, by Application, by Region and Companies—Industry Segment Outlook, Market Assessment, Competition Scenario, Trends and Forecast 2022-2032* (market.us)
[14] Market Research biz 2022 *Global Graphene Market Analysis, Drivers, Restraints, Opportunities, Threats, Trends, Applications, and Growth Forecast to 2026* (Market Research biz)
[15] Market Research Engine 2022 *Graphene (Graphene Oxide, Graphene Nanoplatelets, Mono-Layer & Bi-Layer Graphene, and Others) Market for Electronics, Aerospace & Defense, Energy, Automotive, Health care, and Other End-users—Global Industry Analysis, Size, Share, Growth, Trends and Forecast 2022–2027* (Market Research Engine)
[16] Market Research Future 2018 *Graphene Market Research Report- Forecast to 2023* (Market Research Future)
[17] MarkNtel Advisors 2020 *Global Graphene Market Analysis, 2020* (MarkNtel Advisors)
[18] Mordor Intelligence 2021 *Graphene Market—Growth, Trends, COVID-19 Impact, and Forecasts (2021–2026)* (Mordor Intelligence)
[19] Mordor Intelligence 2022 *Graphene Market—Growth, Trends, Covid-19 Impact, and Forecasts (2022–2027)* (Mordor Intelligence)
[20] MarketDigits 2020 *Graphene Market, by Product (Graphene Oxide (GO), Graphene Nanoplatelets (GNP), Others), Application, (Electronics, Composites, Energy, Coatings, Sensors, Catalyst) and Geography—Global Forecast to 2026* (MarketDigits)
[21] Markets and Markets 2015 *Graphene Market by Type (Graphene Oxide (GO), Graphene Nanoplatelets (GNP), and Others), by Application (Electronics, Composites, Energy, Coatings, Sensors, Catalyst and Others), by Region—Global Trends and Forecasts to 2020* (Markets and Markets)
[22] Markets and Markets 2021 *Graphene Market by Type (Bulk, Monolayer), Application (Composites, Paints, Energy Storage, Electronics, Catalyst and Tire), End-Use Industry (Automotive, Aerospace, Electronics, Military and Construction) and Region—Global Forecast to 2025* (Markets and Markets)
[23] Market Growth Reports 2022 *Global Graphene Market 2022 by Manufacturers, Regions, Type and Application, Forecast to 2028* (Market Growth Reports)

