Global Markets for Advanced Aerospace Materials

December 2023

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Report Code: AVM192B

Additional segmentations and data sets available upon request. Email custom@bccresearch.com.

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Introduction

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Chapter 1: Introduction

Overview

The aerospace industry's constant pursuit of higher fuel economy, lower emissions and minimal material utilization can be accomplished by substituting old, heavy materials with new, light, high-strength advanced materials. Both weight reduction and performance improvement can be accomplished by lightweighting. This idea has found widespread acceptance and application, particularly in the design of aeronautical systems and components. Cutting-edge lightweight materials and numerical structural optimization made possible by sophisticated manufacturing techniques are the key components of the lightweighting design process. The aerospace sector has a history of adopting new materials quickly, such as tailored panels, titanium alloys, superalloys, advanced composites and improved aluminum alloys. But new materials also come with a host of brand-new difficulties. Fabrication technologies must advance further for aircraft makers to successfully process a wider variety of materials and use them in brand-new aircraft designs. This report deep dives into understanding the dynamics of a range of advanced aerospace materials.

Study Goals and Objectives

The objective of this study is to provide an analysis of advanced aerospace materials in terms of current and forecast usage, with an emphasis on developments since 2021. New developments in advanced aerospace materials have resulted in the expanded use of lightweight, high-strength materials across all key categories of aerospace applications. These trends are discussed and quantified. The competition among advanced materials—ranging from advanced and lightweight alloys to composites and composite ceramics—is also discussed and quantified, with realistic forecasts through 2028. This study provides a comprehensive review of markets for key emerging aerospace material, focusing on the most relevant, largest, and fastest-growing technologies and applications. The study is relevant to companies, individuals and others operating in the aerospace industry, as well as upstream suppliers, downstream end users, investors, and other players in this sector.

This report aims to provide an up-to-date analysis of current and future markets for advanced aerospace materials. It comprehensively analyzes global markets in a multi-client format. It presents a thorough and updated global assessment of the market. This will help industry participants, suppliers, government bodies, associations and customers make the informed decisions needed to compete and succeed in the marketplace. The research is meant to give the reader a comprehensive overview of the market's size, growth and direction, including an assessment of its driving factors, technological hurdles and advances.

This report highlights the role of emerging material in various aerospace applications, explains the technology and innovations behind material development and production, and analyzes significant market trends by region. It details new developments in the aerospace materials industry, offering continuous improvements in environmental performance. It analyzes the market for various material types, such as advanced aluminum alloys, titanium alloys, advanced steel alloys, superalloys, advanced composites and advanced adhesives. It also reviews the demand for and new products using these technologies.

The goals and objectives of this study include:

- Identify trends that affect the use of advanced aerospace materials and significant growth factors.
- Review, analyze and forecast specific applications of advanced aerospace materials in different aircraft types.
- Analyze market trends driving or restraining the market for advanced aerospace materials.
- Calculate the current global market size and project growth over the next five years based on the previous year's market trends and ongoing research activities.
- Examine region-specific developments in the industry.
- Assess the industry's long-term outlook.
- Identify potential applications in the future.
- Estimate the potential net impact of advanced aerospace materials on the global energy balance.
- Profile prominent product manufacturers and suppliers and analyze their core competencies and strategies.

Reasons for Doing This Study

New and growing technology trends suggest that the market for advanced aerospace materials will continue to grow over the next five years. Advancements in aerospace materials can potentially transform the aviation sector. Materials with improved mechanical, thermal and electrical properties can lead to enhanced aircraft performance, including fuel efficiency, greater speed, range and payload capacity. The high demand for efficient aircraft from customers like passengers and cargo shippers draws increased investments to the aerospace and defense sector. Innovations in materials can reduce manufacturing, maintenance, and operating costs, making aerospace more economically viable. This report is a business opportunity report intended especially for developers and vendors of advanced materials that target the aerospace industry.

Developers of aerospace materials are constantly seeking to improve the base materials for the aerospace industry. Moreover, the industry operates as a starting point, testing ground and commercialization hotbed for the development of new materials that also have application outside the aerospace industry. Therefore, understanding how the markets for these materials will move forward, within the aerospace industry specifically, will provide insight not only in that industry, but also into the process by which materials like carbon fiber reinforced polymers and ceramic composites will ultimately be commercialized more fully, come down in price, and potentially expand into adjacent markets and applications.

Making sense of the full picture of the global industry for advanced aerospace materials and associated markets is an exciting challenge—one that requires careful review of the industry itself, and also an interdisciplinary-oriented understanding of the many common applications of advanced aerospace materials. Key goals for completing this study included the following: quantifying this expansive market space, identifying key areas of growth, highlighting regions where advanced aerospace materials and their applications are in highest demand, and providing a basis for improved understanding of the global advanced aerospace materials industry and associated markets. Therefore, this study is meant to serve as a guide map for those already invested in the industry, as well as for those considering investment or development in the industry. Rewards and returns promise to be significant and substantial for a well-positioned market entry, expansion, acquisition or other business development strategy.

This report is oriented to the interests and concerns of a non-technical audience, but it contains a great deal of technical information that should also interest scientists and engineers working in the aerospace materials fields. At its core, the overarching goal of this study is to provide detailed information on the industry via a macro-level view of trends and significant influencing factors. The need for technically advanced yet economical materials with critical product design and profile developments forces engineers to think of innovative solutions.

For a company to succeed in a competitive market, product opportunities must be identified from the viewpoint of the company's strengths. This necessitates understanding the size and growth rate of opportunities and the competitive atmosphere in which the company operates. This report is the ideal medium for readers to understand the exciting opportunities related to advanced aerospace materials. This report is designed to provide information and data for readers to understand the market and to make knowledgeable, informed decisions regarding their industry involvement.

Scope of Report

This report examines the emerging materials in the aerospace industry. Definitive and detailed estimates and forecasts of the global market are provided, followed by a detailed analysis of each material, application and regions. The report also focuses on the regulations, relevant industry organizations and government-supported programs impacting this market. Regionally, the focus of the study will be the markets of the Americas, Europe and Asia-Pacific. BCC Research has not considered the rest of the world in its research scope because the major contributions and developments in emerging materials in the aerospace sector is from the Americas, Europe and Asia-Pacific only.

The scope of the advanced aerospace materials industry is continually expanding as new discoveries are made and as researchers and industries explore innovative ways to harness the unique properties of advanced materials and manufacturing technologies. This report, however, concentrates on emerging materials that are currently in commercial use or are likely to be commercialized by 2028. Other applications that, while promising, are not likely to make it out of the laboratory by 2028 are not covered in depth. Sales value estimates are based on prices in the supply chain. Market-driving forces and industry structures are examined. International aspects are analyzed for all global regions.

This study reviews the following material categories, along with relevant market and production information, technological descriptions and issues, key applications and major market factors. This report organizes material type into the following segments:

- Advanced steel alloys.
- Advanced aluminum alloys.
- Titanium alloys.
- Superalloys.
- Advanced composites—CFRP, GFRP.
- Ceramic-matrix composites.
- Advanced adhesives.

The following applications for advanced aerospace materials are also examined, with market breakdowns for each by region:

- Commercial passenger aircraft.
- Commercial transport aircraft (for cargo).
- General aviation.
- Helicopters.
- Defense industry and government.
- Commercial space industry.

There are several technologies of interest—including those that could someday capture significant market share—that have not yet developed to the point of achieving significant market share. Listed below are some technologies that are similar to the target materials but do not meet the definition of advanced aerospace materials considered in this study.

- Conventional steel plate, carbon steel and other conventional metals that are used in some cases for basic structural elements.
- Carpeting, vinyl, foams and other non-structural cabin elements that use conventional materials.
- Pure aluminum (only aluminum alloys are considered in this study).

The market analysis completed in support of this study was developed over two phases. The initial phase of the analysis included a review of each of the advanced aerospace materials under study, as well as a review of the industry trends and factors likely to impact or affect their market development and growth potential. Regional markets were in many cases variable for this study. In the second phase, the focus of the analysis was on sales of advanced aerospace materials with respect to a specific end use. Market calculations were originally developed based on trade volumes for each of the categories considered, to the extent that this data was available. Market values were then developed using typical pricing for each of the advanced aerospace materials categories that were considered.

Within this framework, it should be noted that the study did not consider the ultimate final end-product value. For example, BCC Research do not quantify the value of an airplane that is sold by Boeing to American Airlines. Instead, we consider the value of the specific relevant materials that are included in the airplane, based on their purchase cost by Boeing. The market values shown are normalized to 2022 U.S. dollars, and they discount the effects of past or future inflation on market values.

Once the initial technology-level data was developed, application-level data was cross-referenced against the technology data. Applications were also investigated based on future anticipated deployment and potential for changes in leading and secondary technologies over time. We further developed country-level splits based on a combination of regional and national level sales and revenue data. In some cases, country-level splits were estimated for segments where national-level data was limited or unavailable. All estimates were completed based on the available technology- and application-level data, and then benchmarked against other data collected, where available.

What's New in This Update?

The previous version of the report, AVM192A *Global Markets for Emerging Materials in Aerospace*, used 2019 as the base year and provided market forecasts from 2020 to 2025. This update, AVM192B, researched and written in 2023, uses 2022 as the base year and provides market forecasting from 2023 to 2028. The market data from 2023 was updated using secondary and primary research. The report observes and explains the changes seen in the five-year compound annual growth rate (CAGR) compared to the earlier version. It considers the overall impact of the COVID-19 pandemic, and it includes revised analyses to provide a holistic view of the global market for advanced aerospace materials.

Some sections align with the previous version of the report, but the updated quantitative and qualitative sections are based on current findings. All the market segments, application and regional data are based on secondary and primary research data. The global market size in value (given in U.S. $ millions) has been estimated and provided for each market segment. Detailed company profiling for the top market players and a list of abbreviations have also been added to the report.

BCC Research has included the following additions in this 2023 update:

- Global level analysis of the market for advanced aerospace materials with respect to different regions and applications.
- Updated market breakdown by type, applications and region.
- A detailed description of various trends, drivers, restraints and opportunities in the market.
- ESG developments in the advanced aerospace materials industry.
- Updated company profiles, latest developments, financial information and strategic outlook.
- Impact of the Russia-Ukraine war on the global market for advanced aerospace materials.
- Global-level competitive analysis and emerging technologies for the market for advanced aerospace materials.
- An updated patent analysis, as well as a merger and acquisition overlook.
- Updated laws, regulations and standards concerning advanced aerospace materials.

Research Methodology

This report is a descriptive study with a trend analysis of the global market for advanced aerospace materials that uses quantitative and qualitative approaches. BCC Research conducted a comprehensive literature search of technical newsletters, journals and open-access academic literature. Primary and secondary sources were also considered, including interviews with industry vendors, white papers, business journals, public financial proceedings and historical market data from the internet. Significant sources, including the International Monetary Fund, along with data from government associations (e.g., American Institute of Aeronautics & Astronautics, European Chemicals Agency, SAE International, ASME – Aerospace Division, Aerospace Industries Association, NASA.) and companies across the market for advanced aerospace materials, were also considered to fully understand the market. Additionally, the data provided in this report was compared with other industry data to ensure relevance, applicability and accuracy.

Market data were assessed and validated considering interrelated market attributes and the impact of global economic variables. Interviews, which were the primary basis for information regarding the development of market size, were obtained via Zoom, email and telephone. Interviews were also used to confirm and/or adjust market size and market share estimates, as well as to formulate market projections. Data was collected through interviews and correspondence with advanced aerospace materials market players, service providers, technology developers, raw material suppliers and new entrants. The methodologies developed in this report are also the result of extensive discussions with a diverse set of technological, statistical and business experts.

In addition, another approach was followed. It involved considering advanced materials (advanced aluminum alloys, titanium alloys, superalloys, advanced steel alloys, advanced composites, advanced adhesives and ceramic-matrix composites) as a parent market and then extracting their application in aerospace using a combination of secondary and primary research. In order to confirm the highest material consumption, total number of deliveries of aircraft families from top manufacturers like Airbus, Boeing, Embraer in 2022 are multiplied with the percentage of material distribution in each aircraft type using a weighted average method.

Where information gaps or inaccuracies were identified, estimates were made using applicable and available benchmarking tools, including national-level or regional-level changes in relevant indices, applications, regional regulations and standards, industry standards and requirements, and, where available, data on sales to and from other supply chain levels within the industry, as well as industry-specific data and trends.

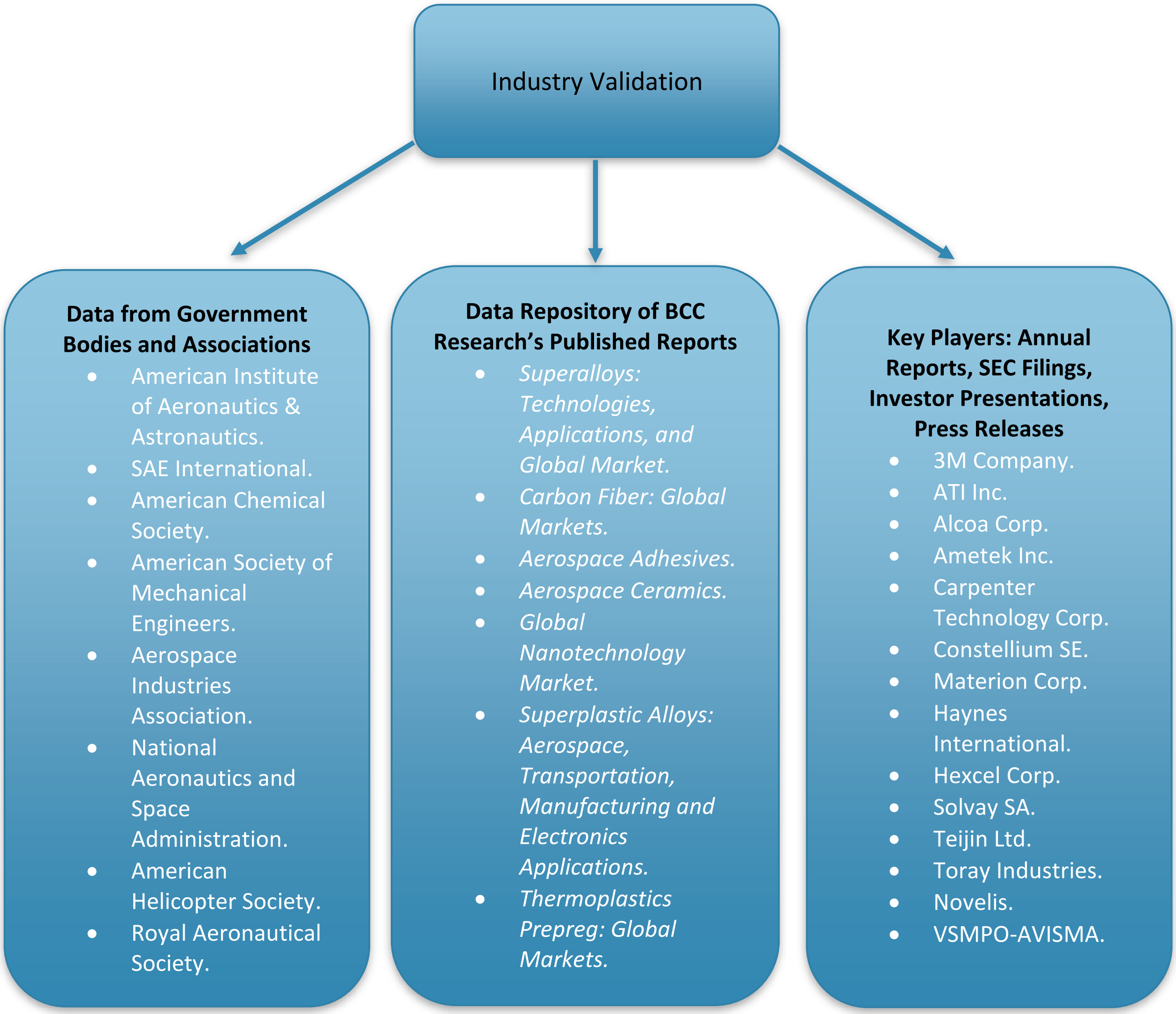
Projections were based on estimates, including the average prices, supply of key players, annual revenues of key players and forward-looking statements. The market value was then obtained through a combination of bottom-up and top-down approaches using exclusive market modeling tools to generate BCC Research's market data and forecasts. The estimated values used were based on manufacturers' total revenues. Product prices were obtained using actual quotes provided by leading distributors, vendors and suppliers. The average rate was calculated to derive market revenue considering price quotes for different ports. Prices varied across regions based on raw material availability and manufacturing cost.

Estimates of market demand are made for 2023 and then projected over five years, with 2022 serving as the base year. Projections are made in terms of constant U.S. dollars. Growth is presented in terms of a compound annual growth rate (CAGR). Market values represent manufacturer revenue. It is the value at the final point of sale that has been calculated; this is not the same in all cases as manufacturer revenue, as many agents and converters take percentages. The company market share analysis is derived from production capacity, sales, product portfolio and business diversification.

Parameters considered for forecasting on a regional level include:

- Expected capacity addition across the industry.
- Technology innovation and sustainability trends.
- Raw material supply situation.
- Feedback received from key industry players.
- Sales revenue reported by major companies.
- Anticipated regulatory updates.

Figure A
Research Methodology Used in This Report



Source: BCC Research

Information Sources

The findings and conclusions of this report are based on information gathered from developers and manufacturers of advanced aerospace materials, as well as concerned governmental, industry and professional organizations. Interview data were combined with information gathered through an extensive review of secondary sources, including trade publications, trade associations, SEC filings, industry presentations, company literature and online databases to produce the baseline market estimates contained in this report. The Web of Science database was used for bibliometric analysis.

Research for this report began with an analysis of the available technical and business literature. Conversations with industry experts, environmental analysts and company representatives, along with a review of published works, provide the backbone for the evaluation of the industry.

Information sources for the study include online research, patent literature, technical journals, white papers and trade magazines covering the emerging aerospace industry. Databases include OneSource, Factiva, Bloomberg, the U.S. Securities and Exchange Commission (SEC) for company filings, Reuters, and company websites. Information was obtained from various industry experts and government agencies, including the U.S. Census Bureau, the U.S. Environmental Protection Agency (EPA), the World Bank and the U.S. Central Intelligence Agency (CIA), as well as patent offices and other nongovernmental bodies. The following table summarizes the information sources for each of the major sections of this market analysis and the related applications covered in this study.

Geographic Breakdown

Segmentation Breakdown

BY TYPE

- Advanced Aluminum Alloys
- Advanced Composites
- Titanium Alloys
- Superalloys
- Advanced Steel Alloys
- Ceramic-Matrix Composites
- Advanced Adhesives

BY APPLICATION

- Commercial Passenger Aircraft
- Commercial Transport Aircraft
- Defense Industry and Government
- General Aviation
- Commercial Space Industry
- Helicopters

BY REGION

- Americas
- Europe
- Asia-Pacific

Chapter 2

Summary and Highlights

Chapter 2: Summary and Highlights

Market Outlook

The outlook for the emerging materials in the aerospace market looks promising as technological advancements and industry trends continue to drive the development and adoption of innovative materials. Various factors along with the continuous pursuit of improvement in aircraft performance drive advancements in aerospace materials. The aerospace sector will continue to emphasize using lightweight materials, such as advanced composites and lightweight alloys, to increase aircraft performance and improve fuel economy.

Market Size	The overall global market for advanced aerospace materials was valued at $25.1 billion in 2022, and it is projected to reach $38.7 billion by 2028.
CAGR	The global market for market for advanced aerospace materials is expected to witness a CAGR of 8.0% from 2023 to 2028.
High Growth Region	The Americas region contributed to 50.1% of the global market in terms of value in 2022, followed by Europe and Asia-Pacific.
Market Drivers and Opportunities	• Growth of Air Traffic Worldwide. • Stringent Environmental Regulations. • Rising Adoption of Advanced Composites in Aerospace and Defence. • Space Exploration.
Restraints and Challenges	• Certification and Regulatory Hurdles. • Complex Supply Chain for Emerging Materials.

ESG Development	The 3M Co. scored the highest score on the environmental and social front in the industry, while Toray Industries scored the highest score on the governance scale front and outperformed peer performance. The industry has been actively focusing on environmental sustainability and responsible sourcing.
Emerging Technologies	Nanomaterials, metamaterials, shape memory alloys, smart materials, advanced manufacturing, self-healing materials, digital twins, high-entropy alloys, lightweight aerofoils.
Top Vendors	• Hexcel Corp. • Solvay SA. • Toray Industries. • Constellium SE. • Alcoa.

Market Summary

The emerging materials in the aerospace market is anticipated to continue its growth trajectory, driven by advancements in research and development, increased adoption across the aerospace industry, and ongoing innovations in materials and processes. Global governments, academia and industries are investing in emerging materials, which indicates a solid commitment to its development. The demand for lightweight, high-strength, sustainable and technologically advanced materials is driven by the pursuit of greater fuel efficiency, improved safety and environmental sustainability. Stringent emissions standards are compelling the aviation industry to develop materials and technologies that significantly reduce carbon footprint.

One of the exciting initiatives for global advanced aerospace materials is NASA's Advanced Materials Initiatives, which explore the development of advanced materials in space exploration. This includes materials for spacecraft, habitats and spacesuits designed to withstand the harsh conditions of space. Currently, NASA is seeking concepts from the U.S. industry to develop advanced materials and products in space that could benefit life on earth and grow the low earth orbit economy. In addition, a European research and innovation program called Clean Sky 2 is devoted to creating and advancing cutting-edge technology for a more environmentally friendly aviation sector. It is an extension of the original Clean Sky program and a component of the Horizon 2020 Framework Program. The principal initiative for research and innovation in the European Union focuses on reducing carbon dioxide (CO_2) and nitrogen oxide (NOx) emissions.

Using additive manufacturing technology opens up possibilities for complicated geometries, unique components and rapid prototyping. It lowers material waste and streamlines production. These innovations in materials that can withstand the rigors of space travel boost interest in space exploration and hypersonic flights. They also represent growth opportunities in developing advanced ceramics, CMCs and high-temperature alloys.

The Americas region dominates the emerging materials in the aerospace market, with a 50.1% share in 2022, due to the high concentration of commercial and defense aircraft manufacturers in the area. Several firms in the U.S. are engaged in the development of aerospace materials as well as component-based products and solutions. Government agencies such as the National Science Foundation (NSF), the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA) provide substantial funding for aerospace materials research. This funding supports fundamental research and applied projects to drive innovation and technological advancement.

Rising competition among global market for advanced aerospace materials players is continuously helping in product differentiation, cost reduction and innovation, which fuels market development. The advanced aerospace materials industry is driven by technological innovation, with companies constantly developing new and improved products that integrate advanced materials. Acquisition, capacity expansion and technological collaborations are other trends observed in the industry ecosystem.

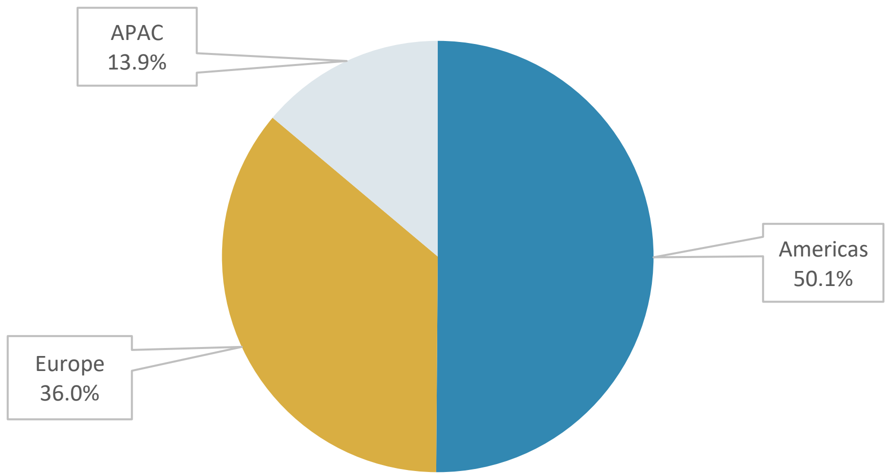
Summary Table: Global Market for Advanced Aerospace Materials, by Region, Through 2028 ($ Millions)

Region	2022	2023	2028	CAGR% 2023-2028
Americas	12,579.8	12,973.3	17,324.4	6.0
Europe	9,040.2	9,733.9	16,071.4	10.5
Asia-Pacific	3,482.6	3,650.5	5,315.8	7.8
Total*	25,102.6	26,357.7	38,711.6	8.0

*Note: Totals in this report's tables and figures might not match exactly due to rounding.

Source: BCC Research

Summary Figure:
Global Market Shares of Advanced Aerospace Materials, by Region, 2022
(%)



Source: BCC Research

Chapter 3

Market Overview

Chapter 3: Market Overview

Overview

The emerging materials in the aerospace industry is a dynamic sector that concentrates on creating and applying cutting-edge materials to improve the functionality, security and sustainability of airplanes and spacecraft. The market for advanced aerospace materials covers many advanced materials that offer improved performance, lighter weight, higher strength, improved safety and, in some cases, lower cost than conventional technologies. Where materials costs are higher, many advanced aerospace materials can improve their target applications enough that they can, over their lifetime, more than offset their high initial cost through reduced operational cost, fuel usage, and lower maintenance and repair costs.

Fuel efficiency is highly valued in aerospace since it lowers operational costs and carbon emissions. The key to reaching fuel efficiency goals is the development of lighter, more aerodynamic materials. The aerospace industry is placing more and more emphasis on sustainability issues, including the use of environmentally friendly materials and manufacturing techniques. Although such trends drive growth in the market, emerging materials can be expensive to develop and manufacture, and this negatively impacts their adoption.

Technology Background

Rising demand for improved fuel efficiency, enhanced performance and greater safety has long driven the aerospace industry to deploy new, lighter-weight, stronger materials that were often considered too costly or difficult to utilize for day-to-day production activities. Historically, the aerospace materials market transitioned from aluminum to carbon fiber-based composites in the mid to late 20th century and continued into the 21st century. This transition occurred gradually over several decades and was driven by the need for lighter and more fuel-efficient aircraft, as well as improved performance and durability. These days, manufacturers increasingly rely on carbon fiber reinforced polymers (CFRPs) wherever possible. At the same time, the industry has begun to view heavy working components of the airplane with increased scrutiny, looking to develop and deploy physically lighter materials and alloys. The “holy grail” for such alloys would be materials that are at once lighter and offer greater temperature resistance, as both of these properties can contribute to improved fuel efficiency.

Advanced materials are essential in current engine designs. Today’s lean-burn engines carry temperature potentials of up to about 3,800°F. Therefore, these high-efficiency systems also burn extra-hot, often at temperatures surpassing the melting point of currently available superalloys, which is roughly 3,500°F. Superalloys are still a mainstay in the engine/turbine production industry. Nevertheless, their weight and limited thermal properties leave the engine production industry ripe for a transition to a new class of heat-resistant, lighter-weight materials. The classes of newer materials include heat-resistant superalloys and nonmetal composites, including ceramics.

The nascent commercial space industry, although still in its early days, is growing in market size. Over 80 countries now have satellites in space, and private companies such as SpaceX, OneWeb Satellites and Planet Labs Inc. are increasingly making headlines as commercial players in the marketplace. As of January 2023, a total of 542 satellites had been delivered to orbit by OneWeb Satellites. Market volumes for space industry specialty materials are still small and will likely remain so for the next five years. As a result, these are not considered in this report. However, the material overlap with the commercial airplane industry is significant, as many of the same materials used for space-related activities and equipment have also been adopted for airplanes. The advanced technologies used in the production process of various materials are discussed below in detail.

Advanced Steel Alloys

Advanced steel alloys, often called high-performance or advanced high-strength steel (AHSS), are materials engineered to possess exceptional mechanical properties, making them suitable for a wide range of applications in the aerospace sector. Advanced steel alloys are exceptionally versatile and resilient material with attributes subject to modification by adjusting the alloying element composition. They exhibit exceptional flexibility, and thus they can be stretched and bent into various shapes and sizes without undergoing fracture. This characteristic improves their crashworthiness, making advanced steel alloys valuable for aircraft components where impact resistance and safety are critical.

Advanced steel alloys differ from normal steel in that they are made by carefully controlling alloying components including silicon, vanadium and carbon and other elements like boron and chromium. These alloying components are specifically chosen to improve qualities like high strength-to-weight ratio, toughness and corrosion resistance. These improved versions exhibit greater formability, making them suitable for complex-shaped components and forming processes.

To fulfill the requirements of the aerospace and aircraft manufacturing sectors, the parts and components produced must be crafted from high-precision metals capable of withstanding challenging environmental conditions. High-quality steel alloys are particularly well-suited for aircraft manufacturing, as they can endure the extreme altitudes and temperature fluctuations that characterize aerospace and aviation operations. Alloyed stainless steel aerospace forgings find use across various applications within the aerospace industry, including aircraft frames, landing gear, and engine components. The strength and durability inherent in these steel forgings render them exceptional fitting for specific applications. Moreover, the steel's resistance to corrosion makes it highly suitable for deployment in the demanding aerospace environment.

Over the past two decades, the field of steelmaking technology has undergone significant transformation due to mounting demand, evolving specifications and the imperative to curtail energy and material consumption. One prevalent method is the blast-furnace-basic oxygen converter route, where sintered iron ores undergo reduction to yield raw iron in the blast furnace. Subsequently, the raw iron is converted into crude steel within the oxygen converter, generating energy. To manage temperature, extra scrap is introduced into this operation.

An alternative approach is the electric arc furnace route. In this process, a cold metallic charge, primarily composed of scrap, is melted through the energy generated by electric arcs formed between the tips of graphite electrodes and the conductive metallic charge. To introduce scrap, the three electrodes and the furnace roof are raised and pivoted away from the shell.

Trends in Steel Industry: Green Steel

Approximately 75% of steel production is conducted in coal-fired blast furnaces, releasing significant carbon dioxide into the environment. Substantial energy inputs are required to elevate the furnace temperatures beyond 1,000°C. Collectively, steel manufacturing contributes to roughly 8% of global emissions. As per the International Energy Agency (IEA), emissions from steel must be reduced by 50% by 2050 from 2022 and then continue to fall to meet the global climate goals. Molten Oxide Electrolysis (MOE) is one of the key developments to cater to the need to reduce emissions from steel production. This method depends on using electricity rather than carbon to eliminate oxygen. It passes an electrical current through a cell containing a blend of dissolved iron oxides and other substances. The electric current heats the cell to approximately 1,600°C (almost 3,000°F), causing everything within it to melt into a high-temperature oxide mixture.

According to Swiss Steel Group recent press release, beginning in 2023, ThyssenKrupp Aerospace, a supplier to the top aerospace and aviation businesses worldwide, will receive green forged and rolled bar and bright steel from Swiss Steel Group. This material is manufactured in a particularly environmentally benign manner, with in-process emissions 80–95% lower than the industry norm.

Advanced Aluminum Alloys

Advanced aluminum alloys are aluminum-based materials engineered to possess exceptional properties and characteristics. They are well-suited for many demanding applications where stress and fatigue resistance are critical. They are often used in aerospace structural components where strength and lightweight properties are essential. Aluminum constitutes the highest proportion (approximately 8.1%) of any metal in the earth’s crust but is rarely found in its pure form in nature. Typically, it is found in minerals such as cryolite and bauxite. There are various processes to extract aluminum from natural minerals. Advanced aluminum alloys continue to play a crucial role in the aerospace industry. They remain the most widely used lightweight alloys due to their favorable workability and cost-effectiveness.

Advanced aluminum alloys differ from normal aluminum alloys in composition, properties and intended applications. Advanced aluminum alloys are developed using precise control of alloying elements, including additional elements such as copper, zinc, magnesium and other rare-earth elements. They offer excellent protection against corrosion, higher tensile strength and yield strength compared to normal aluminum alloys. Moreover, the material undergoes complex alloying, heat treatment and processing steps to achieve the desired properties.

Technology plays a crucial role in reshaping the future of aluminum production, impacting everything from extraction and manufacturing processes to recycling and energy efficiency. Technological advancements fundamentally transform the aluminum industry, increasing productivity and sustainability during the design and application. Emerging technologies, including 3D printing, hot extrusion, hybrid extrusion, nanostructured aluminum, recycling methods, artificial intelligence, and robotics, are set to define the future landscape of aluminum extrusion.

Aluminum alloy plays a critical role in ensuring aircraft safety during flight. Aerospace and military applications demand significant weight reduction and predominantly rely on high-strength aluminum alloys known for their exceptional performance. In the aerospace sector, some of the primary aluminum alloys used are 7075, 2024, 2219 and 7050, among others.

Trends in Aluminum Industry

Some of the major key trends in the aluminum industry are:

- Advanced Extraction Methods: Technological advancements have facilitated the development of more efficient and environmentally friendly techniques for extracting aluminum. Improvements in smelting and electrolysis processes have saved energy and reduced greenhouse gas emissions. The Hall-Héroult smelting process is the foundation for all commercial aluminum production, wherein aluminum and oxygen within alumina are separated through electrolysis.

- Automation and Robotics: Automation and robotics are increasingly integrated into primary aluminum production and manufacturing products. This integration eliminates human errors and the associated safety risks, enhancing productivity, precision and safety. Robotic systems handle material handling, quality control and maintenance tasks.

- Recycling and Circular Economy: Technology is pivotal in advancing recycling capabilities within the aluminum sector. Advanced sorting and separation technologies enable efficient recycling of aluminum products, reducing the reliance on primary production from raw materials. Additionally, digital tracking systems and blockchain technology are explored to establish transparent supply chains, facilitating the tracking and verification of recycled aluminum.

- Energy Efficiency: Technology is aiding in enhancing energy efficiency in the aluminum industry. Advanced control systems, real-time monitoring and predictive maintenance technologies enable more precise energy management and process optimization. This results in reduced energy consumption and costs while minimizing environmental impact.

- Smart Manufacturing: Smart manufacturing, also known as Industry 4.0 or the Industrial Internet of Things (IoT), is making significant inroads into the aluminum industry. By integrating sensors, connectivity and data analytics, companies can establish interconnected systems that provide real-time insights into manufacturing processes, supply chains and equipment performance. This enables proactive decision-making, predictive maintenance and overall operational efficiency.

- Additive manufacturing (AM) has gained significance, enabling the production of alloys through this cutting-edge technology and offers specific advantages such as:

    - Topological optimization (TO) is applied for improved efficiency and weight reduction.
    - The optimization of maintenance, repair and overhaul (MRO) operations to reduce costs related to downtime. MRO operation includes coating fixing, inspection, refilling of gases and lubricants, replacing damaged parts, etc.
    - Reduction in the "buy-to-fly" ratio minimizes the waste material and contributes to lower manufacturing costs. The buy-to-fly ratio is the mass of raw material needed per unit mass of the finished component. The buy-to-fly ratio is 12-25 for aircraft components made of Al alloys and manufactured through conventional processes.

Titanium Alloys

Titanium alloys (Titanium 6Al-4V, Titanium 6Al-2Sn-4Zr-6Mo, Titanium 10V-2Fe-3Al and Titanium 3Al-2.5V) are a class of titanium that has been specifically engineered to meet the stringent requirements of the aerospace industry. These advanced alloys offer an excellent balance of strength, creep resistance and lightweight characteristics. They have lower levels of impurities, particularly oxygen and iron, making them suitable for aerospace and spacecraft engines that require high purity.

The aerospace industry is allocating substantial portions of budgets to developing manufacturing processes that enhance the cost-effectiveness of titanium component production. As production costs decrease, titanium will become increasingly attractive to the aerospace industry due to its material properties. Beyond their application in aircraft components and airframes, titanium alloys are also used to construct modern turbine engines. Numerous aircraft manufacturers have adopted titanium alloys in engine manufacturing due to titanium's low weight and high strength. Aircraft with engines made from titanium alloys exhibit superior flight performance compared to those constructed from other metal alloys.

Trends in Titanium Industry: Laser Wire Additive Manufacturing and Titanium Recycling

While current methods, such as casting or machining titanium alloys from billets, are considered the most efficient, emerging technologies like laser wire additive manufacturing have the potential to reduce production costs and accelerate timelines by enabling the large-scale printing of titanium alloys and reducing the time-consuming machining of titanium. Additive manufacturing faces several challenges when it comes to working with titanium, including the high cost of titanium powder; issues related to surface roughness, thermally induced residual stresses and distortions; the expense of inspection methods; and the variability in the manufacturing process, which can lead to variations in component properties. Several AM technologies are currently used to produce titanium alloys in the U.S.

As the aerospace sector continues to emphasize the increasing significance of scrap within the titanium supply chain, numerous companies are actively developing technologies to maximize the material's worth. In September 2023, IperionX Ltd. and Heroux-Devtek collaborated to underpin a 100% recycled supply chain using scrap titanium metal from the aerospace industry. In this collaboration, Heroux-Devtek will provide IperionX with scrap metal composed of Ti-6Al-4V alloy, which is generated during the production of landing gear, and IperionX will utilize its patented titanium processing methods to transform this titanium scrap into low-carbon titanium for future uses. The aerospace industry uses titanium alloys of Ti-5553 and Ti-10-2-3 grades. IperionX's technologies can repurpose these titanium alloys, eliminating the need for a remelting process and enabling the utilization of these alloys in various new high-performance applications.

Superalloys

There are three basic categories of superalloys: nickel-, iron- and cobalt-based superalloys. Superalloys are used in engine components such as high-pressure turbine blades, discs, combustion chambers, afterburners and thrust reversers. Extensive modifications were required in the conventional steel and alloy manufacturing procedures to produce these materials. In addition to introducing new processing techniques, stricter monitoring and control of process parameters became imperative. Nickel-based superalloys are typically cast to attain their final shape. While a few applications involve cold-forming shapes from ingots, they tend to result in inferior material properties compared to the casting process.

Trends in Superalloys Industry: Fusion-Based Additive Manufacturing and X-Ray Fluorescence (XRF) Technology

The utilization of fusion-based additive manufacturing has seen substantial growth in the production of nickel-based superalloys, offering extensive design flexibility across various length scales. Various phenomena, including interactions between feedstock, energy sources and the melt pool and processes like solidification and phase transformations, occur during additive manufacturing processes using nickel-based superalloys. These phenomena collectively govern the constructed components' eventual microstructure and mechanical characteristics.

X-ray fluorescence (XRF) technology is used for elemental analysis of specialty alloys, ensuring that the correct alloys are blended in the correct proportions and that the final material adheres to precise manufacturing specifications. Specifically designed handheld XRF analyzers are engineered to deliver top-notch analysis and verification capabilities required for a wide spectrum of aerospace alloys, including high-temperature, nickel, titanium, aluminum alloys and superalloys. These analyzers can determine the elemental composition of a sample in a matter of seconds.

Composite Materials: CFRPs

Carbon fiber reinforced polymer (CFRP) is a composite material in three distinct formats: bars, strips and sheets. CFRP materials are frequently used to enhance the strength and structural support of infrastructure elements such as bridges and large buildings. Remarkably, carbon fiber boasts a strength of five times that of steel and is twice as rigid. The manufacturing process of CFRP comprises several stages. Initially, carbon fibers are arranged into a fabric or mat. Subsequently, this fabric or mat is saturated with a polymer resin, commonly epoxy, to create a composite. This composite is subjected to high temperatures and pressures during curing, forming a solid material. Companies are investing in research and development activities to boost the deployment of this technology.

In February 2023, Toray Industries Inc. unveiled an integrated molding technique designed to rapidly produce carbon fiber-reinforced plastic components used in mobility applications. This innovation involves incorporating a lightweight, porous carbon fiber-reinforced foam (CFRF) core enveloped by a thermosetting prepreg skin, resulting in exceptional mechanical characteristics. These components can weigh as little as half of their steel counterparts. Toray will continue its research and development efforts to expedite the deployment of this technology, where weight reduction and speedy production are paramount.

Advanced Composites

Ceramic-matrix composites (CMCs) use ceramic fibers within a ceramic-matrix to create high-performance structures capable of withstanding elevated temperatures. Initially, CMC technology was pioneered for constructing rocket nozzles for missiles and space launch vehicles. Subsequently, it found applications in thermal protection systems (TPS) for reentry vehicles and manufacturing discs/rotors for aircraft brakes. Ceramic composites were developed to address and mitigate issues associated with commonly used ceramics like silicon carbide, alumina, silicon nitride, aluminum nitride and zirconia. These conventional ceramics were susceptible to easy fracturing, displaying scratches and cracks when subjected to mechanical and thermo-mechanical stresses. The primary manufacturing techniques used for CMCs encompass CVI, polymer infiltration, pyrolysis and hot press sintering methods. Among these, polymer infiltration and pyrolysis are the most prevalent. The primary objective is to have precise control over the thermal and mechanical properties of the resulting CMC. However, factors such as the distribution of the final phase formed, and the processing approach used in composite synthesis are crucial to consider.

Advanced Adhesives

Advanced adhesives for aerospace include several categories of aerospace tapes and adhesives. In aerospace, tapes and films of cyanoacrylate resins, structural acrylics, epoxies, polyurethane and anaerobic adhesives are frequently employed. These adhesives play a crucial role in aircraft and spacecraft construction, where they are used for bonding, sealing and joining various materials and components. Aerospace adhesives must meet strict performance standards, including high strength, durability and resistance to extreme environmental conditions.

Trends in Advanced Adhesives Industry: Sustainability

Industries are focusing on sustainability more than ever before. The aerospace adhesives sector is no exception. Companies providing adhesives to the aerospace industry are focusing on formulating eco-friendly properties and contributing to more sustainable aviation practices, thereby helping to reduce the environmental footprint of the airline travel industry. In September 2023, in alignment with Henkel's commitment to sustainability, the aerospace manufacturing facility located in Montornès achieved the distinction of being the first carbon-neutral production site within the adhesive technologies industry. This accomplishment has been realized through a combination of on-site renewable energy generation and the procurement of green energy.

Key Properties of Advanced Aerospace Materials

The aerospace sector has been at the forefront of introducing a diverse range of materials to facilitate the growth of cutting-edge aerospace innovations. These materials encompass metals, composites, ceramics, coatings and related processes. In aerospace applications, there is often a demand for outstanding performance, strength or heat resistance, even if achieving these qualities entails significant expenditure in production or traditional machining processes.

The material selection process is important within aerospace applications due to the challenges posed by high velocities, elevated temperatures, radiation exposure, material stress and other factors inherent to aerospace travel. Beyond safety considerations, lightweight and high-strength materials can also offer economic advantages, particularly fuel efficiency.

Table 1
Properties of Advanced Aerospace Materials

Materials	Properties
Advanced Steel Alloys	• High strength. • Toughness. • Yield strength. • Tensile strength. • Malleability. • Ductility. • Resistance to corrosion and heat.
Advanced Aluminum Alloys	• High fracture toughness. • High fatigue performance. • High formability. • High strength-to-weight ratio. • Good mechanical properties. • Superplasticity.
Titanium and Alloys	• Lightweight. • High strength. • Corrosion resistant. • Biocompatible. • Heat resistant. • Nonmagnetic. • Ductile. • Low thermal expansion. • Fatigue resistance.
Superalloys	• Temperature resistance. • High strength. • Strong corrosion resistance. • Good machinability. • Low thermal expansion. • Weldability. • Excellent wear resistance. • Good creep resistance.
Composite Materials: CFRPs	• High resistance to deformed. • Resistance to tension. • Low thermal conductivity. • Low thermal expansion. • Lightweight. • Corrosion-resistant. • High strength-to-weight ratio.
Advanced Composites: CMCs	• High mechanical strength, even at exceptionally high temperatures. • Stiffness. • Mechanical stability. • Thermal stability. • Dimensional stability. • Chemical resistance.

Materials	Properties
	• Corrosion resistance. • Fracture resistance. • Ultra-lightweight. • High durability.
Advanced Adhesives	• Low sag. • High modulus. • High strength.

Source: BCC Research

Market Regulations

Federal Aviation Regulations (FAR)

The Federal Aviation Administration (FAA) sets forth regulations that govern all aviation activities within the U.S. These regulations, known as the Federal Aviation Regulations (FARs), are encompassed within Title 14 of the Code of Federal Regulations (CFR). The major goals of the FARs are to establish and uphold secure aviation practices and initiatives. In addition to safeguarding the well-being of aviation personnel and the general public, these regulations also protect the U.S.'s national security. Given the diverse range of aviation activities, the FARs are categorized into sections under the CFR based on their specific aviation function, with certain sections comprising numerous provisions.

For instance, regulated aviation activities cover a broad spectrum, including temporary flight restrictions related to national events or presidential matters, aircraft design, pilot training, parachute operations, flight schools, maintenance training schools, repair stations, and even activities such as hot-air ballooning, to mention a few.

AMS (Aerospace Material Specifications) Standards

In the aerospace sector, components must adhere to the standards for the materials used in their construction. The Society of Automotive Engineers (SAE) has formulated aerospace material specifications to achieve this objective, often denoted as AMS. These AMS specifications constitute an extensive repository of guidelines that standardize aerospace industry practices, equipment and protocols. As process technologies evolve and materials science advancements occur, these aerospace material specifications are periodically revised to remain current. Aerospace material standards help global companies conduct uniform testing to assess each material's thermal, mechanical, optical, chemical and electrical characteristics. These standards promote consistency in the manufacturing processes for aerospace industry products, playing a vital role in guaranteeing the safety and performance of aerospace materials and components.

AMS-certified aluminum denotes aluminum verified to meet the criteria outlined in AMS standards. The use of AMS-certified aluminum, whether in aerospace-related applications or other fields, offers many advantages. These alloys exhibit exceptional characteristics capable of withstanding demanding conditions and extreme temperatures. Their compliance with the specified AMS requirements ensures the reliability of their mechanical properties and chemical composition.

Aerospace Adhesive Standards

Aerospace adhesive standards are related to applying adhesive and sealant materials within aerospace vehicles. They address the creation of specifications for sealant materials and recommend aerospace practices for sealing procedures and associated tasks. This is especially relevant in instances such as the sealing of integral fuel tanks. Society of Automotive Engineers (SAE International) coordinates multiple technical committees that shape these aerospace adhesive standards. These standards are related to various adhesive categories used in aerospace applications.

Table 2
SAE Adhesive Standards for Aerospace

Adhesives	Sub-Category	Standards
Adhesive Compounds	Compound, Silicone Rubber Remover Aircraft Turbine Engine Components Room Temperature Application	SAE AMS 1386A-2004 (SAE AMS1386A-2004)
	Adhesive Compound, Epoxy Room Temperature Curing	SAE AMS 3690D-2016
	Adhesive Compound, Epoxy Resin, High Temperature Application	SAE AMS 3692C-1995 (SAE AMS3692C-1995)
	Shims, Filled Resin Compound	SAE AMS 3726E-2011 (SAE AMS3726E-2011)
	Mixing Resins, Adhesives and Potting Compounds	SAE ARP 5256-1997
Epoxy Primer	Primer, Adhesive, Corrosion-Inhibiting, High Durability Epoxy	SAE AMS 3107/1A-1991 (SAE AMS3107/1A-1991)
	Primer, Adhesive, Corrosion-Inhibiting, High Durability Epoxy	SAE AMS 3107/2A-1991 (SAE AMS3107/2A-1991)
	Primer, Adhesive, Corrosion-Inhibiting, For High Durability Structural Adhesive Bonding	SAE AMS 3107A-1991 (SAE AMS3107A-1991)
	Primer, Adhesive, Electrodeposited	SAE AMS 3109-1991 (SAE AMS3109-1991)
Sealing Compound	Sealing Compound, Integral Fuel Tanks and General Purpose, Intermittent Use to 360-degree F (182 degrees C)	SAE AMS 3276G-2016
	Sealing and Coating Compound, Polyurethane (PUR) Fuel Resistant High Tensile Strength/ Elongation for Integral Fuel Tanks/Fuel Cavities /General Purpose	SAE AMS 3278B-2016
	Sealing Compound, Low Adhesion, for Removable Panels and Fuel Tank Inspection Plates	SAE AMS 3284C-2017
Adhesive Film	Adhesive Film, Epoxy Base, For High Durability Structural Adhesive Bonding	SAE AMS 3695-1983 (SAE AMS3695-1983)
	Adhesive Film, Epoxy Base, High Durability	SAE AMS 3695/1-1983 (SAE AMS3695/1-1983)
	Adhesive Film, Epoxy Base, High Durability	SAE AMS 3695/2-1983 (SAE AMS3695/2-1983)
	Adhesive Film, Epoxy Base, High Durability	SAE AMS 3695/3-1983

Adhesives	Sub-Category	Standards
	Adhesive Film, Epoxy Base, High Durability	SAE AMS 3695/4-1983
	Adhesive, Film Form, Metallic Structural Sandwich Construction	SAE AMS-A-25463-1999
Adhesive Tape	Tape, Adhesive, Pressure-Sensitive Thermal Radiation Resistant, Aluminum Foil/Glass Cloth	SAE AMS 3779/1B-2016 (SAE AMS3779/1B-2016)
	Tape, Adhesive, Pressure-Sensitive Thermal Radiation Resistant, Aluminum Coated Glass Cloth	SAE AMS 3779/2B-2016 (SAE AMS3779/2B-2016)
	Tape, Adhesive, Pressure-Sensitive Thermal Radiation Resistant	SAE AMS 3779B-2016 (SAE AMS3779B-2016)
	Tape, Aluminum Foil, Sound and Vibration Damping Pressure Sensitive Adhesive	SAE AMS 3807C-2016 (SAE AMS3807C-2016)
	Tape, Adhesive, Pressure-Sensitive Masking	SAE AMS 3808B-2015 (SAE AMS3808B-2015)
	Tape, Adhesive, Pressure-Sensitive, Double-Faced, Carpet Tie Down	SAE AMS 3809A-2015 (SAE AMS3809A-2015)
	Tapes, Pressure-Sensitive Adhesive, Masking, Non-Staining - for Aircraft Painting Applications	SAE AMS-T-21595-1998 (SAE AMS-T-21595-1998)
	Tapes, Pressure-Sensitive, Adhesive, Preservation and Sealing	SAE AMS-T-22085-1999 (SAE AMS-T-22085-1999)
Surface Preparation	Surface Preparation and Priming of Aluminum Alloy Parts for High Durability Structural Adhesive Bonding	SAE ARP 1524A-1990 (SAE ARP1524A-1990)
	Surface Preparation for Structural Adhesive Bonding, Aluminum Alloy and Low Alloy Steel Parts	SAE ARP 1842-1984 (SAE ARP1842-1984)
	Surface Preparation for Structural Adhesive Bonding, Titanium Alloy Parts	SAE ARP 1843A-1991 (SAE ARP1843A-1991)
Other Adhesive Standards	Remover, Decal Adhesive	SAE AMS 1320A-1991 (SAE AMS1320A-1991)
	Paste Adhesive for Core Restoration Part 1 ~ General Requirements.	SAE AMS 2950/1-2008 (SAE AMS2950/1-2008)
	Adhesive/Sealant, Fluorosilicone Aromatic Fuel Resistant, One-Part Room Temperature Vulcanizing	SAE AMS 3375C-2012 (SAE AMS3375C-2012)
	Protective Film, High Performance, Polymeric Pressure Sensitive Adhesive for Aircraft Exterior Applications	SAE AMS 3603A-2002 (SAE AMS3603A-2002)
	Adhesive, Electrically Conductive Silver-Filled Epoxy Resin	SAE AMS 3681F-2019
	Adhesive, Contact Polychloroprene (CR) Rubber, Resin Modified	SAE AMS 3704B-2019
	Epoxy Resin, Cycloaliphatic Liquid	SAE AMS 3705A-1993 (SAE AMS3705A-1993)
	Epoxy Cresol Novolac Resin Low Molecular Weight	SAE AMS 3728A-1994 (SAE AMS3728A-1994)
	Acceptance Criteria Adhesive-Bonded Metal-Faced Sandwich Structures	SAE AMS 3920A-1996 (SAE AMS3920A-1996)

Adhesives	Sub-Category	Standards
	Adhesive, Film Form, Metallic Structural Sandwich Construction	SAE AMS-A-25463-1999 (SAE AMS-A-25463-1999)
	Adhesive, Acrylic Base for Acrylic Plastic	SAE AMS-A-8576A-2016 (SAE AMS-A-8576A-2016)
	Physical-Chemical Characterization Techniques, Epoxy Adhesive and Prepreg Resin Systems	SAE ARP 1610A-1985 (SAE ARP1610A-1985)
	Structural Weld Bonding of Aluminum Structures	SAE ARP 1675-1990 (SAE ARP1675-1990)
	Adhesion Promoter for Polysulfide Sealing Compounds	SAE AMS 3100E-2021

Source: American National Standards Institute (ANSI)

Industry and Key Research Organizations

Globally there are several industry organizations that focus on supporting the emerging materials/aerospace industry. They include manufacturers and others involved in the production and deployment of the technologies and applications considered in this study. Industry organizations provide support to manufacturers, researchers, developers, standards developers and others. They are critical to the industry in that they support information sharing and the development of technical expertise; provide training; provide lobbying activities; write legal and industrial manufacturing guidelines and standards; and fulfill other functions. Some industry organizations also collect manufacturing and product development data, which they may share with their members. The following table summarizes the major global industry organizations and a selection of scientific organizations operating within the aerospace industry.

Table 3
Industry and Scientific Organizations Relevant to Advanced Aerospace Materials

Name	Region	Description
ASM International	Global	ASM International, formerly known as the American Society of Metals, is the world’s largest association of materials-centric engineers and scientists. It seeks to educate and connect the materials community to solve problems and to stimulate innovation around the world. The organization is the longest-established materials information society, and it connects its members through a global network of peers by providing access to trusted information about materials through a combination of reference content and data, educational coursework, international events, and research. ASM provides resources designed to help predict the behavior of materials and to help overcome design challenges, and it supports the transfer of knowledge to help achieve superior materials-related product performance. The organizations provides technical guides and publishes the journal Superalloys.

Name	Region	Description
Cobalt Institute	Global	The Cobalt Institute is a trade association composed of producers, users, recyclers and traders of cobalt. The organization promotes the sustainable and responsible production and use of cobalt in all its forms. The organization seeks to act as a knowledge center for governments, agencies, industry, the media and the public on all matters, including health, safety and environmental issues, concerning cobalt and cobalt-containing substances.
International Chromium Development Association (ICDA)	Global	The ICDA functions as the international association of the chromium industry. Based in Paris, France, the association was created in 1984 as a nonprofit association. The organization's members include producers of chromite ore and many users of chromite, including producers of ferrochrome, stainless steel, chromium metal, chromium chemicals, refractory bricks and foundry sands, trading companies, end users and service providers. The ICDA's purpose and objective are to promote free competition and to provide benefit to consumers of chromium.
International Nickel Study Group (INSG)	Global	The INSG operates as an autonomous, intergovernmental organization located in Lisbon, Portugal. The organization was established in 1990, and its members consist of countries that produce, use and trade nickel. The INSG is not involved in market stabilization activities or market intervention of any kind. The primary objectives of the organization are to collect and publish statistics on nickel markets, including production, consumption, trade, stocks, prices and recycling; publish data on industry facilities and environmental regulations; provide a forum for discussions on nickel issues; and perform economic analysis of nickel markets and related topics.
Metal Powder Industries Federation (MPIF)	Global	The MPIF comprises six individual trade associations representing various aspects of powder metallurgy, metal powders and particulate materials. The MPIF focuses on promoting and helping to deploy powder metallurgy. It provides its member companies with services that help to advance powder metallurgy while seeking to promote technological benefits to prospective end users.
European Foundry Association	Europe	The European Foundry Association (CAEF) was established in 1953 and serves as an umbrella organization for the European foundry industry. The organization supports its members by managing industry interests in light of economic, legal, technical, and social issues and concerns. The organization's membership includes each of the national foundry organizations from a total of 22 European countries. CAEF is headquartered in Dusseldorf, Germany, and distributes various types of data and information including ferrous and non-ferrous foundry production data, along with employment data for those foundries on an annual basis. To its members, the organization provides additional information regarding industry-specific verticals and processes, including automotive castings, wind turbine casting, continuous casting, continuous casting, steel casings industry and general engineering, among others.
European Foundry Equipment Suppliers Association	Europe	The European Foundry Equipment Suppliers Association (CEMAFON) was founded in 1972. The organization functions as a lobbying voice for European manufacturers of foundry machinery,

Name	Region	Description
		as well as plants and products for the foundry industry. The organization incorporates various relevant national associations and, by extension, all major manufacturers of foundry machinery and plants, furnaces and products for the foundry industry in Europe. Member countries include Germany, Italy, Denmark, Spain, and Switzerland.
European Investment Casters' Federation	Europe	The European Investment Casters' Federation is the Investment Casting Association of reference in Europe representing the interests of the European investment casting industry, to improve its working methods and practices and to widen the markets for its products.
Plastics Europe	Europe	Plastics Europe is a leading pan-European association and represents plastics manufacturers active in the European plastics industry. The plastics industry in Europe is a vibrant sector that helps improve the quality of life by enabling innovation, facilitating resource efficiency and enhancing climate protection. In addition to the plastics manufacturers, represented by Plastics Europe, the plastics industry includes converters, represented by European Plastics Converters (EuPC), recyclers, represented by European Plastics Recyclers (PRE), and machine manufacturers, represented by European Plastics and Rubber Machinery (EUROMAP). Plastics Europe is a leading European trade association, with centers in Brussels, Frankfurt, London, Madrid, Milan and Paris. The organization networks with European and national plastics associations and have more than 100 member companies, who are responsible for producing more than 90% of all polymers across the 28 member states of the European Union, plus Norway, Switzerland and Turkey. On a global level, Plastics Europe actively supports the World Plastics Council (WPC) and the Global Plastics Alliance (GPA).
General Association of German Plastics Processing Industry (GKV)	Germany	The GKV is the umbrella organization of the German plastics processing industry. It represents the shared interests of the member companies of its carrier associations (plastics packaging, plastics end-consumer, performance plastics and reinforced plastics industries).
German Engineering Association (VDMA)	Germany	The VDMA represents 3,600 German and European mechanical and plant engineering companies. Among other services, members receive support in the form of global market information in the mechanical engineering and client industry sectors
Nickel Institute	Global	The Nickel Institute is a global association of the world's primary nickel producers, which collectively account for roughly 85% of worldwide annual nickel production outside of China. The Nickel Institute grows and supports markets for new and existing nickel applications, including stainless steel. It also promotes sound science, risk management and socioeconomic benefits as the basis for public policy and regulation. Through its science division, Nickel Producers Environmental Research Association (NiPERA), the institute also conducts scientific research relevant to human health and the environment and nickel as a material. The organization maintains offices in Asia-Pacific, Europe and North America.

Name	Region	Description
Society of Plastics Engineers	Global	The organization operates and has members in 84 countries, with more than 22,500 members globally. The organization seeks to unite plastics industry professionals worldwide helping them succeed and strengthening their skills through networking, events, training and knowledge sharing. The organization supports the industry across its full value chain, from scientists to engineers, technical personnel and senior executives, irrespective of education level, gender, culture or age. The organization focuses strongly on helping its members to meet personal and professional goals. The organization seeks to be responsible also for making the plastics industry better by providing a forum that generates a strong awareness of issues facing the plastics community, to help identify solutions that will benefit everyone.
The Minerals, Metals, and Materials Society (TMS)	Global	The TMS is headquartered in the U.S. but maintains an international focus in both its membership and its activities. TMS has a relatively broad scope, encompassing a wide range of materials and engineering. Aspects of the materials industry represented include materials processing, and primary metals production, basic research and advanced materials applications.
E-Foundry	India	E-Foundry seeks to serve educators and industry professionals with information about metal casting and manufacturing. The organization seeks to empower teachers in engineering and polytechnic institutes to enhance the interest and employability of students in metal casting, which it views as a key facet of the country's manufacturing sector. The organization is directly supported by the National Knowledge Network mission of Government of India, New Delhi, and provides educational content that is largely derived from courses and R&D projects at the Indian Institute of Technology in Bombay. E-Foundry offers an online simulation laboratory with 3D modeling capabilities and an alloy database, information on casting processes, a library of information on alloys and their casting, and model simulation cases.
National Metallurgical Laboratory	India	The National Metallurgical Laboratory was founded in 1946, and the laboratory was formally inaugurated in 1950. The lab was part of what was at that time termed India's Great Plan, for providing India with a network of research institutes capable of moving the country forward in science and technology. Today, the laboratory remains nationally run and oversees a range of R&D. Its divisions include applied chemistry and corrosion, business development and monitoring, engineering, materials science and technology, metal extraction and forming, and mineral processing. The organization also maintains four centers for analytical chemistry, information management and dissemination, calibration, and nondestructive evaluation.
Canadian Institute of Mining, Metallurgy and Petroleum (CIM)	North America	CIM was founded in 1898 and is the leading nonprofit technical society of professionals in the Canadian minerals, metals, materials and energy industries. The organization has three goals: to create, curate and deliver cutting-edge knowledge; to foster a connected and engaged CIM community; and to expand awareness of the contribution mining makes to society.

Name	Region	Description
Forging Industry Association (FIA)	North America	The FIA is focused on metals forging. It provides support and services to its members in activities such as: industry benchmarking (orders and shipments, profits, safety and compensation); global networking, through meetings, an annual Forge Fair and technical conferences; training and education, including online Forging University, manufacturing workshops and business seminars. The FIA also provides public policy advocacy, including a political action committee (PAC). It also drives demand for North American forgings through electronic customer RFQs and by educating customers of the value of designing with forgings. It also is engaged in the development and transfer of technologies, including leveraging industry and government resources for R&D.
North American Die Casting Association (NADCA)	North America	The organization seeks to increase and promote industry awareness, as well as domestic growth in the global marketplace, and member exposure. Based in Arlington Heights, Illinois, the organization includes a combination of individual and corporate members located across the U.S., Canada and Mexico. The NADCA provides an array of support mechanisms to its members and also to the die casting industry in general. The organization presents its members with monthly magazines and e-newsletters designed to keep them up to date on industry events and technical updates. The organization also provides die casting design assistance, discounts on publications and services, access to sales leads and enhanced exposure to OEMs. Other facets of NADCA's program include outreach through meetings and expositions, education, design assistance, government affairs and advocacy, chapter relations, and research and industry related updates for members and the public at large.
Foundry Equipment and Supplies Association (FESA)	U.K.	FESA was initiated almost 100 years ago to promote quality in foundry equipment, technology, knowledge and materials. FESA works with the U.K.'s foundries to ensure that they remain at the forefront of their technology, and practice and implementation. FESA members now provide this service to the global cast metals industry. FESA hosts several annual gatherings that include the World Foundry Organization Technical Forum, the World Foundry Congress, the International Foundry Forum and Ankiros.
Institute of Materials, Minerals and Mining (IOM3)	U.K.	IOM3 is an engineering-based industry organization based in the U.K. Its activities encompass the entire materials cycle, from exploration and extraction, through characterization, processing, forming, finishing and application, to product recycling and land reuse. The organization seeks to promote and develop all aspects of materials science and engineering, geology, mining and associated technologies, mineral and petroleum engineering and extraction metallurgy.
American Chemical Society (ACS)	U.S.	A self-governed individual membership organization that consists of more than 159,000 members at all degree levels and in all fields of chemistry. The organization provides a broad range of opportunities for peer interaction and career development, regardless of professional or scientific interests. The programs and

Name	Region	Description
		activities facilitated by ACS today are the products of a tradition of excellence in meeting member needs that dates from the Society's founding in 1876.
American Chemistry Council	U.S.	The American Chemistry Council (ACC) represents a diverse set of companies engaged in the primary business of chemistry. The organization seeks to solve major challenges relevant to the industry in the U.S. and globally. The organization's stated mission is to deliver value to its members through advocacy, using best-in-class member engagement, political advocacy, communications and scientific research. The organization is committed to fostering progress in our economy, environment and society. The organization supports various chemistry-oriented industries, including plastics as well as chemical production and various others.
American Foundry Society and Institute (AFS)	U.S.	AFS is a nonprofit association that serves members of the metal casting supply chain worldwide. AFS provides members with advocacy efforts in Washington, D.C., along with technical education. AFS supports the transfer of research and technology from researchers to the metallurgy and metal casting industry, suppliers, and buyers of castings. Examples include vacuum-assisted casting, counter gravity for investment casting, V-processes, and vacuum melting. AFS members function within three markets: metal casting and production of metal cast parts; metal casting suppliers; and casting buyers or OEMs. The AFS Division Council works to develop and transfer research and technology to the metal casting industry.
American Institute of Aeronautics and Astronautics (AIAA)	U.S.	The AIAA was founded in 1963 from the merger of two earlier societies: the American Rocket Society (ARS), founded in 1930 as the American Interplanetary Society (AIS), and the Institute of the Aerospace Sciences (IAS), founded in 1932 as the Institute of the Aeronautical Sciences. It is the largest technical society dedicated to the global aerospace profession. AIAA's stated mission is to advance the future of aerospace for the benefit of humanity. AIAA provides outreach to its members through technical publications, journals and reports; career enhancement and development activities; public policy support that encompasses state and federal advocacy and lobbying, development of policy papers, testimony and speeches and identification of key issues; and conferences, courses, workshops and forums.
American Mold Builders Association	U.S.	Established in 1973, the American Mold Builders Association (AMBA) is the largest grassroots organization in the U.S. dedicated solely to the mold manufacturing industry. As a national nonprofit trade association serving over 200 member companies and over 50 partner companies (supplier members), AMBA provides its members with access to the most powerful networking in the industry. AMBA is driven by a Board of Director's made up of owners and presidents of leading mold manufacturing companies. Having over 1,000 industry professionals involved in the organization provides a variety of channels to expedite solutions and build momentum for continued growth and development in areas that will positively impact the mold manufacturing industry.

