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Market research for a cutting-edge composite solid propellant

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INDEX

Introduction

The objective of the present thesis is to study potential applications of an innovative production method of composite solid propellants developed by researchers of Polytechnic of Turin for which a patent titled "Photo-polymerization for additive manufacturing of composite solid propellants" was granted.

Solid propellants represent pivotal constituents of propulsion systems of rockets and missiles, implemented as gas generators necessary to produce the thrust required at liftoff and in the first phases of the ascent.
The market research is aimed at providing an estimate of the market size of this sector and at corroborating if different exploitations of composite solid propellants are conceivable. Thus, the market sizing of solid propellants employed in other industrial applications was also carried out, specifically in airbag's inflation system and fire extinguishers, through a TAM SAM SOM analysis, one of the most common methods to define the economic potential of new start-ups.

Subsequent chapters will provide a comprehensive contextual understanding of solid propellants technology by outlining the different stages within the production process and will define the general methodology implemented for the market research, while the detailed process pursued will be described in the proper paragraphs: for each market segment the TAM SAM SOM analysis was performed, adopting different approaches in order to adapt to the different types of sources available, and the most important players in each segment were identified.

Finally, in the final paragraph the outcomes gathered from the respective analyses will be synthesized, spotlighting the insights and trying to suggest a plausible initial go-to-market strategy.

1. State of the Art

1.1 Solid Propellant

Solid propellants are energetic materials designed to generate high-temperature gaseous byproducts upon combustion, thereby allowing the creation of thrust, essential to rocket propulsion.
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: 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 behavior 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.

1.2 Benefits and Drawbacks

Solid propellants are frequently lauded for their ease of storage and handling, a trait attributed for 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 necessary 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, the combustion of solid propellants cannot be controlled or interrupted. 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 enabled 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.

1.3 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.
- 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. Hydroxyl-terminated polybutadiene (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, the prevalent method employed for its creation will be henceforth presented. 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 powder 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 casted into a mold 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 been 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 summarizes the process described above:

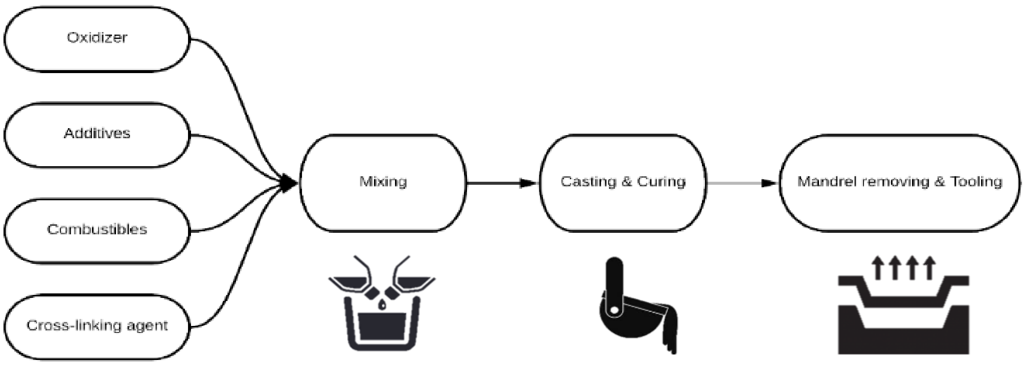

Figure 1 - Conventional solid propellant production process (Garino et al, 2022)

1.4 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).

1.5 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 the 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, 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.

Additional constraints arise from the traditional, time-consuming casting and curing procedures, which are inherently restricted in their adaptability to a limited spectrum of grain 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.

1.6 Remedies within the new Approach

The recently patented method 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 eluded 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 crucial for fine-tuning grain performance but also widens the applicability of the product. 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 andgrain finishing	Critical phase due to associated risks (grain damage) and unintended triggering	Elimination of spindlesby continuous deposition
Casting and curingprocess	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

2. Market Research Methodology

2.1 TAM SAM SOM Analysis

Market analysis is an assessment of the economic, social, and technological conditions in which a company operates, its main objective is to gain a thorough understanding of the target market, evaluating the trends and dynamics that influence it.
To assess the economic potential of the technology introduced the procedure chosen was the TAM SAM SOM analysis, implemented to estimate the size, on monetary terms, of three viable markets where it could be applied. The main objective is to preliminarily verify the economic feasibility of a conceivable start-up, estimate its actual growth possibilities, and identify the main players in the markets, potential customers or partners in the development of the technology.

Tam Sam and Som are indicators used to define and measure the target market areas in which a start-up aims to enter. Specifically, these are used to make an estimate of:
- market size,
- potential of its product or service in a given market,
- profit that can be generated

Tam Sam Som can be calculated either in units (thus in terms of number of potential customers) or in monetary value: henceforth, this latter viewpoint will be considered so the estimate obtained will determine the economic value of the markets.

- TAM (Total Addressable Market) refers to the total market demand for a product or a service, it’s the total available market assuming there are no limitations on factors such as geography, price, or distribution. TAM has high relevance because it helps potential investors to estimate the size of a market segment, which is the maximum revenue a business idea can generate by selling a service or a product in a specific market: potentially, if a company were to be present in every country and had no competition it would generate TAM as revenues. Moreover, since it represents the maximum possible growth in that segment, it reflects the market potential because it provides an idea of how scalable that market is in the long term.

Generally, investors tend to prefer a total market that is as large as possible: a particularly high TAM might indicate a market with great potential to be scaled and therefore a great opportunity to make profits, but at the same time it might also attract a large number of competitors, whereas if the total market turns out to be smaller in size, there will be less competition but that might be an indicator of a less attractive market.

Two main approaches can be adopted to calculate TAM, top-down or bottom-up:

- The top-down approach uses industry research and reports conducted by national agencies, independent organizations, or private consulting firms, to estimate, for example, 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
- The bottom-up approach is considered to be more reliable because it is based on primary market research. It is estimated by calculating the potential turnover by multiplying the quantities sold by the sales price, considering a specific time frame.

Both approaches will be used subsequently, depending on the availability and reliability of the sources found.

- SAM (Served Available Market) – a skimming of the TAM, it is the potentially available market based on the specific characteristics of the business; it represents the demand for that type of product within reach, so it identifies the existing concrete market opportunity, and the upside potential of a specific business in the future. SAM determines the share of revenues that can be obtained in the medium-term and it gives a more defined context of the niche market by differentiating the customer segment based on geography, demographics, technology, with a focus on the company's specific product.

- SOM (Serviceable and Obtainable Market) - Represents a portion of the SAM, it is the market that is realistically obtainable and the target that the organization proposes to satisfy in the short term. The calculation of SOM allows to understand the revenue that is actually achievable considering the current resources at disposal and the prevailing environment and is thus circumscribed by the limitations of the organization’s business model. To calculate SOM several factors must be consider, including production capacity, existing competition, and marketing and sales strategies.

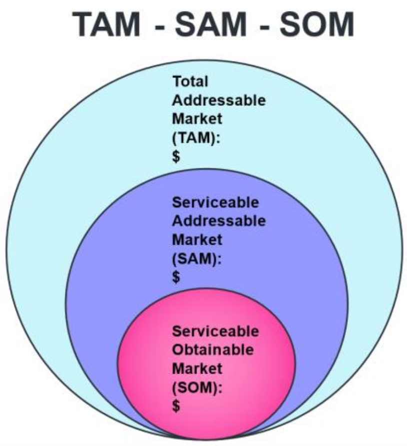

Fig. 2.1 – A visual representation of the connection between TAM-SAM-SOM

Tam Sam Som calculations are one of the tools most used by entrepreneurs and investors to make a preliminary assessment of the growth potential of startups and to identify opportunities and risks for possible financing. For this reason, they must be realistic estimates based on verified and truthful data: the focus of the analysis conducted has been primarily on getting the most accurate numbers, rather than the biggest possible values.

Tam Sam Som have different purposes, but they are estimates dependent on each other. Summarizing, they allow to define the short and long-term potential of the business idea: SOM indicates the short term sales potential while SAM the target market share, both help to curtail the perception of investment risk in the early-stage (i.e. figuring with the minimum possible of capital if the start-up has a market); TAM enables to assess the upside potential, necessary to provide investors a target return: all play an important role in assessing an investment opportunity.

The exact process pursued and the assumptions applied will be further explained on the appropriate paragraphs of the different market segments taken into account in the context of this thesis.

2.2 PATENT LANDSCAPE

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, society relies on a pivotal system known as the Intellectual Property Rights (IPR) system. It serves the purpose of safeguarding intellectual property, fostering an environment that nurtures creativity.

Various types of intellectual property exist, but in this work the focus will only be on patents: a study dating back to 1986 asserts that 80% of the information contained within patents is exclusive and not available elsewhere (Levine, 1986). Therefore, studying the patent scenario is imperative for conducting a thorough and effective analysis: the objective in this thesis is not to create a Patent Landscape Report (PLR), but to assess the Research and Development scenario in order to gain valuable insights on the actual state of the exploitation of the technology presented in the markets examined. The results will be then taken into account when making assumptions, particularly for the SOM estimations.

A patent is a government-granted exclusive right or license that provides inventors with legal protection for their inventions. It bestows exclusive rights for industrial exploitation over a specified period of time, typically around 20 years, meaning that it offers the inventors the authority to prevent others from 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. Applications for patents must be submitted to a national or regional patent office and undergo examination before being either granted or refused.

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.

Patents are semi-structured documents, exhibiting various discernible sections. The data that will be the focus of the analysis are:

Application number: the unique identifier of the patent application.

Applicant: defined as the individual or entity applying for an Intellectual Property Right. Upon the patent's approval, the applicant enjoys full rights, even if they're not the original inventor.

Inventor: defined as the individual responsible for creating an innovation, holds the right to be acknowledged as the originator of the invention within the patent documentation.

Priority date: refers to the earliest filing date in a family of patent applications in any country. Where only a single patent application is involved, the priority date would be the filing date of the sole application. It enables the applicant to invoke a 'priority right'.

IPC codes: International Patent Classification codes, are a standardized system used to classify patents based on the technical features of the inventions they cover. They provide a systematic categorization of inventions across different countries and technology fields and therefore represent an important tool for identifying the major areas of application.

Abstract: is a summary of the main features and purposes of the invention. Moreover, patents encompass a detailed description delineating the technology involved, and in particular the claims section holds paramount significance, serving as the segment that specifically outlines the scope of protection sought or granted for the invention.

The primary objective of the brief analysis conducted is to discern whether there are possible application concerning solid propellants in the domains considered: specifically, whether the scientific research envisages their usage in airbags and fire extinguishers. For this reason, the approach implemented focuses on isolating specific patent that encompass the use of solid propellant in the scope of the market segments chosen. The source selected to proceed with the analysis was The Lens, a database that comprises patents across multiple jurisdictions and offers proprietary analytical tools: a dataset was selected through tailored queries implying keywords and filters needed to identify patents specifically related to solid propellants, ensuring that the latter primarily revolve around this subject. To achieve this, the keywords, confined to the titles and abstracts of patents, aim to comprehensively cover synonymous terms associated with solid propellants, so the set chosen was: “solid propellant; propellant grain; solid grain; composite propellant”.
Subsequently, additional filters were implemented for each market segment: the keywords “airbags” and “fire extinguishers” were added and applied to the whole text of the patents. The temporal scope selected spans from January 1, 2000, to June 30, 2023, selected due to its alignment with the typical lifespan of patents (20 years), thereby encompassing a period that remains relevant while mitigating the inclusion of obsolete patents. Finally, filters restricting the IPC codes will be intentionally omitted.

3. Space launchers

The most important application of composite solid propellants is undoubtedly their employment in space propulsion. For this reason, the first target market analyzed in order to assess the potential of the technology introduced is space launchers' production.

A space launcher is a vehicle designed to transport payloads into space, placing them into Earth orbits or on interplanetary trajectories. Its primary purpose is to overcome Earth's gravitational force and carry the payload (such as satellites, space probes, spacecraft modules or other devices) from the Earth's surface into space. Space launchers utilize rocket propulsion principles to generate the thrust necessary to overcome Earth's atmospheric resistance and reach the desired orbit through the combustion of solid or liquid propellants.

Space launchers consist of several stages, each with its own engines and propulsion systems. Each stage is tasked with accelerating the spacecraft to a certain altitude and velocity before separating to reduce the overall weight and increase the efficiency of the remaining vehicle. The main components of a space launcher include:

1. **Launch Stage (or Booster):** This is the first stage of the launcher; it provides the spacecraft with the initial thrust through the first ascent. It may consist of one or more engines, depending on the size, total weight and required performance.
2. **Intermediate Stages:** In some cases, the launcher may be equipped with intermediate stages, each with its own propulsion capabilities, to reach specific orbits or flight conditions.
3. **Upper Stage:** This stage is responsible for placing the payload into orbit or transferring it onto the desired trajectory.

Space launchers are essential for space activities and are an integral part of the Space Economy, which refers to the collective set of economic and commercial activities related to the exploitation and utilization of outer space to generate economic value. Following the definition formulated by the US Bureau of Economic Analysis (BEA):

"The space economy consists of space-related goods and services, both public and private. This includes goods and services that:
- are used in space, or directly support those used in space.
- require direct input from space to function, or directly support those that do.
- are associated with studying space" [1]

[1] OECD Handbook on Measuring The Space Economy, 2ND EDITION, 2022

Space Economy is continuously expanding due to the development of new technologies and increasing involvement of the private sector: the different applications of space activities evolve constantly as space technologies become progressively embedded in systems and services used in everyday life. Space Economy encompasses a wide range of sectors, including:

- Space transportation: the development, production and use of launch vehicles and related subsystems. This includes launch services for spacecraft and the transport of payloads into orbit or beyond, government and commercial spaceports, logistics services for transportation between orbits, etc.
- Satellite communications: The development and use of satellites and related subsystems to send signals to Earth for telecommunications, satellite navigation and other communication purposes, or for localization, positioning, and timing services.
- Earth observation: The development and/or use of satellites to collect data and images to observe Earth for applications such as climate monitoring, weather forecasting and natural resource management.
- Space exploration: Research and exploration activities in space, including the development of crewed and uncrewed spacecraft, scientific missions, and exploration of the solar system (e.g. International Space Station and astronaut-related activities).
- Science: includes a wide range of scientific activities including space science, i.e. the various scientific fields that relate to space flight or any phenomena occurring in space or on other planets (e.g. astrophysics, planetary science); and space-related earth science, i.e. the various science fields that use space-based observations to study the physical and chemical constitution of the Earth and its atmosphere (e.g. atmospheric science, climate research).
- Space Tourism: services involving private individuals traveling to space.

Space launchers are a key element in the value chain of the space economy: following the segmentation proposed by OECD's "Handbook on measuring the space economy", which divides the space economy into three segments for measurement purposes and to allow for better international comparisons, they are included in the upstream segment (as shown in Figure 4.1), which represents the scientific and technological foundations of space programs (e.g. science, R&D, manufacturing and launch): the main focus of the present work, propellants, are included in the same main group of activities but belong to the "design and manufacture of space equipment and subsystems" subgroup. [1]

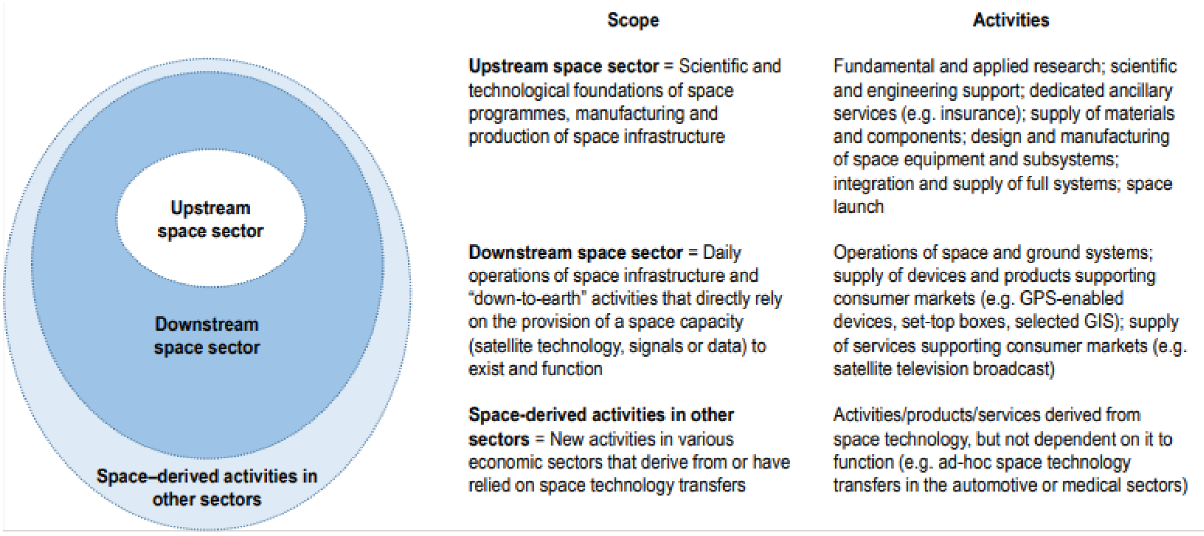

Fig. 3.1 Defining the main market segments of the space economy [1]

3.1 Estimation method

To estimate the market size of space rockets, the approach adopted for the TAM SAM SOM analysis was bottom-up, meaning that the TAM obtained is not extracted from ready-made reports, but extensive research was necessary to put together all the information needed, thus an estimate of market value was calculated as:

- Number of launches performed in a year multiplied by the amount of propellant used and its price, and then assumptions were applied to drill-down the value obtained to calculate the SOM.

For this purpose, the process undertaken was as follows: data about the number of space launches performed over the past 5 years starting in 2019 up to 2023 was collected, using as sources the annual deliverables (Yearbooks 2022, 2021, 2020 and 2019) and the monthly Insights of the year 2023 up to November, the last month for which data was available, made publicly available by ESPI, European Space Policy Institute, an international association founded by the European Space Agency (ESA) and the Austrian Research Promotion Agency (FFG), based in Vienna and established as an independent non-profit organization.
Subsequently, all the different launchers that made at least an official flight over the years considered were analyzed: they were initially segmented according to the type of propellant used, solid or liquid, both directly or indirectly, meaning that for the purpose of this research were also classified as "solid" those launchers that are not made up of any stages powered by solid rocket motors but that require strap-on boosters or add-on upper stages to increase payload capacity or when higher than normal velocities are needed. Therefore, to estimate the TAM, those launchers that are not composed of at least one stage or that do not use external solid-propellant boosters were excluded. In addition, hybrid motors, propulsion systems that implement both liquid or gas and solid propellants (usually, it is the fuel that is solid

hydroxyl-terminated polybutadiene HTPB, with liquid or gaseous oxidizer, liquid oxygen LOX, or hydrogen peroxide, kept in a pressure vessel) were also not considered, because they are used far less than either (as an example, Virgin Galactic's SpaceShipTwo uses an upgraded version of the hybrid motor).