[24] Imarc 2021 *Graphene Market: Global Industry Trends, Share, Size, Growth, Opportunity and Forecast 2021-2026* (Imarc)
[25] Inkwood Research 2021 *Global Graphene Market Forecast 2021-2026* (Inkwood Research)
[26] Innova Research 2015 *The World Market for Graphene—2015 Edition* (Innova Research)
[27] Zion Market Research 2021 *Graphene Market—Global Industry Analysis* (Zion Market Research)
[28] IDTechEx 2020 *Graphene Market & 2D Materials Assessment 2021-2031* (IDTechEx)
[29] IDTechEx 2022 *Graphene Market & 2D Materials Assessment 2023-2033* (IDTechEx)
[30] Lux Research 2013 (Lux Research)
[31] Market Data Forecast 2020 *Graphene Market Analysis Report Segmented by Product Type (Graphene Nanoplatelets, Graphene Oxide & Others), by Application (Electronics, Composites, Energy & Others), by Region (North America, Latin America, Europe, Asia Pacific and Middle East & Africa)—Global Industry Analysis on Size, Share, Trends, Growth, Demand & Forecast | 2020–2025* (Market Data Forecast)
[32] Market Data Forecast 2022 *Graphene Market Analysis Report Segmented by Product Type (Graphene Nanoplatelets, Graphene Oxide & Others), by Application (Electronics, Composites, Energy & Others), by Region (North America, Latin America, Europe, Asia Pacific and Middle East & Africa)—Global Industry Analysis on Size, Share, Trends, Growth, Demand & Forecast | 2022–2027* (Market Data Forecast)
[33] Knowledge Sourcing 2022 *Global Graphene Market Size, Share, Opportunities, COVID-19 Impact, and Trends by Product (Graphene Oxide, Graphene Flakes, Graphene Sheets, Graphene Inks), by End-User Industry (Consumer Electronics, Energy and Power, Aerospace & Defense, Others), and by Geography—Forecasts From 2022 to 2027* (Knowledge Sourcing)
[34] LP Information 2021 *Global Graphene Market Growth 2021-2026* (LP Information)
[35] Lucintel 2021 *Graphene Market Report: Trends, Forecast and Competitive Analysis* (Lucintel)
[36] P&S Intelligence 2020 *Graphene Market Research Report: by Form (Powder, Dispersion), Application (Electrical & Electronics, Composites, Energy, Biomedical)—Global Industry Analysis and Demand Forecast to 2030* (P&S Intelligence)
[37] Transparency Market Research 2016 *Graphene Market—Global Industry Analysis, Size, Share, Growth, Trends and Forecast 2015–2023* (Transparency Market Research)
[38] Value Market Research 2021 *Global Graphene Market Report by Product Type (Graphene Sheets and Films, Nanoribbons, Nanoplatelets, Graphene Oxide, and Other Product Types), End User (Electronics and Telecommunication, Bio-Medical & Healthcare, Energy, Aerospace & Defense, and Other End-User Industries) and by Regions—Industry Trends, Size, Share, Growth, Estimation and Forecast, 2022-2030* (Value Market Research)
[39] Vantage Market Research 2022 *Graphene Market by Material (Graphene Nano-Platelets, Graphene Oxide, Reduced Graphene Oxide, Others), by Application (Composites, Paints, Coatings, and Inks, Energy Storage & Harvesting, Electronics), by End Use (Automotive & Transportation, Aerospace, Electronics, Military & Defense), by Region (North America, Europe, Asia Pacific, Latin America)—Global Industry Assessment (2016–2021) & Forecast (2022–2028)* (Vantage market research)
[40] Technavio 2017 *Global Graphene Market 2017-2021* (Technavio)
[41] The Brainy Insights 2021 *Graphene Market Size by Product (Graphene Oxide, Graphene Nanoplatelets, Others), Application (Electronics, Energy, Composites, Others), Regions, Global Industry Analysis, Share, Growth, Trends, and Forecast 2021–2030* (The Brainy Insights)
[42] The Insight Partners 2022 *Graphene Market Forecast to 2028—COVID-19 Impact and Global Analysis by Type (Monolayer and Bilayer, Graphene Nano-Platelets, Graphene Oxide, and Others) and Application (Composites; Functional Inks, Paints and Coatings; Energy Storage; Electronics; Polymer Additives; RFID; and Others)* (The Insight Partners)
[43] Wise Guy Reports 2017 *Graphene—Global Market Outlook (2016-2022)* (Wise Guy Reports)
[44] Yole Développement 2014 *Graphene Materials for Opto & Electronic Applications* (Yole Développement)
[45] Zion Market Research 2017 *Graphene Market (Mono-Layer & Bi-Layer Graphene, Few Layer Graphene, Graphene Oxide and Graphene Nano Platelets) for Composites, Energy Storage, Electronics and Others Applications: Global Industry Perspective, Comprehensive Analysis, and Forecast, 2016–2022* (Zion Market Research)
[46] Verified Market Research 2018 *Global Graphene Market Size and Forecast to 2025* (Verified Market Research)
[47] Verified Market Research 2018 *Global Graphene Market Size by Application, by Type, by Geographical Analysis and Forecast* (Verified Market Research)
[48] Verified Market Research 2021 *Graphene Market Size and Forecast* (Verified Market Research)
[49] Stratistics MRC 2021 *Graphene Market Forecasts to 2028—Global Analysis by Application (Composite Materials, Energy Storage, Batteries) End User (Electronics, Military & Defense, Aerospace, Automotive, Healthcare, Chemical) and by Geography* (Stratistics MRC)
[50] Quadintel 2022 *Global Graphene Market Size Study, by Type (Mono-Layer & Bi-Layer Graphene, Few Layer Graphene (FLG), Graphene Oxide (GO), Graphene Nano Platelets (GNP)), by Application (RFID, Composites, Sensors, Research & Development, Energy Storage, Others) and Regional Forecasts 2020-2027* (Quadintel)
[51] Reports and Data 2020 *Graphene Market by Technology (Graphene Exfoliation, Chemical Vapor Deposition), by Product Type (Graphene Oxide, Graphene Nanoplatelets, Monolayer Graphene, Bilayer Graphene), by Application (Composites, Energy Storage, Coatings and Inks, Tires, Catalyst), by Industry Vertical (Aerospace, Automotive, Energy, Healthcare, Electronics, Military and Defense), and by Region and Forecast to 2028* (Reports and Data)
[52] Research In China 2018 *Global and China Graphene Industry Report, 2018–2023* (Research In China)
[53] P&S Intelligence 2021 *Graphene Market Research Report: by Form (Powder, Dispersion), Application (Electrical & Electronics, Composites, Energy, Biomedical)—Global Industry Analysis and Revenue Estimation to 2030* (P&S Intelligence)
[54] Persistence Market Research 2016 *Graphene Market: Global Industry Analysis and Forecast 2016–2026* (Persistence Market Research)
[55] Polaris Market Research 2021 *Graphene Market Share, Size, Trends, Industry Analysis Report, by Type; by End-Use (Electronics, Energy, Automotive, Aerospace & Defense, Healthcare & Pharmaceutical); by Region; Segment Forecast, 2021–2028* (Polaris Market Research)
[56] Spherical Insights 2022 *Global Graphene Market Size, Share, and COVID-19 Impact Analysis, by Product Type (Few-Layer Graphene, Graphene Nano Platelets Graphene Oxide, and Mono-Layer and Bi-Layer Graphene), by Application (Composites, Polymer Additives, Sensors, Research and Development, Tire, Coatings, Energy Storage, Functional Ink, RFID, and Others), by Region (North America, Europe, Asia-Pacific, Latin America, Middle East, and Africa), Analysis and Forecast 2021–2030* (Spherical Insights)
[57] Stellar Market Research 2022 *Graphene Market: Global Industry Analysis and Forecast (2021-2027) by Material*