Name	Region	Description
American Society of Mechanical Engineers (ASME)	U.S.	Founded in 1880, ASME is a nonprofit membership organization that supports collaboration, knowledge sharing, career enrichment and skills development across all engineering disciplines. ASME maintains standards for engineering certifications. Publications include journals that focus on advanced materials and alloys/superalloys, such as the Journal of Engineering Materials and Technology.
Investment Casting Institute	U.S.	The Investment Casting Institute is based in the U.S. and primarily serves the casting industry for that country, although it increasingly includes international industry participants from Europe, Asia-Pacific and Australia. The organization produces several types of publications, including the Investment Casting Handbook, INCAST - the official magazine of the Investment Casting Institute, as well as various CDs, booklets, books, case studies and other media. The organization maintains several types of annual events, which include industry certification courses, an annual technical conference and exposition, and its annual World Conference on Investment Casting and Equipment Exposition.
Plastic Pioneers Association	U.S.	The Plastics Pioneers Association is an organization of individuals that supports scholarships, educational programs, a history center and more to engage the next generation of people in the world of plastics. The organization gives back by supplying educational grants and scholarships that help students pursuing careers in the various fields of plastics and materials science and by providing monetary donations. Specifically, the organization helps to maintain the National Plastics Center at Syracuse University. The organization contributes to educational support programs such as the SPR foundation's Plastivan, which caters to school-age children. This program is designed to excite students about opportunities in science and engineering within the plastics industry.
Society for Mining, Metallurgy and Exploration (SME)	U.S.	SME has over 15,000 members, in more than 100 countries, representing all categories of professionals who serve the minerals industry, including engineers, geologists, metallurgists, educators, students and researchers. The organization also seeks to advance the worldwide mining and underground construction community through information exchange and professional development. SME is based in Englewood, Colorado.
Aluminum Association	U.S.	The Aluminum Association serves as the aluminum industry's lobbying voice at the federal level in the U.S. The association is committed to advancing aluminum as a sustainable metal of choice. It focuses on areas outside of superalloys, which comprise a small portion of the overall aluminum market. The association provides timely industry statistics and information on emerging issues; create, maintain and advocate for standards and technical documents that encourage the use of aluminum; advance regulatory and legislative policy in state, federal and international arenas; and convene forums on emerging issues.

Source: BCC Research

Pricing Analysis

Emerging aerospace materials must meet demanding performance requirements, such as corrosion resistance, high strength-to-weight ratio and the ability to withstand extreme pressures and temperatures. The pricing of advanced aerospace materials is complex and subject to the influence of various factors, such as the type of material, its intended application and its properties. For instance, the cost of aerospace-grade aluminum alloys such as 7075, 6061, 2024 can range from around $2,500 to $7,000 per metric ton. However, this cost may vary significantly based on factors like alloy condition (e.g., annealed, heat-treated), alloy size (e.g., thickness or diameter), and the supplier's pricing structure.

The cost of aerospace-grade titanium alloys can vary significantly based on the specific alloy type, form (sheet, plate, bar, etc.), quantity, supplier and market conditions. Typically, the cost of common titanium alloys such as Ti-6Al-4V, Ti-6Al-4V ELI, Ti-6Al-2Sn-4Zr-6Mo and Ti-3Al-2.5V can range from $13,000 to $26,000 per metric ton. Similarly, the cost of aerospace-grade CFRP prepreg can range from approximately $15,000 to $30,000 per metric ton. These materials are gaining a high acceptance rate among aerospace component manufacturers. Therefore, it is anticipated that the prices of these materials will decline in coming years.

Superalloys are high-performance materials known for their exceptional heat, strength and corrosion resistance, making them suitable for the aerospace industry, especially in engine components. They are generally distinguished based on material type such as nickel-based, cobalt-based and iron-based. Their cost can range from $10,000 per metric ton for iron to $50,000 per metric ton for cobalt and nickel.

Silicon carbide fiber-reinforced silicon carbide matrix, alumina fibers in an alumina matrix and carbon fiber-reinforced silicon carbide matrix are some of the commonly used aerospace grade ceramic matrix composites (CMC's). Currently, their costs could range from $25,000 to $70,000 per metric ton in the commercial market Aerospace-grade adhesives are subject to strict quality control and testing requirements, which can influence pricing. Their cost can vary based on the specific adhesive type, the performance specifications of the application, the form (premixed, film, liquid, etc.), and market conditions. Common aerospace grade adhesives include epoxy, cyanoacrylate, polyurethane, methacrylate and their costs ranges from $4,000 to $16,000 per metric ton.

Key factors that support the pricing structure and other cost components of the advanced aerospace materials are:

- Performance: Materials with superior properties, such as high strength, low weight and good corrosion resistance, are generally more expensive than those with less desirable properties. For instance, titanium alloys are more expensive than aluminum alloys because they are lighter and stronger.

- Material availability: Materials that are scarce or difficult to produce are typically more expensive than those that are more readily available. For instance, specialty alloys developed for specific aerospace applications may be more expensive than common materials.

- Application of material: Materials used in critical aircraft components, such as engines and landing gear, are typically more expensive than those used in less critical components. This is because the failure of a critical component could have catastrophic consequences.

Along with these key factors, the pricing of aerospace materials is also influenced by forces such as the cost of raw materials and supply and demand. When demand for a particular material is high, prices tend to rise. Conversely, when demand is low, prices tend to fall. The cost of raw materials also plays a role in pricing. For instance, if the price of aluminum increases, aluminum alloys will also increase.

The high cost of emerging materials used in aerospace is a major hurdle for aircraft manufacturing companies. Many emerging materials are still in the early stages of development, and their production costs are high. This makes them less competitive with traditional materials, such as aluminum and titanium. The selection of materials for aerospace components is a key factor in aerospace component design. This selection impacts various aspects, such as aircraft performance, from initial design stages to ultimate disposal. These effects include structural efficiency, flight performance, payload capacity, energy consumption, safety, reliability, lifecycle costs, recyclability and disposability.

Aerospace structural materials are bound by stringent criteria, necessitating specific mechanical, physical and chemical properties. These criteria encompass attributes such as superior strength, stiffness, fatigue resistance, damage tolerance, low density, high thermal stability, robust corrosion and oxide resistance, and practical considerations such as cost-effectiveness, ease of servicing and manufacturability. Research findings have highlighted that the most effective way to boost structural efficiency is by reducing the material density, i.e., using lightweight materials.

Chapter 4

Market Dynamics

Chapter 4: Market Dynamics

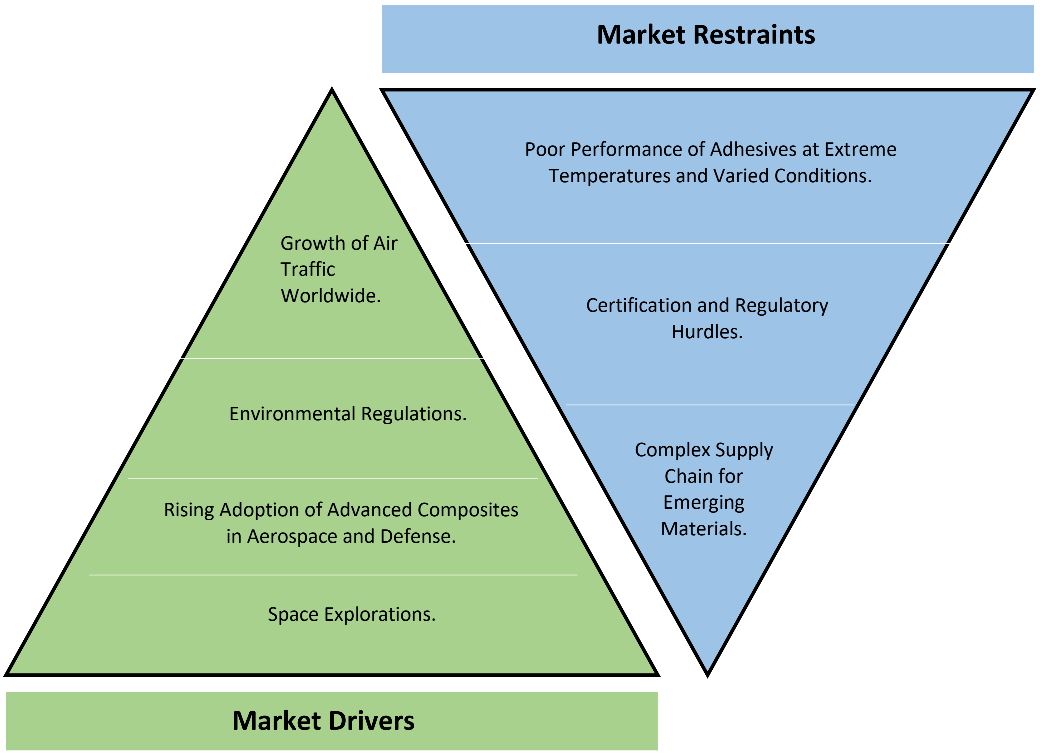
Market Dynamics

The aerospace industry is constantly evolving, and emerging materials are crucial in shaping its market dynamics. Aerospace technology breakthroughs frequently go hand in hand with emerging materials. The need for improved materials may be influenced by, for instance, the creation of new propulsion or navigational technologies. Continued advancements in aerospace industry heavily rely on research and development efforts as they lead to breakthroughs in advanced materials such as aluminum alloys, composites, titanium alloys, superalloys, adhesives and other areas. As researchers uncover novel applications and properties of advanced composite materials, new opportunities for innovation and commercialization emerge.

The availability of funding, both from public and private sources, plays a significant role in driving advanced aerospace materials research and commercialization. Funding supports the exploration of new applications, the refinement of manufacturing techniques and the commercialization of innovative products. Due to the fierce competition in the aerospace sector, businesses are always seeking ways to gain an advantage.

In the production of aerospace products, material costs play a big role. Although advanced materials can be pricey, they might result in long-term cost benefits because of enhanced performance, increased fuel efficiency and decreased maintenance. Moreover, the materials used in the aircraft sector are subject to strict safety and performance regulations. The dynamics of the market are significantly influenced by compliance with these restrictions.

Figure 1
Market Dynamics: Advanced Aerospace Materials



Source: BCC Research

Growth Drivers

Growth of Air Traffic Worldwide

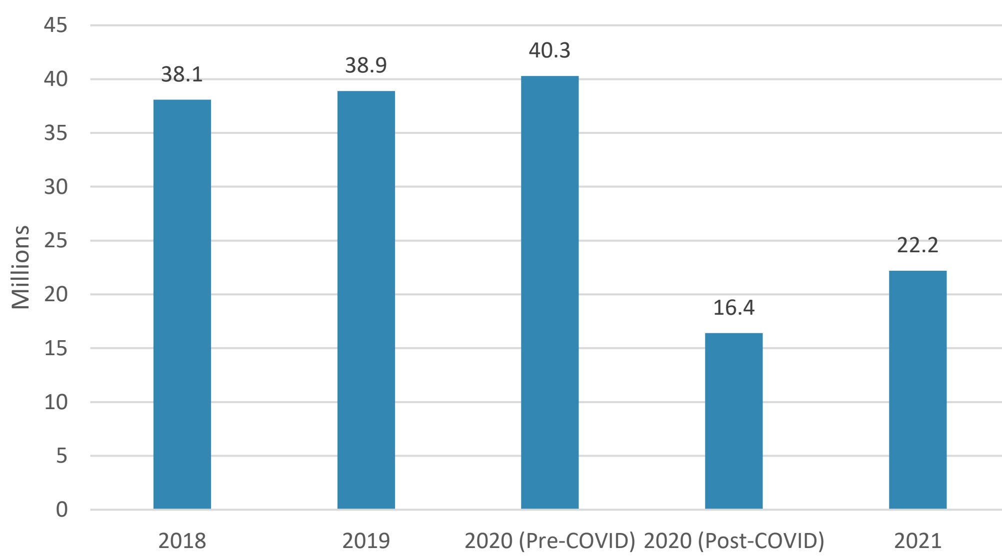
The continual rise in global air travel significantly boosts the demand for advanced materials within the aerospace sector. This growth is due to the constant demand for lighter, stronger and more durable materials from aircraft manufacturers. Advanced materials can help reduce aircraft weight, leading to significant fuel savings and reducing aircraft emissions by making aircraft more fuel-efficient and enabling them to use alternative fuels. According to the International Air Transport Association (IATA), the number of domestic and global airline flights worldwide was 22.2 million in 2021. COVID-19 hugely impacted the annual growth of airline flights; after a consistent upward trend until 2020, there was a steep decline of 46.7% in February 2021 due to the pandemic. As per IATA World Air Transport Statistics (WATS) publication, in 2020, the rate for international passenger demand (Revenue Passenger Kilometers)dropped by 75.6% and domestic air passenger demand (Revenue Passenger Kilometers)by 48.8% compared to 2019.

The decline in air passengers transported in 2020 was the largest recorded since global Revenue Passenger Kilometers started being tracked around 1950 However, the airline industry started to gain its pace back post-impact and is estimated to regain momentum in upcoming years. In 2022, global air travel was at 68.5% of pre-pandemic (2019) levels, according to the International Air Transport Association (IATA). Compared to 2021, international traffic increased by 152.7% in 2022 and surpassed

2019 levels by 62.2%. While domestic traffic in 2022 increased by only 10.9% over the previous year, overall domestic traffic performance in 2022 was at 79.6% of pre-pandemic levels. The year 2024 is expected to be a milestone for global passenger traffic recovery as it reaches 9.4 billion passengers, surpassing the year 2019 mark.

IATA reported a significant increase in travel demand for March 2023. According to IATA, international traffic increased 68.9% compared to March 2022, with significant growth seen across the board (once again, driven by carriers in the Asia-Pacific region). International RPKs (Revenue Passenger Kilometers) reached 81.6% of March 2019 levels, while the load factor of 81.3% was 10.1 percentage points higher than in March 2019. This was driven by a threefold increase in demand for Asia-Pacific carriers as China's reopening gained traction.

Figure 2
Number of Flights, 2018-2021
(Millions)



Source: International Air Transport Association 2021

Table 4
International Air Transport Association: Global Outlook for Air Transport, 2023

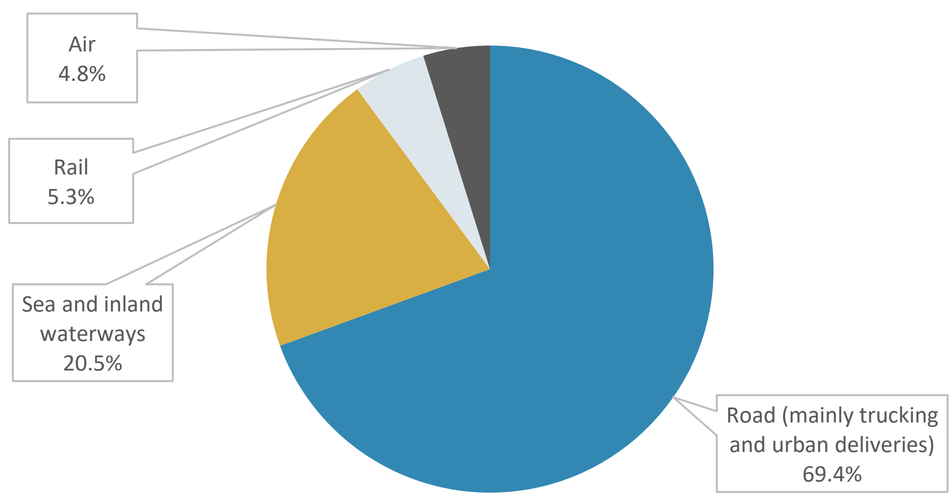
Passenger Traffic (RPK) % Change vs. Previous Year				
Global commercial airlines	**2020**	**2021**	**2022 E**	**2023 F**
Global	-65.8%	21.8%	64.2%	28.3%

Source: International Air Transport Association

Stringent Environmental Regulations

Flights are energy-intensive and depend on fossil fuels. Stringent regulations related to emissions and environmental impacts are driving the aerospace industry to adopt more ecofriendly materials that result in lower greenhouse gas emissions. This is because aircraft emissions are a major contributor to climate change; air freight transport contributes approximately 5% of total CO_2 emissions emitted by type of freight transport. But this mere 5% has much more impact on the environment than other contributors because aircraft emissions are released high in the atmosphere and thus have a potent climate impact, triggering chemical reactions and atmospheric effects that heat the planet.

Figure 3
Distribution Share of CO_2 Emissions, by Freight Transport Type, 2021
(%)



Source: Massachusetts Institute of Technology Climate Portal

Mitigating emissions from aviation poses a significant challenge, even though the industry is making active efforts to minimize fuel consumption. At the same time, new aircraft and innovative technologies offer potential solutions in aircraft manufacturing. Manufacturers are focusing more on enhancing operational practices, such as optimizing flight paths for increased efficiency and having the capacity to manage fuel consumption with applied limitations. Emissions from aviation have been growing faster than any other mode of transport. Moreover, aircraft design plays a critical role in emissions. Older aircraft models are less fuel-efficient and emit more pollutants. The industry's transition to more efficient aircraft, like the Boeing 787 and Airbus A350, has helped. However, many older, less efficient planes are still in operation. if unmitigated, aviation emissions could more than double by 2050 compared to 2019 levels.

With respect to fuel choices or manufacturing specifications, regulating emissions control is necessary for the aviation industry. Hence, governments worldwide are taking steps to mitigate emissions and manage the future impact of them. On November 15, 2021, EPA filed a motion to govern in the litigation on a rule that put in place commercial aircraft greenhouse gas (GHG) emission standards, which EPA promulgated in early 2021. That rule implemented the historic international agreement the Obama Administration negotiated in 2016 through the International Civil Aviation Organization (ICAO) to set the first-ever GHG emission standards for airplanes. In October 2022, member states of the International Civil Aviation Organization (ICAO) agreed to a long-term aspirational goal (LTAG) of net-zero carbon dioxide (CO_2) emissions from aviation by 2050.

Material Development and Commercial Availability of Composite Material

Composite materials, such as carbon fiber-reinforced composites, are increasingly popular in the aerospace industry due to their lightweight and high-strength properties, with large manufacturers attracted by the potential for significant reductions in fuel usage and carbon dioxide emissions. Composite materials offer advantages over traditional aluminum due to reduced weight, lower corrosion susceptibility and diminished fatigue failure risk. These characteristics enhance fuel efficiency and increase cargo capacity, reducing operational expenses. Despite having higher initial costs than metals, composites provide substantial long-term cost savings. While composites demand less maintenance than conventional materials, their repair costs can be relatively higher. An inherent drawback of composites is their non-biodegradability; however, they offer environmental benefits owing to their durability and fuel-efficiency improvements.

Product innovation in aircraft materials and manufacturing technologies have enabled growth in fuel-efficient materials such as composites. Various composites such as polymer-based, ceramic-based, Ti-based alloys, and Mg-based and Al-based composites have been developed for the aerospace industry. The accelerated growth in the aviation industry backs up these innovations. Some of the developments that support the wide adoption of composite materials in aircraft are:

The Boeing 787 uses composite materials in its airframe and primary structure more than any previous Boeing commercial airplane. The result is an airframe that is comprised of nearly half carbon fiber-reinforced plastic and other composites. This approach offers an average weight savings of 20% compared to conventional aluminum designs. 80% of the Boeing 787 Dreamliner is made of FRP composites. This results in lighter planes and consequently lowers energy consumption and carbon emissions.

Airbus is actively participating in using composite materials; as per the sources, the company is adding composites to its range of aircraft. Today, the A350 XWB uses composites on more than 50% of its structure. In addition, some 70% of the materials used to make every Airbus A220 are advanced materials, with 46% being composite materials and 24%, aluminum-lithium.

Rising Adoption of Advanced Composites in Aerospace and Defense

The aerospace industry is witnessing moderate growth with increasing air travel demand, reduced airfares, increased disposable income and enormous backlogs for new aircraft manufacturing. Continuous technological advancements and deployment of high-performance materials enhance aircraft operational efficiency, lower noise and offer increased payload capacity. The demand for high-performance composites to replace traditional materials is growing. These materials can reduce the weight of parts while retaining high performance. The Asia-Pacific, mainly led by China, Japan, South Korea and India, will have the highest new airplane demand. Regional growth is primarily attributed to escalating economic growth. Airport authorities and governments, mainly in ASEAN countries, are willing to extend aviation infrastructure to capitalize on trade and tourism.

There is a constant increase in global defense expenditure, year on year. This can be attributed to the arms race between China, India, the U.S. and Russia. The rise in Indian defense spending is attributed to replacing old Soviet aircraft and the planned development of aircraft fleets. According to data released by Stockholm International Peace Research Institute (SIPRI), global military expenditures reached $2.2 trillion. Roughly 60% of global military spending came from five countries: the U.S., China, Saudi Arabia, India and France. As global defense expenditure increases, demand for new-generation combat aircraft, rockets and helicopters increases, eventually leading to higher consumption of aerospace materials.

According to *Aviation Week*, from 2024 to 2033 period, 22,120 new aircraft are going to be delivered. Over the same period of time, 11,600 aircraft are going to be retired (although some of these will go into passenger-to-freighter conversion and therefore still be flown). Overall, the global fleet will grow by 12,500 units. In 2022, the global aircraft maintenance, repair, and operations (MRO) market stood at $80 billion; 40% of MRO came from field maintenance, followed by 32% from component and depot maintenance. Airbus estimates that by 2036, the global maintenance, repair and operations sector will be worth $120 billion annually. This growth signifies an increasing number of aircraft in operation. Therefore, aerospace companies can benefit from increased sales of spare parts to MRO providers, both domestically and internationally.

Given the current fleet age, more than 3% of the in-service fleet will be retired yearly. This will positively impact demand in the advanced aerospace materials market. *Aviation Week* reports that North America, Europe and the Asia-Pacific will primarily drive MRO demand. There is a constant need for new-generation combat aircraft. This is generally associated with the retirement of older aircraft and the need for new, superior aircraft.

Various advanced materials after getting testing certifications are used in the military. In the defense sector, CFRP materials can create stealthy and radar-absorbing structures, which are critical for reducing an aircraft's detectability by enemy radar systems. The U.S. spends more than any other country on its military, and its defense budget represents 40% of global military expenditures. While the U.S. had by far the most significant military budget in 2022, at $877 billion, China's was also quite large, at $224.8 billion. The other three nations had more modest outlays, ranging from Saudi Arabia's $53.8 billion to India's $72.6 billion. Continuous increases in defense will drive the market for advanced aerospace materials.

Space Explorations

There is a growing need for cutting-edge materials suited for spacecraft and launch systems due to the expansion of commercial space exploration. The aircraft materials market is becoming more innovative because of this trend. The American government has historically funded space exploration missions through NASA. To create crewed spacecraft for low earth orbit (LEO) missions, NASA's Commercial Crew Program has recently participated in collaborations with private aerospace firms. This program has increased commercial space access and stimulated the space sector. In addition, private businesses like SpaceX, Blue Origin and Virgin Galactic have invested significant money in space exploration, spurring innovation and opening new prospects.

With the advent of space tourism, companies like Virgin Galactic and Blue Origin are actively pursuing space tourism ventures, opening new commercial opportunities and expanding the consumer market for space exploration. Reusable rockets and advancements in propulsion systems have reduced the cost of reaching orbit. Moreover, establishing new spaceports, such as the Spaceport America in New Mexico and the Mid-Atlantic Regional Spaceport in Virginia, has facilitated more launch activity. These factors will play a key role in driving demand for advanced aerospace materials in coming years.

By 2024, NASA's Artemis program plans to send astronauts back to the Moon, focusing on long-term lunar exploration. With a strong emphasis on commercial and international partnerships, this program has sparked innovation in spacecraft and lunar technologies. In addition, large-scale satellite constellations are being constructed by businesses like SpaceX and OneWeb to offer global broadband internet connectivity. The creation and use of these constellations has increased demand for satellite production and launch services, thereby promoting advanced materials market growth.

Rising Demand for Aircrafts in Asia-Pacific and the Middle East
Asia-Pacific has attained unparalleled long-term growth in the commercial flying market. This has generated a significant financial impact. The aviation industry catalyzes the region's global positioning and helps foster greater global connectivity. Greater connectivity helps the growth of aviation-dependent businesses like tourism, local consumer goods and many other small-scale industries. In addition, the e-commerce boom in Asia-Pacific has led to a surge in air cargo demand to transport goods quickly and efficiently. Apart from commercial aviation, there has been a growth in air force spending in Asia-Pacific. This has increased aircraft manufacturing in the region, especially in India, Australia, China and Japan. This high growth is likely to continue due to the large number of airplanes scheduled to be delivered to the region. The International Air Transport Association (IATA) estimates that the monetary input of the aviation industry is one of the major economic drivers in the Asia-Pacific region.

Apart from Asia-Pacific, the Middle East also focuses on its aviation industry. There has been a significant increase in aircrafts and commercial aviation in the region, due to increasing tourism in Saudi Arabia and UAE. The region is a hub for long-haul international flights, connecting passengers between Asia, Europe, Africa and the Americas. Airports like Dubai International, Hamad International in Doha, and King Abdulaziz International in Jeddah have become major international transfer hubs. Thus, this is also a major driver for the aerospace materials market. The rising aircraft demand in the Asia-Pacific and the Middle East is increasing the MRO and OEM application in the aviation industry. This in turn is positively affecting the demand for aerospace materials.

Market Challenges/Restraints

Poor Performance of Adhesives at Extreme Temperatures and Varied Conditions
Adhesives are extensively used in various spacecraft, mainly for mechanical, structural and electrical purposes. This includes potting, bonding, compressing, sealing and venturing. Most adhesives used in and on spacecrafts are not protected from atomic oxygen and are not exposed to ionizing radiation, since they are in between the parts they hold together. But these adhesives are supposed to withstand high pressure and adverse, cold conditions. Thus, they are supposed to function well irrespective of the surrounding environments without corrupting other space components.

Extreme temperature changes can be experienced by aerospace components, from the bitter cold of high-altitude flight to the sweltering heat produced during re-entry. Over a wide temperature range, adhesives must maintain their structural stability and adhesive qualities. When the temperature changes, metals and composite materials used in aerospace expand and shrink. For adhesives to prevent delamination or failure at the bonded joints, they must have comparable coefficients of thermal expansion. Spacecraft and high-altitude aircraft are exposed to intense ultraviolet (UV) radiation, which can degrade adhesive polymers and weaken bonds over time.

Adhesives in spacecrafts are usually near optical devices. In these sites, contamination can lead to grave operational glitches. For instance, many adhesives vaporize, possibly releasing unstable products that contaminate optical, and other precision, instruments. This contamination can damage the performance of the total system. Therefore, it is very important to have regular maintenance checks and to replace adhesives, especially in spacecrafts.

Aerospace engineers and materials scientists have developed specialized adhesives and adhesive bonding techniques to mitigate these challenges. For instance, low-outgassing adhesives are formulated to release minimal gas when exposed to vacuum to prevent outgassing in space applications. Similarly, hybrid bonding is used where mechanical fasteners are deployed in conjunction with adhesives. Engineers assess how adhesives behave using strain gauges and finite element analysis to ensure that bond strength is maintained during stress and vibration.

Certification and Regulatory Hurdles

Materials used in the aerospace industry must undergo stringent certification procedures to meet performance and safety requirements. It can be time-consuming and expensive to demonstrate that novel materials suit essential aerospace components. Some emerging materials could have inconsistent qualities, making it difficult to manufacture and manage the quality of products. Materials used in the aerospace industry must adhere to environmental laws, which include limitations on dangerous compounds and restrictions concerning their disposal after their useful lives. Environmental impact studies are playing a bigger role in certification processes.

The Federal Aviation Administration (FAA) in the U.S., the European Union Aviation Safety Agency (EASA) in Europe, and other aviation authorities have established special rules and regulations for aerospace materials. These rules cover the materials' characteristics, the methods used to produce them and the means by which their quality is assured. Aerospace materials must also adhere to specific material and process standards, such as those defined by organizations like ASTM to gain credibility in the market.

Complex Supply Chain for Emerging Materials

The supply chain for emerging materials is often less mature than that for traditional materials. This can make it difficult for aircraft manufacturers to obtain the needed materials on time. The supply chain for emerging materials for aircraft manufacturers is complex and global. It involves many companies, from raw material suppliers to component manufacturers to aircraft manufacturers. The supply chain for emerging materials begins with the mining and extracting raw materials. These raw materials are then processed and refined into materials used in aircraft components. The processed materials are then sold to component manufacturers, who use them to produce components such as wings, fuselages and engines. The component manufacturers then sell their components to aircraft manufacturers, who assemble them into complete aircraft. The supply chain for emerging materials for aircraft manufacturers is a complex and global system. Some examples of companies involved in the supply chain for emerging materials for aircraft manufacturers are described in the table below.

Table 5
Companies Involved in the Supply Chain of Advanced Aerospace Materials

Category	List of Companies with Details
Raw material suppliers	Solvay, Toray Industries and Teijin are major raw materials suppliers for CFRP production.
Material processors	Hexcel, Cytec and Huntsman Corp. process raw materials into aerospace grade materials used in aircraft components.
Component manufacturers	Spirit AeroSystems, Safran and GE Aviation manufacture aircraft components using emerging materials.
Aircraft manufacturers	Boeing, Airbus and Bombardier assemble aircraft using components made from emerging materials.

Source: BCC Research

Many materials and components in aircraft manufacturing are sourced from various countries, making international collaboration and trade vital to the supply chain's functioning. The supply chain for emerging materials in aircraft manufacturing demands a high level of coordination, quality control and compliance with strict safety and regulatory standards to ensure the reliability and safety of aircraft. Collaboration and innovation are essential to drive the development and adoption of advanced materials in the aerospace industry.

Companies are adopting a wide range of strategies to manage the challenge of a concentrated supply chain of emerging materials. Suppliers' diversification is expected to continue as a trend in the industry, with more aerospace companies exploring new sourcing options and building more resilient supply chains. This trend is expected to drive innovation and competition in the aerospace industry as new suppliers enter the market.

Time-Intensive Training in Advanced Aerospace Materials

Revolutionizing manufacturing processes has a powerful impact on globalization by changing the workforce and increasing access to new skills and knowledge. As per the World Economic Forum, by 2025, 50% of all employees will need re-skilling due to the adoption of new technology. The aerospace sector is no different and will require frequent updates on the technology front. Training employees to handle emerging materials is indeed a time-consuming process. Emerging aerospace, engineering and manufacturing materials often have unique properties and require specialized knowledge and skills. For example, carbon fiber-reinforced plastics (CFRPs) are very strong and lightweight but also brittle—meaning they can be damaged if they are not handled properly. Titanium alloys are also strong and lightweight, but they are more difficult to machine and weld than traditional materials such as aluminum.

To ensure that emerging materials are handled safely and effectively, workers must be trained on each material's specific properties and handling requirements. This training can include both classroom instruction and hands-on experience. The time required to shift from training to handle emerging materials will vary depending on the material's complexity and the worker's experience. However, it is common for workers to complete several weeks or even months of training before being qualified to handle emerging materials safely and effectively.

The time-consuming nature of training to handle emerging materials can be challenging for aerospace manufacturers. However, it is important to invest in training to ensure workers are properly qualified to handle these materials. This helps to reduce the risk of accidents and injuries, and it also helps to ensure the quality and safety of aircraft components and assemblies.

Aerospace manufacturers increasingly recognize the importance of training their workers on emerging materials despite the challenges. This is because emerging materials offer several potential benefits, such as improved fuel efficiency, reduced emissions and increased performance. By investing in training, aerospace manufacturers can ensure that they can safely and effectively use emerging materials to produce next-generation aircraft.

Market Opportunities

The following section summarizes current opportunities in the global advanced aerospace materials market.

Global Airplane Industry Trends

The commercial, military and general aviation sectors all fall under the umbrella of the worldwide airplane industry, which is continuously evolving in response to several trends and events. The aviation industry is placing a lot of emphasis on sustainability and fuel efficiency due to environmental concerns. Airlines are investing in more fuel-efficient aircraft, such as the Boeing 737 MAX and Airbus A320neo, to limit operating costs and carbon emissions. Moreover, airlines and aerospace manufacturers are forming strategic partnerships and participating in mergers to enhance their global reach and to share resources and expertise.

The aviation industry is also changing as electric and hybrid-electric aircraft become more prevalent. Innovative electric propulsion systems are being developed by new and existing businesses to build more ecologically friendly airplanes. Smart and practical materials with attributes like shape memory, self-healing or multifunctionality are being employed in the aviation industry. These components can significantly improve the upkeep and operation of airplanes.

Integration of Nanomaterials and Nanocomposites in Future Aircrafts

Integrating nanotechnology into aerospace materials represents an emerging and rapidly developing area. Nanomaterials and nanocomposites offer enhanced thermal and electrical conductivity, increased strength-to-weight ratios and improved mechanical characteristics. Nanotechnology is still relatively new but can potentially revolutionize the aerospace industry. By integrating nanotechnology into aerospace materials, engineers can create new materials that are lighter, stronger, more durable and more functional than traditional materials. This can significantly improve aircraft and spacecraft's performance, safety and reliability. Research and development in this area can lead to breakthroughs in aerospace material technology.

Nanomaterials can create new materials much lighter than traditional materials, such as metals and polymers. This can lead to significant weight savings for aircraft and spacecraft, improving fuel efficiency and performance. Over the years, there has been a continuous trend toward reducing the weight of aircraft, and the introduction of nanomaterials, known for their small size and lightweight characteristics, offers an opportunity to further enhance the lightweight nature of aircraft. In aircraft construction, composites play a pivotal role in shaping the airframe. Integrating nanomaterials into these composites increases the stiffness, strength and overall durability of the airframe and internal components while reducing the aircraft's weight. With increased funding in aerospace applications, several nanomaterial manufacturers have collaborated with the aerospace industry to enhance aircraft components and systems using these advanced materials.

Nanomaterials also hold significant potential for safeguarding aircraft against the formidable environmental conditions they encounter during flight. An example of an external hazard that aircraft face is lightning strikes, which pose a significant threat, particularly to the wings. Inadequate dissipation of lightning energy can lead to substantial structural damage. However, by incorporating or coating highly conductive nanomaterials, such as graphene, into the aircraft's wing structure, a lightweight solution can effectively dissipate the energy from lightning strikes.

Numerous nanomaterials, particularly inorganic materials and select organic materials like graphene, exhibit high-temperature resistance, allowing them to withstand elevated temperatures without degradation. These materials confer fire-retardant properties when integrated into various materials, whether in the plastics used throughout the aircraft or in the textiles employed for upholstery.

Nanotechnology is making substantial inroads in aerospace engineering through two primary ways. Firstly, it enhances the properties of aluminum, which is widely used in aircraft fuselages. Research has revealed that aluminum alloys, when examined with electron microscopes, exhibit discolorations, grain boundaries and voids that contribute to weakening the material, leading to cracks and structural issues. The use of cobalt nanoparticles has been found to significantly enhance the strength of aircraft fuselages. Preliminary studies indicate that a fault-free fuselage can be up to 100 times stronger than those currently in production. This reduces material requirements, resulting in lighter aircraft and reduced jet fuel consumption. This aligns with the aviation industry's dual goals of improving fuel efficiency and producing safer, stronger, cost-effective materials. Secondly, nanotechnology is playing a pivotal role in advancing composite materials. Composite materials, comprising fibers such as carbon woven into a polymer matrix, are valued for their lightweight and robust properties. Nevertheless, their interaction with external factors, including UV radiation, impacts, moisture, delamination and lightning, is not fully understood.

In sum, nanomaterials and nanocomposites, by boosting the quality and efficiency of aircraft through various means, present lucrative opportunities for emerging materials in the aerospace industry and will play a significant role in the market.

Efficiency and Fuel Cost

Today's commercial aircraft are more efficient than ever. Leveraging continual advances in superalloy technology, today's jet turbines can burn hotter and more efficiently than their predecessors. This shift to hotter-burning engines has helped to drive continued R&D in the superalloy industry while contributing to greater demand for advanced and advanced aerospace materials. Fuel efficiency is also a growing consideration for military applications, where improved efficiency can mean longer mission times and reduced refueling requirements.

Aerospace parts are frequently made from high-strength, lightweight alloys like superalloys, titanium and aluminum alloys, which are constantly being researched. These alloys contribute to the lighter construction, engines and componentry of airplanes, resulting in fuel savings. The global airline industry players are following balanced approach to seek high profit margins. Part of their plan has been to consolidate less profitable routes. The other part of its approach, which has both benefited airplane manufacturers and material suppliers, centered on increasing fuel efficiency. However, only limited gains in fuel efficiency can be achieved by updating older technologies with new components. For more substantial improvements in fuel efficiency, whole system upgrades—that is, airplane replacement—are needed. The industry responded to this accordingly, resulting in an uptick in demand for high-efficiency planes.

Lightweighting is a significant driver for using advanced aerospace materials in airplanes. Advanced composite materials are a key trend. Carbon fiber-reinforced composites, for example, are valued for their high strength-to-weight ratio. Compared to conventional technologies, these materials are stronger, and they offer lower weight profiles and better performance. While market fundamentals in the airplane manufacturing industry will likely see increased variability in the coming years, BCC Research expects a strong and continued push toward increased lightweighting.

Rotary/Helicopter Markets

The markets for advanced materials for helicopter rotary applications strongly depend on helicopter-related market demand factors. To this end, the commercial helicopter market is different from commercial passenger and cargo aircraft markets in that it is driven by wholly different global market trends and influencing factors. Manufacturers of helicopters are developing new platforms with improved functionality, speed and performance. These include cutting-edge civil models like the Bell Nexus, Sikorsky S-97 Raider and the newest military helicopters.

Large segments of the global helicopter market are supported by offshore industrial operations—particularly operations relating to the oil and gas industries. Helicopters support offshore oil and gas operations, including personnel transport and equipment transfer. As offshore drilling activities increase, so does the demand for helicopters.

Rising demand for helicopters in onshore civil deployments include emergency medical service (EMS) applications, and possibly police or surveillance. Growth has been observed in select EMS markets, particularly in Asia-Pacific, where sector growth has been in the low- to mid-single digits. However, helicopters are increasingly considered for urban air mobility solutions, including air taxis and on-demand transportation services.

Military Markets

Global military markets for aerospace equipment are driven entirely by government allocations. These can be variable based on leadership changes, evolving leadership goals and shifting global security scenarios. In the U.S., which is by far the largest contributor to global defense spending, spending on defense increased by $71 billion from 2021 to 2022, in part due to military aid sent to support Ukraine in its ongoing conflict with Russia. Other global entities, particularly China, have been ramping up military spending, although much of this is outside the aircraft industry.

Advanced aerospace materials in the military market such as ceramics and sophisticated metallic alloys play a key role in providing ballistic protection and armor plating. These materials can significantly improve the security of military people and equipment. These innovative materials also meet performance and operational requirements for developing next-generation military aircraft such as fighter planes and unmanned systems. Suppliers of aerospace materials play a crucial role in fulfilling these demands and capitalizing growth possibilities in the military industry.

Space Industry

Today's space industry has exceptionally high visibility as companies, governments and, increasingly, investors look toward the future. Global leaders including SpaceX, Boeing, Virgin and various global government-funded programs are showing strong interest in space over the next two decades. At present, however, although much innovation is occurring, commercial volumes remain small, only a fraction of the commercial airplane industry. Moreover, currently available space industry equipment is manufactured by only a handful of companies, and that is on a piece-by-piece basis. This equipment is not mass manufactured. Therefore, although many new and technologically exciting developments are coming out of the industry, and more are likely to come, markets are not there yet. BCC Research does, however, anticipate a significant increase in market volume for the global space industry in the coming years.

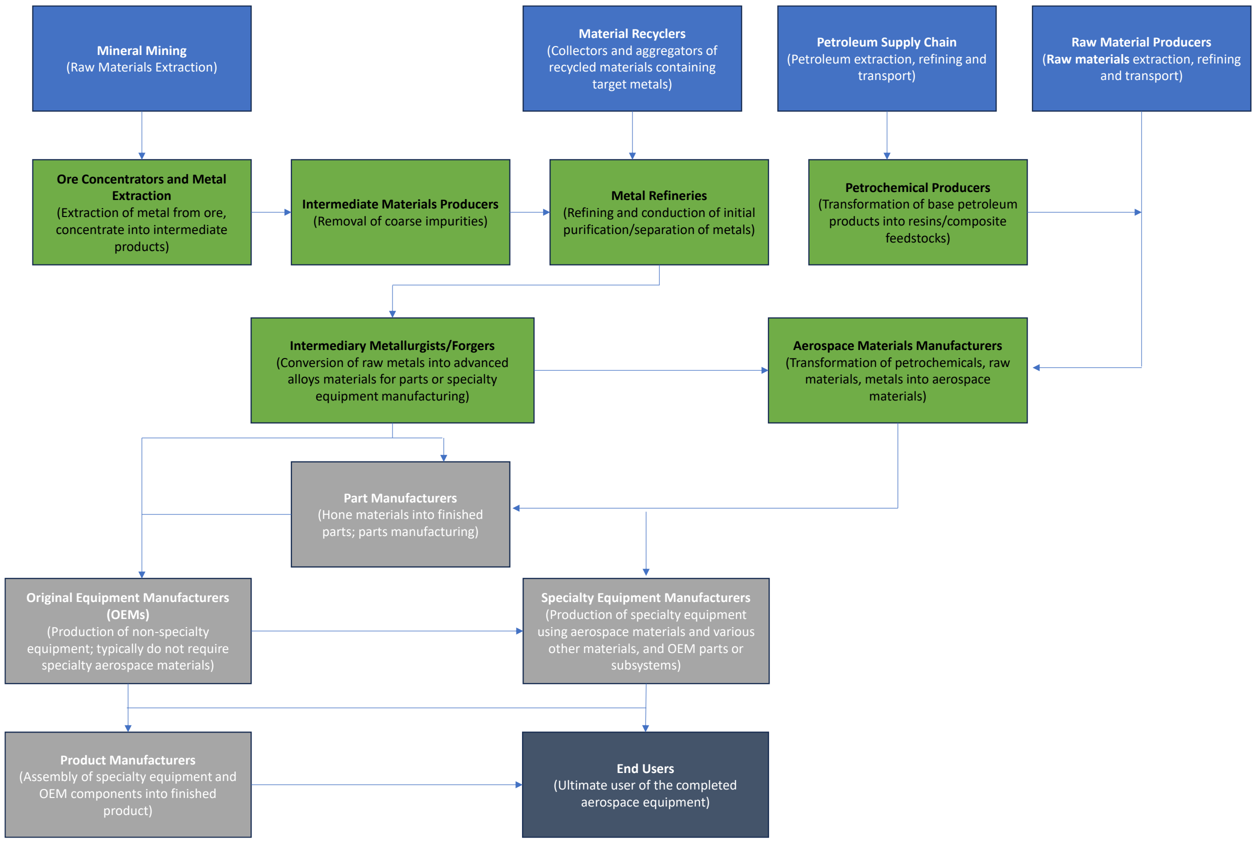
Private and government organizations invest huge funds to manage the cost of developing spacecraft. Continuous advancements make launching a spacecraft ten times cheaper than it was a decade ago. In the last two decades, space start-up companies have proven they can compete against heavyweight aerospace contractors such as Lockheed Martin and Boeing. Currently, a SpaceX rocket launch is 97% cheaper than a ride on a Russian Soyuz was in the 1960s. Increasing competition among private players and rising interest in space tourism will boost the spacecraft industry and drive the race to make these spacecrafts more sustainable and efficient in terms of fuel, prices and materials. This will result in the opening of lucrative opportunities in the market for advanced aerospace materials.

Supply Chain Analysis

Emerging aerospace materials follow a slightly different upstream supply chain based on their material composition. The supply chain for advanced aerospace materials needs to ensure rigorous quality control, traceability, and documentation throughout the manufacturing and distribution process. Due to the sensitive nature of aerospace materials and technologies, security and confidentiality are paramount. The supply chain must ensure the protection of intellectual property, prevent counterfeiting, and maintain strict control over the movement of materials.

Aerospace materials often need to be customized to meet the specific requirements of a particular aircraft or component. This can include adjustments in composition, heat treatment, and other factors. As a result, the supply chain for aerospace materials must be flexible and responsive to these customization needs. For example, materials that incorporate ceramics or composites require different source materials (and therefore different upstream supply chains) from materials that are exclusively metal based. There is also a considerable difference in end users. For example, selling to government-based defense programs is a very different process than selling to end users in the civilian air industry.

Figure 4
Supply Chain Analysis of Advanced Aerospace Materials Market



Source: BCC Research

Mineral Mining for Metals/Alloy Production

This category includes the mining of ore-containing minerals from the ground. Major components—nickel, cobalt, aluminum, titanium and iron—are mined by large companies worldwide. Key players include BHP Billiton Ltd., Rio Tinto, Fortescue, Vale SA, Norilsk Nickel, Jinchuan Group, Xstrata Plc, Jervois Mining, Glencore and Rusal. Other metal and alloy components may be mined or separated as components of an ore targeted for another metal, or individually mined, by large mining corporations or specialty companies targeting rare or small-volume metals. Mineral extraction and mining include initial cleaning and separation steps to remove impurities from the extracted ore and reduce the volume of rejects transported to the next stage in the supply chain.

Specific minerals and metals are needed for alloy production in the aerospace sector to produce materials with the appropriate qualities, such as strength, endurance and resistance to harsh environments. Aircraft manufacturers and operators receive the materials, including the specialty alloys made from mined minerals, ensuring that the materials fulfill the exacting quality and safety standards for aircraft applications.

Material Recyclers

Metals are highly recyclable, and alloys are no exception, but recycling many alloys is more complex than recycling other types of scrap metal. If recycled to produce additional advanced alloys, recycled material must first be purified by removing non-target metals and other compounds. After this process, the resulting materials are injected into the metals/alloy supply chain, with metal commonly being returned for purification and, ultimately, reuse.

Raw Materials Producers

Raw materials producers extract from the earth or otherwise produce raw material needed to produce advanced aerospace materials. Here the focus is primarily on minerals and ceramics base materials used in composites and ceramics. Common activities include mining and extraction of mineral elements that are used in the manufacture of advanced aerospace materials. Raw materials producers also generate base materials for other industries, including ceramics, glass and fiberglass, and other key raw materials needed for various end uses. Some raw materials producers focus on recycling and recover target materials from used/spent materials. Raw materials producers operate in an entirely commodified market, to the extent that standard prices can be determined within a margin of error before contacting a raw materials producer.

Petroleum Supply Chain

The petroleum supply chain includes all upstream oil extraction and recovery and transport of crude oil, natural gas and other raw petroleum products to centralized refineries, storage and other raw natural resources management infrastructure and elements. The petroleum supply chain is the major supply system relevant to the manufacture of resins and plastics, including those used in aerospace composites. Moreover, petrochemicals of various types serve as base materials for advanced aerospace materials. The petroleum supply chain is entirely commodified, subject to global geopolitical pressures, and traditional supply and demand-oriented drivers.

Ore Concentration and Metal Extraction

Following mining, metals needed for superalloy production are extracted from their ore. The extraction process can take variable forms depending on the metal and the qualities and composition of the base material. Incoming ores are often compound ores, meaning several metals may be present in the same base rock. For example, cobalt, copper and nickel are commonly present together in extracted ore. During the concentration process, the ore body is crushed or pulverized, and then subjected to separation based on its specific gravity; this is usually done in water, where heavier target particles sink first, while lighter fines are released as tailings. Downstream of concentration, the extraction process may involve additional crushing or pulverizing as well as heat and may also include chemicals that separate the target metal(s) from its surrounding rock. Other processes include electrorefining or straight smelting without additional chemical usage. Ore concentration can be completed at the mine site, while the metal extraction is typically completed at a separate location. Concentration and extraction may be completed by the same entity or separate entities depending on the target metal and local supply chain variability and characteristics.

Intermediate Materials Producers

Intermediate materials producers frequently overlap with the metal extractors. These producers coarsely remove impurities from extracted metal, so the resulting material might be considered low- to moderate-purity aluminum, nickel, iron or cobalt, or other metals or blends of metals with some residual contamination. However, some impurities remain in these materials in varying quantities.

Metal Refineries

Metal refineries take the next step in purifying incoming metals into single metals. Refineries for small-volume, higher-value metals used in advanced alloy production may refine various metals, including those needed for superalloys. Refineries for larger- volume metals such as aluminum, iron or nickel may include dedicated facilities that specifically run these materials. Metal refineries generally produce billets or ingots or other forms of their target metal to facilitate shipment to separate metal refineries. In product-oriented supply chains, metal refineries are also referred to as raw materials producers.

Petrochemicals Producers

Petrochemicals producers include refiners and facilities downstream of the refining process that convert base/raw crude oil and other natural energy extractables into base chemicals and preliminary products. Petrochemical producers generate base materials, often through steam cracking and reforming, such as olefins (ethylene, propylene and butene), aromatics such as benzene, toluene and xylenes, and other chemicals. Petrochemical producers are also responsible for some of the base materials downstream chemicals producers use to manufacture and synthesize advanced aerospace materials.

Intermediary Metallurgists/Forgers

This supply chain step may be integrated into specialty equipment manufacturers or parts manufacturers, or in some cases, metal refiners, but is not typically integrated into original equipment manufacturers (OEMs). Intermediary metallurgists proceed through a computer-controlled process that involves one or more superalloy production processes. Intermediary metallurgists and forgers generally complete their process for advanced alloys by forming the resulting metals into billets or other standard forms for transport and delivery.

Aerospace Materials Manufacturers

Under this supply chain step, materials from the metals, petroleum and/or raw materials (including ceramics) supply chains are integrated to produce base materials used in the aerospace industry. For practical purposes, this category can be up- or down-integrated with other supply chain elements or can be a standalone element.

Parts Manufacturers

The primary role of parts manufacturers is to hone raw aerospace materials into usable parts; this may be achieved through various processes. Parts manufacturers may be physically separate from other supply chain steps discussed here, combined with intermediary metallurgists, forgers, or equipment manufacturers, as well as methods consistent with resin, composite and ceramics parts manufacturing. Parts manufacturers may use powder metallurgy or other casting techniques for alloys to produce the target parts and other equipment components.

OEMs

OEMs take basic materials from upstream supply chain elements, combine them with other parts from other fabricators, and assemble these into components that specialty equipment manufacturers or product manufacturers use. Within superalloys, most OEMs produce auxiliary equipment such as motors, pumps and actuators, rather than equipment that directly uses superalloys. OEMs may produce products that can be easily branded by downstream supply chain participants, particularly by specialty equipment manufacturers.

Regardless of whether intermediary rebranding occurs, a single OEM in the superalloy supply chain is necessary to construct the basic working parts used for many aerospace applications. Typically, OEM choice depends on a combination of price and delivery schedule, especially where various potential suppliers meet minimum/adequate manufacturing standards.

Specialty Equipment Manufacturers

Specialty equipment manufacturers produce specialized components. They maintain patents in their area of expertise. Some of the largest specialty equipment manufacturers, such as Siemens, produce various products for many industries. Larger specialty equipment manufacturers may also overlap with mid-stream supply chain participants. Most smaller specialty equipment manufacturers specialize in a specific product line, relying on OEMs or other specialty equipment manufacturers to supply non-specialized components, such motors, actuators, pumps, gauges and piping. Specialty equipment manufacturers produce the many critical working components of equipment that utilizes advanced aerospace materials. The quality and dependability of end products depend significantly on the products these manufacturers produce.

Product Manufacturers

Product manufacturers fulfill a role complementary to specialty equipment manufacturers in the aerospace industry. They may rely on using advanced materials to support their manufacturing process. Still, the end products they make under their business model may not be explicitly specialized to be used solely in the aerospace industry. For example, a manufacturer of fire extinguishers for the aerospace industry may rely on advanced lightweight materials when producing fire extinguishers for commercial airplanes. But they may also produce other fire extinguishers that do not rely on advanced materials, for use in other industries.

End Users

The end users are the final owners or operators of the completed product or system with advanced aerospace materials. End users are generally responsible for operation and use of the final product, including its maintenance; this is common in the commercial airplane industry, where airlines typically manage their maintenance process, as well as in the defense industry, although the defense industry may also rely on specialized contractors to fulfill these roles. Aerospace manufacturers include Boeing, Airbus, Lockheed Martin, Northrop Grumman and many others. These manufacturers receive components to fabricate aircraft structures, engines, avionics and other aerospace systems. Space agencies, such as NASA and ESA, are end users of aerospace components for space missions. They require materials for constructing spacecraft, launch vehicles, satellites and space exploration equipment.

Impact of the Russia-Ukraine War on the Market

On 24 February 2022, Russia invaded Ukraine in an escalation of the Russo-Ukrainian War that started in 2014.The conflict has significantly impacted many industrial sectors, including the market for advanced aerospace materials. The conflict has disrupted supply chains, including those related to advanced materials such as aluminum alloys, titanium alloys, superalloys, composites and equipment industry. Russia and Ukraine are both important players in the production and supply of advanced materials, so the economic instability caused by the conflict could impact the investments and funding available for companies operating in this market. For instance, titanium, a key component in aerospace applications, is one of the major raw materials produced in Ukraine. The availability of resources like titanium has been heavily impacted by the conflict, and this has in turn influenced global aerospace production. The conflict in eastern Ukraine has also interrupted the supply chain of raw materials for aircraft manufacturing. It has led to uncertainties in the availability and transportation of these materials, which has affected the market.

In addition, the conflict has affected global trade and geopolitical relations, which could indirectly impact the aerospace industry in several ways. Prices for commodities like titanium have fluctuated because of supply disruptions in Ukraine. The increased market uncertainty has affected the cost of producing aircraft components. Export restrictions have hindered the ability to acquire and maintain aircraft. Moreover, the sanctions and trade restrictions imposed on Russia by the U.S. and other Western countries have disrupted the global supply chain. Manufacturers of aircraft products are diversifying their sources for advanced materials in response to these supply chain disruptions. This diversification strategy may involve looking into alternative suppliers outside of the area to create a more resilient supply chain. The geopolitical tensions associated with the war can lead to market fragmentation. This fragmentation can lead to the emergence of new supply chains, changes in market dynamics and increased competition among suppliers.

The conflict has also led to logistical challenges in the transporting of aerospace materials. Border closures, increased security measures and infrastructure damage has disrupted transportation routes, making it difficult to move aerospace materials efficiently and reliably. This has cause delays and disruptions in the supply chain, affecting the timely delivery of materials to aerospace component manufacturers. Many producers and raw material suppliers are withdrawing operations from Russia, which impacts the market. Other industries are also likely to be hit with logistical problems, as most international material shipping companies (e.g., Maersk, MSC) face delays in moving goods in and out of Russia.

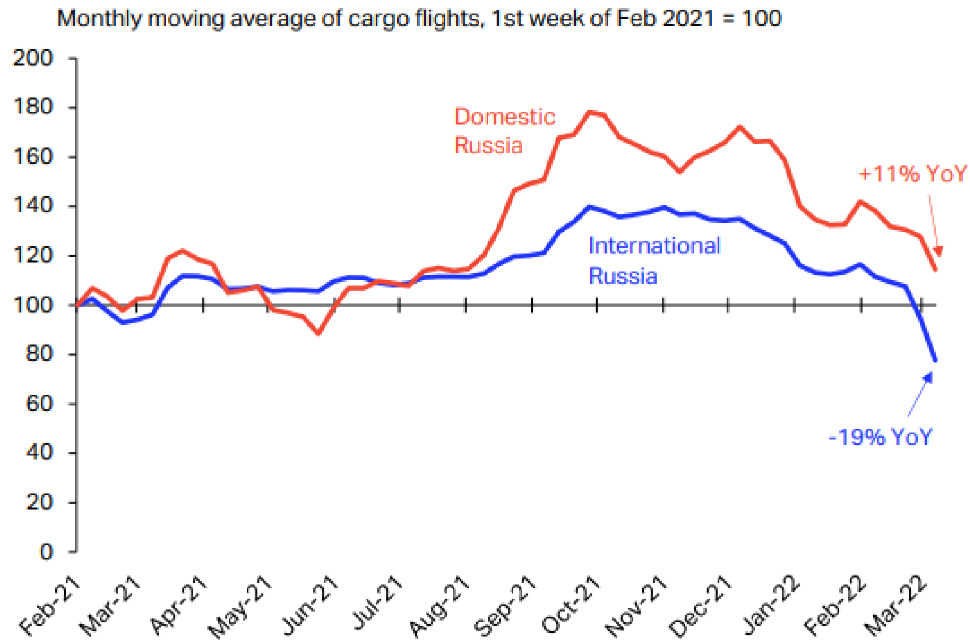
The Russia-Ukraine war has already proved to be the biggest shock for the Russian economy since the collapse of the Soviet Union. Over 400 Western companies have suspended operations in the country, citing reputational risks and logistical issues. Some large-scale producers joined the trend; Rio Tinto was the first major mining company to announce plans to cut all ties with Russian businesses. BP said it was planning to exit its 19.75% stake in Rosneft, Russia's biggest oil company, and suspending their joint ventures, which had amounted to one of the biggest foreign investments in Russia. Exxon also pledged to exit its last remaining oil and gas project in Russia and not to invest in new developments in the country. Since the beginning of the Russia-Ukraine war in 2014, a significant hike of roughly 70% in natural gas prices and crude oil exceeded $105 a barrel for the first time in the history of Europe. These macroeconomic trends have forced aerospace industry players to move toward a sustainable option.

The conflict has also resulted in airspace restrictions in Ukraine and its neighboring nations. Airlines have had to change flight patterns, resulting in longer travel times and higher fuel expenses. As of March 25, 2022, the U.K., the U.S., and 34 other nations have prohibited Russian airlines from using their airspace. In response, Russia imposed its own ban, and airlines from the majority of those nations are not permitted to fly into or over Russia.

The number of airlines operating to/from Russia has also temporarily decreased in several non-sanctioned nations, such as Japan and South Korea. The most heavily impacted markets are Europe-Asia and Asia-North America. This includes flights between the U.S. and Northeast Asia, and between Northern Europe and most of Asia. This directly gives a competitive advantage to airlines from China or from the Middle East.

Both domestic and international dedicated cargo flights for Russia deteriorated markedly since the conflict escalated in Feb. 2024. International flights were 19% down year-on-year during the same period, following growth rates in the range of 10-20% earlier in 2022. According to FlightRadar24, Russia accounted for 2.5% of all dedicated cargo flights globally in 2021. It will be challenging to replace the capacity that these flights will provide for international heavy-weight freight due to their significance. Since the crisis widened, specialized domestic and international cargo flights for Russia significantly degraded Flight bans and sanctions will cause a loss of capacity, especially affecting Europe-Asia and exacerbating the current capacity crunch.

Figure 5
Dedicated Air Cargo Flights in Russia, February 2021 to March 2022
(% Y-o-Y)



Source: IATA Economics using data provided under license by FlightRadar24

Since the start of the conflict, jet fuel prices have increased significantly. In 2022, fuel prices rose to a 14 year high amidst the conflict. According to IATA, prices rose by an incredible 70% just in the first six months of 2022. Well over a year into the war, oil and jet fuel prices are heading back down. As of June 2023, the jet fuel price was $2.25 per gallon (with a corresponding crude oil price of $73.85 per barrel). This is now back to pre-invasion prices. In January 2022, the average price was $2.45 per gallon.

The war has diverted resources, attention and funding from research and development efforts in Russia and Ukraine. Emerging aerospace materials require significant investments in research, innovation and infrastructure. With the focus on the conflict, funding and support for advanced aerospace materials projects have been reduced, slowing down advancements in the field. Economic sanctions, trade disruptions and political tensions have led to an uncertain business environment. This instability has deterred investors and businesses from making long-term commitments, including in the advanced aerospace materials sector. Reduced investment is likely to hinder the region's growth and commercialization of aerospace products.

The conflict has further strained the collaboration and cooperation between Russian and Ukrainian scientists and researchers. Developing advanced aerospace materials often relies on international collaborations to exchange knowledge, share resources and develop new technologies. War and its resulting political tensions can hinder such collaborations, limiting, in this case, the progress of research in aerospace materials. The geopolitical tensions between Russia and Ukraine have also created uncertainty in the global market. Businesses may hesitate to invest in the aerospace industry due to concerns regarding the region’s stability and the potential for further conflict. This could decrease demand, particularly in countries that rely heavily on regional imports.

The ongoing conflict could also affect the regulations on advanced aerospace materials in the affected region. For instance, in Ukraine, the conflict may have disrupted the government’s ability to regulate and enforce environmental laws, including those related to advanced aerospace materials. The conflict in Ukraine has exacerbated material inflation and availability challenges, particularly concerning the impact it has had on fuel prices and the price of other precious metals that are procured in the supply chain. If the conflict is extended or spreads into a larger geographic portion of Europe, the results of operations in future periods could be materially and adversely impacted.

Chapter 5

Emerging Technologies and Developments

bcc Publishing

Chapter 5: Emerging Technologies and Developments

Key Highlights

The modern aerospace industry's rapid growth has resulted in advancements in airplane materials. The three main driving factors are falling costs, lightweighting, and the increasing operational life of the parts in airplane structures. Carbon fiber-reinforced polymer (CFRP) composites have recently emerged as a critical material for aircraft equipment due to their small size, exceptional durability and corrosion-resistant qualities. Carbon fiber-reinforced carbon matrix composites, usually called carbon/carbon (C/C) composites is a high-strength composite, that consists of a carbon or graphite matrix, that is fortified with very strong carbon fibers. Aerospace companies are reassessing and diversifying their supply chains to guarantee the availability of cutting-edge materials and components.

