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Patent Landscape Report on solid propellant manufacturing technologies

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Abstract

This thesis endeavors to present a comprehensive overview of the global state of solid propellant technology. Its genesis lies in the imperative to furnish contextual backing for a patent conceived, titled " Photo-polymerization for additive manufacturing of composite solid propellants", aimed at subsequent coherent market analysis.

Solid propellants represent pivotal constituents utilized as propulsion fuel in rockets, missiles, and analogous systems. Comprised of solid chemical compounds, such as polymers, aluminum compounds, or graphite dioxide, combined with oxidizers and adjunctive additives, these materials furnish a steadfast energy source and exhibit prolonged stability, rendering them versatile for multifarious applications encompassing rocketry, launcher mechanisms, fire extinguishing agents, and airbag expansion.

This work assumes the form of a Patent Landscape Report (PLR), wherein meticulous data processing and manipulation from a discerningly curated Patent Database will distill pertinent information and delineate trends germane to solid propellant technology. Patents are recognized as potent repositories of information, and PLRs are purposefully devised to distill intrinsic insights from these documents, thereby evaluating the extant technological progress within a sector and furnishing strategic support to companies and institutions within the field.

Additionally, this endeavor aspires to provide an encompassing contextual understanding of solid propellants by delineating the distinct stages within the production process. Moreover, it endeavors to proffer an exhaustive introduction to the realm of patents, facilitating a robust foundational understanding pivotal for a more nuanced comprehension of the ensuing analytical processes.

The exploration and analysis of the collected data will be executed utilizing R, an open-source programming language widely acclaimed for its prowess in data manipulation and visualization. Such an approach ensures comprehensive visual reinforcement for this scholarly pursuit. Subsequently, the outcomes gleaned from the varied analyses will be synthesized, thereby spotlighting key trends and insights in the conclusive and final deliberations.

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1. Introduction

The primary objective of this thesis, as outlined in the abstract, is to present a comprehensive analysis of the current state of solid propellant technology. This entails elucidating the geographical areas exhibiting prominent technological advancements in this domain, delineating trends of innovation surges and declines, identifying key application domains, major innovators, all while considering the legal aspects of patents in their respective jurisdictions.

Subsequent chapters will commence by establishing a foundational understanding, providing an introductory discourse on solid propellants, including their manufacturing intricacies. Additionally, a comprehensive overview of intellectual property, particularly patents, will be provided as this form the foundational units for our analytical approach. The formulation of this document will adhere to the guidelines established by the World Intellectual Property Organization (WIPO), the agency of the United Nations responsible for promoting the protection of intellectual property throughout the world.

A patent landscape report relies heavily on data extracted and acquired from patent databases, necessitating the precise identification and classification of patents pertinent to the technology under scrutiny.

Patents, representing intellectual property rights, confer exclusive usage rights to an invention for a predetermined period, contingent upon the disclosure of the invention. Therefore, serving as the elemental units of our analysis, patents not only furnish information about the technology but concurrently serve as sources for evaluating the commercial potency of the proprietors, who attain a limited monopoly through this instrument, concomitant with an expiration date.

Online repositories offer a different platforms, both free and subscription-based, tailored for patent data aggregation. In this pursuit, the lens.org platform, equipped with a proprietary language for querying its non-relational database, will serve as the principal tool. Leveraging keywords embedded within patent titles, abstracts, and employing filters, this platform enables the extraction of patent subsets specific to solid propellant technology. Subsequent subsets will be meticulously isolated to facilitate nuanced analyses of distinct methodologies and specialized application domains.

However, it is imperative to acknowledge that this form of analysis (PLR), while a substantial instrument for gauging the state of the art in a specific technology, is not devoid of limitations:

- **Data completeness**: The robustness of patent landscape reports is contingent upon the comprehensiveness of available sources, and as such, may not encompass the entirety of patents filed within the sector. Discrepancies or omissions may be present, thereby diminishing the holistic completeness of the analysis.
- **Exclusion of secret or unpublished technologies**: The report's efficacy may be hampered by the omission of patents yet to be made public or technologies safeguarded by industrial secrecy, thereby limiting a comprehensive comprehension of the landscape.
- **Limitations in qualitative analysis**: Despite the quantitative rigor applied to patent analysis, constraints may be encountered in qualitatively interpreting innovation or gauging the technological significance of patents. Notwithstanding, pragmatic methods for estimating patent quality will be employed, striking a balance between expediency and comprehensiveness.

Upon outlining the data extraction methods, these datasets will be imported into the R studio environment. Leveraging the R programming language, diverse analyses encompassing geographic, historical, and application scopes, including identification of major innovators, will be undertaken.

Consequently, the findings from each analytical endeavor will be consolidated and expounded upon in the final conclusions.

2. State of the Art

2.1 Solid Propellant

Solid propellants, integral to rocket propulsion, are energetic materials designed to generate high-temperature gaseous byproducts upon combustion, thereby facilitating the creation of essential thrust. A conventional solid propellant comprises a combination of distinct chemical constituents, including oxidizers, fuels, binders, plasticizers, curing agents, stabilizers, and cross-linking agents. However, the specific formulation of these constituents varies significantly based on the particular mission's requisites and objectives. As a result, customization is a common practice in solid propellant manufacturing to tailor combustion characteristics to specific mission parameters.

Notably, the chemical composition determines the propellant's combustion attributes, leading to tailored properties. Propellants engineered for elevated flame temperatures find utility in military and propulsion applications. Conversely, formulations capable of producing lower temperatures and non-toxic combustion byproducts serve as gas generators in applications such as airbags and fire extinguishing systems.

Within the realm of propulsion, comprehending propellant combustion holds paramount importance. It dictates the selection of propellants suitable for distinct propulsion systems, considering their behaviour under diverse combustion conditions. The intricate interplay among varied chemical ingredients and their ratios determines a propellant's unique physical and chemical traits, combustion dynamics, and overall performance characteristics.

2.2 Benefits and Drawbacks

Solid propellants are frequently lauded for their ease of storage and handling, a trait attributed to several compelling reasons. In comparison to their liquid counterparts, which are the predominant alternative in this domain, solid propellants present distinctive advantages in this regard:

- **Long-Term Stability**: Solid propellants exhibit enhanced long-term stability compared to liquid propellants. They boast the capability to endure extended storage durations without necessitating special precautions such as refilling or periodic topping up.
- **Less Stringent Storage Requirements**: The storage conditions demanded by solid propellants are generally less exacting than those stipulated for liquid propellants. Unlike liquid counterparts that may mandate temperature adjustments, cooling systems, or pressurization to maintain integrity, solid propellants often require less delicate storage conditions.
- **Ease of Transport**: Solid propellants, existing in a solid state, offer advantages during transport. They are typically less sensitive to environmental conditions compared to liquid propellants, which demand meticulous environmental control to prevent undesired reactions or leakage.

The inherent limitations of solid propellants must also be taken into account. The main challenge lies in their control, which presents difficulties in two key aspects:

- **Difficulties in Controlling Combustion**: Once ignited, solid propellants prove challenging to control or interrupt. In contrast to liquid propellants that offer the capability to be easily switched off and on again, solid propellants burn continuously until fully exhausted.

- **Limited Adjustment Flexibility**: The composition of solid propellants cannot be altered or modified during engine operation, in stark contrast to the adaptability afforded by liquid propellants. This limitation curtails the capacity to dynamically adjust thrust or make real-time modifications during the propulsion process. These constraints pose notable challenges in the effective control and flexibility of solid propellants, distinguishing them from their liquid counterparts.

2.3 Conventional Production Process

Solid propellants consist of various elements working together to generate thrust. Their main components are:

- **Fuel**: This is the component that provides the energy for the chemical reaction. It's usually made up of carbon-based polymers such as polystyrene, polybutadiene, or hydroxyl-terminated polybutadiene (HTPB)
- **Oxidizer**: It's the substance that provides the necessary oxygen for combustion. The most common one is ammonium perchlorate, but nitrates or chlorates can also be used.
- **Binder**: It's used to hold the other components together and give the propellant a solid structure. HTPB is the most commonly used binder.
- **Additives**: These may be included to enhance specific characteristics of the propellant, such as stabilizers to increase its shelf life, catalysts to control the combustion rate, or materials to modify the ignition temperature.
- **Cross-linking Agent**: This component helps in creating a network structure within the propellant, enhancing its mechanical properties and stability. Cross-linking agents often work with binders like HTPB to create a solid, durable structure that holds the other components together during combustion.

Having established the essential components required for solid propellant production, let's delve into the prevalent method employed for its creation. The following delineates the step-by-step process constituting the most widely adopted approach in manufacturing typical propellants.

- **Mixing**: This stage involves precisely measuring and mixing the components of the propellant - oxidizer, combustibles, additives, and cross-linking agents. The components are typically in powdered or liquid form. The mixing process is critical to ensure a homogeneous blend of all ingredients, which is vital for consistent performance and safety. This can be done using specialized mixers or blending equipment to achieve a uniform mixture.
- **Casting and Curing**: Once the propellant mixture is thoroughly mixed, it's poured or cast into a mould or around a mandrel (a central core around which the propellant is shaped). This process requires careful control of temperature, pressure, and environmental conditions to prevent air bubbles and ensure proper adhesion to the mandrel. The propellant is then cured or allowed to set, a process that involves chemical reactions or physical changes to solidify the mixture. Curing times and conditions can vary based on the specific propellant formulation.
- **Mandrel Removing**: After the propellant has sufficiently cured and solidified, the next step involves removing the mandrel if one was used. This could be done mechanically, chemically, or through a combination of methods depending on the nature of the mandrel material and the propellant. Care must be taken during this step to avoid damaging the delicate propellant structure.
- **Tooling**: Once the propellant is formed and the mandrel is removed, it might undergo additional processes for shaping, cutting, or sizing to achieve the desired

final form. This might involve precision machining or tooling to create specific geometries or configurations suitable for the intended use, such as in rocket motor casings or other applications.

The following image visually summarises the process described above:

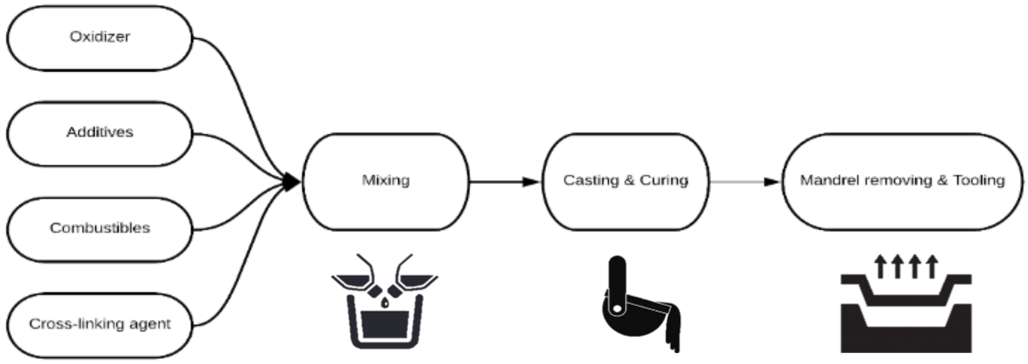


Figure 1 - Conventional solid propellant production process (Garino et al, 2022)

2.4 Grain Geometry

The geometry of grains within solid propellants is a crucial factor determining the performance of the solid propellant and its characteristics. Various aspects of grain geometry significantly impact its functionality:

- **Combustion Surface**: The configuration of grains directly shapes the total combustion surface area. A larger area fosters increased gas production, translating into higher thrust output.
- **Combustion Speed**: The geometry dictates the rate at which the propellant burns. Precise control of this burning speed is pivotal for maintaining desired thrust levels and governing the rocket's motion.
- **Pressure Distribution**: Grain arrangement affects pressure distribution within, for instance, a rocket engine. A uniform distribution enhances both efficiency and safety across the thruster.
- **Thrust Modulation**: Different grain shapes and layouts influence the capacity to regulate thrust output. Some geometries offer superior control, impacting the ability to adjust thrust.
- **Combustion Stability**: Grain geometry plays a pivotal role in sustaining stable combustion. Inadequate shapes or distributions might trigger irregularities, leading to undesirable occurrences like abnormal flames or engine instability (with regard to rockets and launchers).

2.5 Challenges with the Conventional Process

The predominant method in the current state of the art for producing composite solid propellant grains is the mix-cast-cure process, which employs potentially hazardous chemicals. In a majority of instances, the polyaddition of oligomers incorporates isocyanate functional groups (Garino et al, 2021).

Isocyanate functional groups are chemical groups composed of an -N=C=O arrangement. They are commonly used in various manufacturing processes, including the production of certain polymers, adhesives, and coatings. They are powerful irritants to the eyes, can cause respiratory problems as asthma, direct skin contact can also cause marked inflammation and can also sensitize workers.

They can contain cancer-causing components for animals (Occupational Safety and Health Administration, 2014)

> Additional constraints arise from the traditional, time-consuming casting and curing procedures, which are inherently restricted in their adaptability to a limited spectrum of geometries. This constraint consequently confines the pressure-time characteristics of solid propellants to predetermined configurations, limiting their versatility.
>
> Finally, the phase involving spindle removal and grain finishing introduces inherent risks, including the potential for grain damage and unintended initiation. (Garino et al, 2021)

2.6 Remedies within the new Approach

The recently patented method instead for propellant grain production, based on UV curing, surpasses previous limitations by enabling the creation of more intricate grain geometries. This advancement opens avenues for novel propulsive missions, offering customized thrust-time profiles and localized composition adjustments. The innovative UV-sensitive components utilized in this curative method replace isocyanates, thereby reducing chemical hazards for operators.

Additionally, the traditional challenges associated with spindle removal and grain finishing are circumvented through a continuous deposition method, eliminating prior constraints. The expedited curing process, facilitated by a tailored photo-initiator responsive to ultraviolet light, accelerates the reaction compared to conventional methods.

This novel approach not only unlocks previously unachievable geometries but also widens the applicability of the product. The method facilitates the realization of complex geometries crucial for fine-tuning grain performance. Moreover, it reduces production costs and associated risks by minimizing the creation of non-compliant grains, enabling continuous monitoring, defect detection, and repair within the production process.

Finally, it enables cost-effective prototyping and testing of new compositions and geometries, enhancing exploration and experimentation within the field (Garino et al, 2021)

The table provides a summary of the above considerations:

Description	Problem	Solution
Spindle removal and grain finishing	Critical phase due to associated risks (grain damage) and unintended triggering	Elimination of spindles by continuous deposition
Casting and curing process	Critical phase due to associated risks (grain damage) and involuntary activation	Photo-initiation
Chemical composition	Cross-linking elements known to be carcinogenic	Substitution of toxic elements - modification of chemical composition

Table 1 - Challenges with the conventional method and solutions offered by the new approach

3. Intellectual Property

3.1 Introduction

In this chapter, we'll lay the groundwork for understanding intellectual property rights, with a particular emphasis on patents—the fundamental focus of our study. We'll offer an initial legal framework detailing the procedures required for patent filing and the components comprising a patent document.

Patents serve as a vital wellspring of information. A study dating back to 1986, referencing a report from 1977, asserts that a remarkable 80% of the information contained within patents is exclusive and not available elsewhere (Levine, 1986). Therefore, a comprehensive comprehension of the patent system is imperative for conducting a thorough and effective analysis.

3.2 The Different Type of intellectual property

In today's business landscape, innovation stands as a cornerstone for success within companies. Achieving a competitive edge often stems from strategic investments in Research and Development (R&D). Yet, these investments come with substantial costs and are fraught with risks, especially in a globalized and fiercely competitive market. To strike a balance between technological progress and economic interests, we rely on a pivotal system known as the Intellectual Property Rights (IPR) System.

This system serves the purpose of safeguarding intellectual property, fostering an environment that nurtures creativity. Within this framework, various types of intellectual property exist, which can be categorized into:

- **Patents**: These grants, issued by government authorities, bestow exclusive rights for industrial exploitation over a specified period, typically around 20 years. Applications for patents must be submitted to a national or regional patent office and undergo examination before being either granted or refused.
- **Utility Models**: Similar to patents but less robust in terms of power, utility models acknowledge IP rights to simple inventions that may not meet the stringent patentability criteria but hold significance in driving sectoral innovation. They provide basic protection and offer the advantage of quicker grant periods.
- **Copyright**: Automatically established upon the creation of an author's original work, copyright safeguards any form of original, creative, or intellectual expression. It shields various creations like novels, scientific literature, software, photographs, music, and more. Typically, copyright duration spans the author's lifetime plus an additional 70 years, contingent on the specific circumstances and country.
- **Trademarks**: These are distinctive symbols distinguishing the commercial origin of goods or services. They encompass words, logos, names, colours, and other identifiers, including product shapes or packaging, sounds, or even smells. Beyond identification, trademarks serve roles in fostering goodwill and advertising.
- **Registered Designs**: Representing the aesthetic aspects of an article, registered designs encapsulate the external appearance of a product or its components. This includes three-dimensional features such as the shape of an item, or two-dimensional aspects like patterns, lines, or colours. For registration, a design must possess novelty and individual character, presenting a distinct impression compared to any previously disclosed design. The duration of protection for a European Community registered design extends up to 25 years from the application date, granted in renewable five-year terms.

- **Unregistered designs**: This right is obtained by a legal entity upon disclosing a design to the public without formal registration. It grants the entity the authority to prohibit others from copying the design for a limited duration, typically suited for designs with a short lifespan. The maximum protection period for a community unregistered design spans three years from the design's publication within the European Union.
- **Trade secrets**: These encompass any confidential business information offering a competitive advantage to an enterprise. Unlike other forms of intellectual property, trade secrets receive protection without the need for procedural formalities, allowing for potential indefinite protection. To qualify as a trade secret, the information must remain confidential, hold commercial value due to its secrecy, and have been subjected to reasonable measures by the rightful holder to maintain confidentiality (such as non-disclosure agreements with employees and business partners, and efforts to prevent industrial espionage).