Moreover, launchers were classified as "Active", "Retired" or "To be Launched" according to their usage up until the end of 2023, differentiating them respectively between launchers currently in use, those that were launched for the last time in the years considered and therefore now withdrawn from the market, and those that will make their maiden flight in the near future, if already confirmed and made official by their owners.
It will be then studied the difference between launchers based on the type of mission for which they are intended, their capacity in terms of transportable payload and the layer of the atmosphere they are meant to reach (GEO, LEO, MEO as example).
It must be remarked that the subjects of the analysis to calculate the Total Addressable Market of solid propellants are only launchers used for space missions; thus, sounding rockets, small vehicles used to send payloads to suborbital altitudes, which mostly use solid propellant, and ballistic missiles used in military were not considered. In addition, only official launches were regarded, and not those necessary to carry out preliminary tests (e.g. static fire tests).

Hence, in order to calculate the total amount of solid propellant used in the context previously established, it was subsequentially collected data regarding the maximum amount of solid propellant that each solid rocket or booster can storage in their tanks: lacking more detailed information, the maximum suitable amount of transportable propellant was always considered for each launch performed. Then, these values were multiplied with the number of yearly launches performed by each rocket in the time frame selected, and then added up to obtain the total amount of solid propellant used each year for space activities. Whenever possible, the information was gathered through the most up-to-date versions of the User's Manuals of the different launchers available online or through specialized forums, if deemed reliable.
Determined the total number of official launches and subsequently the total quantity, it was estimated the price of the propellant. The cost of solid propellants and its raw materials is an industrial sensitive subject and little information in open literature is available, and the few published information's may present significant difference concerning the cost sharing of the different components of a solid motor: it is not clear how much the cost of solid propellant impacts the total cost of solid rockets or strap-on boosters, and consequently of total launch cost. An estimate of the impact of propellant on total launch cost can be found in the following article: "How Much Does Rocket Fuel Really Cost?"[2] by Space Impulse, which proposes a cost of

[2] "How Much Does Rocket Fuel Really Cost?", Space Impulse, Last modified: January 7, 2024, (Accessed 25.01.2024)

$10/kg, and in the following report dated 23/02/2018 which is the result of the project GRAIL funded by European Union's Horizon 2020 research and innovation program, "Launcher analysis and cost benefits"[3], that states a production cost of $20/Kg and that affects the 20-30% of the total cost of the motor for the propellant used as reference (in that case a new type of propellant that was the main focus of the project): thus, the cost of the raw material was estimated to be in the range of one third to one half of the cost of the grain and around 3.5% to 5% of the total cost of a booster. Taken into account the difficulties faced to gather accurate and reliable industry data about prices, it was decided to adopt the formula presented in the TRANSCOST model, a cost-estimation method developed by applied to early-phase space mission planning, Handbook of Cost Engineering and Design of Space Transportation Systems, Koelle, D. E.: (2013)[4]. More detail about the price chosen to perform the TAM estimation will be provided in paragraph 3.2.1.

Finally, with the gathered data regarding the number of launches for each vehicle, the maximum amount of solid propellant storable and the price-for-kilo, it was possible to calculate the TAM of composite solid propellant in the market segment of rockets for space missions. Subsequentially, to calculate SAM and SOM the launchers considered as "retired" were discarded, as well as those vehicles produced in country with whom a possible commercial partnership is excluded a-priori for geopolitical reasons. These assumptions will be further elaborated in paragraphs 3.2.2 and 3.2.3.

[3] The report mentioned can be found here: www.grail-h2020.eu

[4] Koelle, D. E.: Handbook of Cost Engineering and Design of Space Transportation Systems. Revision 4b (2013)

3.2 Market research

3.2.1 TAM

To start the analysis an enumeration of every launch made in the years 2019 to 2023 was conducted, followed by singling out the vehicles relevant to the scope of the research and then counting the number of flights performed by those. The objective is to confront the actual application of the two main materials used in space propulsion, liquid and solid propellant.

3.2.2.1 Number of yearly launches

The TAM of the spacecraft market was estimated by considering only those launchers having at least one stage or strap-on boosters powered by solid rocket motors, therefore requiring solid propellant. For this reason, liquid-propellant launchers such as Falcon-9, Soyuz (in its numerous versions), and the Long March/CZ series (excluding CZ-2C and CZ-11), which collectively account for 66,7% of launchers flown in 2023, were disregarded (SpaceX's Falcon-9 and Falcon Heavy have made 61 launches in 2022 and 96 in 2023, and accounts for 33% and 43% of the total launches made in 2022 and 2023 respectively. Unfortunately, their Merlin motors use LOX and Rp-1, both liquid propellants).
The assumption made here is that because of the switch costs that would be necessary to adopt the new technology those launchers will continue to use liquid engines (moreover the development of the technology is moving towards reutilization of some stages of the rockets, if not of the entire vehicle: unfortunately while solid rocket motors may allow reusability, the process of recovery, inspection and refurbish of the solid boosters seems to be more challenging and economically less feasible compared to the reusability of liquid rocket engines). In addition, it is plausible that the companies that construct them will not be available to cooperate to develop the innovation proposed or to buy the patent. Hence, these are out of the scope of the analysis and therefore must be omitted from the market segment. However, it is evident that liquid is the prevalent technology in this market and launchers using solid propellant actually represent a minority. Nonetheless, some launchers of global importance are composed of stages that use solid motors or external boosters as support to achieve greater thrust and increase their capacity in terms of transportable payload: Ariane-5 and the SLS use 2 strap-on solid boosters, Ariane 6 that will debut in 2024 will be equipped with 2 or 4 solid rockets depending on the version used, Vega-C is composed of 3 stages that make use of 3 different motors that employ different amounts of solid propellant, and the vehicles launched by the National's space agencies of India and Japan have a similar structure. More information about the launchers and the solid propellant implemented are represented in Table 3.2 and will be further explored later.

The total number of orbital launches attempts from Earth has been steadily increasing, rising from 102 in 2019 up to 223 in 2023 (remarkable is the 41% increase during the Covid-19 period), of which 211 successfully reached orbit, prompted by the intensified activities involved in all the Space Economy, particularly by the satellite industry. In the graph below is also highlighted the number of launches with solid propellant: while the absolute number of flights has increased, surging from 33 in 2019 and 29 in 2021 to 46 in 2023, the actual market penetration of solid technology has decreased from 32,35% in 2019 to 20,63%. Even though it is mainly attributable to the increased activities of SpaceX's Falcon rockets (as stated before, they adopt only liquid technology), this might indicate that the potential of the proposed innovation to scale the space market may be limited. Moreover, it must be noted (it will be displayed in table 3.1) that the recent growth is mostly due to the intensified activities of Chinese launchers, while Europe carried out only 3 launches in 2023 compared to 9 in 2019: this is one of the reasons for the reduction of the estimated SOM in 2023 compared to the previous years (with the exception of 2021, which saw the maiden flight of the SLS in the first mission of Nasa' Artemis program, that might be considered an outlier as long as that launcher starts its operational life as planned in the program).

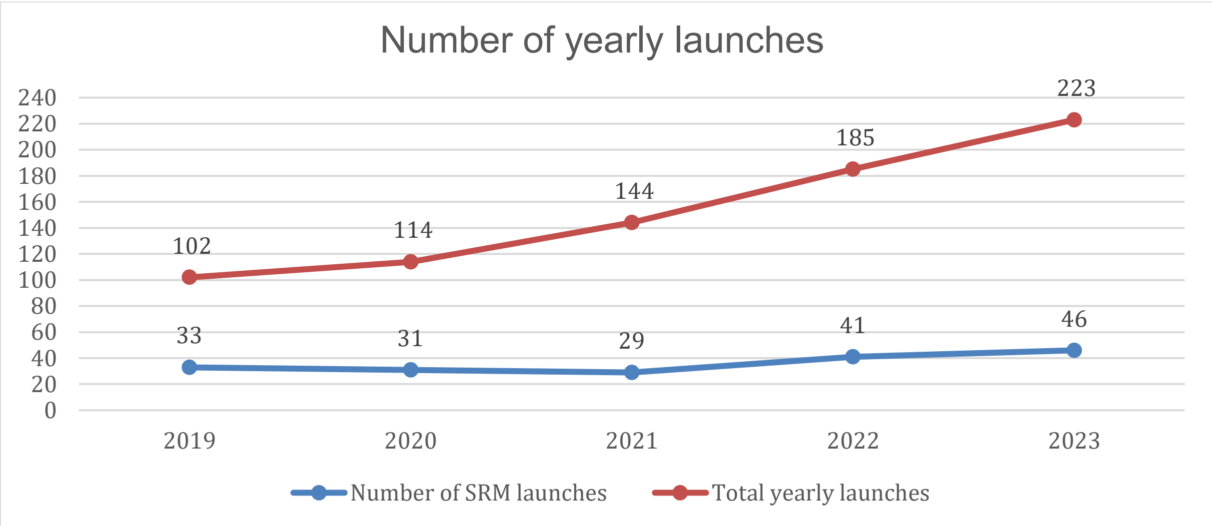

Fig. 3.2 Graph showing the Total number of launches and the number of flights with solid propellant involved.

"Europe's independent access to space is in a temporary crisis, with the halt of Soyuz from Europe's Spaceport, the stop of Ariane 5 exploitation and the delay of the development of Ariane 6, the grounding of Vega C after failure in December 2022" [5]. In contrast, while it will not be taken into account in the estimations, during the Council of the European Space Agency (ESA) taken place on November 6th, 2023, an increased prospect of the minimum number of European institutional

[5] ESA, Lifting Europe's Ambitions for a Green and Sustainable Future, Access to Space and Space Exploration, November 6th, 2023, https://esamultimedia.esa.int/docs/dgproposal_summit2023_EN.pdf

launches was proposed, both for Ariane 6 (4 flights per year) and Vega C (3 flights per year), thanks to the growth of various European satellite programs [6].
Despite the diversity of players in the space industry (firms originating from 22 different countries in 2023 were clients for launch commercial providers, meaning manufacturers of payloads transported in each flight), just two countries – the United States and China – currently dominate launch activities, the bulk of which is devoted to the deployment of commercial broadband services. While most of US launches were carried out by a single private, SpaceX, the established market leader in commercial space transportation, which with a record 96 launches accounted for 82% of the US total, China, with its 67 launches also set a record in 2023: this is part of the country's ambitious space program, comprising human spaceflight (its space station is completed and inhabited), exploration science, as well as various government applications. In addition, several Chinese commercial actors have emerged since the deregulation of Chinese space activities in 2015, with new space vehicles being manufactured by private start-ups like Ex-Pace, i-Space, One Space, Zhongke Aerospace and Galactic Energy.

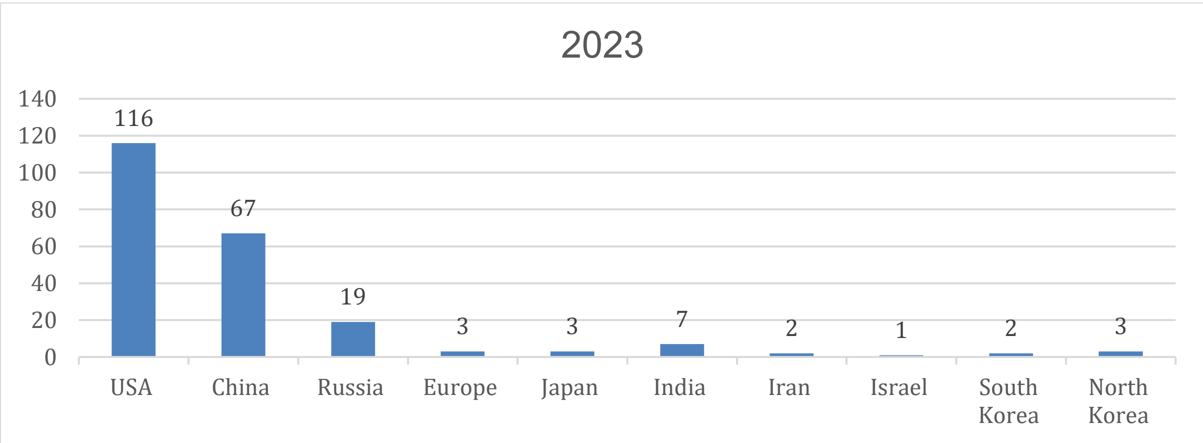

Fig. 3.3 Total number of launches performed by country of origin of the rocket (The Arianespace-managed Soyuz launch from French Guiana was counted as Russian; Electron is considered to be USA even though the launch was performed in New Zealand)

Space has become strategic for the prosperity of any nation and today has unprecedented potential to contribute to address global challenges. Space economy or "new space" is undergoing a radical paradigm shift towards a more competitive scenario with private companies revolutionizing the landscape from space transportation (with a new next generation of launchers) to exploration and space-enabled technologies. One of the key legacies of "new space" is in fact the "democratization" of access to space, space technologies and resource exploitation, both in the geographic sense and from a user perspective, thanks to product innovations lowering launch costs that attract the interest of many commercial actors, leading to unprecedented levels of launch frequency and orbit occupancy,

[6] Avio S.p.A press release, November 7th, 2023, https://www.avio.com/press-release/esa-ministerial-council-important-decisions-regarding-ariane-6-vega-c-and-vega

thus maximizing the potential gains of space exploitation. Due to lower entry barriers there are more opportunities for small, innovative actors, such as universities and start-ups, and commercial operators now dominate in both the geostationary (GEO) and low-earth orbits (LEO).

At the previously mentioned Space Summit, with the objective to spur new European commercial space transportation services and in order to empower Europe to regain its commercial position, ESA launched a competition between innovative private companies, solely based in Europe, to develop a space cargo return service that will see a European commercial provider deliver supplies to the International Space Station by 2028 and return cargo to Earth [7] [8].
Another proposal from ESA and the European Commission announced on October 23rd, 2023, is the “European Flight Ticket Initiative”: the effort is intended to stimulate demand for European launch services by enhancing open competition for missions in the EU’s “In-Orbit Demonstration and Validation” technology program [9]. On January 23rd, 2024, they disclosed the five launch companies selected to participate in the new program, they will compete for task orders for launching specific missions. Four of the companies selected for the Flight Ticket Initiative are startups working on small launch vehicles: Isar Aerospace, Orbex, PLD Space and Rocket Factory Augsburg. None of them have yet conducted an orbital flight (but are expected to do so within the next two years), but their in-house manufactured launchers are all powered by liquid engines.

These new programs in Europe, combined with new projects to develop additively manufactured solid rocket motors and solid propellant by the likes of X-Bow Systems, Ursa Major Technologies and Australian’ Black Sky Aerospace, are presented to display the potential of the solid propellant market, since these are not quantitative measures that can be applied to the analysis. It can be stated that the results obtained may represent just a starting point, and future growth of the market size is probable.

Will be hereby displayed the results of the research conducted on the number of yearly flights of launchers powered by solid rocket motors and subsequently more detailed information about those (status, total quantity of propellant loadable and the firms responsible of manufacturing the solid rocket motors).

[7] ESA, “Resolution on Lifting Europe’s Ambitions for a Green and Sustainable Future, Access to Space and Space Exploration”, 6th November 2023, accessed from: https://esamultimedia.esa.int/docs/resolution_summit2023_EN.pdf,
[8] ESA, “The ESA Director General’s Proposal on Lifting Europe’s Ambitions for a Green and Sustainable Future, Access to Space and Space Exploration”, 6th November 2023, accessed from: https://esamultimedia.esa.int/docs/dgproposal_summit2023_EN.pdf, pg. 16
[9] EU and ESA, “Launch of the European Flight Ticket Initiative”, 23 October 2023, accessed from https://defence-industry-space.ec.europa.eu/launch-european-flight-ticket-initiative-2023-10-23_en

Number of Launches through Solid Rocket Motors and/or strap-on boosters:

Launchers	2023	2022	2021	2020	2019	Total
Antares-230	1	2	2	2	2	9
Ariane-5 ECA	2	3	3	3	4	15
Atlas-5 (411)	0	0	0	1	0	1
Atlas-5 (421)	0	1	1	0	0	2
Atlas-5 (431)	0	0	0	0	0	0
Atlas-5 (511)	0	1	0	0	0	1
Atlas-5 (521)	0	0	0	0	0	0
Atlas-5 (531)	0	1	0	1	0	2
Atlas-5 (541)	0	2	0	1	0	3
Atlas-5 (551)	1	0	1	1	1	4
Atlas-5 (N22)	0	1	0	0	1	2
Ceres	7	2	1	1	0	11
CZ-11	2	4	0	3	3	12
CZ-2C	9	6	5	3	1	24
Delta-4M+ (4,2)	0	0	0	0	1	1
Delta-4M+ (5,4)	0	0	0	0	1	1
Epsilon L. V.	0	1	1	0	1	3
GSLV	3	1	1	0	1	6
H-2A-202	2	0	1	3	0	6
H-2A-204	0	0	1	0	0	1
H-2B-304	0	0	0	1	1	2
H-3-22S	1	0	0	0	0	1
Hyperbola-1	2	1	2	0	1	6
Jielong	1	1	0	0	1	3
Kuaizhou-11	0	1	0	1	0	2
Kuaizhou-1A	6	4	4	3	5	22
Minotaur-I	0	0	1	0	0	1
Minotaur-IV	0	0	0	1	0	1
OS-M1	0	0	0	0	1	1
Pegasus-XL	0	0	1	0	1	2
PSLV-CA	2	1	0	0	1	4
PSLV-DL	0	0	1	1	1	3
PSLV-QL	0	0	0	0	2	2
PSLV-XL	1	2	0	1	1	5
Qased	1	1	0	1	0	3
Qaem 100	1	0	0	0	0	1
Shavit	1	0	0	1	0	2
SLS	0	1	0	0	0	1
SSLV	1	1	0	0	0	2
Vega	1	0	3	2	2	8
Vega-C	0	2	0	0	0	2
Zhongke-1A	1	1	0	0	0	2
Total	46	41	29	31	33	171

Tab. 3.1 – Number of yearly launches of solid-fueled space lauchers

3.2.2.2 Characteristics of solid-fueled space launchers

Launcher and their respective type and quantity of Solid Propellant employed:

Launcher	Stages or SRB	Propellants	Total Kg of Solid Propellant	Producer of SRM's	Country	Status
Vega-C	3	HTPB 1912 solid	188.440	Avio S.p.A	Europe	Active
Vega	3	HTPB 1912 solid	122.091	Avio S.p.A	Europe	Retired
Ariane-5 ECA	2	HTPB 1912 solid	480.000	Avio S.p.A	Europe	Retired
Ariane-62	2	HTPB 1912 solid	283.268	Avio S.p.A	Europe	To be launched
Ariane-64	4	HTPB 1912 solid	566.536	Avio S.p.A	Europe	To be launched
PSLV-CA	2	HTPB based	145.700	ISRO	India	Active
PSLV-DL	4	HTPB based	154.700	ISRO	India	Active
PSLV-QL	6	HTPB based	154.700	ISRO	India	Active
PSLV-XL	8	HTPB based	157.700	ISRO	India	Active
GSLV	1	HTPB based	138.000	ISRO	India	Active
SSLV	3	HTPB based	99.200	ISRO	India	Active
CZ-2C	1	HTPB/Hydrazine	125	CALT (China Academy of Launch Vehicle Technology)	China	Active
SLS	2	PBAN based	1.298.000	Northrop Grumman	USA	Active
Vulcan	6	QDL-4	287.118	Northrop Grumman	USA	To be launched
Atlas-5 (411)	1	QDL-4 HTPB polymer	44.087	Northrop Grumman	USA	Active
Atlas-5 (511)	1	QDL-4 HTPB polymer,	44.087	Northrop Grumman	USA	Active
Atlas-5 (421)	2	QDL-4 HTPB polymer	88.174	Northrop Grumman	USA	Active
Atlas-5 (521)	2	QDL-4 HTPB polymer	88.174	Northrop Grumman	USA	Active