Outlook, Application Outlook, and Region (Stellar Market Research)
[58] Stratistics MRC 2015 *Graphene Market Outlook—Global Trends, Forecast, and Opportunity Assessment (2014-2022)* (Stratistics MRC)
[59] Research In China 2019 *Global and China Graphene Industry Report, 2019-2025* (Research In China)
[60] Research In China 2021 *Global and China Graphene Industry Report, 2020-2026* (Research In China)
[61] Research Repoertsworld 2022 *Global and United States Graphene Market Report & Forecast 2022-2028* (Research Repoertsworld)
[62] Big Market Research 2016 *World Graphene Market—Opportunities and Forecasts, 2014–2021* (Big Market Research)
[63] Blue Quark Research 2022 *Global Graphene Market Outlook to 2027* (Blue Quark Research)
[64] Blueweave Consulting & Research Pvt Ltd 2021 *Global Graphene Market, by Type; by Applications; by Region Trend Analysis, Competitive Market Share & Forecast, 2017-2027* (Blueweave Consulting & Research Pvt Ltd)
[65] Azoth Analytics 2022 *Global Graphene Market: Analysis by Type, Application, End-User, by Region, by Country (2022 Edition): Market Insights and Forecast with Impact of COVID-19 (2017-2027)* (Azoth Analytics)
[66] BBC Research 2013 *Graphene: Technologies, Applications and Markets* (BBC Research)
[67] BBC Research 2016 *Graphene: Technologies, Applications and Markets* (BBC Research)
[68] Data Bridge Market Research 2021 *Global Graphene Market—Industry Trends and Forecast to 2028* (Data Bridge Market Research)
[69] Data Intelo 2021 *Global Graphene Market by Type (Graphene Powder, Graphene Oxide, Graphene Film), by Application (Photovoltaic Cells, Composite Materials, Biological Engineering, Other) and by Region (North America, Latin America, Europe, Asia Pacific and Middle East & Africa), Forecast to 2028* (Data Intelo)
[70] DataM Intelligence 2022 *Global Graphene Market is Segmented by Type (Mono Layer Graphene, Few-Layer Graphene, Multi-Layer Graphene, Graphene Nano Platelets (GNP), Others (Reduced Graphene Oxide, Graphene Oxide)), by Application (Electronics, Energy and Storage, Bio-Medical, Composites), and by Region (North America, Latin America, Europe, Asia Pacific, Middle East, and Africa)—Share, Size, Outlook, and Opportunity Analysis, 2022-2029* (DataM Intelligence)
[71] Brand Essence Research 2021 *Graphene Market by Product Type (Graphene Oxide, Graphene Nano Platelets), Industry Analysis, Trends, and Forecast 2027* (Brand Essence Research)
[72] Coherent Market Insights 2019 *Graphene Market Analysis* (Coherent Market Insights)
[73] Coherent Market Insights 2022 *Graphene Market Analysis* (Coherent Market Insights)
[74] Allied Market Research 2021 *Graphene Market by Type (Mono-Layer & Bi-Layer Graphene, Few Layer Graphene, Graphene Oxide, and Graphene Nano Platelets), and Application (RFID, Composites, Sensors, Research & Development, Energy Storage, Functional Ink, and Polymer Additives, Tire, Coatings, and Others): Global Opportunity Analysis and Industry Forecast 2020–2027* (Allied Market Research)
[75] 360iResearch 2021 *Graphene Market Research Report by Type (Graphene Nano Platelets (GNP) and Graphene Oxide (GO)), by Application (Biological Engineering, Composite Materials, and Energy Storage), by Region (Americas, Asia-Pacific, and Europe, Middle East & Africa)—Global* (360iResearch)
[76] 360iResearch 2021 *Graphene Market Research Report by Type (Graphene Nano Platelets (GNP) and Graphene Oxide (GO)), by Application (Biological Engineering, Composite Materials, Energy Storage, Optical Electronics, and Photovoltaic Cells)—Global Forecast to 2025—Cumulati* (360iResearch)
[77] 9Dimen Research 2021 *Global Graphene Market Research Report 2021-2025* (9Dimen Research)
[78] IDTechEx 2019 *Graphene, 2D Materials and Carbon Nanotubes: Markets, Technologies and Opportunities 2019-2029* (IDTechEx)
[79] 360 Research Reports 2022 *Global Graphene Market Insights and Forecast to 2028* (360 Research Reports)
[80] 360 ResearchReports 2022 *Global Graphene Market Growth 2022-2028* (360 ResearchReports)
[81] Adroit Market Research 2019 *Global Graphene Market Size 2017 by Type (Graphene Nanoplatelets, Graphene Oxide and Others), by Application (Electronics, Composites, Energy and Others), by Region and Forecast 2018–2025* (Adroit Market Research)
[82] Allied Analytics LLP 2020 *Graphene Market by Type, and Application: Global Opportunity Analysis and Industry Forecast 2020-2027* (Allied Analytics LLP)
[83] Allied Market Research 2014 (Allied Market Research)
[84] Absolute Reports 2019 *Global Graphene Market 2019 by Manufacturers, Regions, Type and Application, Forecast to 2024* (Absolute Reports)
[85] Absolute Reports 2022 *Global Graphene Market Insights and Forecast to 2028* (Absolute Reports)
[86] Acumen Research and Consulting 2019 *Graphene Market (by Product: Graphene Nanoplatelets, Graphene Oxide, Others; by Application: Electronics, Composites, Energy, Others)—Global Industry Size, Share, Trends and Forecast 2019–2026* (Acumen Research and Consulting)
[87] Emergen Research 2021 *Graphene Market by Type (Monolayer Graphene, Bulk Graphene), by Product (Graphene Oxide, Graphene Nanoplatelets, Others), by Application (Electronics, Composites, Catalyst, Energy Storage & Harvesting, Tires, Paints and Coatings, Others), by End-Use, and by Region Forecast to 2028* (Emergen Research)
[88] Grand View Research 2019 *Graphene Market Size, Share & Trends Analysis Report by Application (Electronics, Composites, Energy), by Product (Graphene Nanoplatelets, Graphene Oxide), by Region, and Segment Forecasts, 2019–2025* (Grand View Research)
[89] Grand View Research 2020 *Graphene Market Size, Share & Trends Analysis Report by Application (Electronics, Composites, Energy), by Product (Graphene Nanoplatelets, Graphene Oxide), by Region, And Segment Forecasts, 2020–2027* (Grand View Research)
[90] Grand View Research 2021 *Graphene Market Size, Share & Trends Analysis Report by Material (Graphene Oxide, Graphene Nanoplatelets), by Application (Electronics, Composites), by Region (APAC, Europe), and Segment Forecasts, 2021–2028* (Grand View Research)
[91] GMI Research 2020 *Graphene Market by Type (Monolayer Graphene, Few-Layer Graphene, Multi-layer Graphene, Graphene Nanoplatelets, Reduced Graphene Oxide, Graphene Oxide), by Application (Electronics, Composites, Energy, Healthcare, Others), by Geography—Opportunities and Forecast, 2021-2028* (GMI Research)
[92] Grand View Research 2016 *Graphene Market Analysis by Product (Graphene Nanoplatelets, Graphene Oxide), by Application (Electronics, Composites, Energy) and Segment Forecasts to 2022* (Grand View Research)
[93] Grand View Research 2016 *Graphene Market Size and Trend Analysis by Product (Nanoplatelets, Oxide), by Application (Electronics, Composites, Energy), by Region (North America, Europe, Asia Pacific, Rest of the World), and Segment Forecasts, 2014–2025* (Grand View Research)
[94] IDTechEx 2016 *Graphene, 2D Materials and Carbon Nanotubes: Markets, Technologies and Opportunities 2016-2026* (IDTechEx)