3.3 Patents

A patent is a government-granted exclusive right or license that provides inventors with legal protection for their inventions. It offers the inventor the exclusive authority to prevent others from making, using, selling, or importing the patented invention without their consent.

To qualify for a patent, an invention must meet specific criteria, including novelty, non-obviousness, and utility. Novelty refers to the requirement that the invention must be new and not previously disclosed or publicly known. Non-obviousness denotes that the invention must not be an obvious advancement or an existing knowledge within its field. Lastly, utility pertains to the requirement that the invention must have a practical application or usefulness.

Patents serve as a crucial link between intellectual property owners and society. Owners are motivated by the prospect of gaining a competitive edge over rivals through the exclusivity granted by patent rights. Concurrently, society benefits from this arrangement by fostering an environment that encourages innovation, leading to advancements across various sectors and contributing to the overall well-being of the economy.

3.4 Patent Filing Procedure

The rules that concern the publication patent process could be different from one jurisdiction from another. The Patentable subject matter could change, however, most jurisdictions, that adopt a system with a substantial examination (i.e. where the technology examined have to meet the patentability requirements, such as novelty or industry application), have usually this publication stage: pre-grant, grant and post-grant publications.

The process for generating a patent starts with the first filling of a patent application in a national or a regional patent office, which is called the Office of First Filing (OFF). When protection in further jurisdiction is needed the same invention could be subsequentially filed in other offices, called Office of Second Filing (OSF), generally by claiming the priority of first filling. This sequence of filings generates a patent family, comprising related patent documents across various jurisdictions, all pertaining to the same invention.

Pre-grant publications or applications constitute documents published by most patent authorities approximately 18 months following the filing date or priority date (distinct concepts explained below), particularly when the office acts as an OSF. These documents, though not representing a granted right in their current state, hold the potential for future grant and form a crucial part of the patenting process.

The Patent Cooperation Treaty (PCT), encompassing 148 jurisdictions, introduces a unique application method known as the PCT Application. This system was devised to streamline and simplify the process of filing patent applications across multiple jurisdictions simultaneously. Its primary aim is to standardize the application process and enhance the efficiency of patent filings on an international scale. The system:

- allows applicants to submit a single application through a Receiving Office, streamlining the process for multiple jurisdictions.
- This application triggers a search report and a written opinion from an International Searching Authority within the PCT system. If needed, it can lead to a Supplementary International Search or an International Preliminary Examination, assessing the patentability of the invention.
- This comprehensive evaluation empowers the applicant to make informed decisions regarding the jurisdictions where they intend to seek protection for their invention.
- Following this initial step, the applicant is granted a 30-month window (in most member jurisdictions) to pursue patent protection in each of these countries through national phase entry.
- The extended timeframe provides leeway to assess the invention's commercial viability and postpones the significant expenses associated with prosecuting patents in various jurisdictions, such as translation costs, legal representation, and national fees. (Trippe, 2015)

The second category of documents, termed grant-publications, holds significant importance as they are released upon the official grant of a patent. These documents bear considerable weight as they signify that the patent authority, following meticulous examination, acknowledges the novelty of the invention, thereby affirming the grant of patent protection.

Subsequent to the patent grant, additional documents may be published. This typically occurs in scenarios involving clerical or typographical errors. Moreover, in many instances, these publications arise when third parties initiate an examination procedure. If the outcome of this procedure results in a reduction of the patent's protective scope, a revised document containing modified claims is issued.

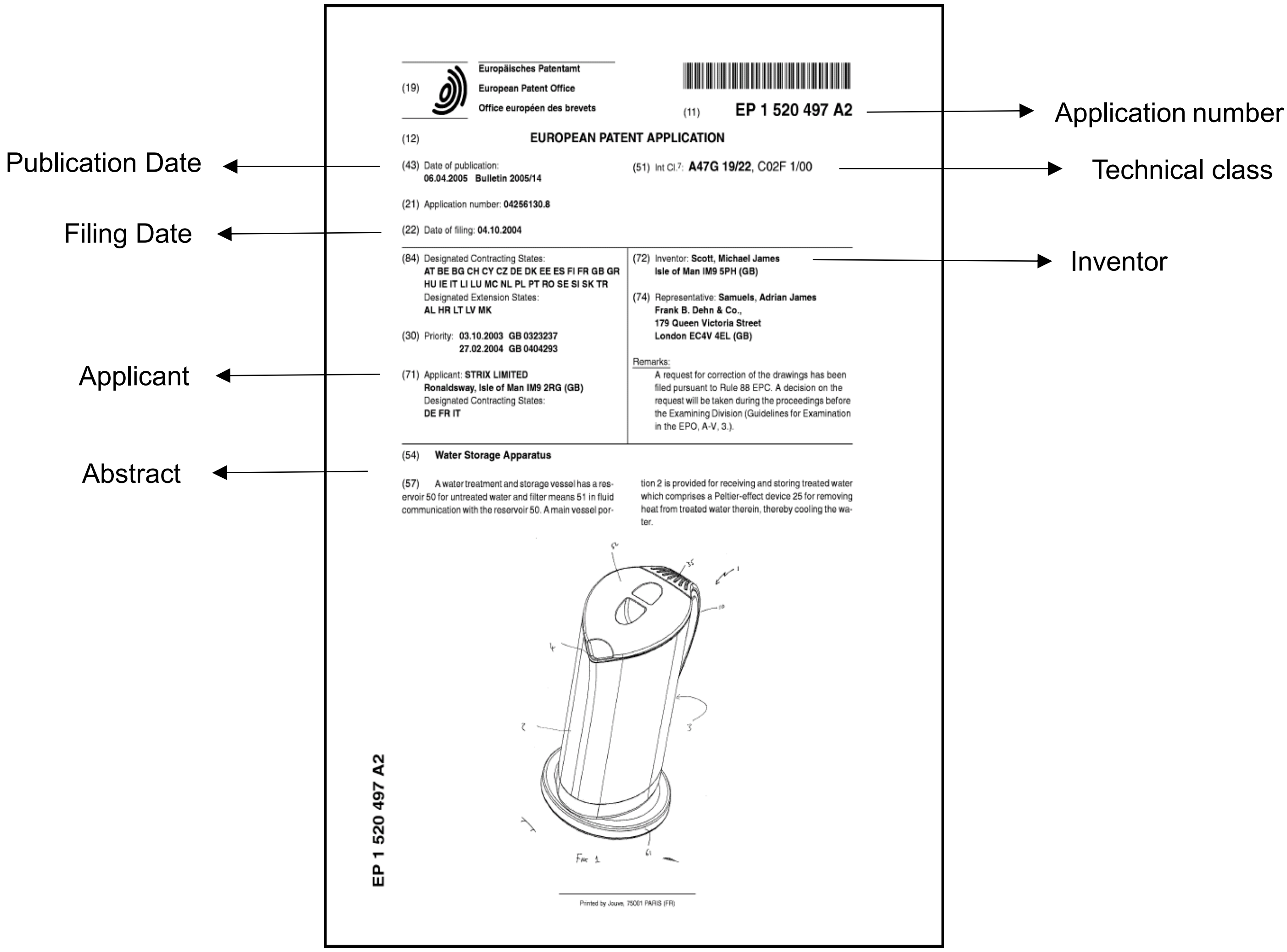
Each document related to patent publication is uniquely identified by a kind code, distinguishing its specific nature and content.

3.5 Components of Patent Documents

Patents are semi-structured documents, exhibiting various discernible sections. At a high level these sections of a patent document are represented by a Front Page with bibliographic data. These data are:

- **Filing date** (or application date): is determinate by the patent authority when it recognizes that the minimum requirements are fulfilled. The filing date differs from the date when the applicant lodges the application with the patenting authority. Not to confuse with the priority date (the date of an earlier application if the applicant claims the priority of that earlier application).
- **Publication Date**: the date when the patent document is published, usually 18 months after the filing date.
- **Applicant**: defined as the individual or entity applying for an Intellectual Property Right, is the presenter of the grant application. Upon the patent's approval, the applicant enjoys full rights, even if they're not the original inventor. This scenario occurs when the inventor relinquishes the rights linked to the invention to another entity, known as the assignee.
- **Inventor**: defined as the individual responsible for creating an innovation, holds the right, as per Article 4ter of the Paris Convention, to be recognized and acknowledged as the originator of the invention within the patent documentation.
- **Technical class**: is the technology field to which the invention relates.
- **Application number**: the unique identifier of the patent application.
- **Abstract**: is a summary of the main features and purposes of the invention.

Moreover, patents typically encompass a detailed description delineating the technology involved, often accompanied by illustrations. Within this documentation, the claims section holds paramount significance, serving as the segment that specifically outlines the scope of protection sought or granted for the invention. Each patent application conventionally comprises at least one claim, with the primary claim encapsulating the core subject matter for which the invention was conceived, encompassing its essential characteristics. Moreover, there exist distinct types of claims within patent documents: dependent claims, which reference the main claim or other subsidiary claims, and independent claims, which stand alone and encompass inventions covering not only devices or products but also methods or processes stemming from the same innovative concept.



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(54) Water Storage Apparatus

(57) A water treatment and storage vessel has a reservoir 50 for untreated water and filter means 51 in fluid communication with the reservoir 50. A main vessel portion 2 is provided for receiving and storing treated water which comprises a Peltier-effect device 25 for removing heat from treated water therein, thereby cooling the water.

EP 1 520 497 A2

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Figure 2 - Patent Application (Intellectual Property Teaching Kit, 2018)

Claims

1. A portable water treatment and storage vessel comprising:

   a reservoir for untreated water;
   filter means in fluid communication with said reservoir; and
   a main vessel portion for receiving and storing treated water;

   wherein said main vessel portion comprises electro-thermal cooling means for removing heat from the treated water therein, thereby cooling the water.

Figure 3 - Patent claims (Intellectual Property Teaching Kit, 2018)

1 EP 1 520 497 A2 2

Description

[0001] The present invention relates to the filtering, storage and cooling of liquids, particularly water, in domestic contexts.

[0002] Although domestic water is often strictly regulated so as to be fit for drinking, there are many possible sources of contamination. Consumer concerns about the potential aesthetic and health related problems resulting from the presence of these contaminants has promoted the development of home water treatment systems to improve the quality of the water supply. Such systems can reduce the presence of common contaminants resulting in clearer, safer and better tasting and smelling water for household use.

[0003] Typically domestic water filtration is carried out using a filter jug which may, for example, comprise a vessel for containing treated water, a reservoir for containing untreated water and a filter cartridge therebetween for treating the water. Such jugs and filters are well known.

[0004] A number of different water filter jugs are available in a variety of shapes and sizes. It has been found that consumers often wish to keep treated water chilled ready for drinking and therefore many available jugs are now sized so as to be suitable for storage within a refrigerator. For example, slim-line jugs are available for keeping in a fridge door.

[0005] Since domestic refrigerators are generally of a compact size the storage available is limited. Thus, it is undesirable for a domestic water filter jug to occupy an excessive amount of space within a refrigerator. Therefore, when purchasing a water filter jug a user must generally choose between a larger capacity worktop jug or a considerably smaller capacity jug, for example 1.5 litres, for storing within a refrigerator. Even if a user chooses a limited capacity jug for storing in a refrigerator, the space occupied by the filter jug within the refrigerator is still likely be inconvenient.

[0006] When viewed form a first aspect the present invention provides a portable water treatment and storage vessel comprising a reservoir for untreated water, filter means in fluid communication with said reservoir and a main vessel portion for receiving and storing treated water, wherein said main vessel portion comprises electro-thermal cooling means for removing heat from the treated water therein, thereby cooling said water.

[0007] Thus it will be appreciated that in accordance with the present invention a filter jug itself may cool and keep cool the filtered water without the need to be placed in a refrigerator.

[0008] One proposal for a device said to be able to keep cold drinks cold as well as keep hot drinks warm is disclosed in US-5842353. The device comprises a cup shaped container with a Peltier device in the base of the container. By using the Peltier effect, the Peltier device may be used either to heat or cool the liquid in the cup by application of the appropriate DC voltage. A heat sink for the Peltier device is provided under the base along with fins to improve heat exchange with the surrounding air.

[0009] One problem with this proposal, which has been identified by the Applicant, is the location of the Peltier device in the base of the cup. This is conventional and effective when used in heating mode. When used in cooling mode however there would be no circulation due to convection since the cooled liquid would be denser than the uncooled liquid and so would remain in the base region of the cup. Therefore, for all of the liquid within the cup to be cooled equally it would be necessary to rely upon conduction within the liquid. This does not provide an efficient cooling mechanism. Whilst this may not be too significant in a small cup sized device, which is primarily intended to maintain the initial temperature of a drink contained in it, the Applicant has appreciated that such a flaw could significantly compromise the effectiveness of an apparatus for bulk cooling of a larger body of water to reduce its temperature.

[0010] In particularly preferred embodiments the electro-thermal cooling means is provided on or in a side wall of the vessel such that, in use, the cooling means encourages circulation of the water being cooled within the vessel. Such an arrangement ensures that as water is cooled by the electro-thermal cooling means, and thus becomes denser, it sinks towards the base of the vessel. When the water reaches the bottom of the vessel it is deflected sideways and thus a convection flow is created, encouraging water from all parts of the vessel to flow past the cooling means. This convection flow enhances the efficiency with which the cooling means may cool all of the water in the vessel since it minimises warm and cool spots within the water and does not just rely on heat conduction.

[0011] This arrangement is novel and inventive in its own right, even if no integral filter means is provided. When viewed from a second aspect therefore, the present invention provides a liquid cooling vessel comprising an electro-thermal cooling means provided on or in a side wall of the vessel such that, in use, the cooling means encourages circulation of the liquid being cooled within the vessel.

[0012] Preferably the vessel in accordance with this aspect of the invention is suitable for cooling water.

[0013] Preferably the electro-thermal cooling means comprises a Peltier-effect device. A Peltier effect device is based on a solid state semiconductor which operates by transferring heat from one face to the opposite face when a suitable electric current is applied. The direction of heat transfer is dependent on the direction of the applied voltage and is thus reversible.

[0014] The cooling means is preferably located in or on the lower half of the side wall of the vessel. Such placement of the cooling means allows for operation of the vessel when only partially full of water.

[0015] The cooling means could comprise a Peltier or similar electro-thermal device simply mounted in or to

2

Figure 4 - Patent description (Intellectual Property Teaching Kit, 2018)

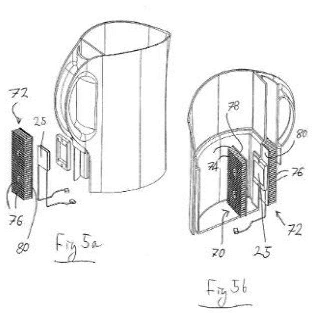

Figure 5 - Patent design (Intellectual Property Teaching Kit, 2018)

3.6 IPC Codes

IPC codes, or International Patent Classification codes, are a standardized system used to categorize and classify patents based on the technical features of the inventions they cover. Developed by the World Intellectual Property Organization (WIPO), IPC codes provide a hierarchical structure that allows for the systematic and uniform categorization of inventions across different countries and technology fields.

IPC codes help in the efficient search and retrieval of patent documents by allowing users to precisely define the technical subject matter of their interest, aiding patent examiners, researchers, and inventors in navigating and accessing relevant patent information. And therefore within the PLRs they represent an important tool for identifying the major areas of application.

Each classification symbol is of the form A01B 1/00.

The code is structured, it can be divided into parts, each part identifies a group hierarchically linked. The section is the first letter consisting of a letter from A to H. These are the section title:

- A: Human Necessities
- B: Performing Operations, Transporting
- C: Chemistry, Metallurgy
- D: Textiles, Paper
- E: Fixed Constructions
- F: Mechanical Engineering, Lighting, Heating, Weapons
- G: Physics
- H: Electricity

The subsequential two-digit number represents the **class** e.g. class A01 represents "Agriculture; forestry; animal husbandry; trapping; fishing". The final letter identifies the **subclass** e.g. A01B represents "Soil working in agriculture or forestry; parts, details, or accessories of agricultural machines or implements, in general"). The subclass is followed by a one-to-three-digit "group" of numbers, an oblique stroke and a number of at least two digits representing the **main group** if the second number is 00 or **subgroup** if it is a different number.

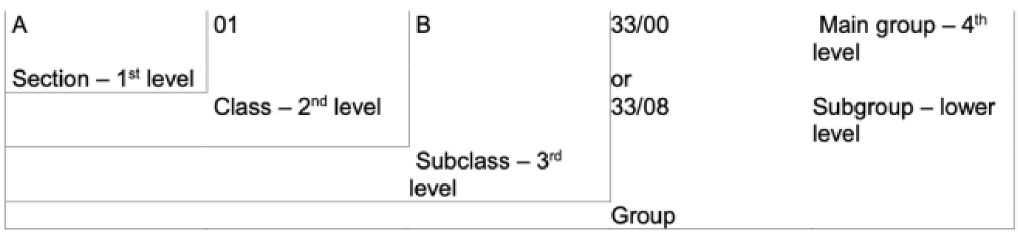

Figure 6 - Graphical representation of the hierarchy used in IPC classification

3.7 PLR and Databases

The Patent Landscape Report (PLR) lacks a definitive definition, yet it primarily entails an analysis of patent documents pertinent to a specific technological domain. However, diverse approaches exist in crafting a PLR, ranging from comprehensive scopes inclusive of market analysis and non-patent data to more focused and specialized investigations. The fundamental goal of a PLR remains providing valuable insights and guidance to companies engaging in Research and Development within a specific technology sector. Presently, public policymakers are increasingly leveraging landscape analyses as a foundational step before delving into higher-level policy considerations, particularly in critical areas such as healthcare, food security, and environmental concerns.