Atlas-5 (N22)	2	QDL-4 HTPB polymer	88.174	Northrop Grumman	USA	Active
Atlas-5 (431)	3	QDL-4 HTPB polymer	132.261	Northrop Grumman	USA	Active
Atlas-5 (531)	3	QDL-4 HTPB polymer	132.261	Northrop Grumman	USA	Active
Atlas-5 (541)	4	QDL-4 HTPB polymer	176.348	Northrop Grumman	USA	Active
Atlas-5 (551)	5	QDL-4 HTPB polymer	220.435	Northrop Grumman	USA	Active
Delta-4M+ (4,2)	2	QEY, HTPB polymer	59.396	Northrop Grumman	USA	Retired
Delta-4M+ (5,4)	4	QEY, HTPB polymer	118.792	Northrop Grumman	USA	Retired
H-2A-202	2	HTPB Composite	130.000	Mitsubishi Heavy Industries	Japan	Active
H-2A-204	4	HTPB Composite	264.000	Mitsubishi Heavy Industries	Japan	Active
H-2B-304	1	HTPB Composite	263.800	Mitsubishi Heavy Industries	Japan	Retired
H-3-22S	2	HTPB Composite	133.600	JAXA	Japan	Active
Epsilon Launch Vehicle	3	Solid HTPB	83.800	IHI AEROSPACE CO., LTD	Japan	Active
Antares-230	1	QDL-1, HTPB polymer	24.924	Northrop Grumman	USA	Active
Antares-232	1	TP-H-3340	44.925	Northrop Grumman	USA	Active
Antares-233	1	QDL-1, HTPB polymer	25.694	Northrop Grumman	USA	Active
Kuaizhou-1A	3	Unkown	25.560	EX-Pace	China	Active
Kuaizhou-11	3	Unkown	25.560	EX-Pace	China	Active
Hyperbola-1	3	HTPB polymer	25.750	i-Space	China	Active
Qased	2	Unkown	1.685	Islamic Revolutionary Guard Corps Aerospace Force	Iran	Active
Shavit	3	HTPB polymer	27.515	Israel Aerospace Industries	Israel	Active
Pegasus-XL	3	QLD-1, HTPB polymer, 19% Aluminium	19.709	Northrop Grumman	USA	Active

Minotaur-I	4	Solid TP-H1011; Solid ANB-3066; QLD-1, HTPB polymer	31.717	Northrop Grumman	USA	Active
Minotaur-IV	1	Solid-NEPE (containing HMX); QLD-1, HTPB polymer	77.750	Northrop Grumman	USA	Active
OS-M1	1	Unkown	-	OneSpace	China	Active
Zhongke-1A	3	Unkown	-	Zhongke Aerospace	China	Active
Kinetica-1A	4	Unkown	-	Zhongke Aerospace	China	Active
Jielong	4	Unkown	-	CALT (China Academy of Launch Vehicle Technology)	China	Active
Ceres	3	HTPB Composite	-	Galactic Energy	China	Active
CZ-11	4	Unkown	-	CALT (China Academy of Launch Vehicle Technology)	China	Active

Tab. 3.2 Launcher and type and quantity of solid propellant employed

The production of the launchers reviewed entails the involvement of companies specializing in the production of technologically advanced rocket engines, as well as in the supply of propellant to fuel the rockets. This industry segment is characterized by low production volumes and high levels of specialization, with a limited number of suppliers. It will be hereby presented a brief description of the main manufacturers of solid rocket engines identified, which could be potential partner or customer for the commercial application of the patent.

- **Avio S.p.A** – Avio is an italian-based company that holds a prominent position in space propulsion that designs, develops, manufactures, and assembles solid, liquid and cryogenic propulsion systems for space launchers and military tactical missiles. Avio developed Zefiro, a family of solid-fuel rocket motors used on Vega rockets (Zefiro 23 and Zefiro 9A, were in use with Vega and Zefiro 40 is used for Vega-C) and the P120 C, that will be implemented as a solid rocket motor for the first stage of Vega C and Vega E and as strap-on booster for the new European rocket Ariane 6. The propellant in all Zefiro models is HTPB 1912, with a composition of 19% of aluminium powder, 69% of ammonium perchlorate with 12% of hydroxyl-terminated polybutadiene (HTPB) binder.

- **Regulus** - Joint Venture between Avio and Ariane Group Regulus (Avio holds 60% of shares, Ariane Group 40%), is a French company with headquarter in French Guiana, that aims to be a global leader in the production and loading of solid propellant into rocket engines. It is the main supplier of propellant for Vega and Ariane rockets.

- **Northrop Grumman**– American multinational aerospace and defense technology company, the leading provider of solid rocket motors for commercial launch service providers for human spaceflight and scientific exploration, and U.S. strategic weapon systems for national defense. Northrop Grumman propulsion systems are employed in the company's Pegasus, Minotaur and Antares rockets as well as on the United Launch Alliance's Atlas V, Vulcan, and also manufactures the five-segment solid rocket boosters for NASA's Space Launch System (SLS), while for defense programs the company produces propulsion systems for the company-built ground-based defense interceptor, as well as for the Trident II D5, Minuteman III and Sentinel strategic missiles.

- China Academy of Launch Vehicle Technology (**CALT**) - A subsidiary of the larger China Aerospace Science and Technology Corporation (CASC), is a major state-owned civilian and military space launch vehicle manufacturer in China. It is the provider of the Long March family of rockets.

- **Mitsubishi Heavy Industries** (MHI) and **IHI AEROSPACE CO., LTD** – The two leading Japanese companies in the aerospace sector, in charge of the development and manufacturing of the solid rocket boosters for the H-IIA and H-III rockets, while the latter, IHI Aerospace, is the sole manufacturer of the Epsilon Launch Vehicle.

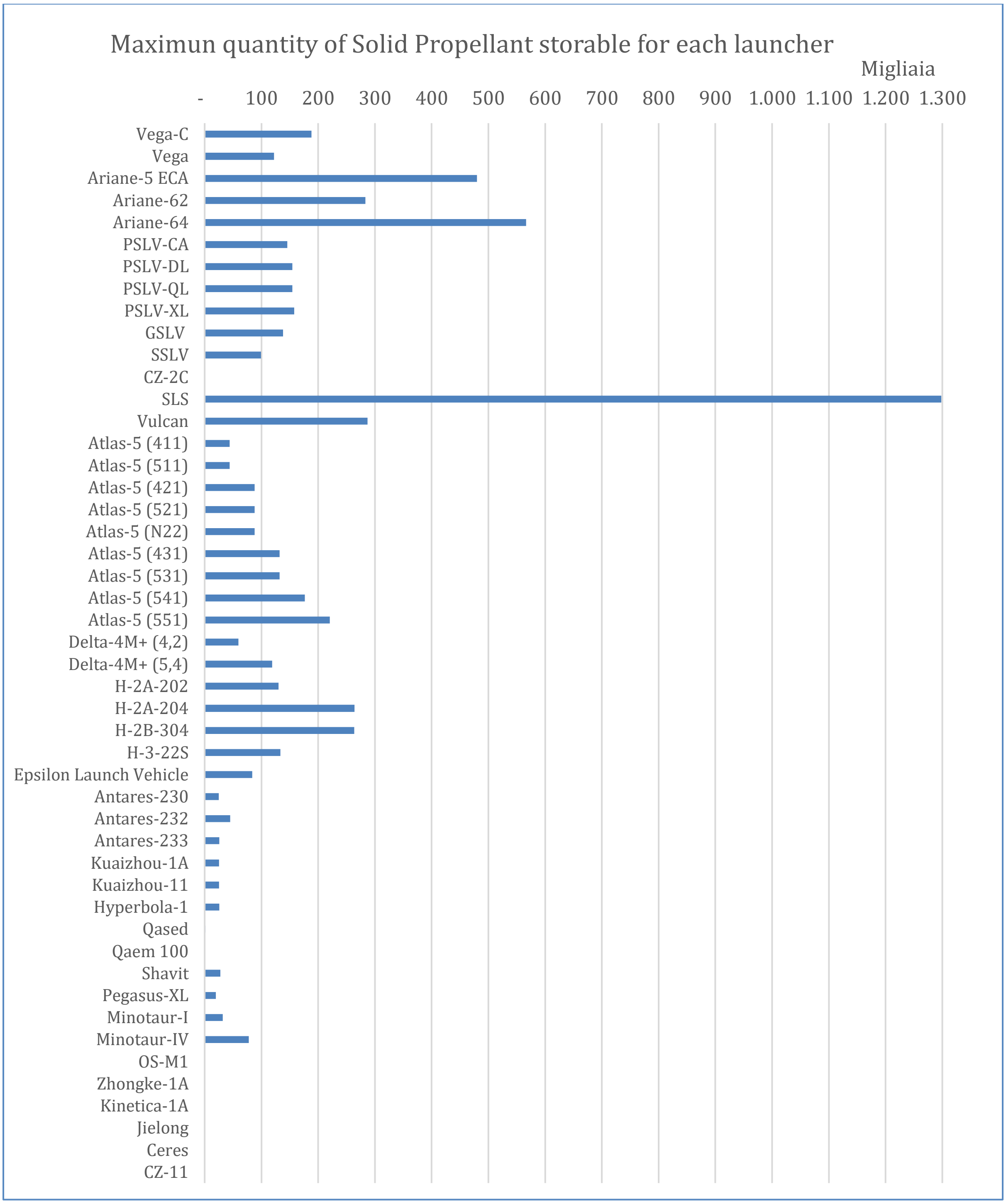

Fig. 3.4 Maximum Solid propellant storable for each Solid Rocket Motor or Booster

No precise and reliable data was found for Iranian and Chinese's private-owned launchers and, those where therefore excluded. Moreover, while SLS is considered "Active" having flown in 2021, recent replanning of the Artemis program delayed the vehicle next two launches at least to 2025 and 2026. Considering its weight on the solid propellant market, as shown in the above figure, and uncertainty regarding Artemis, as stated before it might still be considered an outlier for the market sizing.

3.2.2.3 TAM estimation

After having collected the necessary information regarding the number of flights for each year of the rockets identified, the total quantity of solid propellant needed to be produced for each official launch was calculated. To attain this value, for each launcher and in every year considered, the following calculus was performed: Number of launches * Kg of solid propellant necessary.
The composite solid propellant used as a reference is HTPB 1912, consisting of 19% of aluminum powder, 69% of ammonium perchlorate and 12% of hydroxyl terminated polybutadiene (HTPB) binder. This is the most common solid propellant adopted, and due to the fact that hasn't been possible to evaluate a target price for a propellant made with the patented technology previously briefly described, it will be considered as a common basis for estimating TAM. The information regarding the maximum amount of propellant that can be stored in each rocket was collected using as sources both the launchers' User's Manuals available online and data provided on the official websites of the manufacturing companies.

Taking into account the difficulties involved in the research of industry-related prices of solid propellants, it was decided to adopt Koelle's "TRANSCOST 8.3" presented in the "Handbook of Cost Engineering and Design of Space Transportation Systems", D. E. Koelle, 2013. The TRANSCOST 8.3 model is a top-down cost analysis, which means that costs are determined on a systematic level. Its strength is to provide the user with a first order of magnitude of system costs with an accuracy of ±20 %. It consists mainly of mass-based Cost Estimating Relationships (CERs), in which actual cost data for launch vehicles is plotted against relevant vehicle data and normalized through additional correction factors which consider aspects such as team experience, cost-per-unit reduction due to series production and technical complexity. This allows to estimate development, production and operations cost, and to produce a high-level Cost Breakdown Structure, in which, for every stage, propulsion subsystem cost and overall system cost are shown.
In this context, only the estimate of the propellant cost will be employed.

The propellant costs are the fuel, oxidizer and pressurizing masses combined with the respective costs-per-kilogram (cf, cox and $cpres$ respectively):

$$Propellant\ cost = \frac{Mp}{r+1} * cf + \left(Mp - \frac{Mp}{r+1}\right) * cox + Mpres * cpres$$

Where:

- Mp = Fuel and oxidizer mass
- r = mixture ratio
- cf = cost of Reducer (Aluminum Powder)
- cox = cost of Oxidizer (Ammonium Perchlorate)
- $cpres$ = cost of Binder (HTPB)

The cost of the subcomponents was appointed $c_f = 10\,\$/Kg$, $c_{ox} = 10\,\$/Kg$, $HPTB = 8\,\$/Kg$, as suggested in the following report: “Launcher analysis and cost benefits" [10], deliverable of the GRAIL project funded by the “*European Union’s Horizon 2020 research and innovation programme”.*
With the formula above, the assumption is a propellant cost of $ 13,45/Kg.
Finally, for each year considered the TAM can be obtained as:
Tot Kg SolidPropellant * cost HTPB 1912 ($/Kg)

TAM	2023	2022	2021	2020	2019
Tot Kg SP needed each year	2.952.785	4.962.520	3.004.321	3.404.541	4.104.611
cost HTPB $/Kg	$ 13,45				
TAM	$ 39.714.958	$ 66.261.694	$ 40.408.117	$ 45.791.076	$ 55.207.018

Tab 3.3 TAM estimation

3.2.2 SAM and SOM

The SAM was obtained through the same calculation implemented above, but restricting the number of launchers which would employ the solid propellant’ production method proposed. The assumption made can be explained considering the fact that some of the launches will not be active anymore in the future and have already made their last flight (examples of this case are the Delta-V launchers and the Arianespace’s Ariane-5, whose last launch was made in 2023): in table 3.2 these are signaled as “Retired”. Instead, rockets that already have a booked flight are considered as “Active”, even those that will be replaced in the future: e.g. is confirmed that Atlas-5 that will be launched at least 14 time in the future until 2028, before being completely replaced by ULA’s Vulcan and SLS. Moreover, the rockets that are still in development, denoted as “To be launched” in table 3.2, are not included in the computation, even though it’s confirmed that they will employ solid propellant, as there is still uncertainty on the launch date of their maiden flight, but it must be highlighted that these launchers will certainly propel the solid propellant market.
Finally, have been excluded those launchers coming from countries like China, Iran and Japan, the former for geopolitical reason: it’s very unlikely that these two country would be willing to cooperate with western countries on the development of the technology, and this is shown by the fact that, even though space is a sector in which international collaboration is frequent, at the moment there aren’t any international project in which the Chinese’s National Space Agency CALT has been involved. Moreover, has shown in table 3.2, it wasn’t possible to obtain detailed information about Chinese’s launchers, developed by both private (like iSpace and Galactic Energy) and public companies: it seems that a proper “space race” has started in China, will a multitude of space-related start-ups, which makes

[10] The report mentioned can be found here: www.grail-h2020.eu

international collaboration less feasible; instead, Japan seems to be autonomous and represents a market segment unlikely to be targetable by an eventual start-up.
For these reasons, only European and American launchers have been selected as marketable geographical areas. The SAM estimation stands as follows:

SAM-SOM	2023	2022	2021	2020	2019
Tot Kg SP in EU/USA	1.327.450	3.870.120	2.216.156	2.384.911	2.542.348
HTPB 1912 cost $/Kg	$ 13,45				
SAM	$ 17.854.203	$ 52.053.114	$ 29.807.298	$ 32.077.053	$ 34.194.581
% market penetration assumed	16,15%				
SOM	$ 2.883.502	$ 8.406.720	$ 4.813.960	$ 5.180.532	$ 5.522.518

Tab 3.4 SAM and SOM estimation

3.3 Sounding Rockets

Although it was stated that the TAM estimation would have been made by only considering orbital launches, to correctly evaluate the market potential of the proposed technology a brief overview of suborbital launch vehicles must be performed. That is because, as brought up from the market research conducted, sounding rockets and ballistic missiles mostly use solid propellants and represent not negligible business opportunities to exploit the technology. In opposition to the more detailed analysis presented for orbital space launchers, only high-level data will be hereby presented, also because the exact quantities of propellant used was not available for any rockets identified, and only 2023 is taken as a reference, but nonetheless it will prove relevant to identify distinct aerospace firms from the ones previously mentioned that may prove to be suitable candidates for eventual partnerships and collaborations. The list of launches was derived from the following websites: “List of spaceflight launches in January–June 2023”[11] and “List of spaceflight launches in July–December 2023”[12], after having certified the validity of all the sources reported.
Firstly, an overview of the various suborbital rockets and their type will be presented: ballistic missiles, missiles that usually travel above the atmosphere and into outer

[11] https://en.wikipedia.org/wiki/List_of_spaceflight_launches_in_January_June_2023, accessed 02.02.2024
[12] https://en.wikipedia.org/wiki/List_of_spaceflight_launches_in_July-December_2023, accessed 02.02.2024

space to deliver warheads on specific targets, and sounding rockets, payload-carrying rockets designed to perform scientific experiments during sub-orbital flight and to carry out measurements in specific regions of space, are definitely the most relevant in the market and almost each one implements solid propellant (although little information was found on the most frequent compositions of the propellants, it can be assumed that HTPB-based with aluminum powder and ammonium perchlorate is still the most common), the only exceptions being missiles from North Korea and Iran and two rockets developed respectively by a South Korean start-up, Innospace, and by a student rocketry team from the University of Stuttgart. Suborbital Spaceplane refers to SpaceShipTwo, a spaceplane powered by a hybrid engine which also utilizes a HTPB-based solid component, developed by The Spaceship Company, a subsidiary of Virgin Galactic, for space tourism or “private spaceflight”, a niche market segment of the space economy that seeks to give private individuals the possibility to experience space travel for recreational or business purposes.