[95] IDTechEx 2017 *Graphene, 2D Materials and Carbon Nanotubes: Markets, Technologies and Opportunities 2017-2027* (IDTechEx)
[96] IDTechEx 2018 *Graphene, 2D Materials and Carbon Nanotubes: Markets, Technologies and Opportunities 2018-2028* (IDTechEx)
[97] GraphenePower Blog 2015 *Global Graphene Market* (GraphenePower Blog)
[98] IDTechEx 2014 *Graphene Markets, Technologies and Opportunities 2014-2024* (IDTechEx)
[99] IDTechEx 2015 *Graphene, 2D Materials and Carbon Nanotubes: Markets, Technologies and Opportunities 2015-2025* (IDTechEx)
[100] Global Market Insights 2022 *Graphene Market—by Product (Graphene Oxide, Graphene Nanoplatelets, Mono-Layer & Bi-Layer Graphene), by End User (Electronics, Aerospace & Defense, Energy, Automotive, Healthcare) & Forecast, 2022-2030* (Global Market Insights)
[101] Fortune Business Insights 2020 *Graphene Market Size, Share & COVID-19 Impact Analysis, by Product (Graphene Oxide (GO), Graphene Nanoplatelets (GNP), Others), by EndUse (Electronics, Aerospace & Defense, Automotive, Energy, Others), and Geography Forecast, 2020–2027* (Fortune Business Insights)
[102] Fortune Business Insights 2022 *The global graphene market is projected to grow from USD 388.8 million in 2021 to USD 4,067.1 million in 2028 at a CAGR of 39.8%… Read More at:-* (available at: www.fortunebusinessinsights.com/graphene-market-102930) (Fortune Business Insights)
[103] Frost&Sullivan 2015 *Graphene as a Next Generation Material for Industrial and Commercial Applications* (Frost&Sullivan)
[104] Exactitude Consultancy 2022 *Graphene Market by Type (Bulk, Monolayer), Application (Composites, Paints, Energy Storage, Electronics, Catalyst and Tire), End-Use Industry (Automotive, Aerospace, Electronics, Military and Construction) and Region (North America, Europe, Asia Pacific, South America, Middle East and Africa), Global Trends and Forecast from 2022 to 2029* (Exactitude Consultancy)
[105] Extrapolate 2022 *Global Graphene Market by Product Type (Few Layer Graphene (FLG), Mono-Layer & Bi-Layer Graphene, Graphene Oxide (GO), Graphene Nano Platelets (GNP)), by Form (Powder, Dispersion), by Application (Batteries, Composites, Supercapacitors, Transparent Electrodes, Integrated Circuits, Others), by End User (Electronics, Aerospace & Defense, Energy, Automotive, Healthcare, Others) by Region—Global and Regional Industry Overview, Market Intelligence, Comprehensive Analysis, Historical Data, and Forecasts 2022–2030* (Extrapolate)
[106] Facts & Factors Research 2022 *Graphene Market by Type (Bulk Graphene, Monolayer Graphene), by Application (Composites, Paints, Coatings & Inks, Energy Storage & Harvesting, Electronics, Catalyst, Tires, Others), by End-Use Industry (Automotive & Transportation, Aerospace, Electronics, Military & Defense, Others), and by Region—Global Insights, Growth, Size, Comparative Analysis, Trends and Forecast 2022–2028* (Facts & Factors Research)
[107] Global Info Research 2020 *Global Graphene Electronics Market 2020 by Manufacturers, Regions, Type and Application, Forecast to 2025* (Global Info Research)
[108] Global Market Estimates 2022 *Global Graphene Market* (Global Market Estimates)
[109] Global Market Insights 2019 *Graphene Market Size by Product (Graphene Oxide, Graphene Nanoplatelets, Mono-Layer & Bi-Layer Graphene, Others), by Application (Electronics, Aerospace & Defense, Energy, Automotive, Healthcare, Others), Industry Analysis Report, Regional Outlook, Application Growth Potential, Price Trends, Competitive Market Share & Forecast, 2019–2026* (Global Market Insights)
[110] Future Markets 2019 *The Global Market for Graphene* (Future Markets)
[111] Future Markets 2022 *The Graphene Market Report 2022* (Future Markets)
[112] Global Industry Analysts 2021 *Graphene—Global Market Trajectory & Analytics* (Global Industry Analysts)
[113] 360 Research Reports 2020 *2020–2025 Global Graphene Market Report—Production and Consumption Professional Analysis (Impact of Covid-19)* (360 Research Reports)
[114] Garside M 2021 *Graphite market value worldwide from 2016 to 2025* (available at: www.statista.com/statistics/805506/graphite-global-market-value/) (Accessed 27 July 2023)
[115] www.statista.com/ 2023 *Carbon black market size worldwide in 2016 and 2021, with a forecast for 2027* (available at: www.statista.com/statistics/1350339/global-carbon-black-market-size/) (Accessed 27 July 2023)
[116] Kauling A P, Seefeldt A T, Pisoni D P, Pradeep R C, Bentini R, Oliveira R V B, Novoselov K S and Castro Neto A H 2018 The worldwide graphene flake production *Adv. Mater.* **30** e1803784
[117] Mertens R 2019 *The Graphene Handbook (2019 Edition)* (Lulu.com)
[118] Mertens R 2017 *NanoXplore plans a 10,000 ton graphene powder facility* (available at: www.graphene-info.com/nanoxplore-plans-10000-ton-graphene-powder-facility) (Accessed 27 July 2023)
[119] Williams M 2020 *Rice lab turns trash into valuable graphene in a flash* (available at: https://news.rice.edu/news/2020/rice-lab-turns-trash-valuable-graphene-flash) (Accessed 27 July 2023)
[120] Cabral L M B and Riordan M H 1994 The learning curve, market dominance, and predatory pricing *Econometrica* **62** 1115
[121] Suppliers guide SIO Grafen (available at: https://suppliers.siografen.se/) (Accessed 20 August 2022)
[122] www.thegraphenecouncil.org/ *Graphene Directory—List of Graphene Related Organizations and Resources* (available at: www.thegraphenecouncil.org/general/recommended_links.asp) (Accessed 27 July 2023)
[123] www.graphene-info.com/ *Graphene companies: the comprehensive list* (available at: www.graphene-info.com/companies) (Accessed 27 July 2023)
[124] https://echa.europa.eu/ 2023 *Graphene* (available at: https://echa.europa.eu/de/brief-profile/-/briefprofile/100.227.924) (Accessed 27 July 2023)
[125] Mertens R 2018 *New EU Consortium Launched to Handle REACH Graphene Registrations* (available at: www.graphene-info.com/new-eu-consortium-launched-handle-reach-graphene-registrations) (Accessed 27 July 2023)
[126] Döscher H and Reiss T 2021 Graphene roadmap briefs (No. 1): innovation interfaces of the graphene flagship *2D Mater.* **8** 22004
[127] Schmoch U and Khan M 2019 Methodological Challenges for Creating Accurate Patent Indicators *Springer Handbook of Science and Technology Indicators* (*Springer Handbooks*) ed W Glänzel *et al* (Springer International Publishing) pp 907–27
[128] Maia Research 2022 *2022–2029 Global Graphene Composites Professional Market Research Report, Analysis from Perspective of Segmentation (Competitor Landscape, Type, Application, and Geography)* (Maia Research)
[129] Market Reearch Guru 2022 *Global Graphene Composites Industry Research Report, Competitive Landscape, Market Size, Regional Statusa and Prospect* (Market Reearch Guru)
[130] MMR 2022 *Graphene Composites Market—Global Industry Analysis and Forecast (2022–2029)* (MMR)
[131] LP Information 2021 *Global Graphene Composites Market Growth 2021–2026* (LP Information)
[132] Industry Research 2021 *Global Graphene Composites Market Report, History and Forecast 2016–2027, Breakdown Data by Manufacturers, Key Regions, Types and Application* (Industry Research)