Patent information sources play a pivotal role in constructing a Patent Landscape Report (PLR). These sources primarily fall into two categories:

- **Primary Sources**: These databases are provided directly by the respective Patent authorities. However, the information contained within these databases is limited to the jurisdiction under the authority's purview. Consequently, such sources are typically not utilized in the creation of PLRs.
- **Secondary Sources**: These encompass patent databases that facilitate searches across multiple jurisdictions simultaneously. Certain patent authorities maintain separate secondary sources that are freely accessible, such as PATENTSCOPE by WIPO, Esp@cenet by the European Patent Office, or DEPATISNET by the German Patent and Trademark Office. Additionally, some of these platforms offer free proprietary analytical tools like The Lens by Cambia and PatentInspiration by CREAX, augmenting the search experience with statistical analysis and visualization features.

While primary sources are often free of charge, secondary sources encompass a spectrum from no-cost options offering fundamental bibliographic, text, and/or image data to paid services that furnish additional enhancements, features, and integrated analytical tools for comprehensive patent analysis.

We've selected The Lens among the secondary information sources, as already stated more suitable for a PLR than the primary ones. This platform facilitated our dataset selection through tailored queries and enabled us to conveniently download the resulting dataset in CSV format.

4. Research method

The methodologies employed for database extraction to facilitate our analysis are delineated below. The primary objective of our analysis is to discern the principal domains of application concerning solid propellants. As a deliberate choice, filters restricting the International Patent Classification (IPC) codes will be intentionally omitted.

Our approach focuses on isolating specific patent databases that encompass distinct phases or modes of solid propellant production. This strategic selection aims to unveil the comprehensive coverage of various patents, enabling a comprehensive understanding of the nuanced differences and resemblances among these categories.

Outlined below are the four identified methods, succinctly described once more:

- **Additive manufacturing**: technology used to incrementally deposit and fuse layers of propellant mixture.
- **Light based technologies**: technologies involving the use of light. In particular, an attempt will be made to identify technologies where visible or ultraviolet light can serve as a catalyst to initiate the polymerization process, facilitating the creation of cross-linked structures.
- **Curing**: the chemical or physical process used to harden, set, or solidify a material. It can be connected to the previous point if light is used to achieve hardening and the formation of a resistant three-dimensional grating.
- **Casting**: the manufacturing process of shaping and forming a solid propellant into a specific, desired geometry. This process entails mixing propellant ingredients like fuel, oxidizer, and additives to create a flowable composition, which is then poured into a mould with the desired propellant grain shape and dimensions.

The initial pair of methodologies focus on pinpointing production techniques that share analogous traits with the patented method, specifically centring on 'Photo-polymerization for additive manufacturing of composite solid propellants'. Conversely, the latter two approaches prioritize the exploration of conventional methods in the realm of solid propellant production.

Moreover, the temporal scope selected for our analysis spans from January 1, 2000, to June 30, 2023, encapsulating the outset of the millennium. This duration was deliberated upon due to its alignment with the typical lifespan of patents, thereby encompassing a period that remains relevant while mitigating the inclusion of excessively antiquated patents.

Next, we delineate the keywords and filters utilized in the dataset identification process. Initially, our objective is to differentiate patents specifically related to solid propellants from others, ensuring that the latter primarily revolve around this subject. To achieve this, keyword searches are confined to the titles and abstracts of patents accessible through TheLens platform. The chosen keywords aim to comprehensively cover synonymous terms associated with solid propellants, fostering a robust and inclusive search approach. Below, we present the set of keywords chosen:

Solid propellant, propellant grain, solid grain, composite propellant

Subsequently, additional filters will be implemented for each previously identified category. However, in this instance, our focus shifts from the primary subject of the patent to the descriptive presence of the method within the patent itself. To facilitate this broader exploration, keyword searches will encompass the description and claims sections. The table below outlines the specific keywords designated for each of the four categories.

Category	Keywords
Additive manufacturing	Additive manufacturing, 3D printing, words that have as root deposit
Light based technologies	words that have as root phot
Curing	Curing
Casting	Casting, Molding

Table 2 - Keywords used to identify categories

5. Data exploration

5.1 Introduction

The purpose of this chapter will be to gain a preliminary understanding of the characteristics, structure and patterns of the datasets, commencing with a detailed exposition of its attributes, encompassing the dataset description and the cleaning processes applied to the extracted datasets. Additionally, it elucidates the software platforms and libraries employed throughout the analysis.

5.2 Software Settings

The programming language used for the development of the study R (version 4.1.2). It is a widely used programming language in the contest of statistical computing and data visualization. Specifically, we will utilize the following packages, which offer valuable functions for data manipulation with the datasets at our disposal:

- **Tidyverse** (Wickham et al, 2019): Comprehensive collection for data science tasks;
- **Janitor** (Firke, 2021): Focuses on data cleaning and tidying;
- **KableExtra** (Zhu, 2021): Enhances table formatting in R;
- **Lubridate** (Ushey, Allaire, Tang, 2021): Streamlines date-time manipulation;
- **Ggpubr** (Kassambara, 2021): Extends ggplot2 for publication-ready plots;
- **RColorBrewer** (Neuwirth, 2014): Provides diverse colour schemes for visuals.

5.3 Dataset cleaning

The datasets were exported from the lens.org platform in csv format and then later integrated into our working environment.

The datasets comprise 33 attributes, however, for the purpose of our analysis, we will focus exclusively on the attributes listed below:

- **Earliest priority date**: is the date of the initial patent application filing for an invention, establishing a reference point for assessing the invention's novelty and prior art.
- **Legal status**: the current legal standing and enforceability.
- **Jurisdiction**: The geographical or legal jurisdiction in which the patent holds validity
- **Ipcr classifications**: the IPC codes that categorize the patent within specific domains areas.
- **Applicants**: are the individuals or entities who formally submit applications or requests for a patent with the aim of securing the associated legal privileges and protections.
- **Cited by patent count**: number of patents documents citing a patent (Forward patent citations).

The number of records in each dataset is presented below. Initially, we refrained from cleaning the datasets, acknowledging the possibility of missing data. As we will demonstrate, we opted to exclude these cases from the analysis due to their limited occurrence within the total dataset. Subsequently, we will implement this approach in each of the five macro-analyses by filtering out patents lacking information in the reference attribute. For instance, a patent with missing applicant data will be excluded from the study which identifies the major applicants. Conversely, if the same patent includes IPC code information, it will be retained within the sample and utilized for identifying the most frequent code associations.

Dataset	Instances
Additive Manufacturing	243
Light based technologies	118
Curing	401
Casting	239

Table 3 - Number of patents per category

5.4 Dataset Manipulation

We began by separately collecting and reading patent datasets for the four identified categories, and then combined these datasets. To ensure traceability of the technology used in each patent, we introduced four attributes:

- **additive**: for the additive manufacturing;
- **photo**: for light based technologies;
- **curing**: for the curing;
- **casting**: for the casting.

Each attribute can hold a Boolean value, indicating the presence or absence of specific technologies or methods within the patent.

This approach enabled us to create a single, consolidated dataset for analysis and manipulation, while still allowing for easy partitioning by filtering the dataset based on one of the four attributes, each corresponding to a particular technology.

Further adaptation on the database done was to extract the year from the earliest priority date by adding it as an additional attribute so that patents could be grouped by year later.

The total number of patents considered is displayed below. It's important to note that the total count is less than the sum of individual categories, as a single patent may involve the use of multiple methods or technologies among those identified. Consequently, the previously defined datasets can be viewed as subsets of a union set, where there are intersections between them.

Dataset	Instances
All technologies	733

Table 4 - Total number of patents

6. Patent Analysis

6.1 Introduction

Following this preliminary data explortion, the subsequent sections will delve into the primary quantitative analyses. These analyses, each treated independently, are listed below:

- **Temporal trend**: we will examine the temporal evolution of patent filings within our technological domain to identify prevailing patterns and discrepancies.
- **Legal status**: We will identify current patents standing or condition in the context of intellectual property law. We will find whether a patent is active, expired, lapsed, revoked, or undergoing any legal proceedings.
- **IPC Codes**: we will conduct a search to identify the prevalent codes with the objective of delineating the principal technological domains.
- **Jurisdictions**: we will determine the primary countries and/or areas where patents hold legal validity.
- **Applicants**: we will ascertain the primary innovations in the production and manufacturing techniques of solid propellants.

Subsequent to these analyses, a qualitative analysis will be conducted, coupled with an evaluation of the significance of these patent types within the portfolios of major applicants.

6.2 Temporal trend

This section provides an analysis of the advancements in solid propellant technologies in the 21st century.

To assess the state of the art's progression, we opted to categorize patents based on their earliest priority date. This date was selected because it signifies the initial filing date of a patent application for a particular invention, serving as a critical reference point for assessing the invention's novelty and prior art. Therefore, it provides a reasonable approximation of when the technology underlying the patent's development concluded, without accounting for the patent's evaluation, confidentiality procedures, or requests for extended validity in other jurisdictions.

Furthermore, the year 2023 was omitted from our analysis, as it had not concluded at the time of our study, and it is anticipated that the number of patents for this year will be relatively small, partly due to the inherent secrecy period associated with patent applications.

Finally, the graph is augmented with a linear regression line computed in relation to the data points within the scatter plot. This inclusion serves the purpose of elucidating discernible trends in temporal progression, whether characterized by an ascending or descending trajectory.

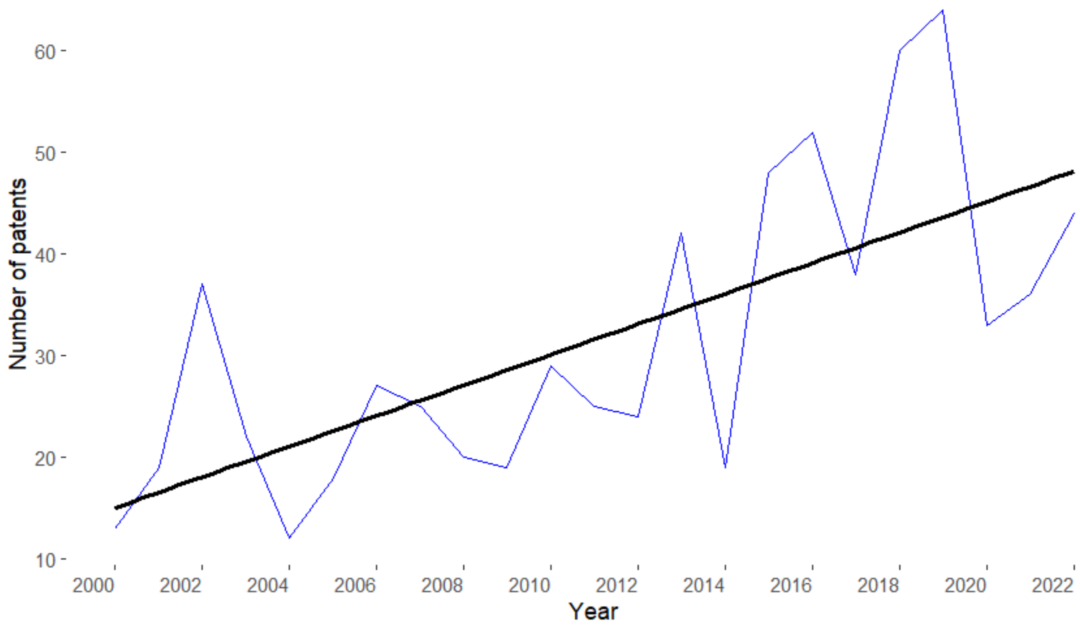

Figure 7 - Solid propellant patent temporal trend over time (2000-2022)

Year	Number of patents
2000	13
2001	19
2002	37
2003	22
2004	12
2005	18
2006	27
2007	25
2008	20
2009	19
2010	29
2011	25
2012	24

Year	Number of patents
2013	42
2014	19
2015	48
2016	52
2017	38
2018	60
2019	64
2020	33
2021	36
2022	44

Table 5 - Number of patents on solid propellants per year

Upon examining the dataset comprehensively, a discernible upward trend becomes apparent, with a consistent increase in the number of patents filed over the years, reaching its zenith at 64 patents in 2019. However, it is important to note that within this ascending trajectory, there were notable declines, notably in 2004 and 2014, as well as in 2020. Regarding the latter year, it is essential to acknowledge that it coincides with the onset of the COVID-19 pandemic, which had a significant impact on the general pace of technological development.

This approach was adopted to prevent the inadvertent removal of potentially significant records that might be crucial for a specific analysis.

6.3 Patent trends by category over time

Let's delve into a more detailed analysis, focusing on the four distinct categories.

Year	Additive manufacturing	Ligth based technologies	Curing	Casting
2000	6	4	1	3
2001	4	7	10	2
2002	14	0	12	26
2003	7	2	10	8
2004	5	4	1	4
2005	2	5	9	8
2006	10	8	10	10
2007	7	3	13	9
2008	6	1	12	10
2009	8	2	9	4
2010	5	4	20	9
2011	5	2	15	3
2012	12	5	4	5
2013	17	14	14	22
2014	6	5	10	8
2015	24	2	27	17
2016	19	6	36	21
2017	18	4	20	10
2018	19	14	33	11
2019	13	8	50	19

Year	Additive manufacturing	Ligth based technologies	Curing	Casting
2020	14	5	26	11
2021	11	7	20	6
2022	11	5	33	10

Table 6 - Number of patents on solid propellants by category and year

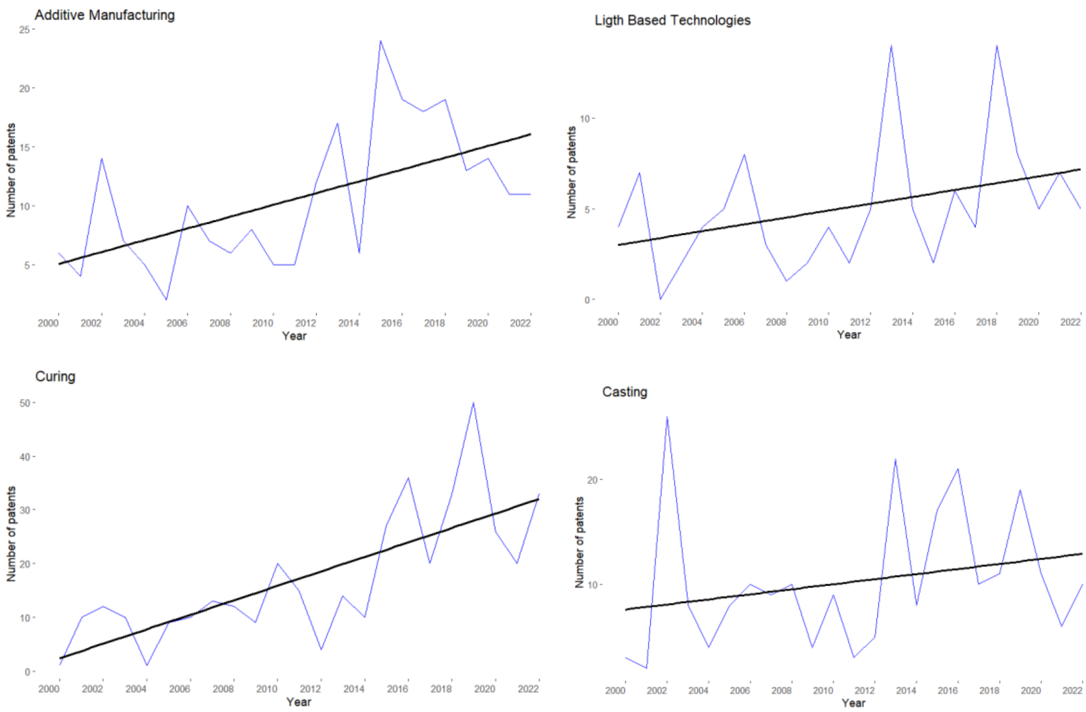

Figure 8 - Solid propellant patent temporal trend over time (2000-2022) by category

The graph and the table reveal the following insights:

- Patents referencing the curing phase exhibit a pattern that closely aligns with the overall dataset encompassing all technologies. It's crucial to note that this subset is the most populous, constituting approximately 55% of the total available records, which naturally contributes to a stronger correlation with the dataset as a whole.
- The year 2002 stands out as a notable peak year for all technologies, except for those associated with light-based methods, which surprisingly had no patents filed during that particular year. In contrast, the other technologies saw more than ten patent applications.
- The patent trends related to technologies utilizing visible and UV light have exhibited a near-constant pattern, punctuated by two peaks in 2014 2018 (14 patents).

- The patent trend for solid propellants involving additive manufacturing is characterized by some fluctuations, and it reached its highest point in 2015 (the number of patents quadrupled compared to the previous year)
- In relation to the patents within our database that pertain to casting, we observed a fluctuating trend, with the most significant peak occurring in 2002 (26 patents).
- Broadly speaking, discernible trends indicate a more pronounced upward trajectory in the additive manufacturing and curing categories. Conversely, within the light-based technology categories, the regression line exhibits a comparatively shallower slope, indicative of a more gradual pace of technological advancement in these specific domains.

6.4 Legal Status Evaluation

According to what the lens platform states on its site [8], legal status can fall into the following categories:

- **Unknown**: If there is not enough information to calculate.
- **Active**:
    1. If granted and calculated term date is before current date.
    2. If it is being renewed.
    3. If Latest legal event is not related to withdrawal or lapse.
    4. If regional application is not withdrawn or lapsed in all designated jurisdictions.
- **Inactive**: If it has lapsed but has not revived before the calculated term date or if application Expiry Date is not before Application Revival Date. (Non-payment of maintenance/ renewal fee).
- **Patented**: If regional application is alive in at least one state or if it is granted but there is not enough information to mark it as active.
- **Expired**: If Calculated Term Date is Before current date And Unnatural Expiry Date is Before current date.
- **Pending**: IP Right has not been granted yet and application is in either filing, examination, pre-grant stage.
- **Discontinued**: Application was discontinued (rejection, withdrawal, refusal, etc), can be revived.