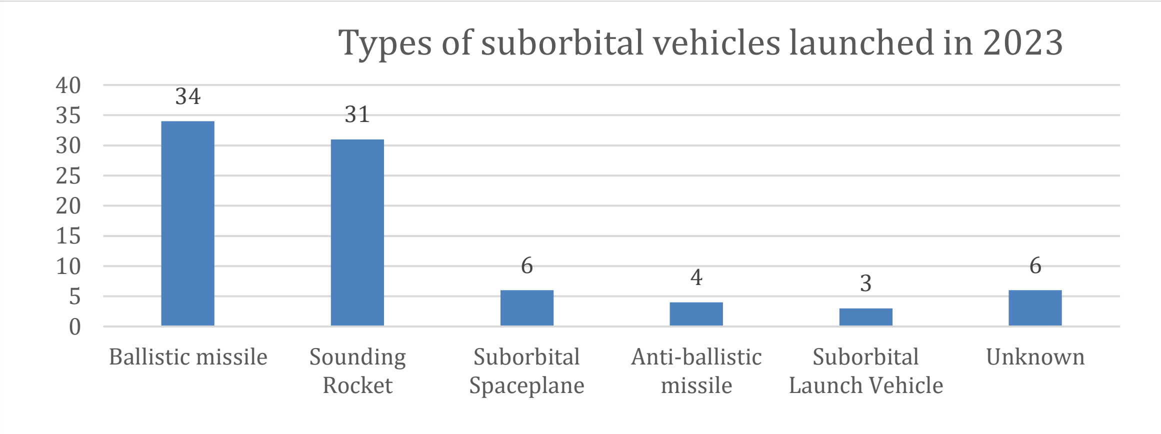

Fig. 3.4 Types of Suborbital spaceplanes

The following table shows the number of the different suborbital vehicles or missiles (in a sub-orbital spaceflight the spacecraft reaches outer space but doesn’t not complete a full orbital revolution and doesn’t reach escape velocity) launched in 2023, dividing them according to the type of propellant needed. In total 84 different launches were performed in 2023.

Data on suborbital flights	2023
Total number of suborbital launchers	48
Launchers with Solid Propellant	27
Launchers with Liquid Propellant	10
Launchers with Hybrid Propellant	2
Type of propellant Unknown	9

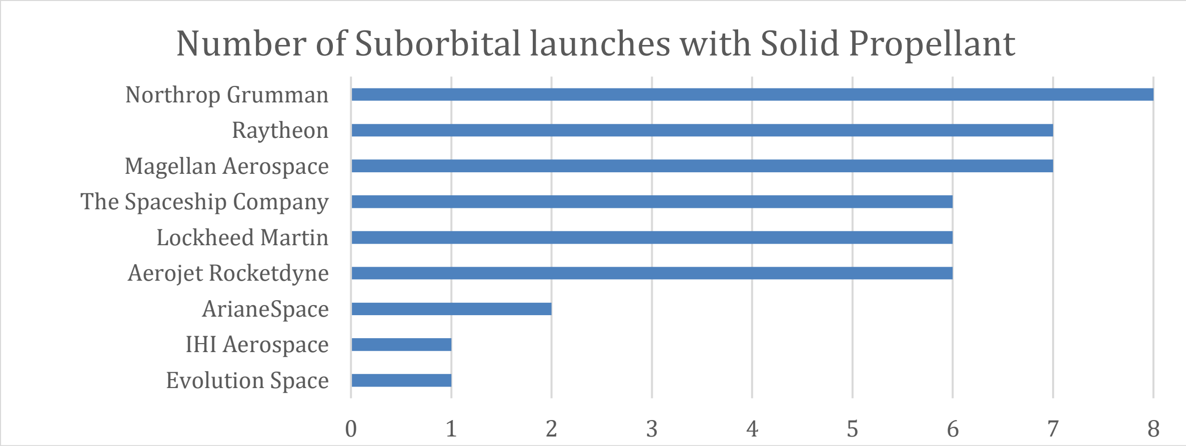

Fig 3.5 Number of Suborbital launches with rockets that implemented solid propellants, divided by the company that manufactured them.

The following table collects all the companies in the aerospace and space propulsion industry identified in the market research.

Company	Headquarters	Product
Avio S.p.A	Italy	Solid Rocket engines
Regulus S.p.A	French Guyana	Solid Propellant – subsidiary of Avio.
Northrop Grumman	USA	Solid Rocket engines
Aerojet Rocketdyne	USA	Solid Rocket engines
Raytheon	USA	Solid Rocket engines
Lockheed Martin	Usa	Solid Rocket engines
ArianeGroup	France	Space launchers
United Launch Alliance	USA	Space launchers – Joint Venture
Mitsubishi Heavy Industries	Japan	Space launchers
IHI Aerospace	Japan	Space launchers, sounding rockets
Magellan Aerospace	Canada	Sounding Rockets
Evolution Space	USA	Sounding Rockets
X-Bow Systems	USA	Solid rocket engines and propellant
Ursa Major Technologies	USA	Solid rocket engines
BlackSky Aerospace	Australia	Solid rocket engines and propellant

Tab. 3.5 List of aerospace companies involved in the space propulsion market segment that produce solid rocket motors or solid propellants.

4. Airbags

Airbag Inflation and most common propellants

An airbag is an inflatable cushion designed to protect automobile occupants from serious injury in the case of a collision. The purpose of an airbag is to absorb the forward-moving energy of the occupant in the event of a crash to slow the passenger's motion as quickly as possible. Inflation occurs in the event of a collision between 16 and 24 kilometers per hour.
An airbag module has three main parts: the bag, the inflator, and the propellant. The bag is made of nylon fabric and can come in different shapes and sizes depending on specific vehicle requirements: the standard volume of an American airbag is 67L, while a European is around 35L.
Airbags are inflated from the products of a chemical reaction: crash sensors located in the front of the automobile detect the sudden deceleration caused by the collision (the crash force should be above a predetermined value) and send an electrical signal activating an initiator that contains a thin wire that heats up and penetrates to the canister that contains the propellants. This system creates the high-temperature condition necessary to ignite a solid propellant, usually sodium azide, a chemical explosive sealed inside the inflator, and to undergo a rapid chemical reaction commonly referred to as a pyrotechnic chain that produces the harmless gas needed to inflate the airbag. The bag bursts from its storage site at up to 322 kph and then the gas undergoes a process that reduces the temperature, removes most of the combustion residue or ash and quickly dissipates through holes in the bag, thus deflating the bag itself; from the time the sensor detects the collision to the time the airbag is fully inflated is only 30 milliseconds.

The inflation system is similar to the one of a solid rocket booster: the standard airbag's inflation system involves the decomposition of sodium azide, NaN_3 a stable salt at ambient temperature, though a series of three chemical reactions inside the gas generator:

1. $2\ NaN_3 \rightarrow 2\ Na + 3\ N_2$ (g)
2. $10\ Na + 2\ KNO_3 \rightarrow K_2O + 5\ Na_2O + N_2$ (g)
3. $K_2O + Na_2O + 2\ SiO_2 \rightarrow K_2SiO_3 + Na_2SiO_3$

Inside the airbag is a metal canister containing a mixture of NaN, and two oxidizers, KNO3, and SiO2: sodium azide (NaN3) can decompose at 275 °C to produce sodium metal (Na) and nitrogen gas N_2 which is the gas that inflates the bag. The purpose of the other chemicals is to react with Na, which is a highly reactive and potentially explosive metal, and to convert it to a harmless and stable glass to minimize the danger of exposure and make less toxic compounds. Based on the chemical equation, to inflate a standard American airbag, which means to produce about 67 liters of nitrogen gas, about 130 grams of the compound are needed.

Due to the considerable toxicity of NaN3, over the recent past stringent government regulations forced airbag manufacturers in efforts towards the adoption of new propellant chemicals, which are non-toxic and do not produce any harmful fumes [13]. Some of the chemicals that are commonly used to affect this controlled explosive reaction include organically derived non-azidic propellants as ammonium nitrate, guanidine nitrate, tri-/tetra-azoles like potassium 5-amino tetrazole and inorganic oxidizers. So new airbags tend to use different chemicals for gas generation, and one of them, guanidine nitrate, will be considered and used as a reference in the following analysis. In more detail, guanidine nitrate produced nitrogen gas through its decomposition:

$[C(NH_2)_3]NO_3 (s) \rightarrow 3 H_2O (g) + 2 N_2 (g) + C (s)$

4.1 Research’s method

The sizing of the airbag market was done through a TAM SAM SOM analysis by adopting a bottom-up approach, that is by constructing an estimate of market size through a calculation of quantities and prices. In detail, the quantity analysis was aimed at sizing the volume of airbags produced annually, and was carried out through the following calculation:
Number of cars produced * Average number of airbags in a car * Average amount of propellant used * Average propellant price/g.

The number of airbags needed is tied to the number of cars produced annually, and their market trend is therefore closely linked to that of new cars: for a forecast of the number of cars produced in the next 5 years, two different scenarios were considered, obtained by cross-referencing data from estimates made by two of the most important "automotive market analyst" companies: S&P Global and AlixPartners, extracted from the following reports, "Global Production Summary of Light Commercial Vehicles" of September 2023 created by S&P Global and "Global Automotive Outlook 2023" published by AlixPartners. It should be noted that the scope of cars considered includes the so-called Light Commercial Vehicle, LCVs, which include passenger cars, and Medium and Heavy Commercial Vehicles (M-HV).

Three alternatives were considered for the average number of airbags in a car, derived from information gathered on safety regulations imposed on automakers by local governments and the state of the art in the market. In detail, 3 different scenarios were created in which the average number of airbags in cars is 2,4 or 6 respectively.
The average amount of propellant needed was estimated by taking as a reference the chemical reaction of guanidine nitrate, in particular its decomposition that

[13] ScienceDirect, https://www.sciencedirect.com/science/article/pii/S0735109723040391, 7th March 2023

produces the gas needed for inflation, from which the grams needed for different sizes of existing airbags (or at least the standard cushion volume, which is different for cars produced in America and Europe. The standard for American airbags was used as a reference to calculate the TAM (since these are larger, the estimate is in excess). an indication of the spread of the different types of propellants used was not possible, so it was decided to consider a standard reference obtained by comparing results from two different propellants, sodium azide, the reference solid propellant in the early years of airbag system development, which while remaining very common may no longer be the most commonly used substance due to technological advancement, and guanidine nitrate (the one finally selected) which is more recent and from the studies conducted appears to have several advantages.
Other chemicals such as Ammonium Nitrate and 5-Aminotetrazole were not considered in the calculation because they are the subject to restraints that will be highlighted later. It must also be affirmed that all the substances most commonly used as gas generators in airbag's inflators are solid propellants, but they are not composites or polymers.
Finally, to obtain the final TAM, the cost per gram of the propellants was considered, obtained from the average market price of guanidine nitrate and sodium azide proposed by some manufacturers of the substances. In the following, the method described above will be presented in more detail.
Finally, due to the uncertainty regarding the estimation made, resulting from the impossibility of having exact information on the types of chemicals used, their quantities and price (which depends on the quantities produced), a top-down approach is also proposed for sizing the market size of the airbag market.

4.2. Market Research

4.2.1 TAM

4.2.1.1 Number of airbags in commercial vehicles

Passive safety systems, that don't require to be activated by the occupants, have played a vital role in reducing the impact of road traffic accidents. Studies show that airbags are very effective when it comes to reducing fatalities and injuries in crashes: according to the United States' National Highway Traffic Administration (NHTSA) frontal airbags alone saved 50,457 lives from 1987 to 2017 (the latest year for which data is available) (National Center for Statistics and Analysis, 2020). The figure is likely to be much higher if airbags in different locations were also included.
While automotive industry's focus on active safety systems such as antilock-braking system (ABS), electronic stability control (ESC) and traction control system (TCS) has increased significantly in the past two decades, they cannot completely eliminate the possibility of accidents happening. For this reason, the role of passive safety systems such as airbags and seatbelts remain as critical in mitigating the impacts of a crash. In fact, over the years the number of airbags per vehicle has gone up significantly: many mass market models now come equipped with six airbags as standard, and some automakers are fitting vehicles with up to 10 airbags to improve occupant safety, clear various crash tests and to achieve higher safety ratings from agencies such as Global New Car Assessment Program (Global NCAP) and EuroNCAP.
Most countries have mandatory fitment regulations for airbags: for example, since the 1999 model year the USA government has required automakers to install frontal airbags in all cars, light trucks and vans, while in India, one the most growing countries in the automotive market, the government has made 6 airbags compulsory on all cars manufactured after October 1 2023 that have a passenger capacity of up to eight people, in order to enhance the safety quotient and reduce the mortality rate in case of accidents. Once the government ruling comes into picture, all cars will be fitted with 6 airbags, including driver front airbag, front passenger airbag, and 4 side-curtain airbags. The drawback of this decision of the government is that it will lead to an increase in prices for these cars.

Their primary limitation is their single-use nature: airbags cannot be reused after deploying because the pyrotechnic process has been designed to be used only once, so replacing a deployed airbag is necessary even if the crash damage isn't severe (and the only replacement that is guaranteed to be safe is if it is replaced by an authorized service). But because most vehicles built prior to 2002 used glass sealing technology which stops moisture from penetrating the igniter, these airbags do not deteriorate. In fact, reports made by NHTSA that use real-world data has proven these system's reliability and longevity (NHTSA has reported that 30-year-old airbags have performed perfectly well in collisions).

Different types of airbag systems

- Frontal airbags - The driver airbag is located in the steering wheel while the passenger airbag is located in the dashboard in front of the passenger's seat. Mandatory in the USA since the 1999 model year in all cars, light trucks and vans, they are designed to inflate in moderate-to-severe frontal crashes to prevent a person's head and chest from contacting hard structures in the vehicle. Newer airbags have safety belt and weight sensors and use algorithms to decide whether to deploy the bag in a given crash.
- Side airbags – There are two main types of side airbags, side torso airbag and curtain airbag: these inflate from the doors of the car if the impact sensors detect a lateral collision to prevent people's heads and chests from contacting parts of the vehicle. Because of the small space between an occupant and the side of the vehicle, they typically are smaller than frontal airbags and must deploy quickly. USA government doesn't specifically mandate side airbags, but automakers have been including them as standard equipment to meet a federal regulation on side-impact that requires all 2018 or newer vehicles to have a certain level of head and torso protection for all occupants and to prevent occupant ejection through side windows (in India, side airbags will be offered on all cars as 6 airbags will be made mandatory).
- Knee airbags - Knee airbags are a new safety feature provided by some manufacturers. These are found beneath the steering column for the driver and below the glove box for front passengers to help prevent leg injuries in crashes.

As technology advances, manufacturers are finding new ways to integrate airbags into vehicles. Some new innovation include: Far-side airbag, introduced by General Motors in 2013, these inflate in a side crash between the front two occupants during a lateral collision to protect against head contact between passengers and drivers; seatbelt airbags, not as common as other airbags, introduced in 2011 by Ford, they are installed directly in seat belts; pre-crash external side airbag system, developed by ZF, designed to reduce crash forces on a vehicle during side crashes, deploys a large external airbag from under the side sill of the vehicle to cover the driver and rear passenger doors: there are currently no production vehicles with this technology.[14]

[14] https://www.iihs.org/topics/airbags, accessed 18th November 2023

Photo taken from: [15] it shows all the existing type of airbag

4.2.2.2 Number of vehicles produced annually

An interval estimate of the number of cars produced globally from 2023 to 2028 was obtained by cross-referencing data obtained from S&P Global's forecast and Alix Automotive Parter's "Global Automotive Outlook 2023 "report. The two firms, which specialize in automotive consulting and their respective studies are globally recognized and considered among the most important barometers of automotive industry trends worldwide. The following table shows S&P Global's estimated 10.2023 production figures for both Light and Medium-Heavy Vehicles, divided by geographic area.

LV + M-HV 01.2024	2022	2023	2024	2025	2026	2027	2028
Europe	16.438.666	18.463.157	18.086.464	18.047.054	17.956.567	18.385.098	18.509.366
Greater China	27.269.635	29.805.072	29.776.748	30.891.284	32.257.036	33.184.685	33.698.157
Japan - Korea	11.292.802	12.937.278	12.544.712	11.882.361	11.301.322	11.144.028	10.929.987
Middle East - Africa	2.295.982	2.344.822	2.319.385	2.409.195	2.642.964	2.734.324	2.745.234
North America	14.906.065	16.246.708	16.296.509	16.670.881	16.811.140	17.208.089	17.083.305
South America	3.031.116	3.046.042	3.184.112	3.421.850	3.549.883	3.791.174	4.021.503
South Asia	10.259.562	10.434.158	10.714.245	11.161.951	11.782.609	12.268.795	12.649.792
Total	85.493.828	93.277.237	92.922.175	94.484.576	96.301.521	98.716.193	99.637.344

Tab. 4.1 – Estimation of the total number of light, medium and heavy vehicles computed by S&P Global - Source: S&P Global Mobility, Data compiled January 2, 2024.

[15] https://www.automotivesafetycouncil.org/safety-technologies/passive-safety/airbags/

The following table that cross-references data from the two reports, which allows for a range of values for estimation:

	2022	2023	2024	2025	2026	2027	2028	CAGR
MIN	85.016.728	85.000.000	88.000.000	94.484.576	96.301.521	98.716.193	99.637.344	2,68%
MAX	85.493.828	93.277.237	92.922.175	98.000.000	100.000.000	101.000.000	111.000.000	4,45%

Tab. 4.2 – Estimation Light, Medium-Heavy's vehicles Production Forecast 2023-2028

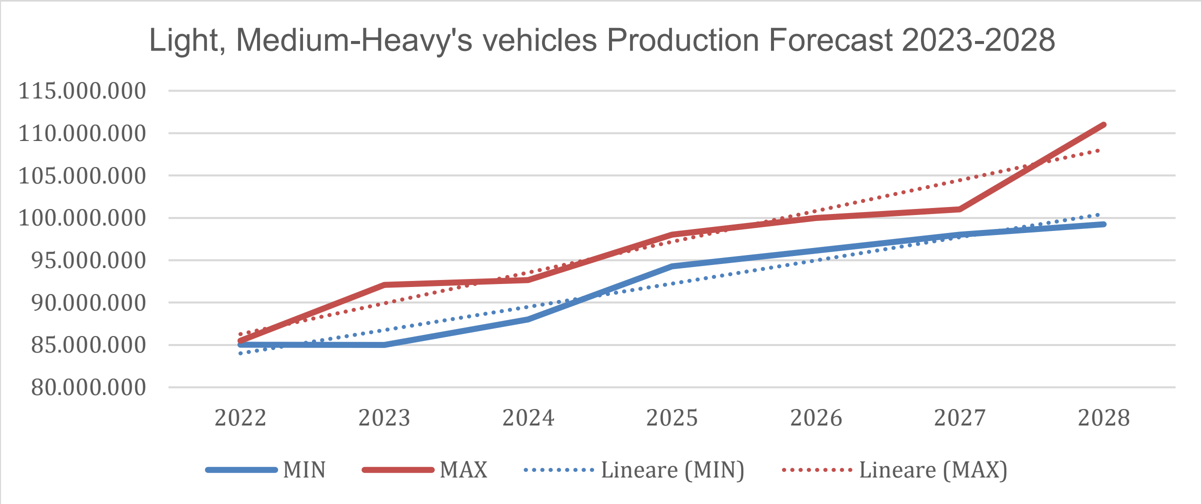

Fig. 4.1 *Light, Medium-Heavy's vehicles Production Forecast 2023-2028, considering two possible scenarios.*

An average annual growth in car production of 2.61 percent and 3.17 percent in the worst and best scenarios, respectively, is observed in the two scenarios. Improvements due to the gradual return to 2019 volumes, after the heavy slowdowns in demand and thus production caused by the pandemic, as shown in the following graph, which depicts the trend of car production from 2000 to 2022, but which is assumed to be reached only in 2025 (a surrounding of 90 million vehicles).