[133] Knowledge Sourcing Intelligence LLP 2021 *Global Graphene Composites Market—Forecasts From 2021 to 2026* (Knowledge Sourcing Intelligence LLP)

[134] Knowledge Sourcing Intelligence LLP 2022 *Global Graphene Composites Market Size, Share, Opportunities, COVID-19 Impact, and Trends by Product Type (Polymer-Based Graphene Composites, Metal-Based Graphene Composites, Ceramic-Based Graphene Composites, Others), by End-User (Aerospace, Buildings and Construction, Electronics, Energy Storage and Generation, Automotive, Others) and by Geography—Forecasts From 2022 to 2027* (Knowledge Sourcing Intelligence LLP)

[135] Transparency Market Research 2019 *Graphene Composites Market to Garner Outstanding CAGR of 40% During 2017–2026, Rising Applications Drive Robust Demand* (Transparency Market Research)

[136] Verified Market Research 2021 *Global Graphene Composites Market Size by Product Type, by Application, by Geographic Scope and Forecast* (Verified Market Research)

[137] Zion Market Research 2018 *Graphene Composites Market: Global Industry Analysis, Size, Share, Growth, Trends, and Forecasts 2018–2026* (Zion Market Research)

[138] Straits 2022 *Graphene Composites Market: Information by Product Type (Polymer-Based, Metal Based, Ceramic Based), Application (Aerospace & Defence, Automotive), and Region—Forecast till 2030* (Straits)

[139] QYResearch 2022 *Global Graphene Composites Market Research Report 2022* (QYResearch)

[140] Research Nester 2022 *Graphene Composites Market Segmentation by Product (Polymer-Based, Ceramic-Based, Metal-Based, and Others); and by End-Use Industry (Electronics, Building and Construction, Aerospace, Automotive, Paints, Energy Storage, and Others)—Global Demand Analysis & Opportunity Outlook 2031* (Research Nester)

[141] Research Reportsworld 2022 *Global Graphene Composites Market Research Report 2022 (Status and Outlook)* (Research Reportsworld)

[142] HNY Research 2021 *2021–2027 Global and Regional Graphene Composites Industry Status and Prospects Professional Market Research Report Standard Version* (HNY Research)

[143] BIS Research 2018 *Global Graphene-Enhanced Composites Market: Focus on Composite Type (Graphene-Enhanced Polymer Composite, Graphene-Enhanced Ceramic Composite, and Graphene-Enhanced Metal Composite), Graphene Type, and Application-Analysis & Forecast, 2018–2023* (BIS Research)