In this section, we will assess the patent categories to gain insights into the current legal status of the patents within the considered database.

Legal status	Number of patents	Percentage
ACTIVE	337	45.98
PENDING	137	18.69
DISCONTINUED	100	13.64
INACTIVE	92	12.55
EXPIRED	63	8.59
PATENTED	3	0.41
UNKNOWN	1	0.14

Table 7 - Patents on solid propellants by legal status

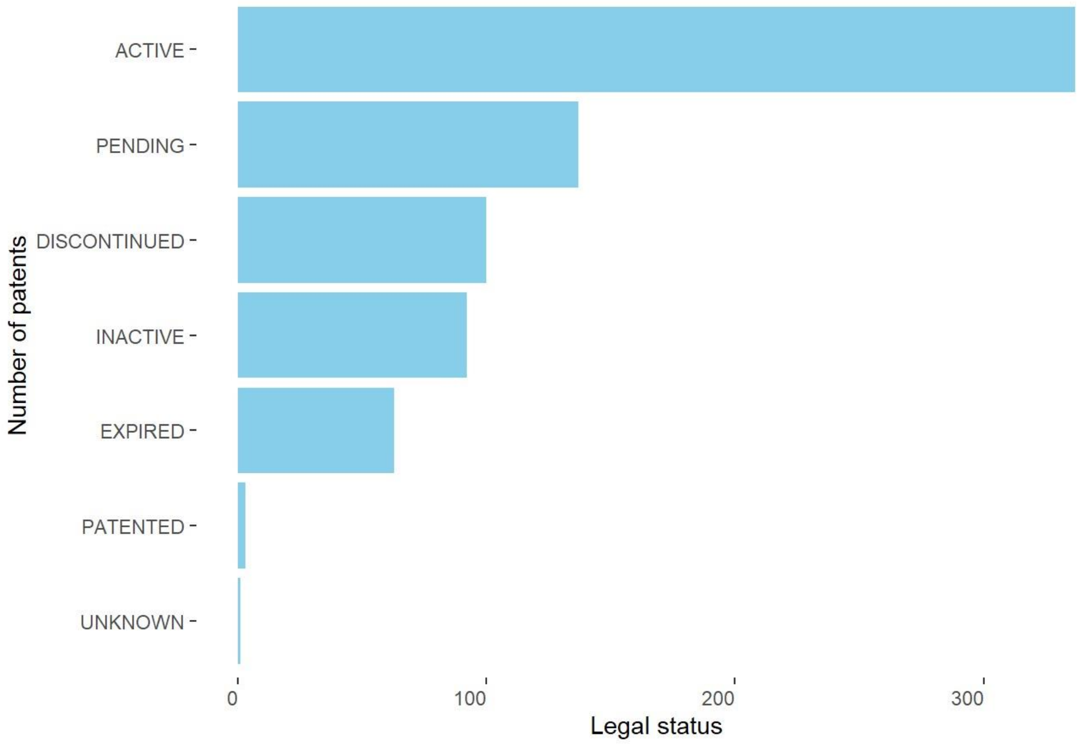

Figure 9 - Solid propellant patent legal status

Approximately half of the considered patents are currently in active status (46%), which represents the most numerous categories. About 18.7% of patents are currently under evaluation, while 13.6% are marked as discontinued but potentially revivable. It's worth noting that patents no longer in force, either due to inactivity or expiration, make up roughly one-fifth of the dataset under consideration.

6.5 Legal Status of Patents Across Technological Domains

The objective of this section is to examine the legal status of patents within various subsets representing the utilization of a specific technology as identified in the patents under study.

Legal Status	Total	Additive manufacturing	Light based technologies	Curing	Casting
ACTIVE	337	117	50	209	106
PENDING	137	58	25	79	41
DISCONTINUED	100	26	18	58	36
INACTIVE	92	24	12	29	28
EXPIRED	63	16	10	25	27
PATENTED	3	2	3	0	0
UNKNOWN	1	0	0	1	1

Table 8 - Patents on solid propellants by legal status & category (absolute terms)

Legal Status	Total %	Additive manufacturing %	Light based technologies %	Curing %	Casting %
ACTIVE	45.98	48.15	42.37	52.12	44.35
PENDING	18.69	23.87	21.19	19.70	17.15
DISCONTINUED	13.64	10.70	15.25	14.46	15.06
INACTIVE	12.55	9.88	10.17	7.23	11.72
EXPIRED	8.59	6.58	8.47	6.23	11.30
PATENTED	0.41	0.82	2.54	0.00	0.00
UNKNOWN	0.14	0.00	0.00	0.25	0.42

Table 9 - Patents on solid propellants by legal status & category (relative terms)

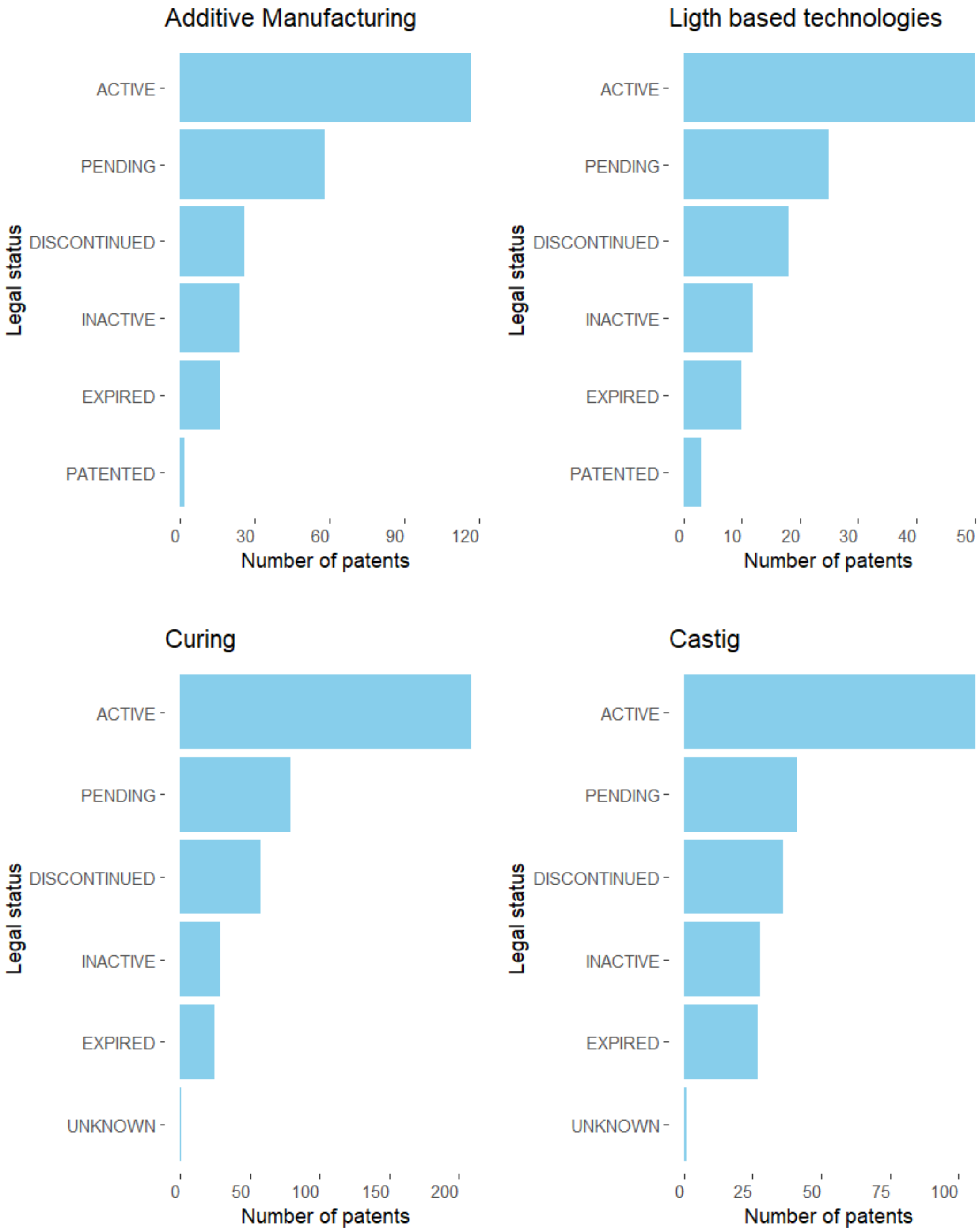

Figure 10 - Solid propellant patent legal status by category

Generally, it is evident that each subset exhibits a distribution of patents among various legal statuses that is relatively consistent when compared to the dataset as a whole.

Notably, it is worth mentioning that patents related to curing demonstrate the highest proportion of active patents in comparison to other categories. Conversely, those pertaining to casting exhibit the highest percentage of inactive or expired patents, accounting for approximately 23% of the total.

6.6 Geographical distribution

This section will evaluate the geographical scope of patent protection sought for the patents under examination. The country abbreviations utilized in the tables and graphs adhere to the ISO 3166-1 alpha-2 format, ensuring standardized representation. It is imperative to emphasize that within this context, the abbreviation “WO” designates international patent applications processed in strict compliance with the provisions of the Patent Cooperation Treaty (PCT). While, “EP” denotes European patents, through which patent protection can be pursued across one or more territories within the European Union, as stipulated by the 1973 Munich-Bavaria Convention.

Jurisdiction	Number of patents	Percentage
CN	267	36.43
US	241	32.88
RU	64	8.73
WO	52	7.09
EP	42	5.73
KR	24	3.27
JP	16	2.18
CA	5	0.68
AU	3	0.41
TW	3	0.41

Table 10 - Leading ten applicants in solid propellant per number of patents

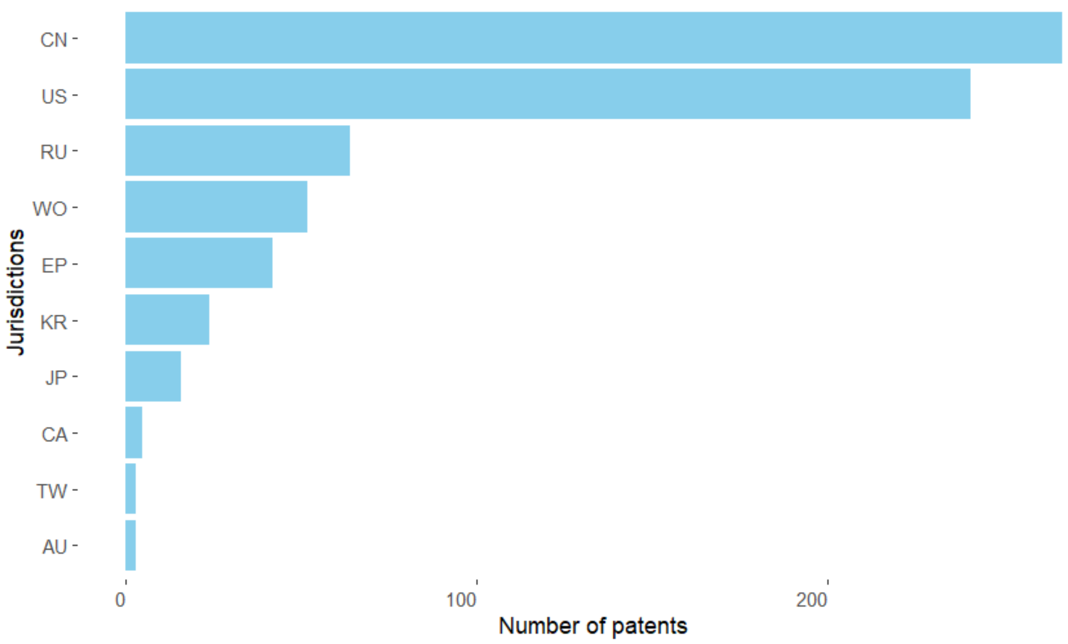

Figure 11 - Leading ten applicants in solid propellant per number of patents

Two nations prominently emerge in terms of patent count, demonstrating significant patent activity: China and the United States of America, each boasting an impressive tally of over 200 patents. Slightly further behind, Russia follows with 64 patents. Additionally, international patents, numbering 52, represent a notable presence within this context.

6.7 Patents jurisdictions across technological domains

This section will undertake an assessment, both in relative and absolute terms, of the most prominent jurisdictions within the four identified categories.

Jurisdiction	Total	Additive manufacturing	Light based technologies	Curing	Casting
CN	267	65	38	160	61
US	241	103	48	138	97
RU	64	6	5	26	27
WO	52	31	16	27	22
EP	42	17	8	21	14
KR	24	0	1	17	7
JP	16	4	1	8	6

Jurisdiction	Total	Additive manufacturing	Light based technologies	Curing	Casting
CA	5	3	0	1	1
AU	3	3	0	0	0
TW	3	0	0	3	0

Table 11 - Leading ten applicants in solid propellant per number of patents - category breakdown (absolute terms)

Jurisdiction	Total %	Additive manufacturing %	Light based technologies %	Curing %	Casting %
CN	36.43	26.75	32.20	39.90	25.52
US	32.88	42.39	40.68	34.41	40.59
RU	8.73	2.47	4.24	6.48	11.30
WO	7.09	12.76	13.56	6.73	9.21
EP	5.73	7.00	6.78	5.24	5.86
KR	3.27	0.00	0.85	4.24	2.93
JP	2.18	1.65	0.85	2.00	2.51
CA	0.68	1.23	0.00	0.25	0.42
AU	0.41	1.23	0.00	0.00	0.00
TW	0.41	0.00	0.00	0.75	0.00

Tabla 12 - Leading ten applicants in solid propellant per number of patents - category breakdown (relative terms)

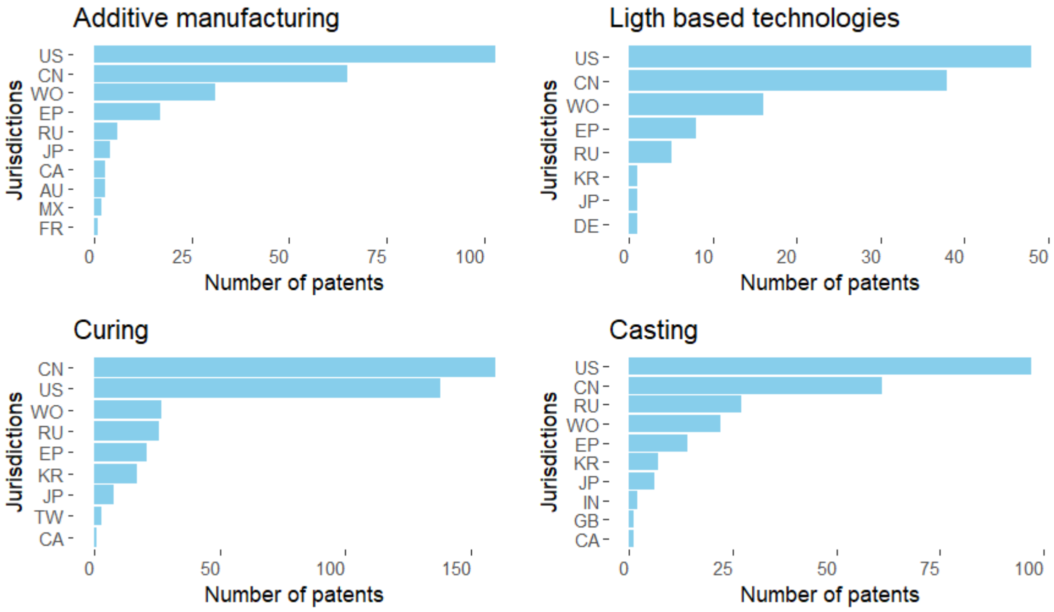

Figure 12 - Leading ten applicants in solid propellant patents by category

Upon a comprehensive examination of the various identified subsets, noteworthy observations come to the forefront:

- In the overall patent ranking, China exhibits a higher aggregate number of patents. However, within specific subcategories, excluding those pertaining to curing technology, the United States consistently attains the top rank in terms of patent quantity.
- Within the additive manufacturing and light-based technologies categories, a noteworthy departure from the prevailing trend is observed, where the count of international and European patents surpasses that of patents for which protection was actively sought. This anomaly contrasts with the broader dataset's dynamics. Conversely, in the curing category, a similar number of patents is noted across these three jurisdictions. While the casting category aligns with the overarching pattern observed in the entire dataset.

6.8 Examination of Application Domains

In this section, we endeavor to pinpoint the most frequently occurring codes IPC with the aim of discerning the primary domains of application.