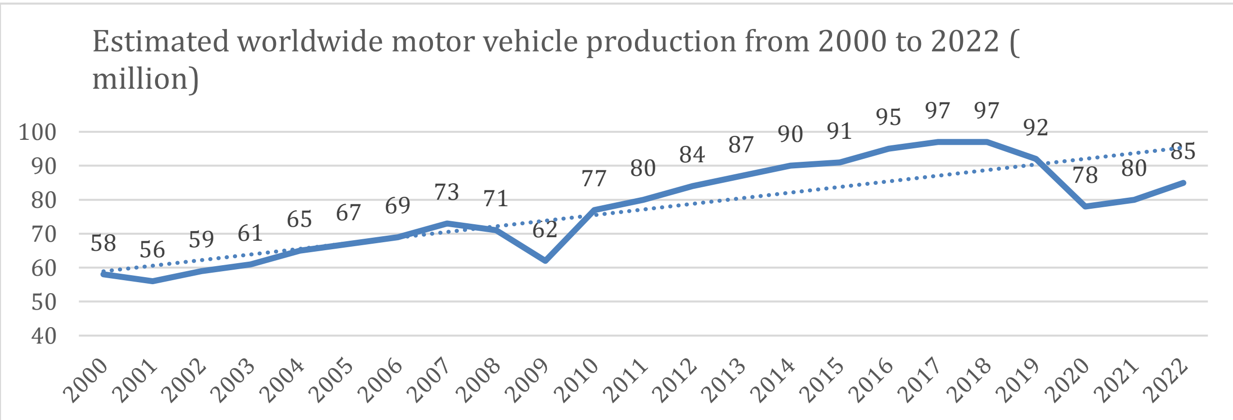

Fig. 4.2 Trend of worldwide vehicle production from 2000

4.2.2.3 Airbag's recalls

Occasionally, the energy required to quickly inflate airbags can cause injury to people sitting too close to the airbag before it deploys: NHTSA estimates that during 1990-2008 more than 290 deaths were caused by frontal airbag (National Center for Statistics and Analysis, 2017), nearly 90 percent of the deaths occurred in vehicles manufactured before 1998, and more than 80 percent of people killed were unbelted or improperly restrained. Today, thanks to changes in government requirements, serious injuries from properly functioning airbags are rare. In 2013, a series of deaths and injuries associated with defective airbag inflators made by the Takata Corporation led the National Highway Traffic Safety Administration (NHTSA) to order the ongoing "Takata airbag recall", involving at least 19 different automobile manufacturers with an estimated 67 million vehicles recalled by 2022[16]. According to IHIS about 100 million inflators have been recalled worldwide and of that number, 11 million have yet to have their frontal airbags replaced, mostly installed in 2002-15 model year cars. This value will be considered when computing the total number of airbags that will be manufactured in the future.

The Takata recalls originally impacted vehicles equipped with ammonium nitrate-based inflators: due to the fact that sodium azide could release toxic fumes, the company tried to replace it with tetrazole, which proved much more expensive, and then eventually developed a propellant using ammonium nitrate (NH4NO3), much cheaper. But ammonium nitrate-based inflators have a distinct flaw because the chemical can become more volatile over time when exposed to moisture and high temperatures, so inflators with long-term exposure to hot and humid climate conditions could rupture during deployment, sending shrapnel debris toward the occupants. "A Dec. 3, 2019, Safety Recall Report identifies the defect as the inflator's foil seal tape, leaking tape seals can cause moisture to enter the inflator, degrade the chemical propellant." [17] As of December 2022, the defect has caused 33 deaths worldwide and more than 400 reported injuries. The NHTSA has specifically stated that the ammonium nitrate-based propellants may not be suitable for inflator designs due to the unknown effects of climate impact, and different manufacturers claimed that they will not use ammonium-nitrate inflators.

Moreover in 2019 and 2020 NHTSA announced new airbag recalls which involves Takata Non-Azide Driver inflators (NADI) which do not contain stabilized ammonium nitrate propellant but NADI 5-Aminotetrazole (5-AT). The successor company to Takata, Joyson Safety Systems (JSS), confirmed the safety risk in certain inflators that were supplied globally (which is the same injury risk that prompted the broader Takata airbag recall). Vehicles containing NADI inflators were manufactured

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16 H.R. Blomquist, Air Bag Inflator Rupture, https://www.nhtsa.gov/sites/nhtsa.gov/files/documents/exhibit_a-blomquist_report_0.pdf
17 Source: https://www.nhtsa.gov/more-takata-air-bags-recalled

by the likes of Toyota, BMW, Audi, Honda, Mitsubishi and BMW, for a total amount of 2.821.673 airbags that still need to be replaced.[18]
In the context of the market research, these have been added to the total count of to the number of airbags annually produced and installed in newly produced vehicles. in the forecast period and it motivates why these chemicals have been excluded from the TAM calculation.

4.2.2.4 TAM computation

The calculation of the TAM is now presented, based on the considerations made earlier. Specifically, the prediction of the number of cars produced will be multiplied by the average number of airbags considered in the previous sections, in which the rationale for the choice is presented. In detail, attention is drawn to the fact that, unless they explode, there is no need to replace an airbag over the lifetime of the vehicle, and that the estimated number of airbags subject to recall were summed evenly over the 5 years considered.

4.2.2.4.1 Total number of airbags produced

Avg number of airbag		**2**	**4**	**6**
2022	85.016.728	170.033.456	340.066.912	510.100.368
2023	85.000.000	181.470.279	351.470.279	521.470.279
2024	88.000.000	187.470.279	363.470.279	539.470.279
2025	94.484.576	200.439.431	389.408.582	578.377.735
2026	96.301.521	204.073.321	396.676.362	589.279.405
2027	98.716.193	208.902.665	406.335.050	603.767.437
2028	99.637.344	210.744.967	410.019.654	609.294.343
CAGR		2,46%	2,53%	2,56%

Tab. 4.2 - Minimum number of airbags to be produced, considering three possible scenarios (2, 4, or 6 airbags per vehicle)

[18] Honda, company’s website, January 2020, https://hondanews.com/en-US/honda-corporate/releases/ statement-by-american-honda-regarding-nadi-airbag-inflator-recall

Considering the upper range of the estimated number of cars results in a total number of airbags to be produced equal to:

Avg number of airbag		2	4	6
2022	85.493.828	170.987.656	341.975.312	512.962.968
2023	93.277.237	198.024.753	384.579.227	571.133.701
2024	92.922.175	197.314.629	383.158.979	569.003.329
2025	98.000.000	207.470.279	403.470.279	599.470.279
2026	100.000.000	211.470.279	411.470.279	611.470.279
2027	101.000.000	213.470.279	415.470.279	617.470.279
2028	111.000.000	233.470.279	455.470.279	677.470.279
CAGR		2,99%	3,08%	3,11%

Tab. 4.3 - Maximum number of airbags to be manufactured, considering three possible scenarios (2, 4, or 6 airbags per vehicle)

4.2.2.4.2 Estimation of unit price

The estimation of the price of propellants was done by researching the market sales prices of the main producers of the chemicals, selected by referring to the PubChem website and considering both proposed prices in marketplaces and by asking for specific quotations. Economies of scale were not considered since the price proposed for the purchase of a fixed quantity of the substances, 100g, corresponding to the amount of propellant needed to generate enough gas to inflate a standard-sized airbag was selected. This price, identified by averaging the prices offered by different manufacturers, was then used to calculate the cost of airbag propellant. The currency used is the U.S. dollar.

Propellant	Quantity	Avg Price	Firms
Sodium azide	100g	$ 0,586	TciChemicals; OakwoodChemical; SigmaAldrich; Strem Chemicals, Inc.; PanReac Applichem; ThermoFisherScientific; Santa Cruz Biotechnology, Inc.
Guanidine Nitrate	100g	$ 0,208	OakwoodChemical; SigmaAldrich; Santa Cruz Biotechnology, Inc.

The amount of propellant needed in an airbag with a volume of 67L is about 139g of sodium azide and 93 of guanidine nitrate, respectively, while for a 35L airbag it is 59g of sodium azide and 49.5 of guanidine nitrate, resulting in a price per airbag of:

- Sodium azide: $81.45 for a volume of 67L; $34.66 for a volume of 35L;
- Guanidine nitrate: $19.32 for a volume of 67L; $10.29 for a volume of 35L;

Finally, TAM is calculated as the total number of airbags × price of propellant per individual airbag.

The lower end of the range is initially considered:

TAM Guanidine Nitrate Min	TAM (2 airbag/car)	TAM (4 airbag/car)	TAM (6 airbag/car)
Avg number of airbags	2	4	6
Price/airbag USA	$ 19,32	$ 19,32	$ 19,32
2022	$ 3.285.046.370	$ 6.570.092.740	$ 9.855.139.110
2023	$ 3.506.005.787	$ 6.790.405.787	$ 10.074.805.787
2024	$ 3.621.925.787	$ 7.022.245.787	$ 10.422.565.787
2025	$ 3.872.489.804	$ 7.523.373.820	$ 11.174.257.837
2026	$ 3.942.696.559	$ 7.663.787.330	$ 11.384.878.101
2027	$ 4.035.999.485	$ 7.850.393.182	$ 11.664.786.880
2028	$ 4.071.592.759	$ 7.921.579.731	$ 11.771.566.704

4.4 - TAM of propellant implied in airbag's inflation, considering the minimum estimation of vehicle's production and three possible scenario and an average price based on USA-standard airbag modules and production's prices

The upper extreme:

TAM Guanidine Nitrate MAX	TAM (2 airbag/car)	TAM (4 airbag/car)	TAM (6 airbag/car)
Avg number of airbags	2	4	6
Price/airbag USA	$ 19,32	$ 19,32	$ 19,32
2022	$ 3.303.481.514	$ 6.606.963.028	$ 9.910.444.542
2023	$ 3.825.838.225	$ 7.430.070.662	$ 11.034.303.100
2024	$ 3.812.118.629	$ 7.402.631.471	$ 10.993.144.313
2025	$ 4.008.325.787	$ 7.795.045.787	$ 11.581.765.787
2026	$ 4.085.605.787	$ 7.949.605.787	$ 11.813.605.787
2027	$ 4.124.245.787	$ 8.026.885.787	$ 11.929.525.787
2028	$ 4.510.645.787	$ 8.799.685.787	$ 13.088.725.787

4.5 - TAM of propellant implied in airbag's inflation considering the maximum estimation of vehicle's production and three possible scenario and an average price based on USA-standard airbag modules and production's prices

Chosen guanidine nitrate as reference the propellant, this gives a TAM in 2023 in the range: $10,074,805,787 to $ 11.034.303.100, and a projection over the next 5 years to 2028 of a TAM in the range of $11.771.566.704 to $13,088,725,787.

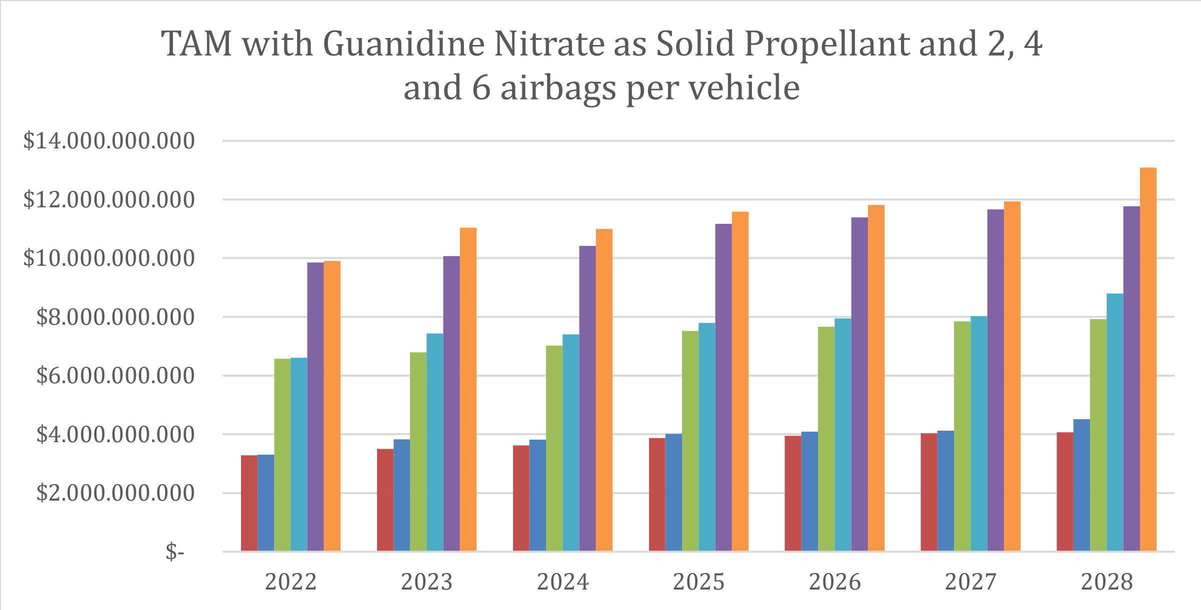


Fig. 4.3 TAM of propellants in airbags, considering both the three different scenarios (2, 4 and 6 airbags per vehicle) and the interval estimate derived from the vehicle's production

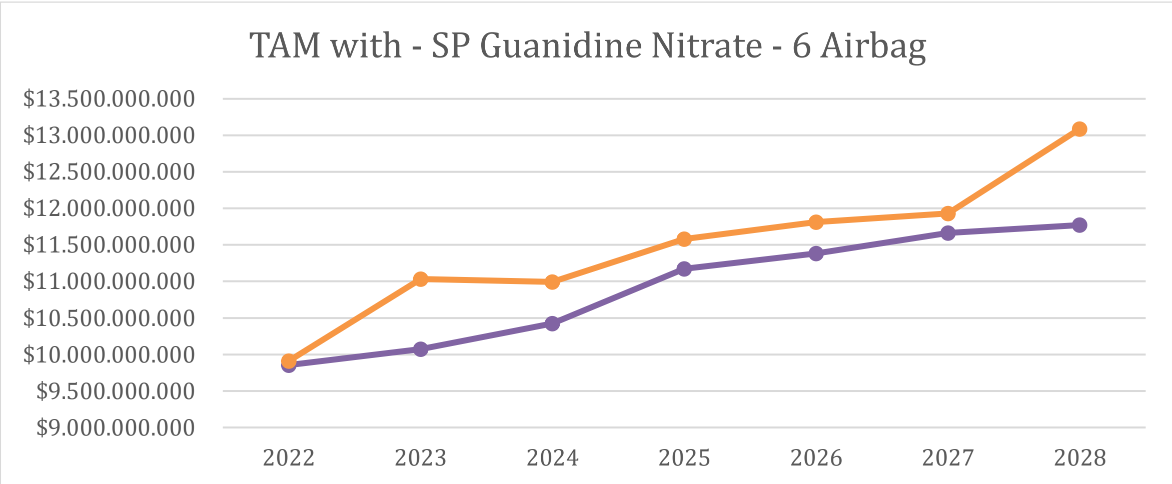


Fig. 4.4 TAM of Guanidine Nitrate assuming an average number of 6 airbags per car and both extremes of the range derived from the estimated vehicle's production

Since airbags are considered an intermediate good, or an input used in the production of a final good, industry demand is driven by the demand for new vehicles and by light-medium-heavy vehicle production volume. In fact, as auto production increases after the collapse caused by covid-19 pandemic, over the five years to 2028 the production and revenues of the car airbag manufacturing industry is expected to rise as well. Moreover, factors such as government regulations (countries starting to formulate laws to make the implementation of airbags mandatory, as seen with India) and safety rating mechanisms like the New Car Assessment Program (NCAP), increasing awareness of the importance of vehicle safety and consequentially more willingness to spend on protection systems, are expected to play a significant role in determining the growth of the demand for airbag modules during the forecast period. Geographically, while EU and North America are expected to grow back to pre-pandemic levels, Asia Pacific is imposing itself as significant region contributing to the market growth of automotive airbags because of the increasing manufacturing of vehicles in countries like Cina and India. Key players in the global market are Joyson Safety Systems, Autoliv Inc., ZF Friedrichshafen AG, Trw Airbag Sys Gmbh and Arc Automotive Inc.

A critical aspect that must be considered in the market analysis is the technological advancement that the industry has witnessed in recent years: as for passive safety systems the introduction of smart airbags, rear-seat airbags, pedestrian airbags, are a game-changing development but it must be noted that these products are still in the testing phase and it’s not clear how many manufacturers are implementing them in their vehicles, so have not been taken into account in determining the average number of airbag in cars, but have to be considered as the principal technological advancements of the product in the near future.
Furthermore, it must be observed how they will be implemented on the rising electric and autonomous vehicles and how they will synergies with the inclusion of advanced technological features like active safety systems as occupant sensors, anticipatory crash technologies and rollover & side impact protection: these may inhibit growth for passive safety, or they will cooperate to enhance safety.
Finally, it must be noted that only cars have been considered, while the introduction of airbags in new segments as two-wheelers may provide growth opportunities for the market players.

4.2.2 SAM

For the calculation of the SAM Service Addressable Market, the European market was selected as the reference market, taking into consideration the initial state of the technology in question and the fact that it is the highest level of detail for which it was possible to find information on car production in the period 2023-2028. The calculation of the number of cars produced in Europe uses as previously the forecasts provided by S&P Global and AlixPartner, applying to the latter, for which only global aggregate estimates are available not divided by geographic area, the market percentages obtained from the S&P Global report, thus obtaining an intervallic estimate.

Vehicle Production (L+M+H)	MIN	MAX
2022	16.202.639	16.438.666
2023	16.774.497	18.463.157
2024	17.780.440	18.086.464

2025	18.047.054	18.680.690
2026	17.956.567	19.061.929
2027	18.385.098	19.252.548
2028	18.509.366	21.158.741
CAGR	2,23%	4,30%

Tab 4.6 - Estimate of the number of V-M-H vehicles produced in Europe in 2022-2028

The procedure used is the same as that used to calculate the TAM: the number of cars produced was multiplied by the average number of airbags in a car considering three different possible scenarios, that is, a number equal to either 2, or 4, or 6 cars in an airbag, for the reasons explained above. Differently from the TAM, however, a smaller airbag volume of 35L was considered, resulting in a smaller amount of propellant needed: keeping the same average price obtained from the manufacturers resulted in a lower price per airbag of $34.66 for sodium azide and $10.29 for guanidine nitrate, respectively. Guanidine nitrate, which is currently the most common propellant, is again considered as the reference propellant, and the price used is assumed to remain constant throughout the period considered.