Environmental concerns are driving the development of sustainable aerospace materials. The aerospace sector is looking into ways to recycle and repurpose materials to minimize waste and lower its environmental impact. This includes recycling carbon composites and aluminum alloys. The goal of net zero by 2050 will require the aviation industry to reduce emissions by a significant amount, which is expected to take place through the use of carbon capture technologies, among other initiatives. The aviation industry must continue to make improvements to conventional aircraft, improving performance to meet such goals.

Lockheed Martin, Raytheon Technologies, Boeing, Airbus and Northrop Grumman are a few companies leading in the world in aerospace technology. These companies stand out more than others with regard to their contribution to aerospace technology. For instance, recently, Airbus announced its plans to launch its first megawatt-class hydrogen fuel-cell aircraft test flight in just under four years from December 2023. Raytheon Technologies announced that its Missile & Defense company had made progress on developing technology that helps defend against hypersonic missiles. In addition, SpaceX developed the Falcon 9 reusable rocket—the first orbital class rocket capable of re-flight. All these companies rely on industrious aerospace material manufacturers.

As interest in hypersonic travel and military applications rises, it is crucial to develop materials that can endure the harsh conditions of hypersonic flight. The use of nanomaterials, such as carbon nanotubes and graphene, to improve the mechanical, thermal and electrical properties of aerospace materials is expanding. Researchers are also drawing inspiration from nature to develop new materials with adaptive, self-healing or other similarly unusual qualities in the future.

Emerging Trends in Aerospace Technologies in 2023

Autonomous Flight Systems

Autonomous flying systems are aircraft that can fly without a human pilot. They are also known as Unmanned Aerial Systems (UAS) or Unmanned Aerial Vehicles (UAVs). These devices fly, navigate and carry out various duties autonomously or partially thanks to a combination of cutting-edge technologies.

They are outfitted with advanced flight control systems that include autopilots, sensors and GPS for guidance, navigation and control.

Supersonic Flight

A supersonic flight occurs when an aircraft moves faster than the speed sound, or Mach 1. Supersonic aircraft can fly at Mach 2 or faster, twice the speed of sound. Supersonic planes can fly at extremely high speeds because they were built for them. Fighter jets, supersonic transports and experimental planes like the Concorde and the X-15 are among these aircraft types. In August of 2022, American Airlines announced its plan to buy new supersonic airliners from Boom Supersonic. These planes are slated to roll out in 2025 and be put to commercial use by 2029.

Artificial Intelligence

The aerospace industry is rapidly coming to rely on artificial intelligence (AI), which is changing numerous facets of aircraft design, manufacturing, operation and maintenance. Engineers can create efficient airplane structures using AI-driven generative design technologies. These technologies may investigate innumerable design alternatives and provide the best options while considering different constraints.

Electric Propulsion

Electric propulsion is becoming more and more significant in the aerospace sector. Both all-electric and hybrid-electric aircraft employ electric propulsion. These aircraft don't require conventional internal combustion engines and instead use electric motors driven by batteries or fuel cells. Electric and hybrid-electric aircraft are being investigated for various uses, including cargo transportation, regional air travel and urban air mobility.

Zero-Fuel Aircraft

In 2020, Airbus revealed three concepts for the first commercial zero-emission aircraft , which might be in service by 2035. By examining multiple technological avenues and aerodynamic configurations, these designs each represent a unique strategy for attaining zero-emission flying, supporting Airbus's goal of becoming the first to decarbonize the entire aviation sector. All of Airbus's designs rely on hydrogen as their main energy source because the company thinks it has great potential as a clean aviation fuel and will likely help the aerospace industry and many other sectors reach their climate-neutral goals.

The three concepts, all codenamed "ZEROe," for the first climate-neutral, zero-emission commercial airplane are as follows:

- A turbofan design (120-200 passengers) with a range of 2,000+ nautical miles, capable of operating trans continentally and powered by a modified gas-turbine engine running on hydrogen, rather than jet fuel, through combustion.

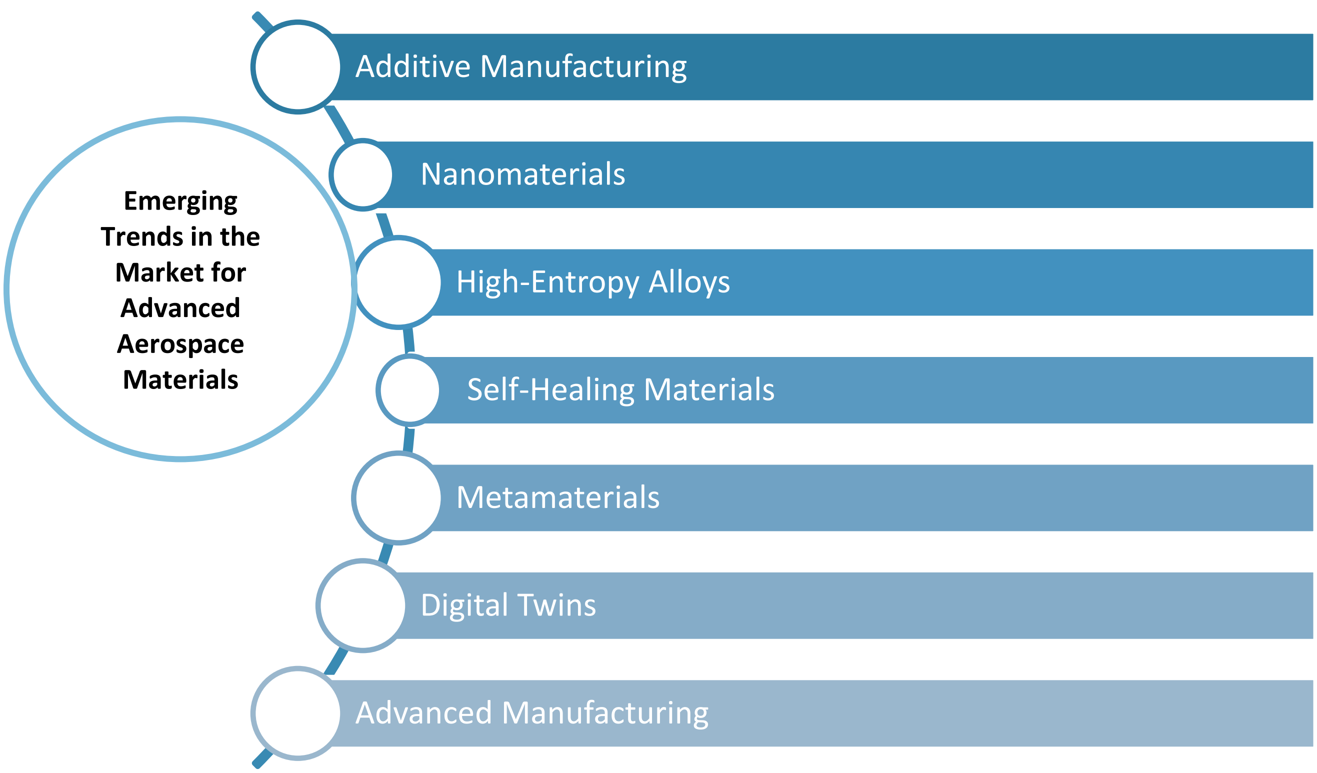
- A turboprop design (up to 100 passengers) using a turboprop engine instead of a turbofan and also powered by hydrogen combustion in modified gas-turbine engines, which would be capable of traveling more than 1,000 nautical miles, making it a suitable option for short-haul trips.

- A "blended-wing body" design (up to 200 passengers) concept in which the wings merge with the main body of the aircraft with a range similar to that of the turbofan concept.

Key Trends in the Market for Advanced Aerospace Materials

The future of aerospace materials holds tremendous potential for transformative advancements driven by evolving customer needs and sustainability considerations. These technologies aim to enhance aircraft and spacecraft performance, sustainability and safety.

Figure 6
Emerging Trends in the Market for Advanced Aerospace Materials



Source: BCC Research

Additive Manufacturing

The aerospace sector has been greatly impacted by additive manufacturing (AM), also known as 3D printing, which has revolutionized the development, manufacture and upkeep of aircraft and spacecraft parts. Engineers may now design and produce extremely complex, lightweight and optimized components that would have been impossible or prohibitively expensive to produce using conventional techniques. Parts with better functionality and less weight are the outcome of this design freedom.

Nanomaterials

Aerospace materials are being revolutionized by nanotechnology. Aerospace materials can be enhanced with carbon nanotubes, graphene and ceramic nanoparticles to increase their thermal stability and resilience with respect to high temperatures. This is especially beneficial for engines, structural components, re-entry vehicles and hypersonic aircraft in the aerospace industry.

High-Entropy Alloys

High-entropy alloys (HEAs) are multi-element, complex materials. They are being investigated for usage in aerospace components including structural materials and turbine blades because of their great strength and thermal stability.

Self-Healing Materials

Materials having the ability to autonomously fix small damage are currently being developed. These materials can lower maintenance costs and increase the longevity of aircraft components.

Metamaterials

Metamaterials are synthetic materials with unique features. They are being studied for use in acoustic camouflage, better radar absorption and stealth technologies.

Digital Twins

Virtual copies of real aircraft or spacecraft are made using digital twin technology. These digital twins provide real-time monitoring, proactive maintenance and simulation for better performance and safety.

Advanced Manufacturing

To enhance the production of composite materials, novel manufacturing techniques are being developed, such as automated fiber placement and resin transfer molding. These techniques boost accuracy while cutting down on waste.

Shape Memory Alloys (SMAs)

SMAs are suitable for morphing wing technologies and adaptive structures that maximize aerodynamic performance since they can return to a specified configuration when heated.

Smart Materials
Smart materials, such as magnetostrictive and piezoelectric materials, are employed in aerospace applications for adaptable structures, vibration control and noise reduction.

Quantum Materials
Research is being done on quantum materials, including quantum dots and superconducting materials, for use in sensors, detectors and quantum computing for aircraft systems.

Lightweight Aerofoils
Aerodynamics and efficiency of aircraft wings are being improved by lightweight aerofoils made of cutting-edge materials and forms, which reduces fuel use and pollutants.

Recycling and Repurposing
Manufacturers in the aerospace sector are developing creative ways to recycle and reuse materials, lowering waste and the sector’s environmental impact.

Chapter 6

Global Market for Advanced Aerospace Materials by Type

Chapter 6: Global Market for Advanced Aerospace Materials by Type

Overview

Emerging materials in aerospace are advanced materials that are integrated into the design and manufacturing of aircraft, spacecraft and other aerospace components. These materials are characterized by their lightweight, high-strength and unique properties that offer improved fuel efficiency and increased durability. When making aircraft, the weight of materials is very important as propulsion depends on weight. Therefore, these advanced aerospace materials are designed to survive high temperatures, radiation and other harsh conditions while carrying the loads placed on the airframe during a variety of flight activities.

Technological advancement has significantly increased the growth of the aerospace market and led to the creation of lightweight components at more cost-effective prices; reduced manufacturing costs; and materials that require less energy to produce. The versatility of lightweighting design, both in terms of material selection and structural optimization, might be considerably increased with advanced manufacturing technology such as additive manufacturing, foam metal production and advanced metal forming.

Materials affect following aspects of the aircraft:

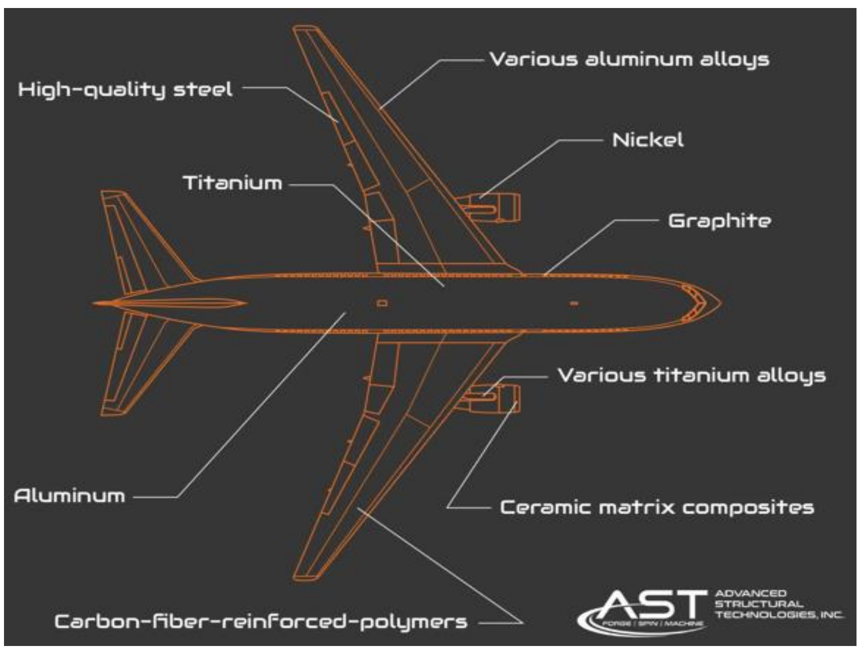
- Purchase cost of new aircraft.
- Cost of structural upgrades to existing aircraft.
- Design options for the airframe, structural components and engines.
- Fuel consumption of the aircraft (light-weighting).
- Operational performance of the aircraft (speed, range and payload).
- Power and fuel efficiency of the engines.
- In-service maintenance (inspection and repair) of the airframe and engines.
- Safety, reliability and operational life of the airframe and engines.
- Disposal and recycling of the aircraft at the end-of-life.

Composites reinforced with carbon fiber are renowned for having a remarkable strength-to-weight ratio. They have high tensile strength, which means they resist breakage under tension. They are widely utilized in the aerospace industry for parts such as rotor blades, wings and aircraft fuselages. Integrating composite materials into new aircraft can enable them to travel greater distances with the same amount of fuel compared to heavier aircraft. Although metal materials, particularly aluminum alloys, continue to dominate the aerospace industry, composite materials are now competing with aluminum alloys in several novel aviation applications.

The proportion of composite materials used in the construction of modern airplanes is increasing significantly. For instance, composite materials account for 50% of the materials of the Boeing 787 Dreamliner. The main structural components of Boeing's 787 Dreamliner are advanced carbon laminate and carbon "sandwich" composites. In answer to the development of the Boeing 787 Dreamliner, Airbus proposed the A350 XWB widebody aircraft, which is 25% more fuel efficient than its aluminum equivalents and is built with more than 50% composite materials. Composites resist damage from moisture and corrosion, and they do not react with water and humid exposure than many metals. Thus, composites give aircrafts durability. This reduces the need for maintenance and repair resulting from moisture damage.

Ceramic-matrix composites are another emerging material gaining high traction in the aerospace industry. They consist of ceramic fibers embedded in a ceramic matrix. They have excellent thermal properties and improved mechanical properties. This makes them perfect candidates for application in the hot section of aero engines. The choice of aerospace materials is essential for designing aerospace components because it impacts various aircraft performance factors, including structural efficiency, flight performance, payload, energy consumption, safety and reliability, life cycle cost, recyclability and disposability.

Figure 7
Aerospace Materials



Source: Advanced Structural Technologies

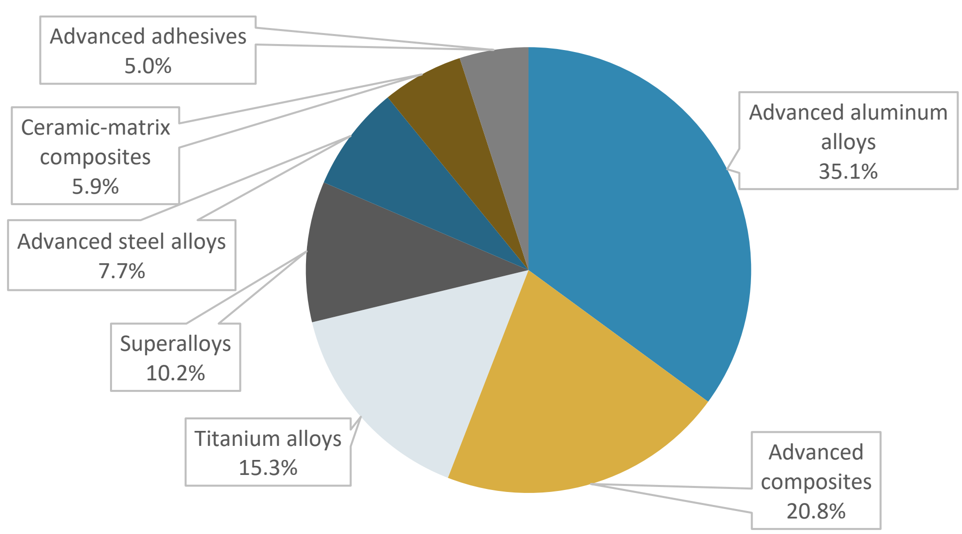
Note that global aerospace manufacturing, as an industry, represents the application for each of the material types considered here. Consistent with the nature of advanced aerospace materials, which are ultimately sold to aerospace manufacturers to make airplanes, helicopters and, increasingly, space-oriented equipment, the markets reported here reflect those sales. Downstream regional sales of manufactured aerospace equipment has not been tracked because that is less important to aerospace materials manufacturers. Instead, regional market segments primarily reflect the demand factors generated by global and regional aerospace manufacturing.

Table 6
Global Market for Advanced Aerospace Materials, by Type, Through 2028
($ Millions)

Type	2022	2023	2028	CAGR% 2023-2028
Advanced aluminum alloys	8,800.6	9,084.3	12,193.6	6.1
Advanced composites	5,231.2	5,756.5	10,391.0	12.5
Titanium alloys	3,850.0	4,085.4	6,314.9	9.1
Superalloys	2,560.0	2,618.9	3,339.2	5.0
Advanced steel alloys	1,925.5	1,954.9	2,379.8	4.0
Ceramic-matrix composites	1,480.4	1,552.8	2,268.7	7.9
Advanced adhesives	1,254.8	1,305.0	1,824.4	6.9
Total	25,102.6	26,357.7	38,711.6	8.0

Source: BCC Research

Figure 8
Global Market Shares of Advanced Aerospace Materials, by Type, 2022
(%)



Source: BCC Research

Advanced Aluminum Alloys

Advanced aluminum alloys are widely used in aerospace due to their lightweight properties and good strength-to-weight ratio. The most widely consumed aluminum alloys in aerospace industries are the Al-Cu alloys (2xxx series), Al-Zn alloys (7xxx series) and Al-Li alloys. Aluminum alloys are the most significant aerospace materials due to their low mass density, high specific strength, good elastic stiffness, excellent ductility, high corrosion resistance, reasonable price and very good manufacturability (extrusion, rolling, bending, welding, repairability, additive manufacturing). They are the material of choice in multiple aerospace structural applications, e.g., the panels used for the entire outer fuselage, upper and lower wing skins, wing stringers, engine parts, etc. The recyclability of advanced aluminum alloys also aligns with environmental goals of the aviation industry.

Al-Li alloys are advanced heat treatable lightweight aluminum alloys that can decrease the density by up to 10% by including 1% to 3% of lithium. As lithium is the lightest metal, its incorporation into aluminum alloys results in a significant reduction in density. Additionally, adding lithium increases the alloys' elastic modulus by 6% for every 10% of lithium added. Al-Li alloys are around 10% lighter and 25% stiffer than AA2xxx and AA7xxx series alloys. For instance, On narrow-body airliners, Arconic Corp. claims up to 10% weight reduction compared to composites, leading to up to 20% better fuel efficiency, at a lower cost than titanium or composites. Al-Li alloys have been employed in the lower wing skins of the Airbus A380, the inner wing structure of the Airbus A350, the fuselage of the Bombardier C series.

Extrusions of AA2099 could be an excellent replacement for conventional aerospace aluminum alloys for application in internal fuselage structures and lower wing stringers. Advanced aluminum alloys are engineered to be lighter while maintaining or improving strength. As aircraft designs evolve to meet fuel efficiency and environmental goals, these alloys will continue to play a crucial role in the development of more efficient and sustainable aircraft. In addition, aluminum-lithium alloys have better performance at cryogenic temperatures, which is advantageous in space exploration where materials must withstand extreme cold.

Aluminum-zinc alloys are known for their high strength. The solubility of zinc in aluminum is 31.6%. Zinc has more solubility in aluminum than any other alloying element. Aluminum-zinc alloys offer excellent mechanical properties, making them suitable for applications where structural integrity and load-bearing capabilities are critical. While not as corrosion-resistant as aluminum-lithium alloys, the 7000 series aluminum-zinc alloys still provide good corrosion resistance. These alloys can be machined and fabricated relatively easily, which is important for manufacturing aerospace components. The most common among the 7000 series is the 7075 alloy. The 7075 alloy is used in the construction of parts that require high strength such as in aircraft fittings, missile parts, gears and shafts, aerospace, and defense applications.

Aluminum-copper alloys are less common in aerospace than aluminum-lithium or aluminum-zinc alloys. However, they still have their place due to several advantages such as high strength, corrosion resistance and heat resistance. Aluminum-copper alloys have good thermal stability, making them suitable for applications that involve exposure to elevated temperatures, such as engine parts and structural elements close to the engine. Magnesium is added to increase the strength of this alloy. This makes the 2000 series alloys that containing magnesium useful in places where high damage tolerance and high resistance to fatigue crack growth is required than other Al alloys. One of the most commonly used 2000 series alloys in the aerospace industry is the 2024-T3 alloy. 2024 aluminum alloy's composition roughly includes 4.3-4.5% copper, 0.5-0.6% manganese, 1.3-1.5% magnesium.

Advanced aluminum alloys are frequently used to build aircraft fuselages, wing structures such as wing spars, ribs, and skin panels. Aircraft need structural support, which is provided by bulkheads and frames made of aluminum alloy. In addition, advanced aluminum alloys are used to construct helicopter airframes, rotor blades and other critical components. For these components to meet performance and safety standards, they must be both sturdy and light. Today's aluminum alloys are high-strength. They can be highly resistant alloys actively designed to serve as upgrades from older, less advanced aluminum alloys such as the 7050-T74 aluminum alloy. However, even 7000 series aluminum alloys are considered exceptionally usable for a wide array of aerospace applications.

Aluminum dominates the global aerospace materials industry, both in terms of total alloy sold into the industry, and in terms of the total market value of that alloy. (Note: Pure aluminum is not considered in this category.) Aluminum alloys rely on various metals as part of their manufacturing process, commonly including copper, manganese, magnesium, silicon and chromium. Advanced aluminum alloys are designed and manufactured for specific and often targeted applications within the aircraft body, thereby helping to balance physical properties and cost of the alloy. More specifically, alloys may be designed for corrosion resistance, finishing ability, physical strength, shearing strength and workability.

Notable features of advanced aluminum alloys in aerospace:

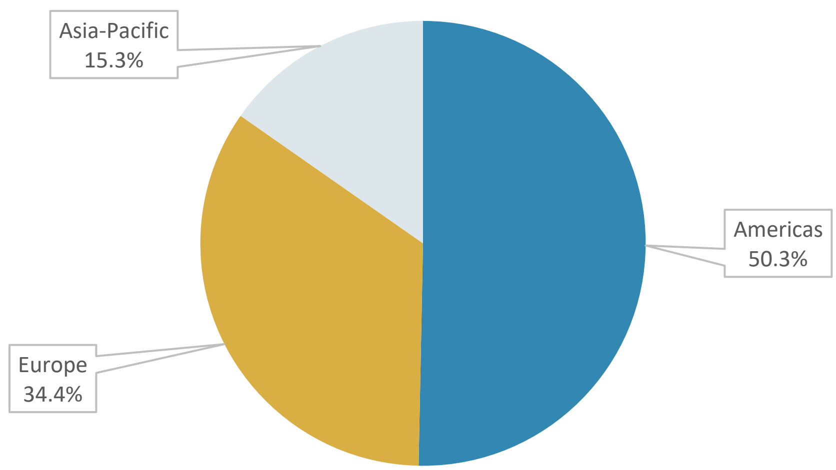
- Offer a low-density solution.
- Exhibit excellent strength-to-weight ratios.
- Are designed in some cases such as aluminum-lithium to have enhanced corrosion resistance.
- Are highly formable, allowing for the efficient manufacturing of complex and intricate shapes.
- Have excellent thermal conductivity, which helps dissipate heat generated by aircraft engines and other systems.
- Possess ductility, enabling them to undergo deformation without losing structural integrity.

Table 7
Global Market for Advanced Aluminum Alloys, by Region, Through 2028
($ Millions)

Region	2022	2023	2028	CAGR% 2023-2028
Americas	4,428.1	4,492.6	5,505.7	4.2
Europe	3,027.6	3,204.4	4,832.7	8.6
Asia-Pacific	1,345.0	1,387.2	1,855.2	6.0
Total	8,800.6	9,084.3	12,193.6	6.1

Source: BCC Research

Figure 9
Global Market Shares of Advanced Aluminum Alloys, by Region, 2022
(%)



Source: BCC Research

Advanced Composites

Advanced composites, which compete with the primary lightweight aircraft materials like aluminum alloys, have attracted more interest in aerospace applications. Aerospace composites often have higher specific stiffness and specific strength at mild temperatures than most metals. A major barrier to using composites is their higher cost when compared to metals. Other benefits of composites include improved fatigue, corrosion and moisture resistance as well as the ability to customize layups for maximum strength and stiffness in required directions. Weight reduction is seen up to 20 to 50% using composites. This segment largely consists of carbon fiber-reinforced polymers.

In CFRP production, thousands of microscopically thin carbon threads are bundled together to make each fiber, which joins others in a matrix that is held together by a robust resin to achieve the required level of rigidity. The composite component is produced in precisely shaped sheets that are laid atop each other and then bonded, typically using heat and pressure in an autoclave oven, in a process that produces a high-quality composite.

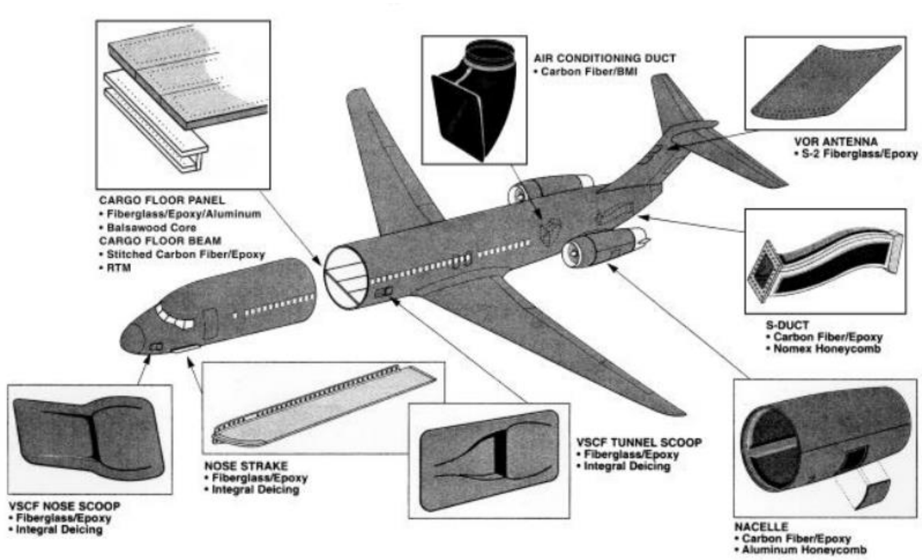
Apart from aluminum alloys, carbon fiber-reinforced polymer is the most widely used structural material in aerospace. It is mostly utilized for control surfaces and structural parts of the wing box, empennage and fuselage. Wherever strong impact resistance is required, aramid fiber polymers are employed. Other types of composites with applications in aerospace (particularly in the Airbus A380) include glass fiber-reinforced aluminum (GLARE), which has improved mechanical properties over monolithic metals such as reduced density, high strength, stiffness and fatigue resistance. Composites such as CFRPs and GLAREs usually have much higher specific strength and stiffness than metals, which makes composites an attractive choice for lightweighting design for many aerospace components and systems. However, metals have the advantages of ease of manufacture and availability and much lower cost, making them still extensively used in many aerospace applications.

Within the CFRP matrix, the carbon fibers themselves provide strength to CFRP systems. Carbon fiber mesh or fabric is then set within a thermosetting resin, an epoxy, vinyl ester or polyester polymer. In addition to standard CFRPs, this category also includes carbon fiber-reinforced thermoplastic composites. These materials are structurally similar to standard CFRPs, except they provide increased heat resistance, thanks to a reliance on a thermoplastic base for the thermosetting resin. As a result, these materials can withstand higher operating temperatures than standard CFRPs, including those that rely on thermoplastics, and offer the following beneficial properties:

- High Strength to Weight Ratio. Carbon fiber composites are typically much stronger than conventional metals and alloys, on a weight basis. For example, CFRP is typically about five times stronger than an equivalent mass of structural steel. As a result, significantly less mass is required to provide the same structural support as a conventional steel frame, for example. A good estimate is that CFRP is approximately 1.5 times stronger than aluminum, on a mass basis.

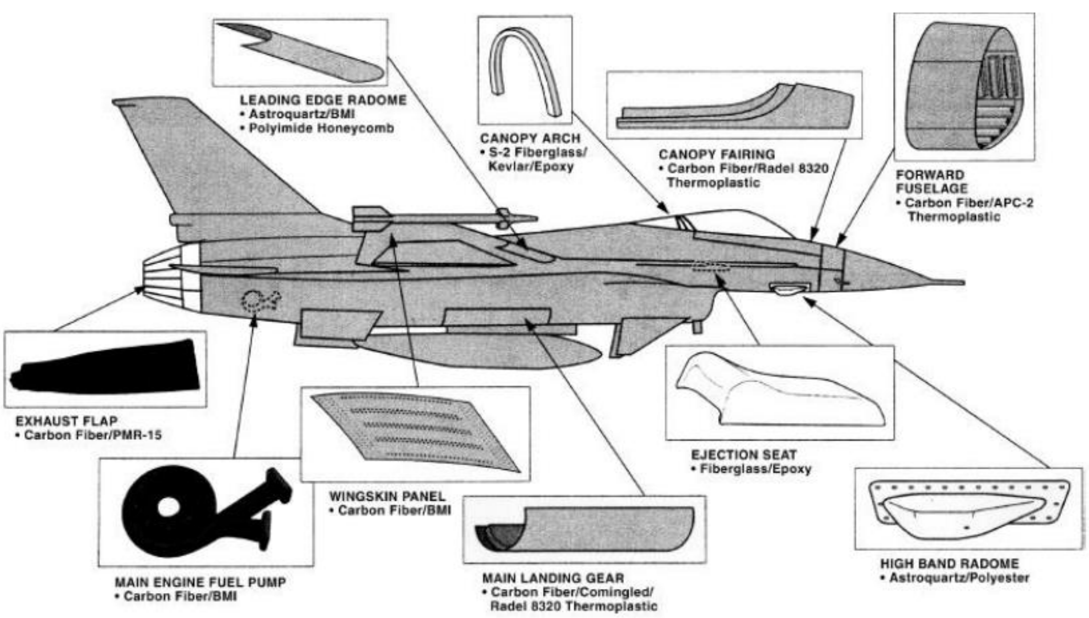
- Lightweight. Lightweighting is a key consideration for the aerospace industry, and CFRP typically have a density of only about 0.055 lbs. per cubic inch. In contrast, conventional fiberglass-reinforced plastic has a density of about 0.065 lbs. per cubic inch, while aluminum ranks at 0.098 and steel at 0.29.

Figure 10
Commercial Aircraft Composite Structures



Source: Composite Horizon Inc.

Figure 11
Military Aircraft Composite Structures



Source: Composite Horizon Inc.

Over fifty percent of the airframes of the two highly popular long-range aircraft, the Airbus A350 and the Boeing 787, are CFRPs. The A380 was the first aircraft to feature a CFRP composite core wing box, saving up to 1.5 tons compared to the planes that used most advanced aluminum alloys. CFRP-based composites are expected, in the long run, to slowly edge out many of the other materials currently being used for manufacturing and constructing equipment in the global aerospace industry.

CFRP composites can be molded into complex shapes and profiles, improving aerodynamic efficiency. The versatility of CFRP composites allows engineers to tailor material properties by adjusting the fiber orientation and resin matrix. CFRP composites have become integral to the aerospace industry's pursuit of more efficient, environmentally friendly, high-performance aircraft and spacecraft.

The primary knock against CFRPs is their cost, which can be several times higher than an equivalent amount of metals or metal alloys, even when compared to advanced and specialized metal alloys. While BCC Research generally expects incremental reductions in the cost of CFRP composites in the coming years, compared to metal alloys, their use will continue to be hampered primarily by cost during the forecast period. One of the other hurdles that slows the incorporation of CFRPs into the aerospace industry is the difference in their basic properties compared to those of plastics or metals. Due to this difference, most equipment elements cannot simply be re-formed in carbon fiber using their same design. Additional design requirements and updates are needed—often substantial updates—to account for the specific properties of CFRPs. Full-scale redesign is not uncommon for this process. Despite these challenges, demand for strong lightweight materials is growing and will push markets forward significantly through 2028.

Notable features of advanced composites in aerospace:

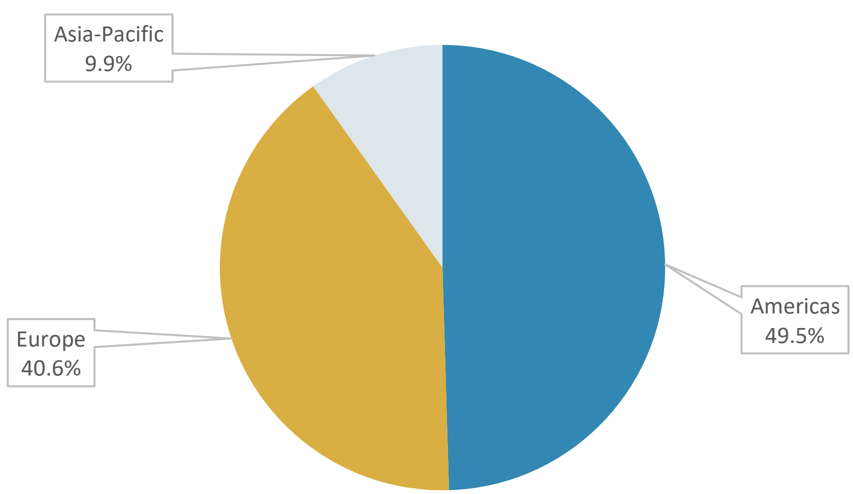
- Are exceptionally lightweight, improving fuel efficiency, extended range and increased payload capacity.
- Are inherently corrosion resistant.
- Provide an outstanding strength-to-weight ratio.
- Are known for their durability and resistance to corrosion and fatigue, resulting in reduced maintenance requirements and lower operating costs for aerospace vehicles.
- Maintain their properties in extreme temperature variations and environmental conditions, making them suitable for subsonic and supersonic flight.
- Have excellent vibration-damping properties.

Table 8
Global Market for Advanced Composites, by Region, Through 2028
($ Millions)

Region	2022	2023	2028	CAGR% 2023-2028
Americas	2,591.4	2,797.7	4,571.9	10.3
Europe	2,124.0	2,380.9	4,706.5	14.6
Asia-Pacific	515.8	577.9	1,112.6	14.0
Total	5,231.2	5,756.5	10,391.0	12.5

Source: BCC Research

Figure 12
Global Market Shares of Advanced Composites, by Region, 2022
(%)



Source: BCC Research

Titanium Alloys

Titanium alloys provide exceptional lightness and strength. They are also more expensive than many common steel and aluminum alloys. The key advances in titanium alloys are focused on how to incorporate lower-cost raw materials and thereby reduce the cost of the alloys overall. Other key benefits of titanium alloys can include improved ductility, castability and good compatibility with CFRP. The amount of titanium used in fuel-efficient aircraft has been growing significantly. In fact, these days, fuel-efficient aircraft can have two to three times more titanium than conventional aircraft.

Titanium and its alloys are increasingly being considered for airframe structural components. In frames and joints, where high-strength steel was once required, titanium alloys are frequently used to save weight. Titanium is also being incorporated into select elements of turbo fan engines. While superalloys are still required in jet engines' combustion and turbine sections, titanium alloys are increasingly used in the cooler compressor sections that feed the combustion and turbine segments. Here, lower temperatures enable the use of titanium alloys. Newer uses for titanium and its alloys include reinforcement for air frame structure conversions, support for cargo loading platforms, conveyor systems and installation of over-size doors and hatches.

Titanium alloys in the aerospace industry may include roll formed stringers, extrusions, seat track to sheet, plate, bar and tubing elements. These are common structural elements for air frames, tail sections, wings, bulk heads and other plane segments. New titanium alloys that provide increased casting performance and further ductility improvements could result in widespread adoption across aerospace platforms. Moreover, titanium alloys find extensive use in military and defense aircraft, where their strength, durability and resistance to corrosion and extreme temperatures are critical.

The advantages of titanium alloys over other metals are their high specific strength, heat resistance, cryogenic embrittlement resistance and low thermal expansion. In airframe and engine applications, titanium alloys are a great substitute for steels and aluminum alloys due to these benefits; however, their extensive use is constrained due to their poor manufacturability and high cost (which is typically about 8 times that of commercial aluminum alloys). As a result, titanium alloys are employed in applications that call for great strength yet have a constrained amount of area and strong corrosion resistance. Titanium alloys are used mostly in aerospace airframe and engine components, accounting for 7% and 36% of the total weight, respectively.

Notable features of titanium alloys in aerospace:

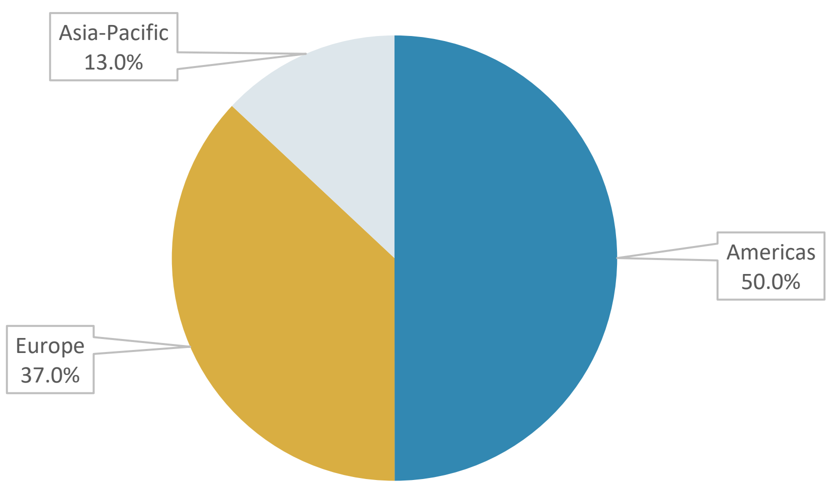
- Are highly corrosion-resistant, particularly in harsh environments like saltwater and acidic conditions.
- Exhibit excellent fatigue resistance, allowing them to withstand repeated cyclic loading during flight.
- Are non-magnetic.
- Advances in manufacturing technologies, including additive manufacturing (3D printing), have made producing complex titanium components with high precision easier and more cost-effective.
- Are used in spacecraft and satellites due to their lightweight properties.

Table 9
Global Market for Titanium Alloys, by Region, Through 2028
($ Millions)

Region	2022	2023	2028	CAGR% 2023-2028
Americas	1,924.7	2,004.4	2,806.5	7.0
Europe	1,423.8	1,547.7	2,675.9	11.6
Asia-Pacific	501.5	533.3	832.5	9.3
Total	3,850.0	4,085.4	6,314.9	9.1

Source: BCC Research

Figure 13
Global Market Shares of Titanium Alloys, by Region, 2022
(%)



Source: BCC Research

Superalloys

Superalloys are a group of nickel, iron-nickel and cobalt alloys used in jet engines. These metals have excellent heat resistant properties and retain their stiffness, strength, toughness and dimensional stability at temperatures much higher than the other aerospace structural materials. The continuous development of high-performance jet engines for commercial and military aircraft demands materials that can withstand the high temperatures and stresses in the engine's hot sections. Superalloys are essential for these applications.

There are three basic categories of superalloys: nickel, iron and cobalt-based superalloys. Nickel-based superalloys dominate the market. This trend relates directly to the composition of superalloys used in a typical jet turbine. High-stress compression and expansion phases of the turbine are typically constructed of nickel-based superalloys, which provide the most favorable combination of strength, resilience and heat resistance for these regions of the turbine. In the turbine combustion area, the physical strain is lower, and the temperature higher, and cobalt superalloys may be used. Iron-based superalloys are not common in jet engines.

Nickel Superalloys

Nickel-based superalloys are best suited to power generation and air jet turbine applications, with primary solutes in the nickel matrix being chromium, aluminum and titanium. Nickel superalloys are the most common in production volumes and applications, relying on nickel as a primary base metal. The table below shows a typical range of compositions for nickel-based superalloys.

Table 10
Nickel Superalloys: Typical Range of Composition
(%)

Metal	Typical Percentage Composition
Nickel	Base metal (up to 95%)
Chromium	10% to 20%
Aluminum	Up to 8%
Titanium	Up to 8%
Cobalt	5% to 10%
Boron	Up to about 3%
Zircon	Up to about 3%
Carbon	Up to about 3%
Molybdenum	Trace amount
Tungsten	Trace amount
Tantalum	Trace amount
Hafnium	Trace amount
Niobium	Trace amount
Rhenium	Trace amount

Source: BCC Research

Nickel superalloys find wide use in load bearing structures, especially within the combustion section of gas turbine engines. They provide the highest homologous temperature of common alloy systems, retaining their strength at up to 90% of their melting point. Combining a nickel base metal with up to about 10% (or sometimes 20% or more) of aluminum, chromium and titanium, generates a two-phase equilibrium microstructure. These consist of gamma and gamma prime microstructures, largely responsible for the elevated temperature strength and other keystone properties exhibited by superalloys.

Iron Superalloys

Iron-based superalloys are generally considered to be of a lower grade than nickel or cobalt-based superalloys. Iron superalloys are also less costly to produce. Iron-based superalloys are classified by the American Iron and Steel Institute (AISI), as follows:

- AISI 601 through 604: Martensitic low-alloy steels.
- AISI 610 through 613: Martensitic secondary hardening steels.
- AISI 614 through 619: Martensitic chromium steels.
- AISI 630 through 635: Semi-austenitic and martensitic precipitation-hardening stainless steels.
- AISI 650 through 653: Austenitic steels strengthened by hot/cold work.
- AISI 660 through 665: Austenitic superalloys; all grades except alloy 661 are strengthened by second-phase precipitation.

Like other superalloys, iron-based superalloys are generally characterized by strength and resistance to creep, corrosion resistance, oxidation resistance and wear resistance at high temperature. Iron-based superalloys also exhibit these properties under room-temperature conditions. Wear resistance is a particular strength of iron-based superalloys, particularly when they incorporate increasing carbon levels, which enhances this property. Oxidation resistance can also be enhanced with increasing chromium content.

Iron-based superalloys are available in all conventional mill forms, including billet, bar, sheet and forgings. Special shapes are also readily available for most iron-based superalloys. In general, austenitic (containing chromium and nickel, as well as sometimes molybdenum and nitrogen) alloys are more difficult to machine than martensitic (typically at least 12% chromium, and up to about 1.2% carbon content) types, which machine best in the annealed condition. Austenitic alloys are usually best when machined after partially aged or fully hardened.

Note that iron-based superalloys are not used for gas turbine blades, jet engines or other turbomachinery components that endure extremely high-stress conditions. They are used for selecting additional components, but as a result, their market share in the target industry of this study is somewhat limited.

Cobalt Superalloys

Cobalt-based superalloys derive from a series of Stellite alloys originally patented in the early 1900s by American inventor and metallurgist Elwood Haynes. They can be engineered to have higher melting points than nickel or iron-based superalloys. This property can enable them to absorb stress under a higher absolute temperature. Due to the high chromium content in many cobalt-based superalloys, they can support increased corrosion resistance, even in high-performance gas turbines.

Many cobalt alloys provide enhanced resistance to thermal fatigue and weldability compared to nickel-based superalloys. Like nickel-based superalloys, cobalt-based superalloys also carry a face-centered cubic structure, when stabilized (such as at room temperature). Precipitation of carbides can harden cobalt superalloys, and therefore these alloys typically contain carbon as an additive. Chromium is frequently added to enhance corrosion resistance, while other metals may be added to enhance other specific properties. Other metals such as tungsten, molybdenum, tantalum, niobium, zirconium and hafnium can strengthen the solid solution.

Compared to nickel-based superalloys, the stress rupture curve for cobalt alloys is flatter and shows lower strength up to about 930°C. The greater stability of carbides, which strengthen cobalt alloys, then asserts itself. This is why cobalt alloys are used in the lower-stress, higher-temperature stationary vanes for gas turbines.

Superalloys are used exclusively in aerospace engines. Therefore, superalloy markets are closely tied to engines used in the aerospace industry. Note that superalloys are also used extensively outside of the aerospace industry, including for the production of turbines for power generation, industrial, oil and gas, and some automotive applications (primarily for the production of turbochargers). Therefore, while superalloys are highly specialized, their markets are relatively diverse, and their development can be impacted by external factors relevant to markets outside of the aerospace industry. On another point, superalloys are heavy. Although they have been the best available technology for decades, their weight remains a key concern. New materials such as composites that are based on ceramics have the potential to nudge superalloys out of certain high-heat, high-stress applications.

Superalloys brands include:

- Inconel: Inconel is a nickel-chromium alloy that works well in high heat applications, such as those involving aircraft turbine engines. Inconel also provides good corrosion protection.
- Monel: This superalloy blends nickel with other metals such as titanium, copper, aluminum and iron. Monel works well in aerospace applications because it will maintain its strength at high temperatures.

Notable features of superalloys in aerospace:

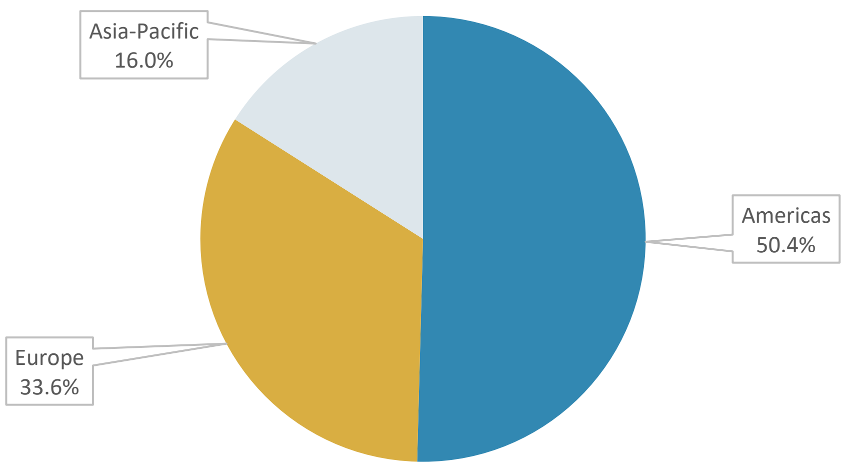
- Maintain their mechanical strength even at elevated temperatures.
- Exhibit excellent resistance to creep, which is the slow deformation of materials under constant load at high temperatures.
- Offer long-term durability and reliability, contributing to the extended service life of aerospace components and reducing maintenance requirements.
- Are compatible with aerospace fluids, such as jet fuel and lubricants, ensuring the integrity of components that come into contact with these substances.

Table 11
Global Market for Superalloys, by Region, Through 2028
($ Millions)

Region	2022	2023	2028	CAGR% 2023-2028
Americas	1,290.7	1,298.6	1,517.6	3.2
Europe	859.7	901.4	1,287.3	7.4
Asia-Pacific	409.6	418.9	534.2	5.0
Total	2,560.0	2,618.9	3,339.2	5.0

Source: BCC Research

Figure 14
Global Market Shares of Superalloys, by Region, 2022
(%)



Source: BCC Research

Advanced Steel Alloys

Conventional steels include carbon steel and steel plate. Advanced steel alloys, particularly those that provide high strength or are highly resistant to wear or corrosion, find frequent application in the global aerospace industry. Some of the critical advantages that high-performance steel alloys offer can be difficult to reproduce using other materials. For example, high-strength carburizing steel can offer exceptional hardness, good fracture resistance, high fatigue strength, excellent corrosion resistance and high temperature resistance—all in a single alloy.

The primary drawback of steel is its weight. High-strength steels do, however, help to manage weight to some degree. For example, high-strength steel alloys are stronger than conventional steel and therefore using them involves less mass/material. This reduced mass translates into reduced weight, typically on the order of 10% in terms of weight reduction. High density and other disadvantages, such as their relatively high susceptibility to corrosion and embrittlement, restrict the application of high-strength steels in aerospace components and systems.

Despite the limitations, high-strength steels are still the choice for safety-critical components where extremely high strength and stiffness are required. The major applications for high-strength steels in aerospace are gearing, bearings and undercarriage applications. Other applications include structural elements, helicopter and propeller transmissions and drivetrain elements, rotor shafts, fasteners, other highly loaded components, landing gear hook shank components, landing gears, actuators, munitions, gun barrels, blast-resistant applications and impact containment.

The selection of an appropriate steel alloy for aerospace industry manufacturing requires a careful consideration of the specific physical and thermochemical stressors that the target steel must endure. Due to their high weight compared to the other advanced aerospace materials considered here, advanced steel alloys are used sparingly in aircraft. Much of their application focuses on high stress points: actuators, hinges, mechanical shafts, landing gear, engine components, generators and other mechanical equipment that is subject to high stress or that requires very high physical strength and/or physical and chemical resistance. As a result, within the overall footprint of an airplane or helicopter, advanced steel alloys can be found in select areas and locations rather than spread across the entire piece of equipment, as is the case, for example, with lighter structural materials like aluminum. Markets for advanced steel alloys reflect this comparatively limited usage.

Notable features of advanced steel alloys in aerospace:

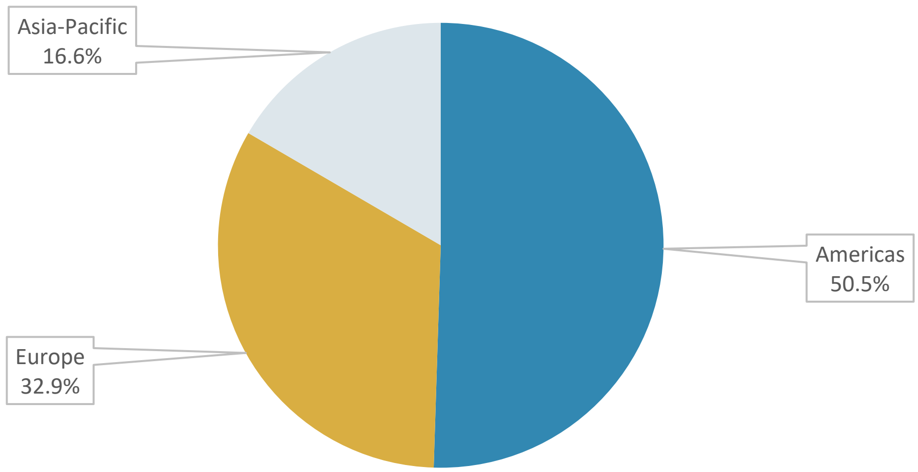
- Are known for their durability and resistance to wear and fatigue.
- Are relatively easy to machine and fabricate.
- Is a cost-effective material compared to high-performance alternatives like titanium and composites.
- Have, in some cases, low thermal expansion coefficients.

Table 12
Global Market for Advanced Steel Alloys, by Region, Through 2028
($ Millions)

Region	2022	2023	2028	CAGR% 2023-2028
Americas	972.4	971.7	1,089.7	2.3
Europe	633.7	659.0	895.2	6.3
Asia-Pacific	319.4	324.2	395.0	4.0
Total	1,925.5	1,954.9	2,379.8	4.0

Source: BCC Research

Figure 15
Global Market Shares of Advanced Steel Alloys, by Region, 2022
(%)



Source: BCC Research

Ceramic-Matrix Composites

Ceramic-matrix composites are a special composite type in which both the reinforcement (refractory fibers) and matrix materials are ceramics. With high strength and strength-to-density ratios, high strength at high temperatures, high stiffness-to-density ratios, improved fatigue strength, controlled thermal expansion and conductivity, improved hardness and erosion resistance, and the ability to tailor properties for end use specifications, CMCs try to retain the desirable properties of ceramics while also making up for their weaknesses. One of the primary applications of CMCs in aerospace is in the hot sections of aircraft engines, such as the combustion chamber and exhaust nozzles. The use of CMCs allows an increase in turbine inlet temperature from the current 1,200° C to 1,500° C, leading to a 6% to 8% increase in fuel efficiency.

Unlike traditional monolithic ceramics, which are brittle and have limited toughness, CMCs combine the strength and stiffness of ceramics with enhanced toughness and fracture resistance. Hotter-burning engines tend to increase fuel efficiency. As a result, there is a continued push to increase the operating temperature of aerospace engines. Historically, engine temperatures have been limited by the upper limits supported by superalloys. However, ceramic-matrix composites can outperform superalloys in terms of heat resistance. Therefore, ceramic-based composites are now used as a coating or external refractory layer for superalloys in turbine-based engines. In the future, increased market penetration of CMCs and replacement of turbine fan blades and other key elements with ceramic-matrix composites is expected to be seen over the forecast period.

The primary driver behind the development of advanced composites is the need to maintain operability even under extremely high temperatures-up to 1,800°F or higher. Applications for these advanced composites include high-stress/high-temperature operations. These can include turbine blades, stator vanes, bulletproof armor, heating elements, heat exchangers, burner parts, refractory elements, jet engine thrust control flaps, insulation, heat shields, burner stabilizers, rocket propulsion equipment, thermo-photovoltaic burners, jet engine/turbo components and combustion liners/refractory elements for gas turbine engines.

Notable features of ceramic-matrix composites in aerospace:

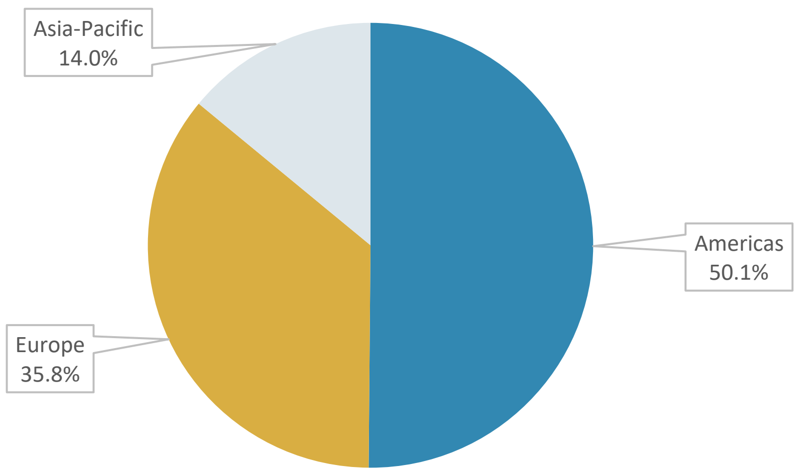
- Are lightweight compared to traditional materials like metals, contributing to improved fuel efficiency and increased payload capacity in aerospace vehicles.
- Can withstand extremely high temperatures, often more than 2,000°C (3,600 °F).
- Contain reinforcing fibers, usually made of ceramics like carbon or silicon carbide.
- Can provide thermal insulation, which is valuable in applications where heat needs to be controlled or protected against, such as spacecraft heat shields.

Table 13
Global Market for Ceramic-Matrix Composites, by Region, Through 2028
($ Millions)

Region	2022	2023	2028	CAGR% 2023-2028
Americas	742.2	764.1	1,011.7	5.8
Europe	530.7	570.4	933.7	10.4
Asia-Pacific	207.6	218.3	323.2	8.2
Total	1,480.4	1,552.8	2,268.7	7.9

Source: BCC Research

Figure 16
Global Market Shares of Ceramic-Matrix Composites, by Region, 2022
(%)



Source: BCC Research

Advanced Adhesives

Advanced adhesives are the only non-structural material category considered in this study. Advanced adhesives will become increasingly important as the use of advanced composites continues to grow across the global aerospace industry. Advanced adhesives are also widely used in the overall assembly process for the aerospace industry, and new adhesives that provide long-term adhesion and sealing will continue to develop over the forecast period.

Advanced adhesives for aerospace include several categories of aerospace tapes and adhesives. Common tape products include polyurethane protective tape and structural adhesive film. Other advanced adhesives used in the aerospace industry include urethane adhesive, epoxy adhesives, specific bonding adhesives for, for example, brackets, structural adhesives and structural adhesive films. Advanced adhesives offer robust and long-lasting bonding options, frequently with load-bearing capacities that are on par with or better than conventional mechanical fasteners. This improves the structural integrity of structures and parts used in aerospace. Moreover, adhesive bonding can streamline manufacturing processes by eliminating the need for drilling holes, inserting fasteners and performing riveting operations. This can result in faster production times and reduced labor costs.

Critical parts of aircraft and spacecraft, such as wings, fuselage sections and tail assemblies, are bonded using structural adhesives. These adhesives are strong and long-lasting, frequently matching or outperforming conventional mechanical fasteners like rivets and bolts. They aid in weight reduction, enhance aerodynamics and distribute loads across bonded surfaces equally. For space applications, where extreme cold is encountered in space and during launch, cryogenic adhesives are used. These adhesives remain flexible and maintain their bond strength at cryogenic temperatures, ensuring the reliability of components in space missions.

Aerospace structures could be subject to vibration, stress, and thermal expansion and contraction during flight. Flexible adhesives are made to withstand these erratic forces and still retain dependable connections. They are utilized for tasks like insulating materials and installing inside cabin components.

Historically, aerospace adhesives have been used to bond insulation, internal panels and flight control surfaces. These uses continue today, such as bonding faceskins to honeycomb core in sandwich constructions. However, it is anticipated that applications and opportunities for advanced adhesives will grow significantly in composite primary and secondary structural elements and associated assemblies. Adhesive properties can be tailored to specific uses. The results can include substantial changes in their overall properties and function. For example, advanced adhesive formulation can target changes in viscosity, cure time, toughness, heat resistance, chemical resistance and other properties.

A small percentage of advanced adhesives can be considered structural in the aerospace industry. To meet industry standards, such a material must maintain its strength under a shear force of 1,000 pound-force per square inch (psi), when tested according to standard industry practices. These adhesives are commonly available as a paste, adhesive film or sheet. Pastes can be used to fill bridge gaps and can also be deployed to bond parts together. Adhesive films, in contrast, are used in large areas to provide structural bonding, and usually focus more extensively on bonding composites, rather than metals. Some adhesives work by forming covalent bonds between surfaces, further enhancing their bond strength, ultimately resulting in a more effective bonding environment.

Notable features of advanced adhesives in aerospace:

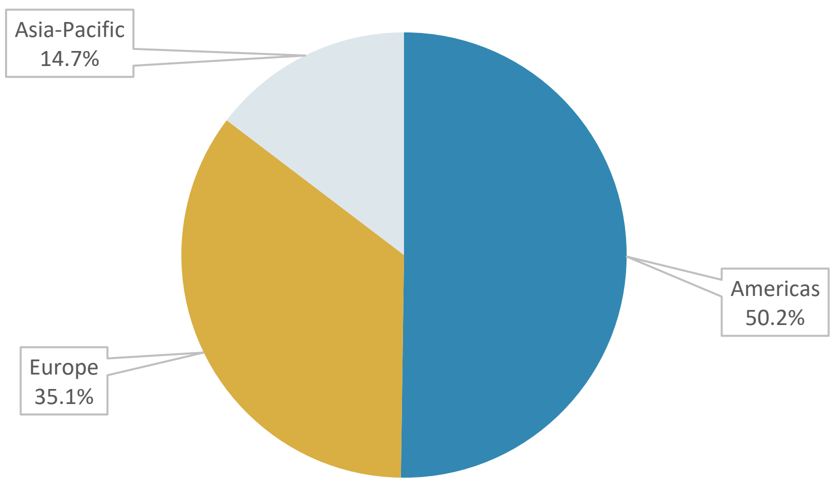
- Are often easy to apply and can be used with automated processes, enhancing manufacturing efficiency.
- Can help distribute loads evenly, reducing stress concentrations.
- Can be used, in some cases, for *in situ* repairs, reducing the need for extensive disassembly and downtime during maintenance operations.
- Can help dampen vibrations and reduce noise levels.

Table 14
Global Market for Advanced Adhesives, by Region, Through 2028
($ Millions)

Region	2022	2023	2028	CAGR% 2023-2028
Americas	630.2	644.1	821.2	5.0
Europe	440.7	470.1	740.1	9.5
Asia-Pacific	183.9	190.7	263.1	6.6
Total	1,254.8	1,305.0	1,824.4	6.9

Source: BCC Research

Figure 17
Global Market Shares of Advanced Adhesives, by Region, 2022
(%)



Source: BCC Research

Chapter 7

Global Market for Advanced Aerospace Materials by Application

bcc Publishing

Chapter 7: Global Market for Advanced Aerospace Materials by Application

Overview

Based on application, the advanced aerospace materials holds a major market share in the commercial passenger aircraft closely followed by the commercial transport aircraft applications. Increased air travel due to the expansion of the middle class in emerging nations, particularly in the Asia-Pacific region, has enabled airlines to grow their fleets. China is one of the aviation markets in the world that is expanding at a high rate. Large orders have been placed for various aircraft types, including narrow-body and wide-body jets, by the country's major airlines, including Air China, China Southern Airlines and China Eastern Airlines. To meet both home and foreign demand, indigenous Chinese producers like COMAC (Commercial Aircraft Corp. of China) have been creating new aircraft models. In addition, Japanese airlines are updating their fleets with modern, fuel-efficient aircraft like the Boeing 787 Dreamliner, including All Nippon Airways (ANA) and Japan Airlines (JAL). Furthermore, new carriers with cutting-edge fleets, like Peach Aviation and Vanilla Air, have begun to appear in Japan. Factors like these will propel commercial passenger aircraft demand in the coming years.

Demand for commercial transport aircraft in the Americas has seen a noticeable increase, particularly in the U.S. The necessity for cargo transportation, the expansion of airline operations, fleet modernization and the need for environmentally friendly and fuel-efficient aircraft are some factors contributing to this rise. Open Skies Accords and other bilateral and international agreements that liberalize air traffic rights have encouraged competition and expansion in the aviation sector, resulting in increased travel and trade. The Airbus A320 family of aircraft has continued to be added to the fleets of various American airlines, including well-known operators like Delta Air Lines, JetBlue Airways and Spirit Airlines. These narrow-body planes are popular for short- to medium-haul routes. Moreover, the Boeing 737 MAX family of aircraft has also played a key role in the U.S. Airlines including Southwest Airlines, American Airlines and United Airlines have bought and received deliveries of the 737 MAX, which, despite a brief grounding owing to safety concerns, promises greater fuel efficiency and passenger comfort.