IPC Code	Number of patents	Percentage
C06B21/00	121	16.51
C06B45/10	74	10.10
C06B23/00	72	9.82
C06D5/00	57	7.78
C06D5/06	53	7.23
F02K9/24	42	5.73
C06B45/00	41	5.59
C06B33/06	36	4.91
F02K9/10	35	4.77
F02K9/34	34	4.64

Table 13 - Most frequent IPC codes within patents on solid propellants

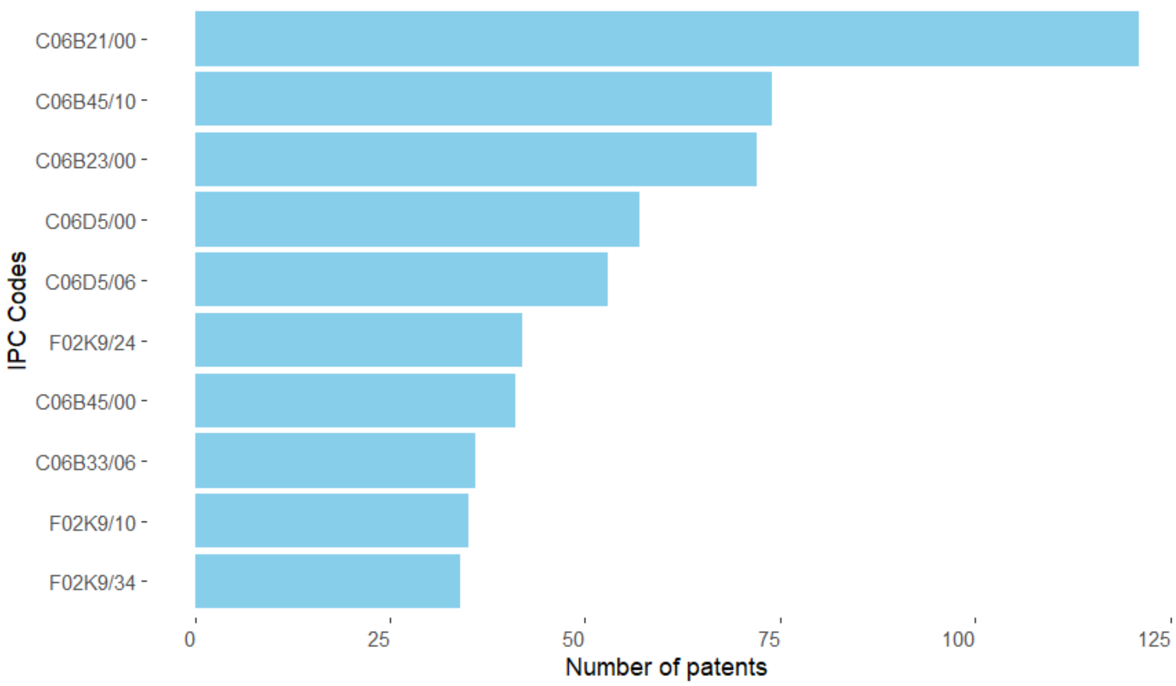

Figure 13 - Most frequent IPC codes within patents on solid propellants

The majority of the classified codes predominantly fall within two broad categories: Category C06B, encompassing the multifaceted domain of "Explosive Materials" involving their creation, production, and utilization, and Category F02K, which centres on "Jet Propulsion." Category F02K pertains to an extensive spectrum of topics concerning jet engines and propulsion systems, addressing aspects like design, construction, operation, and their versatile applications in domains such as aviation, aerospace, and transportation.

Nevertheless, the former exhibits a greater number of patents than the latter, with C06B21/00 emerging as the predominant field of application.

In an effort to offer a more elucidating context, we have endeavored to construct a table that highlights the ten most prevalent codes, each accompanied by its corresponding description.

IPC_codes	Description
C06B21/00	Apparatus or methods for working-up explosives, e.g. forming, cutting, drying.
C06B45/10	Apparatus for drying explosives, e.g. nitrocellulose
C06B23/00	Methods for drying explosives, e.g. ammonium nitrate
C06D5/00	Preparation of explosives by nitration, by forming ammonium nitrate
C06D5/06	Manufacture of water-in-oil emulsions, e.g. explosives
F02K9/24	Methods and systems for the treatment of exhaust gases from internal combustion engines
C06B45/00	Preparation of nitrocellulose
C06B33/06	Preparation of smokeless powder
F02K9/10	Carburettors with means for controlling emission of hydrocarbons
F02K9/34	Supplying mixtures of liquid and gas to combustion chambers of piston engines

Table 14 - Most frequent IPC codes within patents on solid propellants description

6.9 IPC codes across technological domains

When examining various subsets, it becomes readily apparent that:

- Regardless of the type, the subset the most frequent code remains C06B21/00
- In the specific domain of additive manufacturing, an analysis of frequent codes reveals the emergence of new identifiers, in contrast to the outcomes obtained from our comprehensive dataset analysis. Notably, we identify the presence of B33Y (B33Y10/00, B33Y30/00, B33Y70/00) codes, which are indicative of additive manufacturing technologies, as might have been expected. Furthermore, B22F1 (B22F1/065, B22F1/052) codes surface, signifying their association with metal powder production.

- In the realm of light-based technologies, a similar pattern emerges. However, in contrast to the prior scenario, the classification code B33Y30/00 does not feature among the top ten patent applicants. It is imperative to highlight the presence of two novel codes within this context, A62C35/02 and B28B1/00. The classification code A62C35/02 pertains to firefighting equipment, with a particular focus on fixed firefighting apparatus. This code encompasses the utilization of a propellant for the dispersion and propagation of extinguishing materials in the event of a fire outbreak. While the code B28B1/00 is centred on methodologies employed for the delineation of material shapes.
- The prevailing codes within the subset related to curing closely resemble those derived from the comprehensive dataset. Notably, these codes continue to fall within the overarching categories of C06B and F02K9.
- The casting subcategory comprises a collection of codes that closely mirrors the broader dataset, encompassing the same codes. Additionally, it includes the codes: B33Y10/00, B33Y70/00 related to additive manufacturing.

Below are the data for each of the 4 categories in both tabular and graphical form.

IPC Codes	Total	Additive manufacturing	Light based technologies	Curing	Casting
C06B21/00	121	40	13	77	56
C06B45/10	74	20	7	65	17
C06B23/00	72	14	8	61	21
C06D5/00	57	7	2	34	20
C06D5/06	53	12	6	46	10
F02K9/24	42	13	6	27	26
C06B45/00	41	11	3	27	26
C06B33/06	36	15	7	30	7
F02K9/10	35	11	2	27	13
F02K9/34	34	14	4	18	16

Table 15 - Most frequent IPC codes within patents on solid propellants - category breakdown (absolute terms)

IPC Codes	Total %	Additive manufacturing %	Light based technologies %	Curing %	Casting %
C06B21/00	16.51	16.46	11.02	19.20	23.43
C06B45/10	10.10	8.23	5.93	16.21	7.11
C06B23/00	9.82	5.76	6.78	15.21	8.79
C06D5/00	7.78	2.88	1.69	8.48	8.37
C06D5/06	7.23	4.94	5.08	11.47	4.18
F02K9/24	5.73	5.35	5.08	6.73	10.88
C06B45/00	5.59	4.53	2.54	6.73	10.88
C06B33/06	4.91	6.17	5.93	7.48	2.93
F02K9/10	4.77	4.53	1.69	6.73	5.44
F02K9/34	4.64	5.76	3.39	4.49	6.69

Table 16 - Most frequent IPC codes within patents on solid propellants - category breakdown (relative terms)

IPC Codes	Number of patents	Percentage
C06B21/00	40	5.46
B33Y10/00	30	4.09
C06B45/10	20	2.73
B22F1/065	17	2.32
B22F1/052	16	2.18
B33Y70/00	16	2.18
B33Y30/00	15	2.05
C06B33/06	15	2.05
C06B23/00	14	1.91
F02K9/34	14	1.91

Table 17 - Most frequent IPC codes within patents on solid propellants propellants that cite additive manufacturing technologies

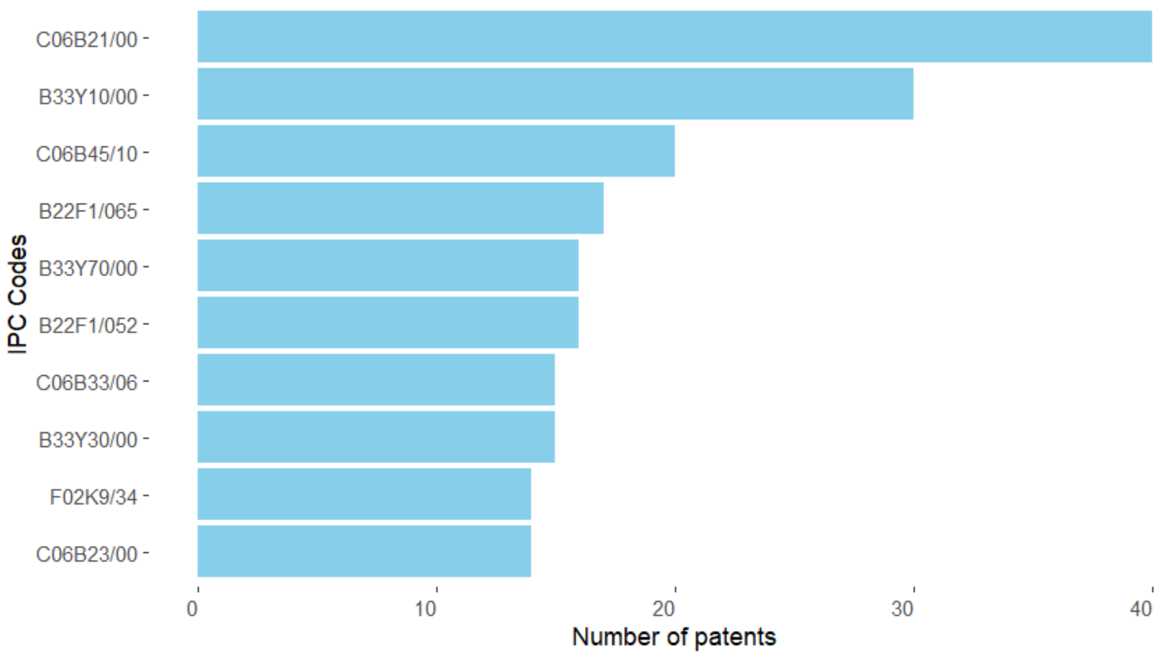

Figure 14 - Most frequent IPC codes within patents on solid propellants that cite additive manufacturing technologies

IPC Codes	Number of patents	Percentage
C06B21/00	13	1.77
B33Y10/00	12	1.64
A62C35/02	9	1.23
B22F1/052	9	1.23
B22F1/065	9	1.23
C06B23/00	8	1.09
B28B1/00	7	0.95
B33Y70/00	7	0.95
C04B20/00	7	0.95
C04B35/56	7	0.95

Table 18 - Most frequent IPC codes within patents on solid propellants that cite ligth based technologies

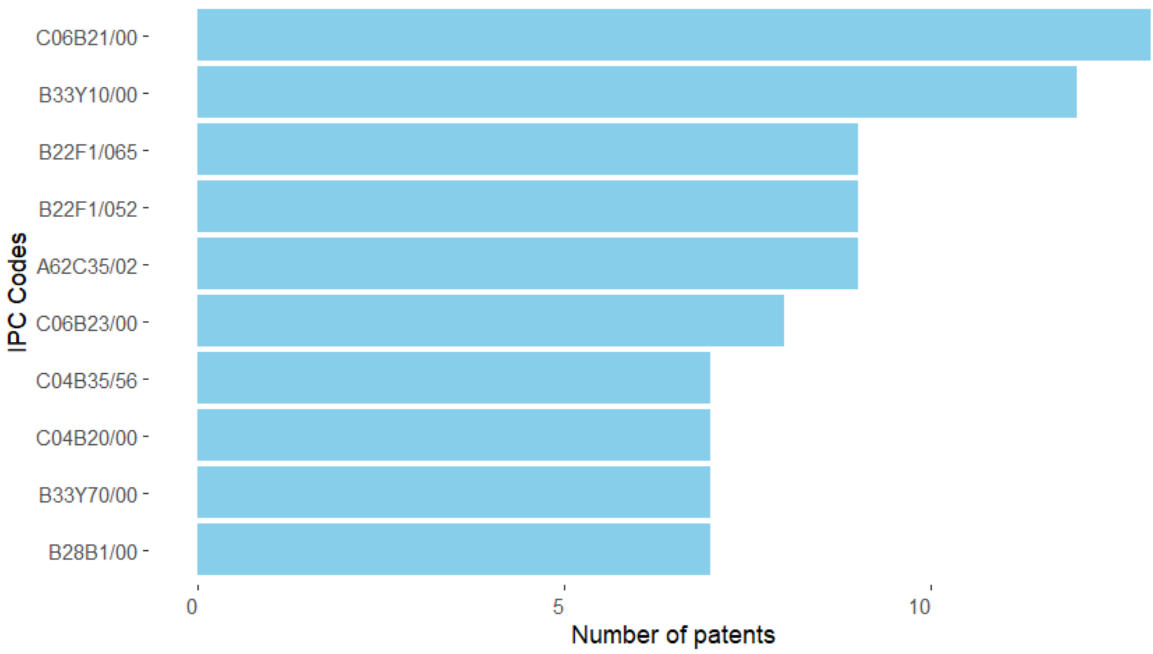

Figure 15 - Most frequent IPC codes within patents on solid propellants that cite ligth based technologies

IPC Codes	Number of patents	Percentage
C06B21/00	77	10.50
C06B45/10	65	8.87
C06B23/00	61	8.32
C06D5/06	46	6.28
C06D5/00	34	4.64
C06B33/06	30	4.09
C06B45/00	27	3.68
F02K9/10	27	3.68
F02K9/24	27	3.68
C06B29/22	25	3.41

Table 19 - Most frequent IPC codes within patents on solid propellants that cite the curing phase

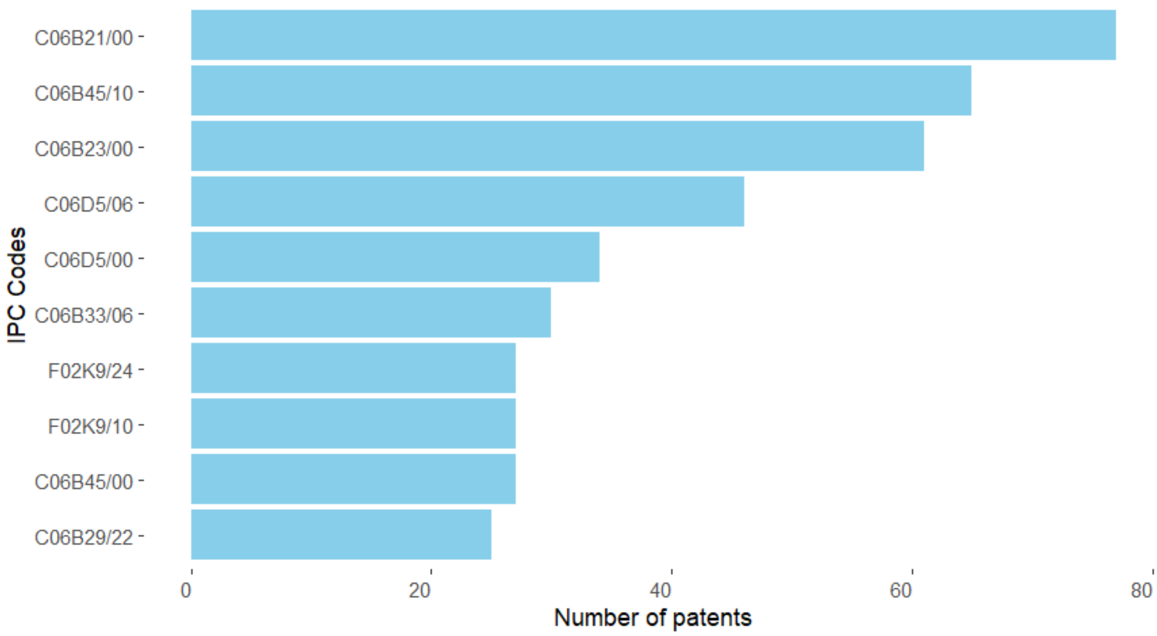

Figure 16 - Most frequent IPC codes within patents on solid propellants that cite the curing phase

IPC Codes	Number of patents	Percentage
C06B21/00	56	7.64
C06B45/00	26	3.55
F02K9/24	26	3.55
C06B23/00	21	2.86
B33Y10/00	20	2.73
C06D5/00	20	2.73
C06B45/10	17	2.32
F02K9/34	16	2.18
B33Y70/00	13	1.77
F02K9/10	13	1.77

Table 20 - Most frequent IPC codes within patents on solid propellants that cite the casting phase

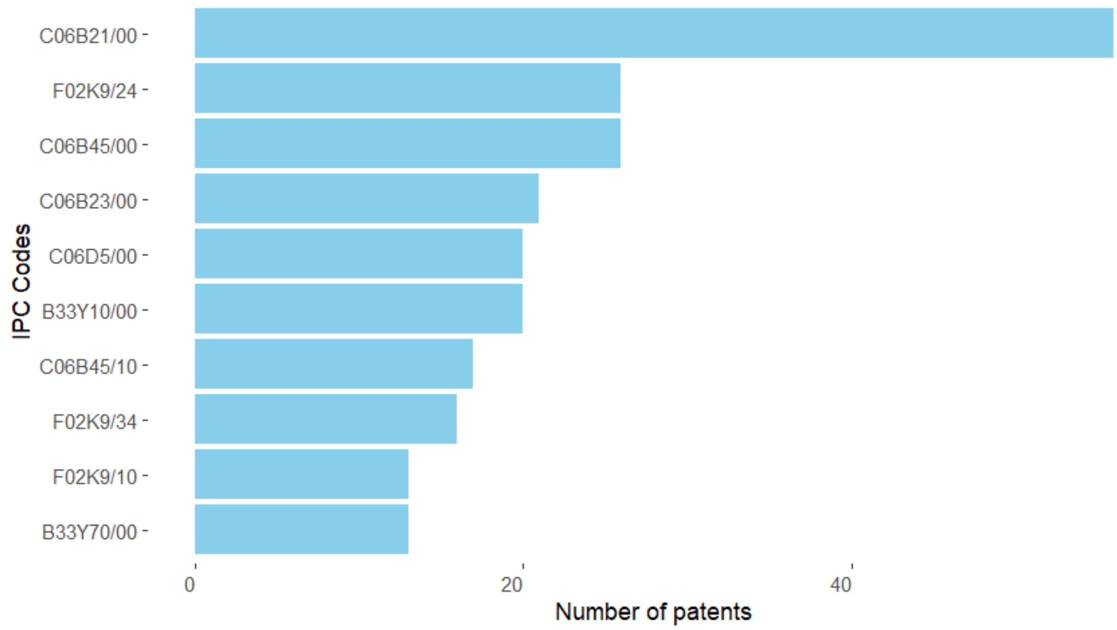

Figure 17 - Most frequent IPC codes within patents on solid propellants that cite the casting phase

6.10 Applicants

In this section, our focus shifts towards the recognition of prominent innovators. Presented below is a table and chart enumerating the top ten leaders in the field.