[144] Custom Market Insights 2022 *Global Graphene Composites Market Size/Share Worth 112.1 Million by 2030 at a 38.8% CAGR: Custom Market Insights (Analysis, Outlook, Leaders, Report, Trends, Forecast, Segmentation, Growth)* (Custom Market Insights)

[145] Custom Market Insights 2022 *Graphene Composites Market Size, Trends and Insights by Product Type (Polymer Based, Metal Based, Ceramic Based, Others), by End-User (Sport & Wearable Goods, Aerospace & Defense, Automotive, Building & Construction, Energy Storage & Generation, Others), and by Region—Global Industry Overview, Statistical Data, Competitive Analysis, Share, Outlook, and Forecast 2023–2032* (Custom Market Insights)

[146] Allied Market Research 2021 *Graphene Composites Market by Product Type (Polymer Based, Metal Based, Ceramic Based, and Others), and Application (Sports & Wearable Goods, Aerospace & Defense, Automotive, Building & Construction, Energy Storage & Generation, and Others): Global Opportunity Analysis and Industry Forecast 2020–2027* (Allied Market Research)

[147] 360 Market Research 2020 *Global Graphene Composites Market Insights and Forecast to 2026* (360 Market Research)

[148] 9Dimen Research 2021 *Global Graphene Composites Market Research Report 2021–2025* (9Dimen Research)

[149] 9Dimen Research 2021 *Global Graphene Nanocomposites Market Research Report 2021–2025* (9Dimen Research)

[150] Global Industry Analysts 2021 *Graphene Composites* (Global Industry Analysts)

[151] Global Info Research 2021 *Global Graphene Nanocomposites Market 2021 by Manufacturers, Regions, Type and Application, Forecast to 2026* (Global Info Research)

[152] Global Information 2022 *Graphene Composites Market Report: Trends, Forecast and Competitive Analysis* (Global Information)

[153] Future Market Insights 2019 *Graphene Nanocomposites Market: Towering R&D Investments and Emerging Application Areas to Offer a Collective Push to Demand Growth: Global Industry Analysis 2013–2017 and Opportunity Assessment 2018–2028* (Future Market Insights)

[154] Data bridge market research 2021 *Global Graphene Composites Market—Industry Trends and Forecast to 2028* (Data bridge market research)

[155] Data Intello 2022 *Global Graphene Composites Market by Type (Graphene Oxide, Graphene Film, Graphene Nanoplatelets), by Application (Paints and Coatings, Energy Storage, Electronics and Semiconductors, Photovoltaics, Healthcare, Textile Industry) and by Region (North America, Latin America, Europe, Asia Pacific and Middle East & Africa), Forecast From 2022 to 2030* (Data Intello)

[156] Fact.MR 2021 *Graphene Composites Market* (Fact.MR)

[157] Market Research.biz 2021 *Global Graphene Electronics Market Covid-19 Impact Analysis, Drivers, Restraints, Opportunities, Threats, Trends, Applications, and Growth Forecast to 2031* (Market Research.biz)

[158] Market Research.com 2022 *Graphene Electronics Market* (Market Research.com)

[159] Markets and Markets 2015 *Graphene Electronics Market by Materials (PV, Electronics), Devices (Super capacitors, Transistors, Spintronics, Sensors, ICs & Chips, Lenses), Products (Computing, Consumer, Memory, Display), Developments (Nanotubes & Ribbons, Fullerenes) & Geography—Analysis & Forecast 2013–2020* (Markets and Markets)

[160] Market Research Community 2022 *Graphene Electronics Market Size, Share & Trends Analysis, by Product (Computing, Consumer, Memory, Display), Application (Computing, Data Storage, Consumer, Communication, Thermal Management), by Device (Transistors, Super Capacitors), Region and Forecast Period 2022–2030* (Market Research Community)

[161] LP Information 2021 *Global Graphene Electronics Market Growth 2021–2026* (LP Information)

[162] LP Information 2022 *Global Graphene Electronics Market Growth 2022–2028* (LP Information)

[163] Maia Research 2022 *2022–2029 Global Graphene Electronics Professional Market Research Report, Analysis from Perspective of Segmentation (Competitor Landscape, Type, Application, and Geography)* (Maia Research)

[164] Markets and Research.biz 2022 *Global Graphene Electronics Market 2022 by Manufacturers, Regions, Type and Application, Forecast to 2028* (Markets and Research.biz)

[165] Reports n Reports 2022 *Global Graphene Electronic Market 2022 by Manufacturers, Regions, Type and Application, Forecast to 2028* (Reports n Reports)

[166] up market research 2021 *Global Graphene Electronics Market by Type (Graphene Transistors, Graphene Supercapacitors, Graphene Sensors, Graphene Ics & Chips, Others), by Application (Batteries and Ultracapacitors, Display, Sensors, Electro Mechanical Systems (EMS), Solar Cells, Others) and Region (North America, Latin America, Europe, Asia Pacific and Middle East & Africa), Forecast to 2028* (up market research)

[167] Vynz Research 2022 *Global Graphene Electronics Market—Analysis and Forecast (2021–2027)* (Vynz Research)