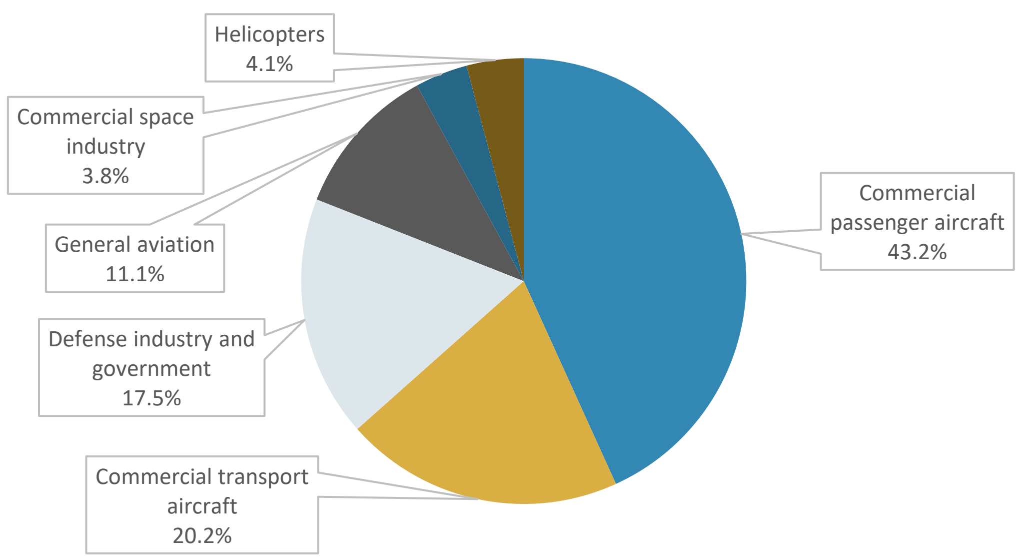
The development and manufacture of military aircraft have been undertaken by several nations and businesses throughout Europe, which has a thriving defense aircraft sector. The French multi-role fighter aircraft Dassault Rafale has seen export success throughout Europe and beyond. France is among the top five largest defense exporters and stands in third position only after US and Russia. For instance, France signed a crucial arms export deals for Rafale combat aircraft with several countries. United Arab Emirates brought 80 French Rafale jets in a $19 billion arms deal in December 2021 when France President Emmanuel Macron visited the Gulf nation. During Indian Prime Minister Narendra Modi's visit to Paris, Dassault Aviation confirmed that 26 Naval variant Rafale jets will be added to the existing fleet of 36 Rafale aircraft. India approved the proposal to acquire 26 Naval variant Rafale jets.

Table 15
Global Market for Advanced Aerospace Materials, by Application, Through 2028
($ Millions)

Application	2022	2023	2028	CAGR% 2023-2028
Commercial passenger aircraft	10,844.6	11,155.6	14,686.4	5.7
Defense industry and government	4,400.3	4,767.4	8,082.1	11.1
Commercial transport aircraft	5,081.2	5,340.6	7,883.1	8.1
General aviation	2,778.0	2,826.2	3,485.2	4.3
Commercial space industry	958.1	1,185.0	3,055.1	20.9
Helicopters	1,040.4	1,082.8	1,519.7	7.0
Total	25,102.6	26,357.7	38,711.6	8.0

Source: BCC Research

Figure 18
Global Market Shares of Advanced Aerospace Materials,
by Application, 2022
(%)



Source: BCC Research

Commercial Passenger Aircraft

The largest segment by application of the market for advanced aerospace materials is the commercial passenger aircraft segment. Note that commercial passenger and commercial cargo/transport aircraft rely almost exclusively on the same base airplane models. These models are designed to serve both industries but have, in many cases, a stronger bias toward passenger aircraft. Therefore, the primary difference between commercial passenger aircraft and commercial cargo/transport aircraft markets is one of size only. The materials makeup is largely the same across these two categories.

Commercial passenger airplanes have witnessed a substantial increase in the use of composite materials such as carbon fiber-reinforced composites. These materials are utilized to build the fuselage, wings and empennage (tail) structures, among other structural elements. For instance, the Boeing 787 Dreamliner has a composite fuselage, which helps lowers its weight and improves its fuel efficiency.

The most successful commercial passenger aircraft globally are the Boeing 737 class of airplanes, followed by the Airbus A320 aircraft. As of December 2022, the total number of deliveries of Boeing 737 family aircraft and Airbus A320 family aircraft were 11,264 and 516, respectively. These short- to medium-haul jets can hold approximately 120 to 240 passengers. Demand for the jets has grown in recent years thanks to the increasing focus among airlines on flying more direct flights and having fewer centralized transfers. This trend has resulted in demand for small to mid-sized planes capable of meeting regional demand at mid-sized airports, while avoiding excess capacity.

Commercial passenger aircraft, like commercial cargo/transport aircraft, can be purchased as either base-efficiency or high-efficiency models. The latter represents a growing fraction of the overall market, particularly as global airlines seek to decarbonize. High-efficiency models tend to rely more heavily on advanced materials, because being lighter in weight translates into reduced energy consumption. Furthermore, the cost premium for a higher-efficiency commercial airplane enables manufacturers to invest more heavily in using titanium, carbon fiber, ceramic composites and other advanced materials, because the cost of these materials can be pushed on to the cost of the airplane. The technologies piloted in these high-efficiency systems tend to trickle down over into conventional airplanes, although at a lower rate and intensity. But it should nonetheless be noted that this process is one of the keyways that advanced materials are continuing to make inroads into the overall commercial aircraft market.

Boeing and Airbus are not the only players in the commercial aircraft space. Other key players include:

- Bombardier Aircraft.
- Embraer Aircraft.
- Fokker.
- McDonnell Douglas.
- Mitsubishi.
- Sukhoi.
- Irkut.
- Comac.

The growth of low-cost carriers (LCCs) in Asia-Pacific has been remarkable. Airlines like AirAsia, Jetstar Airways and Scoot have expanded their fleets with modern narrow-body aircraft to cater to the region’s growing demand for budget-friendly air travel. As a result of the Asia-Pacific region’s increasing popularity as a tourist and business travel destination, air travel is becoming more prevalent, and demand for passenger aircraft is rising. BOC Aviation and SMBC Aviation Capital are two Asia-Pacific-based airplane-leasing firms that are actively buying and leasing aircraft to airlines worldwide, helping fuel the rise of commercial passenger aircrafts. In addition, Middle Eastern carriers like Emirates, Qatar

Airways and Etihad Airways play a significant role in connecting Asia-Pacific with the rest of the world. Recently, these airlines have ordered and operated large fleets of wide-body aircraft to serve long-haul routes.

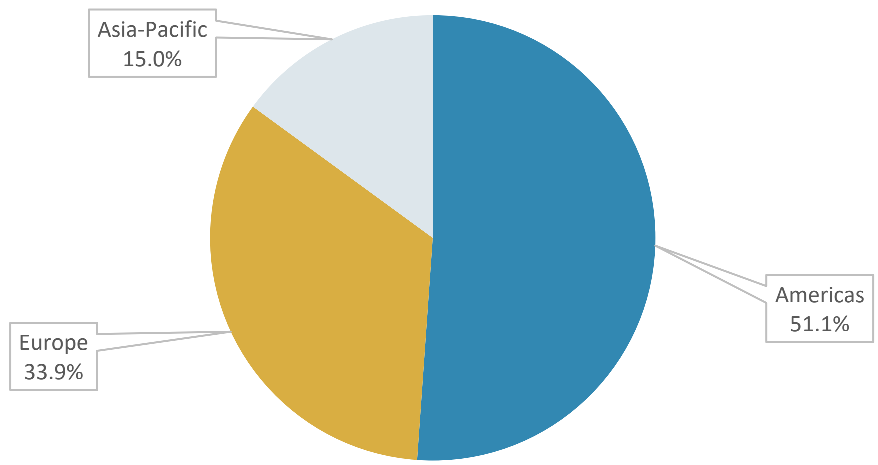
The commercial passenger aircraft market has experienced tremendous expansion in the Asia-Pacific region. Airbus A320 family planes are in high demand among airlines in the Asia-Pacific region, notably LCCs like AirAsia and IndiGo. These short- to medium-haul routes are perfect for these narrow-body jets, which have evolved into the mainstays of many regional airlines. Additionally, the Asia-Pacific region has seen a lot of success with the Boeing 787 Dreamliner. These wide-body aircraft, which offer passengers more comfort and fuel economy, are used on long-haul flights by airlines including ANA (All Nippon Airways), Japan Airlines (JAL) and Qantas.

Table 16
Global Market for Advanced Materials for Commercial Passenger Aircraft, by Region, Through 2028
($ Millions)

Region	2022	2023	2028	CAGR% 2023-2028
Americas	5,543.6	5,607.3	6,755.4	3.8
Europe	3,678.0	3,877.9	5,723.3	8.1
Asia-Pacific	1,623.1	1,670.4	2,207.7	5.7
Total	10,844.6	11,155.6	14,686.4	5.7

Source: BCC Research

Figure 19
Global Market Shares of Advanced Materials for Commercial Passenger Aircraft, by Region, 2022
(%)



Source: BCC Research

Commercial Transport Aircraft

Commercial transport aircraft represents the second largest segment considered in this study in terms of value. This generally includes transporting of high-value cargo, such as luxury goods, electronics and perishable items. Composite materials, particularly carbon fiber-reinforced composites, have revolutionized the aerospace industry. For instance, the Airbus A350 incorporates composite materials extensively in its airframe, reducing weight and improving fuel efficiency. The growth of e-commerce and global trade increases the need for cargo aircraft, which often share design elements with passenger aircraft. These factors will propel demand for commercial transport aircraft in coming years.

To meet delivery dates, carriers like FedEx, UPS and DHL have expanded their express cargo services, necessitating the purchase and use of more cargo planes. The growth of cross-border e-commerce has increased demand for international cargo transportation, especially for small packages and parcels. Moreover, just in time (JIT) inventory management has become popular in many industries, including the automobile and electronics sectors. Transport aircraft make it easier to transport materials and components on schedule, which lowers the expense of stocking up on supplies. Additionally, cooperation between airlines and cargo alliances can increase cargo traffic, making the operation of certain transport aircraft economical. These factors will further enhance the emerging materials portfolio in the aerospace industry.

The Americas region has seen significant growth in the commercial transport aircraft sector due to various factors, including e-commerce expansion, global trade and the need for efficient and timely freight transportation. FedEx Express is one of the biggest cargo carriers in the Americas and the entire world. It has a sizable fleet of freight aircraft, including the Boeing 777F, MD-11 and Boeing 767F. To keep up with the demands of e-commerce and international transportation, FedEx has consistently increased the size of its cargo operations. Similarly, Amazon has launched Amazon Air, a cargo airline, to support its quickly expanding e-commerce company. The corporation has invested in a fleet of Boeing 767-300 and 767-200 aircraft for improved delivery and logistics.

UPS is another major American cargo operator, operating a large fleet of cargo aircraft, including Boeing 747, Boeing 767 and Airbus A300 freighters. UPS has expanded its air cargo network to handle the increasing volume of packages generated by e-commerce. In addition, DHL Express operates an extensive network of cargo aircraft in the Americas, connecting the region with international destinations. DHL utilizes various aircraft types, including Boeing 777, Boeing 767 and Airbus A300 freighters. Such factors will collectively increase demand for deploying advanced materials in the aerospace industry.

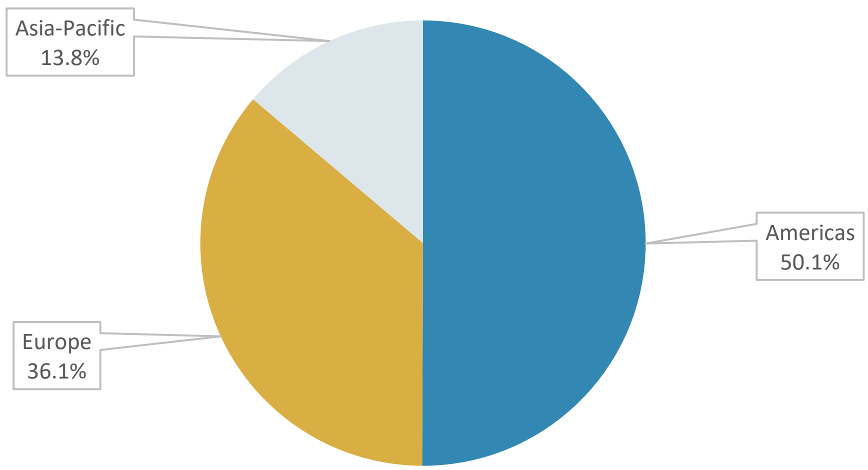
Pratt & Whitney is one of the few engine manufacturers in the world. The company opened a 60,000-sq.-ft. engineering and development facility in California for CMC materials. GE Aviation, another jet engine manufacturer, uses CMC nozzles, fan stators, CMC shrouds, combustor liners and fan blades manufactured in U.S. for its GE9X engine. This engine is the largest commercial jet engine in the world, and it is being used in Boeing 777X aircraft. With increasing demand for these aircraft, demand for emerging materials will also increase.

Table 17
Global Market for Advanced Materials for Commercial Transport Aircraft, by Region, Through 2028
($ Millions)

Region	2022	2023	2028	CAGR% 2023-2028
Americas	2,543.8	2,625.9	3,523.6	6.1
Europe	1,835.2	1,977.9	3,281.4	10.7
Asia-Pacific	702.2	736.8	1,078.1	7.9
Total	5,081.2	5,340.6	7,883.1	8.1

Source: BCC Research

Figure 20
Global Market Shares of Advanced Materials for Commercial Transport Aircraft, by Region, 2022
(%)



Source: BCC Research

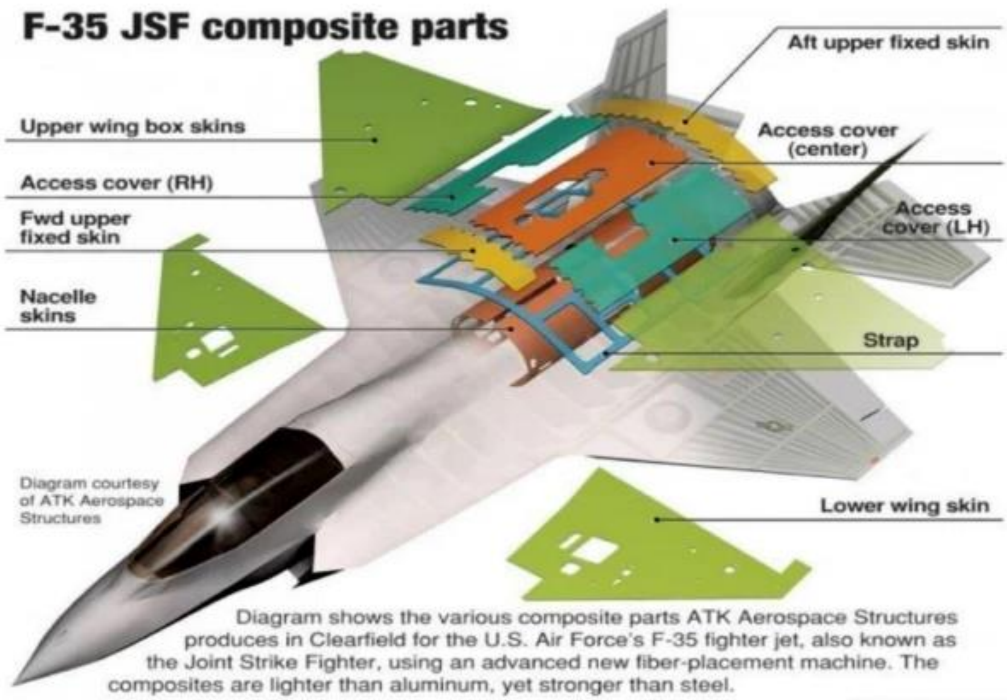
Defense Industry and Government

Military equipment is typically more specialized than commercial end products and thus is often manufactured separately. Military and defense specific applications can include military jets, turboprops, military helicopters and military amphibious planes and helicopters. Military jets are typically supersonic fighter jets that are used primarily to bomb strategic targets on the ground or otherwise engage with military targets. These jets cost billions of dollars to develop (development costs are not included in this study) and are typically deployed from air force bases and navy aircraft carriers. The aircraft built for the defense industry and governments also include defense-specific applications, such as missiles, rockets and other similar equipment and applications. These advanced design systems are specialty systems developed explicitly for the global defense industry.

Evolving security needs, technological advancements and changes in global geopolitics have led to the modernization and expansion of military air forces. Ensuring national security remains a paramount driver for investments in military aircraft. Advances in aerospace technology, including stealth, electronic warfare and unmanned systems, drive the development of next-generation military aircraft. Developed countries are making significant investments in modernizing their armed forces, which involves buying cutting-edge aircraft, to maintain military superiority. This is essential for responding to global threats.

The Americas region has a robust defense industry, and its aerospace sector plays a significant role in developing and producing military aircraft. For instance, the F-35 program, led by Lockheed Martin, is one of the most significant and expensive defense aircraft projects in the Americas. It involves developing and producing three variants of the F-35 (F-35A, F-35B and F-35C) for the U.S. military and international partners. The F-35 is a fifth-generation multirole fighter designed for various air force and naval aviation requirements. High-strength carbon fiber composites are heavily utilized in the construction of the F-35. Carbon fiber composites are used in skin, wing and body structural components. The F-35's carbon-fiber composites comprise a third of the wing's weight and a quarter of the entire aircraft. Possibly the biggest weight-saving strategy used on the F-35 is carbon fiber.

Figure 21
F-35 Composite Penetration



Source: Xiamen LFT Composite

The other military aircraft that the American army uses is the adaptable attack helicopter known as the AH-64 Apache. It has been constantly improved and is still an essential tool for anti-tank and ground support missions. Similarly, the B-21 Raider, a stealth bomber developed by Northrop Grumman for the U.S. Air Force, is expected to replace the aging B-2 Spirit Bomber. The Americas region is one of the world's largest and most influential players in the aerospace and defense industry. Major defense firms like Lockheed Martin, Boeing, Northrop Grumman and Raytheon have headquarters there. The American military, which consists of the Air Force, Navy and Space Force, among other branches, makes significant investments in aerospace and defense material technologies.

Higher defense spending by major regional powers such as India, China and Japan will likely contribute to global sector growth in the Asia-Pacific region. In Europe, members of NATO are also increasing defense budgets to reach a defense spending target of 2% of GDP. Several European nations were becoming more involved in joint defense initiatives, such as the Eurofighter Typhoon and A400M transport aircraft programs, that aim to advance interoperability and strengthen the defense sector. Germany is also working on the Future Combat Air System (FCAS), a project to create next-generation combat aircraft, in collaboration with France and Spain. This project aims to improve defense cooperation between Europe and Germany.

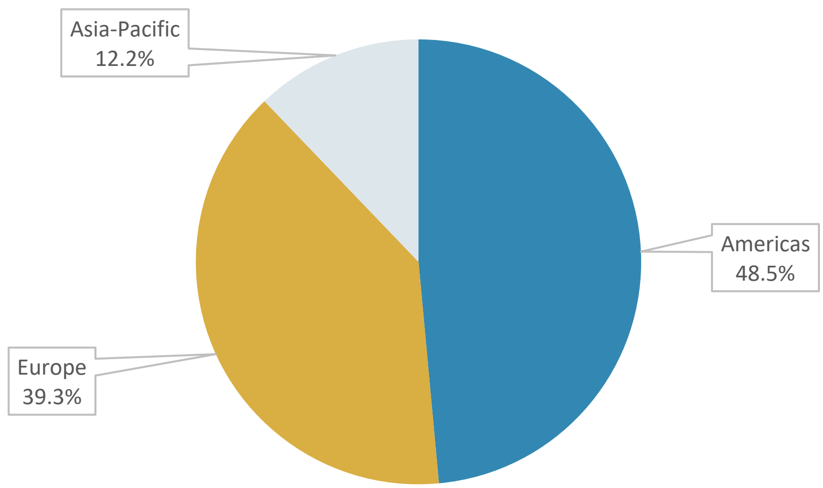
Russia's invasion of Ukraine has exposed the European defense sector's difficulties in meeting the rising demand for ammunition in the aftermath of a fundamentally altered security climate in Europe. Russia has a significant presence in the defense industry, focusing on military technology and aerospace capabilities. Russian defense companies like Rostec and United Aircraft Corp. (UAC) are major players in the global market. Additionally, European nations are facing new security challenges, such as cyber threats and terrorism, which have prompted them to modernize and expand their defense capabilities. Such factors will boost the utility of emerging materials in the defense industry and government application in the coming years.

Table 18
Global Market for Advanced Materials in the Defense Industry and Government, by Region, Through 2028
($ Millions)

Region	2022	2023	2028	CAGR% 2023-2028
Americas	2,135.8	2,272.4	3,500.5	9.0
Europe	1,729.4	1,914.5	3,593.2	13.4
Asia-Pacific	535.1	580.5	988.3	11.2
Total	4,400.3	4,767.4	8,082.1	11.1

Source: BCC Research

Figure 22
Global Market Shares of Advanced Materials in the Defense Industry and Government, by Region, 2022
(%)



Source: BCC Research

General Aviation

The general aviation category includes mostly smaller planes that are generally not used for commercial transport or large-scale movement of passengers. It encompasses a wide range of activities, including private or recreational flying to business and agricultural aviation. In addition, tourism-driven scenic flights are growing in number in Asian countries, providing travelers with a unique experience.

General aviation, as defined in this study, includes the following airplane categories:

- Very light jets.
- Light business jets.
- Mid-size business jets.
- Heavy business jets.
- Private single engine.
- Twin turboprops.

The general aviation category supports various charter-run businesses, as well as private aircraft that are used for business. The category also includes very small recreational craft and transport craft and local commercial and public use aircraft. These include small-scale government patrols, local rapid transport and general service operations. A strong economy leads to increased disposable income, which can drive private aircraft purchase for personal and business use. Moreover, several businesses rely on general aviation for executive travel as well as transportation of personnel and cargo. General aviation also enables access to remote and underserved areas that may not have commercial air service. This is vital for transportation, medical emergencies and business activities. These factors are driving demand for general aviation aircraft.

General aviation has expanded significantly in China. To promote general aviation and ease restrictions, the government has loosened regulations. There are more flight schools and private aircraft owners. Companies in the Chinese market include Textron Aviation and Cirrus Aircraft.

The network of flight academies and schools in the U.S. is extensive and diversified. Many prospective aviators are pursuing advanced ratings and private pilot licenses, indicating that there is still a high need for pilot training. In addition, the introduction and growth of Light Sport Aircraft (LSA) have created new possibilities for pilots and enthusiasts. Associations and organizations, such as the Aircraft Owners and Pilots Association (AOPA), promote and support general aviation. They play a key role in industry growth, thus driving demand for advanced aerospace materials.

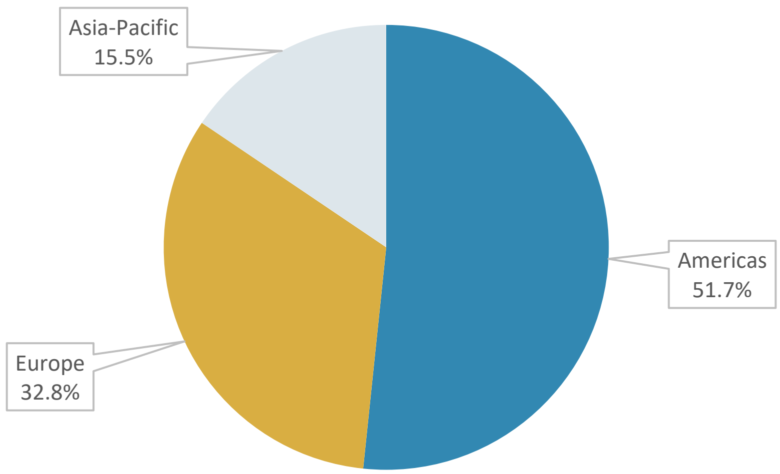
General aviation encompasses multiple use categories, reflecting the combined market drivers for those various end uses. Small and mid-sized business craft are the largest subsegment in this category, accounting for more than half of the total market. Note that this category includes small jets, prop engines and turboprops. Therefore, some of the materials required in this category differ from those in the prior two applications considered here, which were exclusively jets. There is less reliance on superalloys in this category than in those categories where jet engines are ubiquitous. Similarly, reliance on advanced ceramic composites is also more limited.

Table 19
Global Market for Advanced Materials in General Aviation, by Region, Through 2028
($ Millions)

Region	2022	2023	2028	CAGR% 2023-2028
Americas	1,434.9	1,436.7	1,631.4	2.6
Europe	911.2	948.9	1,300.3	6.5
Asia-Pacific	431.9	440.6	553.5	4.7
Total	2,778.0	2,826.2	3,485.2	4.3

Source: BCC Research

Figure 23
Global Market Shares of Advanced Materials in General Aviation, by Region, 2022
(%)



Source: BCC Research

Commercial Space Industry

The commercial space industry currently focuses primarily on satellite placement and launch. Today's commercial space industry derives most of its revenues from launching satellites into space, and commercial launch providers are primarily responsible for putting government and commercial/private satellites into orbit. The commercial space industry is allowed only to launch from specific sites globally. There are multiple such sites in the U.S. as well as in China and Russia. Note that this study focuses specifically on commercial space industry vehicles and does not consider revenues associated with satellites, equipment or manufacturing.

Technology breakthroughs, growing private sector involvement and growing potential in space-related activities have all contributed to the commercial space industry's tremendous expansion. Launching payloads into space is far cheaper because businesses like SpaceX and Blue Origin have developed reusable rockets. This has increased space access and made it more affordable for various uses, including satellite deployment and space travel. Numerous commercial satellites have been developed and launched because of the rising demand for satellite-based services including worldwide internet access, earth observation and satellite communications. Developments in miniaturization and lower launch costs have further boosted the satellite business. Such factors will propel the demand for emerging materials in the aerospace industry.

Initiatives like SpaceX's Starlink and OneWeb aim to provide global internet coverage through large low earth orbit satellite constellations. This can bridge the digital divide and create substantial business opportunities. The space industry is driving advancements in materials science, 3D printing and other manufacturing technologies, with applications on earth and in space. The space industry is also working on technologies to reduce space debris and minimize the environmental impact of space activities. Moreover, the Chandrayaan missions, led by the Indian Space Research Organization (ISRO), have had a notable impact on the commercial space industry in Asia. As ISRO continues to develop its space capabilities and expertise, it creates opportunities for commercial space companies to collaborate and provide services in the region.

The well-publicized space industry activity associated with the international space station and other manned and research missions are the subject of much public outreach and interest. However, these activities represent only a small fraction of the overall activities in this segment. Increasingly, there has been interest from global superpowers—in particular, the U.S., China and Russia—to start moving a greater portion of their defense logistics toward space. These efforts are presently negligible in revenue generation, but can be expected to increase more substantially, particularly five to 10 years from now.

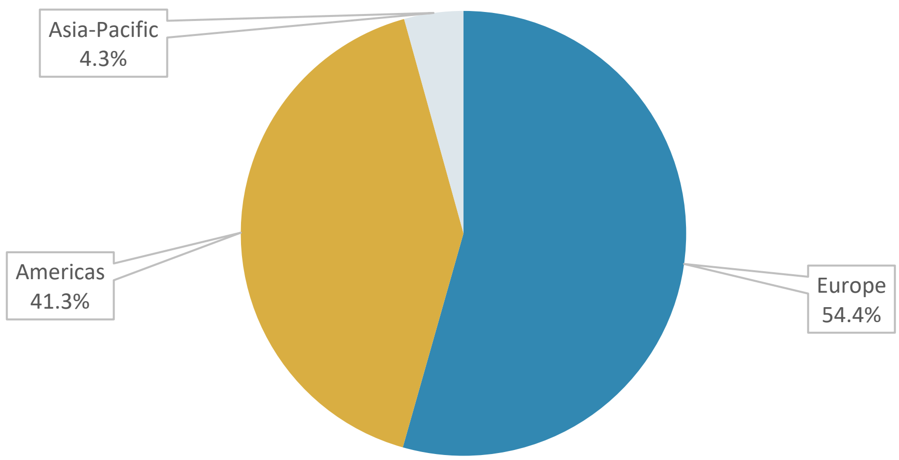
The global commercial space industry is in its fledgling stage, and the major players operating within are SpaceX, Boeing and Virgin Galactic, as well as Lockheed Martin Corp., HEICO and others. There are two primary categories of service: very expensive commercial travel targeting the very wealthy and commercial services. The latter overwhelmingly includes satellite launches, space-oriented transport and various demonstrations, and it represents a fraction of the total market. The other segment, travel, has excellent potential to impact and change the global commercial air travel market forever, reducing flight times from one side of the globe to the other to a matter of a couple of hours, at speeds of up to Mach 5. However, that goal is still far off, likely at least a decade. Therefore, the market currently remains primarily focused on satellite transport.

Table 20
Global Market for Advanced Materials in the Commercial Space Industry, by Region, Through 2028
($ Millions)

Region	2022	2023	2028	CAGR% 2023-2028
Americas	395.8	493.1	1,225.6	20.0
Europe	521.2	624.9	1,557.8	20.0
Asia-Pacific	41.2	67.1	271.7	32.3
Total	958.1	1,185.0	3,055.1	20.9

Source: BCC Research

Figure 24
Global Market Shares of Advanced Materials in the Commercial Space Industry, by Region, 2022
(%)



Source: BCC Research

Helicopters

The commercial helicopter market is strongly decoupled from commercial passenger and transport aircraft markets in that it is driven by wholly different global market trends and influencing factors. The oil industry supports a large segment of the global helicopter market, particularly the offshore oil and gas industry. A helicopter is the transport method of choice for moving staff and small to mid-sized items, supplies and equipment to and from offshore oil and gas rigs.

Helicopters are also used for other purposes and end uses, including:

- General transport of people and cargo.
- Medical transport.
- Construction.
- Search and rescue.
- Tourism.
- Agriculture, including crop application.
- Law enforcement.
- Aerial observation.
- Recreation.
- Scientific purposes.

Helicopters markets bridge several end uses, including oil and gas/offshore, as well as utility, personal use, government use and various commercial uses. As a result, similar to the market for general aviation, this category reflects an amalgamation of many different end uses. The need for helicopters in air ambulance and medical evacuation services is constantly increasing due to their capacity to deliver urgent and essential healthcare transportation, particularly in rural or disaster-affected areas. Companies like Air Methods and PHI Air Medical operate large fleets of medical helicopters to serve communities across the Americas regions. Aerial tours of beautiful cities and landscapes are just a few of the unique tourist opportunities provided by helicopters. The demand for such experiences and the expansion of tourism both support the helicopter business, thereby driving demand for the use of emerging materials in helicopters.

The Americas region is home to prominent helicopter manufacturers such as Sikorsky, Bell Textron and MD Helicopters. These manufacturers contribute to growth and innovation in the industry. The American military uses helicopters for various operations, such as medevac missions, reconnaissance and troop transport. Industry development is fueled by the expansion of military helicopter programs, such as the Future Vertical Lift (FVL) program of the U.S. Army.

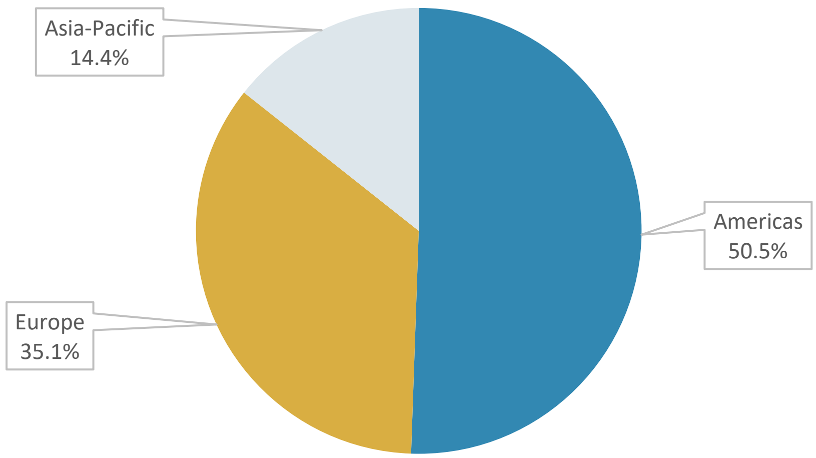
Helicopters with firefighting equipment are essential to fighting wildfires. The need for these firefighting helicopters has been fueled by the rising fire threats resulting from climate change. In addition, Urban Air Mobility is a young field that aspires to use electric vertical takeoff and landing (eVTOL) planes and helicopters to provide short-range urban transportation. UAM offers the helicopter industry new prospects as cities expand and traffic congestion worsens.

Table 21
Global Market for Advanced Materials for Helicopters, by Region, Through 2028
($ Millions)

Region	2022	2023	2028	CAGR% 2023-2028
Americas	525.9	537.8	687.7	5.0
Europe	365.2	389.8	615.4	9.6
Asia-Pacific	149.3	155.2	216.6	6.9
Total	1,040.4	1,082.8	1,519.7	7.0

Source: BCC Research

Figure 25
Global Market Shares of Advanced Materials for Helicopters, by Region, 2022
(%)



Source: BCC Research

Chapter 8

Global Market for Advanced Aerospace Materials by Region

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Chapter 8: Global Market for Advanced Aerospace Materials by Region

Overview

The aviation industry is preparing for its most significant transformation since the jet age, driven by the need to achieve Net Zero in aviation by 2050. The Aerospace Technology Institute (ATI) estimates the global market for new aircraft deliveries to be $5.6 trillion (£4.6 trillion) from 2022 to 2050. This transformation will require the development of new and modern aircraft types fabricated with advanced materials, and thus represents a significant market growth opportunity for aerospace material companies.

The global markets for advanced aerospace materials is highly dynamic. Ongoing advances in materials science, nanotechnology and composite materials are driving the development of novel aircraft materials with improved qualities. New materials with greater strength and durability may enable commercial and military airplanes to carry more payloads. Some of the most significant aerospace corporations in the world, including Boeing, Lockheed Martin, Northrop Grumman, Embraer, General Electric and Pratt & Whitney, are based in the Americas region. To preserve their competitive edge and meet the demands of the international aviation and defense sectors, these businesses continuously push the boundaries of innovation in aerospace materials.

The U.S. alone has one of the largest fleet sizes in the world. The country's government allocated $768.2 billion for national defense projects in its 2022 defense budget, a 2% increase from the Biden administration's first budget request and a sign of the sector's increasing use of aerospace materials. The manufacturing activities in the aerospace industry have been driven by strong exports of aerospace components to nations like France, China and Germany as well as strong consumer spending in the U.S. This is anticipated to create positive momentum for the country's aerospace materials market.

The U.S. is home to major aerospace manufacturers such as Boeing and several Airbus production facilities. These companies have significant orders from both domestic and international customers. The region has a robust cargo industry, with a high demand for freighter aircraft to transport goods domestically and internationally. Many of the world's largest aircraft leasing companies are in the Americas. These companies purchase and lease aircraft to airlines globally, contributing to the demand for new aircraft.

European aerospace clusters, such as Toulouse in France and Bristol in the U.K., are hubs for research and innovation. Governments in Europe are taking initiatives to promote the use of advanced materials. For instance, Horizon Europe Program, is a European Union's flagship research and innovation program that allocates a significant budget to support aerospace research, including advanced materials. The program includes clusters, partnerships and missions focused on aerospace and related industries.

The European space industry, represented by European Space Agency and companies like Ariane Group, drives aerospace materials innovation. Space materials must withstand extreme conditions, making them a focal point for research and development. Moreover, Europe is home to some of the world's leading aerospace manufacturers, including Airbus, Rolls-Royce, Safran, Westland Helicopter and BAE Systems. The presence of advanced manufacturing facilities, such as the Airbus production sites and research centers, that enable the development and production of complex aerospace components will create lucrative opportunities for aerospace materials manufacturers.

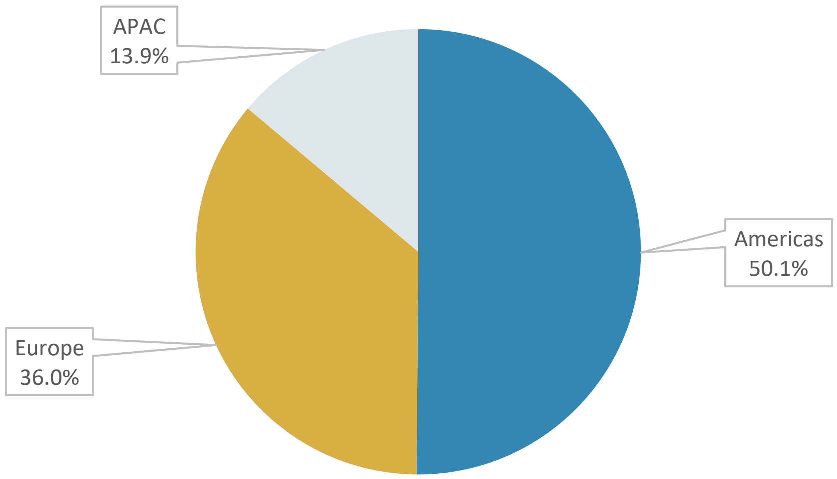
The Russia-Ukraine war has made a significant impact on the aerospace industry. These regions are major commodity producers, so the disruption has caused global prices to soar, especially in the oil and natural gas sector. In March 2022, the OECD warned that the conflict could inflict a one-percentage-point hit on global growth. The entire global economy has felt the effects of the crisis through steeper inflation, slower growth and trade disruptions. Unprecedented sanctions on Russia has impair financial intermediation and trade. The ruble's depreciation is fueling inflation, further diminishing living standards for the population. These factors will impede market growth in Russia and Ukraine in the coming years.

Table 22
Global Market for Advanced Aerospace Materials, by Region, Through 2028
($ Millions)

Region	2022	2023	2028	CAGR% 2023-2028
Americas	12,579.8	12,973.3	17,324.4	6.0
Europe	9,040.2	9,733.9	16,071.4	10.5
Asia-Pacific	3,482.6	3,650.5	5,315.8	7.8
Total	25,102.6	26,357.7	38,711.6	8.0

Source: BCC Research

Figure 26
Global Market Shares of Advanced Aerospace Materials, by Region, 2022
(%)



Source: BCC Research

Americas

The Americas region's market is segmented into the U.S., Canada and Brazil. This region accounted for 50.1% of the global market for advanced aerospace materials in 2022, and it offers lucrative opportunities for growth. Growth in the market is projected at a CAGR of 6.0% through 2028. The U.S. is a major market for advanced aerospace materials in the Americas due to the presence of many manufacturers, suppliers and distributors in the country. Major U.S. players are partnering with aircraft manufacturers to accommodate increased demand. For instance, recently in 2022, Hexcel and Dassault entered into a long-term for Hexcel to provide carbon fiber prepreg for Dassault's Falcon 10X program. This is the first Dassault business jet program to use high-performance advanced carbon fiber composites to create aircraft wings.

Moreover, various government initiatives in the Americas region are engaged in promoting advanced aerospace materials. NASA invests heavily in research into cutting-edge materials for aerospace, aircraft and space exploration. The organization invests in material development and testing for space missions through its Space Technology Mission Directorate to improve aviation efficiency and reduce environmental impact.

The U.S. Department of Defense funds projects for aerospace materials research and development to improve military capabilities. These initiatives aid in creating components for military, aerospace and other systems. Advanced materials research initiatives, such as composites, superalloys and nanomaterials, are frequently started by the Defense Advanced Research initiatives Agency (DARPA). The Americas region is home to the most proactive and technologically advanced industries in the world. It is also a receptive market for scientific research, having perfected a blend of government, academic and industry partnerships. Introducing new standards and technologies, evolving regulatory requirements and increasing customer demand for longer-lasting, high-performance products will impact aerospace materials supply. Product manufacturing and consumption trends in the U.S. will positively influence the regional market.

The presence of major aircraft manufacturers (e.g., Lockheed Martin, Boeing, among others) across the Americas region will likely produce good growth possibilities. The U.S. Department of Defense and the National Aeronautics and Space Administration are the largest consumers of aerospace technology and high-performance materials. These factors will open lucrative opportunities for raw material manufacturers in the region. In addition, the growth of the commercial space industry, including companies like SpaceX and Blue Origin, has sparked interest in new materials to support space exploration and transportation.

A key development in the defense segment was that Lockheed Martin, a leading manufacturer of military aircraft, saw an increasing demand for its F-35 in 2023, and in response the company soon plans to lower the cost of the F-35 further to push this demand even higher. Over 2,500 jets currently on order over a planned 14 years of remaining production. That works out to a rate of roughly 180 jets a year if the existing schedule holds. Another key development was that Boeing successfully tested the MQ-21, a refueling UAV with U.S. Air Force. This drone UAV can transport fuel to fighter jets for midair fueling. These trends will fuel the demand for advanced materials in the defense segment in the U.S.

Brazil and Canada are home to growing aerospace and defense industries, and this is creating potential growth prospects for the advanced aircraft materials market in these countries. With businesses like Embraer, one of the top regional jet producers worldwide, Brazil already has a well-established aircraft manufacturing sector. In the meantime, with the Alcântara Launch Center serving as a key resource, Brazil's space industry is only just getting started. The development of improved materials for rockets and spacecraft can support Brazil's aspirations in satellite technology and space exploration.

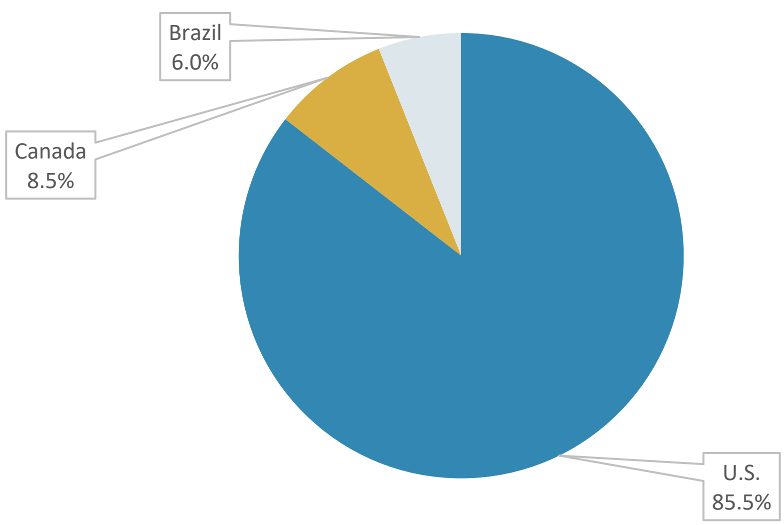
Similarly, Canada is home to major aerospace companies like Bombardier and its successor, Airbus Canada. The aerospace materials industry is expanding due to the usage of cutting-edge materials like composites and lightweight metals, which can improve aircraft performance and fuel efficiency. The domestic aerospace industry in Canada can design and manufacture commercial aircrafts, gas turbine engines, flight simulator systems and landing gears. The industry also caters to the demand for aerostructures, and components made of advanced materials, including ceramics and composites. The Canadian aerospace industry predominantly focuses on exports, primarily to the U.S. and European countries. However, the industry has always been a leading destination of aircraft and components from the U.S.

Table 23
Americas Market for Advanced Aerospace Materials, by Country, Through 2028
($ Millions)

Country	2022	2023	2028	CAGR% 2023-2028
U.S.	10,755.7	11,129.1	15,108.6	6.3
Canada	1,064.3	1,080.7	1,330.5	4.2
Brazil	759.8	763.5	885.3	3.0
Total	12,579.8	12,973.3	17,324.4	6.0

Source: BCC Research

Figure 27
Americas Market Shares of Advanced Aerospace Materials,
by Country, 2022
(%)



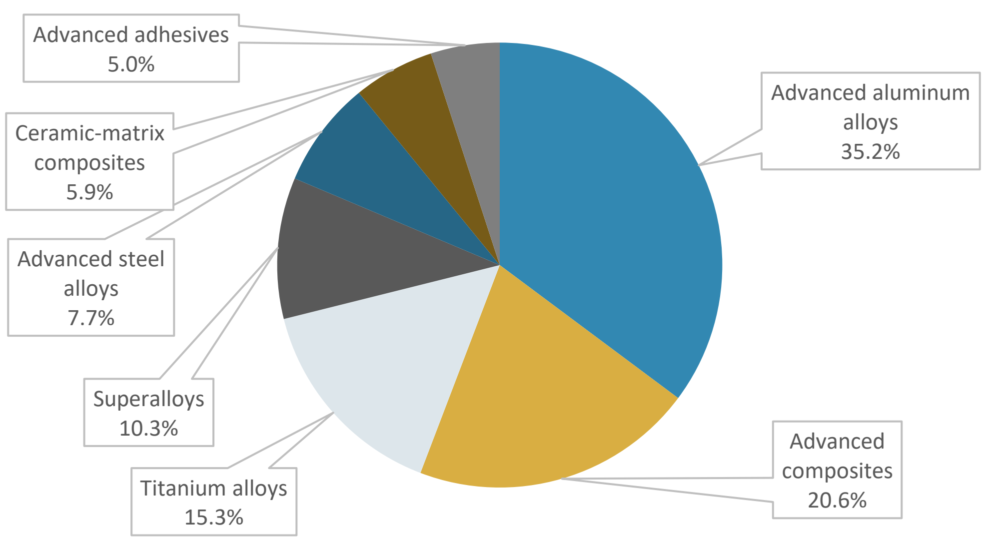
Source: BCC Research

Table 24
Americas Market for Advanced Aerospace Materials, by Type, Through 2028
($ Millions)

Type	2022	2023	2028	CAGR% 2023-2028
Advanced aluminum alloys	4,428.1	4,492.6	5,505.7	4.2
Advanced composites	2,591.4	2,797.7	4,571.9	10.3
Titanium alloys	1,924.7	2,004.4	2,806.5	7.0
Superalloys	1,290.7	1,298.6	1,517.6	3.2
Advanced steel alloys	972.4	971.7	1,089.7	2.3
Ceramic-matrix composites	742.2	764.1	1,011.7	5.8
Advanced adhesives	630.2	644.1	821.2	5.0
Total	12,579.8	12,973.3	17,324.4	6.0

Source: BCC Research

Figure 28
Americas Market Shares of Advanced Aerospace Materials, by Type, 2022
(%)



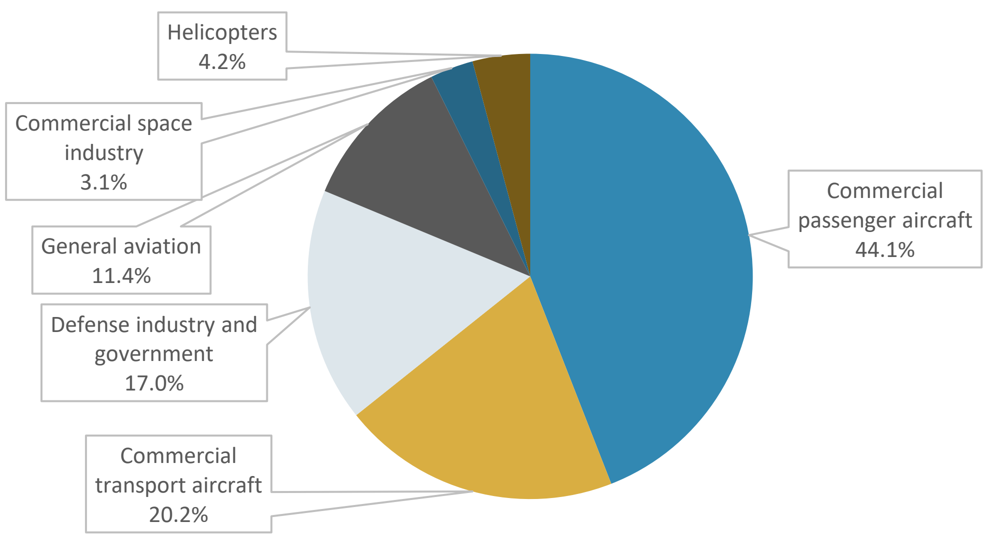
Source: BCC Research

Table 25
Americas Market for Advanced Aerospace Materials, by Application, Through 2028
($ Millions)

Application	2022	2023	2028	CAGR% 2023-2028
Commercial passenger aircraft	5,543.6	5,607.3	6,755.4	3.8
Commercial transport aircraft	2,543.8	2,625.9	3,523.6	6.1
Defense industry and government	2,135.8	2,272.4	3,500.5	9.0
General aviation	1,434.9	1,436.7	1,631.4	2.6
Commercial space industry	395.8	493.1	1,225.6	20.0
Helicopters	525.9	537.8	687.7	5.0
Total	12,579.8	12,973.3	17,324.4	6.0

Source: BCC Research

Figure 29
Americas Market Shares of Advanced Aerospace Materials, by Application, 2022
(%)



Source: BCC Research

Europe

Europe is actively pursuing a transition to a low-carbon economy and reducing its greenhouse gas emissions. Emerging aerospace materials such as composites, advance aluminum alloys and titanium alloys offer innovative solutions to address these challenges and support sustainable aviation. Increasing usage of advanced materials such as composites in aircraft maintenance and repair to extend the service life of existing aircraft, reduce operational costs and improve safety will provide lucrative opportunities for European market players. French companies like Air France Industries KLM Engineering & Maintenance (AFI KLM E&M) have expanded their MRO capabilities, providing services to airlines and aircraft operators worldwide.

Europe is a crucial region in the global aviation since it is home to numerous significant airlines, aircraft producers and airports. European airlines like Lufthansa, British Airways and Ryanair have increased the size of their fleets and network of routes. They have expanded their frequency, introduced additional destinations and updated their fleets with more fuel-efficient planes. Increased passenger numbers result from the growing popularity of low-cost airlines like Ryanair, EasyJet and Wizz Air. These airlines provide reasonably priced travel options, creating new markets and routes. Airbus has responded by increasing the manufacturing of various aircraft, including its A320, A350 and A380 families. Moreover, the replacement of older aircraft with more fuel-efficient models, like the Airbus A320neo and Boeing 737 MAX, has improved the overall efficiency of European airline fleets. These factors will collectively product high demand for advanced aerospace materials in the European region.

European governments and institutions have recognized the potential of advanced aerospace materials and are providing substantial support through funding programs and initiatives. These include programs like Horizon Europe, European Structural and Investment Funds (ESIF) and Clean Sky, all of which promote the use of innovative technologies, including advanced materials, to create lighter and more fuel-efficient aircraft. Many European nations have their own programs for aeronautical research and development. To support their country’s aerospace industry, these national programs frequently incorporate innovative material developments. Two examples of such projects are, the ATI of the U.K. and the CORAC (Council for Civil Aeronautics Research) of France.

France has a vibrant aerospace sector, featuring leaders in innovation like Airbus, Safran, Thales and Dassault Aviation. These businesses invest heavily in innovative alloys, composites and lightweight materials for airplanes and spacecraft. Toulouse, sometimes known as the “Aerospace Valley,” is France’s primary aerospace research and development center. It is home to many aerospace businesses, research facilities and academic institutions that promote innovation and growth. To advance innovative materials, aerospace companies and French academic institutions work together. Research in materials science and aerodynamics is done by organizations like ONERA (Office National d’Études et de Recherches Aérospatiales). Moreover, France is a leader in space launch capabilities, with companies like Ariane Group being a prominent player. The Ariane family of launch vehicles is known for its reliability and efficiency, contributing to France’s reputation as a leading space-faring nation.

The U.K. aerospace industry comprises some of the top companies from the global aerospace industry contributing to the local aircraft production. Some of these companies are BAE Systems, Cobham, GKN, Meggitt, QinetiQ, Rolls-Royce and Ultra Electronics, along with Boeing, Bombardier, Airbus, GE, Lockheed Martin, MBDA, Safran and Thales. These companies drive the demand for advanced aerospace materials in the country. For instance, Airbus assembles the wings for all Airbus civil aircraft in the U.K. Also, Bombardier manufactures lightweight composite wings for its C Series. Boeing has a production facility in Sheffield near the Advanced Manufacturing Research Centre. The research center focuses on the development of advanced materials such as composites.

To support its aerospace industry, the U.K. government has taken a leading role in encouraging the creation and application of cutting-edge aerospace materials. To ensure the safety and dependability of aircraft, government organizations like the Civil Aviation Authority (CAA) collaborate with aerospace businesses to set rules and regulations for using sophisticated materials in aircraft. Innovate U.K., a government organization, also provides financing options for initiatives involving the study and development of aircraft materials. The U.K. is home to various low-cost airlines like Ryanair and EasyJet that have increased their operations and routes to make flying more accessible to a larger spectrum of people. With the growth of e-commerce and international trade, the cargo and logistics segment of the aviation business in the U.K. has also expanded dramatically. Cargo hubs like London Heathrow now handle enormous volumes of cargo.

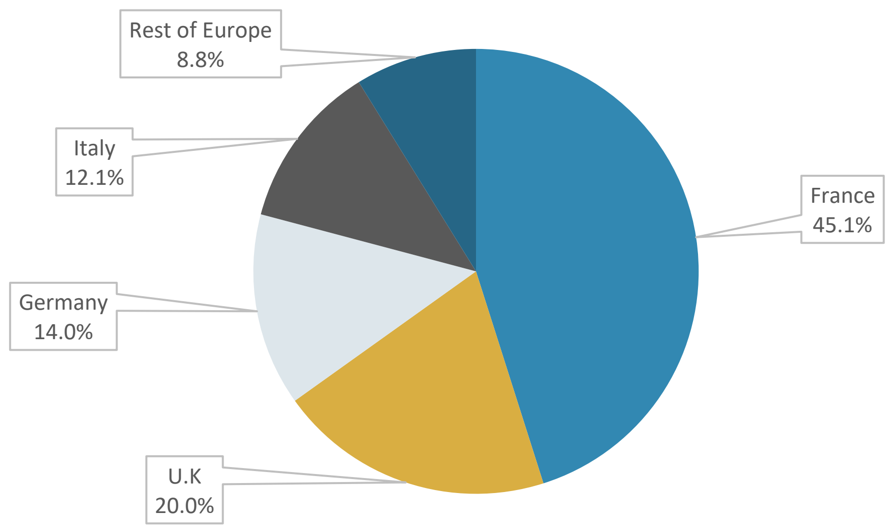
Germany, renowned for having robust technical and industrial sectors, has taken a leading role in creating and using cutting-edge aircraft materials. Composite materials, especially carbon fiber-reinforced composites, are produced by businesses like SGL Carbon and Premium AEROTEC and utilized in aircraft constructions to reduce weight and increase fuel efficiency. The area has participated in numerous space missions and is a significant financial supporter of the European Space Agency. The nation is home to aerospace clusters like Hamburg Aviation and BavAIRia that promote innovation and teamwork in the industry, including creating cutting-edge materials.

Table 26
European Market for Advanced Aerospace Materials, by Country, Through 2028
($ Millions)

Country	2022	2023	2028	CAGR% 2023-2028
France	4,077.1	4,469.8	8,038.9	12.5
U.K.	1,809.8	1,930.2	3,034.3	9.5
Italy	1,089.3	1,172.9	1,936.6	10.5
Germany	1,266.5	1,331.6	1,933.4	7.7
Rest of Europe	797.3	829.3	1,128.2	6.3
Total	9,040.2	9,733.9	16,071.4	10.5

Source: BCC Research

Figure 30
European Market Shares of Advanced Aerospace Materials, by Country, 2022
(%)



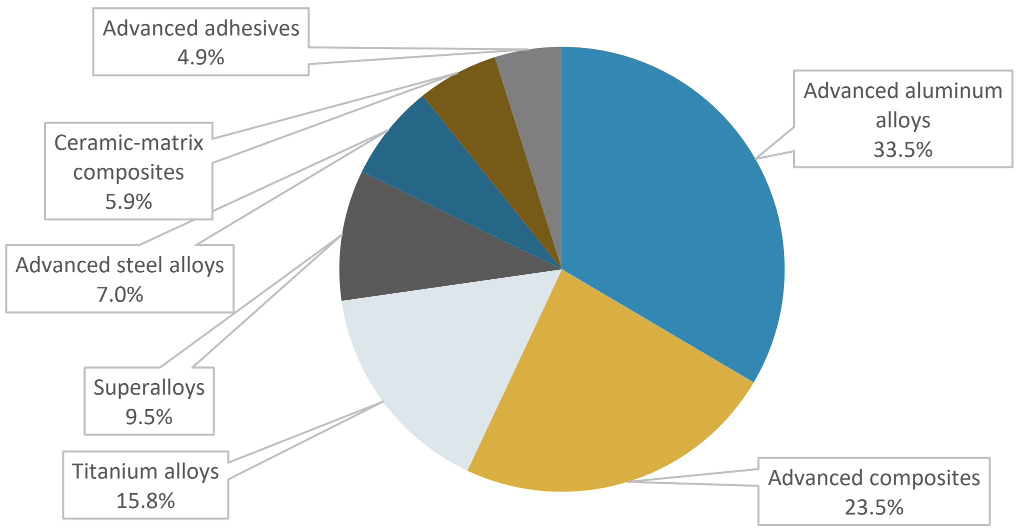
Source: BCC Research

Table 27
European Market for Advanced Aerospace Materials, by Type, Through 2028
($ Millions)

Type	2022	2023	2028	CAGR% 2023-2028
Advanced aluminum alloys	3,027.6	3,204.4	4,832.7	8.6
Advanced composites	2,124.0	2,380.9	4,706.5	14.6
Titanium alloys	1,423.8	1,547.7	2,675.9	11.6
Superalloys	859.7	901.4	1,287.3	7.4
Ceramic-matrix composites	530.7	570.4	933.7	10.4
Advanced steel alloys	633.7	659.0	895.2	6.3
Advanced adhesives	440.7	470.1	740.1	9.5
Total	9,040.2	9,733.9	16,071.4	10.5

Source: BCC Research

Figure 31
European Market Shares of Advanced Aerospace Materials, by Type, 2022
(%)



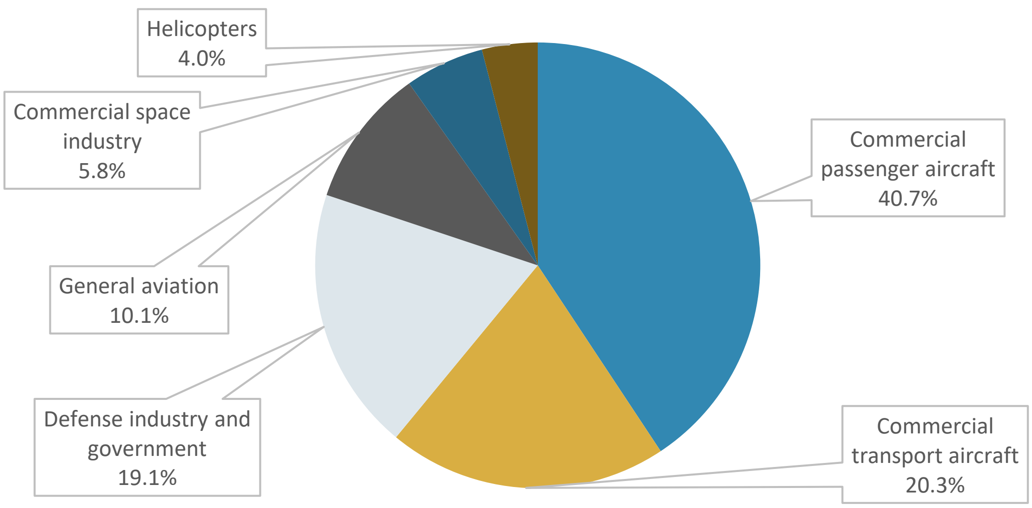
Source: BCC Research

Table 28
European Market for Advanced Aerospace Materials, by Application, Through 2028
($ Millions)

Application	2022	2023	2028	CAGR% 2023-2028
Commercial passenger aircraft	3,678.0	3,877.9	5,723.3	8.1
Defense industry and government	1,729.4	1,914.5	3,593.2	13.4
Commercial transport aircraft	1,835.2	1,977.9	3,281.4	10.7
Commercial space industry	521.2	624.9	1,557.8	20.0
General aviation	911.2	948.9	1,300.3	6.5
Helicopters	365.2	389.8	615.4	9.6
Total	9,040.2	9,733.9	16,071.4	10.5

Source: BCC Research

Figure 32
European Market Shares of Advanced Aerospace Materials, by Application, 2022
(%)



Source: BCC Research

Asia-Pacific

In Asia-Pacific, China and Japan lead the regional aircraft manufacturing industry followed by South Korea. APAC is the largest manufacturer of CFRP, a composite widely used in the aerospace industry. This gives the region a strategic advantage regarding raw material availability for aerostructure production. With a growing disposable income and increasing defense budgets in the region, the domestic market for airline service and aircraft has increased in the last decade in Asia-Pacific.

Airlines in the Asia-Pacific area have ordered numerous aircraft to accommodate the rising demand. For instance, Chinese airlines like China Southern, China Eastern and Air China have placed several orders for aircraft from producers like Boeing and Airbus in recent years. Furthermore, nations like China and India have invested heavily in satellite technology and space exploration. The space industry has the potential to expand thanks to the use of advanced materials for components of rockets, spacecraft and satellites.

Companies such as Airbus and Boeing are expanding their production capacity in APAC to leverage the rising demand for low-cost carriers like AirAsia, IndiGo and Lion Air. Also, domestic competitors such as Commercial Aircraft Corp. of China (COMAC) and Mitsubishi Aircraft Corp. have been strengthening their capabilities. With recovering domestic and international aircraft manufacturing activities, the local production for aircraft components and aerostructures will grow rapidly, increasing demand for advanced metals and composites in aerospace applications in the region at higher rates.

The Chinese government is focusing on increasing its domestic aircraft production capacity to reduce its dependency on U.S.-based manufacturers. The government's plan "Made in China 2025," puts aerospace in the spotlight to leverage existing capabilities and build China up as a trustworthy brand for aerospace products. The government's civil and military fusion strategy has also boosted China's aircraft manufacturing industry growth. With the government's support, Chinese manufacturer COMAC enjoyed a stable volume of orders. COMAC caters to the demand for commercial aircraft with three models, the C919, ARJ21 and CR929. These models cover the short-to-medium range turbofan and long-range widebody aircraft. The CR929 is a dual-aisle civil aircraft jointly developed by China and Russia. China has also established aerospace innovation hubs and technology clusters, such as the Xi'an Aviation Base and the Zhuhai Aerospace Park, to promote collaboration in the industry.

Japan's aerospace industry primarily started with production of defense aircraft. Even now, the country manufactures leading defense aircraft, such as the F-2 fighter, OH-1 observation helicopter, the T-4 and T-7 trainer, and the U.S.-2 search and rescue flying boat. However, over the last decade, the focus has shifted toward commercial and space vehicles. The shift can be observed by increased employment and commercial aircraft and spacecraft segment turnover. Japan plays a crucial role in the supply chain of leading commercial aircraft manufacturers Boeing and Airbus, specifically, in the production of Boeing's 767, 777, 777X and 787 family of airplanes and the Airbus's A320, A330, A350 XWB and A380 aircraft. It is also involved in the production of jet engines such as the V2500, Trent1000, GEnx, GE9X and PW1100G-JM. Indeed, Japanese manufacturers contribute more than 20% of the main structural components of the Boeing 777X.

Like China, the aerospace industry players in Japan are trying to make the industry homegrown by developing and manufacturing commercial aircraft. The Mitsubishi Spacejet is one such attempt. Mitsubishi Aircraft Corp. manufactured this aircraft to meet the demand for regional jets in the country. Considering Japanese aircraft manufacturers' experience and expertise, this trend can help shift the production hub from the Americas and European regions to Asian countries in coming years. Japan is also a major player in satellite technology and space exploration. The country's space agency, JAXA (Japan Aerospace Exploration Agency), has significantly contributed to space exploration. Creating components for satellites, launch vehicles and spacecraft requires advanced materials. Hence, there is significant growth potential in Japan for this industry.