Guanidine Nitrate MIN		SAM		SAM		SAM
Avg number of airbags		2		4		6
Price/airbag EU	$	10,29	$	10,29	$	10,29
2022	$	333.375.140	$	666.750.280	$	1.000.125.420
2023	$	345.141.322	$	690.282.643	$	1.035.423.965
2024	$	365.838.964	$	731.677.928	$	1.097.516.893
2025	$	371.324.633	$	742.649.266	$	1.113.973.899
2026	$	369.462.830	$	738.925.661	$	1.108.388.491
2027	$	378.280.010	$	756.560.020	$	1.134.840.030
2028	$	380.836.869	$	761.673.738	$	1.142.510.606

Tab 4.7 - SAM considering the Minimum estimate of number of cars produced in Europe, an average price of $10,29 and three different scenarios (2, 4, 6 airbag/vehicle)

Considering the upper end of the range of cars produced in Europe:

Guanidine Nitrate MAX	SAM		SAM		SAM	
Avg number of airbags	2		4		6	
Price/airbag EU	$	10,29	$	10,29	$	10,29
2022	$	338.231.471	$	676.462.942	$	1.014.694.413
2023	$	379.886.102	$	759.772.204	$	1.139.658.306
2024	$	372.135.508	$	744.271.016	$	1.116.406.524
2025	$	384.361.926	$	768.723.852	$	1.153.085.779
2026	$	392.206.047	$	784.412.094	$	1.176.618.142
2027	$	396.128.108	$	792.256.215	$	1.188.384.323
2028	$	435.348.712	$	870.697.425	$	1.306.046.137

Tab 4.8 SAM considering the Maximum estimate of the number of cars produced in Europe, an average price of $10,29 and three different scenarios (2, 4, 6 airbag/vehicle)

This results in a SAM in the range of $1.035.423.965 - $1.139.658.306 in 2023 and $1.142.510.606 - $1.306.046.137 in 2028, with a CAGR of 1.31% in the worst-case scenario and 1.95% in the best-case scenario.

4.2.3 SOM

The computation of the Service Obtainable Market picks up from the identified SAM and was obtained by applying again the innovation theory proposed by W.J. Abernathy and J.M. Utterback in their work: “A Dynamic Model of Process and Product Innovation”. Although the state-of-the-art of airbag's inflators technology involves the use of solid propellants, they are not composite, it is therefore assumed that Research&Development and especially intensive testing is needed, considering the increasing attention on safety issues and the numerous tests that cars have to pass in order to be considered reliable. It should also be taken into account that the development of technologies in the field of safety in cars is more directed toward the improvement of active prevention and protection systems, so great attention is being paid to sensors and automatic activation of the braking system, while in active protection systems, in addition to the development of new types of airbags, hybrid inflators and automatic airbag activation technologies, smart and dual-stage airbags, which use compressed gas in addition to pyrotechnic material, are now common. This is to indicate that research in the field of propellants used for gas generation in airbag’s inflators seems to have reached an established technological standard, or a so-called dominant design in the Innovation’s Theory, as illustrated by the small number of patents found in the Patent Landscape Report. In fact, subsequently a brief analysis of the patent landscape will be conducted, in order to evaluate if recent improvements of the design and manufacturing of inflators involve composite solid propellants. The dataset was selected through the patent database "The Lens" and applying the following query:

- (title: "solid propellant" OR abstract: "solid propellant" OR title: "propellant grain" OR abstract: "propellant grain" OR title: "solid grain" OR abstract: "solid grain" OR title: "composite propellant" OR abstract: "composite propellant") AND (full_text: airbag) AND earliest_priority_claim_date: [2000-01-01 TO 2023-06-31]

The set of keywords "solid propellant, propellant grain, solid grain, composite propellant" was applied to the title and the abstract of the patents, the temporal scope was set to include only those patents who may still be relevant at the present day (considering that the typical lifespan of patents is 20 years), and finally the word "airbag" was searched throughout the full text to capture likely correlation between the technologies. The focus will be on the number of patents found and the applicants.
In total 64 patents were found by the query, the most recent dating back to 2020, 25 are actually granted patents, of which 24 are still active, while 38 are deemed as applications. Only 3 patents have been filed since 2019, and the trend shows a stagnating scenario for the technology: moreover, it must be noted that the patents identified might not directly propose innovative solutions embracing composite solid propellant and therefore should not be considered when evaluating the patent landscape for the presented production method. A much more detailed Patent Landscape Report will be discussed in a parallel thesis, while in the scope of this research the objective is to look for patents that might depict feasible applications of composite solid propellant as gas generators in airbags, in order to obtain more information to support the assumptions made when evaluating the SOM.

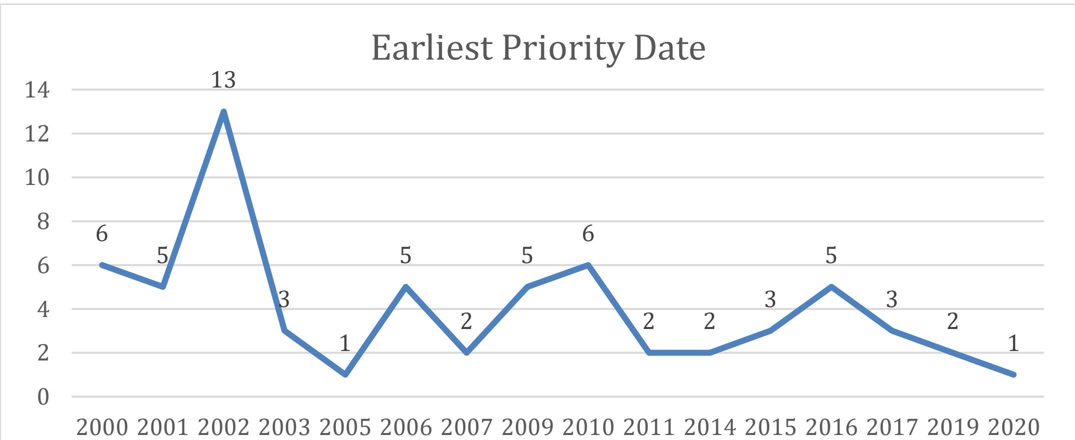
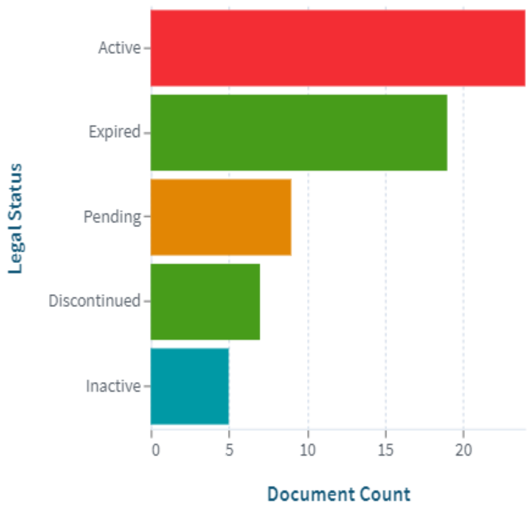
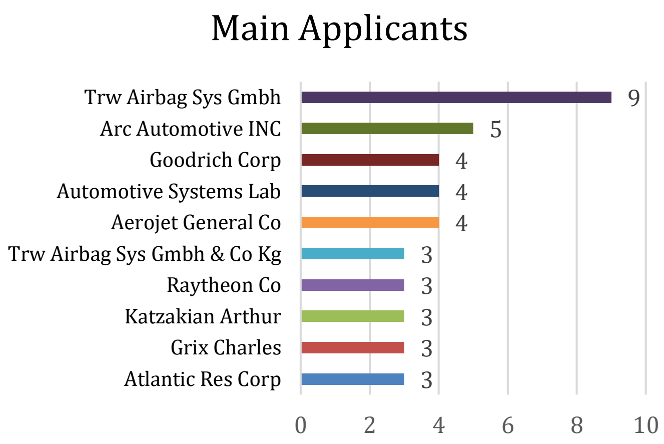


Fig. 4.5 Trend of patents involving composite solid propellant and airbags through 2000 to 2023.

- CN 110891924 A – "Gas generating device for inflating airbag comprising secondary powder charge for reducing risk of explosion", Patent Application Discontinued, Earliest Priority: Apr 3, 2017, Applicant: Seva Tech.
  The invention relates to a gas generating device for inflating an airbag made up of a first chamber containing a pyrotechnic-solid propellant composition. 19
- US 10046728 B2 – "Inflator, especially for a Vehicle Safety System, Airbag Module, Vehicle Safety System and Method of Manufacturing and Operating an Inflator", Legal Status: Active, Earliest Priority: Jul 30, 2015, Applicants: Trw Airbag Systems Gmbh
- US 2013/0200601 A1- "Solid Fuel Body, Gas Generator, Module Having a Gas Generator, and Pyrotechnic Drive Unit", Patent Application, Legal Status: Active, Earliest Priority: Oct 29, 2010, Applicants: Niehaus Michael, Lorbeer Bernd, Berg Torsten, Trw Airbag Sys Gmbh
- EP 2408650 B1 – "Solid Propellant/liquid Type Hybrid Gas Generator", Granted Patent, Legal Status: Active, Earliest Priority: Mar 16, 2009, Applicants: Arc Automotive Inc
- US 6616183 B2 – "Gas generator", Granted Patent, Legal Status: Expired, Earliest Priority: Apr 25, 2001, Applicants: Trw Airbag Sys Gmbh & Co Kg





Looking at the applicants transpired, some of the most important players in the airbag's production market emerged as the most relevant innovators (Trw Airbag Sys Gmbh and Arc Automotive Inc. in particular), but it cannot be stated that composite solid propellants are commonly employed as gas generators in inflators, and neither that the industry is evolving towards a feasible application of this technology: while alternatives to sodium azide have been widely explored in recent years, it seems that guanidine nitrate and tetrazoles proved to be effective and reliable replacements (nonetheless sodium azide is still widely implemented) and represent now the dominant design of the product.

[19] CN 110891924 A – "Gas generating device for inflating airbag comprising secondary powder charge for reducing risk of explosion"

For these reasons, we assume a market penetration index identical to that assumed for the fire safety systems market, with 0% assigned to the first 2 years until 2025, and then a gradual increase up to 2% in 2028, an assumption made by reckoning innovation curves and considering a state of early adoption.

Guanidine Nitrate MIN	Market penetration	SOM	SOM	SOM
Avg number of airbags		2	4	6
Price/airbag EU		$ 10,29	$ 10,29	$ 10,29
2023	0%	$ -	$ -	$ -
2024	0%	$ -	$ -	$ -
2025	0%	$ -	$ -	$ -
2026	1%	$ 3.694.628	$ 7.389.257	$ 11.083.885
2027	1,5%	$ 5.674.200	$ 11.348.400	$ 17.022.600
2028	2%	$ 7.616.737	$ 15.233.475	$ 22.850.212

4.9 - SOM of propellants for airbag's inflation's market segment (lower interval)

Considering the upper extreme of the interval:

Guanidine Nitrate MIN	Market penetration	SOM	SOM	SOM
Avg number of airbags		2	4	6
Price/airbag EU		$ 10,29	$ 10,29	$ 10,29
2023	0%	$ -	$ -	$ -
2024	0%	$ -	$ -	$ -
2025	0%	$ -	$ -	$ -
2026	1%	$ 3.922.060	$ 7.844.121	$ 11.766.181
2027	1,5%	$ 5.941.922	$ 11.883.843	$ 17.825.765
2028	2%	$ 8.706.974	$ 17.413.948	$ 26.120.923

4.10 - SOM of propellants for airbag's inflation's market segment (upper interval)

The SOM obtained is then 0 in 2023 and up to 2025, and then according to the estimate comes in the range of $22.850.212 - $26.120.923 in 2028.

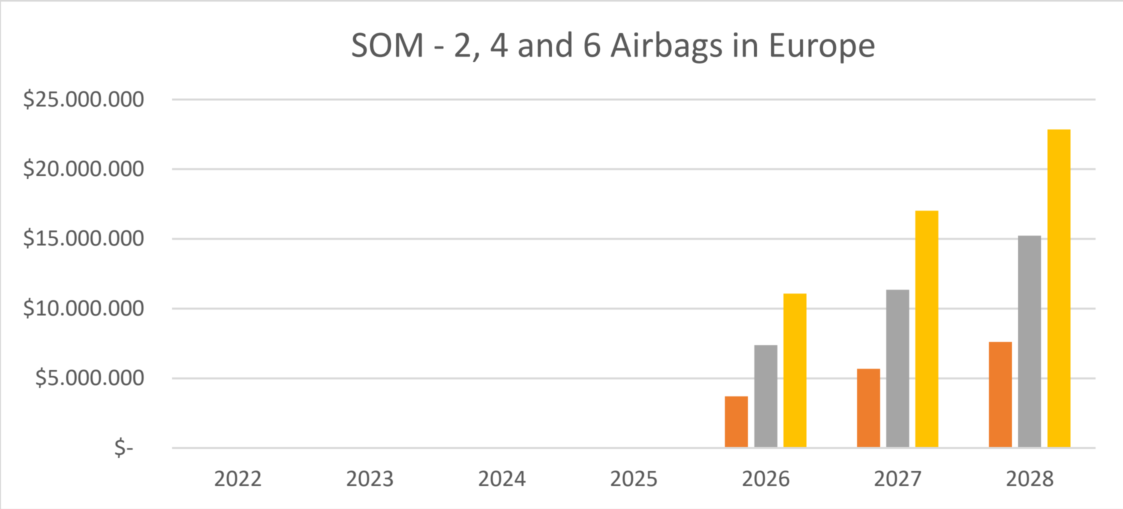


Fig. 4.6 – Estimation of the SOM for the years 2024-2028, considering 3 possible scenarios (2, 4, 6 average number of airbags per vehicle) and Guanidine Nitrate-based propellants chosen as reference

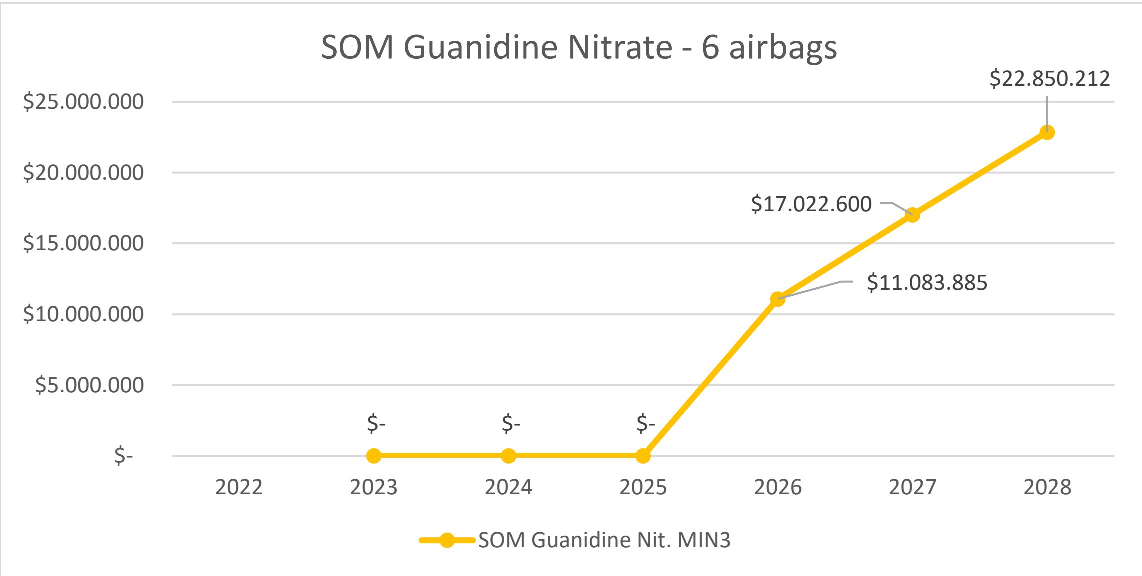


Fig. 4.7 – Detail of the SOM's estimation for the years 2024-2028 with 6 airbags per vehicle and Guanidine Nitrate-based propellants chosen as reference

5. Fire Extinguishers

Fire extinguishers are portable firefighting devices designed to control and extinguish fire principles by expelling an extinguishing agent through the pressure of a propellant gas, usually compressed and contained in tanks within them, thus ensuring the safety of buildings and vehicles. Attention will be paid exclusively to the technology that allows the expulsion of extinguishing agents, since this would be the only possible application of solid propellants in this product, that is, as gas generators by combustion of pyrotechnic nature.

The main extinguishing agents are water, carbon dioxide, foam and chemical powders, while the most common propellants used are air or inert gases, among which nitrogen, carbon dioxide and rarely helium and argon are used; generally, nitrogen or air is used in permanent contact with the extinguishing agent (permanent pressure or pressurized fire extinguishers), while carbon dioxide is often stored in closed cylinders and brought into contact with the extinguishing agent only immediately before use (internal or external cylinder fire extinguishers). Fire extinguishers using CO2 as the extinguishing agent turn out to be peculiar cases because they are self-propelled: it is therefore clear that the operation of fire extinguishers by means of propellant gas generated by pyrotechnic-type explosive charges would be limited to fire extinguishers that make use of chemical foams and powders, since solutions with water and carbon dioxide at most makes use of pressurized gas contained in tanks contiguous to those of the extinguishing agents themselves. Therefore, the feasible degree of market penetration of solid propellants in this sector would be very small, considering also that these types of extinguishing agents are suitable to fight only limited types of fire classes, A, B and C, according to the classification defined by CEN (European Committee for Standardization) depending on the type of fuel. Finally, due to the nature of the estimation method used, the distinction of fire extinguishers by fire class, by method of use (manual, remotely operated, or automatic), or by size and transportability (portable or wheeled) will not be taken into account, since it is not relevant to the research.

5.1 Estimation’s Method

Given the difficulty of applying the top-down approach in calculating the TAM for this type of product, the analysis of the fire extinguisher market was carried out by seeking the major global companies producing fire extinguishers and fire safety services and summing their turnover whenever available on ORBIS, the database available to Polytechnic’s students that holds information on a large number of companies and other entities across the globe, one of the most powerful data resource on private firms, or AIDA, it’s counterpart for firms based in Italy. Where the information on ORBIS was deemed to be unreliable, either because it was not

complete or too far back in time and therefore not accurate, the data was collected relying on the publicly available financial statements of large corporations, and in this case an attempt was made to obtain the most detailed figure possible by drill-down of the information contained in the documents (since the financial statements of large corporate groups are consolidated, the most atomic figure available in the document itself was considered whenever possible, particularly if the turnover was presented already segmented by production sectors, such as the "Fire&Security" segment of Carrier Global Corporation); if the data from ORBIS and the information in the financial statements were discordant, it was preferred to use the data from the latter. Alternatively, missing information was found through web surfing by relying on information provided either by the companies themselves in their official communication channels such as websites or brochures, or from websites deemed reliable based on comparisons with official information.
Because the TAM, Total Addressable Market, expresses the global market demand, the perimeter of the companies considered is on a multinational scale, and comprises the following geographic areas: Asia, including Japan, China, and India; the U.S.; Europe, including Italy, Spain, Germany, France, and the UK.
Proceeding with the estimation of SAM, it was decided to filter all the non-Italian based companies: in this case, the SAM calculated is a subpart of the TAM in which geographical assumptions are made.

The analysis performed initially does not consider a key piece of information: as evident by the description of the product above, the use of solid propellants is not widespread in the fire extinguisher market, and research on their possible application in firefighting systems is still in its early stages: this observation will be evaluated in subsequent SOM estimates.