[168] Qurate Research 2022 *Global Graphene Electronics Market Research Report with Opportunities and Strategies to Boost Growth- COVID-19 Impact and Recovery—2022 Update* (Qurate Research)
[169] Maximize Market Research 2022 *Graphene Electronics Market: Emerging Opportunities, Trends and Forecast Analysis (2021–2027) by Type, Application and Region* (Maximize Market Research)
[170] OG Analysis 2020 *2020 Graphene Electronics Market Size, Outlook and Opportunities—2026* (OG Analysis)
[171] Qualket Research 2021 *Graphene Electronics Market Size, Trends & Growth Opportunity by Device Type (Graphene transistors, Graphene Sensors, Graphene Chips), by Application (Consumer Electronics, Data Storage), by Region and Forecast till 2027* (Qualket Research)
[172] Global Info Research 2022 *Global Graphene Electronics Market 2022 by Manufacturers, Regions, Type and Application, Forecast to 2028* (Global Info Research)
[173] Global Market Insights 2022 *Graphene Market—by Product (Graphene Oxide, Graphene Nanoplatelets, Mono-Layer & Bi-Layer Graphene), by End User (Electronics, Aerospace & Defense, Energy, Automotive, Healthcare) & Forecast, 2022–2030* (Global Market Insights)
[174] Global Industry Analysts 2021 *Graphene Electronics* (Global Industry Analysts)
[175] Acute Market Reports 2019 *Graphene Electronics Market by Technology (Graphite Ore, Chemical Vapor Deposition, Others), by Material (Graphene Nano Technology Materials, Electronic Materials, Structured Materials, Others), by Device (Graphene Transistors, Graphene Sensors, Graphene Chips and ICs, Lenses, Others), by Application (Computing & Communications, Data Storage, Sensing, Display & Touch, Solar, PV and Green Tech, Thermal Management, Others)—Growth, Future Prospects & Competitive Analysis, 2021–2029* (Acute Market Reports)
[176] Credence Research 2019 *Graphene Electronics Market by Technology (Graphite Ore, Chemical Vapor Deposition, Others), by Material Type (Graphene Nano Technology Materials, Electronic Materials, Structured Materials, Others), by Device Type (Graphene Transistors, Graphene Sensors, Graphene Chips and ICs, Lenses, Others), by Application (Computing & Communications, Data Storage, Sensing, Display & Touch, Solar, PV and Green Tech, Thermal Management, Others)—Growth, Future Prospects & Competitive Analysis, 2019–2027* (Credence Research)
[177] Data Intello 2022 *Global Graphene Electronics Market by Type (Photo-Voltaic Graphene Materials, Graphene Nano-Technology Materials, Structured Materials, Electronic Materials, Nanotechnology Materials, Electric and Conducting Materials, Photovoltaic Materials), by Application (Batteries and Ultracapacitors, Display, Sensors, Electro Mechanical Systems (EMS), Solar Cells) and by Region (North America, Latin America, Europe, Asia Pacific and Middle East & Africa), Forecast From 2022 to 2030* (Data Intello)
[178] Global Market Insights 2021 *Graphene Electronics Market Size, Industry Analysis Report, Regional Outlook (U.S., Canada, Mexico, Germany, UK, France, Italy, Spain, Poland, Belgium, Netherlands, Russia, Japan, China, India, South Korea, Malaysia, Sri Lanka, Brazil, Argentina, UAE, South Africa, Saudi Arabia), Application Development Potential, Price Trend, Competitive Market Share & Forecast, 2022–2028* (Global Market Insights)
[179] Intelligence Market Report 2022 *Global Graphene Electronics Market Research Report 2022 (Status and Outlook)* (Intelligence Market Report)
[180] Knowledge Sourcing Intelligence 2022 *Graphene Electronics Market* (Knowledge Sourcing Intelligence)
[181] Knowledge Sourcing Intelligence LLP 2018 *Graphene Electronics Market—Forecasts From 2018 to 2023* (Knowledge Sourcing Intelligence LLP)
[182] Industry ARC 2021 *Graphene Electronics Market—Forecast (2022–2027)* (Industry ARC)
[183] Grand View Research 2018 *Graphene Electronics Market Size, Share & Trends Analysis Report by Product, by Technology, Regional Outlook, Competitive Strategies, and Segment Forecasts, 2019–2025* (Grand View Research)
[184] HYN Research 2021 *2021–2027 Global and Regional Graphene Electronics Industry Status and Prospects Professional Market Research Report Standard Version* (HYN Research)
[185] Industry ARC 2020 *Graphene Electronics Market—Forecast (2020–2025)* (Industry ARC)
[186] Report Ocean 2022 *Global Graphene Battery Market, 2021–2027* (Report Ocean)
[187] QYResearch 2022 *Global and United States Graphene Battery Market Report & Forecast 2022–2028* (QYResearch)
[188] Report Ocean 2021 *Global Graphene Battery Market Report 2021* (Report Ocean)
[189] Report Ocean 2020 *Global Graphene Battery Market Size Study With Covid-19 Impact, by Type (Lithium-Ion Graphene Battery, Graphene Supercapacitor, Lithium-Sulfur Graphene Battery and Others), End Use Industry (Automotive, Consumer Electronics, Industrial, Power and Others) and Regional Forecasts 2020–2026* (Report Ocean)
[190] Markets and Markets 2020 *Graphene Battery Market* (Markets and Markets)
[191] Market Research Future 2022 *Graphene Battery Market Research Report Information: by Type (Li-Ion Battery, Li-Sulphur Battery, Supercapacitor, Lead-Acid Battery), End-Use Industry (Automobiles, Electrical & Electronics, Aerospace & Defense and Others)—Forecast Till 2030* (Market Research Future)
[192] QYResearch 2021 *Graphene Battery Market* (QYResearch)
[193] Maximize Market Research 2021 *Graphene Battery Market-Industry Analysis and Forecast (2019–2027): By Type, by End User, and by Region* (Maximize Market Research)
[194] Valuates Reports 2020 *Graphene Battery Market Size, Share & Trends Analysis Report by Battery Type, by Application, and Segment Forecasts, 2020–2027* (Valuates Reports)
[195] Staris Research 2022 *Graphene Battery Market: Information by Battery Type (Li-Ion Batteries, Li-Sulfur Batteries), Application (Automotive, Electronics), and Region-Forecast till 2030* (Staris Research)
[196] Verified Market Research 2022 *Global Graphene Battery Market Size by Technology (Lithium-Ion Battery, Lithium Sulphur Battery), by Application (Automotive, Electronics), by Geographic Scope and Forecast* (Verified Market Research)
[197] Value Market Research 2021 *Global Graphene Battery Market Report by Battery Type (Li-Ion Batteries, Li-Sulfur Batteries, Supercapacitors, Ead-Acid BatteriesL), by Application (Automotive, Electronics, Energy, Aerospace & Defense, Industrial Robotics, Healthcare) and by Regions—Industry Trends, Size, Share, Growth, Estimation and Forecast, 2022–2030* (Value Market Research)
[198] Research Reportsworld 2022 *Global Graphene Battery Industry Research Report, Competitive Landscape, Market Size, Regional Status and Prospect* (Research Reportsworld)
[199] Reports n Reports 2020 *Graphene Battery Market by Type (Lithium-Ion Graphene Battery, Lithium-Sulfur Graphene Battery, Graphene Supercapacitor), End-Use Industry (Consumer Electronics, Automotive, Industrial, Power), Region—Global Forecast to 2030* (Reports n Reports)
[200] Skyquest 2022 *Graphene Battery Market Size, Share, Growth Analysis, by Battery type (Li-Ion Batteries, Li-Sulfur Batteries), by Application (Automotive, Electronics), by Region (North America, U.S.)—Industry Forecast 2023–2030* (Skyquest)
[201] Research and Markets 2020 *Graphene Battery Market by Type (Lithium-Ion Graphene Battery, Lithium-Sulfur Graphene Battery, Graphene Supercapacitor), End-Use Industry (Consumer Electronics, Automotive, Industrial, Power), Region—Global Forecast to 2030* (Research and Markets)