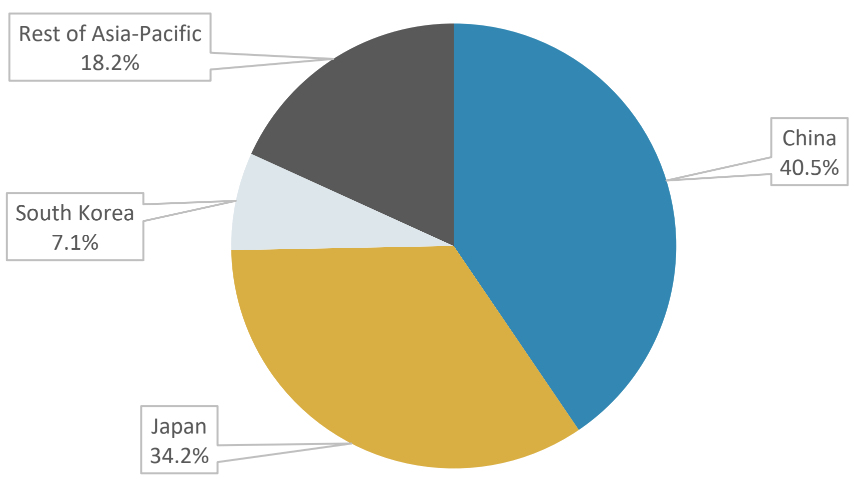
Korea Aerospace Industries (KAI), among other businesses, has significantly contributed to the production of commercial and military aircraft in South Korea. Modern materials such as lightweight composites and high-strength alloys can improve airplane performance and fuel efficiency. In the field of commercial aircraft production, South Korea has advanced significantly. Firms like Korea Aerospace Industries have been developing and producing aircraft parts including wings and fuselages for international aircraft manufacturers. South Korea has a burgeoning UAV business with uses in defense, surveillance and agriculture. This expansion is facilitated by the creation and application of cutting-edge materials in manufacturing UAVs.

Table 29
Asia-Pacific Market for Advanced Aerospace Materials, by Country, Through 2028
($ Millions)

Country	2022	2023	2028	CAGR% 2023-2028
China	1,410.5	1,510.6	2,433.6	10.0
Japan	1,191.1	1,231.0	1,664.9	6.2
South Korea	247.3	259.6	380.6	8.0
Rest of Asia-Pacific	633.8	649.4	836.7	5.2
Total	3,482.6	3,650.5	5,315.8	7.8

Source: BCC Research

Figure 33
Asia-Pacific Market Shares of Advanced Aerospace Materials,
by Country, 2022
(%)



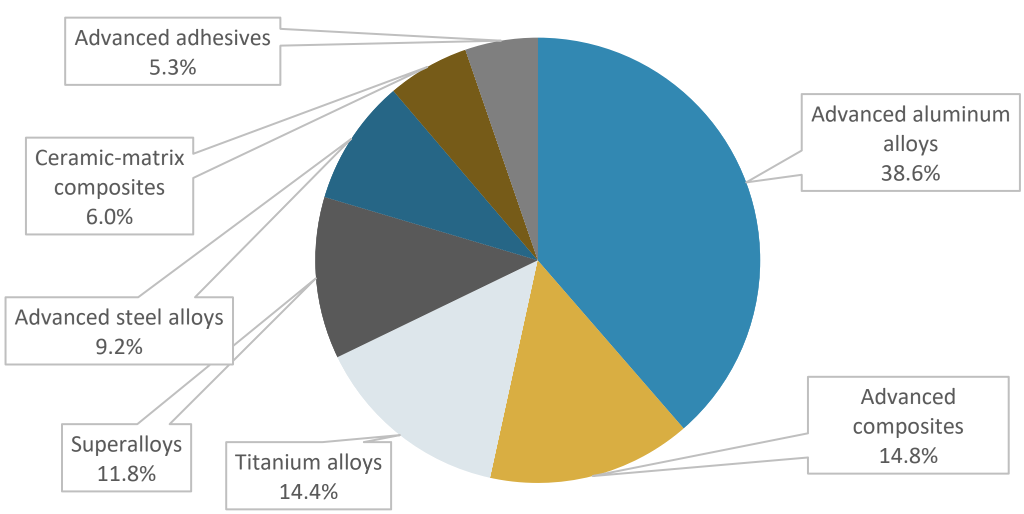
Source: BCC Research

Table 30
Asia-Pacific Market for Advanced Aerospace Materials, by Type, Through 2028
($ Millions)

Type	2022	2023	2028	CAGR% 2023-2028
Advanced aluminum alloys	1,345.0	1,387.2	1,855.2	6.0
Advanced composites	515.8	577.9	1,112.6	14.0
Titanium alloys	501.5	533.3	832.5	9.3
Superalloys	409.6	418.9	534.2	5.0
Advanced steel alloys	319.4	324.2	395.0	4.0
Ceramic-matrix composites	207.6	218.3	323.2	8.2
Advanced adhesives	183.9	190.7	263.1	6.6
Total	3,482.6	3,650.5	5,315.8	7.8

Source: BCC Research

Figure 34
Asia-Pacific Market Shares of Advanced Aerospace Materials, by Type, 2022
(%)



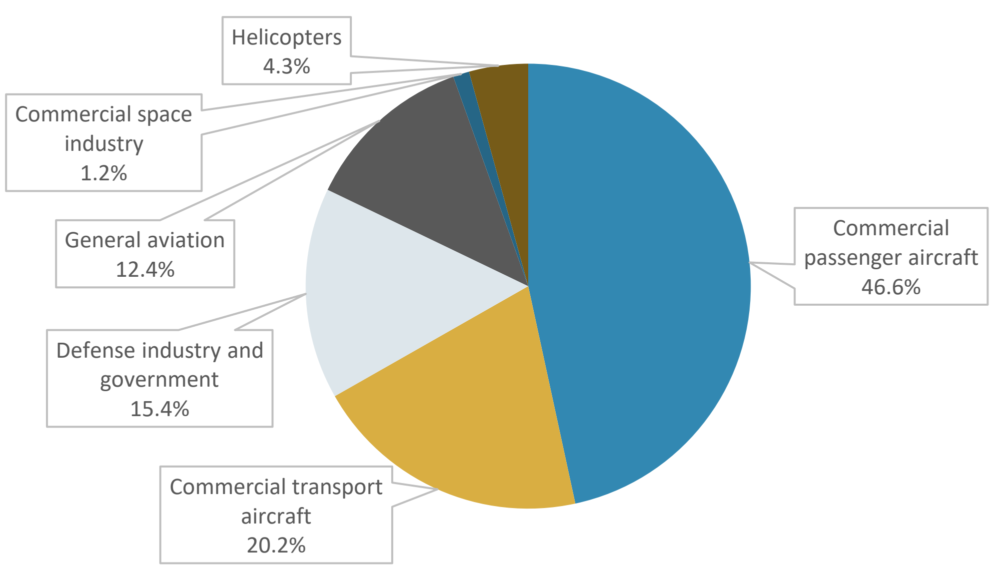
Source: BCC Research

Table 31
Asia-Pacific Market for Advanced Aerospace Materials, by Application, Through 2028
($ Millions)

Application	2022	2023	2028	CAGR% 2023-2028
Commercial passenger aircraft	1,623.1	1,670.4	2,207.7	5.7
Commercial transport aircraft	702.2	736.8	1,078.1	7.9
Defense industry and government	535.1	580.5	988.3	11.2
General aviation	431.9	440.6	553.5	4.7
Commercial space industry	41.2	67.1	271.7	32.3
Helicopters	149.3	155.2	216.6	6.9
Total	3,482.6	3,650.5	5,315.8	7.8

Source: BCC Research

Figure 35
Asia-Pacific Market Shares of Advanced Aerospace Materials, by Application, 2022
(%)



Source: BCC Research

Chapter 9

Sustainability in the Market:
An ESG Perspective

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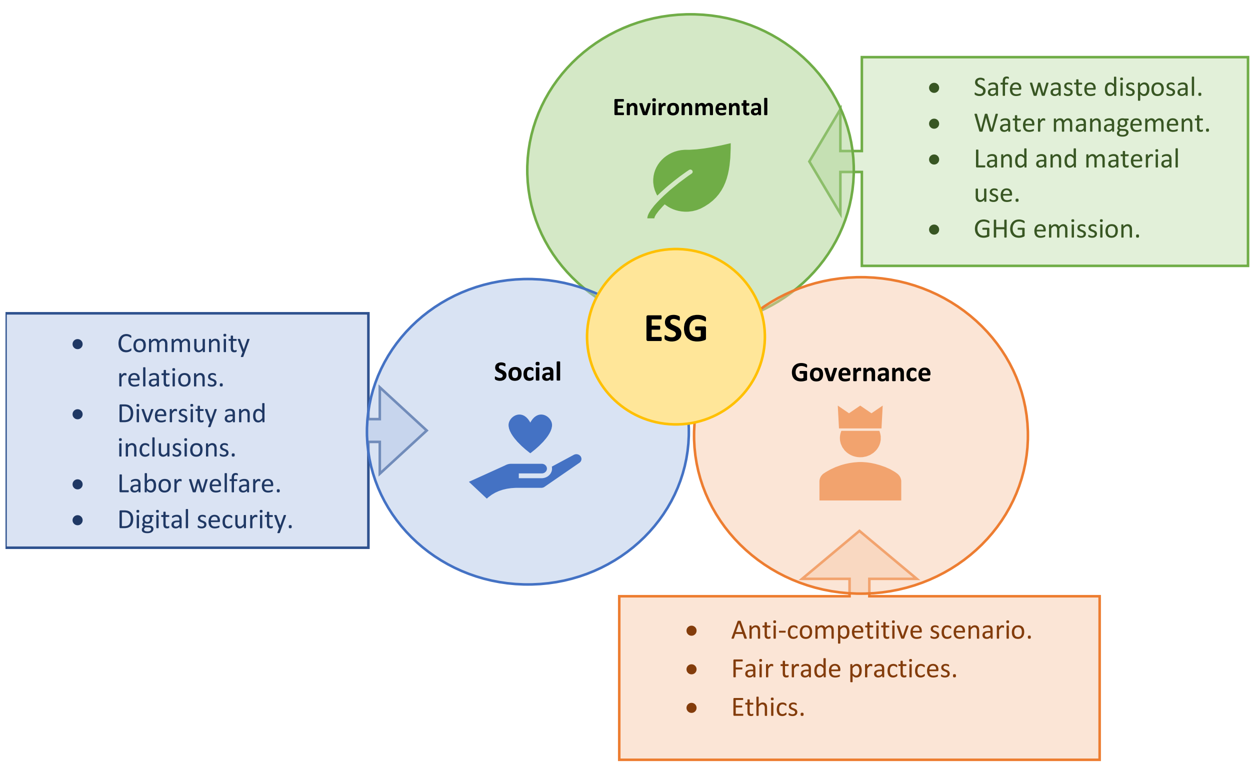
Chapter 9: Sustainability in the Market: An ESG Perspective

Importance of Environmental, Social and Governance (ESG) in the Market for Advanced Aerospace Materials

Figure 36
Environmental, Social and Governance in the Market for Advanced Aerospace Materials



Source: BCC Research

As aircraft contributes to greenhouse gas emissions and other environmental effects, the aerospace industry is under pressure to minimize its environmental impact. In order to reduce the total environmental impact of the industry, aerospace materials firms can create and offer more environmentally friendly products, methods and technology by using fundamental ESG principles. In addition to being required by law, compliance with these principles is essential for preserving a company's reputation and avoiding expensive fines.

Aerospace materials and processes can have both positive and negative environmental impacts. On the positive side, developing lightweight materials can help reduce fuel consumption and lower emissions during aircraft operation, and exploring alternative manufacturing methods can help mitigate these emissions. The use of some materials, however, may also pose environmental risks, e.g., coatings and adhesives can have adverse environmental effects. Moreover, aerospace materials manufacturing generates waste, including byproducts, scrap materials and pollutants, that can harm the environment if not properly managed. Strong environmental considerations ensure that aerospace material companies minimize their negative environmental footprint and prioritize sustainability in their operations.

With respect to the market for advanced aerospace materials, social responsibility covers concerns about creating safe and healthy working environments, pursuing ethical raw material sourcing, promoting diversity and inclusion within the workforce, developing educational programs and initiatives, maintaining strict quality control processes, etc. Social responsibility may also entail promoting supplier diversity by working with a diverse range of suppliers, building trust with stakeholders and contributing positively to society while maintaining ethical, fair and sustainable business practices.

Ethical governance practices are vital in maintaining transparency, accountability and responsible decision-making within the advanced aerospace materials industry. Effective governance includes the identification, assessment and management of risks, including supply chain, operational and financial risks. It also involves making efforts to mitigate the potential risks associated with environmental accidents, product liabilities, regulatory non-compliance and negative social impacts.

Companies can protect their reputations and avoid reputational damage by proactively managing ESG factors. Many countries have implemented or are in the process of developing regulations specifically related to advanced aerospace materials. By integrating ESG considerations into their practices, aerospace material companies can ensure compliance with existing and future regulations, reducing the risk of fines or other penalties. Implementing sustainable practices can drive an organization's research and development efforts toward developing greener technologies and cleaner solutions, which can ultimately lead to generating a competitive advantage for the company in this market.

Table 32
Interpretation of ESG Ratings and Metrics for the Market for Advanced Aerospace Materials

ESG Rating/Metric	Definition	Interpretation
Carbon footprint	Measures the amount of greenhouse gas emissions produced by a company's operations.	A lower carbon footprint indicates a more environmentally sustainable company.
Waste reduction	Measures the amount of waste produced by a company's operations and the effectiveness of its waste management practices.	Companies with effective waste reduction strategies demonstrate a commitment to sustainability.
Supply chain transparency	Measures the transparency of a company's supply chain, including its sourcing practices and labor conditions.	Companies that demonstrate transparency and accountability throughout their supply chain are likelier to have positive ESG ratings.
Employee safety and labor practices	Employee safety measures the company's safety performance and the mechanisms to maintain a safe and healthy workplace environment. Labor practices measure the various points related to labor practices, such as minimum labor rights and employee benefits.	A safe workplace offers sustainable working conditions and long-term stability in the company. Labor is a crucial factor in the production process. Fair practices make strong working culture and business operations smooth.
Diversity and inclusion	Assesses the diversity of a company's workforce, as well as its efforts to promote inclusion and equality.	Companies with diverse and inclusive workplaces are committed to social responsibility and good governance.
Board diversity	Measures the diversity of a company's board of directors, including factors such as gender, race and ethnicity.	Companies with diverse boards are more likely to have varying perspectives and ideas, which can lead to better decision-making.
Resource efficiency and emissions	Resource efficiency measures the use of renewable sources for the company's energy production and volume of water usage. Emission control measures the company's emissions, such as water and air emissions.	It is essential for the sustainable growth of an organization; renewable sources emit little to no greenhouse gases and are readily available, and in most cases, are less expensive than coal, oil or gas. A lower carbon footprint indicates a more environmentally sustainable company.
Sustainable supply chain	Measures the transparency of a company's supply chain, including	Companies that demonstrate transparency and accountability throughout their supply chain are likelier to have positive ESG ratings.

ESG Rating/Metric	Definition	Interpretation
	its sourcing practices and pollution generated during logistic trials.	

Source: BCC Research

Key ESG Issues in the Advanced Aerospace Materials Industry

Given the rapid advancements and ever-changing landscape observed in the advanced aerospace materials industry, some ESG issues are particularly relevant if not critical. These issues highlight what companies in this market must focus on to ensure sustainable and responsible practices. The primary ESG issues in the advanced aerospace materials industry include:

- Concerns related to responsible mining, recycling and exploring alternative sources of materials.
- Emerging materials must help create lighter, more fuel-efficient aircraft designs as the industry works to lessen its carbon footprint. This calls for developments that improve energy efficiency over the course of the materials' lifetimes.
- Concerns regarding workforce training and development, diversity, equitable employment opportunities and fair wages.
- Companies that manufacture aerospace materials should interact with the communities in which they do business, resolving any social issues and promoting community well-being.
- Transparent communication with stakeholders is critical in the industry.
- Aerospace materials are responsibly sourced, and ethical practices are maintained throughout the supply chain.
- Protecting intellectual property rights and managing innovation processes responsibly are key governance concerns.
- Encouraging research and development practices that prioritize sustainability, safety and ethical considerations is essential.
- Ensuring the safety and quality of materials, as well as their compliance with industry standards.
- Protecting sensitive data and intellectual property through robust data privacy and cybersecurity measures is crucial for responsible innovation.

Table 33
ESG Carbon Footprint Issue Analysis

ESG Carbon Footprint Issue Analysis	
Definition	Key Player Initiatives
Greenhouse gas emissions: • Scope 1 emissions: Direct greenhouse gas emissions from a company's sources. • Scope 2 emissions: Indirect greenhouse gas emissions from the generation of purchased energy. • Scope 3 emissions: Indirect greenhouse gas emissions from sources outside a company's operations, such as suppliers and customers.	3M company has taken initiatives to reduce Scope 1 and 2 market-based GHG emissions by at least 50% by 2030 and 80% by 2040, and to achieve carbon neutrality in its operations by 2050. In 2022, BASF targets to reduce its absolute CO_2 emission by 25% by 2030. Regular monitoring and assessing its emissions into the air is part of BASF's environmental management. In 2023, DuPont has taken initiatives to reduce Scope 1 and 2 GHG emissions by 50% from the 2019 base year and deliver carbon-neutral operations by 2050, and reduce Scope 3 emissions from purchased goods and services and end-of-life of sold products by 25% by 2030 from the 2020 base year. Source 60% of power to its operations from renewable sources by 2030 as part of its RE100 commitment. In 2022, ATI Inc. aimed for a 45% decline in greenhouse gas (GHG) emissions in all of it manufacturing facilities, compared to 2018. Level. In 2021, Ametek Inc. established a greenhouse gas (GHG) emission reduction goal to reduce combined Scope 1 and 2 emissions by 40%, normalized to sales, by 2035, from a 2019 baseline. In 2022, Arconic Corp. set goals to reduce Scope 1, 2 and 3 GHG emissions intensity by 30% and achieve a 10% reduction in energy intensity by 2030. In 2022, Arconic worked to decrease emissions from purchased metal, which is the largest contributor to Scope 3 emissions, by reducing primary metal volume by 11% and increasing scrap volume by 54%. The strategy resulted in a 13% reduction in the carbon intensity of purchased metal, leading to an approximate 11% reduction in Scope 3 emissions intensity. In 2022, Constellium's greenhouse gas (GHG) emissions intensity increased despite observed improvement in energy efficiency at most of its sites. This increase is mostly due to changes in electricity grid mixes (Scope 1 and 2) and increase of primary metal footprint purchased by European operations (Scope 3), as a consequence of the metal and

ESG Carbon Footprint Issue Analysis	
	energy crises. Despite this challenging environment, Constellium's aims to reach 30% reduction targets by 2030. As a critical component of climate actions, Hexcel committed to a 30% reduction in greenhouse gas emissions intensity between 2019-2030. In 2021, Solvay announced its plan to target carbon neutrality before 2050 and raised its 2030 GHG emissions reduction target to -30% (from -26% initially). Solvay recently announced it would accelerate the pace toward net zero emissions with a new Scope 3 target. The Group plans to reduce Scope 3 greenhouse gas emissions by -24% by 2030 against a 2018 baseline, incorporating 90% of the Group's total Scope 3 GHG emissions occurring upstream and downstream of Solvay's plants.
Environmental management	In 2022, 3M announced it would exit both per- and polyfluoroalkyl substance (PFAS) manufacturing and work to discontinue using PFAS across its product portfolio by the end of 2025. In 2022, Alcoa announced a cost-competitive decarbonization initiative through "Refinery of the Future" program. This program aims to reduce the emissions that are generated from the thermal energy used in the refining process, which are the third-largest contributor to carbon footprint of aluminum after power- and smelting-related emissions.
Energy efficiency	3M company has taken initiatives to: • Improve energy efficiency, indexed to net sales, by 30% by 2025. • Help its customers reduce their GHGs by 250 million tons of CO_2 equivalent emissions by using 3M products by 2025. • Increase renewable energy to 50% of total electricity use by 2025 and 100% by 2050.
Sustainability management	In 2022, DuPont conducted over 1,000 product stewardship reviews and identified opportunities to enhance the sustainability of existing products and avoid the use of substances of concern in the design of new products.
Renewably sourced electricity	86% of electricity powering Alcoa Corp. smelters came from renewable sources in 2022.
Environmental management	In 2022, Alcoa Corp. made 0.8% (per metric ton of alumina produced) reduction in bauxite residue land requirements.
Environmental stewardship	Hexcel specific targets for 2019-2030 include: • 30% reduction in greenhouse gas emissions intensity. • 30% reduction in landfilled waste. • 20% reduction in once-through freshwater use.

ESG Carbon Footprint Issue Analysis	
Promoting biodiversity	Solvay plans to reduce pressure on biodiversity by 30%, in areas such as terrestrial acidification, water eutrophication and marine ecotoxicity.

Source: Company sustainability reports

Table 34
ESG Water and Waste Reduction Issues Analysis

ESG Water and Waste Reduction Issues Analysis	
Definition	Key Player Initiatives
Circular economy: Designing products and processes to reduce waste and maximize resource efficiency.	In 2021, 3M company took initiatives to: • Reduce manufacturing waste by an additional 10%, indexed to sales, by 2025. • Achieve zero landfill status at more than 30% of manufacturing sites by 2025. • Reduce global water usage by 10% by 2022, 20% by 2025 and 25% by 2030, indexed to sales. • Engage 100% of water-stressed/scarce communities where 3M manufactures on communitywide approaches to water management by 2025. • Reduce dependence on virgin, fossil-based plastic by 125 million pounds by the end of 2025. • Drive supply chain sustainability through targeted raw material traceability and supplier performance assurance by 2025. In Dec. 2022, BASF aims to move toward a more circular economy by increasingly using recycled and renewable feedstocks, shaping new material cycles and creating new business models. BASF therefore launched a new Circular Economy Program. By 2030, the company aims to double its sales generated with solutions for the circular economy to \$18.8 billion (€17 billion). To achieve this, the company concentrates on three action areas: circular feedstocks, new material cycles and new business models. By 2025, BASF aims to process 250,000 metric tons of recycled and waste-based raw materials annually, replacing fossil raw materials. BASF is a member of the Ellen MacArthur Foundation, an organization to accelerate the transformation to a circular economy. BASF is taking part in the New Plastics Economy Initiative. In 2022, DuPont took the following initiatives to promote a circular economy: • Design circular products: Improved the design of its chemical mechanical planarization (CMP) pads to reduce process waste and improve efficiency, resulting in a 40% extension in pad lifetime.

ESG Water and Waste Reduction Issues Analysis	
	• Source circular raw materials: Expanded the use of recycled tin and copper (instead of mined) to support customers of Semiconductor Technologies and Interconnect Solutions businesses to expand its portfolio of solutions using 100% recycled metals. • Recapture valuable materials: Completed a mixed plastic waste recycling pilot project for DuPont Tyvek Healthcare Packaging with a large U.S. university healthcare system that diverted 13,792 pounds of plastic waste from landfill during the first nine months of the project.
Water management	In 2021, 3M and Clean Harbors, a waste handling and disposal services provider, announced a new collaborative effort to bring best-in-class status to waste handling and management aspects of 3M's operations. Through this collaborative effort, Clean Harbors will assume primary responsibility for end-to-end waste management from more than 90 sites to their dedicated facilities. In 2022, BASF introduced sustainable water management at its production sites in water stress areas and its Verbund sites by 2030. BASF joined the World Plastics Council (WPC), a global organization of leading companies in the plastics industry. The WPC promotes industry topics of global relevance, like the responsible use of plastics, efficient waste management and solutions to marine littering. By 2030, DuPont aims to implement 4R (Reduce, Reuse, Repurpose, Recycle) waste management and reduction programs at its manufacturing sites. At sites prioritized based on waste volume, hazard and reclaim value, it is setting specific milestones for reducing waste at locations where there will be the most impact. For all sites, DuPont has defined minimum expectations for a 4R program, including the requirement for a site-level waste reduction goal. In 2022, 55 of its sites had 4R programs in place. In 2022, ATI Inc. recycled more than 7 billion gallons of water at its manufacturing facilities. As a result of a series of process optimization and water efficiency and recycling initiatives, Arconic Corp.'s water withdrawal and consumption decreased by 3% and 9%, respectively, in 2022, representing a 4% decrease in overall water intensity. By 2030, Hexcel will reduce its once-through freshwater use in its manufacturing processes by 20%. In 2021, Solvay commits to decreasing its impact on freshwater withdrawal by reducing -25% freshwater intake.
Waste diversion: The percentage of waste that is diverted from landfills through recycling, composting or other means	BASF has become a partner of the Operation Clean Sweep (OSC) initiative to prove its commitment to a clean environment by signing the OCS pledge. OCS is an international program that strives

ESG Water and Waste Reduction Issues Analysis	
	to prevent plastic pellet, flake and powder loss and to ensure that these materials do not end up in the environment. In 2021, DuPont reduced its waste generated through operations and from the value chain by diverting 1,230 metric tons of waste from landfill. A 51% higher than in 2020 through 2LM (Second Life Materials) partnership with various businesses. In 2022, Arconic Corp. diverted 73% of total waste from disposal in 2022.
Solution to sustainability challenges	BASF co-founded the Alliance to End Plastic Waste (AEPW) with other companies from along the value chain—from plastics producers and consumer goods manufacturers to waste disposal companies. The AEPW has around 50 members who aim to develop solutions that stop plastic waste from entering the environment, especially the ocean. BASF supports the AEPW's goal of establishing a circular economy for plastics with its ChemCycling project. DuPont is taking initiatives to: • Reduce effluent discharge: Reduce the volume and pollution under minimum standards in environmental regulations and sustainability goals. • Reuse wastewater: Achieve savings by reducing wastewater surcharges, recycling wastewater against other water sources, or improving water availability in water scarcity regions. • Recycle by-products: Recover salts and more from wastewater streams to compensate for operation costs. • Access to affordable, safe drinking water for healthier homes and communities: DuPont offers proven water-treatment solutions—from municipal to residential—and partners with Water.org to innovate and deploy scalable, climate resilient, sustainable water solutions to vulnerable people in communities around the world. From 2018 to 2022, Alco Corp. had a ratio of 0.82:1 in active mining disturbance to mine rehabilitation.
Waste management	In 2022, Alcoa Corp. achieved 2.5% decrease in landfill waste. Out of the total waste generated in 2022 by Arconic Corp., 73% was repurposed, recovered, recycled or composted, consistent with the prior year. Hexcel is committed to reducing landfilled waste by 30% between 2019-2030. Solvay will reduce to -30% non-recoverable industrial waste, such as landfill and incineration without energy recovery.
Recovery and recycling	Approximately 25% of Hexcel's total waste is recycled, including paper, cardboard, metal, plastics, oil, solvents and production

ESG Water and Waste Reduction Issues Analysis	
	scrap. The company recycle over 80% of the dry carbon fiber waste generated by its European and U.S. operations.

Source: Company sustainability reports

Table 35
ESG Analysis of Diversity Issues

ESG Analysis of Diversity Issues	
Definition	Key Player Initiatives
Community engagement	3M company fosters and promotes a culture of diversity, equity and inclusion and the company has recently taken initiatives to: • Invest \$50 million to address racial opportunity gaps in the U.S. through workforce development and STEM education initiatives by the end of 2025. • Provide training to 5 million people globally on worker and patient safety by 2025. • Invest cash and products for education, community and environmental programs by 2025. • Provide 300,000 work hours of skills-based volunteerism by 3M employees to improve lives and help solve society's toughest challenges by the end of 2025. In 2022, Alcoa Corp. invested \$7 million in communities through Alcoa Foundation grants and corporate giving programs. In 2021, Arconic Foundation awarded \$7.8 million in grants to 137 organizations that support its communities in seven countries, including Canada, China, France, Germany, Hungary, the U.K., and the U.S. In 2022, Hexcel grant at least \$50 per employee per site annually to local nonprofit organizations, and it will increase giving through the Hexcel Foundation by 10% a year from 2022 through 2025.
Diversity, equity and inclusion: recent initiatives	In 2022, 3M has taken initiatives to: • Double the pipeline of diverse talent in management globally to build a diverse workforce by 2030. • Double the representation of underrepresented groups in management positions in our U.S. workforce. • Maintain or achieve 100% pay equity globally. 3M has also signed the Human Rights Campaign (HRC) Business Coalition for the Equality Act in the U.S. Joining HRC's Business Coalition for the Equality Act is a step forward on its path toward becoming a more inclusive company and an acknowledgment of the support for the LGBTQI+ community and equal rights for all.

ESG Analysis of Diversity Issues	
	In 2022, DuPont introduced the DE&I Excellence Awards to recognize the outstanding achievements and contributions of individuals and teams to advance diversity, equity and inclusion at DuPont and within its communities. Over 40% of 2022 new hires by ATI Inc. were diversity/inclusion candidates. In addition, the company sets an enterprise-wide target for 80% of all open job slates to include a minimum of 30% of diverse candidates. Arconic Corp. focuses on attracting and retaining diverse talent, and it has made progress on that front, with ethnic diversity in its U.S. workforce jumping from 22.6% in 2021 to 25.6% in 2022.
Empowering women	In 2022, the percentage of women in Constellium's workforce increased from 13% to 14%, while the percentage of new female hires jumped from 24% to 31%. 22% of the company's professional and management roles were held by women, vs. 21% in 2021, and Constellium is on track to reach its target of 25% in 2025. By 2022, Alcoa Corp. had 18.4% female workforce. In order to amplify focus on gender diversity, Arconic Corp. has established a goal to increase women representation from 31% to 35% within its salaried global workforce by 2030. BASF has taken initiatives to increase the proportion of women in leadership positions with disciplinary responsibility to 30% by 2030.
Employee development	Arconic Corp, is investing in employees' health and wellness, skills, career development and safety. For instance, in 2021, over 3,300 salaried employees completed more than 27,000 hours of skills training through its global learning system. In addition, the company's employees and contractors completed approximately 160,391 combined hours of EHS training during the year.
Funding stem scholarships	As part of its commitment to creating more significant equity in its communities, business practices and workplaces, 3M set a new global, education-focused goal. The company will advance economic equity by creating five million unique STEM and skilled trades learning experiences for underrepresented individuals by the end of 2025.
Food Fortification	The Food Fortification Initiative is part of BASF and constitutes a flagship shared value initiative that addresses a humanitarian challenge in an economically sustainable manner in over 40 developing countries.

Source: Company sustainability reports

Table 36
ESG Employee Safety and Labor Practices Issue Analysis

Definition	Key Player Initiatives
Ethics and compliance	Every year, DuPont requires every employee to adhere to the Code of Conduct and complete the DuPont Code of Conduct course, a web-based training module covering ethics, anti-corruption, compliance issues and related topics. Hexcel actively promote 100% compliance with all laws, regulations and company policies governing human trafficking, forced and child labor, discrimination, harassment, privacy rights, fair labor practices and freedom of association.
Human rights management	In 2022, Alco Corp scored 90 out of 100 on the Human Rights Campaign Foundation's Corporate Equality Index.
Incident prevention	In 2022, Alcoa's fatality and severe injury/illness potential (FSI-P) rate was 0.88 incidents per 100 full-time workers, which was a 17% decrease compared to 2021. In 2022, Constellium delivered a recordable case rate of 1.85 per million hours worked vs. a target of 1.5 per million hours worked in 2025. Six of its sites reached milestones of more than 1 million hours worked without a recordable case. In 2022, Hexcel aims to improve its total recordable incident rate (TRIR) by 50% between 2019-2030, based on 200,000 worker hours.
Performance and quality	In 2022, 17 locations of Alcoa Corp. were certified by ASI's Performance Standard. The company is among top 1% within the manufacture of basic precious and other non-ferrous metals industry according to EcoVadis. In 2022, Arconic had 4 ASI Performance Standard certified sites, 13 maintained ISO 14001 certified sites and five ISO 50001 energy management systems (EnMS) certified sites, which supports its 2030 targets for energy and emissions reduction. By 2025, all manufacturing sites owned by Hexcel for more than two years will be certified to ISO 14001:2015 and ISO 45001:2018.

Source: Company sustainability reports

Table 37
ESG Resource Efficiency and Emissions Issue Analysis

Definition	Key Player Initiatives
Air emissions: Lowering air emissions (including GHGs) with harmful pollutants improve the sustainability goals of an organization.	BASF planned to reduce absolute CO_2 emissions by 25% by 2030 from 21.9 MMT in 2018. In 2022, Alco Corp. reached 4.6% decrease in CO_2 emissions. Toray provides lightweight and strong carbon fiber that can reduce the weight of aircraft, to improve fuel economy and reduce CO_2 emissions.
Cobalt initiative	BASF SE and partners launched “Cobalt for Development,” a joint pilot project in the Democratic Republic of the Congo. It seeks to identify workable solutions that lead to better working conditions at the mine site.
Process Safety Events (PSEs)	BASF has set goals to reduce worldwide process safety incidents per 200,000 working hours to ≤0.1 by 2025. It also commits to reduce worldwide lost time injury rate per 200,000 working hours to ≤0.1 by 2025.
Resource efficiency	DuPont has set a goal to certify all global manufacturing sites to ISO 14001 by 2025 and to require all areas to conform to the RC 14001 management system by 2030. Approximately 75% of DuPont manufacturing sites are currently certified to ISO 14001 or RC 14001, and new sites acquired through mergers and acquisitions, where DuPont has a controlling interest, will be approved to meet these standards as part of its (Environmental, Health, and Safety Center) EH&S integration process. By 2022, ATI Inc. used more than 120,000 tons of recycled materials in production (73% of all feedstocks). In addition, for 2022, ATI’s energy consumed by its 19 manufacturing facilities was lower than its 2018 baseline year. Specifically, energy consumption declined from approximately 13.8 million GJ in 2018 to approximately 11.8 million GJ in 2022. In 2022, Arconic Corp. reached 11% reduction in primary metal volume, with 13% reduction in the carbon intensity of purchased metal and 10% reduction in overall GHG emissions intensity compared to 2021 baseline year.
Sustainability governance	In 2021, DuPont added a Sustainability Modifier to its annual employee Short-Term Incentive Program (STIP) to enhance accountability for sustainability across organization.
Research and Development	In 2022, Arconic Corp. invested $37 million in research and development, focused on innovative products and technologies that enable customers in end markets to provide consumers with greater fuel efficiency, higher safety ratings and improved thermal properties.
Recycling	In 2022, 41% of Constellium’s aluminum input came from recycled sources. As the company continues to increase its recycling capacity, including a new recycling center in facility in Neuf-Brisach, France, Constellium is on track to achieve target of 50% recycled input by 2030.

Source: Company sustainability reports

Table 38

ESG Sustainable Supply Chain Issue Analysis

Definition	Key Player Initiatives
Supply chain management	In 2022, 3M opened a new overseas shipping site in Charleston, South Carolina, to mitigate supply-chain challenges and reduce shipping time for customers in the Asia-Pacific region. In an effort to enhance supply chain sustainability, Arconic Corp. has established a goal to ensure 80% of high-risk suppliers meet its supply chain management criteria by 2030. To achieve this target, the company developed a roadmap to advance supplier sustainability by enforcing policies, increasing the traceability of sourced materials and promoting ongoing dialogue and best practices sharing.
Business for Inclusive Growth (B4IG) coalition	BASF is member of the G7 Business for Inclusive Growth (B4IG) coalition, powered by the OECD. It aims to pool and strengthen efforts by private companies to reduce inequalities linked to opportunity, gender and territories, and to build greater synergies with government-led efforts.
Supplier diversity	In 2022 DuPont increased its diverse supplier spending to $440.6 million, an increase of 23% over the prior year, and initiated the program's expansion worldwide. It is constantly working to include small and diverse businesses among sources of supply and help these businesses develop into competitive suppliers.

Source: Company sustainability reports

Table 39

ESG Data Privacy and Security Issue Analysis

Definition	Key Player Initiatives
Third-party risk management program	DuPont is developing its third-party risk management program (TPRM) by expanding the current process to address additional risk areas and third-party relationships. Under the updated TPRM program, all third parties will be screened and receive basic due diligence. Utilizing a risk-based approach, some third parties will be subject to additional and enhanced due diligence processes on business ethics; integrity; anti-corruption and bribery; trade compliance; and environmental, social and human rights.

Source: Company sustainability reports

Current Status of ESG in the Market for Advanced Aerospace Materials

ESG Score Analysis

An ESG score measures a company's risk exposure, management and value creation across ESG factors. It is used to reflect material non-financial risks and to identify focus points to analyze when assessing the value of an investment. Scoring in the previous table scales from 1 to 40 (total score), 40 being the highest, with the average companies hovering at roughly 25.

Table 40
ESG Score Analysis of Market for Advanced Aerospace Materials

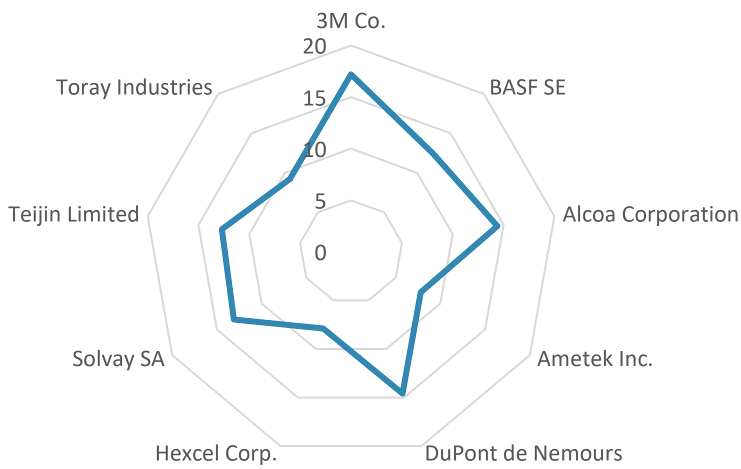
Company Name	Environmental Score	Social Score	Governance Score	Total Score
3M Co.	17.2	15.4	7.1	39.7
ATI Inc.	-	-	-	37.7
BASF SE	12.4	6.8	5.9	25.1
Alcoa Corp.	14.4	7.8	4.3	26.5
Ametek Inc.	7.8	8.7	6.9	23.4
Carpenter Technology Corp.	-	-	-	34.8
Constellium SE	-	-	-	22.8
DuPont de Nemours	14.6	7.9	5.9	28.4
Materion Corp.	-	-	-	42.1
Haynes International	-	-	-	36.8
Hexcel Corp.	7.9	13.6	7.4	28.9
Solvay SA	13.1	5.1	5.8	24.0
Teijin Ltd.	12.7	2.6	8.0	23.3
Toray Industries	9.2	3.3	8.7	21.2

Note: The hyphen indicates that the data for individual metric is not available, instead total score is provided.

Source: PitchBook Data Inc.

Environmental Score

Figure 37
Environmental Score of Major Companies in the Market for Advanced Aerospace Materials

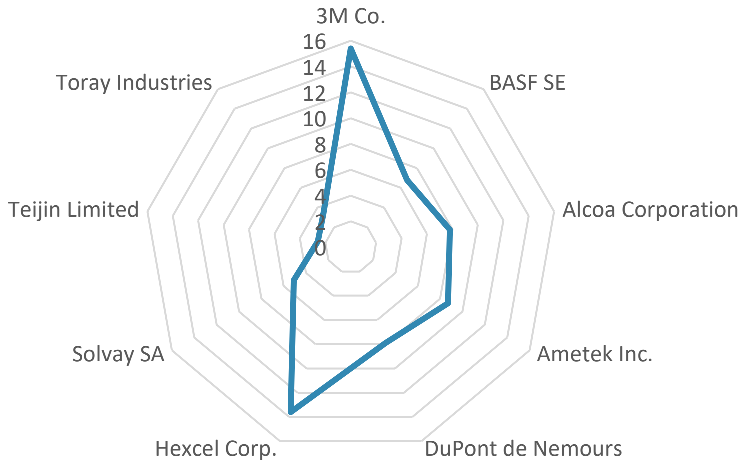


Source: PitchBook Data Inc.

Each axis represents an environmental score for a different company—3M scored 17.2, BASF SE, 12.4. 3M Co. scored the highest score in terms of the environmental scale, whereas Ametek secured the lowest position.

Social Score

Figure 38
Social Scores of Major Companies in the Market for Advanced Aerospace Materials

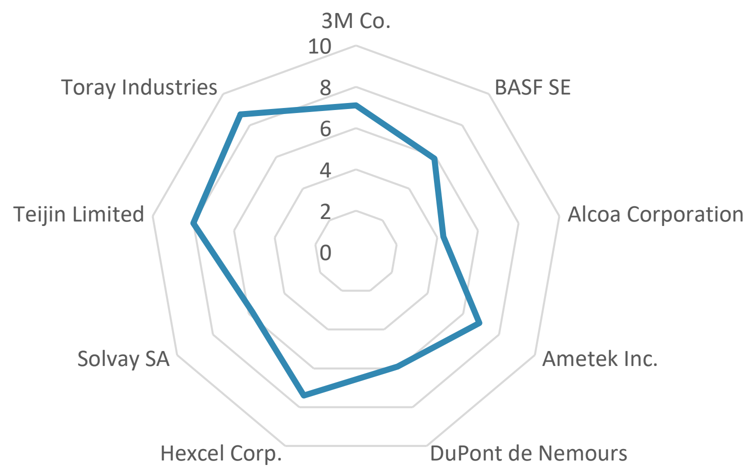


Source: PitchBook Data Inc.

Each axis represents a comparative social score for a different company—Hexcel scored 13.6, Alcoa, 7.8 and 3M Co. scored the highest in terms of the social scale and outperformed its peers' performance. Teijin Ltd. secured the lowest position, with a rating of 2.6.

Governance Score

Figure 39
Governance Scores of Major Companies in the Market for Advanced Aerospace Materials



Source: PitchBook Data Inc.

Each axis represents a comparative governance score for a different company—3M scored 7.1, BASF SE, 5.9. Toray Industries scored the highest on the front of the governance scale and outperformed peer performance, whereas Alcoa Corp. secured the lowest position, with a rating of 4.3.

Risk Scale, Exposure Scale and Management Scale

Risk Scale

The risk scale is divided into five categories: negligible, low, medium, high and severe. Based on the scale, a lower score indicates better company sustainability. Toray Industries, Teijin Ltd. and Hexcel fall under the medium category, which refers to the company's value having a medium risk of material financial impacts driven by ESG factors. 3M Co. and Materion Corp. have an increased risk of material financial impacts driven by ESG factors.

Exposure Scale

The exposure scale is divided into three categories: low, medium and high. The exposure scale presents the extent to which a company is exposed to different material ESG issues. Risk exposure can be considered a set of ESG-related factors that pose potential economic risks for companies, or a company's sensitivity or vulnerability to ESG risks. Based on the scale, a low exposure rating indicates better company sustainability. Materion, Alcoa and ATI are at high exposure risk, whereas Ametek, Toray. and Teijin are at medium exposure risk.

Management Scale

The management scale is divided into three categories: strong, average and weak. The management scale presents how well a company manages the ESG risks to which it is exposed. Based on the scale, a strong management rating indicates a better company's robustness. Alcoa, Constellium, Solvay and Toray are markedly strong, whereas other companies are rated average for their ESG exposure.

Table 41
Risk Scale, Exposure Scale and Management Scale

Company	Risk Scale	Exposure Scale	Management Scale
3M Co.	39.7	65.0	42.9
ATI Inc.	37.7	66.5	47.5
Alcoa Corp.	26.4	67.6	67.2
Ametek Inc.	23.3	38.6	41.3
BASF SE	25.2	50.7	55.9
Carpenter Technology Corp.	34.8	65.9	51.8
Constellium SE	22.8	58.3	66.8
DuPont de Nemours	28.6	56.6	55.1
Materion Corp.	42.2	68.9	44.1
Haynes International	36.9	61.6	44.1
Solvay SA	24.0	55.3	63.0
Hexcel Corp.	28.8	50.1	46.3
Teijin Ltd.	23.4	43.6	52.1
Toray Industries	21.2	42.8	56.7

Source: PitchBook Data Inc.

Key Indicators

Risk Scale

Metric	Risk Scale
Negligible	0-10
Low	10-20
Medium	20-30
High	30-40
Severe	40+

Source: PitchBook Data Inc.

Exposure Scale

Metric	Risk Scale
Low	0-35
Medium	35-55
High	55+

Source: PitchBook Data Inc.

Management Scale

Metric	Risk Scale
Strong	100-50
Avg	50-25
Weak	25-0

Source: PitchBook Data Inc.

Case Study: Examples of Successful ESG Implementation

Founded in 1902 and headquartered in St. Paul, Minnesota, 3M Co. operates as a diversified global technology services and manufacturing company. 3M is known for developing and manufacturing advanced materials that can be used in various industries, including aerospace. These materials include lightweight composites, coatings, adhesives, and thermal management solutions, which are crucial for improving the efficiency, safety, and performance of aerospace components.

It has successfully implemented ESG practices. Because 3M believes that the business activities of a company should be sustainable and should contribute to minimizing the company's global environmental impact, it strives to make effective use of resources, such as water, energy and raw materials, and helps reduce environmental pollution.

Environmental Initiatives

3M adheres to design circularity in 3M products and packaging. The company has also implemented several initiatives to reduce its carbon footprint and promote waste circularity in its operations.

- Waste
  - 3M reduces waste and strives to achieve zero-landfill status. The zero-landfill goal is intended to drive its manufacturing sites to increase product and process optimization, on-site and offsite recycling, and composting. 3M considers a site to have zero-landfill status when no byproduct has been sent directly to a landfill in a full calendar year.
  - 3M has set goals to achieve zero-landfill status at more than 30% of its manufacturing sites by 2025.

    - 3M has set goals to reduce manufacturing waste by an additional 10%, indexed to sales, by 2025.
- Water
    - 3M has decreased total water consumption by 52.8% between 2005 and 2022, indexed to corporate-wide net sales.
    - 3M has set goals to enhance the quality of water returned to the environment from industrial processes by 2030. Its initial focus is on implementing state-of-the-art water purification technology at the most significant global water-use locations and having them fully operational by 2024.
- Climate and Energy
    - 3M requires a Sustainability Value Commitment (SVC) for every new product.
    - 3M helps its customers reduce their GHGs by 250 million tons of CO_2 equivalent emissions by using 3M products by 2025.
    - The company aims to improve energy efficiency, indexed to net sales, by 30% by 2025; to reduce Scope 1 and 2 market-based GHG emissions by at least 50% by 2030 and 80% by 2040; and to achieve carbon neutrality in its operations by 2050.
    - 3M will increase renewable energy to 50% of total electricity use by 2025 and 100% by 2050.

Examples include:

- 3M partnered with the U.S. Department of Energy (DOE) on its Better Plants Challenge, part of the DOE's Better Buildings initiative designed to drive leadership in energy innovation. 3M is also involved in the Better Climate Challenge to reduce portfolio wide GHG emissions (Scope 1 and 2) by at least 50% within 10 years.

- 3M is partnering with Closed Loop Partners' Center for the Circular Economy and relevant stakeholders to conduct a 20-month study of food-grade polypropylene, which will help evaluate the feasibility of new end markets.

- 3M's 3P program is based on the belief that preventing pollution is more environmentally effective, socially acceptable and economical than treatment. The program has prevented 2.88 million short tons of pollutants and saved more than $2.37 billion.

Social Initiatives

3M recognizes the importance of equal access to science, technology, engineering and mathematics (STEM) education and careers. Equitable opportunities in STEM lead to stronger communities, a stronger brand and a brighter collective future. It also commits to advancing diversity, equity, inclusion, and social and environmental justice within the company and communities. The company has also recently taken several social initiatives, including:

- Diversity, equity and inclusion (DEI)
    - The company aims to double the pipeline of diverse global talent in management to build a diverse workforce by 2030.

    - The company aims to double the representation of underrepresented groups from entry-level through management in the U.S. workforce.
    - The company aims to maintain or achieve 100% global pay equity.
    - The company aims to double the pipeline of diverse global talent in management to build a diverse workforce by 2030.
- Community engagement
    - Invest $50 million to address racial opportunity gaps in the U.S. through workforce development and STEM education initiatives by the end of 2025.
    - Advance economic equity by creating 5 million unique STEM and skilled trades learning experiences for underrepresented individuals by the end of 2025.
    - Invest cash and products for education, community and environmental programs by 2025.
    - Provide 300,000 work hours of skills-based volunteerism by 3M employees to improve lives and help solve society's toughest challenges by the end of 2025.
    - Provide training to 5 million people globally on worker and patient safety by 2025.

Examples include:

- 3M included REAL (Reflect, Empathize, Act, Learn) Allyship training in its all-employee Learning Tracks course. More than 70,000 employees interacted with this module. Adding it to Learning Tracks underscores that allyship and inclusion are core tenets of the 3M culture.

- The 3M Community Coalition is a group of diverse leaders across Minneapolis and St. Paul, Minn. Formed in 2020, it helps guide its $50-million investment in racial equity challenges in St. Paul. The coalition's input guided 3M's decision to invest in students' basic needs, expand its internal equity initiatives and leverage 3M's assets and competencies to advance equity.

- In 2022, 3M introduced 3M Learn, a new integrated learning and development platform that replaces several disparate learning platforms and consolidates them into one flexible central system. 3M provided 25 hours of learning and development experience for its full-time equivalent (FTE) employees in 2022.

- In 2022, 3M created the role of Director of Environmental Justice to develop and elevate a global environmental justice program. It has advanced a cohesive strategy for working alongside underserved communities and starting to implement it at initial sites.

- Through 2025, 3M will advance economic equity by investing in nonprofit partnerships, creating 5 million skilled trades and STEM learning experiences designed to inspire curiosity, improve educational outcomes and provide transformational opportunities for underrepresented individuals.

Governance Initiatives

3M's robust sustainability governance structure includes oversight by its Board of Directors, which receives regular sustainability updates and reviews related to risks as part of 3M's enterprise risk management. The Science, Technology and Sustainability Committee is primarily responsible for 3M's sustainability and stewardship activities, including environmental and product stewardship efforts, environmental, health and safety, and legal and regulatory compliance. 3M's Environmental Responsibility and Sustainability Committee, comprised of top 3M executive management, provides leadership, oversight, and strategy for sustainability and develops, and monitors adherence with related policies and procedures. The company has also recently taken several governance initiatives, including:

- Reduce dependence on virgin fossil-based plastic by 125 million pounds by the end of 2025.
- Drive supply chain sustainability through targeted raw material traceability and supplier performance assurance by 2025.
- Ensure adequate recognition and ownership of the most significant potential risks to the company through the Enterprise Risk Management (ERM) initiative. In 2022, 3M added climate change risk, previously integrated as part of several high-risk areas, as a discrete risk to proactively monitor, measure and manage.

Examples include:

- In 2022, 3M created enhanced Ethics and Compliance metrics dashboards for analyzing emerging issues across different employee populations (e.g., seniority, tenure, location.). New dashboards were created for third-party due diligence and business courtesies (e.g., gifts, entertainment, meals). It monitors metrics to inform investigations and prioritize program evaluations.
- The 3M product stewardship framework incorporates a lifecycle management (LCM) approach to identify risk; assure compliance; and manage every product's environmental, health and safety profile. Its New Product Introduction (NPI) process provides a robust framework to develop products from idea to launch.
- 3M has developed a sustainability priority matrix. The matrix shows priority topics and demonstrates how sustainability goals align with the United Nations 2030 Agenda for Sustainable Development, which includes 17 Sustainable Development Goals (SDGs).
- 3M aims to meet and exceed its expanded internal diversity goals and those of the U.S. federal government, which requires certain levels of spend with small and diverse businesses. In 2022, 3M engaged a third-party provider to collect data and manage the certification process. This has helped 3M to track and contain its supplier's diversity of information, leading to more complete and accurate data.

Outcomes

The implementation of ESG practices has had several positive outcomes for 3M. The company has gained a reputation as a sustainable and socially responsible brand, which has helped to differentiate it from competitors. Embracing ESG leads to building innovative strategies, such as creating adaptive organization, developing core enabling technology competency and growing into adjacent and emerging markets. The company's commitment to ESG practices delivers progress toward its goals. 3M can therefore enhance its reputation as an environmentally responsible company and attract environmentally conscious customers and investors.

Adopting ESG practices allows 3M to address social issues and contribute to the well-being of communities. The group has determined “diversity and inclusion,” “safe people and operations” and “growth with communities” as important issues related to society. This can also involve employee volunteer programs, philanthropic activities and nonprofit partnerships. By supporting education, healthcare and community development projects, 3M can positively impact society while strengthening its brand and employee engagement.

Strong governance practices are essential for long-term sustainability and ethical conduct. 3M can ensure transparency, accountability and integrity in its operations by adhering to high standards of corporate governance. This includes maintaining an independent board of directors, implementing effective risk management processes and promoting ethical behavior throughout the organization. Good governance strengthens investor confidence, reduces legal and reputational risks, and supports long-term value creation.

3M’s successful implementation of ESG practices has helped to establish the company as a leader in environmental sustainability and social responsibility in the advanced aerospace materials industry. The company’s commitment to ESG practices has also helped to attract and retain customers who prioritize sustainable and ethical products, which has led to positive financial outcomes for the company. Major contributions by 3M in the emerging materials In aerospace industry includes:

- 3M is known for its adhesive and tape technologies. In the aerospace industry, these products are used for bonding, sealing, and fastening various components, ensuring structural integrity and safety.

- 3M develops aerospace materials that are designed to reduce the environmental impact, such as lightweight composites that improve fuel efficiency or materials with longer lifespans that reduce waste.

- The company promote the use of recyclable or upcycled materials in aerospace applications, contributing to a circular economy.

- 3M focus on improving resource efficiency in its manufacturing processes to reduce energy consumption, emissions, and waste generation.

- 3M adhere to ethical business practices and transparency in its dealings with suppliers, customers, and stakeholders.

- Ensuring compliance with environmental and safety regulations in the aerospace sector is crucial for good governance.

Future of ESG: Emerging Trends and Opportunities

The future of ESG in the advanced aerospace materials industry looks promising. Companies in the industry are likely to focus more on sustainably sourcing raw materials. They also prioritize employee well-being, diversity and inclusion, and community engagement initiatives as part of their strategies. Future ESG reporting standards are expected to become more robust and standardized, allowing stakeholders to make better-informed decisions. As sustainability and responsible business practices gain importance, ESG considerations will significantly shape the industry's future.

Key aspects include:

- Manufacturers of aerospace materials are likely to concentrate on getting materials in a more ethical and sustainable way. This entails lowering the negative effects of mining and extraction on the environment, assuring ethical material procurement and minimizing any resulting social and environmental harm.

- Adoption of circular economy practices to minimize waste and promote recycling. This could involve take-back programs, energy-efficient production processes and designing products with end-of-life considerations.

- Companies may set targets to achieve carbon neutrality in their operations. They might also invest in carbon offset programs to balance out their emissions, contributing to their overall sustainability efforts.

- Production of aerospace materials will change to be more ecologically friendly. Reducing energy use, pollution, and waste during the production of innovative materials is necessary.

- One of the most important aspects of ESG efforts will be ensuring an ethical and accountable supplier chain. This includes keeping an eye on and managing suppliers to adhere to ethical and sustainable standards.

Concluding Remarks from BCC Research

ESG has recently gained significant attention as businesses and industries increasingly recognize the importance of sustainability and responsible practices. ESG considerations will play an increasingly pivotal role in shaping the direction of advanced aerospace materials research, development and commercialization. Many industries, including the advanced materials sectors, incorporate ESG principles into their operations and decision-making processes. Responsible waste management and minimizing potential risks associated with metals and composites will be paramount here. Researchers are exploring life cycle assessment (LCA) of emerging materials to evaluate their ecological footprints from raw material extraction to disposal. The aim is to identify potential risks, minimize resource consumption and develop sustainable production processes.

Social considerations in the advanced aerospace materials industry has also been gaining recognition. Stakeholder engagement and public perception are playing vital roles in shaping responsible practices. Other important considerations include prioritizing workers' health and safety, promoting fair labor practices and engaging with local communities. A positive relationship with employees and stakeholders can contribute to long-term business success and reputation. Efforts are being made to ensure transparent communication regarding novel aerospace alloys and composites benefits and potential risks, addressing public concerns and incorporating societal needs into research and development processes. Companies are investing in environmental education and awareness initiatives to promote sustainable practices and responsible resource management. This can involve organizing workshops, seminars or educational campaigns for employees, local communities, and schools to raise awareness regarding social and environmental issues and encourage sustainable behavior.

Governance initiatives (e.g., transparency, accountability) are essential for building consumer trust. Ensuring responsible practices throughout the supply chain is crucial. Companies can establish supplier codes of conduct, conduct due diligence to assess supplier compliance and promote responsible sourcing practices, including environmental and social criteria, when selecting suppliers. Some companies are making progress by disclosing their ESG practices and improvement, but many others still have not yet made these commitments. Governments and regulatory bodies are working toward establishing guidelines and standards to ensure safe and responsible use of advanced aerospace materials. Effective governance frameworks can enhance operational efficiency, reduce risks and build stakeholder trust. The regulatory landscape, however, varies across regions, and harmonization efforts are ongoing to create consistent guidelines.

In conclusion, the successful integration of ESG in the advanced aerospace materials industry will contribute to its growth and profitability and play a pivotal role in addressing global challenges and building a more sustainable and equitable future for all.

Chapter 10

Patent Analysis

Chapter 10: Patent Analysis

Patent Activity Analysis

Patent Lens is a reliable information source related to advanced aerospace materials. In this chapter, issued patents are analyzed with respect to numbers and technologies to better understand the global market for advanced aerospace materials. This analysis does not include patent applications that were not approved or are currently under review.

From a business standpoint, patents are paramount, as they provide the necessary protection for newly developed products or processes. Primary inventions adequately protected by patents have created new industries and companies. Patents' wide-ranging economic significance is that they can prevent competitors from exploiting inventions for up to 20 years. This enables inventors to recoup development costs and gives them time to obtain a fair return on their investment. Adequate patent protection is a stimulus to R&D and an essential requirement for raising venture capital. It fosters technical innovation crucial to competitiveness and overall economic growth.

Importance of Patent Analysis

The use of patent analysis to evaluate and understand trends in the development of technologies and the competitive positioning of organizations within areas of technology is an evolving field with many exciting recent developments. These include improved techniques for the following:

- Assessing the technological and competitive landscape in which an organization operates.
- Changing emphasis in activities over time.
- Identifying the key technologies on which an organization's portfolio is built.

Patent Screening: The patent database was searched using several parameters to understand the technologies and their importance in the current marketplace. Screening-related information has been described below:

- The first screening used "advanced aluminum alloys in aerospace" keywords in the patent descriptive text. A search of all active patents revealed 437 patents using this term.

- The second screening used "advanced steel alloys in aerospace" keywords in the patent descriptive text. A search of all active patents revealed 366 patents using this term.

- The third screening used "superalloys in aerospace" keywords in the patent descriptive text. A search of all active patents revealed 396 patents using this term.

- The fourth screening used "CFRP in aerospace" keywords in the patent descriptive text. A search of all active patents revealed 379 patents using this term.

- The fifth screening used "titanium alloys in aerospace" keywords in the patent descriptive text. A search of all active patents revealed 1,653 patents using this term.
- The sixth screening used "ceramic-matrix composites in aerospace" keywords in the patent descriptive text. A search of all active patents revealed 1,095 patents using this term.
- The seventh screening used "advanced adhesives in aerospace" keywords in the patent descriptive text. A search of all active patents revealed 804 patents using this term.

Patent Analysis Based on Country of Origin for Advanced Aluminum Alloys in Aerospace

The following table depicts the number of patents related to advanced aluminum alloys in aerospace that were issued from January 2021 to October 2023 to various companies based on their country of operation.

Table 42
Patents Related to Advanced Aluminum Alloys in Aerospace, by Region of Origin, January 2021 to October 2023
(No. of Patents)

Country of Origin	No. of Patents
U.S.	379
Europe	58
Total	437

Source: BCC Research

Patent Analysis Based on Year Issued for Advanced Aluminum Alloys in Aerospace

The following table depicts the number of patents related to advanced aluminum alloys in aerospace that were issued from January 2021 to October 2023 based on the year the patent was issued.

Table 43
Patents Related to Advanced Aluminum Alloys in Aerospace, by Year Issued, January 2021 to October 2023
(No. of Patents)

2021	2022	Through October 2023	No. of Patents
142	142	153	437

Source: BCC Research

Patent Analysis Based on Companies to Which Patents Were Issued for Advanced Aluminum Alloys in Aerospace

The following table depicts the patents issued to companies worldwide for various technologies and products connected to advanced aluminum alloys in aerospace from January 2021 to October 2023.

Table 44
Patents Related to Advanced Aluminum Alloys in Aerospace, by Company, January 2021 to October 2023
(No. of Patents)

Company	No. of Patents
Monolithic 3D Inc.	22
Sila Nanotechnologies Inc.	18
Applied Materials Inc.	14
Boeing Co.	11
Cytec Industries Inc.	11
Other companies	361
Total	437

Source: BCC Research

Table 45

List of Patents on Advanced Aluminum Alloys in Aerospace, 2022

Display Key	Application Date	Title	Applicants
US 11565811 B1	1/28/2022	Blended wing body aircraft with transparent panels	Blended Wing Aircraft Inc.
US 11684959 B2	2/4/2022	Extrusion processes for forming extrusions of a desired composition from a feedstock	Battelle Memorial Institute
US 11633926 B2	2/23/2022	Aligned fiber-reinforced molding	Arris Composites Inc.
US 11342214 B1	3/10/2022	Methods for producing a 3D semiconductor memory device and structure	Monolithic 3D Inc.
US 11769601 B2	3/4/2022	Material configuration enables the flexibility of a structure using rigid components.	Stemrad Ltd.
US 11726502 B2	4/4/2022	Control systems for unmanned aerial vehicles	Teledyne Flir Detection Inc.
US 11697507 B1	4/28/2022	Aircraft with a multi-walled fuel tank and a method of manufacturing	Blended Wing Aircraft Inc.
US 11508605 B2	5/2/2022	3D semiconductor memory device and structure	Monolithic 3D Inc.
US 11682801 B1	6/8/2022	Processes for recycling spent catalysts, recycling rechargeable batteries, and integrated processes thereof	Aleon Renewable Metals LLC
US 11685969 B2	6/28/2022	Electrodes for biosensors	Materion Corp
US 11688855 B2	6/8/2022	Battery electrode composition comprising biomass-derived carbon	Sila Nanotechnologies Inc.
US 11569117 B2	6/30/2022	3D semiconductor device and structure with single-crystal layers	Monolithic 3D Inc.
US 11610802 B2	6/22/2022	Method for producing a 3D semiconductor device and structure with single crystal transistors and metal gate electrodes	Monolithic 3D Inc.
US 11560804 B2	6/3/2022	Methods for depositing coatings on aerospace components	Applied Materials Inc.
US 11635803 B2	6/8/2022	Industrial safety systems and/or methods for creating and passively detecting changes in electrical fields	Guardian Glass LLC
US 11635804 B2	6/8/2022	Systems and/or methods incorporating electrical tomography-related algorithms and circuits	Guardian Glass LLC
US 11661641 B2	7/21/2022	Hydrogen storage systems using non-pyrophoric hydrogen storage alloys	Harnyss IP LLC
US 11613817 B2	8/16/2022	Negative emission, large-scale carbon capture for clean fossil fuel power generation	Lyten Inc.
US 11691001 B2	8/3/2022	Methods for transcutaneous facial nerve stimulation and applications thereof	Neurotrigger Ltd.
US 11746434 B2	7/20/2022	Methods of forming a metal coated article	Battelle Energy Alliance LLC
US 11615977 B2	9/15/2022	3D semiconductor memory device and structure	Monolithic 3D Inc.
US 11735462 B2	12/25/2022	3D semiconductor device and structure with single-crystal layers	Monolithic 3D Inc.