Taking into account the previous statement, inferred after extensive research on the fire extinguisher sub-components and customer-validation activities carried with industry' experts representing some of the italian companies detected, the SOM will be estimated considering the common theory of innovation's breakthrough and a brief analysis of the current state of the technological advancements in this domain, specifically if solid propellants application in the context of fire protection's systems have been recently investigated by researchers or industry operators, made through an overview of intellectual property rights, particularly patents.

5.2 Market Research

5.2.1 TAM and SAM

The TAM of the fire suppression systems market was calculated by summing the revenues in 2023 earned by the major international fire extinguisher companies. It should be noted that the total turnover is not only the result of the sale of that product but also of the offering of complementary products and services, such as prevention and detection systems (alarms and sensors) and services such as installation support, monitoring and maintenance. For this reason, whenever possible (mainly for large corporations), was considered the atomic figure corresponding to the market segment closest to that of fire extinguisher production. The list of companies considered is presented below.

Companies with headquarters outside of Italy:

- API GROUP CORPORATION - Corporation holding some of the most important fire extinguisher companies including Chubb Fire and Security, acquired on January 1, 2022, from Carrier Global Corp, Premium Fire and VFP Fire Systems. The turnover considered comes from the "Safety Services" segment excluding the revenues obtained from HVAC (ventilation and space heating products), therefore considering only the values belonging to the "Life Safety" section, which also includes the profits of the aforementioned companies. It obtained a 120% surge compared to 2021 mainly due to the acquisitions made, particularly the one of Chubb. Looking at the available revenue figures (up to 2020), there is a steady growth of revenues in this segment of about 200M per year, even though EBITDA dropped from 13,8% in 2021 to 10.8% of total net revenues in 2022 mainly due to inflation and supply chain disruptions (Consolidated Financial Statements 2022 p.47,79).[20]
- CARRIER GLOBAL CORP. - Corporation holding the KIDDE Group S.p.A., a historic British fire extinguisher manufacturer. Net sales of the Fire&Security segment for the year 2022 was considered (Consolidated Financial Statements 2022 p. 29, 65). Carriere registers a decrease in Net Sales of 35% compared to 2021 due to the sale of the Chubb Fire and Security business to API Group Corporation, but excluding the results due to Chubb's profits, the segment shows an increase of 6% compared to the previous year. [21]
- RESIDEO TECHNOLOGIES INC. – A spin-off of Honeywall International Inc, from the "Products and Solutions" operational business sector presented in

[20] API Group, Annual Report 2022, accessible from: https://s201.q4cdn.com/155847588/files/doc_financials/2022/ar/APG-2022-Annual-Report_Final.pdf

[21] Carrier, Annual Report 2022, accessible from: https://ir.carrier.com/static-files/a1cbf4fd-899a-4810-8bf1-e166a3cff5ff

the consolidated financial statements. (Consolidated Financial Statements 2022 p. 50-51) was derived the profit of the “Saferty and Security” segment, which amounts to $913 M in 2022 and includes the financial results of First Alert and BRK starting April 2022.[22]

- JOHNSON CONTROL – Ireland-based multinational corporation that became Johnson Control International following a merger in 2016 with Tyco International, one of the global leaders in fire safety systems, it is the holding company of some of the major firms in this market, including Tyco, Ansul, Pyrochem and Chemguard. The data presented report publicly available refers to the “Fiscal Year ended September 30, 2022”. An important statement reported on page 5 of the public consolidated financial statements claims as follows: "In fiscal 2022, approximately 37% of sales originated from product offerings, 39% of sales originated from installations and 24% of sales originated from service offerings," (Consolidated Financial Statements 2022, p. 5) which gives an indication of the breakdown of total sales between products sold and services offered. Considering this information, it was possible to obtain a somewhat more detailed figure of the turnover derived solely from the sales of fire protection systems: following the partition proposed by the company, only 37% of the profits reported in the "Fire&Security" segment were considered (Consolidated Financial Statements 2022, p. 67 of the financial statements), [23] obtaining a value of about $876M.
- RYAN FIREPROTECTION INC
- FIRETRACE INTERNATIONAL LLC
- FIKE CORP
- AMAREX CORP
- BUCKEYE FIRE EQUIPMENT CO
- JL INDUSTRIES
- RUSOH, INC.
- Britannia Fire LTD
- SAFELINCS LIMITED
- SURVITEC GROUP LIMITED
- CEASEFIRE INDUSTRIES PRIVATE LIMITED
- KANEX FIRE
- HATSUTA SEISAKUSHO CO.,LTD
- YAMATO PROTEC CORPORATION
- MORITA HOLDINGS CORPORATION – Financial results for this Japanese Corporation are available for the full year 2022, disaggregated by segment,

[22] Resideo, 2022 Annual Report, accessible from: https://s27.q4cdn.com/999644081/files/doc_financials/2022/ar/2023-proxy-statement-and-10-k.pdf
[23] JOHNSON CONTROLS INTERNATIONAL PLC, Annual Report 2022, accessible from: https://investors.johnsoncontrols.com/~/media/Files/J/Johnson-Controls-IR/quarterly-reports/2022/fy2022-fourth-quarter-form-10-q-jci-plc.pdf

specifically related to “Fire Protection Equipment & Systems (FPES)” containing the business lines of fire extinguishers and firefighting equipment. made up 26% of the company's total sales in 2022, achieving net sales of 20.8 billion Yen, up from the 19.4 B achieved in 2021, yielding a market share of 36% according to the available report. [24]

- FLAMESTOP AUSTRALIA PTY. LTD.
- NATIONAL FIRE FIGHTING MANUFACTURING FZCO
- SURELAND INDUSTRIAL FIRE SAFETY LIMITED - For this Chinese company the ORBIS code is available, but the data showed dates back to 2018, so it was not considered in the total TAM tally.
- CHINA FIRE-FIGHTING GROUP CO., LTD - For this Chinese company the ORBIS code is available, but the data showed dates back to 2017, so it was not considered in the total TAM tally.
- MINIMAX VIKING GMBH – Company resulting from the merger of Minimax and the Viking Group.
- PRESTO AB + JOCKEL BRANDSCHUTZTECHNIK-SERVICE GMBH – On 02/08/2023 it was announced that the Swedish company Presto would acquire Jockel, the leader in the German fire protection systems market. The turnover considered was then the sum of that of the two companies, which is available on the official website of Presto AB.[25]
- FEUERSCHUTZ JOCKEL GMBH & CO. KG – A company that is part of the Jockel Group but will remain independent after the aforementioned acquisition by Presto AB.
- BAVARIA FIRE FIGHITING SOLUTIONS (BAVARIA HOLDING)
- OGNIOCHRON S.A.
- ANSUL – Belgian company separate from "Ansul" part of Johnson Control
- DESAUTEL
- EXTINTORES FAEX SL – leading company in the Spanish market

In the following table (tab 5.1) is reported for each company the revenues registered in 2022 (the most recent year for which data was consistently available), the headquarter location, and the source consulted. As previously stated, ORBIS is one of the world’s most reliable data resource on private companies, however because the turnover of most of the companies considered was not available on ORBIS apart of 2022, it was not possible to make an analysis of the global market trend in recent years and assess its reaction to contextual events as the COVID-19 pandemic. Moreover, for the large corporation the data reported in the financial statement was selected, while in other cases (e.g. Chinese firms) the information was not present: those companies are still listed down below but only the Orbis BVD is pointed out.

[24] https://www.morita119.com/en/ir/pdf/2023_0516.pdf
[25] Presto AB, company’s webpage, https://www.presto.se/en-eu/nyheter/presto-acquires-the-german-market-leader-jockel-to-become-the-leading-european-safety-services-group

Company	Revenues 2022	Country	Source	IDOrbis (BVD)
AMEREX CORP	$155.000.000	USA	ORBIS	US120135196L
ANSUL	$36.900.000	Belgium	ORBIS	BE0441557163
API GROUP CORPORATION	$4.025.000.000	UK	Financial report	US981510303
BAVARIA FIRE FIGHITING SOLUTIONS		Germany	Zoominfo.com	DE2190335425
Britannia Fire LTD		UK	Zoominfo.com	GB06935191
BUCKEYE FIRE EQUIPMENT CO	$26.000.000	USA	ORBIS	US138445491L
CARRIER GLOBAL CORP.	$3.570.000.000	USA	Financial report	US834051582
CEASEFIRE INDUSTRIES PRIVATE LTD	$18.900.000	India	ORBIS	IN0001944537
CHINA FIRE-FIGHTING GROUP CO., LTD		Cina	ORBIS	CN9463393661
DESAUTEL	$210.000.000	France	ORBIS	FR955503982
EXTINTORES FAEX SL	$12.400.000	Spain	ORBIS	ESB50723790
FIKE CORP	$258.000.000	USA	ORBIS	US136358211L
FIRETRACE INTERNATIONAL LLC	$32.300.000	USA	ORBIS	US150036113L
FLAMESTOP AUSTRALIA PTY. LTD.		Australia	Zoominfo.com	AU060627965
HATSUTA SEISAKUSHO CO., LTD	$155.000.000	Japan	ORBIS	JP6120001150363
Jhonson Controls	$875.790.000	Ireland	Financial report	IE543654
JL INDUSTRIES	$17.600.000	USA	ORBIS	US128750289L

Kanex Fire		India	Zoominfo.com	
MINIMAX VIKING GMBH	$2.440.000.000	Germany	ORBIS	DE2390324453
MORITA HOLDINGS CORPORATION	$139.246.868	Japan	Financial report	JP7120001019062
NATIONAL FIRE FIGHTING MANUFACTURING FZCO	$100.000.000	UAE	ORBIS	AE0000038368
OGNIOCHRON S.A.	$33.000.000	Poland	ORBIS	PL070909888
PRESTO AB + JOCKEL BRANDSCHUTZTECHNIK-SERVICE GMBH	227.800.000 €	Sweden	Presto's website	SE5561120584
RESIDEO TECHNOLOGIES INC.	$913.000.000	USA	Financial report	US825318796
Rusoh, inc.	$7.670.000	USA	ORBIS	US280650659L
RYAN FIREPROTECTION INC	$53.000.000	USA	ORBIS	US130416443L
SAFELINCS LIMITED	$32.500.000	UK	ORBIS	GB04715788
SURELAND INDUSTRIAL FIRE SAFETY LIMITED		Cina	ORBIS	CN9458009745
SURVITEC GROUP LIMITED	$139.000.000	UK	ORBIS	GB00905173
YAMATO PROTEC CORPORATION	$227.000.000	Japan	ORBIS	JP7120001013874
Total	**$13.705.106.868**			

Tab 5.1 List of non-italian firms who produce fire extinguishers, their revenues in 2022, the source consulted and their identification code in the database.

The following graph shows the aforementioned companies, excluding the big corporations, which hold some of the most notable players in the fire protection market: Chubb, Premium Fire, VFP Fire Systems, First Alert, BRK Electronics, Tyco, Ansul, Pyro-Chem, Chemguard, and KIDDE. As stated, their revenues are encompassed in the turnaround of their respective holder.

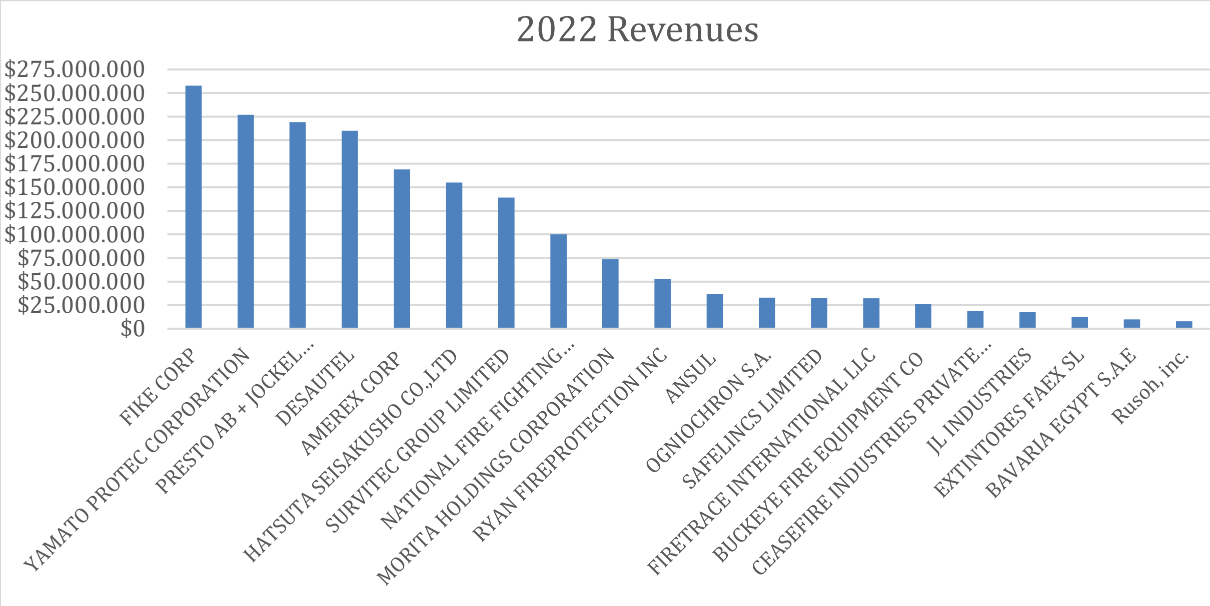


Fig. 5.1 Histogram of independent firms in the global fire protection market

Subsequently, firms located in Italy were considered: the TAM is the sum of the italian and non-italian company's revenues, while the SAM will be expressed by the former. The following is the list of the companies located in Italy:

- Emme Antincendio S.r.l.
- Cea Estintori Spa
- Gi.Bi Estintori S.r.l.
- Gielle Industries
- Sanco - Sistemi Antincendio Costruzioni Spa
- Azg Antincendio S.r.l.
- Anaf Fire Protection Spa
- Sanal Italia Societa' A Responsabilita' Limitata
- M.B. S.r.l.
- Universo S.r.l.
- Csq Estintori S.r.l.
- Air Fire Spa.
- Biogenesis S.r.l
- Camm Antincendio S.r.l.
- Fas Estintori Societa' A Responsabilita' Limitata
- Ama S.r.l.
- Gardenale Estintori S.r.l.
- Reflex Italy S.r.l.
- Ciodue Spa

Company	Revenue 2022	Source	ORBIS ID	ATECO CODE 2007
EMME ANTINCENDIO S.R.L.	$23.100.000	ORBIS	IT11208251006	282999
CEA ESTINTORI S.P.A.	$17.762.386	ORBIS	IT03574360370	282999
GI.BI ESTINTORI SRL	$427.000	ORBIS	IT12304070969	282999
GIELLE INDUSTRIES	$5.035.380	ORBIS	IT05157680728	282999
SANCO - SISTEMI ANTINCENDIO COSTRUZIONI S.P.A.	$33.500.000	ORBIS	IT01842700039	263021
AZG ANTINCENDIO S.R.L	$10.300.000	ORBIS	IT11996460157	432203
ANAF FIRE PROTECTION S.P.A	$47.321.525	ORBIS	IT02610340180	282999
SANAL ITALIA S.r.l.	$687.414	ORBIS	IT03391580796	432203
M.B. SRL	$37.954.439	ORBIS	IT12869830153	282999
Universo Srl	$4.560.436	ORBIS	IT01052510672	282999
CSQ ESTINTORI S.r.l.	$5.037.641	ORBIS	IT02144240682	282999
AIR FIRE SPA.	$51.312.399	ORBIS	IT06305150580	432203
Biogenesis S.r.l.	$7.864.167	ORBIS	IT07573060725	432203
PII SRL	$6.093.020	ORBIS	IT08908100152	282999
CAMM ANTINCENDIO S.r.l.	$699.904	ORBIS	IT13264380158	432203
FAS ESTINTORI S.r.l.	$4.127.550	ORBIS	IT13776241005	282999
AMA S.R.L.	$3.789.543	ORBIS	IT04738940487	282999
Gardenale Estintori S.r.l.	$804.797	ORBIS	IT01389230291	282999
Reflex Italy S.r.l.	$2.869.124	ORBIS	IT02018540209	469000
CIODUE SPA	$20.544.476	ORBIS	IT00753370154	432203
Total	**$283.791.201**			

Tab. 5.2 List of Italian-based fire extinguishers' producers

In the previous table besides the revenues and the ORBIS BVD, which identifies the various firms in the database, the ATECO code is presented, which is an alphanumeric combination that identifies an economic activity, the numbers (two to six digits) represent, with varying degrees of detail, the specific segments and subcategories of the sectors. It was pivotal to the identification of the italian players in the market, specifically to select only those companies that actually produce fire extinguishers (code 282999 stand for “Manufacture of other mechanical equipment and other general-purpose machinery” and includes “manufacturer of gas generators and thermal lances”. Only few firms that have a different code are considered, after having ascertained that those were in fact producers of the product).

Finally, the TAM and SAM of the fire extinguisher’s market can be determined:

TAM (Total revenues)	$14.116.404.211
SAM (italian market)	$283.791.201

Tab. 5.3 TAM and SAM of fire extinguisher’s market

As already mentioned, for the calculation of the SAM Service Addreassable Market, it was decided to restrict the geographical area only to the italian market. The rationale behind this decision is due to the uncertainty on the practical application in this industry’ sector of the technology presented: in fact, preliminary market validation and customer validation analysis carried out by getting in touch with engineers and managers of some of the main Italian fire extinguisher firms showed that there are currently no plans to apply solid propellants in the fire suppression systems market. This statement will be further discussed later in the SOM calculation. Therefore, it was decided to consider initially a local market in which it would be possible to carry out R&D and introductory tests, a segment that in any case turns out not to be of negligible size: in fact, from the analyses carried out, the italian market appears to be of sufficient size for a potential introduction of the new technology, which at the moment would be disruptive.

The following table shows the trend over the past 5 years of the total turnover earned by the companies considered:

	2018	2019	2020	2021	2022
SAM	$209.220.645	$214.851.146	$234.756.755	$274.779.442	$283.791.201
Growth (%)	-	2,69%	9,26%	17,05%	3,28%

Tab. 5.4 trend of the italian fire extinguisher market in the last 5 years (2023 in not included because the data is still not available)

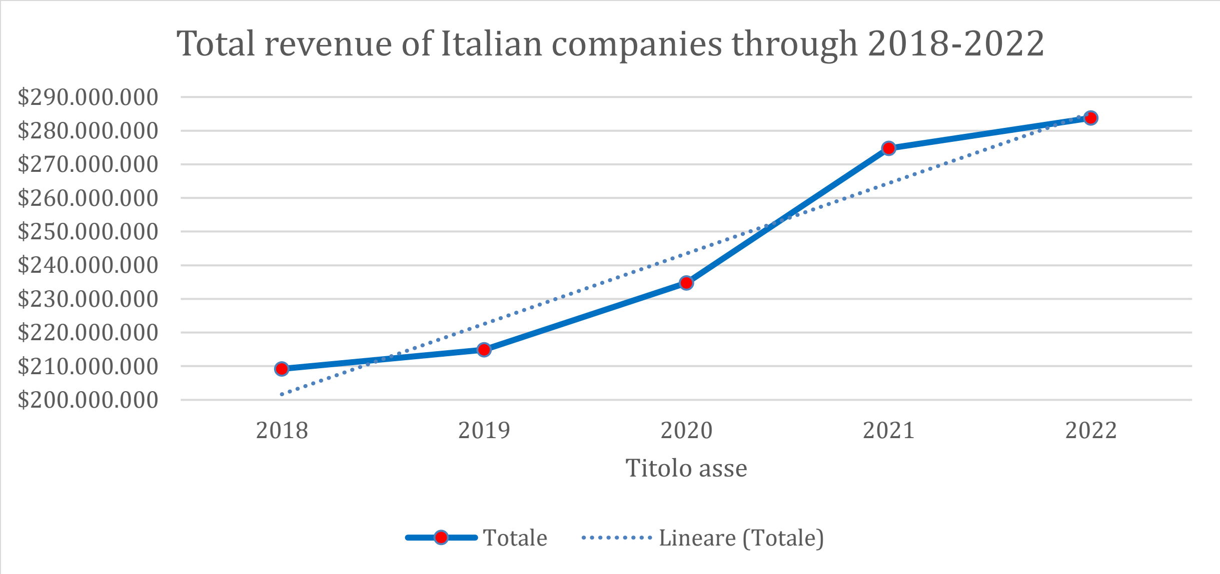


Fig. 5.2 Graph that shows the recent trend in the italian fire extinguisher's production market.