[202] Market Data Forecast 2022 *Graphene Battery Market Research Report—Segmented by Type (Lithium-Ion Graphene Battery, Lithium Sulphur Graphene Battery and Graphene Supercapacitor), by End Use Industry (Consumer Electronics, Automotive, Industrial and Power), and Region—Industry Forecast of 2022–2027* (Market Data Forecast)
[203] Global Info Research 2022 *Global Graphene Battery Technology Market 2022 by Company, Regions, Type and Application, Forecast to 2028* (Global Info Research)
[204] Global Info Research 2021 *Global Graphene Battery Market 2021 by Manufacturers, Regions, Type and Application, Forecast to 2026* (Global Info Research)
[205] GMInsight 2017 *Graphene Battery Market* (GMInsight)
[206] GMI Research 2021 *Graphene Battery Market by Type (Lithium-Ion Graphene Battery, Lithium-Sulfur Graphene Battery, Graphene Supercapacitor, and Others), by End-Use Industry (Consumer Electronics, Automotive, Industrial, Power, and Others), and by Region—Global Opportunities & Forecast, 2021–2028* (GMI Research)
[207] Data Bridge Market Research 2022 *Global Graphene Battery Market—Industry Trends and Forecast to 2029* (Data Bridge Market Research)
[208] Allied Market Research 2019 *Graphene Battery Market* (Allied Market Research)
[209] Fortune Business Insights 2022 *Graphene Battery Market Size, Share & Industry Analysis, by Type (Lithium-Ion Battery, Lithium-Sulphur Battery, Graphene Supercapacitor, Others (Metal-Air, Lithium Titanate, Lead Acid)), by Application (Consumer Electronics, Automotive, Industrial, Power, Others (Aerospace, Defense, Marine, Medical)) and Regional Forecast 2023–2030* (Fortune Business Insights)
[210] Envisage Market Research 2022 *Global Graphene Battery Market Recent Trends, In-Depth Analysis, Size and Forecast to 2030* (Envisage Market Research)
[211] Knowledge Sourcing Intelligence LLP 2018 *Graphene Battery Market* (Knowledge Sourcing Intelligence LLP)
[212] Knowledge Sourcing Intelligence 2021 *Graphene Battery Market Size, Share, Opportunities, COVID-19 Impact, and Trends by End-User Industry (Consumer Electronics, Automotive, Others), and by Geography—Forecasts From 2021 to 2026* (Knowledge Sourcing Intelligence)
[213] Market Data Forecast 2021 *Graphene Battery Market* (Market Data Forecast)
[214] LP Information 2021 *Global Graphene Battery Market Growth 2021–2026* (LP Information)
[215] Inkwood Research 2020 *Global Graphene Battery Market* (Inkwood Research)
[216] Imarc 2022 *Graphene Battery Market: Global Industry Trends, Share, Size, Growth, Opportunity and Forecast 2022–2027* (Imarc)
[217] Kenneth Reseach 2022 *Graphene Battery Market Segmentation by Battery Type (Li-Ion Batteries, Li-Sulphur Batteries, Supercapacitor, and Lead-Acid Batteries); by Application (Automotive, Electronics, Energy, Aerospace & Defense, Industrial Robotics, and Healthcare)-Global Demand Analysis and Opportunity Outlook 2031* (Kenneth Research)
[218] Inkwood Research 2022 *Global Graphene Battery Market by Battery Type (Li-Ion Batteries, Li-Sulfur Batteries, Supercapacitors, Lead-Acid Batteries) by End-User (Automotive, Electronics, Energy, Aerospace & Defense, Industrial Robotics, Healthcare) and by Geography* (Inkwood Research)