Display Key	Application Date	Title	Applicants
US 11585731 B2	9/8/2022	Sensors incorporated into semi-rigid structural members to detect physical characteristic changes.	Lyten Inc.

Note: Not all patents dated from 2021 to 2023 were listed in the table above. The list of patents included here has been filtered based on application date, not publication date.

Source: Patent Lens

Patent Analysis Based on Country of Origin for Advanced Steel Alloys in Aerospace

The following table depicts the number of patents issued from January 2021 to October 2023 to various companies based on their country of operation.

Table 46
Patents Related to Advanced Steel Alloys in Aerospace, by Country of Origin, January 2021 to October 2023
(No. of Patents)

Country of Origin	No. of Patents
U.S.	310
Europe	56
Total	366

Source: BCC Research

Patent Analysis Based on Year Issued for Advanced Steel Alloys in Aerospace

The following table depicts the number of advanced steel alloys in aerospace patents issued from January 2021 to October 2023, based on the year the patent was issued.

Table 47
Patents Related to Advanced Steel Alloys in Aerospace, by Year Issued, January 2021 to October 2023
(No. of Patents)

2021	2022	Through October 2023	No. of Patents
123	119	124	366

Source: BCC Research

Patent Analysis Based on Companies to Which Patents Were Issued for Advanced Steel Alloys in Aerospace

The following table depicts the patents issued to companies worldwide for various technologies and products connected to advanced steel alloys in aerospace from January 2021 to October 2023.

Table 48
Patents Related to Advanced Steel Alloys in Aerospace, by Company, January 2021 to October 2023
(No. of Patents)

Company	No. of Patents
Applied Materials Inc.	14
May Patents Ltd.	7
Sila Nanotechnologies Inc.	6
XR Reserve LLC	5
XR Downhole LLC	5
Toyota Motor Engineering and Manufacturing North America Inc.	5
Toyota Motor Corp.	5
RTX Corp.	5
Lyten Inc.	5
California Institute of Technology	5
Other companies	304
Total	366

Source: BCC Research

Table 49
List of Patents on Advanced Steel Alloys in Aerospace, 2022

Display Key	Application Date	Title	Applicants
US 11684959 B2	2/4/2022	Extrusion processes for forming extrusions of a desired composition from a feedstock	Battelle Memorial Institute
US 11661641 B2	7/21/2022	Hydrogen storage systems using non-pyrophoric hydrogen storage alloys	Harnyss IP LLC
US 11746875 B2	10/4/2022	Cam follower with polycrystalline diamond engagement element	XR Reserve LLC
US 11746434 B2	7/20/2022	Methods of forming a metal coated article	Battelle Energy Alliance LLC
US 11578958 B2	1/16/2022	High explosive fragmentation mortars	Omnitek Partners LLC
US 11682801 B1	6/8/2022	Processes for recycling spent catalysts, recycling rechargeable batteries, and integrated processes thereof	Aleon Renewable Metals LLC
US 11685969 B2	6/28/2022	Electrodes for biosensors	Materion Corp.
US 11565811 B1	1/28/2022	Blended wing body aircraft with transparent panels	Blended Wing Aircraft Inc.

Display Key	Application Date	Title	Applicants
US 11697507 B1	4/28/2022	Aircraft with a multi-walled fuel tank and a method of manufacturing	Blended Wing Aircraft Inc.
US 11613817 B2	8/16/2022	Negative emission, large-scale carbon capture for clean fossil fuel power generation	Lyten Inc.
US 11585731 B2	9/8/2022	Sensors incorporated into semi-rigid structural members to detect physical characteristic changes.	Lyten Inc.
US 11555761 B1	9/8/2022	Sensors incorporated into elastomeric components to detect physical characteristic changes.	Lyten Inc.
US 11639427 B2	7/11/2022	Method for manufacturing prepreg, coating device, and apparatus for manufacturing prepreg	Toray Industries
US 11633926 B2	2/23/2022	Aligned fiber-reinforced molding	Arris Composites Inc.
US 11688855 B2	6/8/2022	Battery electrode composition comprising biomass-derived carbon	Sila Nanotechnologies Inc.
US 11643653 B2	4/25/2022	Treating and preventing microbial infections	SNIPR Biome ApS
US 11560804 B2	6/3/2022	Methods for depositing coatings on aerospace components	Applied Materials Inc.
US 11563932 B2	3/3/2022	Estimating the real-time delay of a video data stream	Edgy Bees Ltd.
US 11639134 B1	3/1/2022	Interior rearview mirror assembly with driver monitoring system	Magna Mirrors of America Inc.
US 11761441 B1	8/19/2022	Spring controlling valve	Vulcan Ind Holdings LLC

Note: Not all patents dated from 2021 to 2023 were listed in the table above. The list of patents included here has been filtered based on application date, not publication date.

Source: Patent Lens

Patent Analysis Based on Country of Origin for Superalloys in Aerospace

The following table depicts the number of patents related to superalloys that were issued from January 2021 to October 2023 to various companies based on their country of operation.

Table 50
Patents Related to Superalloys in Aerospace, by Country of Origin, January 2021 to October 2023
(No. of Patents)

Country of Origin	No. of Patents
U.S.	324
Europe	72
Total	396

Source: BCC Research

Patent Analysis Based on Year Issued for Superalloys in Aerospace

The following table depicts the number of superalloys in aerospace patents issued from January 2021 to October 2023, based on the year the patent was issued.

Table 51
Patents Related to Superalloys in Aerospace, by Year Issued, January 2021 to October 2023
(No. of Patents)

2021	2022	Through October 2023	No. of Patents
155	141	100	396

Source: BCC Research

Patent Analysis Based on Companies to Which Patents Were Issued for Superalloys in Aerospace

The following table depicts the patents issued to companies worldwide for various technologies and products related to superalloys in aerospace from January 2021 to October 2023.

Table 52
Patents Related to Superalloys in Aerospace, by Company, January 2021 to October 2023
(No. of Patents)

Company	No. of Patents
RTX Corp.	129
Raytheon Technologies Corp.	19
Applied Materials Inc.	14
The Boeing Co.	12
Solar Turbines Inc.	11
Honeywell International Inc.	11
General Electric Co.	10
Other companies	190
Total	396

Source: BCC Research

Table 53
List of Patents on Superalloys in Aerospace, 2022

Display Key	Application Date	Title	Applicants
US 11560804 B2	6/3/2022	Methods for depositing coatings on aerospace components	Applied Materials Inc.
US 11725261 B2	4/6/2022	A nickel-based superalloy, single-crystal blade and turbomachine	Safran and Office National Detudes Rech Aerospatiales
US 11753704 B2	1/18/2022	Low-melt superalloy powder for liquid-assisted additive manufacturing of a superalloy component	Siemens Energy Inc.
US 11697865 B2	1/18/2022	High-melt superalloy powder for liquid-assisted additive manufacturing of a superalloy component	Siemens Energy Inc.
US 11746875 B2	10/4/2022	Cam follower with polycrystalline diamond engagement element	XR Reserve LLC
US 11666994 B2	7/25/2022	Integrated horn structures for heat exchanger headers	Hamilton Sundstrand Corp.
US 11635021 B2	3/17/2022	Compression in a gas turbine engine	Rolls Royce Plc
US 11629663 B2	1/28/2022	Energy conversion apparatus	Gen Electric
US 11754094 B2	3/8/2022	Modal noise reduction for gas turbine engine	Raytheon Tech Corp and RTX Corp.
US 11725670 B2	8/22/2022	Compressor flow path	Raytheon Tech Corp.
US 11549387 B2	3/8/2022	Gas turbine engine forward bearing compartment architecture	Raytheon Tech Corp.
US 11680492 B2	4/1/2022	Epicyclic gear train	Raytheon Tech Corp.
US 11585268 B2	5/5/2022	Geared turbofan engine with targeted modular efficiency	Raytheon Tech Corp.
US 11608786 B2	4/27/2022	Gas turbine engine with power density range	Raytheon Tech Corp.

Note: Not all patents dated from 2021 to 2023 were listed in the table above. The list of patents included here has been filtered based on application date, not publication date.

Source: Patent Lens

Patent Analysis Based on Country of Origin for CFRP in Aerospace

The following table depicts the number of patents for CFRP in aerospace that were issued from January 2021 to October 2023 to various companies based on their country of operation.

Table 54
Patents Related to CFRP in Aerospace, by Country of Origin, January 2021 to October 2023
(No. of Patents)

Country of Origin	No. of Patents
U.S.	267
Europe	110
Germany	2
Total	379

Source: BCC Research

Patent Analysis Based on Year Issued for CFRP in Aerospace

The following table depicts the number of CFRP in aerospace patents issued from January 2021 to October 2023, based on the year the patent was issued.

Table 55
Patents Related to CFRP in Aerospace, by Year Issued, January 2021 to October 2023
(No. of Patents)

2021	2022	Through October 2023	No. of Patents
121	123	135	379

Source: BCC Research

Patent Analysis Based on Companies to Which Patents Were Issued for CFRP in Aerospace

The following table depicts the patents issued to companies worldwide for various technologies and products related to CFRP in aerospace from January 2021 to October 2023.

Table 56
Patents Related to CFRP in Aerospace, by Company, January 2021 to October 2023
(No. of Patents)

Company	No. of Patents
The Boeing Co.	139
Toray Industries	12
Rolls Royce Plc	12
Airbus Operations GmbH	10
Other companies	206
Total	379

Source: BCC Research

Table 57
List of Patents on CFRP in Aerospace, 2022

Display Key	Application Date	Title	Applicants
US 11767128 B2	2/28/2022	Lightning protection in aircraft constructed with carbon fiber-reinforced plastic	The Boeing Co.
US 11713732 B2	5/16/2022	Laminates of polysilazane and carbon fiber-reinforced polymer	Boeing Co.
US 11639427 B2	7/11/2022	Method for manufacturing prepreg, coating device, and apparatus for manufacturing prepreg	Toray Industries
US 11661518 B2	3/16/2022	Anisotropic ice-phobic coating	Integran Tech Inc.
US 11565811 B1	1/28/2022	Blended wing body aircraft with transparent panels	Blended Wing Aircraft Inc.
US 11667798 B2	3/16/2022	Anisotropic ice phobic and biocidal coatings	Integran Tech Inc.
US 11697507 B1	4/28/2022	Aircraft with a multi-walled fuel tank and a method of manufacturing	Blended Wing Aircraft Inc.

Note: Not all patents dated from 2021 to 2023 were listed in the table above. The list of patents included here has been filtered based on application date, not publication date.

Source: Patent Lens

Patent Analysis Based on Country of Origin for Titanium Alloys in Aerospace

The following table depicts the number of patents related to titanium alloys in aerospace that were issued from January 2021 to October 2023 to various companies based on their country of operation.

Table 58

Patents Related to Titanium Alloys in Aerospace, by Country of Origin, January 2021 to October 2023

(No. of Patents)

Country of Origin	No. of Patents
U.S.	1,245
Europe	403
Russia	4
Saudi Arabia	1
Total	1,653

Source: BCC Research

Patent Analysis Based on Year Issued for Titanium Alloys in Aerospace

The following table depicts the number of titanium alloys in aerospace patents issued from January 2021 to October 2023, based on the year the patent was issued.

Table 59

Patents Related to Titanium Alloys in Aerospace, by Year Issued, January 2021 to October 2023

(No. of Patents)

2021	2022	Through October 2023	No. of Patents
591	562	500	1,653

Source: BCC Research

Patent Analysis Based on Companies to Which Patents Were Issued for Titanium Alloys in Aerospace

The following table depicts the patents issued to companies worldwide for various technologies and products related to titanium alloys in aerospace from January 2021 to October 2023.

Table 60
Patents Related to Titanium Alloys in Aerospace, by Company, January 2021 to October 2023
(No. of Patents)

Company	No. of Patents
The Boeing Co.	144
RTX Corp.	41
Raytheon Technologies Corp.	24
Rolls-Royce Plc	21
PRC-Desoto International Inc.	18
Monolithic 3D Inc.	18
PPG Industries Ohio Inc.	17
General Electric Co.	16
GM Global Technology Operation	14
Applied Materials Inc.	14
Other companies	1,326
Total	1,653

Source: BCC Research

Table 61
List of Patents on Titanium Alloys in Aerospace, 2022

Display Key	Application Date	Title	Applicants
US 11560804 B2	6/3/2022	Methods for depositing coatings on aerospace components	Applied Materials Inc.
US 11629394 B2	8/4/2022	Method for preparing gradient-hardened titanium alloy	Beijing Institute Tech
US 11618935 B1	3/30/2022	Manufacturing method of aluminum alloy with high thermal conductivity	Charng Chyi Aluminum Co. Ltd.
US 11684959 B2	2/4/2022	Extrusion processes for forming extrusions of a desired composition from a feedstock	Battelle Memorial Institute

Display Key	Application Date	Title	Applicants
US 11661641 B2	7/21/2022	Hydrogen storage systems using non-pyrophoric hydrogen storage alloys	Harnyss IP LLC
US 11703107 B2	6/7/2022	Compact modular right-angle drive gear-aligned actuator	Raytheon Co.
US 11746434 B2	7/20/2022	Methods of forming a metal coated article	Battelle Energy Alliance LLC
US 11725261 B2	4/6/2022	A nickel-based superalloy, single-crystal blade and turbomachine	Safran and Office National Detudes Rech Aerospatiales
US 11724313 B2	6/3/2022	Scandium-containing aluminum alloy for powder metallurgical technologies	Airbus Defense & Space GmbH
US 11767574 B2	7/15/2022	Ultrahigh strength maraging stainless steel with multiphase strengthening and preparation method thereof	Harbin Engineering University
US 11708629 B2	5/3/2022	High-strength ductile 6000 series aluminum alloy extrusions	GM Global Tech Operations LLC
US 11661518 B2	3/16/2022	Anisotropic ice-phobic coating	Integran Tech Inc.
US 11685969 B2	6/28/2022	Electrodes for biosensors	Materion Corp.
US 11724334 B2	3/11/2022	Continuous ultrasonic additive manufacturing	Honda Motor Co. Ltd. and Ohio State Innovation Foundation
US 11746875 B2	10/4/2022	Cam follower with polycrystalline diamond engagement element	XR Reserve LLC
US 11667798 B2	3/16/2022	Anisotropic ice phobic and biocidal coatings	Integran Tech Inc.
US 11718896 B2	6/30/2022	Nano-lanthanum oxide reinforced tungsten-based composite material and preparation method thereof	Chongqing Inst Green & Intelligent Tech Cas
US 11611256 B2	1/10/2022	Electric drive systems	Rolls Royce PLC
US 11684974 B2	6/17/2022	Additive manufactured ducted heat exchanger system	Raytheon Tech Corp.
US 11767128 B2	2/28/2022	Lightning protection in aircraft constructed with carbon fiber-reinforced plastic	The Boeing Co.
US 11753704 B2	1/18/2022	Low-melt superalloy powder for liquid-assisted additive manufacturing of a superalloy component	Siemens Energy Inc.
US 11697865 B2	1/18/2022	High-melt superalloy powder for liquid-assisted additive manufacturing of a superalloy component	Siemens Energy Inc.
US 11739595 B2	7/11/2022	Mechanical connector utilizing shear pins to transfer torque	Wajnikonis Krzysztof Jan
US 11613937 B2	7/11/2022	Mechanical connector utilizing keys to transfer torque	Wajnikonis Krzysztof Jan
US 11703430 B1	12/30/2022	In-situ tensile device for X-ray tests	Chinalco Materials Application Res Institute Co Ltd. and Chinalco Materials Application Res Inst Co
US 11719103 B1	4/7/2022	Components having composite laminate with co-cured chopped fibers	Gen Electric

Display Key	Application Date	Title	Applicants
US 11742582 B2	3/22/2022	Aerial vehicles have antenna assemblies, antenna assemblies, and related methods and components.	Northrop Grumman Systems Corp.
US 11611397 B1	3/21/2022	Optical modulating device and apparatus, including the same	Samsung Electronics Co. Ltd.
US 11688855 B2	6/8/2022	Battery electrode composition comprising biomass-derived carbon	Sila Nanotechnologies Inc.
US 11697507 B1	4/28/2022	Aircraft with a multi-walled fuel tank and a method of manufacturing	Blended Wing Aircraft Inc.
US 11635021 B2	3/17/2022	Compression in a gas turbine engine	Rolls Royce Plc
US 11565811 B1	1/28/2022	Blended wing body aircraft with transparent panels	Blended Wing Aircraft Inc.
US 11639134 B1	3/1/2022	Interior rearview mirror assembly with driver monitoring system	Magna Mirrors of America Inc
US 11639427 B2	7/11/2022	Method for manufacturing prepreg, coating device, and apparatus for manufacturing prepreg	Toray Industries
US 11735716 B2	8/30/2022	Fluorides in nanoporous, electrically conductive scaffolding matrix for metal and metal-ion batteries	Sila Nanotechnologies Inc.
US 11585731 B2	9/8/2022	Sensors incorporated into semi-rigid structural members to detect physical characteristic changes.	Lyten Inc.
US 11555761 B1	9/8/2022	Sensors incorporated into elastomeric components to detect physical characteristic changes.	Lyten Inc.
US 11670826 B2	4/22/2022	Length-wise welded electrodes incorporated in cylindrical cell format lithium-sulfur batteries.	Lyten Inc.
US 11600876 B2	4/22/2022	Wound cylindrical lithium-sulfur battery, including electrically conductive carbonaceous materials	Lyten Inc.
US 11629663 B2	1/28/2022	Energy conversion apparatus	Gen Electric
US 11735462 B2	12/25/2022	3D semiconductor device and structure with single-crystal layers	Monolithic 3D Inc.
US 11508605 B2	5/2/2022	3D semiconductor memory device and structure	Monolithic 3D Inc.
US 11610802 B2	6/22/2022	Method for producing a 3D semiconductor device and structure with single crystal transistors and metal gate electrodes	Monolithic 3D Inc.
US 11342214 B1	3/10/2022	Methods for producing a 3D semiconductor memory device and structure	Monolithic 3D Inc.
US 11569117 B2	6/30/2022	3D semiconductor device and structure with single-crystal layers	Monolithic 3D Inc.
US 11615977 B2	9/15/2022	3D semiconductor memory device and structure	Monolithic 3D Inc.

Display Key	Application Date	Title	Applicants
US 11635803 B2	6/8/2022	Industrial safety systems and/or methods for creating and passively detecting changes in electrical fields	Guardian Glass LLC
US 11635804 B2	6/8/2022	Systems and/or methods incorporating electrical tomography-related algorithms and circuits	Guardian Glass LLC

Note: Not all patents dated from 2021 to 2023 were listed in the table above. The list of patents included here has been filtered based on application date, not publication date.

Source: Patent Lens

Patent Analysis Based on Country of Origin for Ceramic-Matrix Composites in Aerospace

The following table depicts the number of patents related to ceramic-matrix composites in aerospace that were issued from January 2021 to October 2023 to various companies based on their country of operation.

Table 62
Patents Related to Ceramic-Matrix Composites in Aerospace, by Country of Origin, January 2021 to October 2023
(No. of Patents)

Country of Origin	No. of Patents
U.S.	855
Europe	239
Russia	1
Total	1,095

Source: BCC Research

Patent Analysis Based on Year Issued for Ceramic-Matrix Composites in Aerospace

The following table depicts the number of ceramic-matrix composites in aerospace patents issued from January 2021 to October 2023, based on the year the patent was issued.

Table 63
Patents Related to Ceramic-Matrix Composites in Aerospace, by Year Issued, January 2021 to October 2023
(No. of Patents)

2021	2022	Through October 2023	No. of Patents
421	351	323	1,095

Source: BCC Research

Patent Analysis Based on Companies to Which Patents Were Issued for Ceramic-Matrix Composites in Aerospace

The following table depicts the patents issued to companies worldwide for various technologies and products related to ceramic-matrix composites in aerospace from January 2021 to October 2023.

Table 64
Patents Related to Ceramic-Matrix Composites in Aerospace, by Company, January 2021 to October 2023
(No. of Patents)

Company	No. of Patents
RTX Corp.	143
The Boeing Co.	80
Rolls-Royce Corp.	56
United Technologies Corp.	25
Raytheon Technologies Corp.	19
Rolls-Royce Plc	17
Sila Nanotechnologies	16
Align Technology Inc.	14
General Electric Co.	13
Other companies	712
Total	1,095

Source: BCC Research

Table 65
List of Patents on Ceramic-Matrix Composites in Aerospace, 2022

Display Key	Application Date	Title	Applicants
US 11666974 B2	2/7/2022	Method of making components with metal matrix composites and components made from that place	Purdue Research Foundation
US 11607852 B2	1/20/2022	Resistance welding methods and apparatus	Spirit Aerosys Inc. and Stitching Tprc
US 11767607 B1	7/13/2022	Method of depositing a metal layer on a component	General Electric Co.
US 11719103 B1	4/7/2022	Components having composite laminate with co-cured chopped fibers	General Electric Co.
US 11633926 B2	2/23/2022	Aligned fiber-reinforced molding	Arris Composites Inc.
US 11732604 B1	12/1/2022	Ceramic matrix composite blade track segment with integrated cooling passages	Rolls Royce Corp.
US 11661518 B2	3/16/2022	Anisotropic ice-phobic coating	Integran Tech Inc.
US 11713694 B1	11/30/2022	Ceramic matrix composite blade track segment with two-piece carrier	Rolls Royce Corp.

Display Key	Application Date	Title	Applicants
US 11724334 B2	3/11/2022	Continuous ultrasonic additive manufacturing	Honda Motor Co. Ltd. and Ohio State Innovation Foundation
US 11735716 B2	8/30/2022	Fluorides in nanoporous, electrically-conductive scaffolding matrix for metal and metal-ion batteries	Sila Nanotechnologies Inc.
US 11742582 B2	3/22/2022	Aerial vehicles have antenna assemblies, antenna assemblies, and related methods and components.	Northrop Grumman Systems Corp.
US 11732738 B1	4/28/2022	Potted-in inserts comprising a lattice structure, method of securing objects to sandwich panels therewith, and methods for producing the same	Honeywell International Inc.
US 11667798 B2	3/16/2022	Anisotropic ice phobic and biocidal coatings	Integran Tech Inc.
US 11670750 B2	2/22/2022	Curved two-dimensional nanocomposites for battery electrodes	Georgia Tech Res Inst
US 11621409 B2	2/3/2022	Curved two-dimensional nanocomposites for battery electrodes	Georgia Tech Res Inst.
US 11685977 B2	1/31/2022	Stable undercooled metallic particles for filling a void	Univ Iowa State Res Found Inc.
US 11674031 B1	3/30/2022	Container formed of a composite material including three-dimensional (3D) graphene	Lyten Inc.
US 11591457 B1	3/30/2022	Composite material, including three-dimensional (3D) graphene and malleated copolymers	Lyten Inc.
US 11543388 B2	3/1/2022	In-process quality assessment for additive manufacturing	Jentek Sensors Inc.
US 11747304 B2	1/2/2023	In-process quality assessment for additive manufacturing	Jentek Sensors Inc.
US 11613817 B2	8/16/2022	Negative emission, large-scale carbon capture for clean fossil fuel power generation	Lyten Inc.
US 11702949 B2	10/5/2022	Turbine shroud assembly with forward and aft pin shroud attachment	Rolls Royce Corp.
US 11476540 B2	2/3/2022	Microstructures and methods of making and using thereof	Dynami Battery Corp.
US 11688855 B2	6/8/2022	Battery electrode composition comprising biomass-derived carbon	Sila Nanotechnologies Inc.
US 11565811 B1	1/28/2022	Blended wing body aircraft with transparent panels	Blended Wing Aircraft Inc.
US 11585731 B2	9/8/2022	Sensors incorporated into semi-rigid structural members to detect physical characteristic changes.	Lyten Inc.
US 11555761 B1	9/8/2022	Sensors incorporated into elastomeric components to detect physical characteristic changes.	Lyten Inc.
US 11759298 B2	6/8/2022	Photopolymerizable compositions, including a urethane component and a monofunctional reactive diluent, articles, and methods	3M Innovative Properties Co.

Display Key	Application Date	Title	Applicants
US 11600876 B2	4/22/2022	Wound cylindrical lithium-sulfur battery, including electrically conductive carbonaceous materials	Lyten Inc.
US 11670826 B2	4/22/2022	Length-wise welded electrodes incorporated in cylindrical cell format lithium-sulfur batteries.	Lyten Inc.

Note: Not all patents dated from 2021 to 2023 were listed in the table above. The list of patents included here has been filtered based on application date, not publication date.

Source: Patent Lens

Patent Analysis Based on Country of Origin for Advanced Adhesives in Aerospace

The following table depicts the number of patents related to advanced adhesives in aerospace that were issued from January 2021 to October 2023 to various companies based on their country of operation.

Table 66
Patents Related to Advanced Adhesives in Aerospace, by Country of Origin, January 2021 to October 2023
(No. of Patents)

Country of Origin	No. of Patents
U.S.	670
Europe	134
Total	804

Source: BCC Research

Patent Analysis Based on Year Issued for Advanced Adhesives in Aerospace

The following table depicts the number of advanced adhesives in aerospace patents issued from January 2021 to October 2023, based on the year the patent was issued.

Table 67
Patents Related to Advanced Adhesives in Aerospace, by Year Issued,
January 2021 to October 2023
(No. of Patents)

2021	2022	Through October 2023	No. of Patents
300	283	221	804

Source: BCC Research

Patent Analysis Based on Companies to Which Patents Were Issued for Advanced Adhesives in Aerospace

The following table depicts the patents issued to companies worldwide for various technologies and products related to advanced adhesives in aerospace from January 2021 to October 2023.

Table 68
Patents Related to Advanced Adhesives in Aerospace, by Company,
January 2021 to October 2023
(No. of Patents)

Company	No. of Patents
Align Technology Inc.	125
Strong Force IoT Portfolio 2016 LLC	77
The Boeing Co.	33
Monolithic 3D Inc.	20
Toray Industries Inc.	17
GranBio Intellectual Property Holdings LLC	10
3M Innovative Properties Co.	9
Cytec Industries Inc.	8
Other companies	505
Total	804

Source: BCC Research

Table 69
List of Patents on Advanced Adhesives in Aerospace, 2022

Display Key	Application Date	Title	Applicants
US 11578958 B2	1/16/2022	High explosive fragmentation mortars	Omnitek Partners LLC
US 11639427 B2	7/11/2022	Method for manufacturing prepreg, coating device, and apparatus for manufacturing prepreg	Toray Industries
US 11710957 B1	12/29/2022	Systems and methods for redundant control of active fuses for battery pack safety	Archer Aviation Inc.
US 11633926 B2	2/23/2022	Aligned fiber-reinforced molding	Arris Composites Inc.
US 11565811 B1	1/28/2022	Blended wing body aircraft with transparent panels	Blended Wing Aircraft Inc.
US 11697507 B1	4/28/2022	Aircraft with a multi-walled fuel tank and a method of manufacturing	Blended Wing Aircraft Inc.

Note: Not all patents dated from 2021 to 2023 were listed in the table above. The list of patents included here has been filtered based on application date, not publication date.

Source: Patent Lens

Granted Patented Technologies

Table 70
Granted Patented Technologies on Advanced Aerospace Materials, 2020-2023

Company Name	Year	Patent No.	Year of Expiry	Description
Beta Air LLC	2023	US20230282034A1	-	Systems and methods for fleet management
LM Group Holdings Inc.	2023	US20230191527A1	-	Ultrasonic additive manufacturing of cladded amorphous metal products
University of South Carolina	2023	US20230278284A1	-	3D printing system nozzle assembly for printing of fiber-reinforced parts
Zephyros Inc.	2023	US20230257633A1	-	Structural adhesives
Nanjing Guore Metal Materials Research Institute Co. Ltd.	2023	CN116790959A	-	In-situ self-generated micro-nano double-scale nitride reinforced superalloy and preparation method thereof
Wuxi Yiyuan Technology Machinery	2023	CN116732372A	-	Preparation method of GH4151 nickel-based superalloy

Company Name	Year	Patent No.	Year of Expiry	Description
Zephyros Inc.	2023	US20230241863A1	-	Composite materials
Immunolight LLC	2023	US20230191747A1	-	Adhesive bonding composition and method of use
Joby Aviation Inc.	2023	US20230166838A1	2040	VTOL Aircraft
Birkeland Current LLC, Verifi Technologies LLC	2022	US20220412925A1	-	System for non-destructive testing of composites
Immunolight LLC	2022	US11476222B2	2037	Adhesive bonding composition and electronic components prepared from the same
Purdue Research Foundation	2022	US11492524B2	2036	Adhesives and methods of making the same
Raytheon Technologies Corp	2020	EP3019721B1	2034	Plated polymer nacelle
Hunan Oriental Scandium	2020	CN111471905A	2040	Al-Zn-Mg-Sc aluminum alloy wire for 3D printing and preparation method
NASA [U.S.], U.S. Administrator of National Aeronautics and Space Administration	2020	US10590000B1	-	Rare-earth aluminum alloy material having high ductility and high strength and preparation method therefore
Questek Innovations LLC	2020	US2020078860A1	-	Titanium alloys
Toray Industries	2020	RU2715237C1	-	Epoxy resin composition, cured epoxy resin product, prepreg and fiber-reinforced composite material.
3M Innovative Properties Co.	2020	EP3606978A1	-	Epoxy-silicone hybrid sealant composition with low shrinkage and lower postcuring properties with chemical resistance for aerospace applications.
3M Innovative Properties Co.	2020	US2020017738A1	-	Epoxy-silicone hybrid sealant composition with low shrinkage and lower postcuring properties with chemical resistance for aerospace applications

Source: BCC Research

Chapter 11

Competitive Intelligence

bcc Publishing

Chapter 11: Competitive Intelligence

Overview

The market for advanced aerospace materials is highly competitive and fragmented. It is characterized by a combination of established aerospace giants, specialized materials manufacturers and innovative start-ups. This emerging materials industry sector is essential to the aerospace sector's continued pursuit of performance enhancements, fuel efficiency and sustainability. Companies offer technical support, customization options and value-added services. Strong customer relationships and reputation contribute to customer loyalty and market share.

A rise in private-public collaborations reflects enhanced developments in advanced aerospace materials. As demonstrated by the number of patents they produce, collaborative research and development efforts between public and private institutions is growing. By combining resources, expertise and technologies, innovators can more effectively confront the difficulties of advanced material innovation. For instance, Boeing and Airbus collaborate with materials experts to develop advanced materials for their aircraft. Companies strive to develop new and advanced materials that offer improved performance, weight reduction and fuel efficiency. Certain nations appear to have created solid institutional structures and close institutional networks between entities engaged in aerospace materials. Strengthening these may be essential for expanding or increasing their footprint globally.

Emerging aerospace materials, such as CFRP, titanium alloys and ceramic-matrix composites, are currently gaining attention. The competition in these emerging fields was particularly intense as researchers and companies vie for first-mover advantage. Many smaller companies and start-ups are also entering the market, focusing on developing lightweight and durable materials to meet the growing demand in the aviation sector. However, the aerospace materials industry has high barriers to entry due to the need for substantial capital investment, technical expertise and strict regulatory standards. These barriers contribute to rivalry among established players.

Aerospace companies source components and materials from suppliers around the world. Managing a worldwide supply chain increases complexity and rivalry, with suppliers frequently competing to become important business partners for aircraft manufacturers. Businesses often compete for lucrative government contracts for military and aerospace defense programs. Successful enterprises must demonstrate their expertise and value to taxpayers to get these contracts, which frequently require competitive bidding processes.

Despite its potential, the advanced aerospace materials industry may face safety, regulatory compliance and public perception challenges. Compliance with industry standards and regulatory requirements is essential in the emerging materials industry. The aerospace sector has its material requirements and standards, frequently referred to as Aerospace Material Specifications or MIL (Military Specifications). To ensure that materials meet aviation safety and airworthiness standards, independent certification bodies, such as the Federal Aviation Administration in the U.S. and the European Union Aviation Safety Agency (EASA), play a critical role. To guarantee that materials fulfill the necessary standards for quality, performance and safety, manufacturers must abide by these regulations. To meet the criteria of the aerospace sector, materials must go through rigorous testing, certification and qualification procedures.

Extensive laboratory testing, destructive testing and review for compliance with defined standards are frequently part of these processes.

The aerospace industry experiences cyclical demand patterns. Commercial aviation often does well while a region's economy is booming, but demand can decline dramatically during recessions. Therefore, businesses must be ready to compete successfully in upturns and downturns. Increasing investments in the industry value chain suggest there is room for domestic and global competitors, including small and medium businesses, design, procurement, development contractors, design and engineering companies, and consultants.

Company Market Share Analysis

Several factors, including the product offerings, R&D, technological advancements, pricing strategies and distribution channels of various companies, determine the market share of the advanced aerospace materials industry. Given the broad scope of the market and its diverse range of sectors, the market is characterized by many players, ongoing research and a constant influx of new ideas and innovations. This dynamic environment encourages collaboration, partnerships and the emergence of new companies specializing in advanced aerospace materials.

Table 71
Global Market Shares of Advanced Aerospace Materials, by Leading Suppliers, 2022
(%)

Suppliers	Market Share (%)
Prominent players (e.g., Toray, Solvay, Hexcel, Constellium, ATI Inc., Teijin, 3M Co., Alcoa, BASF, Ametek, Carpenter Technology Corp., DuPont de Nemours)	46 to 52
Second-tier players (e.g., Materion Corp., Haynes International, Arconic Corp., Doncaster Group, Fort Wayne Metals, High Performance Alloys, Kymera, Novelis, Special Metals Corp., Timet, VSMPO-AVISMA)	18 to 22
Others	26 to 36

Source: BCC Research

The emerging materials in the aerospace market is relatively complex and diversified. It collectively combines different markets segments of advanced materials that belong to different industries under one roof solely for aerospace application. Collaborations between companies, research institutions and government entities are common due to the fragmented nature of the market. However, no single dominant player or a small number of companies completely dominates the market. Each application (e.g., commercial passenger aircraft, commercial transport aircraft, defense industry, general aviation, commercial space industry and helicopters) encompasses various subsectors. Each subsector has specialized component manufacturing companies and research organizations focusing on applying advanced aerospace materials to address specific challenges and opportunities. As a result, the market is distributed across various players rather than consolidated under a few companies.

The industry is expected to remain innovation-led, with frequent strategic alliances and new product development adopted as the key strategies by the players to increase industry presence. Government support and funding play crucial roles in shaping the competitive landscape. Countries and regions with significant government initiatives and funding for aerospace material research and development create a competitive environment where companies strive to secure grants, contracts and partnerships. Over the years, several material specialists has established a network of experts, universities, colleges and independent labs that perform R&D to generate intellectual property to expand the role of aerospace materials in new modern aircraft. This allows them to lead market changes in the industry and turn customer input into proprietary materials.

Global manufacturers in this market target public-private partnerships and venture capital as crucial development strategies to accelerate their growth. For instance, recently in 2023, seven U.S. companies, including players like Northrop Grumman, Sierra Space and Blue Origin, collaborated with NASA to advance space capabilities. Similarly, the National Composites Centre, U.K., collaborates with government agencies, aerospace companies and academic institutions for developing and testing composite materials and manufacturing processes for aerospace applications. These partnerships give the aerospace industry access to knowledge, financing and resources from public and commercial organizations, eventually spurring innovation and advances in materials and technology.

Toray Industries held a significant market share in the total advanced aerospace materials industry in 2022. This Japanese multinational attained its a leading market position through capacity expansions, new product development and strategic collaborations aimed at increasing its industry presence in different geographic locations. Toray supplies its carbon fiber portfolio in the industry through its brand TORAYCA to meet evolving aircraft lightweighting needs. The company's Cetex suite of high-performance thermoplastic composite materials exhibit excellent mechanical properties, enabling high-rate production and automation for large-scale primary and secondary aircraft structure parts as utilized in next-generation aerospace programs such as HiCAM and Clean Sky2. In the area of zero-emissions air mobility, TORAYCA carbon fiber, Toray thermoset and Cetex thermoplastic composites are the materials of choice of eVTOL (electric Vertical Takeoff and Landing) programs currently in development.

Hexcel is another significant market player in the global market for advanced aerospace materials. It is a leading carbon fiber and other composite materials supplier for the commercial aerospace industry. Hexcel was awarded a contract by Airbus to supply HexPly prepreg reinforced with HexTow carbon fiber for all composite primary structures of the A350 XWB. In 2022, Archer Aviation and Hexcel announced plans to advance production capabilities for eVTOL aircraft. Hexcel will provide Archer with high-performance carbon fiber and resin systems to fabricate composite parts for Archer's production aircraft, such as Midnight. Moreover, in 2023, Hexcel inaugurated a new center of research and technology excellence in Utah that will support next-generation developments in advanced composites technologies.

Constellium SE is another important manufacturer with a global sales network. In 2023, Constellium and TARMAC Aerosave partnered to advance towards full aluminum circularity in commercial aviation. This collaboration reflects the company's continuous efforts to achieve the decarbonation targets that the commercial aviation sector sets. Also in 2023, Constellium entered into a multi-year contract with Daher to supply a wide range of flat-rolled aluminum products, particularly for the TBM and Kodiak aircraft. With this new agreement, Constellium expands its customer portfolio for business and regional jets and becomes the strategic aluminum supplier for Daher.

ATI Inc. commercializes titanium alloy, superalloys and steel alloys for critical aerospace applications. To increase focus on aerospace and defense markets in 2022, ATI Inc. has undergone strategic repositioning of its Specialty Rolled Products (SRP) business, a process that included the retiring of lower-margin standard stainless sheet products. In the same year, ATI entered a multi-year agreement with GKN Aerospace to supply high-value titanium materials that will be used to manufacture commercial and military airframes.

Emerging materials in aerospace represents significant value creation. Consumers and suppliers to the industry are engaged in captive source of raw materials, quality assurance and shorter supply chains with greater profit realization. These integration elements have been evident in the industry over the past few years.

Strategic Analysis

Table 72
Mergers and Acquisitions in the Market for Advanced Aerospace Materials, 2020-2023

Company	Strategy
Arconic Corp.	In 2023, Arconic and Apollo announced that Apollo Funds have completed the previously announced acquisition of Arconic., which includes a minority investment from funds managed by affiliates of Irenic Capital Management (“Irenic”). However, the company will continue to operate under the Arconic name and brand after the acquisition.
Aubert & Duval	In 2023, a consortium composed of Airbus, Safran and Tikehau Capital finalized the acquisition of Aubert & Duval from Eramet. The acquisition of Aubert & Duval reflects the quickening pace of transformation and consolidation in the aerospace sector.
Fort Wayne Metals	In 2023, Fort Wayne Metals acquired certain equipment and assets to support tantalum production from Plansee SE, a leading materials manufacturer in Austria.
Doncasters Group	In 2022, Doncasters Group acquired Uni-Pol, a global business specializing in manufacturing superalloy cast parts. This acquisition places Doncasters amongst the largest manufacturers of high-precision alloy components in the global supply chain.
Novelis Inc.	In 2020, Novelis Inc. completed its acquisition of Aleris Corp., a global supplier of rolled aluminum products.

Source: PitchBook Data Inc.

Chapter 12

Company Profiles

Chapter 12: Company Profiles

3M CO.

3M Center
Saint Paul, MN 55144-1000
Tel: 800/328-6276
Website: www.3m.com

Company Overview

3M Co. provides diversified technology services in the U.S. and internationally. The company operates in four segments: Safety and Industrial; Transportation and Electronics; Health Care; and Consumer. The Transportation and Electronics segment provides ceramic solutions; attachment tapes, films, sound, and temperature management for transportation vehicles; packaging and interconnection solutions etc. The Safety and Industrial segment offers structural adhesives, tapes and other sealant/adhesive systems for end-use industries. It offers its products through e-commerce and traditional wholesalers, retailers, jobbers, distributors and dealers. 3M Co. was founded in 1902 and is headquartered in St. Paul, Minnesota. The company's products are sold under numerous trademarks to various end-use industries such as energy, transportation, commercial solutions, design and construction, electronics, healthcare and consumer market. The company is active across the Americas (U.S., Latin America, and Canada), the Asia-Pacific, Europe, Middle East and Africa.

Key Highlights

- 3M has reduced its carbon footprint by more than 35% and water usage by more than 15% since 2019. In the last two years alone, 3M has reduced its use of virgin fossil-based plastic by over 50 million pounds.

- 3M invested $3.6 billion in research and development and capital expenditures to accelerate its innovation pipeline. Over the past five years, its scientists have earned an average of 3,500 patents annually.

- In 2022, organic growth companywide was 1.2%.

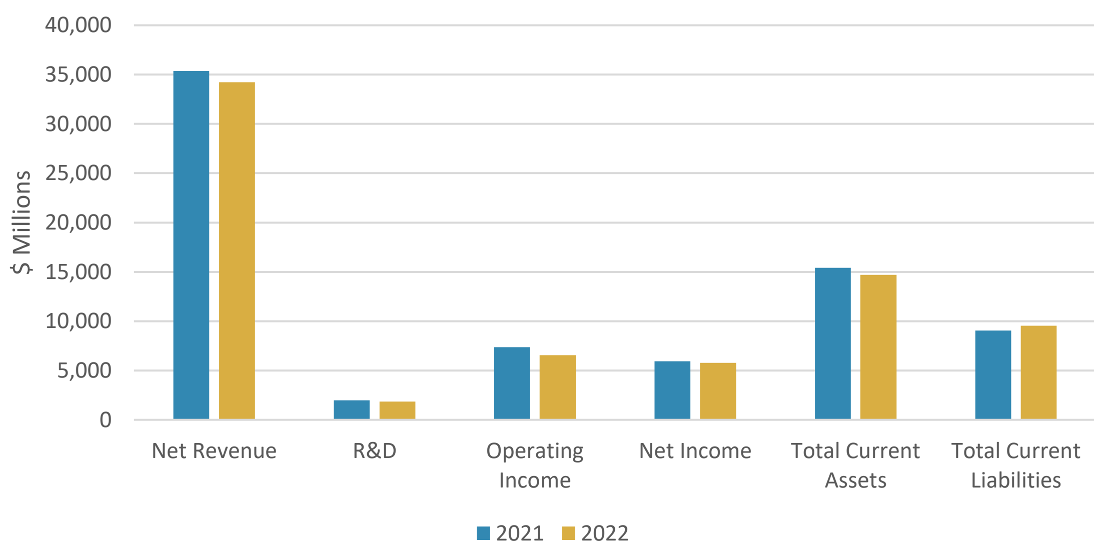
Financials

Table 73
3M Co.: Annual Revenue, 2022
($ Millions)

Financials	Revenue ($ Millions)
Net revenue	34,229.0
R&D	1,862.0
Operating income	6,539.0
Net income	5,777.0
Total current assets	14,688.0
Total current liabilities	9,523.0

Source: Company annual report

Figure 40
3M Co.: Annual Revenue, 2021 and 2022
($ Millions)



Source: Company annual report

ESG Trends

- In 2022, 3M expanded research and development into emerging technologies focused on decarbonization and renewable fuels. Through cross-functional global teams, 3M Corporate Research and 3M Ventures, , the company is investing in and developing innovative materials for green hydrogen and low-carbon intensity energy separations.

- In 2021, 3M announced it expects to invest approximately $1 billion over the next 20 years to accelerate new environmental goals: achieve carbon neutrality by 2050, reduce water use by 25% at its facilities and return higher quality water to the environment after use in manufacturing operations.

- In 2021, 3M announced it will be included in the State Street Global Advisors' (SSGA) Gender Diversity Index ETF. The SSGA is a select group of large-scale U.S. companies closing gender gaps and advancing women through gender diversity.

Product Offerings

Table 74
3M Co.: Product Portfolio

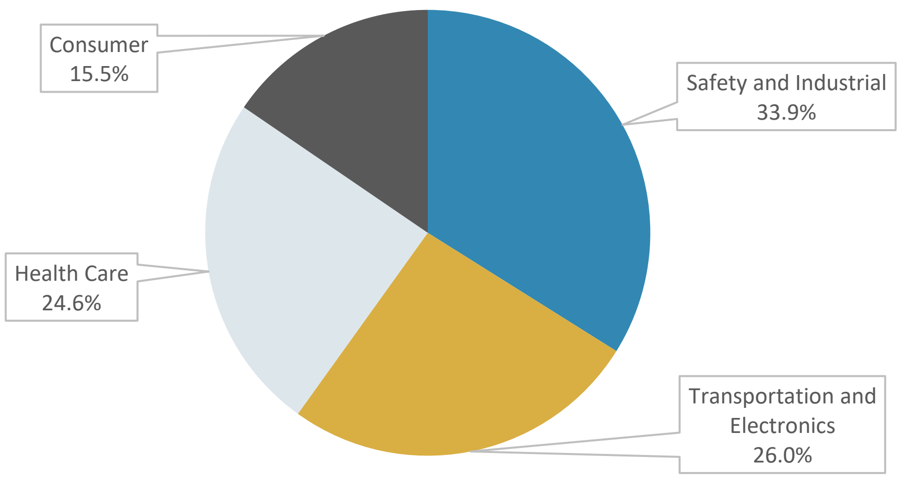
Brands/Product	Description/Specifications
3M Scotch-Weld Structural Adhesives	• Excellent performance from -67°F (55°C) to 225°F (107°C). • Designed to bond precured graphite epoxy composites. • Non-Sagging thixotropic formula holds its shape for precise bond line control and less rework.
3M Scotch-Weld Toughened Epoxy Adhesives	• Two-part formula cures at room temperature (75°F) to a strong, durable bond in 3-7 days, or in less than an hour at 200°F. • Enables high performance design and provides high shear and peel strength. • Highly flexible formula helps improve service life and reduce damage.
3M VHB Tape	• 3M's VHB (Very High Bond) tapes are used for bonding exterior aircraft components. It can replace mechanical fasteners (rivets, welding, screws) or liquid adhesives.
3M Scotch-Weld Low Odor Acrylic Adhesive	• Low temperature performance with structural strength down to -40°C (-40°F). • 113% elongation that provides enhanced flexibility for dissimilar material bonding.

Brands/Product	Description/Specifications
3M Aerospace Sealant	• 3M aerospace sealants range are used for sealing seams, joints, and gaps in aircraft structures. • Helps reduce shrinkage and rework for total cost reduction. • These sealants provide protection against moisture, chemicals and temperature variations.

Source: Company website

Product Financials

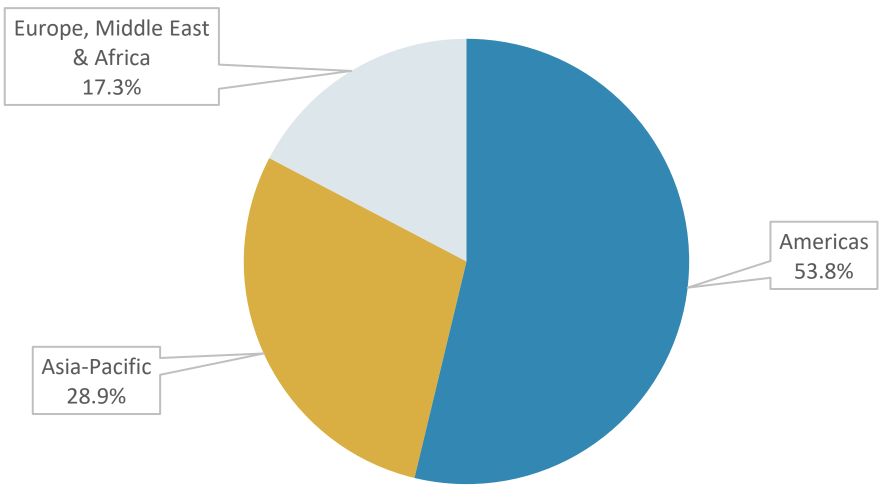
Figure 41
3M Co.: Revenue Share, by Business Unit, 2022
(%)



Source: Company annual report

Regional Financials

Figure 42
3M Co.: Revenue Share, by Region, 2022
(%)



Source: Company annual report

ATI INC.

ATI Corporate
2021 McKinney Avenue, Suite 1100
Dallas, TX 75201
Tel: 412/394-2908
Website: www.atimaterials.com

Company Overview
ATI Inc. is a producer of specialty materials and components for major markets including aerospace and defense, oil and gas and hydrocarbon processing, electrical energy, automotive and medical. High Performance Materials & Components (HPMC) and Advanced Alloys & Solutions (AA&S) are its two business segments. The HPMC business unit manufactures a wide range of materials, including titanium and titanium-based alloys, nickel- and cobalt-based alloys and superalloys, advanced powder alloys and other specialty materials, in long product forms like ingots, billets, bars, wire, shapes and rectangles and seamless tubes, as well as precise forgings, parts and machined pieces. The AA&S business manufactures specialty alloys, nickel-based alloys, titanium and titanium-based alloys, zirconium and related alloys, including hafnium and niobium, in a range of forms, including plate, sheet and precision rolled strip products. It also provides hot-rolling conversion services, including carbon steel products.

The company was formerly known as Allegheny Technologies Incorporated. ATI Inc. was founded in 1960 and is headquartered in Dallas, Texas.

Key Highlights

- In 2022, as both narrowbody and widebody production accelerates, ATI's jet engine sales doubled from the prior year and airframe sales grew 79% versus 2021.
- In December 2020, ATI announced a strategic repositioning of its Specialty Rolled Products (SRP) business, which was substantially completed in 2022 and included the exit of lower-margin standard stainless sheet products, making certain capital investments to increase focus on aerospace and defense end markets.
- The High-Performance Materials & Components Segment derived 80% of 2022 revenues from the aerospace & defense markets.
- ATI have approximately 6,700 active employees, of which approximately 15% are located outside the U.S.
- Gross profit of $714 million, more than doubled compared to $333 million in 2021.
- In 2022, ATI completed the sale of its Sheffield, U.K. operations and recognized a loss in 2022 on sales of $141.0 million.
- In 2022, ATI completed the sale of the small Pico Rivera, CA operations as part of the strategy to exit standard stainless products.

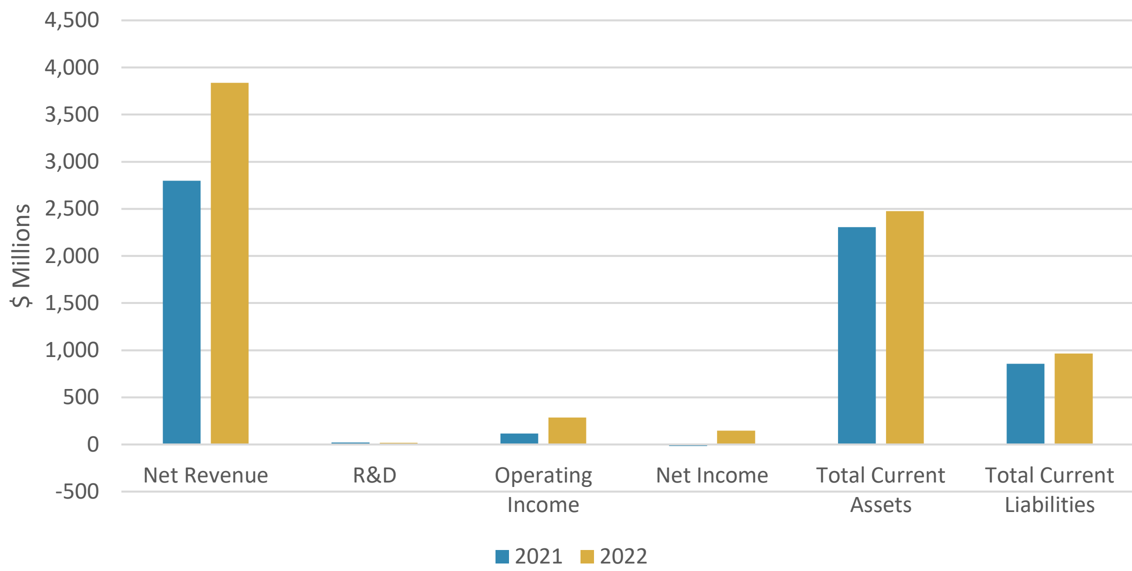
Financials

Table 75
ATI Inc.: Annual Revenue, 2022
($ Millions)

Financials	Revenue ($ Millions)
Net revenue	3,836.0
R&D	17.7
Operating income	287.3
Net income	146.5
Total current assets	2,476.4
Total current liabilities	963.9

Source: Company annual report

Figure 43
ATI Inc.: Annual Revenue, 2021 and 2022
($ Millions)



Note: The bars for R&D may not be visible as their values are very small compared to other values depicted in the figure.

Source: Company annual report

News/Key Developments

Table 76
ATI Inc.: News, 2021 and 2022

Year	Strategy	Development
2022	Expansion	ATI Inc. established a dedicated additive manufacturing facility outside Fort Lauderdale, Florida to support a contract by Bechtel Plant Machinery Inc. (BPMI) for development of highly engineered part solutions in support of the U.S. Naval Nuclear Propulsion Program.
2022	Agreement	ATI Inc. announced it had reached a new multi-year agreement with GKN Aerospace to supply high-value titanium materials used in the manufacture of commercial and military airframes.
2022	Termination of joint venture	ATI announced the termination of Uniti LLC, its joint venture with Russian-based VSMPO-AVISMA to market and sell a range of commercially pure titanium products. The joint venture primarily focused on selling to industrial markets such as power generation, chemical and petroleum processing, automotive and transportation.

Year	Strategy	Development
2021	Agreement	ATI announced that it had reached tentative agreement for its labor contract with the United Steelworkers (USW) covering approximately 1,300 represented employees located primarily within the Advanced Alloys & Solutions segment operations for the term covering March 1, 2021 to February 28, 2025.

Source: Company website

ESG Trends

- 45% decline in greenhouse gas (GHG) emissions including all manufacturing facilities, since 2018.
- More than 7 billion gallons of water will be recycled by its manufacturing facilities in 2022.
- Over 40% of 2022 new hires were diversity/inclusion candidates.
- More than 120,000 tons of recycled materials are used in production (73% of all feedstocks).

Product Offerings

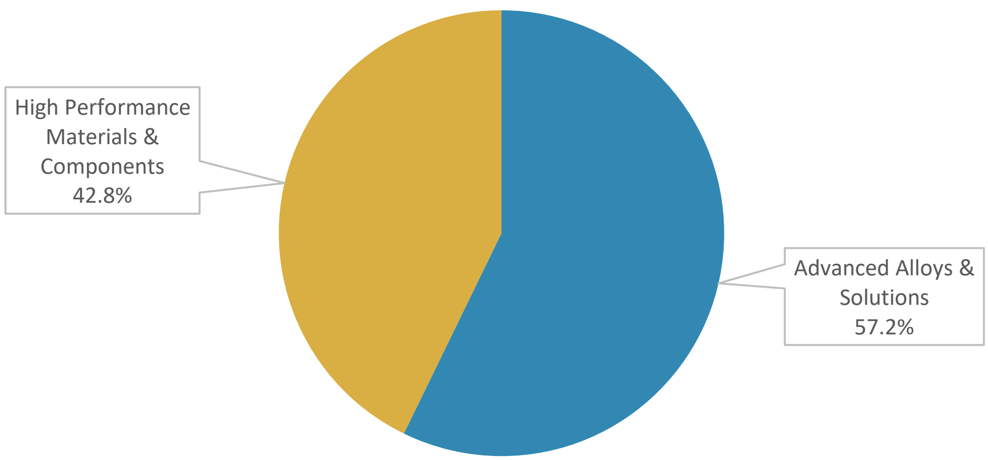
Table 77
ATI Inc.: Product Portfolio

Product	Specifications
Titanium alloy	ATI 45Nb Alloy is an ideal candidate for rivets that secure aluminum aircraft panels, particularly in areas exposed to high engine exhaust temperatures. It offers high strength and ductility at temperatures up to 427°C (801°F). Titanium alloys are used in jet engine components, as well as critical airframe applications where high-strength and fracture toughness are necessary. Titanium is also used for fasteners and tubing throughout commercial and military aircraft.
Superalloys	They are used in jet engines components, airframe structures and other aerospace applications where there is no margin for error and common stainless steels may not provide adequate performance.
Steel alloys	They are known for their excellent corrosion and heat resistance with applications in engine shafts, landing gear and other critical applications for aerospace components.

Source: Company website

Product Financials

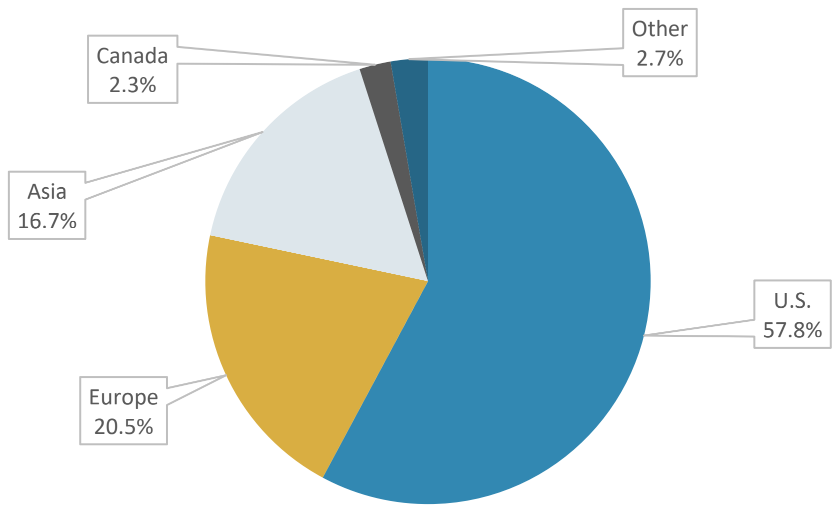
Figure 44
ATI Inc.: Revenue Share, by Business Unit, 2022
(%)



Source: Company annual report

Regional Financials

Figure 45
ATI Inc.: Revenue Share, by Country/Region, 2022
(%)



Source: Company annual report

ALCOA CORP.

201 Isabella Street, Suite 500
Pittsburgh, PA 15212-5858
Tel: 412/315-2900
Website: www.alcoa.com

Company Overview
Alcoa Corp., together with its subsidiaries, produces and sells bauxite, alumina and aluminum products in the U.S., Spain, Australia, Iceland, Norway, Brazil, Canada and internationally. The company operates through three segments: Bauxite, Alumina and Aluminum. The company offers primary aluminum in the form of alloy ingot or value-add ingot to customers that produce products for the transportation, building and construction, packaging, wire and other industrial markets. The company was formerly known as Alcoa Upstream Corp. and changed its name to Alcoa Corp. in October 2016. The company was founded in 1886 and is headquartered in Pittsburgh, Pennsylvania.

Key Highlights

- In 2022, Alcoa continued to grow the product margins and volume of its Sustana line, which is portfolio of alumina and aluminum products made with lower greenhouse gas emissions.
- As of December 31, 2022, Alcoa's worldwide patent portfolio consisted of approximately 400 granted patents and 180 pending patent applications.
- In 2022, capital expenditures for new or expanded facilities for environmental control were approximately $136 and approximately $162 is expected in 2023.
- In March 2022, in response to the conflict between Russia and Ukraine, Alcoa announced that it would cease the purchase of raw materials from, or the selling of products to, Russian businesses.

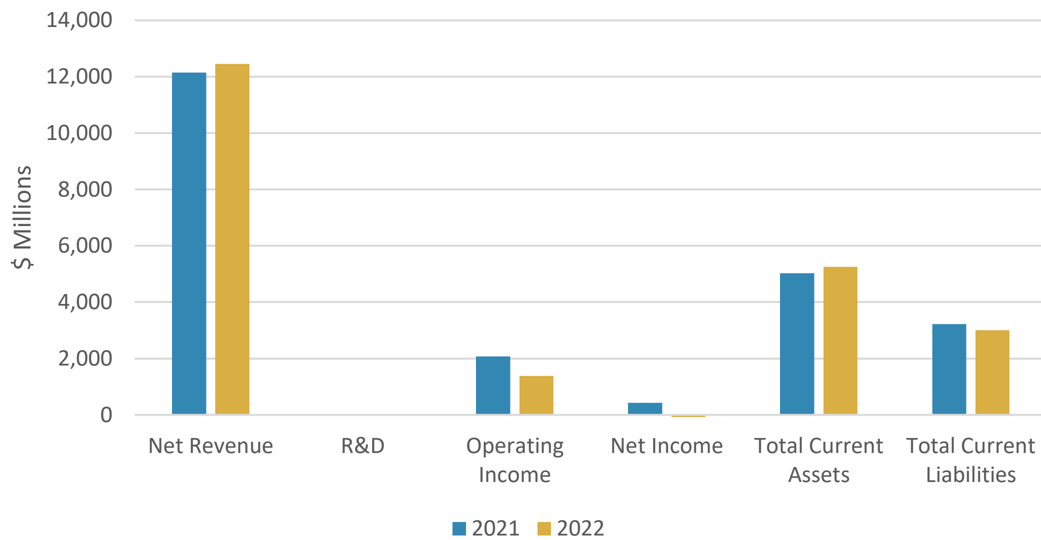
Financials

Table 78
Alcoa Corp.: Annual Revenue, 2022
($ Millions)

Financials	Revenue ($ Millions)
Net revenue	12,451.0
R&D	32.0
Operating income	1,386.0
Net income	-102.0
Total current assets	5,250.0
Total current liabilities	3,004.0

Source: Company annual report

Figure 46
Alcoa Corp.: Annual Revenue, 2021 and 2022
($ Millions)



Note: The bars for R&D and Net Income may not be visible as their values are very small compared to other values depicted in the figure.

Source: Company annual report

News/Key Developments

Table 79
Alcoa Corp.: News, 2021 and 2022

Year	Strategy	Development
2022	Agreement	Alcoa Corp. announced that it had entered into a supply agreement to provide low-carbon EcoLum TM aluminum to Speira, a global aluminum rolling and recycling company. Alcoa's EcoLum brand is part of the company's Sustana family of low-carbon products.
2021	Termination	Alcoa Corp. announced the closure of 146,000 metric tons of aluminum smelting capacity at the Wenatchee Works aluminum smelter located in the state of Washington.
2021	Expansion	Alcoa Corp. announced that the Portland Aluminum joint venture plans to restart 35,000 metric tons per year (mtpy) of curtailed capacity at its aluminum smelter in the State of Victoria in Australia.

Source: Company website

ESG Trends

Some ESG trends observed at Alcoa in 2022 include:

- 4.6% decrease in carbon dioxide equivalent emissions.
- 86% of electricity powering its smelters came from renewable sources.
- 36.6% increase in new hires from underrepresented groups.
- 17 locations certified to the ASI Performance Standard.
- $7 million invested in communities through Alcoa community grants and the Alcoa Foundation.