Applicants	Number of patents
HUBEI INST AEROSPACE CHEMOTECHNOLOGY	48
XIAN MODERN CHEMISTRY RES INST	34
RAYTHEON CO	28
GOODRICH CORP	26
AVIO SPA	21
AEROJET ROCKETDYNE INC	17
UNIV PRINCETON	17
AGENCY DEFENSE DEV	16
FEDERAL NOE GUP NII POLIMERNYK	14
HOPKINS ADAM BAYNE	9

Table 21 - Leading ten applicants in solid èropellant patents

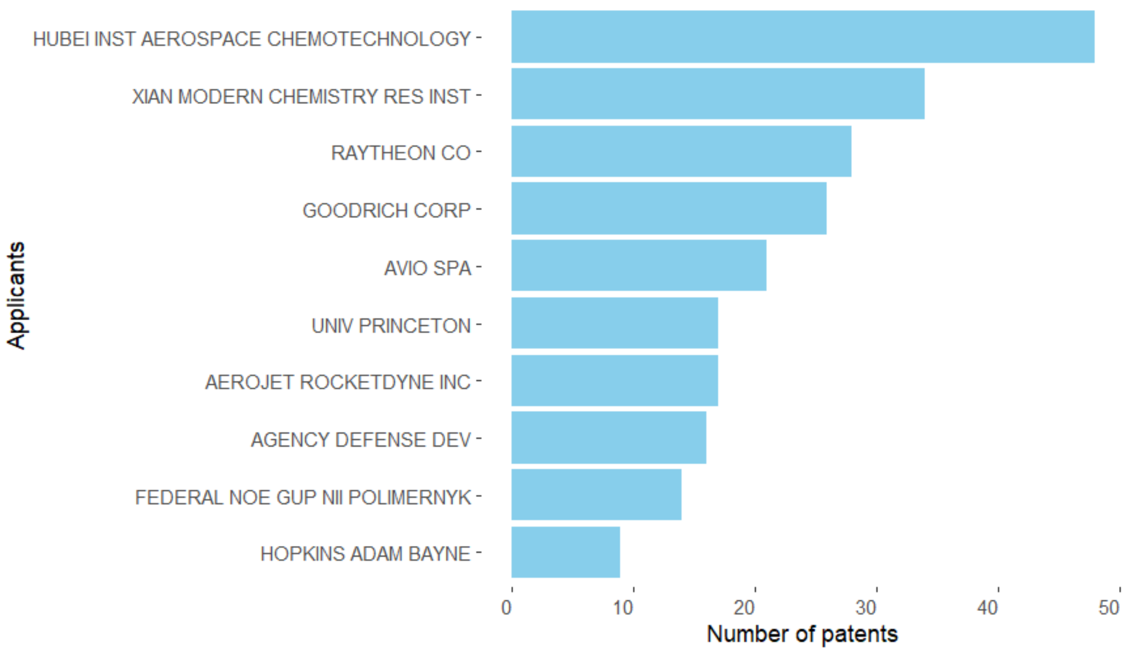

Figure 18 - Leading ten applicants in solid propellant patents

The following list provides a concise overview of the principal applicants, aiming to elucidate their geographic locations and primary areas of interest.

- **Hubei Institute of Aerospace Chemotechnology** (China): is an institute that focuses on research and development in the field of aerospace chemical technology.
- **Xian Modern Chemistry Research Institute** (China): A research institution focused on modern chemistry.
- **Raytheon Company** (USA): A major American defense and technology company.
- **Goodrich Corporation** (USA): An American aerospace and defense corporation.
- **Avio S.p.a**. (Italy): An Italian company specializing in aerospace and defense technology.
- **Aerojet Rocketdyne** (USA): A prominent American aerospace and defense technology firm.
- **Princeton University** (USA): renowned university and research institution.
- **Agency for Defense Development** (South Korea): National agency for research and development in defense technology.
- **Federal NOE GUP NII Polimernyk** (Russia): Federal state institution focused on polymer research.
- **Hopkins Adam Bayne**: Former researcher at the Princeton University

6.10.1 Applicant Profile Comparison: Companies and Institutes

The objective of this section is to delineate between private enterprises and public institutions among the applicants. These distinct categories inherently pursue divergent objectives due to the nature of their endeavors. Public institutions primarily engage in fundamental research, while private companies focus on commercial applications, albeit often conducting research to bolster their business operations. This differentiation yields valuable insights into the research orientation and utilization of patents.

To establish a pertinent and rational approach for distinguishing between applicants for positions within companies and research institutes or universities, we deemed it appropriate to categorize applicants based on the presence of keywords “INST” and “UNIV” within their names.

It's pertinent to note that an applicant can also represent an individual, and in our categorization, we'll amalgamate individual applicants with private companies.

Number of institutes	Number of companies
72	378

Table 22 - Applicants: Institute and Companies number

The data clearly demonstrates a substantial prevalence of corporate applicants, outnumbering research institutes by more than fivefold. This stark contrast underscores a pronounced inclination toward commercial applications within the patents being examined.

6.10.2 Applicants across technological domains

Applicants	Number of patents	Percentage
RAYTHEON CO	20	8.23
UNIV PRINCETON	17	7.00
AVIO SPA	16	6.58
AEROJET ROCKETDYNE INC	11	4.53
HOPKINS ADAM BAYNE	9	3.70
HUBEI INST AEROSPACE CHEMOTECHNOLOGY	7	2.88
CU AEROSPACE LLC	5	2.06
UTAH STATE UNIV SPACE DYNAMICS LABORATORY	5	2.06
LOCKHEED CORP	4	1.65
UNIFORMITY LABS INC	4	1.65

Table 23 - Leading ten applicants in Solid Propellant Patents that cite additive manufacturing technologies

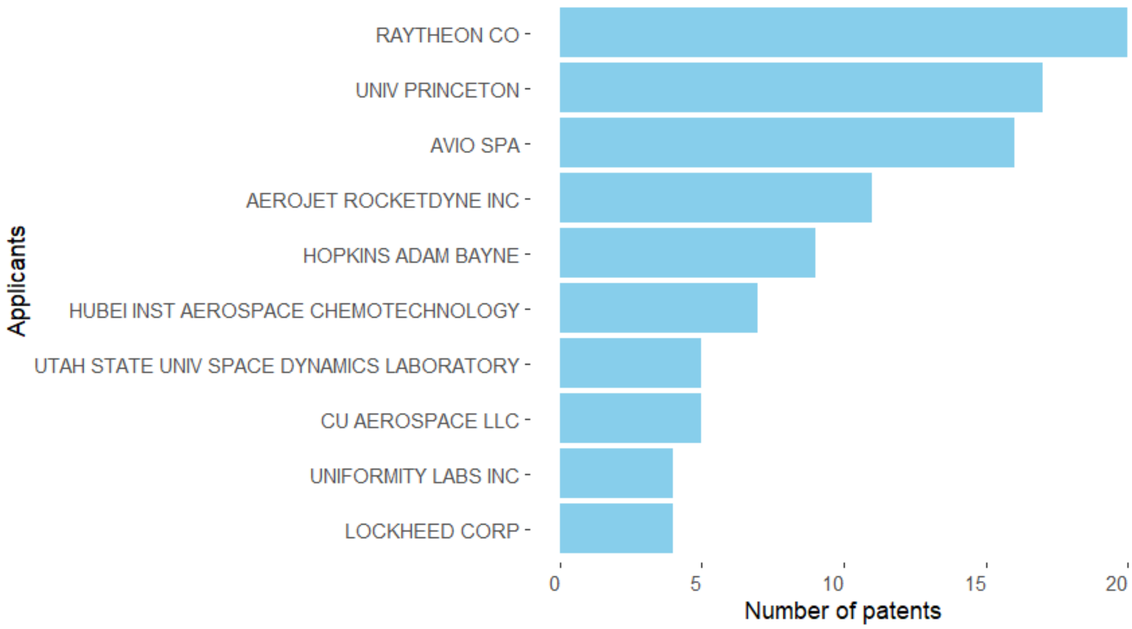

Figure 19 - Leading ten applicants in solid propellant patents that cite additive manufacturing technologies

In the subset of patents related to additive manufacturing, Company Raytheon emerges as the predominant innovator, maintaining a portion of the key innovators identified in the comprehensive dataset. Notably, there is an inclusion of four additional institutions and companies from the United States in the lower ranks of the list:

- **CU Aerospace LLC** (USA): An American aerospace company known for its aerospace technologies.
- **Utah State University Space Dynamics Laboratory** (USA): A research institution at Utah State University specializing in space-related research.
- **Lockheed Corporation** (USA): A renowned American aerospace and defense company.
- **Uniformity labs INC** (USA): company that focuses on research and development in the field of additive manufacturing. Hopkins Adam Bayne is the actual CEO of the company.

Applicants	Number of patents	Percentage
UNIV PRINCETON	9	7.63
UNIV NANJING SCIENCE & TECH	5	4.24
XIAN MODERN CHEMISTRY RES INST	5	4.24
HOPKINS ADAM BAYNE	4	3.39
N2 TOWERS INC	4	3.39
UNIV CENTRAL FLORIDA RES FOUND	4	3.39
UNIVERSAL PROPULSION CO	4	3.39
US ARMY	4	3.39
GOETZ GEORGE	3	2.54
HUBEI SANJIANG AEROSPACE JIANGHE CHEMICAL TECH CO LTD	3	2.54

Table 24 - Leading ten applicants in Solid Propellant Patents that cite Ligth based technologies

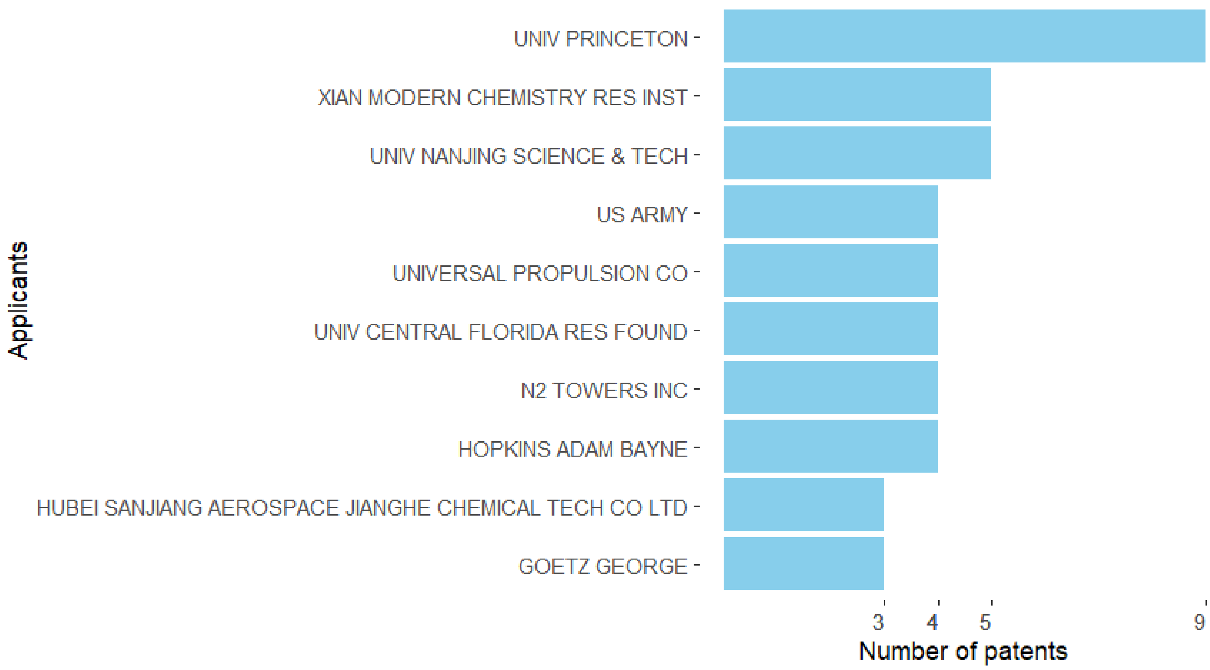

Figure 20 - Leading ten applicants in solid propellant patents that cite Ligth based technologies

In the subset of patents related to light-based technologies, Princeton University emerges as the primary innovator. Notably, this subset introduces the inclusion of several American and Chinese companies and research institutes that were not featured in the broader analysis.

Applicants	Number of patents	Percentage
HUBEI INST AEROSPACE CHEMOTECHNOLOGY	41	5.59
GOODRICH CORP	25	3.41
XIAN MODERN CHEMISTRY RES INST	24	3.27
RAYTHEON CO	20	2.73
AEROJET ROCKETDYNE INC	16	2.18
AGENCY DEFENSE DEV	15	2.05
HUBEI SANJIANG AEROSPACE JIANGHE CHEMICAL TECH CO LTD	8	1.09
SHANGHAI AVIATION CHEMICAL APPLICATION RES INSTITUTE	8	1.09
ORBITAL ATK INC	7	0.95
BEIJING INSTITUTE TECH	6	0.82

Table 25 - Leading ten applicants in Solid Propellant Patents that cite the curing phase

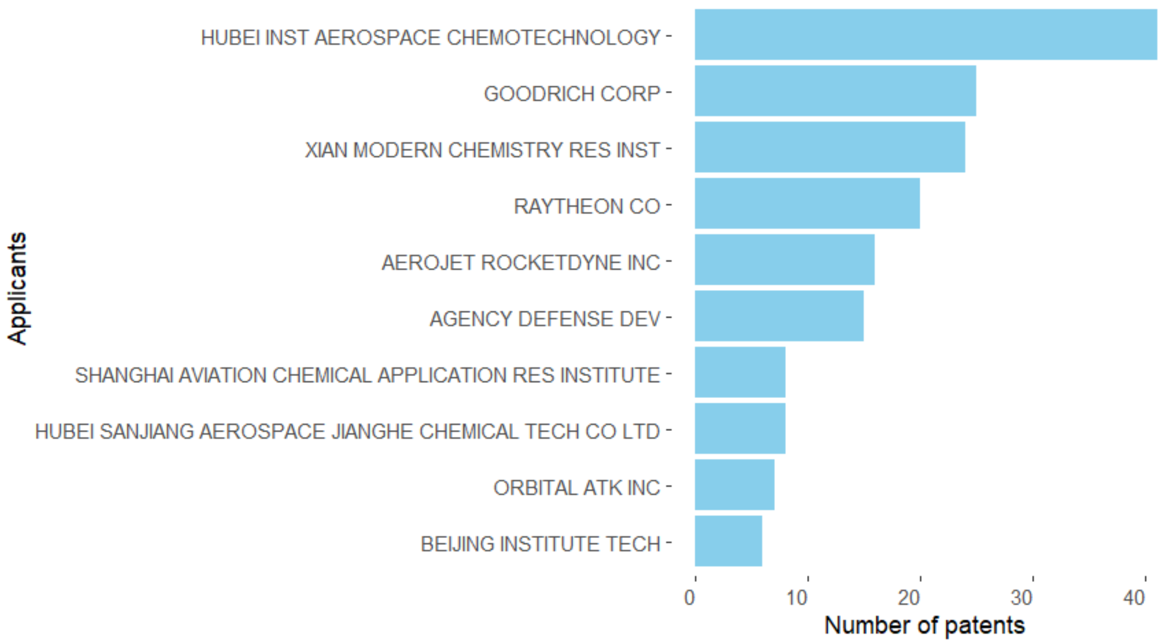

Figure 21 - Leading ten applicants in solid propellant patents that cite the curing phase

In the subset of patents related to curing technologies, the Hubei Institute of Aerospace Chemotechnology takes a prominent role as the major innovator. Notably, the top six positions feature companies and institutions that were initially identified during the analysis of the comprehensive dataset.