Rapid growth is observed in the years affected by the Covid-19 pandemic, with increases of 9% and 17% in 2020 and 2021 compared to previous years, and more contained growth in 2022. The CAGR will subsequently be calculated for the estimate future growth of the market.

5.2.2 SOM

As highlighted in the introduction of this section, the technologies concerning the activation of fire extinguishers implement CO2 and inert gases as main agents: research in this field has not seen notable evolutions in recent years given the effectiveness and reliability of the state-of-the-art technology, which is deemed to have achieved optimal safety standards.
It should also be considered that in general the use of intellectual property rights is very limited in this sector, since they are products subjected to approval by the Italian Ministry and in particular to the PED Directive (Pressure Equipment Directive) 2014/68/EU of the European parliament, which regulates "pressure equipment and assemblies which are new on the Union market at the time of their placing on the market, as confirmed also by the low number of outstanding patents involving the terms "propellant solid" and variants with "fire extinguisher," i.e., it is in fact testimony to the limited research on the application of such technology to the product under exam.

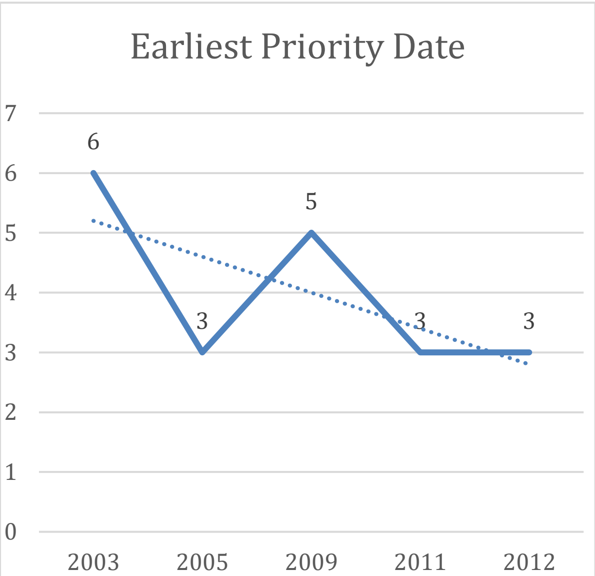
5.2.2.1 Solid Propellant and fire extinguisher patent landscape

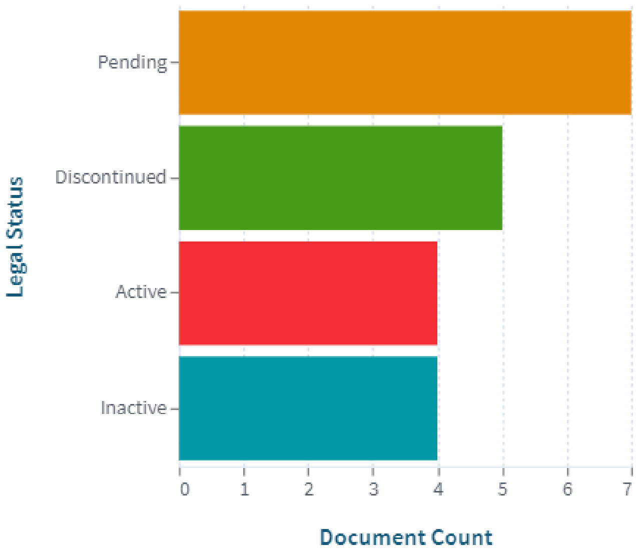
In this paragraph will be conducted a brief analysis of the patent landscape concerning fire extinguishers and solid propellant. As stated in paragraph 2.2, the objective is to determine through intellectual property rights if industry' players or the scientific research have been studying possible applications of solid propellant in fire protection's products. In order to proceed with the analysis, the dataset was obtained using the patent database The Lens and applying the following query:

- (title: "solid propellant" OR abstract: "solid propellant" OR title: "propellant grain" OR abstract: "propellant grain" OR title: "solid grain" OR abstract: "solid grain" OR title: "composite propellant" OR abstract: "composite propellant") AND (full_text: extinguisher) AND earliest_priority_claim_date:[2000-01-01 TO 2023-06-31]

The set of keywords "solid propellant, propellant grain, solid grain, composite propellant" was applied to the title and the abstract of the patents, the temporal scope was set to include only those patents who may still be relevant at the present day (considering that the typical lifespan of patents is 20 years), and finally the words "fire extinguishers" were searched throughout the full text, to make sure to capture the correlation between the two technologies. The focus will be on the total number of patents found, the applicants and the IPC code.

In total 20 patents were found by the query, the most recent ones dating back to 2012, only 5 are actually granted patents while 14 are still deemed as applications. Of those, 7 are still pending, while only 4 are active and 9 are either inactive or discontinued.



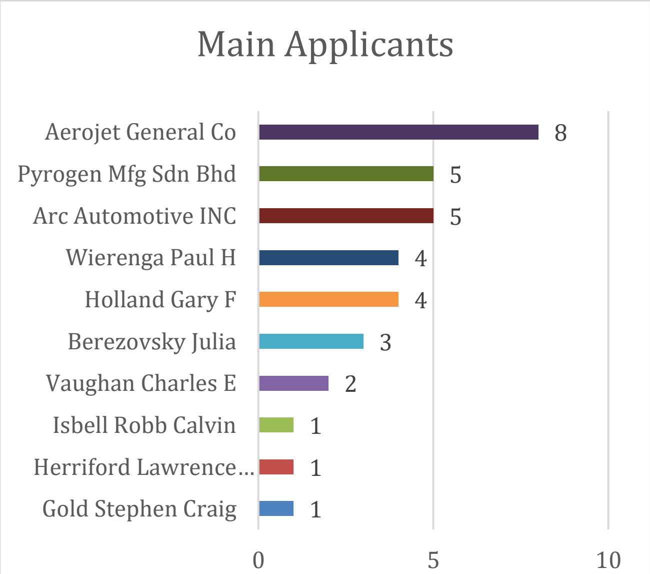


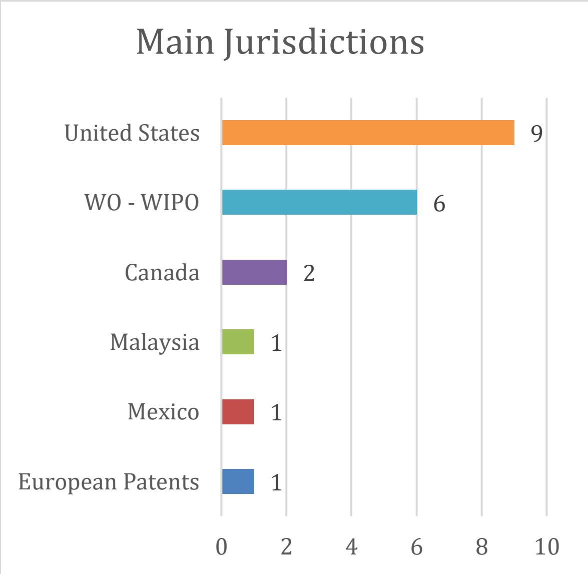
Looking at the granted patents, only three actually revolve around a potential application of solid propellant in fire extinguishers and just two are still active,

- US 9409045 B2 “Solid propellant fire extinguishing system”, Earliest priority in 2011, Applicants: Berezovsky Julia, Pyrogen Mfg Sdn Bhd
- MY 170386 A ”Portable Fire Extinguisher”, Earliest priority in 2012, Applicants: Pyrogen Mfg Sdn Bhd

Of the applicant and owners found, only Pyrogen Manufacturing SDN BHD, based in Malaysia, actually manufactures and distributes fire suppression systems and in particular seems to offer a non-pressurized fire protection system mainly for cars and buses, the so-called IPEX module, which uses a solid gas generator to expel an extinguishing powder [26] (which seems to be the industrial application of the patent mentioned US 9409045 B2, the details on the functionality of the technology will not be explored in this context).
Another feasible application of solid propellants as gas generators in fire extinguishers can be found on the following patent application, even if not granted:

- WO 2006/138733 A2 “Hybrid Fire Extinguisher for Extended Suppression Times, Earliest Priority: Jun 17, 2005, Applicants: Aerojet General Co, Vaughan Charles, Wierenga Paul, Holland Gary.
  (Aerojet GenCorp merged in 2013 with the former Pratt & Whitney Rocketdyne to form Aerojet Rocketdyne, one of the most important manufactures of rocket and electric propulsive systems for space, defense, and commercial applications)





From the brief analysis presented is evident that solid propellants are not commonly employed as gas generators in fire extinguishers and is plausible that they will not be featured in this product in the near future.

[26] https://pyrogenindonesia.com/wp-content/uploads/2018/03/Pyrogen-IPEX-Extinguishing-System-in-Vehicles.pdf

Therefore, considering this aspect, the calculation of the SOM was carried out selecting a time span of 5 years and following two possible scenarios: the innovation will not be accepted into the market in the period considered, and this evidently leads to a SOM equal to 0, or it will be accepted as disruptive technology. In this last case we follow the Abernathy-Utterback model of the development of innovations, represented by S-curves that express the rate of improvement in the performance of the technology and the rate of diffusion of the product cumulative over time: the two phenomena are distinct but related, both increase progressively and slowly in the first years thanks to improvements both in the technology itself through investments and R&D and in its knowledge and understanding by users. In the case in question, the diffusion of the product is estimated as the fraction of the total market turnover that the technology considered could obtain. Furthermore, given the conditions expressed above, only the initial phase of the two curves is considered, the one defined as "incubation": the practical application of solid composite propellants in fire extinguishers as an automatic activation method is not currently included in the state of the art of these products and would require in-depth Research & Development studies, numerous safety tests and approval by certifying bodies. Any companies interested in innovation would be classified following Rogers' 1963 model as "early adopters".

Now that the aleatory of the analysis conducted has been once again ascertained, we will consider the market diffusion curve, defined in this case as the fraction of turnover potentially achievable in the initial phase of the possible introduction of the technology. Taking the SAM previously obtained as a reference, the growth of the Italian fire extinguisher market is estimated over a period of 5 years, therefore up to 2028, calculating the CAGR obtained from the growth in turnover between the years 2018 and 2022 and projecting the same growth up to 2028 (the CAGR, Compounded Average Growth Rate, is the compound annual growth rate and represents the average percentage growth of a quantity over a period of time. In this case it indicates the average annual percentage growth of the total turnover of the Italian market). The CAGR therefore only provides an average estimate of market performance and above all refers to past years, so there are no guarantees that the estimated results will be obtained in the future.

The CAGR calculated as $CAGR = (F_n/F_0)^\wedge 1/n - 1$ where: F_n= Total revenue for 2022; F_0 = total turnover for 2018 and n = Number of periods considered, 5; A CAGR of 7.92% is obtained. Applying this CAGR to estimate the total turnover of the Italian market for the next 5 years we obtain:

2022	2023	2024	2025	2026	2027	2028
$283.791.201	$306.267.464	$330.523.847	$356.701.336	$384.952.082	$415.440.287	$448.343.157

We now consider the scenarios described for the calculation of the SOM:

• Worst case scenario: Solid composite propellants will not find application in fire extinguishers: the SOM will be 0 for all years considered.

• Best case scenario: the technology will give rise to a disruptive innovation which in the period considered, with reference to the S-curve from the model of innovation development, will still be in the incubation phase. Therefore, a market penetration of 0% is considered in the first 3 years until the threshold of 3% is reached in 2028.

	2023	2024	2025	2026	2027	2028
SAM	$306.267.464	$330.523.847	$356.701.336	$384.952.082	$415.440.287	$448.343.157
Market Index	0%	0%	0%	1%	2%	3%
SOM	$0,00	$0,00	$0,00	$3.849.520	$8.308.805	$13.450.294

Therefore, in the worst case scenario the SOM Service Obtainable Market is equal to $0, while in the best case scenario the estimated SOM is equal to $13,450,294 in 2028.

6. Conclusions

The research conducted within this paper involved a market analysis related to an innovative production method, additively manufactured solid propellants, for which a patent has been granted, with the intent to try to assess the economic potential of the new technology.
The invention covered in this thesis proved to be a viable alternative to the currently established and commercially available technologies. As explained in the introductory section of this paper, the invention proposed by the University's research group brings numerous benefits to both the industries implementing solid propellants as well as to the surrounding environment. The photopolymerized solid propellant turns out to be a product committed to provide high performance and inferior production costs, while also solving the problem of obtaining more complex geometries and making the compound less harmful, thanks to the elimination of toxic substances as isocyanates. These features, encapsulated and protected by patent, might help make the developed solution attractive to the market.
In this section a brief summary of the results of the TAM-SAM-SOM analysis performed for each market segment considered will be presented:

Launch Vehicles	2023	2022
TAM	$ 39.714.958	$ 66.261.694
SAM	$ 17.854.203	$ 52.053.114
SOM	$ 2.883.502	$ 8.406.720

Tab. 6.1 TAM-SAM-SOM of composite solid propellants in space rockets

Airbag	2023	2026	2028
Avg number of airbag	6	6	6
TAM	$ 9.855.139.110	$ 11.384.878.101	$ 11.771.566.704
SAM	$ 1.035.423.965	$ 1.108.388.491	$ 1.142.510.606
SOM	$ 0	$ 11.083.885	$ 22.850.212

Tab. 6.2 TAM-SAM-SOM of propellants in airbags inflators

Fire Extinguishers	2022	2023	2026	2028
TAM	$ 14.128.604.211			
SAM	$ 283.791.201	$ 306.267.464	$ 384.952.082	$448.343.157
SOM	$ 0	$ 0	$ 3.849.520	$ 13.450.294

Tab. 6.3 TAM-SAM-SOM of composite solid propellants in fire extinguishers

The main targets for the innovative photopolymerized solid propellant are definitely firms in the aerospace industry, specifically major producers of solid rocket engines, that may be interested in embracing the new technology to improve the performance of their rockets and achieve goals of more efficient space's launches.
The aerospace sector undoubtedly represents one of the most profitable industries, most importantly it is the one in which there is certainty about the exploitation of composite solid propellants, although at the same time it is also one of the most difficult to penetrate. This challenge is mainly attributable to the complexity and high specialization of the technologies involved, that could generate lock-in effects as the costs associated to investing and switching to new technologies could prevent a smooth change.
An additional critical issue, which affects all technological innovations, is that extensive initial market-entry investments are needed, as it requires a significant financial commitment for research, development, certification (fees for the granted patent), and large-scale implementation. These investments are necessary to solve a number of problems, such as fine-tuning production processes and complying with the stringent aerospace regulations. However, these investments represent a key step in overcoming initial challenges and creating a solid foundation for the long-term success in the market. For this reason, collaborations with companies in the industry could be beneficial to the pursuit of the established goal: primary contacts with companies identified as impactful players in the market segment have already been established.
Concerning the alternative market segments analyzed, airbags and fire extinguishers, the possibility of the implementation of the technology appears to be limited: not only companies in this sectors are often reluctant to replace established and reliable technologies currently in use with new and unfamiliar, also due to severe safety regulations imposed by institutional authorities, but also because from the market research and the patent landscape it's apparent that innovations in these sectors are focused on different technologies, like active safety systems in vehicles.

It was not possible to provide an early-stage financial planning, owing to the difficulties encountered when trying to estimate the cost of propellants manufactured with the proposed technology. Thus, considering the results obtained, even though partial and not comprehensive of numerous aspects of the market's segment (as sounding rockets or propellant produced for the testing phases of engines ad rockets) at the moment direct production and sale of solid propellant to aerospace companies through a spinoff assembled from the University's research group is not recommended.

However, the findings of the Patent Landscape Report suggest promising future prospects for the photopolymerized solid propellant. The aerospace industry is showing increasing interest in advanced and sustainable technologies worldwide, also in the propulsion segment as showed by several projects funded in recent years, exemplifications are the aforementioned Rheform project by the European Space Agency, ESA and the "Rapid Energetics & Advanced Rocket Manufacturing" (RE-ARM) program promoted by the U.S. Air Force Research Laboratory, that through the U.S. Air Force Strategic Funding Increase, or STRATFI agreement, granted a 60 million contract to X-Bow Systems, a startup that specializes in solid rocket propulsion to demonstrate additive manufacturing technologies and to help reduce the cost to produce propellants for rocket motors.
As an additional note, the following statement from X-Bow System's CEO and founder Jason Hundley must be reported, because it leaves the possibility of applying the technology to automobile's airbags disputable: to qualify for STRATFI awards, companies need private funding, government contracts and have to show plausible commercial applications for their technology, in this context Hundley affirmed the following: "we're currently focused on the aerospace side, but our manufacturing technology would be just as useful in the automotive sector once we get it mature, there are in-space solid rocket motor applications as well, separation systems and deorbit motors." [27]

Taken into account the existence of start-ups as the aforementioned X-Bow System, Ursa Major Technologies, and of well-established incumbents like Northrop Grumman and L3Harris's Aerojet Rocketdyne in USA and Avio S.p.A and its subsidiary Regulus S.p.A., the market strategy proposed is to follow a business model based on patent licensing or partnerships with aerospace's firms: collaborate with manufacturers of solid rocket engines in order to directly implement additively manufactured composite solid propellant into their rockets while providing consulting and technical support. Sharing knowledge and resources through licensing agreements or partnerships could accelerate the development of photopolymerized solid propellant, while providing a competitive advantage through access to cutting-edge technologies (e.g. 3D printing and UV-curing). Responsiveness to emerging industry needs could make additively manufactured solid propellant a driving force in addressing the most compelling challenges that space launcher's segment in the Space Economy is facing: minimize the costs-per-launch (and cost-per-kilo of payload), and enhance flexibility of the production line by obtaining grains that can be exploited for any size of rocket motors, allowing for rapid iteration thus reducing the time necessary to produce solid rocket motors.

[27] https://spacenews.com/x-bow-announces-60-million-stratfi-agreement/, accessed 10th February 2024

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