Product Offerings

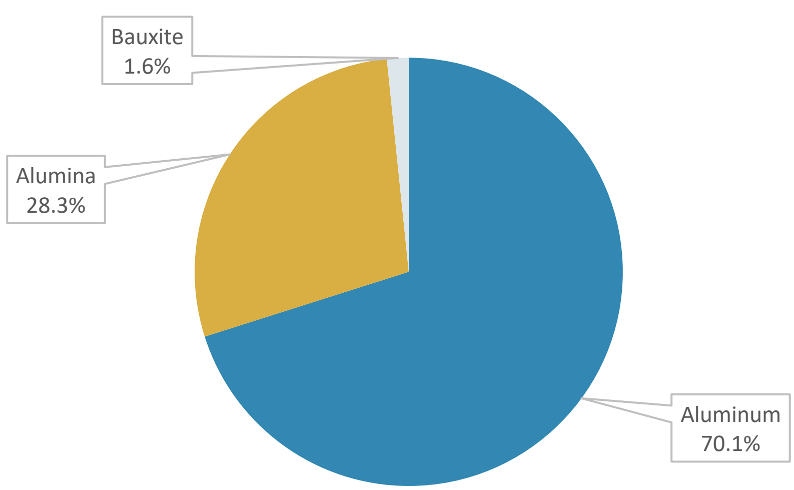
Table 80
Alcoa Corp.: Product Portfolio

Product	Specifications
Advanced aluminum alloys	High fluidity, thermal stability, low shrinkage, casting friendly for body structures.

Source: Company website

Product Financials

Figure 47
Alcoa Corp.: Revenue Share, by Business Unit, 2022
(%)



Source: Company annual report

AMETEK INC.

1100 Cassatt Road
Berwyn, PA 19312-1177
Tel: 610/647-2121
Website: www.ametek.com

Company Overview

Ametek Inc. manufactures electronic instruments and electromechanical devices worldwide. It operates in two segments, Electronic Instruments (EIG) and Electromechanical (EMG). Ametek Specialty Metal Products (SMP) is a business unit of Ametek Inc. a leading global manufacturer of electronic instruments and electromechanical devices with annualized sales of approximately $5.5 billion. The Specialty Metals business unit consists of five brands and operating facilities in the U.S. and the U.K. The company is engaged in manufacture of advanced metallurgical products including precision metal strip, ultra-thin foil, specialty shaped wire, engineered components, thermal management materials, water atomized powders, precision tube and roll-bonded clad plate.

Ametek is a group of six companies, one of which is Hamilton Precision Metals. The Hamilton Precision Metals engineers metal strip and foil in a large variety of alloys to the tightest tolerances and thinnest gauges in the industry. Ametek Inc. was incorporated in 1930 and is headquartered in Berwyn, Pennsylvania.

Key Highlights

- Ametek's sales in 2022 totaled $6.2 billion, an increase of 11% over 2021. Organic sales also increased by 11%. Operating income increased by 15% to $1.5 billion, and operating margins increased by a significant 80 basis points to 24.4% over the previous year.

- Opening new Customer Solutions Centers in Germany, India and Thailand has allowed Ametek to better serve its customers in those countries while displaying its wide range of technological options.

- About 1,900 of the 7,500 employees of the company were employed by EMG as of December 31, 2022. At the end of 2022, EMG has operational locations in the U.S., U.K., China, Germany, France, Italy, Mexico, Serbia, Czechia, Malaysia and Taiwan.

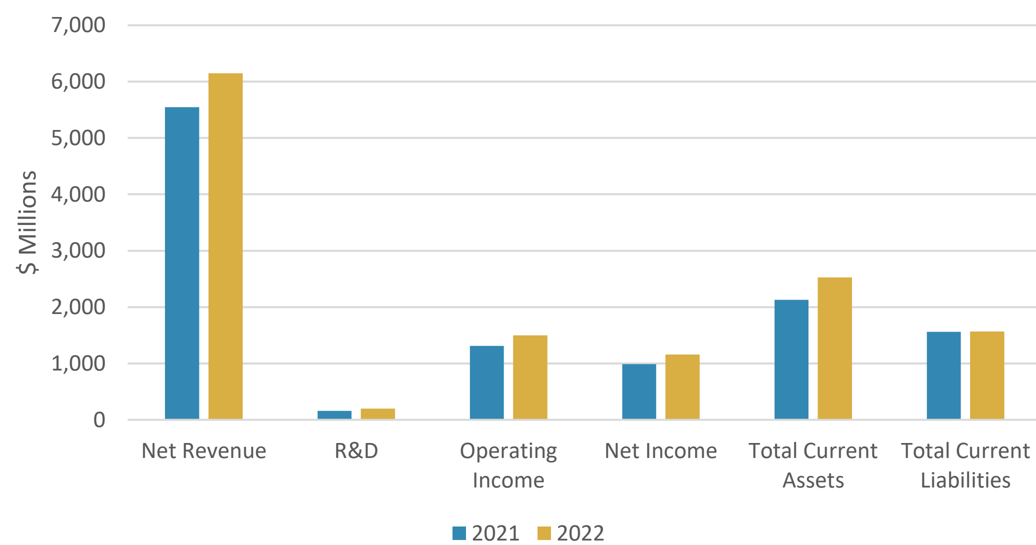
Financials

Table 81
Ametek Inc.: Annual Revenue, 2022
($ Millions)

Financials	Revenue ($ Millions)
Net revenue	6,150.5
R&D	198.8
Operating income	1,500.7
Net Income	1,159.5
Total current assets	2,528.1
Total current liabilities	1,564.2

Source: Company annual report

Figure 48
Ametek Inc.: Annual Revenue, 2021 and 2022
($ Millions)



Source: Company annual report

ESG Trends

Ametek Inc.'s ranking in the electrical equipment industry is 102 out of 260 industries, and its ESG rating is around 24.1, which is a medium risk.

Product Offerings

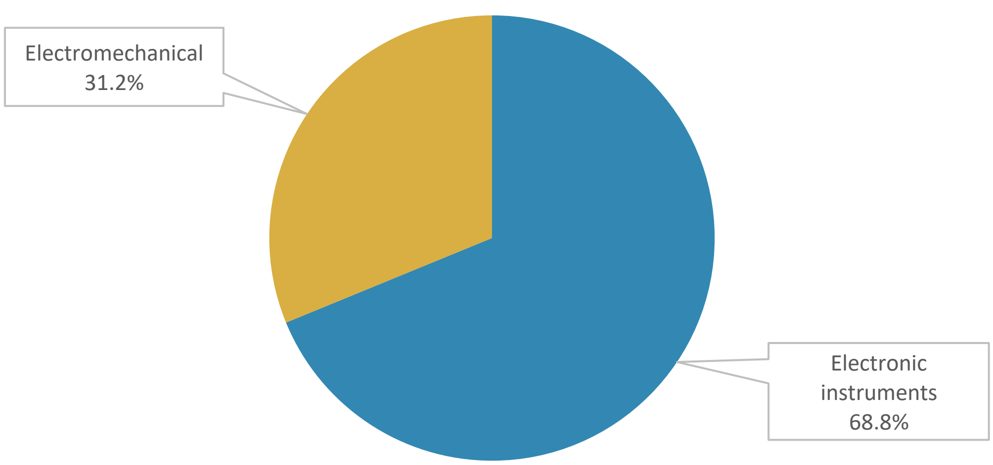
Table 82
Ametek Inc.: Product Portfolio

Product	Specifications/Description
Titanium alloys	They are produced with the addition of vanadium or aluminum for applications such as aerospace.
Nickel alloys	Nickel alloys display high strength and excellent corrosion resistance, making them a great metal for use in highly corrosive environments and high temperature environments.
Steel alloys	Steel is often combined with other alloying elements such as nickel, nitrogen and molybdenum to create the corrosion-resistant product used in aerospace applications.

Source: Company website

Product Financials

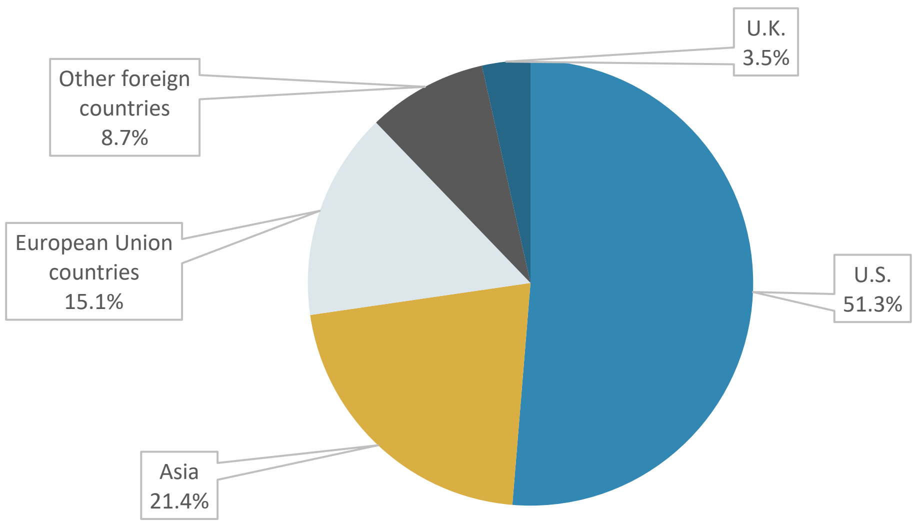
Figure 49
Ametek Inc.: Revenue Share, by Business Unit, 2022
(%)



Source: Company annual report

Regional Financials

Figure 50
Ametek Inc.: Revenue Share, by Country/Region, 2022
(%)



Source: Company annual report

ARCONIC

201 Isabella Street
Pittsburgh, PA 15212
Tel: 412/315-2984
Website: www.arconic.com

Company Overview

Arconic Corp. manufactures aluminum sheet, plate, extrusions and architectural products and systems, serving primarily the aerospace, ground transportation, building and construction, industrial, and packaging end markets. In the aviation sector, the company supplies stronger aluminum and aluminum-lithium components. In 2016, Alcoa Inc. separated its alumina and bauxite operations into Alcoa Corp., and Arconic became the producer of rolled and plate aluminum as well as goods for the industrial and aerospace markets. The company has a global footprint, with 20 primary manufacturing facilities, as well as various sales and service facilities, located across North America, Europe, the U.K. and China. In 2022, the company generated a revenue share of $9.0 billion with a global workforce of 11,550.

Key Highlights

- As of 2022, four of its global locations were certified to the ASI Performance Standard. Additionally, Arconic holds a position on the ASI Standards Committee—the key governance group responsible for revising both Performance and Chain of Custody standards.

- Arconic has maintained ISO 14001 certification for Environmental Management Systems (EMS) for 13 sites across its operating regions. Additionally, five of its sites are certified to ISO 50001 for energy management systems (EnMS), which supports 2030 targets for energy and emissions reduction.

News/Key Developments

Table 83
Arconic: News, 2023

Year	Strategy	Development
2023	Acquisition	Arconic Corp. and Apollo announced that Apollo Funds have completed the previously announced acquisition of the Arconic Corp., which includes a minority investment from funds managed by affiliates of Irenic Capital Management ("Irenic"). The company will continue to operate under the Arconic name and brand.

Source: Company website

ESG Trends

- 25.6% ethnic minority workforce within U.S.
- 27,000 hours of skills training completed through its global learning system.
- $7.8 million in grants awarded by Arconic Foundation.
- Over 0.6% Scope 1 greenhouse gas emissions intensity.
- 5.2% Scope 2 greenhouse gas emissions intensity.
- 10.6% Scope 3 greenhouse gas emissions intensity.

Product Offerings

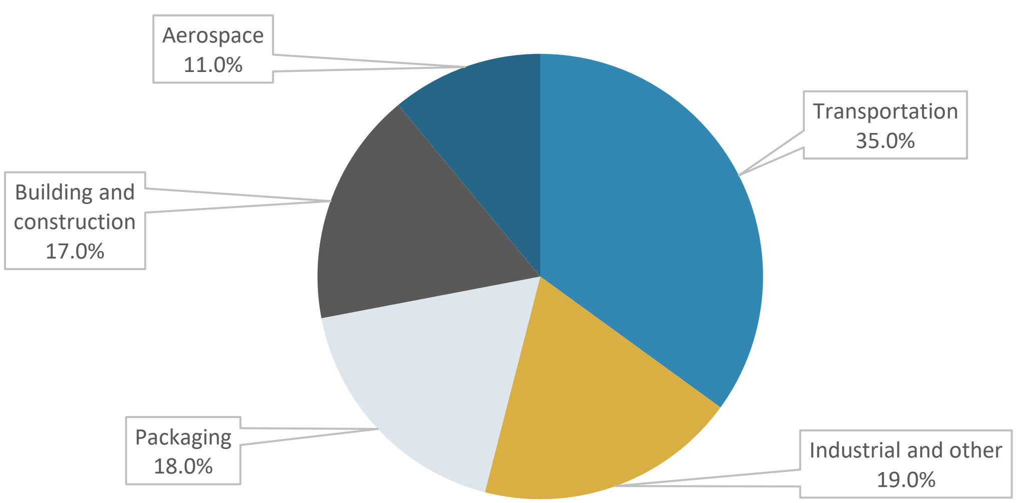
Table 84
Arconic: Product Portfolio

Product	Specifications/Description
Aluminum Alloy	Arconic's aluminum alloys are known for their quality and performance are used in airframes and automotive body panels. The company supplies following grades: • 7000 Series. • 6000 Series. • 2000 Series. • Aluminum-lithium alloys.

Source: Company website

Product Financials

Figure 51
Arconic: Revenue Share, by Business Unit, 2022
(%)



Source: Company annual report

AUBERT & DUVAL

10 Boulevard de Grenelle
CS 63205
75015 Paris
France
Tel: +33 0 1 45 38 38 88
Website: www.aubertduval.com

Company Overview

Aubert & Duval (A&D) is a member of the Alloys branch of Eramet Group, a mining and metallurgical group founded in 1880 with leading positions in nickel, manganese and alloy sectors. Aubert & Duval, headquartered in France, is specialized in the design, melting and processing of materials to manufacture high-performance steels, superalloys, aluminum alloys and titanium alloys in the form of bars, powders, billets, forgings, closed die-forgings, hipped parts or pre-machined parts. As of December 2022, the company has 3,800 employees.

Aubert & Duval produces titanium, high performance steel and aluminum forgings for airframes, including body bulkhead frames, slat tracks, door frames and engine pylon nacelle and wing mount parts. The company is a key player in the aerospace industry that supplies forgings for landing gear in the main Airbus, Boeing and COMAC programs from a wide range of high-performance materials, as well as a key player in helicopter structures, supplying forgings and bars as well as high performance materials.

Key Highlights

In April 2023, a consortium composed of Airbus, Safran and Tikehau Capital finalized the acquisition of Aubert & Duval from Eramet. The acquisition of Aubert & Duval reflects the quickening pace of transformation and consolidation in the aerospace sector.

ESG Trends

All Aubert & Duval facilities are ISO 14001 certified or have a project in progress.

Aubert & Duval has developed AD730, an advanced superalloy that can operate at higher temperatures than other superalloys. This makes AD730 an excellent candidate for parts in the hottest sections of aerospace engines. Engines composed of these materials can be designed to consume less kerosene and emit less CO_2.

Product Offerings

Table 85
Aubert & Duval: Product Portfolio

Product	Specifications
Titanium alloys	Alpha-beta titanium alloy combines mechanical properties and corrosion resistance with light weight.
Nickel-based superalloys	• With the majority component being nickel, NiSA provides specific resistance to very high temperatures and corrosion. • Good high temperature fatigue creep resistance. • High microstructural stability up to 750°C. • Better oxidation resistance than Waspaloy or 720 Alloy.
Steel alloys	• Aerospace range of alloyed steel comes with tightly controlled characteristics. • Excellent resistance to high temperature oxidation up to 950°C. • Good mechanical properties up to 700°C.
Aluminum alloys	• Good weldability. • Average mechanical strength. • Good balance between toughness and stress corrosion resistance.

Source: Company website

BASF SE

Carl-Bosch-Strasse 38
Ludwigshafen am Rhein 67056
Germany
Tel: +49 0 621 60 0
Website: www.basf.com

Company Overview

BASF SE, founded in 1865, operates as a worldwide chemical company. BASF is the world's largest chemical company, with products spanning the full spectrum of commodities to specialties. It operates with its six business units, 11 operating divisions, and 72 Strategic Business Units (SBUs) in 91 countries. It has 239 production facilities (including six Verbund sites) globally. The company operates through the following business segments: chemicals, materials, industrial solutions, surface technologies, nutrition and care, agricultural solutions, and others. Its industrial solutions segment is further categorized into two sub-segments, namely dispersions & resins and the performance chemicals divisions It develops and markets ingredients and additives for industrial applications, such as polymer dispersions, resins, additives, electronic materials and antioxidants. BASF SE had 111,481 employees across the globe as of December 2022.

BASF is a global producer of several products and technologies used in the aerospace industry. These materials include solutions across a range of interior applications such as cabin interiors, seating components, secondary structural materials, additive manufacturing, performance additives and pigments, coatings and sealants, fuel and lubricant solutions, and flame retardants and fire protection. The company also works with manufacturers in the aerospace industry.

Key Highlights

BASF SE reported that worldwide sales increased by 11.1% and gross profit grew by 24.1% in 2022 compared to 2021.

In 2022, the company completely condemned Russia's attack on Ukraine, and as a result, wound down its business activities in Russia. To settle the fluctuations in gas prices, the company has temporarily reduced ammonia production.

The company is focusing on reducing the use of fossil fuels. For instance, it procured more than 1.2 million tons of renewable raw materials in 2022. It also set a target to achieve net zero GHG emissions by 2050.

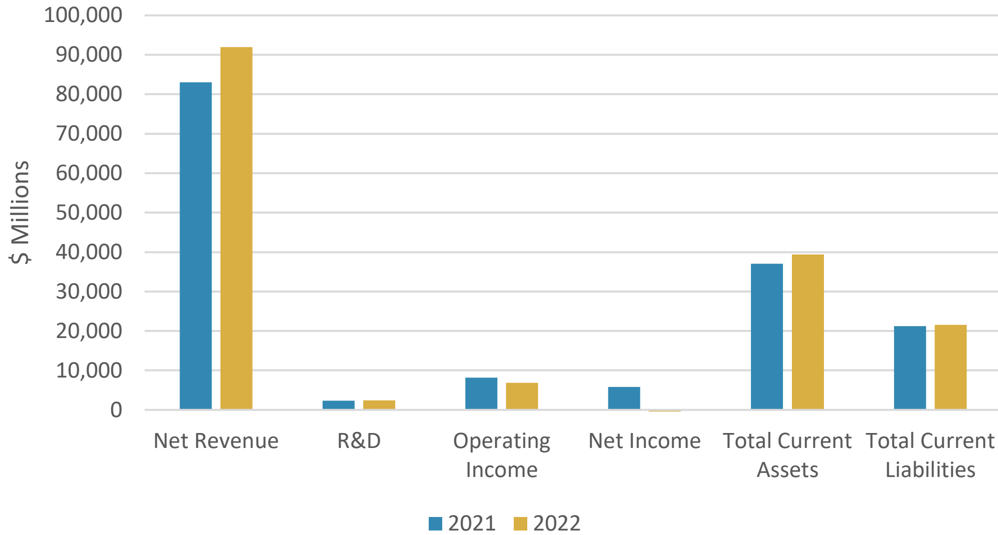
Financials

Table 86
BASF SE: Annual Revenue, 2022
($ Millions)

Financials	Revenue ($ Millions)
Net revenue	91,959.6
R&D	2,419.9
Operating income	6,895.4
Net income	-411.7
Total current assets	39,407.2
Total current liabilities	21,524.3

Source: Company annual report

Figure 52
BASF SE: Annual Revenue, 2021-2022
($ Millions)



Note: The bars for Net Income may not be visible as their values are very small compared to other values depicted in the figure.

Source: Company annual report

ESG Trends

In 2022, BASF SE achieved Prime status in the Institutional Shareholder Services ESG rating. It ranks among the top 7% of the companies assessed under ISS. Additionally, the company received special recognition for focusing on key sustainability issues like environmental management, energy efficiency, and business ethics. In Sustainalytics's ESG Risk Ratings, BASF SE belongs to the best category for "diversified chemicals" with a medium ESG risk, and it was recognized for its risk management, for example, in the areas of CO_2 emissions, wastewater and waste, as well as OHS (occupational health and safety). According to Pitchbook Database, the company's Sustainalytics ESG Rating is 25.22, which indicates a medium risk.

Product Offerings

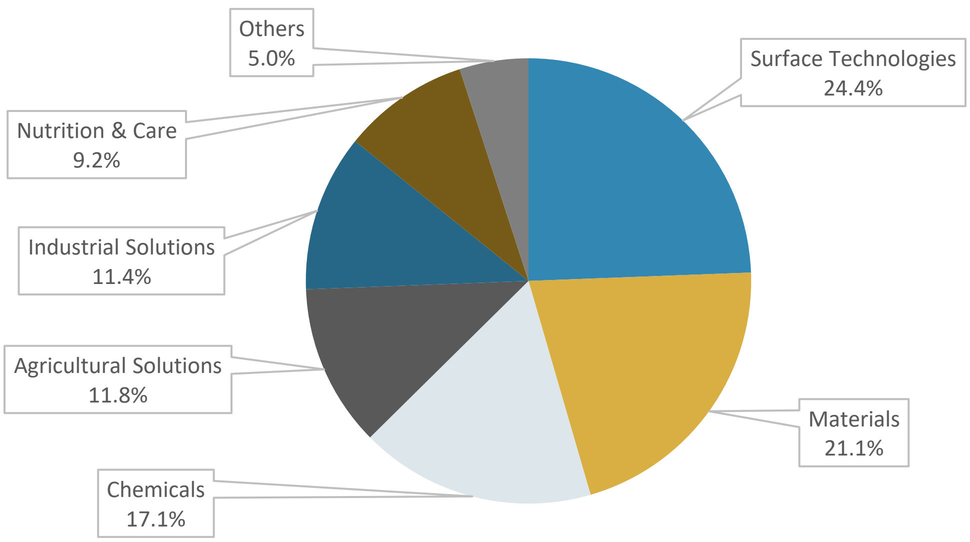
Table 87
BASF SE: Product Portfolio

Product	Specifications
Thermoformable composites	It is formaldehyde free, very low emission binder system that can be used to make fiber composite components up to 40% lighter. Processed using traditional thermoplastic cold forming or thermoset methods, Contoura provides superior mechanical stability, a long shelf life and FST compliant formulations.
Thermoplastic composites	Ultrason polyether sulfones for injection molding and extrusion applications are recyclable and light weight. Carbon fiber-reinforced parts can be used as structural materials in applications requiring high strength and impact resistance. These materials offer significant strength to weight advantages over aluminum.
Naftoseal sealants	Two component polysulfide-based sealants for such applications as fuel tanks, fuselages, access doors and floor panels.

Source: Company website

Product Financials

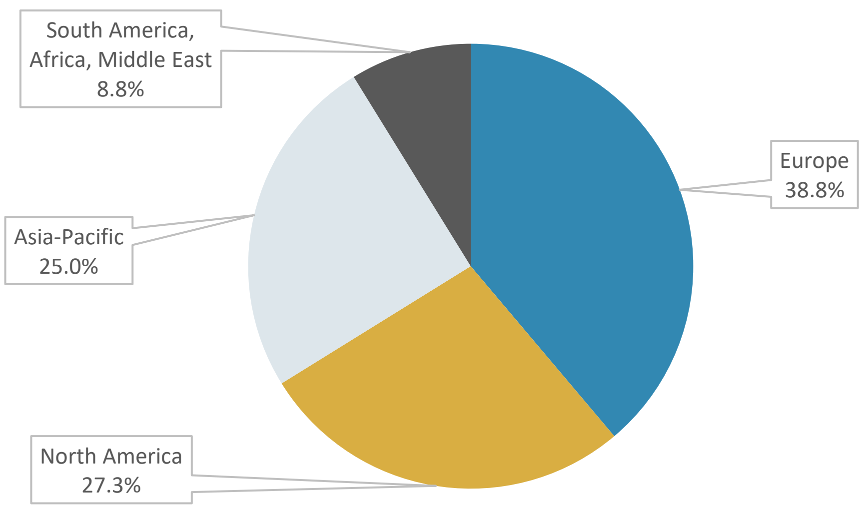
Figure 53
BASF SE: Revenue Share, by Business Unit, 2022
(%)



Source: Company annual report

Regional Financials

Figure 54
BASF SE: Revenue Share, by Country/Region, 2022
(%)



Source: Company annual report

BEIJING BEIYE FUNCTIONAL MATERIALS CORP.

1 Xiaoying East Road
Qinghe Town
Beijing 100192
China
Tel: +86-10-6294 9515
Website: www.bygcg.com

Company Overview

Beijing Beiye Functional Materials Corp. (Beiye) was established in 1960 as a state-owned research institute and became a privately owned company in 2005. Beiye Co. specializes in the research, development and production of special functional metal materials and high-performance structural materials such as precision alloys, high-temperature alloys and special stainless steel required for electric locomotives, power electronics, automobile industry and other industries.

Beiye's manufacturing facility is designed with a high precision strip cold rolling line, bimetal bonding facility, alloy bar production and rod production lines, magnetic core and components production line, permanent magnets production line, and an amorphous crystalline ribbon/core production line. The latter has the following capabilities: air induction melting, vacuum induction melting, superalloy bar casting, sheet, strip and ribbon rolling, rod and wire drawing, tape wound, lamination and punched core fabricating, and metal bonding.

Product Offerings

Table 88
Beiye Co.: Product Portfolio

Product	Specifications
Superalloys (K423(C1023), K4130(C130), K4242(C242), K4163(C263), K213, K232, K418, K18C, K640, GH605, GH536)	The as-cast master superalloy can be used to manufacture turbine laminas, guide laminas and other heat resistant components. These grades of superalloys are known for their exceptional strength, heat resistance and corrosion resistance.

Source: Company website

CARPENTER TECHNOLOGY CORP.

1735 Market Street, 15th Floor
Philadelphia, PA 19103
Tel: 610/208-2000
Website: www.carpentertechnology.com

Company Overview
Carpenter Technology Corp. produces, fabricates and distributes specialized metals across the globe, including in Mexico, Canada, Europe, the Asia-Pacific and the U.S. Specialty Alloys Operations and Performance Engineered Products are its two business segments. The business provides metal powders, parts and specialized alloys, such as titanium alloys, powder metals, stainless steels, alloy steels and tool steels that benefits the consumer, industrial, energy, transportation, medical, aerospace, and defense businesses. Carpenter Technology was established in 1889, and its headquarters is in Philadelphia, Pennsylvania.

Specialty Alloys Operations (SAO), a division of Carpenter Technology, is the company's main premium alloy and stainless-steel manufacturing operation. Customers can obtain high-temperature (nickel, iron and cobalt-base); cast, wrought and powder metallurgy superalloys; high-strength steels; implantable, magnetic and controlled expansion alloys; stainless steels; tool and die steels in long product form from facilities in the U.S., Europe, and Asia.

Key Highlights

- Sales to the aerospace and defense end-use market increased 63% from fiscal year 2022 to $1,290.7 million.

- Gross profit in fiscal year 2023 increased to $337.3 million, or 13.2% of net sales, from $149.8 million, or 8.2% of net sales for fiscal year 2022.

- Selling, general and administrative expenses in fiscal year 2023 were $204.2 million, or 8.0% of net sales (11.0% of net sales excluding surcharge revenue), compared to $174.7 million, or 9.5% of net sales (12.5% of net sales excluding surcharge revenue), in fiscal year 2022.

- Net sales in fiscal year 2023 for the specialty alloys operations segment increased 41% to $2,213.6 million, as compared with $1,565.6 million in fiscal year 2022.

Financials

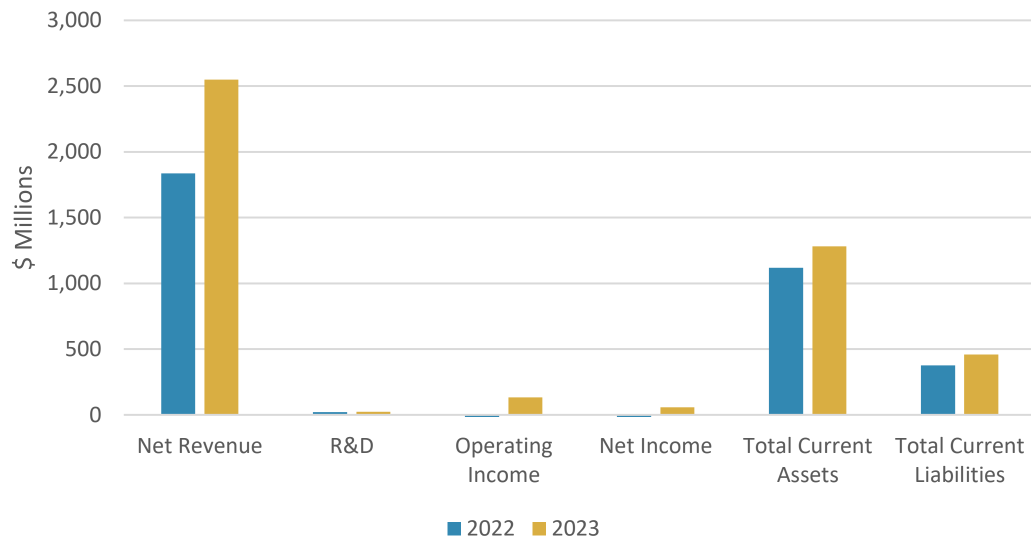
Table 89
Carpenter Technology Corp.: Annual Revenue, 2023
($ Millions)

Financials	Revenue ($ Millions)
Net revenue	2,550.3
R&D	24.4
Operating income	133.1
Net income	56.4
Total current assets	1,281.9
Total current liabilities	459.4

Note: For the year ending June 30.

Source: Company annual report

Figure 55
Carpenter Technology Corp.: Annual Revenue, 2022 and 2023
($ Millions)



Note: For the year ending June 30. The bars for operating and net income may not be visible as their values are very small compared to other values depicted in the figure.

Source: Company annual report

News/Key Developments

Table 90
Carpenter Technology Corp.: News, 2022

Year	Strategy	Development
2022	Price increase	Carpenter Technology Corp. announced that it would increase base prices by an average of 7% to 12% on new, noncontract orders across most of its premium products.

Source: Company website

ESG Trends

- In 2023, Carpenter Technology established environmental targets to:
    - Reduce water withdrawal intensity by 5% by 2035 through various efforts, including increased water recycling and reuse in its production processes.
    - Reduce energy intensity by 5% by 2035 through process improvements and ancillary equipment upgrades.

Product Offerings

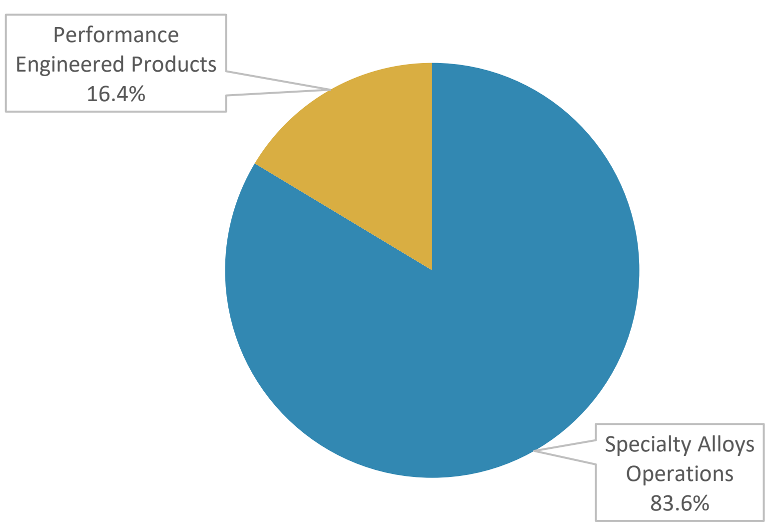
Table 91
Carpenter Technology Corp.: Product Portfolio

Product	Specifications
300M Alloy & Specialty Steel	It is a modified 4340 steel with added silicon allowing for use of a higher tempering temperature. The steel has high hardenability and strength with good ductility and toughness in heavy sections.
NI-CU 400	Ni-Cu 400 is a nickel-copper solid solution binary alloy combining high strength (comparable to structural steel) and toughness over a wide temperature range with excellent resistance to many corrosive environments. Used at temperatures up to 800°F (427°C), and as high as 1,000°F (538°C) in sulfur-free oxidizing atmospheres.
TI 3AL-2.5V	Ti 3Al-2.5V is a titanium near-alpha alloy that represents a good compromise between formability and strength. It is stronger than commercially pure titanium (at both room and elevated temperatures).

Source: Company website

Product Financials

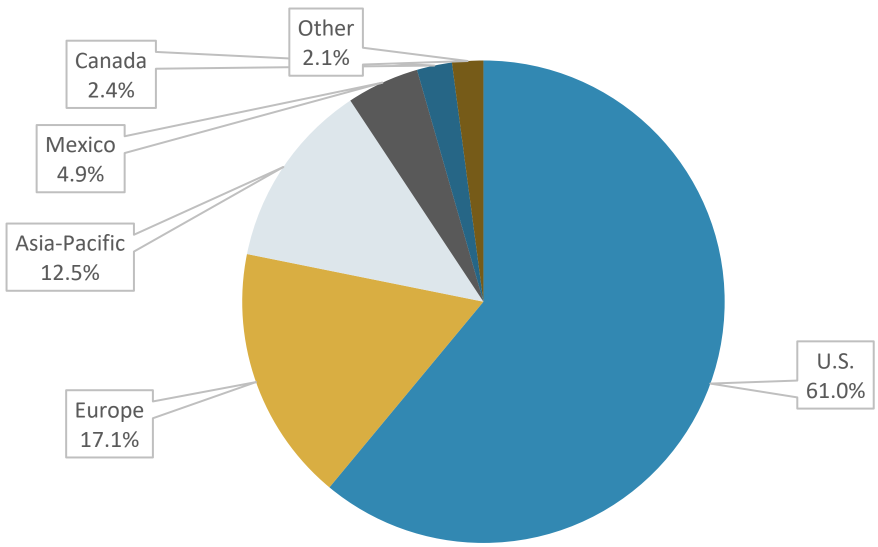
Figure 56
Carpenter Technology Corp.: Revenue Share, by Business Unit, 2022
(%)



Source: Company annual report

Regional Financials

Figure 57
Carpenter Technology Corp.: Revenue Share, by Country/Region, 2022
(%)



Source: Company annual report

CONSTELLIUM SE

Washington Plaza
40-44 Rue Washington
Paris 75008
France
Tel: +33 1 73 01 46 00
Website: www.constellium.com

Company Overview

Constellium SE, together with its subsidiaries, engages in the design, manufacture and sale of specialty rolled and extruded aluminum products for packaging, aerospace, automotive, other transportation and industrial end-markets. The company operates through three segments: Packaging & Automotive Rolled Products, Aerospace & Transportation, and Automotive Structures & Industry. The Aerospace & Transportation segment provides rolled aluminum products, including aerospace plates, sheets and extrusions, and aerospace wing skins, as well as plates and sheets for use in transportation, industry and defense applications. The company sells its products directly or through distributors in France, Germany, the Czech Republic, the U.K., Switzerland, and the U.S., as well as Shanghai and Seoul. Constellium SE was incorporated in 2010 and is headquartered in Paris, France.

Key Highlights

- As of December 2022, Constellium operated 29 manufacturing facilities, three R&D centers and three administrative centers in Baltimore, Maryland; Paris, France; and Zurich, Switzerland.

- In February 2023 Constellium completed the divestment of the Ussel plant to French Investment Holding Noe Industrie.

- In December 2022, approximately 34% of the Aerospace & Transportation Operating segment volume was in aerospace rolled products.

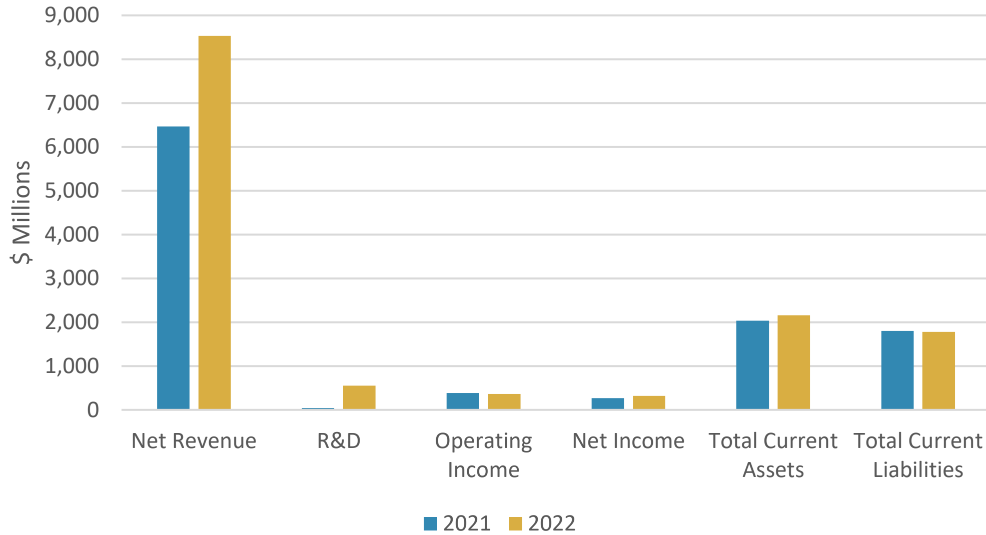
Financials

Table 92
Constellium SE: Annual Revenue, 2022
($ Millions)

Financials	Revenue ($ Millions)
Net revenue	8,531.3
R&D	550.4
Operating income	359.3
Net income	316.2
Total current assets	2,160.1
Total current liabilities	1,778.7

Source: Company annual report

Figure 58
Constellium SE: Annual Revenue, 2021 and 2022
($ Millions)



Note: The bars for net income may not be visible as their values are very small compared to other values depicted in the figure.

Source: Company annual report

News/Key Developments

Table 93
Constellium SE: News, 2022 and 2023

Year	Strategy	Development
2023	Divestment	Constellium announced the completion of the sale of three of its soft alloy extrusion facilities located in Landau, Crailsheim and Burg in Germany to Vaessen Aluminum, for a total cash consideration of $51.2 million (€48.8 million).
2023	Partnership	Constellium and TARMAC Aerosave partnered to advance towards full aluminum circularity in commercial aviation.
2023	Divestment	Constellium announced the completion of the divestment of its Ussel plant to French Investment Holding Noe Industries.
2023	Agreement	Constellium SE announced that it had entered into a multi-year contract with Daher to supply a wide range of flat-rolled aluminum products, particularly for the TBM and Kodiak aircraft. With this new agreement, Constellium expanded its customer portfolio for business and regional jets and became the strategic aluminum supplier for Daher.

Year	Strategy	Development
2022	Agreement	Constellium SE entered into an agreement with Morf3D to provide Aheadd CP1, one of its proprietary additive manufacturing (AM) powder solutions, to Morf3D Inc., a subsidiary of Nikon Corp. and trusted leader in metal additive manufacturing specializing in AM optimization and engineering for the aviation, space and defense industries.

Source: Company website

ESG Trends

- The company has set goals to reach a 1.5 RCR (recordable case rate) in 2025.
- Increase the percentage of women in professional and management roles at Constellium to 25% by 2025.
- Reduce its Scope 1, 2 and 3 GHG emissions intensity by 30% in 2030.
- At least 50% of all aluminum it uses will be from recycled sources by 2030.

Product Offerings

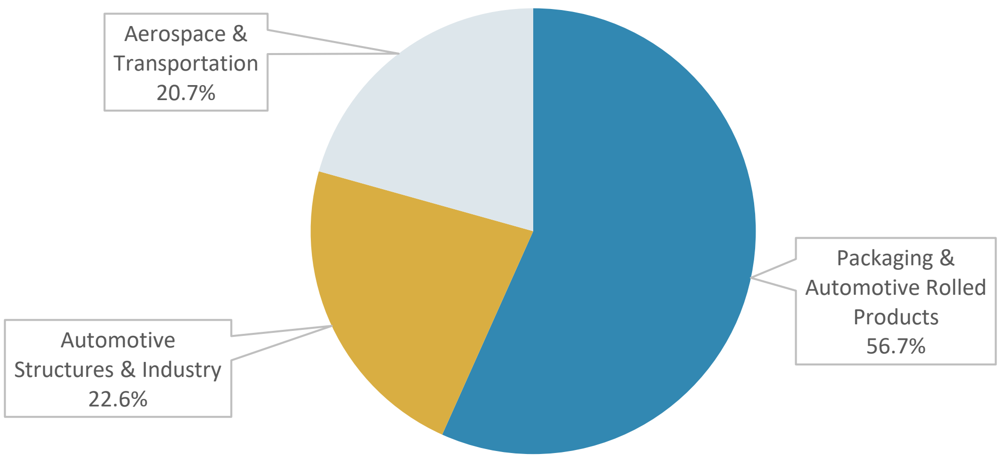
Table 94
Constellium SE: Product Portfolio

Product	Specifications
AIRWARE Aluminum-Lithium Alloys	It was developed to provide lower density, higher modulus and higher corrosion resistance than that which is currently available on incumbent plate alloys such as 7050.
Plates	A low-density aluminum alloy that was developed to provide high toughness combined with improved fatigue and damage tolerance balance versus incumbent alloys.
Sheets	A low-density aluminum sheet product designed to provide high damage tolerance combined with high strength and excellent corrosion resistance.

Source: Company website

Product Financials

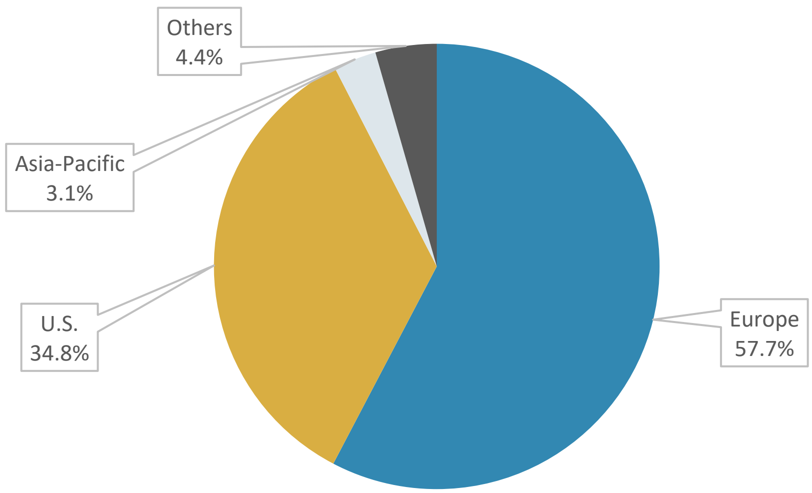
Figure 59
Constellium SE: Revenue Share, by Business Unit, 2022
(%)



Source: Company annual report

Regional Financials

Figure 60
Constellium SE: Revenue Share, by Country/Region, 2022
(%)



Source: Company annual report

DONCASTERS GROUP

Forge Lane
Killamarsh
Sheffield, S21 1BA
United Kingdom
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Website: www.doncasters.com

Company Overview
Established in 1778 by Daniel Doncaster, Doncasters is an international manufacturer of specialist superalloys and high-precision alloy components. It employs nearly 3,000 people at 20 locations in Europe, Asia and America. The company serves the world's leading OEMs in aerospace & defense, industrial gas turbine and automotive markets, whilst also delivering for medical and other specialist industries. Doncaster is a key supplier of superalloy bar stock for the aerospace industry, producing and forming high-temperature alloys critical to efficient aero engine operation.

News/Key Developments

Table 95
Doncasters Group: News, 2021-2023

Year	Strategy	Development
2023	Agreement	Doncasters Group announced the signing of a multi-year contract with Siemens Energy, a world-renowned energy technology company. The deal with an anticipated value exceeding $1 billion, covers the supply of complex precision investment castings for Siemens Energy's gas turbine platforms.
2023	Agreement	Doncasters announced the signing of an agreement with Safran Aircraft Engines to renew and expand the supply of large superalloy structural castings and hot section air flow castings for the LEAP-1A and LEAP-1B platforms.
2022	Investment	As the commercial aircraft market bounces back, Doncasters has invested $12.9 million in Doncasters Precision Castings of Groton and Doncasters Precision Castings--Deritend. The significant investment at Doncasters Precision Castings of Groton will involve building an extension to the current manufacturing facility to house three robot shell coating cells and two final drying systems. The line will commence production in 2023, ramping up to full operating capacity in 2025.
2022	Acquisition	Doncasters acquired Uni-Pol, a global business specializing in the manufacture of superalloy cast parts. This acquisition places Doncasters amongst the largest manufacturers of high-precision alloy components in the global supply chain.

Source: Company website

ESG Trends

- In 2023, the company achieved a 31% reduction in total recordable incident rate.
- 9.3% reduction in tons of carbon dioxide equivalent.
- In terms of Scope 1 & 2 emissions, the company aims to reduce emissions by 40% by 2030 compared to a 2018 base year; for Scope 3 emissions, it aims to reduce emissions by 35% by 2030 compared to a 2018 base year.
- Zero waste to landfill by end of 2024.

Product Offerings

Table 96
Doncasters Group: Product Portfolio

Product	Specifications
Vacuum melted superalloys	These alloys are used across a wide range of performance critical applications as diverse as turbine blades and vanes and other components for aero engines and land-based gas turbines. Melting critical superalloys under high vacuum conditions demands tight controls and strict adherence to approved manufacturing procedures.
Air melted superalloys	The production of air-melted superalloys involves a fully automatic metal mold casting machine delivering molds to two pouring stations. All air-melted ingots are shotblasted, individually inspected and marked before packing and dispatch.

Source: Company website

DUPONT DE NEMOURS INC.

Building 730
974 Centre Road
Wilmington, DE 19805
Tel: 302/992-2941
Website: www.dupont.com

Company Overview
DuPont de Nemours Inc. provides technology-based materials and solutions in the U.S., Canada, Asia-Pacific, Latin America, Europe, the Middle East and Africa. It operates through Electronics & Industrial, Water & Protection, and Corporate & Other segments. DuPont provides a portfolio of materials that provide improved strength, efficiency and safety modern aircraft demand. DuPont Kevlar and DuPont Nomex help deliver durability, lightweight strength, stiffness, thermal and fire protection in aircraft.

The alloy cores that have historically dominated designs for helicopter rotor blades are making way for composites, of which a honeycomb core constructed of Nomex or Kevlar is proving to be a material of preference. Modern helicopters are redefining performance and efficiency with lighter, stronger rotor blades composed of Nomex or Kevlar. Moreover, Kevlar fiber has proven that it is strong enough to survive the extreme forces and temperature fluctuations of space travel.

Key Highlights
As of December 2022, the company had subsidiaries in about 50 countries worldwide and manufacturing operations in about 25 countries.

In July 2022, DuPont announced it had committed to setting science-based targets to reduce greenhouse gas (GHG) emissions in line with the Science Based Targets initiative (SBTi), a partnership between CDP, the UN Global Compact, World Resources Institute (WRI) and the World Wide Fund for Nature (WWF). As part of its commitment, DuPont plans to work closely with SBTi to determine GHG emissions reduction targets for Scope 1 and 2 emissions aligned with the Paris agreement, which sets the goal of limiting global warming to 1.5°C. In addition, DuPont will also work with SBTi to develop its Scope 3 GHG emissions target.

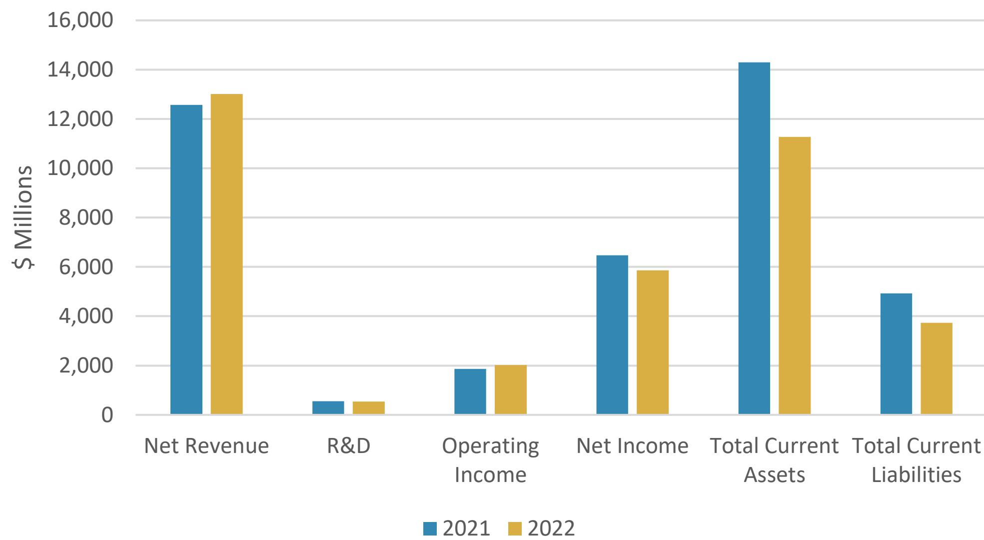
Financials

Table 97
DuPont de Nemours Inc.: Annual Revenue, 2022
($ Millions)

Financials	Revenue ($ Millions)
Net revenue	13,017.0
R&D	536.0
Operating income	2,022.0
Net income	5,868.0
Total current assets	11,270.0
Total current liabilities	3,733.0

Source: Company annual report

Figure 61
DuPont de Nemours Inc.: Annual Revenue, 2021 and 2022
($ Millions)



Source: Company annual report

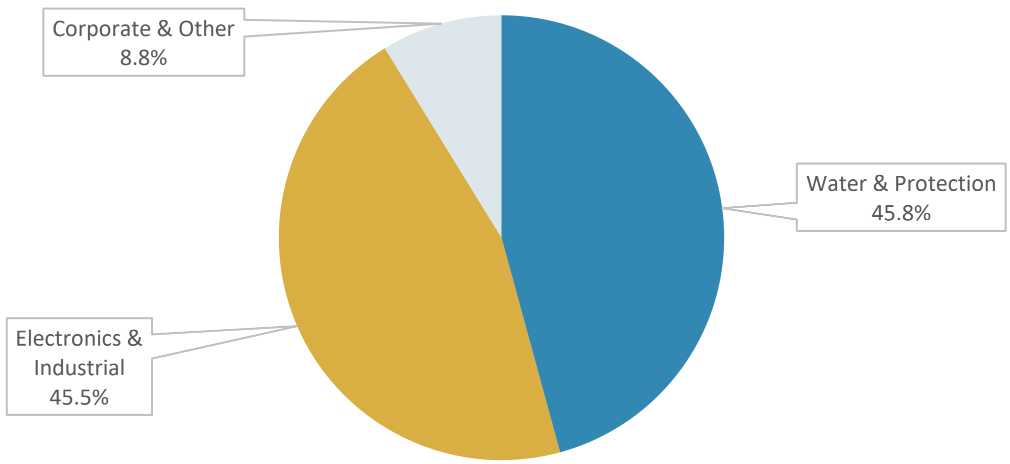
ESG Trends

As of December 31, 2022, the company had eight corporate Employee Resource Groups (ERGs): DuPont Black Employees Network, DuPont Asian Group, DuPont Pride Network, DuPont Latin Network, DuPont Women's Network, DuPont Veterans Network, DuPont Early Career Network, and DuPont Persons with Disabilities and Allies—all of which have regional and local chapters through the company.

DuPont announced its 2030 Sustainability Goals, including its action on climate goal, to reduce its greenhouse gas (GHG) emissions by 30%, measured from a base year of 2019.

Product Financials

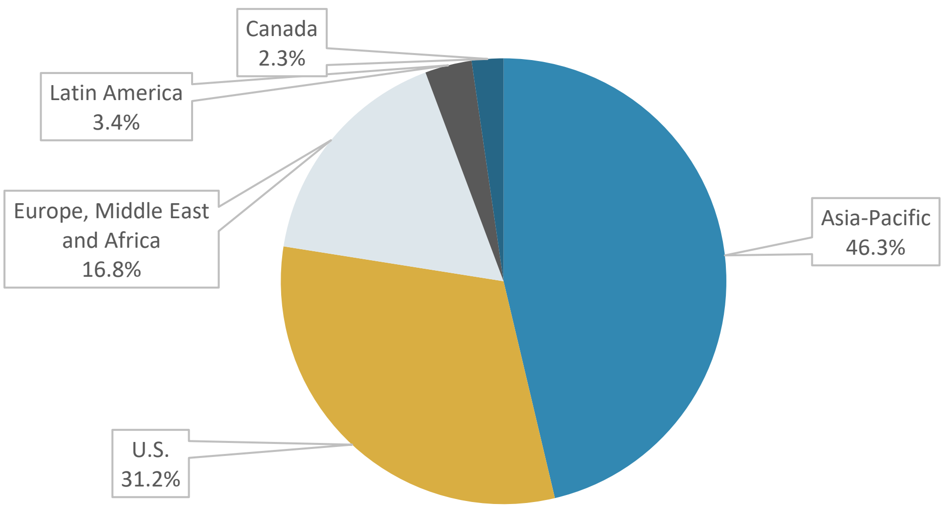
Figure 62
DuPont de Nemours Inc.: Revenue Share, by Business Unit, 2022
(%)



Source: Company annual report

Regional Financials

Figure 63
DuPont de Nemours Inc.: Revenue Share, by Country/Region, 2022
(%)



Source: Company annual report

FORT WAYNE METALS

9609 Ardmore Avenue
Fort Wayne, IN 46809
Tel: 260/747-4154
Website: www.fwmetals.com

Company Overview

Founded in 1970, Fort Wayne Metals deals in the R&D and manufacture of fine-grade precision wire-based materials, with expertise in stainless steel, titanium and titanium alloys and specialty alloys. The company serves the aerospace, defense and other markets. It has manufacturing facilities in Central America, North America, Europe and Asia-Pacific.

Key Highlights

Fort Wayne is ISO 13485:2016 and AS9100/ISO 9001:2015 registered; it also places strict standards with quality management system (QMS).

News/Key Developments

Table 98
Fort Wayne Metals: News, 2023

Year	Strategy	Development
2023	Expansion	Fort Wayne Metals acquired certain equipment and assets to support tantalum production from Plansee SE, a leading materials manufacturer located in Austria.

Source: Company website

Product offerings

Table 99
Fort Wayne Metals: Product Portfolio

Product	Specifications
L-605	L-605 is a cobalt-chromium-tungsten-nickel, nonmagnetic alloy that possess high strength properties at elevated temperatures along with good oxidation and corrosion resistance.
Inconel Alloy 600	Inconel Alloy 600 is a nickel-chromium alloy that possesses good corrosion resistance at elevated temperatures.
MP35N	With tensile strengths comparable to that of 304, MP35N is double melted in order to give this alloy its exceptional combination of strength and corrosion resistance.
Ti 6Al-4V ELI	Featuring 6% Al, 4% V and extra low interstitials (ELI).

Source: Company website

GFE GESELLSCHAFT FÜR ELEKTROMETALLURGIE MBH

Höfener Str. 45
90431 Nürnberg
Germany
Tel: +49 0 911 9315 91
Website: www.gfe.com

Company Overview

Founded in 1911, GfE employs 500 staff at its production sites in Germany and North America. The GfE group comprises four companies GfE Gesellschaft für Elektrometallurgie mbH, Nuremberg, GfE Metalle und Materialien GmbH, Nuremberg, GfE Fremat GmbH, Brand-Erbisdorf and AMG Titanium LLC, New Castle, PA (U.S.). GfE is a company of AMG Critical Materials N.V., Netherlands which deals in the production of special metals and metallurgical products as well as vacuum systems for the aerospace, and specialty metals and chemicals end markets. GfE develops and produces master alloys, titanium aluminides, chemicals, coating materials, powers, semi-finished products and thermal sprays.

News/Key Developments

Table 100
GfE: News, 2019

Year	Strategy	Development
2019	Acquisition	AMG Advanced Metallurgical Group N.V. finalized the acquisition of the assets of International Specialty Alloys ("ISA"), a U.S. producer of titanium master alloys and other binary alloys for the aerospace market, from Kennametal Inc.

Source: Company website

HAYNES INTERNATIONAL INC.

Building 1020 West Park Ave.
P.O. Box 9013
Kokomo, IN 46904-9013
Tel: 765/456-6000
Website: www.haynesintl.com

Company Overview
Haynes International Inc. manufactures and distributes nickel and cobalt-based alloys in sheet, coil and plate forms in the U.S., Europe, China and internationally. The business sells corrosion-resistant alloys (CRA) and high-temperature resistant alloys (HTA). Manufacturers of equipment, including jet engines for the aerospace industry, gas turbine engines for power production, waste incineration and industrial heating equipment, utilize its HTA products. The company also manufactures items in slab, bar, billet, wire, and seamless and welded tube forms. It mostly sells its goods through direct sales companies, a network of independent distributors, and sales representatives. The headquarters of Haynes International Inc. are in Kokomo, Indiana, where it was established in 1912.

Manufacturing facilities for Haynes International are located in Mountain Home, North Carolina; Arcadia, Louisiana; and Kokomo, Indiana. Flat items are the focus of the Kokomo site, tubular products are the focus of the Arcadia facility, and high-performance wire products are the focus of the Mountain Home facility.

Key Highlights
Net revenues of $490.5 million in fiscal 2022, up 45.2% from $337.7 million in fiscal 2021 and net income of $45.1 million, an increase of $53.8 million over the fiscal 2021 net loss of $8.7 million.

In the aerospace engine and industrial gas turbine applications, to meet the increased demands for higher fuel efficiency and consequently higher operating temperatures, its latest generation of alloys such as HAYNES 282, 244 and 233 are being specified for significant engine applications.

Aerospace revenue increased to 47% of sales in the 4th quarter of fiscal 2022, and full-year aerospace revenues grew by 79.6% over fiscal 2021.

Continued expansion of gross margins, which increased to 21.7% in fiscal 2022.

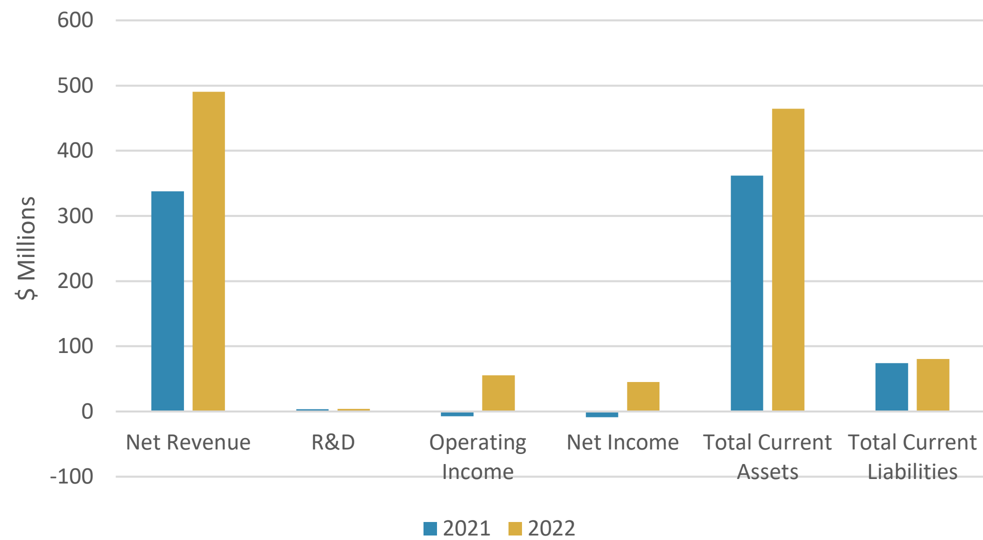
Financials

Table 101
Haynes International Inc.: Annual Revenue, 2022
($ Millions)

Financials	Revenue ($ Millions)
Net revenue	490.4
R&D	3.8
Operating income	55.4
Net income	45.0
Total current assets	464.4
Total current liabilities	80.8

Source: Company annual report

Figure 64
Haynes International Inc.: Annual Revenue, 2021 and 2022
($ Millions)



Note: The bars for operating and net income may not be visible as their values are very small compared to other values depicted in the figure.

Source: Company annual report

News/Key Developments

Table 102
Haynes International Inc.: News, 2021

Year	Strategy	Development
2021	Capital Allocation Strategy	Haynes International Inc. announced a multifaceted capital allocation strategy that includes 1) a share repurchase plan; 2) the recent adoption of a glide path for its U.S. pension plan to help secure improvements in funding percentage realized this fiscal year due to higher-than-expected return on plan assets combined with higher interest rates; and 3) a U.S. pension plan accelerated funding strategy.
2021	Price Increase	Haynes International Inc. initially announced that it increased base prices on all new transactional (non-contract) orders across all its products by 5% to 8%. In May 2021, it further increased base prices on such orders by an additional incremental 2% for new orders placed after that date.

Source: Company website

ESG Trends
In 2023, Haynes international has placed specific targets to reduce electricity consumption per throughput pounds (TPP) by 4% vs. FY18 baseline.

In 2023, Haynes international has placed specific targets to reduce natural gas consumption per throughput pounds (TPP) by 4% vs. FY18 baseline.

In order to integrate a culture of safety and emergency preparedness, Haynes has implemented management systems that conform to the ISO 45001 standard.

Product Offerings

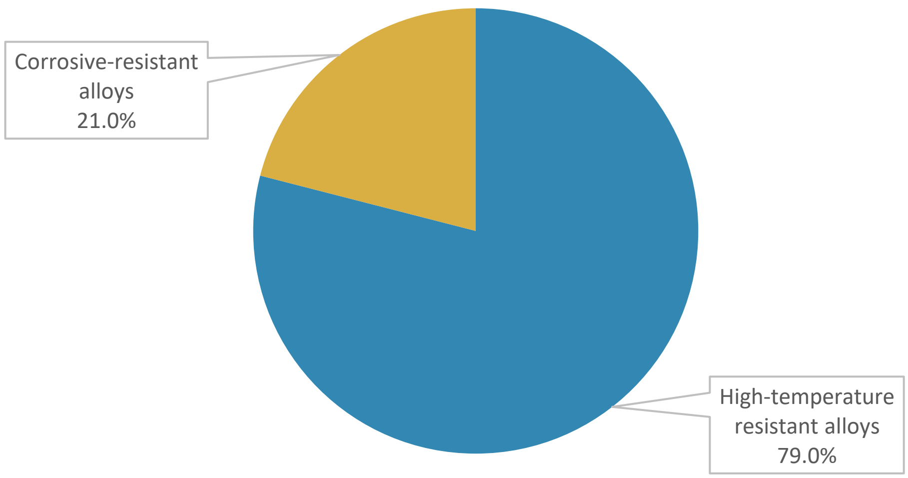
Table 103
Haynes International Inc.: Product Portfolio

Product	Specifications
HAYNES 188 alloy	It is a cobalt-nickel-chromium-tungsten alloy that offers excellent high-temperature strength and superior oxidation resistance up to 2,000°F (1,095°C) and thermal stability. This alloy is used extensively in demanding military and civil aircraft gas turbine engine combustors, transition ducts, and after-burner components.
HAYNES 244® alloy	It is a new, age-hard enable, nickel-molybdenum-chromium-tungsten alloy with an extended operating temperature range to 1,400°F (760°C).
HAYNES Ti-3Al-2.5-V alloy	It was developed for aircraft hydraulic and fuel systems transmission lines, primarily because of its high strength-to-weight ratio. This ratio proves to be a major advantage when used for hydraulic tubing lines to provide required strength levels, but more importantly, reducing weight by as much as 43% when compared to stainless steel.