Applicants	Number of patents	Percentage
RAYTHEON CO	23	3.14
AEROJET ROCKETDYNE INC	10	1.36
FEDERAL NOE GUP NII POLIMERNYK	10	1.36
UNIV PRINCETON	9	1.23
HUBEI INST AEROSPACE CHEMOTECHNOLOGY	8	1.09
AGENCY DEFENSE DEV	7	0.95
XIAN MODERN CHEMISTRY RES INST	7	0.95
AVIO SPA	4	0.55
HOPKINS ADAM BAYNE	4	0.55
OLDEN THOMAS A	4	0.55

Table 26 - Leading ten applicants in Solid Propellant Patents that cite the casting phase

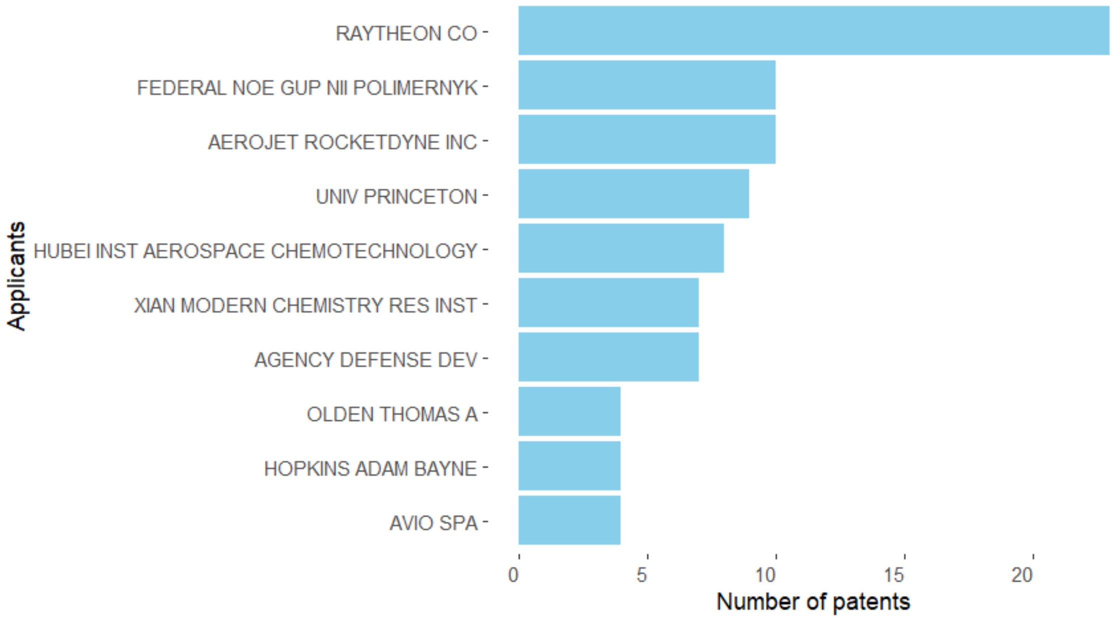

Figure 22 - Leading ten applicants in solid propellant patents that cite the casting phase

In the subset of patents related to casting technologies, Raytheon company emerges as the major innovator. Remarkably, in this context, nine out of the top ten companies remain consistent with those originally identified in the comprehensive database encompassing patents across various technology domains.

6.10.2 Solid Propellant Patent Portfolios: Weight of the Four Categories in Major Applicants

Our next step involves evaluating the extent to which the four technologies contribute to the overall composition of the solid propellant patent portfolio. It's essential to note that in conducting this analysis, we accounted for instances where patents belonged to multiple technology categories or had multiple applicants. In these situations the application was counted for both one technology and the other and also for all applicants listed

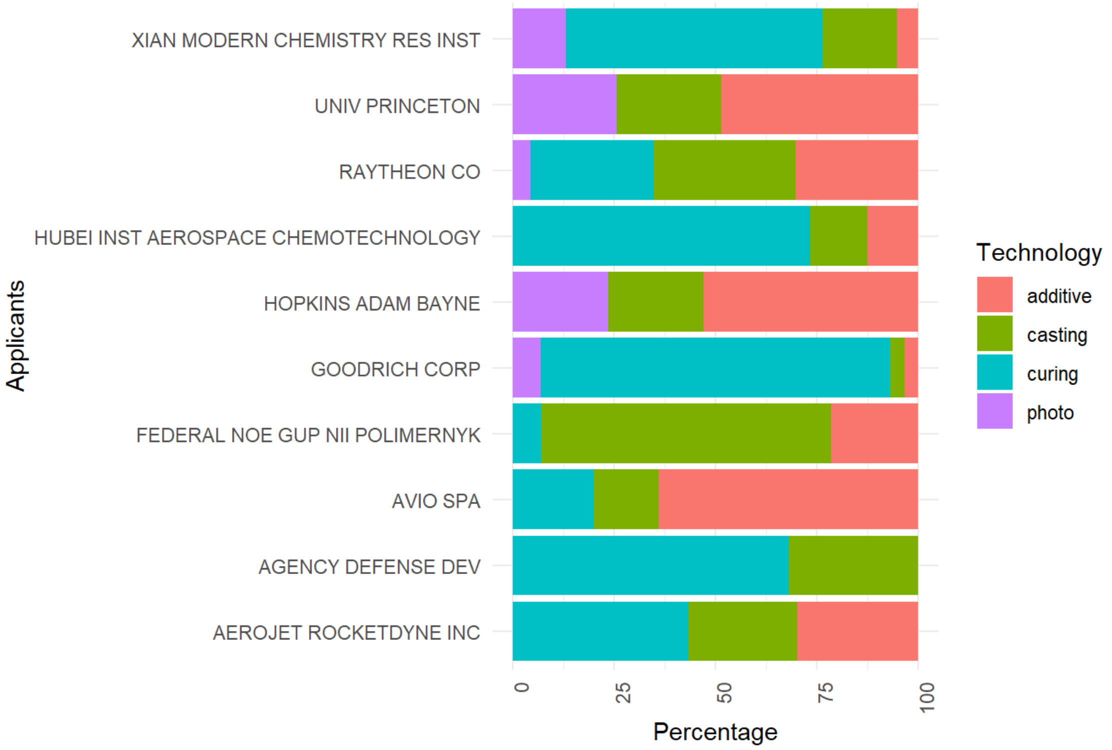

Figure 23 - Weight of the 4 categories within the solid propellant patent portfolios of the major applicants

The graph reveals the following insights:

- The majority of patents held by companies/institutes Hubei Institute of Aerospace Chemotechnology, Agency for Defense Development and Goodrich Corporation belong to the "curing" category, with no patents in this category attributed to the Princeton University and Mr. Hopkins Adam Bayne.
- Applicants showing the most pronounced emphasis on additive manufacturing are Avio and the Princeton University, whereas the Agency for Defense Development stands as the sole applicant not in possession of patents in this specific category.
- Every company maintains patents within their portfolios in the casting category. However, it's noteworthy that among the applicants, company Federal NOE GUP NII Polimernyk predominantly holds patents primarily related to this specific technology.
- Patents related to light-based technologies typically constitute a relatively modest proportion, being present in only half of the major applicants' patent portfolios. Notably, among these ten applicants, the Princeton University has filed the highest number of patents in this category.

6.10.3 Patent legal status of leading applicants

It might be of interest to conduct an analysis of the legal status of patents pertaining to solid propellants for the top 10 applicants. In this examination, we took into account patent applications that involved multiple applicants, as previously discussed. It's important to reiterate that the observations made regarding duplicated instances hold true in this context as well.

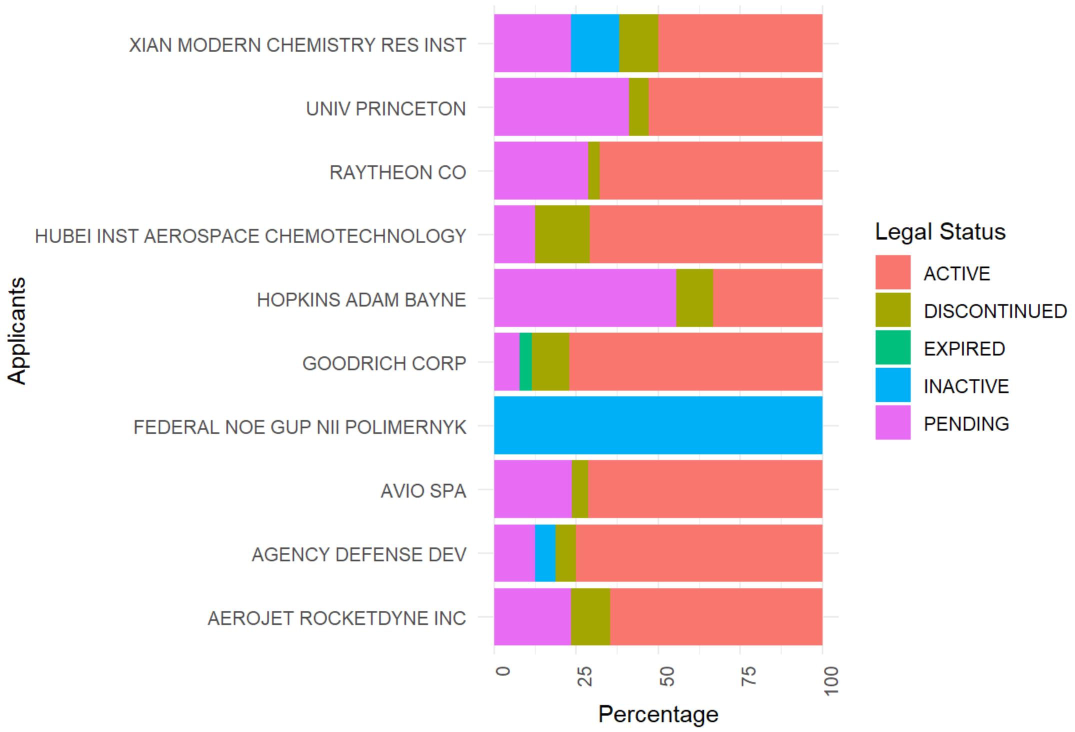

Figure 24 - Patent legal status of the ten leading applicants

The graph reveals the following insights:

- In the case of 8 out of 10 applicants, the predominant portion of their patents remains in an active status.
- For Applicant **Federal NOE GUP NII Polimernyk**, all patents related to solid propellants have lapsed into an inactive state.
- It is noteworthy that a substantial portion of Mr. **Hopkins**' patents are currently undergoing the evaluation process.

6.11 Patent Quality Estimation

Following our quantitative analysis, it is imperative to allocate a segment of our study to qualitative examination. In the academic literature, the quality of patents is frequently assessed through the quantity of citations they receive in other patents, commonly known as “forward citations.” This metric is accessible in our dataset through the “cited_by_patent_count” column. However, when examined in isolation, this metric can be somewhat misleading as it does not account for the patent’s age. Older patents naturally have had more time to accumulate citations. To rectify this distortion, we will normalize the forward citation count by considering the age of the patent.

This normalization process aims to provide a fairer assessment of a patent’s quality, accounting for its age in the analysis.

The following formula is employed to derive the quality value, as elucidated previously:

$$Patent\ quality = \frac{cited\ by\ patent\ count}{patent\ age}$$

Where the patent age is calculated as:

$$patent\ age = 2023 - earliest\ priority\ year$$

In the process of calculation, it is pertinent to acknowledge instances where patents with the earliest priority year of 2023 were encountered. It is worth noting that such occurrences could potentially lead to divisions by zero within our formula. However, patents falling within this category exhibited forward patents of 0. Hence, a decision was made to exclude these patents from the aforementioned calculation by directly assigning them a quality value of zero.

Once we have established this normalized indicator, our objective is to identify the applicants with the highest average quality of patents. In order to discern the companies / institutes that have made a more substantial and impactful contribution to the advancement of the state of the art in this particular domain. This will be accomplished by computing the arithmetic average of the previously calculated patent quality for each applicant.

Applicants	Average Quality	Number of patents
GEOTEC INC	3.04	1
ROHRBAUGH ERIC M.	2.6	1
WHITE JEFFREY M.	2.6	1
UNIV TSINGHUA	2.08	1
MCGEHEE DONALD C	2	1
BECKSTED JR ALBERT MICHAEL	1.89	1
BUCKNER STEVEN WAYNE	1.89	1
CHUNG STEPHEN	1.89	1
JELLISS PAUL	1.89	1
LAKTAS JACOB M	1.89	1

Table 27 - Leading ten applicants in Solid Propellant Patents per average quality

Upon initial examination, it is readily apparent that none of the applicants highlighted in the preceding analyses are featured in the current dataset. Furthermore, it is noteworthy that all entities presented in the table have only a solitary patent application to their name. This observation leads to the inference that these entities are organizations or research institutions that have concentrated their efforts on a specific innovation type, which subsequently garnered recognition within the relevant industry or field of application.

The enterprise exhibiting the most elevated value for this particular index is Geotec Inc, a firm specializing in delivering well treatments for the oil and gas industry. Notably, the company lodged a patent application 23 years ago, and this patent has garnered substantial attention in the form of 70 citations.

The second and third applicants are two individuals who jointly submitted a patent application for a rocket propulsion system. This patent has amassed 52 citations over the course of its 20-year existence.

In any case, to achieve a more comprehensive perspective and account for companies that exhibit a higher frequency of innovation in this domain, we have opted to temporarily exclude entities that have submitted only one patent application in the current millennium. The ensuing table provides a summary of this filtered dataset.

Applicants	Average Quality	Number of patents
UNIV NORTHWESTERN POLYTECHNIC	1.56	2
GRIX CHARLES	1.49	3
KATZAKIAN ARTHUR	1.49	3
SOTEREANOS GEORGE	1.42	2
SOTEREANOS NICHOLAS	1.42	2
DIGITAL SOLID STATE PROPULSION LLC	1.29	5
KRISHNAN VINU B	1.27	3
CHENGDU AONENGPU TECHNOLOGY CO LTD	1.15	2
UNIV SHANDONG	1.08	2
UNIV NANJING SCI & TECH	1.00	4

Table 28 - Leading ten applicants in Solid Propellant Patents per average quality that have filed more than one patent

Once more, within this context, even though we have excluded applicants with only a single patent application, we observe that the count of patents filed by these applicants remains relatively modest, ranging from 2 to 5.

6.11.1 Quality temporal trend

Our investigation also aimed to analyze the evolution of patent quality over time. In the table presented, the most significant values are displayed, with the year 2008 positioned at the top. The line graph depicting these findings illustrates that there is no discernible overarching trend, with increases and declines occurring intermittently across the given time period.

Earliest Priority Date Year	Average Quality
2008	0.56
2017	0.47
2018	0.45
2013	0.44
2000	0.43
2014	0.42
2005	0.40
2006	0.39
2003	0.36
2001	0.34

Table 29 - Top ten years for average patent quality on solid propellants

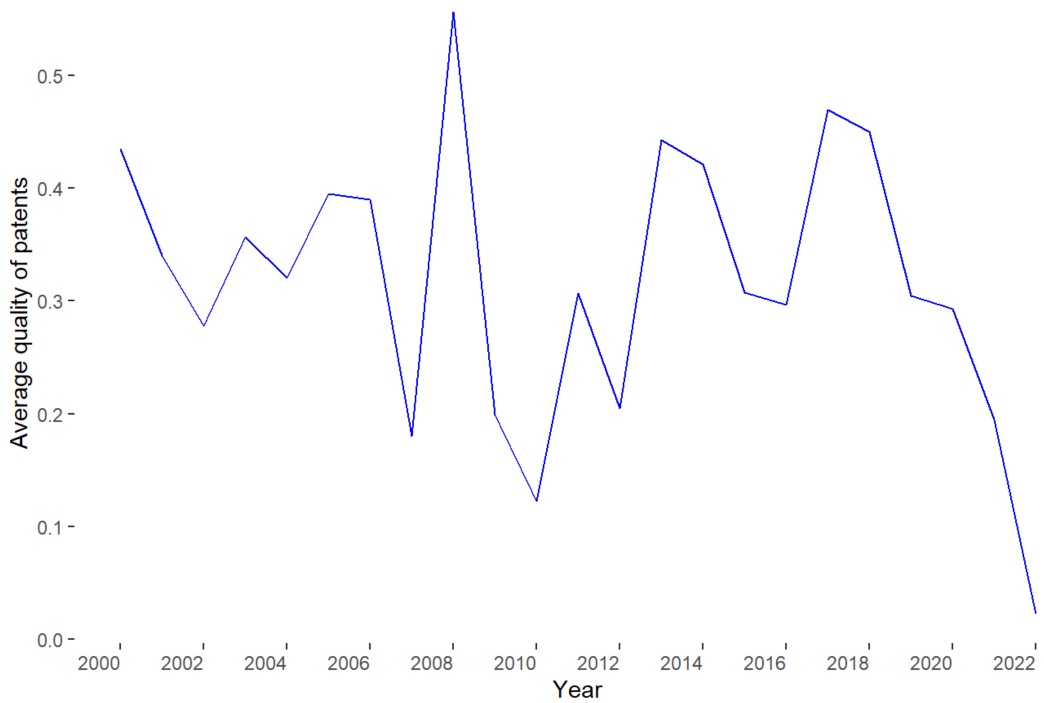

Figure 25 - Patent quality trend over the time (2000-2022)

6.12 Main applicants Patent Portfolio

The primary objective of this section is to assess the significance of patents related to solid propellants within the overall patent portfolio of the major applicants. Our aim is to gain insight into how much importance this technology area holds in comparison to other research domains within the companies under consideration. Subsequently, we aim to pinpoint the principal area of interest by analysing the most frequently occurring patent classification codes within the portfolio.

To achieve this, we initially imported new datasets into our working environment by extracting all filed patents for each of the principal applicants from The Lens. Then, we meticulously analysed each dataset, tailoring the processing to extract specific desired information.

applicants	Solid propellant patents	All patents in portfolio	Solid propellant patents %
HOPKINS ADAM BAYNE	9	13	69.23
FEDERAL NOE GUP NII POLIMERNYK	14	183	7.65
HUBEI INST AEROSPACE CHEMOTECHNOLOGY	48	754	6.37
AVIO SPA	21	367	5.72
AEROJET ROCKETDYNE INC	17	372	4.57
XIAN MODERN CHEMISTRY RES INST	34	2289	1.49
GOODRICH CORP	26	7807	0.33
UNIV PRINCETON	17	5330	0.32
AGENCY DEFENSE DEV	16	7394	0.22
RAYTHEON CO	28	36428	0.08

Table 30 - Weight of patents on solid propellants in the total patent portfolio for top ten applicants

A first observation reveals a significantly higher percentage for Mr. **Hopkins**, which is not surprising because as a natural person and not a company he will focus his attention on research in that specific technological domain. Therefore, we will not take Mr **Hopkins** into consideration. We only consider institutes and companies which, given their size and complexity, will carry out research in multiple areas. Hence, a percentage between 4% and 8% should be considered significant for these applicants. This percentage range is reached by the following four companies, where the use of solid propellants evidently constitutes a strategic pillar:

- Federal NOE GUP NII Polimernyk;
- Hubei Institute of Aerospace Chemotechnology;
- Avio S.p.a.;
- Aerojet Rocketdyne.