Source: Company website

Product Financials

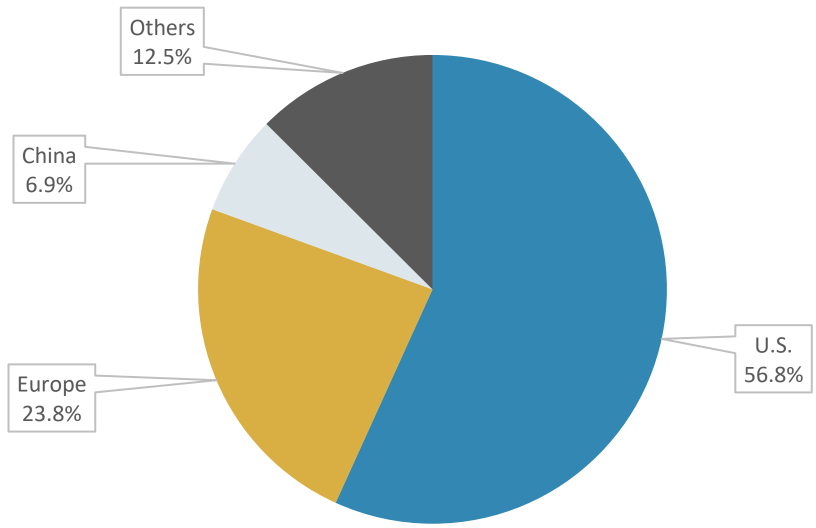
Figure 65
Haynes International Inc.: Revenue Share, by Business Unit, 2022
(%)



Source: Company annual report

Regional Financials

Figure 66
Haynes International Inc.: Revenue Share, by Country/Region, 2022
(%)



Source: Company annual report

HEXCEL CORP.

Two Stamford Plaza
281 Tresser Boulevard, 16th Floor
Stamford, CT 06901-3261
Tel: 203/969-0666
Website: www.hexcel.com

Company Overview
Hexcel Corp. produces and sells carbon fibers, structural reinforcements, honeycomb structures, resins, and composite materials and components for use in industrial, commercial aerospace, space and defense applications. Engineered Products and Composite Materials make up its two business segments. Fabrics, multi-axials, specialty reinforcements, prepregs and other fiber-reinforced matrix materials, structural adhesives, molding compounds, tooling materials, polyurethane systems and laminates are all produced and sold by the Composite Materials segment for use in both military and commercial aircraft.

Hexcel is a leading supplier of carbon fiber, honeycomb and other composite materials for the commercial aerospace industry. In new wide-bodied aircraft such as the Boeing 787 and the Airbus A350 XWB composites account for over 50% of the airframe. Hexcel was awarded the contract by Airbus to supply HexPly prepreg reinforced with HexTow carbon fiber for all composite primary structures of the

A350 XWB. Hexcel’s composites save weight and reduce fuel consumption, increase payload, extend flight range, enhance toughness and durability, optimize design, reduce part count, decrease maintenance cost, and maximize passenger comfort and safety.

Key Highlights

In 2022, Archer Aviation and Hexcel announced plans to advance production capabilities for eVTOL aircraft. Hexcel will provide Archer with high-performance carbon fiber and resin systems, which are needed to fabricate composite parts for Archer’s production aircraft, such as Midnight.

Net sales for the Composite Materials segment to third-party customers were $1,279.7 million in 2022, $1,019.4 million in 2021 and $1,185.9 million in 2020, and they represented about 80% of net sales each year.

Commercial Aerospace represented 58% of Hexcel’s 2022 net sales. Approximately 79% of these revenues can be identified as sales to Airbus, Boeing and their subcontractors to produce commercial aircraft.

In 2022, Hexcel’s Commercial Aerospace sales increased 36.5% compared to 2021. The 2022 increase in sales was driven by higher narrowbody and Airbus A350 sales, along with an increase in sales of Other Commercial Aerospace, which includes business jets and regional aircraft.

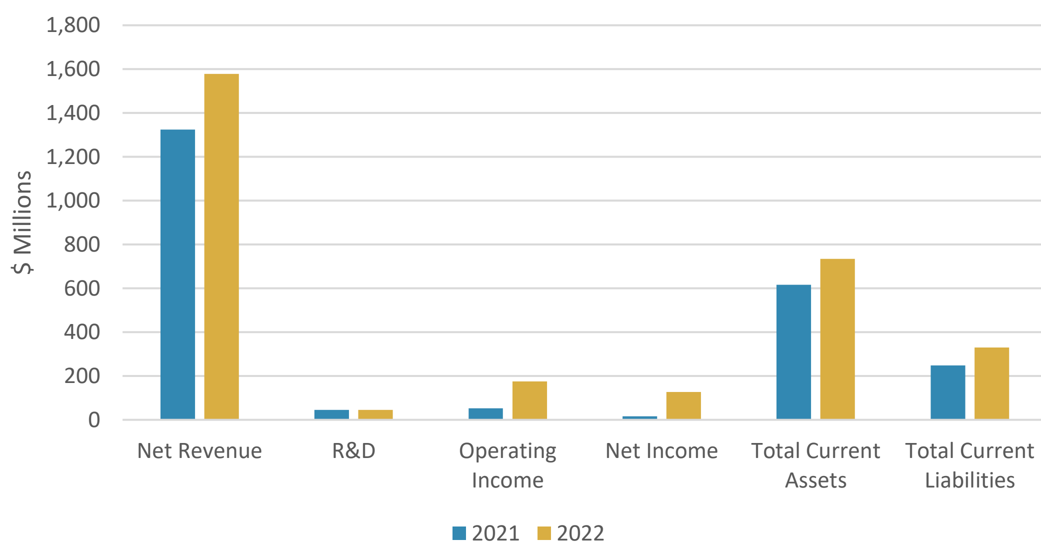
Financials

Table 104
Hexcel Corp.: Annual Revenue, 2022
($ Millions)

Financials	Revenue ($ Millions)
Net revenue	1,577.7
R&D	45.8
Operating income	175.2
Net income	126.3
Total current assets	734.4
Total current liabilities	329.8

Source: Company annual report

Figure 67
Hexcel Corp.: Annual Revenue, 2021 and 2022
($ Millions)



Source: Company annual report

News/Key Developments

Table 105
Hexcel Corp.: News, 2021-2023

Year	Strategy	Development
2023	Expansion	Hexcel Corp. announced the opening of a completed expansion at its engineered core operations plant in Morocco to meet the growing demand for lightweight advanced composite materials for the aerospace industry.
2023	Expansion	Hexcel opened a new center of research & technology excellence in Utah, supporting next-generation developments in advanced composites technologies.
2022	Agreement	Hexcel signed a long-term agreement with Dassault to supply carbon fiber prepreg for the Falcon 10X program. This was the first Dassault business jet program to incorporate high-performance advanced carbon fiber composites in the manufacture of its aircraft wings.
2022	Collaboration	Hexcel Corp. has joined with Spirit AeroSystems Europe in a strategic collaboration at its Aerospace Innovation Centre (AIC) to develop more sustainable aircraft manufacturing technologies for future aircraft production.
2021	Partnership	Hexcel and Fairmat partnered to recycle carbon fiber prepreg from Hexcel European operations for reuse in composite panels sold into commercial markets. As a result, it is intended that most of the carbon fiber prepreg cutoffs generated at Hexcel plants in Europe will be repurposed by the end of 2022.

Source: Company website

ESG Trends

- 30% reduction in greenhouse gas emissions.
- 30% reduction in waste to landfill.
- 20% reduction in freshwater use.
- 50% reduction in total recordable incident rate (TRIR).
- 100% diversity sourcing.

Product Offerings

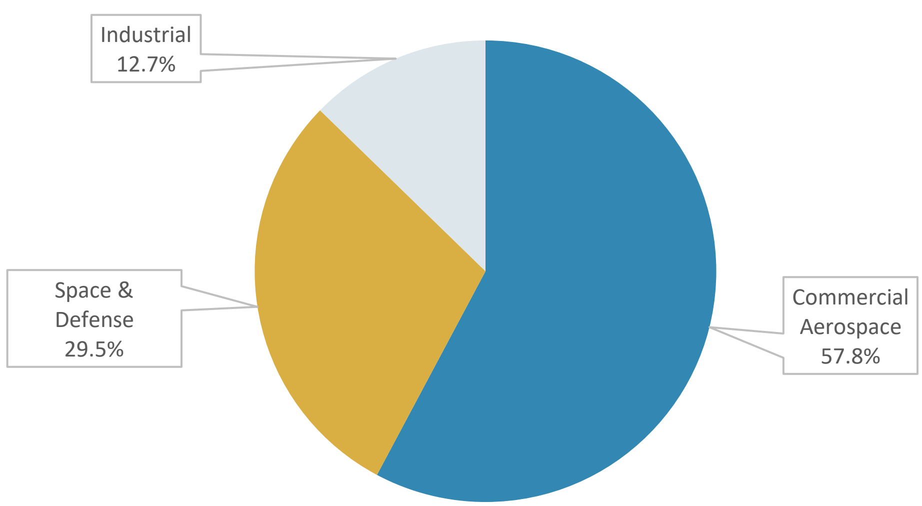
Table 106
Hexcel Corp.: Product Portfolio

Product	Specifications
HexTow Continuous Carbon Fiber	It is chosen for aerospace applications for its high strength, lightweight, superior stiffness, electrical conductivity, low thermal expansion, high thermal conductivity and corrosion resistance.
Hexbond	Low weight film adhesives with high Tg. Used for space applications.
HexTow	High modulus carbon fiber (in UD or woven format) offers superior stiffness for UAV applications.
HexPly Prepregs	HexPly M91 is a new toughened epoxy prepreg offering superior performance for primary aircraft structures and engines.

Source: Company website

Product Financials

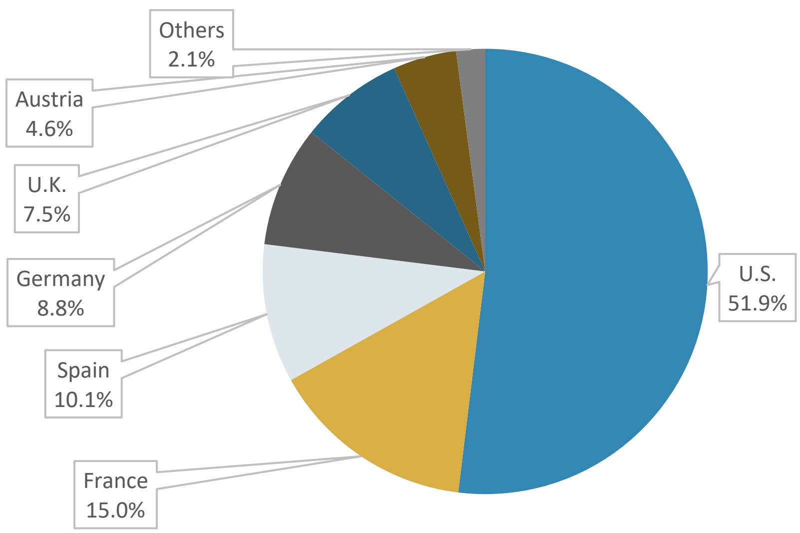
Figure 68
Hexcel Corp.: Revenue Share, by Business Unit, 2022
(%)



Source: Company annual report

Regional Financials

Figure 69
Hexcel Corp.: Revenue Share, by Country/Region, 2022
(%)



Source: Company annual report

HIGH PERFORMANCE ALLOYS INC.

1985 E. 500 N.
Windfall, IN 46076
Tel: 765-945-8230,
Website: www.hpalloy.com

Company Overview
Founded in 1984, High Performance Alloys is a superalloy producer of bars, sheets, plates, forgings and fasteners. In addition to manufacturing its own superalloy products, the company is also a supplier of Hastelloy, Inconel, Monel, Nitronic and Stellite brand superalloys. It serves the aerospace, petrochemical, pharmaceutical and mining industries. The company ship its products to over 48 countries and make sure that its products meet or even exceed the ISO 9001 standards.

JIANGYOU CHANGCHENG SPECIAL STEEL CO. LTD.

No. 195, Jiangdong Road
Jiangyou City
Sichuan Province, 621701
China
Tel: +86 816 3651866
Website: www.cssc.com.cn

Company Overview

The company, which was established in 1965, serves as a major backbone enterprise in Sichuan Province as well as a national center for scientific research and manufacture of special steel. It is a Chinese supplier of comprehensive solutions for premium metal products. The company provide carbon steel, composite steel, bearing steel, spring steel, tool and die steel, stainless steel, high-strength steel, high-temperature alloys, corrosion-resistant alloys, precision alloys, titanium and titanium alloys in accordance with national standards, international standards and user technical conditions. Products are widely used in aviation, aerospace, marine equipment, nuclear power, transportation, machinery, petrochemical and other fields.

The company has undertaken more than 400 scientific research projects in the national high-tech engineering supporting and civil fields.

Product Offerings

Table 107
Jiangyou Changcheng Special Steel Co. Ltd.: Product Portfolio

Product	Specifications
Titanium alloys	These are produced in plates, strips, seamless pipes, welded pipes, ingots and slabs, rods, rolled products and wire products. Titanium alloy are widely used in aviation, aerospace, navigation and nuclear industries.
Corrosion resistant alloy	These high-temperature alloy (corrosion alloy) series products are widely used in high-end fields such as aerospace, aviation, petroleum and petrochemicals.

Source: Company website

MATERION CORP.

6070 Parkland Boulevard
Mayfield Heights, OH 44124
Tel: 216/486-4200
Website: www.materion.com

Company Overview

Materion Corp., through with its subsidiaries, produces advanced engineered materials used in semiconductor, industrial, aerospace and defense, automotive, energy, consumer electronics, and telecom and data center in the U.S., Asia, Europe and internationally. It operates through Performance Materials, Electronic Materials and Precision Optics segments. The Performance Materials segment offers advanced engineered solutions comprising beryllium and non-beryllium containing alloy systems and custom engineered parts in strip, bulk, rod, plate, bar, tube and other customized shapes. The company was formerly known as Brush Engineered Materials Inc. and changed its name to Materion Corp. in 2011. Materion Corp. was incorporated in 1931 and is headquartered in Mayfield Heights, Ohio.

ToughMet alloys, among others, were developed and commercialized by Materion over the course of more than 30 years, enabling advancements in the aerospace sector. ToughMet alloys are used on all types of aircraft to improve component performance, boost reliability and optimize aircraft design. ToughMet alloys meet all relevant Aerospace Material Specifications(AMS) and are approved for use in major commercial and military programs.

Key Highlights

- In 2022, 16% of Materion value-added sales were to customers in the aerospace and defense end market.
- Net sales of $1,757.1 million in 2022 increased to $246.5 million from $1,510.6 million in 2021.
- Gross margin was $343.9 million in 2022, a 21% increase from the $283.8 million gross margin recorded in 2021.
- R&D expense was $29.0 million in 2022, an increase of 9% compared to 2021.

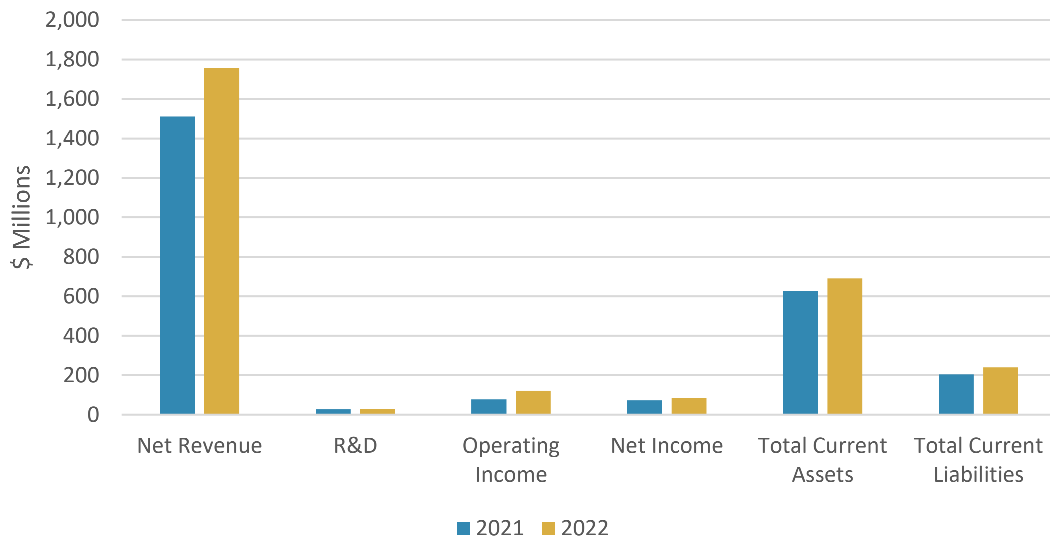
Financials

Table 108
Materion Corp.: Annual Revenue, 2022
($ Millions)

Financials	Revenue ($ Millions)
Net revenue	1,757.1
R&D	28.9
Operating income	121.3
Net income	85.9
Total current assets	690.4
Total current liabilities	238.9

Source: Company annual report

Figure 70
Materion Corp.: Annual Revenue, 2021 and 2022
($ Millions)



Source: Company annual report

News/Key Developments

Table 109
Materion Corp.: News, 2021

Year	Strategy	Development
2021	Acquisition	Materion Corp. announced that it had completed its previously announced acquisition of H.C. Starck Solutions' industry-leading electronic materials business, located in Newton, Massachusetts (HCS-Electronic Materials). HCS-Electronic Materials utilizes proprietary technology and extensive material science know-how to deliver tantalum- and niobium-based premium products and services for the semiconductor, industrial, and aerospace and defense markets.

Source: Company website

ESG Trends

- Materion is focused on:
    - Producing materials that enable technologies to provide a safer and more sustainable environment.
    - Designing, manufacturing and distributing products in a safe and environmentally responsible manner.
    - Maintaining the highest standards of health, safety and security.

Product Offerings

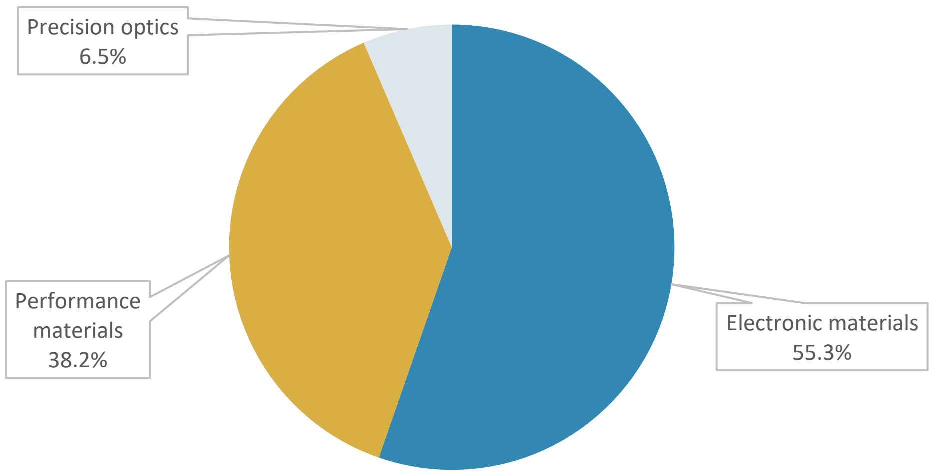
Table 110
Materion Corp.: Product Portfolio

Product	Specifications
ToughMet alloys	ToughMet alloys have superior friction characteristics that make them ideal for bearings and bushings for components of aircraft landing gear and airfoil controls. The materials exhibit stable properties over the wide range of temperatures encountered during flight, and they can operate safely and reliably for extended periods of time in the event of lubrication failure.
AlBeMet & AlBeCast composites	They combine the high modulus and low-density characteristics of beryllium with the fabrication and mechanical properties of aluminum.

Source: Company website

Product Financials

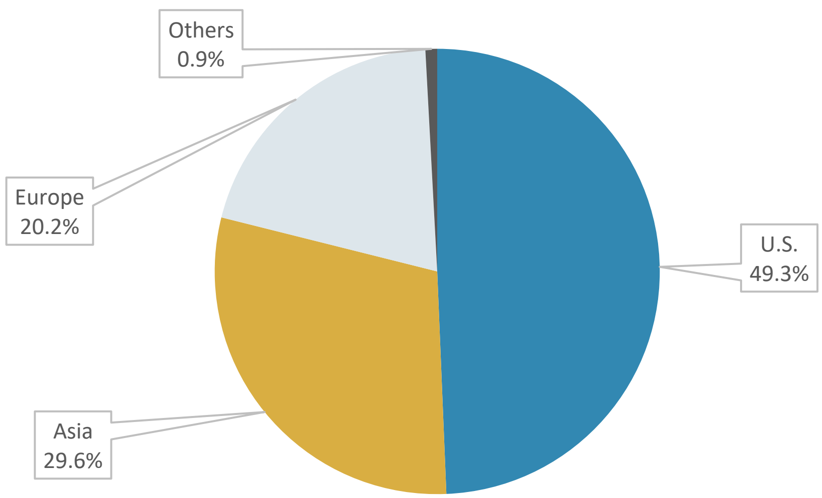
Figure 71
Materion Corp.: Revenue Share, by Business Unit, 2022
(%)



Source: Company annual report

Regional Financials

Figure 72
Materion Corp.: Revenue Share, by Country/Region, 2022
(%)



Source: Company annual report

NOVELIS

3550 Peachtree Rd. NE, Suite 1100
Atlanta, GA 30326
Tel: 404/760-4000
Website: www.novelis.com

Company Overview
Novelis is a subsidiary of Hindalco Industries Ltd., an industry leader in aluminum and copper and metals flagship company of the Aditya Birla Group, a multinational conglomerate based in Mumbai, India. The company is a leading producer of flat-rolled aluminum products and the world's largest recycler of aluminum with facilities across North America, South America, Europe and Asia.

In the aerospace industry, Novelis specializes in the production of rolled aluminum plate and sheet materials for fuselage and wing structure components according to standard or customized specifications. Recently, Novelis introduced new low-density alloys that feature fuel efficiency and lower operating costs for the airline industry. Its innovation centers in Koblenz, Germany, and Zhenjiang, China, focus on the aerospace industry and have developed innovations that include high-strength alloys for structural plate applications and aluminum magnesium scandium alloys for lighter fuselage sheets associated with new joining and forming technologies.

Key Highlights

In financial year 2022, the company's net income from continuing operations was up 122% to $1,018 million, in comparison to financial year 2021.

In financial year 2022, net sales were up 40% to $17.1 billion in comparison to financial year 2021.

In the financial year 2022, adjusted EBITDA was up 19% to $2,045 million in comparison to financial year 2021.

News/Key Developments

Table 111
Novelis: News, 2020-2022

Year	Strategy	Development
2022	Agreement	Novelis Inc. announced that it had signed a Cooperation Research Agreement with Airbus, which will allow for tighter collaboration between the two companies and advance the development of aluminum solutions for the aircrafts.
2022	Partnership	Novelis Inc. announced that it had joined the First Movers Coalition (FMC), a global initiative aimed at decarbonizing eight "hard to abate" sectors.
2022	Expansion	Novelis Inc. announced that it will invest $2.5 billion to build a new low-carbon recycling and rolling plant in Bay Minette, Alabama (U.S.).
2022	Expansion	Novelis Inc. announced that it will invest approximately $50 million to build a recycling center at its Ulsan Aluminum joint venture in South Korea.
2020	Acquisition	Novelis Inc. announced the completion of its acquisition of Aleris Corp., a global supplier of rolled aluminum products.

Source: Company website

ESG Trends

- Novelis sets target:
    - to be a carbon neutral company by 2050.
    - to achieve a 30% reduction in carbon footprint by 2026.
    - 10% reduction in energy intensity by 2026.
    - 10% reduction in water intensity.
    - 20% reduction in waste to landfill.

Product Offerings

Table 112
Novelis: Product Portfolio

Product	Specifications
Aluminum alloys	Low-density alloys offer weight-savings, fuel efficiency and lower operating costs for the airline industry. These alloys are manufactured in different plates in various standard and customer-specified alloys using advanced hot and cold rolling mills.

Source: Company website

ROLLED ALLOYS INC.

125 W. Sterns Road
Temperance, MI 48182
Tel: 800/521-0332
Website: www.rolledalloys.com

Company Overview
Rolled Alloys introduced its first alloy, the wrought RA330, as a replacement for cast HT alloys in the commercial heat treat industry over 70 years ago. The company exports products worldwide from its U.S. locations and has divisions in Canada, Singapore and China. The company is a global supplier of specialty alloys for the aerospace, chemical processing, medical, oil and gas, power generation and thermal processing industries. Rolled Alloys product line includes plate, sheet, bar, pipe, fittings and welding materials in nickel-based alloys, duplex stainless steels, stainless steels, titanium and cobalt-based alloys. The company offers a range of nickel alloys, cobalt alloys, titanium and stainless steels for components in the aerospace industry.

SPECIAL METALS CORP.

4317 Middle Settlement Rd.
New Hartford, NY 13413
Tel: 315/798-2900
Website: www.specialmetals.com

Company Overview
Special Metals Corp. is a division of the PCC Forged Products business, a subsidiary of Precision Castparts (PCC). Special Metals Corp. produces high-nickel, high-performance alloys engineered to offer heat resistance, high-temperature corrosion resistance, durability and strength. Its alloys are used in aerospace engineering, among others. Special Metals INCONEL alloy X-750 was used for the F-1 rocket engine used in the first stage of the NASA Saturn V Booster.

SOLVAY S.A.

Rue de Ransbeek, 310
Brussels 1120
Belgium
Tel: +32 2 264 21 11
Website: www.solvay.com

Company Overview

Solvay S.A. provides advanced materials and specialty chemicals worldwide. It operates through four segments: Materials, Chemicals, Solutions and Corporate & Business Services. The Materials segment offers specialty polymers, including aromatic polymers, high barrier polymers and fluoropolymers for the electronics, automotive, aerospace and healthcare industries; and composite materials for aerospace engineered materials market. Solvay is a leading provider of carbon fiber, advanced composite materials, adhesives and surface films for the aerospace market. The company was founded in 1863 and is headquartered in Brussels, Belgium.

Key Highlights

The combination of strong pricing and volume increase in 2022 helped Solvay deliver 26% growth in net sales, with every business contributing. This in turn drove EBITDA above the 3-billion-euro mark for the first time in the company's history.

In 2022, Solvay provide support for employees significantly impacted by high inflation. It distributed $27.4 million (€25 million), among the Solvay employees proportionally most affected by inflation and working in countries that are not protected by national schemes.

Higher profit and disciplined cash management led to a record annual free cash flow of $1,202 million (€1,094 million). Returns (ROCE) also reached a new record of 16.0%, versus 11.4% in 2021.

At the beginning of 2022, Solvay announced its intention to separate Solvay into two strong, independent, publicly listed companies. One will focus on essential chemicals and the other on specialty chemicals, and both will be leaders in their respective areas. Solvay teams worked hard throughout 2022 to prepare for the split, and it is on track to complete it in December 2023.

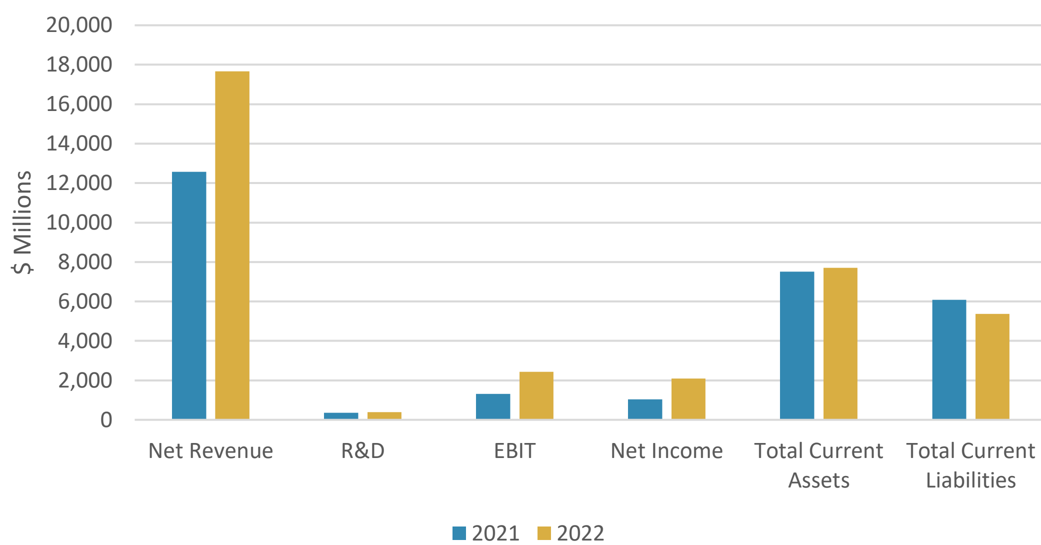
Financials

Table 113
Solvay SA: Annual Revenue, 2022
($ Millions)

Financials	Revenue ($ Millions)
Net revenue	17,659.3
R&D	392.3
EBIT	2,440.5
Net income	2,093.3
Total current assets	7,702.8
Total current liabilities	5,367.8

Source: Company annual report

Figure 73
Solvay SA: Annual Revenue, 2021 and 2022
($ Millions)



Source: Company annual report

News/Key Developments

Table 114
Solvay SA: News, 2021-2023

Year	Strategy	Development
2023	Partnership	Solvay partners with BETA Technologies for Advanced Air Mobility Platform. Solvay will provide BETA with qualification support and advanced materials for the production of their ALIA CTOL, electric fixed-wing aircraft, and ALIA VTOL, electric vertical takeoff and landing aircraft, developed for a variety of applications, including medical, cargo and passenger transportation.
2023	Partnership	Solvay and GKN Aerospace renewed their collaboration agreement. Under the agreement, both businesses are developing a joint thermoplastic composites (TPC) roadmap to explore new materials and manufacturing processes for aerospace structures, while jointly targeting future strategic high-rate programs.
2022	Collaboration	Solvay and Wichita State University's National Institute for Aviation Research (NIAR) officially opened their joint Manufacturing Innovation Center dedicated to enabling the future of flight through advances in composite technologies.
2022	Agreement	Solvay and Trillium Renewable Chemicals have signed a letter of intent to develop the supply chain for bio-based acrylonitrile (bio-ACN). According to agreement, Trillium will supply Solvay with bio-ACN from Trillium's planned commercial asset, and Solvay will evaluate bio-ACN for carbon fiber manufacturing as part of its long-term commitment to developing sustainable solutions from bio-based or recycled sources.
2021	Agreement	Solvay has signed a long-term agreement with Avio to supply advanced composite and adhesive materials for demanding applications in aerospace.

Source: Company website

ESG Trends

In 2022, Solvay advanced toward carbon neutrality by adding 23 emissions reduction projects, bringing its worldwide total to 59. This address phasing out coal from energy production at four plants and significantly progressing renewable energy to power its operations.

Solvay introduced a target to reduce Scope 3 emissions by 24% and its climate targets were validated by the Science Based Targets initiative (SBTi) in early 2023.

In 2022, Solvay made significant progress in embedding diversity, equity and inclusion (DEI) into its company culture, launching a number of different initiatives. These included setting up a new senior leadership team to promote inclusive leadership, expanding Employee Resource Groups (ERGs) and taking action to reduce the gender pay gap.

To meet growing demand for sustainable and circular solutions in a range of markets and develop new business opportunities, Solvay launched a fourth growth platform, focused on renewable materials and biotechnology. The platform covers the entire value chain, from the origin of the product to its end-of-life, reinventing the way it produces chemicals to accelerate the development of more environmentally friendly solutions.

Product Offerings

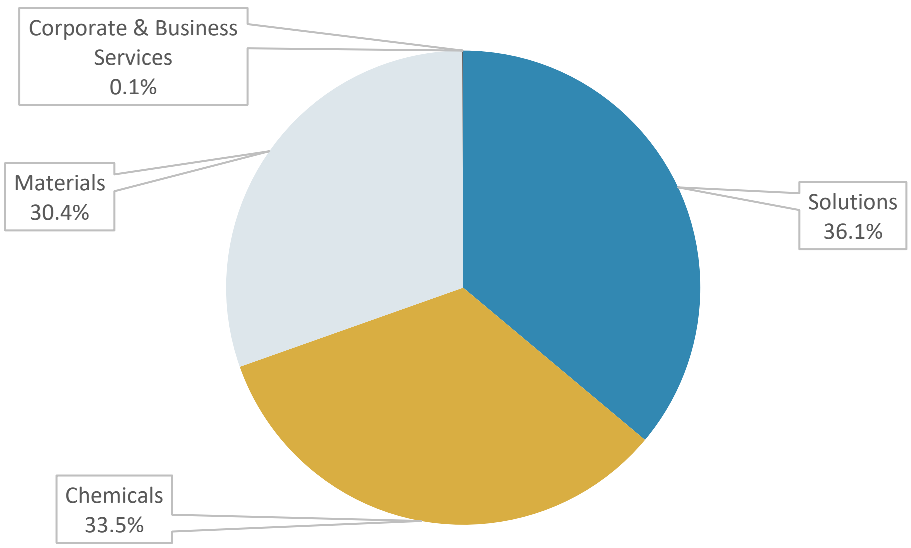
Table 115
Solvay SA: Product Portfolio

Brands	Product
Thermoplastic composites	Solvay thermoplastic composites provide manufacturing efficiency, high performance, chemical and corrosion resistance, the ability to manufacture complex shape and functional integration.
Structural adhesives	These adhesives are suitable for composite-to-composite, composite-to-metal and metal-to-metal bonding. Its properties include: • One and two-part paste adhesives with cure temperatures <200°F (<93°C). • Room temperature cure paste with properties of 250°F (121°C) film adhesive. • Designed for automation and rapid assembly. • Flexible processing and cure conditions. • Composite and metal bonding.
Carbon Fiber	Solvay offers a range of carbon fiber products that deliver superior structural, thermal, electrical and frictional performance for aircraft, brakes and defense systems.

Source: Company website

Product Financials

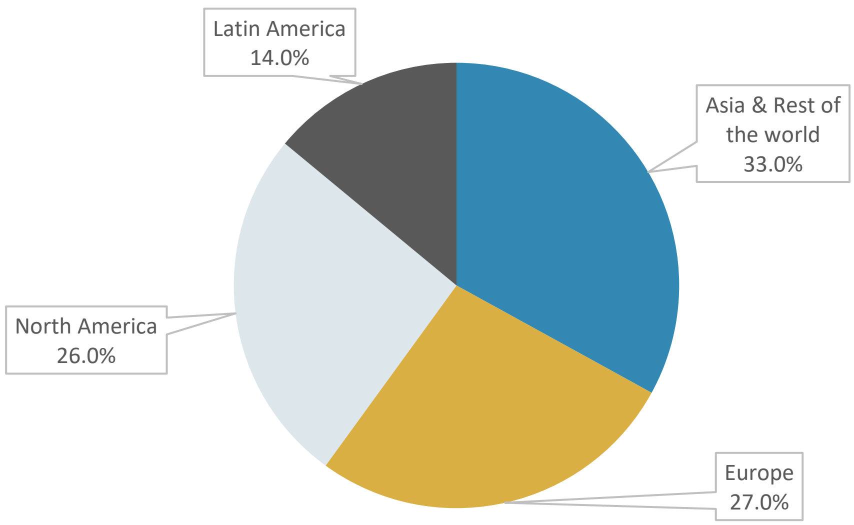
Figure 74
Solvay SA: Revenue Share, by Business Unit, 2022
(%)



Source: Company annual report

Regional Financials

Figure 75
Solvay SA: Revenue Share, by Country/Region, 2022
(%)



Source: Company annual report

TEIJIN LTD.

Kasumigaseki Common Gate West Tower
2-1, Kasumigaseki 3-chome
Chiyoda-ku, Tokyo 100-8585
Japan
Tel: +81-03-3506-4529
Website: www.teijin.com

Company Overview
Teijin Ltd. engages in fibers, films and sheets, composites, healthcare, and IT businesses worldwide. It offers aramid fibers and polyethylene materials; carbon fibers, composite materials, and oxidized PAN fibers; polycarbonate sheets and films; high-density polyethylene porous films and materials; and microporous films. Tenex Carbon Fiber from Teijin enables aircraft, helicopters, and unmanned aerial vehicles (UAVs) to be more aerodynamic, lightweight, and fuel-efficient.

Key Highlights

By implementing roughly 130 newly formulated improvement measures in the areas of sales, procurement, and production, Teijin aims for a $87.3 million (¥13.0 billion) improvement in operating income in this business by the end of fiscal 2023.

Teijin is the first company in the world to acquire International Sustainability and Carbon Certification (ISCC PLUS Certification).

Financials

Table 116

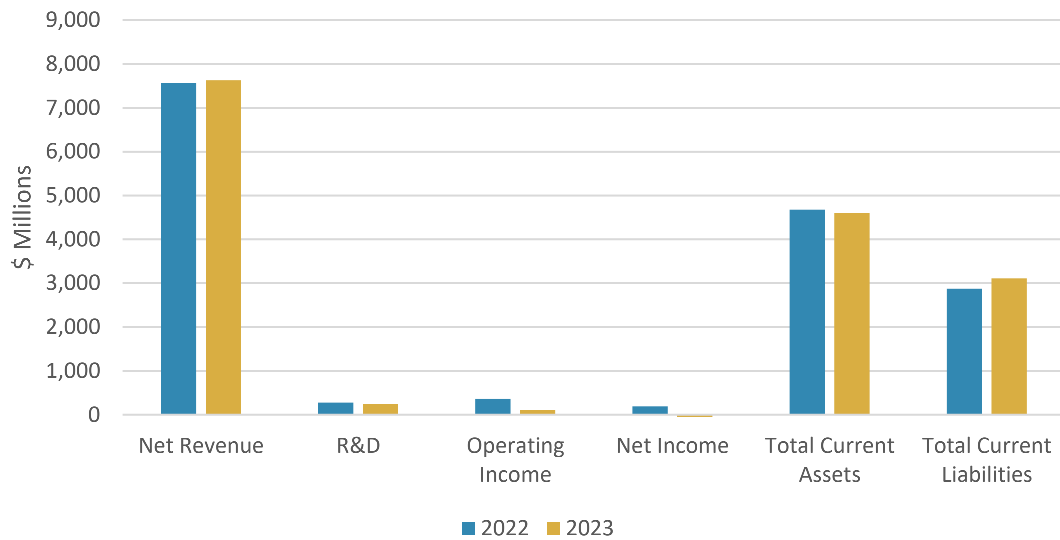
Teijin Ltd.: Annual Revenue, Fiscal Year Ended on March 31,2023

($ Millions)

Financials	Revenue ($ Millions)
Net revenue	7,629.3
R&D	239.1
Operating income	96.3
Net income	-132.5
Total current assets	4,593.2
Total current liabilities	3,106.6

Source: Company annual report

Figure 76
Teijin Ltd.: Annual Revenue, 2022 and 2023
($ Millions)



Note: The bars for operating and net income may not be visible as their values are very small compared to other values depicted in the figure.

Source: Company annual report

News/Key Developments

Table 117
Teijin Ltd.: News, 2021 and 2022

Year	Strategy	Development
2022	Expansion	Teijin Ltd. announced that it had expanded its lineup of carbon fiber thermoplastic intermediate materials with three matrix resins: polypropylene (PP)/polycarbonate (PC), PC and polyamide (PA). The new resins are now being used as base resins in new versions of the company's existing prepreg products, including Tenax, ThermoPlastic UniDirectional (TPUD), Tenax, ThermoPlastic Woven Fabric (TPWF) and Tenax ThermoPlastic Consolidated Laminate (TPCL).
2021	Expansion	Teijin boosted heat-resistant carbon fiber prepreg production at its Renegade Materials Corp. facility by approximately 2.5 times to meet advanced aerospace solutions.

Source: Company website

ESG Trends

The company aims to reach a 30% reduction by fiscal 2030 compared with fiscal 2018.

The company aims to reach net zero emissions by fiscal 2050.

Product Offerings

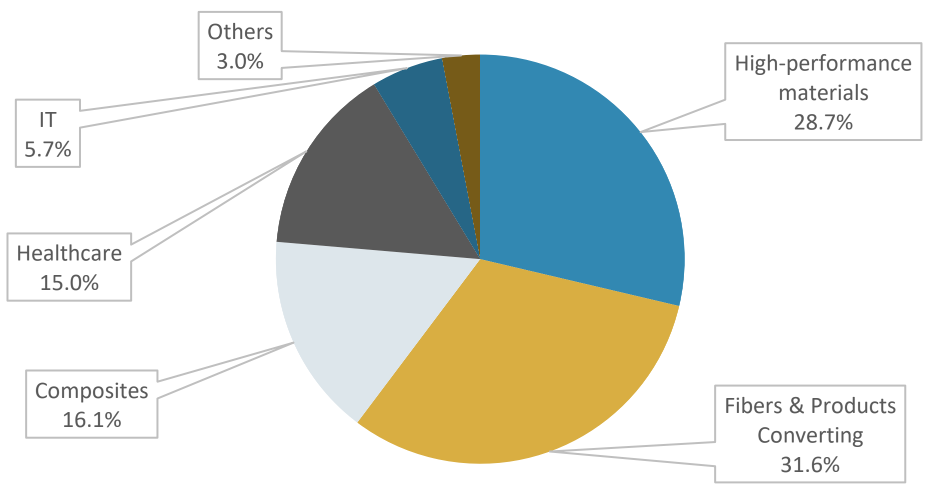
Table 118
Teijin Ltd.: Product Portfolio

Product	Specifications
Tenax Carbon Fiber	Helps reduce the lifetime fuel consumption of aircraft and extend its flight range. It also helps significantly reduce emission, while carbon fiber can be recycled for future applications.

Source: Company website

Product Financials

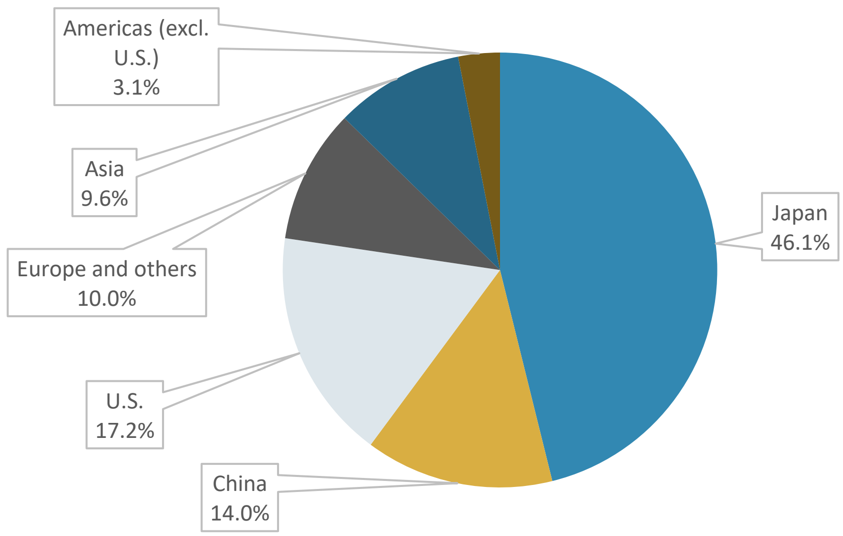
Figure 77
Teijin Ltd.: Revenue Share, by Business Unit, 2023
(%)



Source: Company annual report

Regional Financials

Figure 78
Teijin Ltd.: Revenue Share, by Country/Region, 2023
(%)



Source: Company annual report

TORAY INDUSTRIES INC.

Nihonbashi Mitsui Tower
1-1, Nihonbashi-Muromachi 2-chome
Chuo-ku, Tokyo 103-8666
Japan
Tel: +81-03-3245-5111
Website: www.toray.co.jp

Company Overview

Toray Industries Inc., together with its subsidiaries, manufactures and sells carbon fiber composite materials, carbon fibers, textiles, performance chemicals, environment and engineering products, and life sciences products in Japan, China, North America, Europe and internationally. In the aerospace sector, the company partners early in the design phase with manufacturers to provide a broad portfolio of advanced materials, providing support and material guidance from prototype to high volume production. The company was formerly known as Toyo Rayon Co. Ltd. and changed its name to Toray Industries Inc. in 1970. The company was incorporated in 1926 and is headquartered in Tokyo, Japan.

Key Highlights

In May 2021, Toray Advanced Composites announced the expansion of its thermoplastic composite material capabilities for high-performance applications, with the introduction of a next-generation high-heat laminate press at their Nijverdal (The Netherlands) facility.

In April 2022 Toray launched the Circular Economy Subcommittee, which drives initiatives to achieve a circular economy, including efforts to promote the recycling of fibers and textiles, films, and resin products, the development and commercialization of plant-based bioplastics, and the recovery and recycling of GHGs at the production stage.

In 2022, Toray has decided to increase production facilities for large tow carbon fiber at its U.S. subsidiary Zoltek Companies Inc. This capacity expansion involves plans by Zoltek to increase the production capacity of its Mexican plant from the current 13,000 tons to 20,000 tons/year, which together with the Hungarian plant's 15,000-ton production capacity will bring Zoltek's total annual production capacity to approximately 35,000 tons.

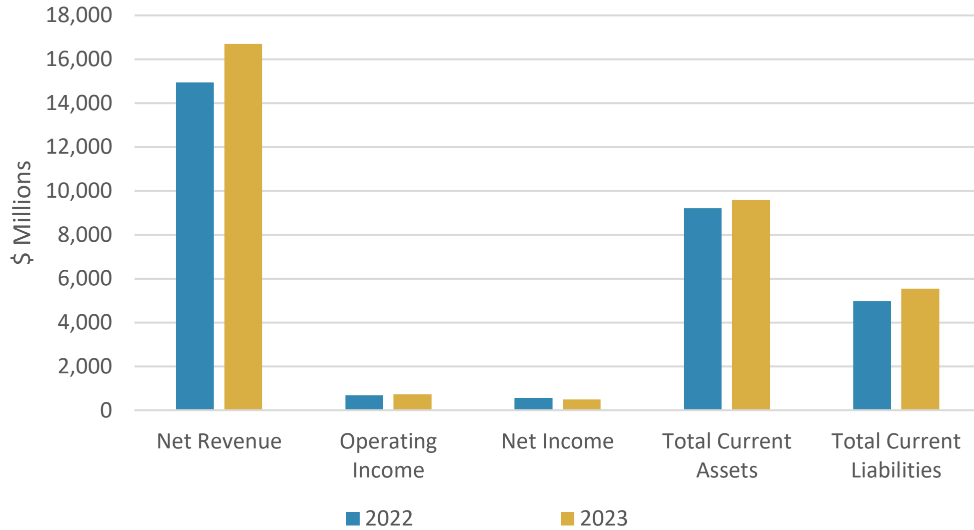
Financials

Table 119
Toray Industries Inc.: Annual Revenue, Fiscal Year Ended on March 31, 2023
($ Millions)

Financials	Revenue ($ Millions)
Net revenue	16,693.5
Operating income	730.9
Net income	488.3
Total current assets	9,584.8
Total current liabilities	5,540.6

Source: Company annual report

Figure 79
Toray Industries Inc.: Annual Revenue, 2022 and 2023
($ Millions)



Source: Company annual report

News/Key Developments

Table 120
Toray Industries Inc.: News, 2020-2023

Year	Strategy	Development
2023	Expansion	Toray Industries Inc. announced that it has decided to expand French subsidiary Toray Carbon Fibers Europe S.A.'s production facilities for regular tow medium- and high-modulus carbon fibers. This move will increase annual capacity at the Abidos plant (South-West France) from 5,000 metric tons annually to 6,000 metric tons. Production is expected to start in 2025.
2020	Collaboration	Toray Advanced Composites announces that it has completed a long-term supply agreement with Joby Aviation for the composite material used for its aircraft. The California-based aircraft company will use Toray's carbon fiber composite materials to bring fast, affordable and zero-emissions aerial ridesharing to global communities.

Source: Company website

ESG Trends

Toray actively strives to reduce CO_2 emissions in manufacturing through process improvements that conserve energy, use renewable energy and reduce the use of coal.

Toray Group announced the Medium-Term Management Program, Project AP-G 2022 “Resilience and Proactive Management”—Sustainable Growth and New Development.

Product Offerings

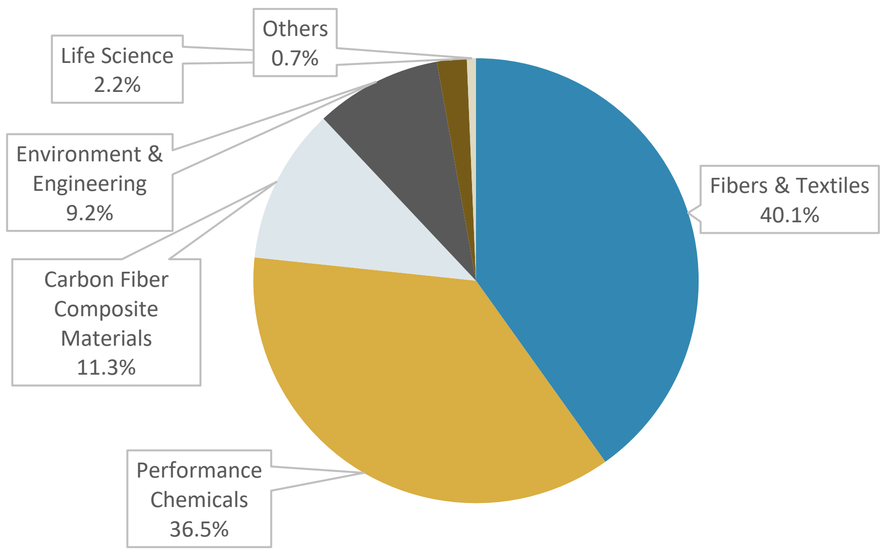
Table 121
Toray Industries Inc.: Product Portfolio

Product	Specifications
TORAYCA Carbon Fiber	Primary aerostructure applications include fuselage, stabilizers, rotor housings and skids, as well as various control surfaces such as flaps, ruddervators, elevators and ailerons.
Toray Epoxy Film Adhesives	Panel, cover and communication applications for eVTOLs include access doors, cargo boxes, radomes and antenna cover.
Steel Alloys	They are known for their excellent corrosion and heat resistance with applications in engine shafts, landing gear and other critical applications for aerospace components.

Source: Company website

Product Financials

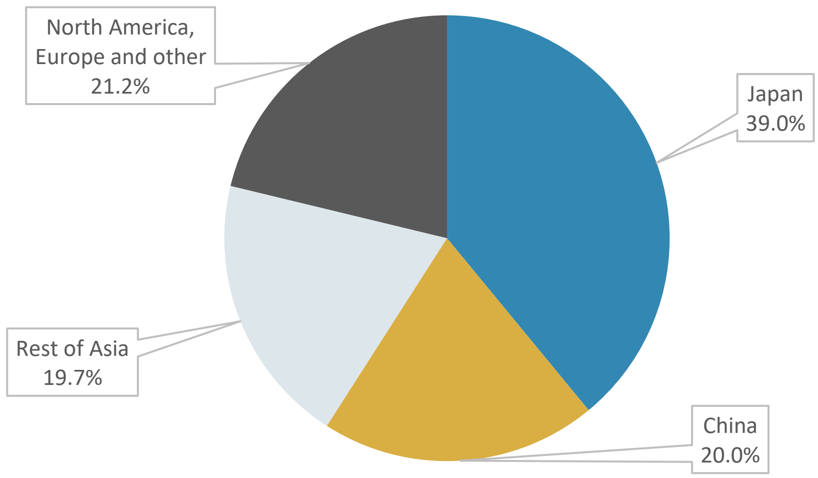
Figure 80
Toray Industries Inc.: Revenue Share, by Business Unit, 2023
(%)



Source: Company annual report

Regional Financials

Figure 81
Toray Industries Inc.: Revenue Share, by Country/Region, 2023
(%)



Source: Company annual report

TIMET (TITANIUM METALS CORP.)

4832 Richmond Road, Suite 100
Warrensville Heights, OH 44128
Tel: 216/910-0770
Website: www.timet.com

Company Overview

Timet is a part of Precision Castparts Corp., which has operated under Berkshire Hathaway since 2016. Timet was founded in 1950 as the Titanium Metals Corp. of America. The company has melt and mill facilities located strategically throughout the world, and it has been issued more than 240 patents. Timet operates a fully integrated supply chain, from raw material through melt and refined ingot and slab, and manufactures mill products. Timet operates five service centers strategically located throughout the U.S. and Europe in major aerospace, industrial and manufacturing hubs. Timet manufactures premium-quality billet and bar for jet engine rotating applications, holding approvals from all major engine manufacturers. Timet is the only OEM-approved source of both flat and proprietary taper-rolled fan blade plate.

Product Offerings

Table 122
Timet: Product Portfolio

Product	Specifications
Plate	Timet offers plates in a broad range of gauges for standard TIMETAL CP and TIMETAL 6Al-4V applications in addition to supplying higher-performance alloys like TIMETAL 6242 and specialty alloys. For example, Timet collaborated with the U.S. Navy to develop TIMETAL 5111 for critical corrosion-resistant naval applications.
Coil/Strip	Timet's coil product encompasses CP and alloy material for industrial and aerospace applications.

Source: Company website

VDM METALS GMBH

Plettenberger Str. 2
58791 Werdohl, Deutschland
Germany
Tel: +49 2392 55 0
Website: www.vdm-metals.com

Company Overview
As part of Acerinox S.A., VDM Metals manufacturers corrosion-resistant, high-temperature, superalloys and expansion alloys. These alloys are produced according to international standards in the form of strips, sheets, rods, billets, wires, etc. VDM Metals is a leading provider of materials for highly demanding applications and processes in the aerospace, automotive and other industries. VDM Metals employs more than 2,000 people worldwide. The company specializes in melting and processing long products in high-alloy materials for non-rotating parts used in aerospace applications.

News/Key Developments

Table 123
VDM Metals: News,2021-2023

Year	Strategy	Development
2023	Association	VDM Metals signs Transparency International's Declaration of Commitment. The association currently has more than 1,300 members from business and the public sector. Transparency International is a global nonprofit NGO founded in Berlin in 1993 and dedicated to fighting corruption.
2021	Expansion	VDM Metals expanded the materials portfolio of its Service Center. The company added stainless steel grades typical for these industries to its portfolio.

Source: Company website

Product Offerings

Table 124
VDM Metals: Product Portfolio

Product	Specifications
Superalloys	VDM Metals superalloys are vacuum-melted in VIM furnaces. The company uses the triple-melt procedure to ensure that materials meet the extremely stringent quality specifications of aerospace applications.
VDM Alloy 75	The high-temperature VDM Alloy 75 is a creep-resistant nickel-chromium-iron alloy with controlled carbon content and a small addition of titanium.
VDM Alloy 188	It is a high-temperature, heat resistant, cobalt-base alloy with equal contents of nickel and chromium, a high tungsten content and a controlled lanthanum addition.
VDM Alloy 718	• Good processing properties in the solution-annealed condition. • Good mechanical short and long-term properties, and great fatigue strength in the age hardened condition. • Good creep resistance up to 700 °C (1,300 °F). • Good oxidation resistance up to approx. 1,000°C (1,830 °F). • Excellent mechanical properties in low temperatures.

Source: Company website

VSMPO-AVISMA

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Website: www.vsmpo.ru

Company Overview

Founded in 1933, the Verkhnesalda Metallurgical Production Association (VSMPO) is one of the few vertically integrated company that manufacture ingots and rolled titanium alloys, extruded products from aluminum alloys, semi-finished products from alloy steels and nickel-based heat-resistant alloys. The corporation, a leader in the global high-tech titanium products market, is deeply integrated into the global aerospace industry and is the main strategic supplier of titanium products for many companies. VSMPO has more than 450 partners, including the world's leading aircraft manufacturing companies, in 50 countries. The main activity of the company is the production of titanium products: ingots, billets, slabs, large stamped forgings of aircraft engine discs and blades, rolled rings, profiles, seamless and welded pipes and other products. The aluminum division includes the production of ingots, extruded sections, panels, pipes, as well as cold-formed pipes and pipes. Along with titanium semi-finished products, VSMPO is working to increase the production of products from aluminum alloys, stampings from heat-resistant nickel alloys and high-strength steels.

News/Key Developments

Table 125
VSMPO-AVISMA: News, 2023

Year	Strategy	Development
2023	Investment	VSMPO-AVISMA Corp. will allocate $25 million (2.5 billion rubles) to social projects in 2024.
2023	Expansion	VSMPO-AVISMA Corp. signed an agreement of intent to implement an investment project for the construction of a long-rolling complex at the site of a special economic zone in Verkhnyaya Salda. The project will begin this year, with the start of production scheduled for 2027.
2023	Expansion	At the production site of PJSC VSMPO-AVISMA Corp., a complex for mechanical processing of titanium parts opened and began work. The new production line is considered unique for Russia.

Source: Company website

ESG Trends

VSMPO-AVISMA implements projects to reduce waste and greenhouse gas emissions, optimize the supply chain, increase the level of involvement of industrial waste in re-production, and also regularly conducts socially oriented events.

Product Offerings

Table 126
VSMPO-AVISMA: Product Portfolio

Product	Specifications
Titanium alloys	They are capable of functioning at temperatures from 0°C to 600°C, and they are used in aircraft engines for discs, blades, shafts and housings. High-strength alloys are widely used in the production of various parts included in the structure of aircraft—from small fasteners that weigh a few grams, to landing gear bogies and large wing beams that weigh up to 1 ton.
Aluminum Alloy (duralumin)	It is an alloy made of aluminum with copper and magnesium. After hardening, this alloy acquires special hardness and becomes approximately 7 times stronger than pure aluminum. At the same time, it is almost three times lighter than iron. It is obtained by alloying aluminum with small additions of copper, magnesium, manganese, silicon and iron. The lightness and strength of aluminum alloys are especially useful in aviation and space technology. For example, helicopter rotors are made from an alloy of aluminum, magnesium and silicon.

Source: Company website

Appendix

Acronyms

Appendix: Acronyms

Table 127
Acronyms Used in This Report

Acronym	Meaning
ACC	American Chemistry Council
ANA	All Nippon Airways
APAC	Asia-Pacific
ASTM	American Society for Testing and Materials
ATI	Aerospace Technology Institute
AI	Artificial intelligence
AM	Additive manufacturing
AMS	Aerospace Material Specifications
Al-Li	Aluminum-lithium
AHSS	Advanced High-Strength Steel
AISI	American Iron and Steel Institute
AOPA	Aircraft Owners and Pilots Association
CAA	Civil Aviation Authority
CMC	Ceramic-matrix composites
CFRP	Carbon fiber-reinforced polymers
CAGR	Compound annual growth rate
COMAC	Commercial Aircraft Corp. of China
CORAC	Council for Civil Aeronautics Research
CO_2	Carbon dioxide
CFR	Code of Federal Regulations
DOE	Department of Energy (U.S.)
DARPA	Defense Advanced Research initiatives Agency
EPA	Environmental Protection Agency (EPA)
ESIF	European Structural and Investment Funds
ESG	Environmental, social and governance
EU	European Union
eVTOL	Electric Vertical Takeoff And Landing
ESA	European Space Agency
EASA	European Union Aviation Safety Agency
FAA	Federal Aviation Administration
FVL	Future Vertical Lift
FCAS	Future Combat Air System
GHG	Greenhouse gas
GLARE	Glass Fiber Reinforced Aluminum
HEAs	High-entropy alloys
ISO	International Organization for Standardization
IEA	International Energy Agency
IATA	International Air Transport Association

Acronym	Meaning
ICAO	International Civil Aviation Organization
ICDA	International Chromium Development Association
INSG	International Nickel Study Group
IIoT	Industrial Internet of Things
ISRO	Indian Space Research Organization
JAL	Japan Airlines
JAXA	Japan Aerospace Exploration Agency
KAI	Korea Aerospace Industries
LCCs	Low-cost carriers
LTAG	long-term aspirational goal
LSA	Light Sport Aircraft
LEO	low earth orbit
MRO	Maintenance, Repair and Overhaul
MPIF	Metal Powder Industries Federation
NOx	Nitrogen oxide
NSF	National Science Foundation
NASA	National Aeronautics and Space Administration
NiPERA	Nickel Producers Environmental Research Association
OSHA	Occupational Safety and Health Administration (U.S.)
ONERA	Office National d'Études et de Recherches Aérospatiales
R&D	Research and development
REACH	Registration, evaluation, authorization and restriction of chemicals
SAF	Sustainable aviation fuel
SBTi	Science-based target initiative
SMA	Shape memory alloys
SAE	Society of Automotive Engineers
SIPRI	Stockholm International Peace Research Institute
TCIR	Total case incident rate
TO	Topological optimization
TPS	Thermal protection systems
TMS	The Minerals, Metals, and Materials Society
tCO2e	Metric tons of carbon dioxide equivalent
U.K.	United Kingdom
U.S.	United States
UAS	Unmanned Aerial Systems
UAVs	Unmanned Aerial Vehicles
UAC	United Aircraft Corp.
WHO	World Health Organization
WPC	World Plastics Council
XRF	X-ray fluorescence

Source: BCC Research

About BCC Research

About BCC Research

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Intended Audience

This report has been written for all readers with a professional or scientific interest in the advanced aerospace materials sector. It is especially tailored to readers involved in the marketing, management and public policy dimensions of the aerospace industry, including producers; distributors; dealers international and governmental organizations with relevant responsibilities in commercial as well as defense industry, foreign trade, investors, financial and analyst communities.

This report is intended for professionals at multiple levels working in the aerospace material field. It is structured around specific technologies, but it is largely nontechnical. It is concerned less with theory and jargon than with what works, how much of the latter is likely to generate revenue and which regions present lucrative opportunities.

Professionals (e.g., analysts, R&D scientists, technology integrators, after-sales service providers, regulatory authorities, business development, corporate strategy developers, investment firms) may benefit from this report. It provides insights and guidance for strategic marketing planning, drivers and limiters, and sales growth opportunities. It is also informative for government agencies and environmental and public policy interest groups concerned with aerospace materials industry.

This report will be beneficial for:

- Managers who must identify market opportunities and develop solid implementation plans for advanced aerospace material activities.
- Research and development professionals who wish to stay on top of competitor initiatives and understand the developments and obstacles within the global market for advanced aerospace materials.
- Business development executives and entrepreneurs who work within the market dynamics and wish to identify possible opportunities and partnerships.
- Information and research center librarians who wish to access vital information.

- Policymakers and government officials who must understand the dynamics and scope of the market they are working to affect.
- Advertising agencies that work with clients involved in the aerospace material industry to design appropriate messages and images.
- Investors and stakeholders who wish to gain a well-rounded view of the market for advanced aerospace materials, including its strengths, weaknesses and likely future direction.

Analyst's Credentials

BCC Research Team possesses expertise and experience in life and physical science domains. They specialize in offering valuable business insights, including industry analysis, competitor intelligence, strategic and financial analysis, and opportunity assessment. The team has in-depth knowledge of various sectors, including healthcare, biotechnology, pharmaceuticals, IT, automation, advanced materials, and energy. They are proficient in qualitative and quantitative market intelligence providing clients with actionable insights. With a vast understanding of the competitive landscape, the team can support clients in making data-driven decisions to help them achieve a competitive edge in their respective markets.

Consulting Editor's Credentials

Jason Chen has been an analyst and consultant for the polymer, composite, fiber, textile and energy industries for 19 years. He works as a researcher, writer and/or editor for the American Composites Manufacturers Association (ACMA), China Textile Academy (CTA), China Chemical Fiber Association (CCFA), International Fiber Journal, Filtration News, Platts Emission Daily, Vision Systems Design, Pesticide and Toxic Chemical News and MobileTex. He has a degree in Civil Engineering, Chemicals and Advanced Materials from Shantou University.

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December 2023