The subsequent phase involves a holistic assessment of the collective portfolio belonging to the top 10 applicants. This evaluation aims to identify the predominant application domains by examining the primary IPC (International Patent Classification) codes recurring in their filed patents. Presented below are the most frequently occurring codes for each applicant.

IPC Codes	Number of patents
C06D5/06	78
C06B23/00	74
C06B21/00	58
C06B33/06	46
C06B33/12	38
C06D5/00	34
C08K3/22	24
C06B33/08	23
C06B33/14	22
C06B45/10	20

Tabla 31 - Most frequent IPC codes within Hubei Institute of Aerospace Chemotechnology patent portfolio

IPC Codes	Number of patents
C06B21/00	130
C07C21/18	121
C06B23/00	107
C06B25/34	77
C07C17/25	74
G01N33/22	70
C07C17/20	60
C06D5/00	54
G01N25/54	45
C09K11/06	41

Table 32 - Most frequent IPC codes within Xian Modern Chemistry Research Institute patent portfolio

IPC Codes	Number of patents
H01Q21/00	888
H01Q3/26	733
H01Q21/06	716
F41G7/22	532
G01S7/02	514
H04N5/33	456
H05K7/20	432
H01Q1/42	413
G01S7/40	387
H05K1/02	374

Table 33 - Most frequent IPC codes within Raytheon Company patent portfolio

IPC Codes	Number of patents
B64D25/14	642
B60T8/17	514
B64D9/00	458
B64C25/42	361
B64D15/12	334
F16D55/36	306
B64C25/60	295
F16D65/12	255
B64C25/44	251
B60T17/22	204

Table 34 - Most frequent IPC codes within Goodrich Corporation patent portfolio

IPC Codes	Number of patents
F02K9/34	35
F01D17/16	27
H02K1/18	22
H02K7/18	20
H02K16/04	18
F01D5/18	17
F02K9/10	17
F02K9/86	17
F16H1/28	17
H02K1/27	16

Table 35 - Most frequent IPC codes within Avio S.p.a. patent portfolio

IPC Codes	Number of patents
B64G1/40	38
F02K9/97	31
F03H1/00	28
F02K9/52	23
C06B45/10	20
F02K9/48	20
B64G1/42	19
F02K9/80	14
F02K9/12	13
F02K9/58	13

Table 36 - Most frequent IPC codes within Aerojet Rocketdyne patent portfolio

IPC Codes	Number of patents
H01L51/00	740
H01L51/30	564
H01L51/50	541
C09K11/06	378
H01L51/42	370
A61P35/00	321
H01L51/52	224
C12Q1/68	212
H05B33/14	208
H05B33/10	201

Table 37 - Most frequent IPC codes within Princeton University patent portfolio

IPC Codes	Number of patents
F42B15/01	111
G06N3/08	101
G05D1/02	94
H04L29/06	82
G01S7/40	81
H01M6/36	78
G01S13/88	71
G01S7/38	68
B64C39/02	65
F41F3/04	64

Table 38 - Most frequent IPC codes within Agency for Defense Development patent portfolio

IPC Codes	Number of patents
C06B21/00	61
C06D5/06	17
C06D5/00	12
F02K9/10	11
F02K9/95	8
F02K9/36	7
C06B25/24	6
C08L63/02	6
G01G13/04	6
C06B29/22	5

Table 39 - Most frequent IPC codes within Federal NOE GUP NII Polimernyk patent portfolio

IPC Codes	Number of patents
B22F1/065	13
B22F1/052	12
B29C67/00	6
B22F3/105	5
C04B20/00	5
C04B35/56	5
C01B33/04	4
C22C1/04	3
C22C1/08	3
C22C29/08	3

Table 40 - Most frequent IPC codes within Hopkins Adam Bayne patent portfolio

Below, we provide an overview of the findings for each applicant.

1. **Hubei Institute of Aerospace Chemotechnology**: The majority of the groups are categorized under Group C (chemistry and metallurgy), which aligns with our expectations for an institute specializing in research on chemicals applied in aerospace. Furthermore, a notable proportion of classification codes align with those commonly identified in patents related to solid propellants.
2. **Xian Modern Chemistry Research Institute**: In this instance as well, the preponderance of groups is situated within the Chemistry and Metallurgy category (Group C), which is consistent with our expectations. However, it is noteworthy that there are two additional classification codes falling under the G01N group: “Investigating or Analysing Materials by Determining Their Chemical or Physical Properties”. These codes are not commonly encountered in patents related to solid propellants.
3. **Raytheon Company**: In this context, a distinct contrast emerges in the areas of relevance when compared to the solid propellant patents. It is evident that the company places a greater emphasis on technologies falling within the Electricity category (H).
4. **Goodrich Corporation**: In this context, the dominant technological domains diverge from the ones observed in patents related to solid propellants. Instead, the predominant classification codes are associated with the B60 and B64 classes, which pertain to the fields of vehicles and aircraft. This alignment with aerospace-related sectors is consistent with the nature of the company’s operations in the aerospace industry.
5. **Avio S.p.a.**: In this context, the predominant technological domains exhibit subtle deviations from those identified in the patents related to solid propellants. While we do encounter the F02K9/34 code, which featured prominently in patents concerning solid propellants, it is noteworthy that Avio demonstrates a heightened emphasis on classification codes within the F02 category. Furthermore, Avio’s patent portfolio extends its focus to the F01 category, indicating innovation in engine-related technologies, and to some extent, the realm of electric power generation (H02).
6. **Aerojet Rocketdyne**: For this particular company, its primary technological focus exhibits some subtle parallels with domains commonly associated with solid propellants. Notably, the presence of the code C06B45/10, the sole category C entry among this company's most prevalent codes, mirrors its frequency in patents linked to solid propellants. Additionally, echoing the trend seen in solid propellant patents, the company's patent portfolio prominently encompasses the F02 class, pertaining to combustion engines. Moreover, Aerojet demonstrates a considerable emphasis on patents related to cosmonautical vehicles (B64G1), aligning strategically with its core business within the aerospace industry.
7. **Princeton University**: In the case of this university, a notable absence of shared classification codes emerges when comparing the prevalent codes typically associated with solid propellants and those predominantly found within the university’s patent portfolio. Evidently, their focus mainly centres on the innovation of electrical components, marking a distinctive strategic orientation in their research and development endeavours.
8. **Agency for Defense Development**: Even within this company, the prevailing classification codes starkly diverge from the customary codes encountered in regulations pertaining to solid propellants.
9. **Federal NOE GUP NII Polimernyk**: For this institution, we observe classification codes closely resembling those associated with solid propellants, primarily falling within the C06 and F02 categories.
10. **Hopkins Adam Bayne**: The patents codes differ from the commonly prevalent ones in solid propellant patents. However, it is noteworthy that there are still

instances of codes within category C, indicating a partial alignment with the field of solid propellants.

7.Market Analysis

In conjunction with the patent landscape report, a concurrent market analysis was conducted, to evaluate the real-world industrial application and economic market penetration of the innovative manufacturing method pioneered by the Politecnico di Milano and Politecnico di Torino. The primary emphasis of this paper is maintained on the patent landscape report. However, the subsequent section will concisely present and analyze the outcomes of the concurrently conducted market analysis. These market findings will be juxtaposed and evaluated in light of the insights gleaned from the patent landscape report.

To enhance comprehension of the rationale underpinning the obtained results, it is imperative to provide a succinct overview of the methodology employed to ascertain the market size in monetary terms.

7.1 TAM SAM SOM

The TAM SAM SOM analysis is a crucial methodology employed to evaluate the economic potential of a technology and assess the viability of a potential start-up. This analysis method assesses the economic potential of a technology by evaluating three key market indicators:

TAM (Total Addressable Market): Represents the total market demand without any limitations. It provides an estimate of the maximum revenue a business idea can generate assuming no constraints in geography, price, or distribution. TAM estimation is crucial for potential investors as it provides an insight into the maximum revenue potential a business idea can achieve within a specific market. Essentially, TAM reflects the maximum growth potential within a market segment, indicating its scalability in the long term. Investors generally favour larger TAMs, which suggest significant market opportunities and potential for scalability. However, a high TAM may also attract intense competition, while a smaller TAM might indicate a less attractive market with fewer competitors. TAM can be calculated using two primary approaches:

- **Top-down approach:** Relies on industry research and reports from national agencies, independent organizations, or consulting firms. For instance, they can be used to estimate the total turnover of all firms in the target market or all the customers potentially available, after having applied logical assumptions to eliminate irrelevant segments.
- **Bottom-up approach:** Considered more reliable as it is based on primary market research. This method estimates potential turnover by multiplying quantities sold by the sales price within a specific timeframe.

SAM (Serviceable Addressable Market): SAM is a subset of TAM and represents the portion of the market that a company can realistically target and serve. SAM identifies the demand for a specific product within reach, pinpointing concrete market opportunities and projecting the upward potential for a particular business in the future. In the medium term, SAM delineates the share of revenues that can be realistically obtained, offering a nuanced understanding of the niche market.

SOM (Serviceable and Obtainable Market): SOM is a more refined subset within the Served Available Market (SAM), specifically denoting the segment of the market that a company can realistically capture or obtain. In essence, SOM represents the portion of the market where the organization can practically make inroads. The calculation of

SOM takes into consideration critical factors, including the company's market share, the competitive landscape, and the efficacy of its marketing and sales strategies. By focusing on SOM, companies gain a pragmatic understanding of their immediate market potential, enabling informed decision-making and strategic resource allocation based on the company's capabilities and market dynamics.

7.2 Market Analysis Results

The investigation encompassed a comprehensive analysis of three primary markets: launchers, airbags, and fire extinguishers. Patent examination highlighted the pre-eminence of solid propellants in propulsion system, particularly within the aerospace industry. The subsequent market analysis reaffirmed this observation, designating the launcher market as the most pertinent sector for the considered technology. The assessment was derived from an examination of launch activities, referencing data provided by the European Space Policy Institute (ESPI), an international organization established by the European Space Agency (ESA), as outlined in their Yearbooks. The presence of Avio S.p.a., a significant applicant identified in the patent landscape report, among the engine manufacturers for these rockets is noteworthy. This underscores the relevance of Avio within the analyzed field, further emphasizing the company's standing and influence in the use of solid propellant in the aerospace industry.

The ensuing table encapsulates the launcher market estimates, based on previously executed launches:

	2023	2022	2021
TAM	$ 39.022.351	$ 69.139.994	$ 40.408.117
SAM	$ 17.854.203	$ 54.931.414	$ 29.807.298
SOM	$ 2.762.718	$ 8.499.960	$ 4.612.312

Tabla 41 - TAM-SAM-SOM of composite solid propellants in space rockets

In the other two markets, market penetration is quite limited. Firstly, with regard to the use of solid propellants for the explosion of airbags, although the state of the art in airbag inflator technology envisages the use of solid propellants, it does not currently envisage the use of composite propellants (B. P. Mason & C. M. Roland, 2019), so there is a need for R&D and, above all, intensive testing, given the growing attention to safety issues and the numerous tests that cars have to pass to be considered reliable. It should also be borne in mind that the development of technologies in the field of automotive safety is increasingly geared towards improving active prevention and protection systems, whereby great attention is being paid to sensors and the automatic activation of the braking system, while in addition to the development of new types of airbags, hybrid inflators and automatic airbag activation technologies, intelligent and dual-stage airbags, which use compressed gas in addition to pyrotechnic material, are now widespread. This indicates that research in the field of propellants used for gas generation in airbag inflators seems to have reached an established technological standard.

To account for this scenario, initial years were characterized by a deliberate choice of zero penetration percentages, followed by gradual and slight increases in subsequent years (1%, 1.5%, 2%). The ensuing table presents the outcomes of this approach:

	2024	2025	2026	2027	2028
TAM	$ 1.097.516.893	$ 1.113.973.899	$ 11.384.878.101	$ 11.664.786.880	$ 11.771.566.704
SAM	$ 1.116.406.524	$ 1.153.085.779	$ 1.108.388.491	$ 1.134.840.030	$ 1.142.510.606
SOM	-	-	$ 11.083.885	$ $17.022.600	$ 22.850.212

Table 42 - TAM-SAM-SOM of solid propellants in airbags inflators

Regarding the fire extinguisher market, certain observations come to light. The activation technologies employed in fire extinguishers predominantly leverage CO_2 and inert gases as primary agents. Recent years have not witnessed significant developments in this domain, as the most advanced technologies are deemed highly effective and reliable, having attained optimal safety standards.

Moreover, a preliminary market and customer validation analysis have identified uncertainties regarding the practical application of the presented technology in the industry. Interviews conducted with engineers and managers of leading fire extinguisher companies in Italy revealed a current lack of intent to integrate solid propellants into fire protection systems.

In this sector, the utilization of intellectual property rights is generally constrained. The discouragement of patent use stems from the necessity for products in this industry, within the specified geographic reference market, to obtain approval from the Italian Ministry. Specifically, adherence to the PED DIRECTIVE (Pressure Equipment Directive) 2014/68/EU of the European Parliament is required. This directive regulates "pressure equipment and assemblies which are new on the Union market at the time of their placing on the market."

Based on the aforementioned considerations, it can be confidently inferred that market penetration is anticipated to remain negligible during the initial two years of assessment. Consequently, this circumstance has prompted the formulation of two distinct scenarios:

- **Worst-case scenario**: Solid composite propellants are unlikely to find practical application in fire extinguishers, resulting in a sustained SOM of 0% throughout the entire evaluation period.
- **Best-case scenario**: The technology has the potential to usher in a disruptive innovation within the specified timeframe. Accordingly, a conservative market penetration estimates of 0% is assumed for the initial 2 years, gradually increasing to a threshold of 3% by the year 2028.

The table below provides quantitative estimates for the best-case scenario:

	2024	2025	2026	2027	2028
SAM	$ 330.523.847	$ 356.701.336	$384.952.082	$ 415.440.287	$ 448.343.157
Market Index	0%	0%	1%	2%	3%
SOM	$ 0,00	$ 0,00	$ 3.849.520	$ 8.308.805	$ 13.450.294

Table 43 - TAM-SAM-SOM of composite solid propellants in fire extinguishers in the best-case scenario

In summary, the results of the market analysis largely correspond with the findings of the patent landscape report, which did not identify any additional areas of interest beyond the aerospace industry application. Indeed, the market analysis conducted in alternative application areas yielded near-zero or negligible market penetration estimates in the short term.

8. Conclusions

The patent analysis has offered a comprehensive overview of the contemporary landscape in solid propellant production. Notably, it is imperative to underscore a discernible surge in the submission of technologies associated with this field, as evidenced by the temporal trend in the quantity of filed patents. This upward trajectory implies a notable upswing in innovation within the realm of solid propellant production.

The analysis of IPC codes unequivocally pinpointed the predominant technical subject, specifically centered around combustion engines and explosion generation to facilitate propulsion thrust. Consequently, the utilization of solid propellants in missiles and launchers emerges as the most compelling area of interest, likely possessing significant economic implications. This assertion is further supported by the parallel market analysis conducted, which identifies the launcher market as the most stable and promising domain for the application of the technology, in comparison to the airbags and extinguisher markets. Hence, considering the utilization of Patent “Photo-polymerization for additive manufacturing of composite solid propellants" within the market appears judicious. Initiating exploration from this sector, characterized by a comprehensive and steadfast chronological evolution within the state of the art, presents a prudent approach. Notably, in our specific scenario, it's crucial to highlight the presence of Avio S.p.a., an Italian company situated in the same geographical domain where the patent originated. Avio possesses a substantial portfolio of patents associated with this technology, representing an accessible and pivotal starting point for evaluating potential applications within the market.

In this context, it's noteworthy to emphasize that, from a geographical standpoint, the jurisdictions where protection has been sought for the highest number of patents are the two reigning global economic powerhouses: China and the USA, both ranking as the top two countries by GDP. This reaffirms the economic significance of this research domain, further highlighted by the notably higher representation of companies compared to universities or research institutes among the applicants.

The extracted information highlights a scarcity of patents referencing technologies that incorporate light in the production process of solid propellants. This characteristic is pivotal in the new method jointly developed by the Politecnico di Torino and the Politecnico di Milano, signifying the novelty and underdeveloped nature of such technologies in this realm. Notably, among the applicants, Princeton University emerges as the institution with the most references to the utilization of phototechnologies. Therefore, it is recommended to establish contact with this university, along with Hopkins Adam Bayne, a former researcher at the university whose patents testify to a strong interest in solid propellant technologies, and Uniformity Labs, the company of which he currently serves as CEO.

The proposed final step involves amalgamating the insights gleaned from this study with the forthcoming information obtained through strategic contacts, aiming to tactfully approach the market. By integrating data from key industry players, major innovators, and the wealth of information garnered from patents, we aim to construct a comprehensive and expansive understanding of the landscape. The proposed strategy advocates adopting a business model centered on patent licenses or collaborative partnerships with aerospace companies, given that the aerospace sector represents the predominant application domain. The focus would be on collaborating with manufacturers of solid-propellant rocket engines to seamlessly integrate the novel solid-propellant manufacturing method. Concurrently, the provision of technical expertise and support would be extended.

Such synergistic endeavors hold promise for both the technology's dissemination in the market and the involved companies, fostering a mutually advantageous scenario. Indeed, the innovative technology can serve as a catalyst in addressing the paramount challenges confronting the space launcher segment within the space economy, namely, the imperative to minimize costs per launch (including costs per kilogram of payload) and augment the flexibility of production lines.

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