FROST & SULLIVAN

FINAL REPORT

Global Market Assessment on the Smart Glass and Safety-Tech Solutions Markets

14 December 2023

The Growth Pipeline™ Company
Powering clients to a future shaped by growth

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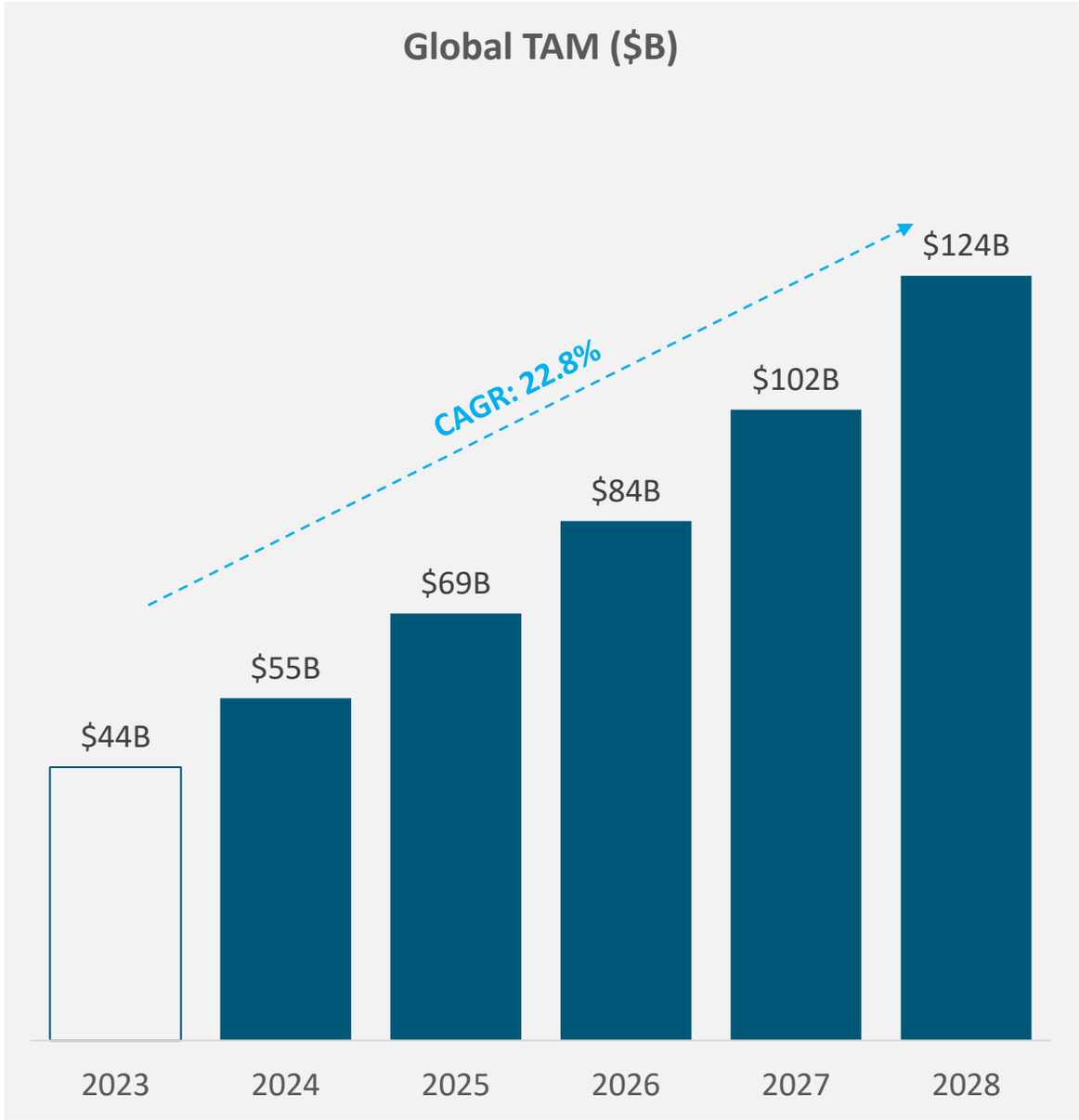
ACRONYMS

TAM	Total Addressable Market
EC	Electrochromic
LC	Liquid Crystal
SPD	Suspended Particle Devices
ADAS	Advanced Driver Assistance Systems
CMS	Camera Monitoring Systems

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

- Global TAM for Smart Glass and Safety-Tech is expected to grow from $44bn. in 2023 to $124bn. in 2028.
- Buildings segment is expected to be the major contributor both in terms of TAM (with $29bn.) in 2023 and growth (23.9%).
- Liquid Crystal (LC) is expected to have a major share for both the interior Buildings and Passenger Vehicle segments for its privacy-enhancing features and energy efficiency.
- Electrochromic (EC) is the preferred material for exterior building facades due to its adjustable transparency, effective light blocking, and aesthetic appeal.
- Suspended Particle Devices (SPD), the newest smart glass segment, is expected to see strong growth in both the Passenger Vehicle (32.8%) and Aeronautics (38.9%) segments.
- Both Buses and Trucks are expected to witness strong growth in Advanced driver assistance systems (ADAS) (21%), Camera Monitoring Systems (CMS) (24.1%), and Drive Protection Doors (21.9%).

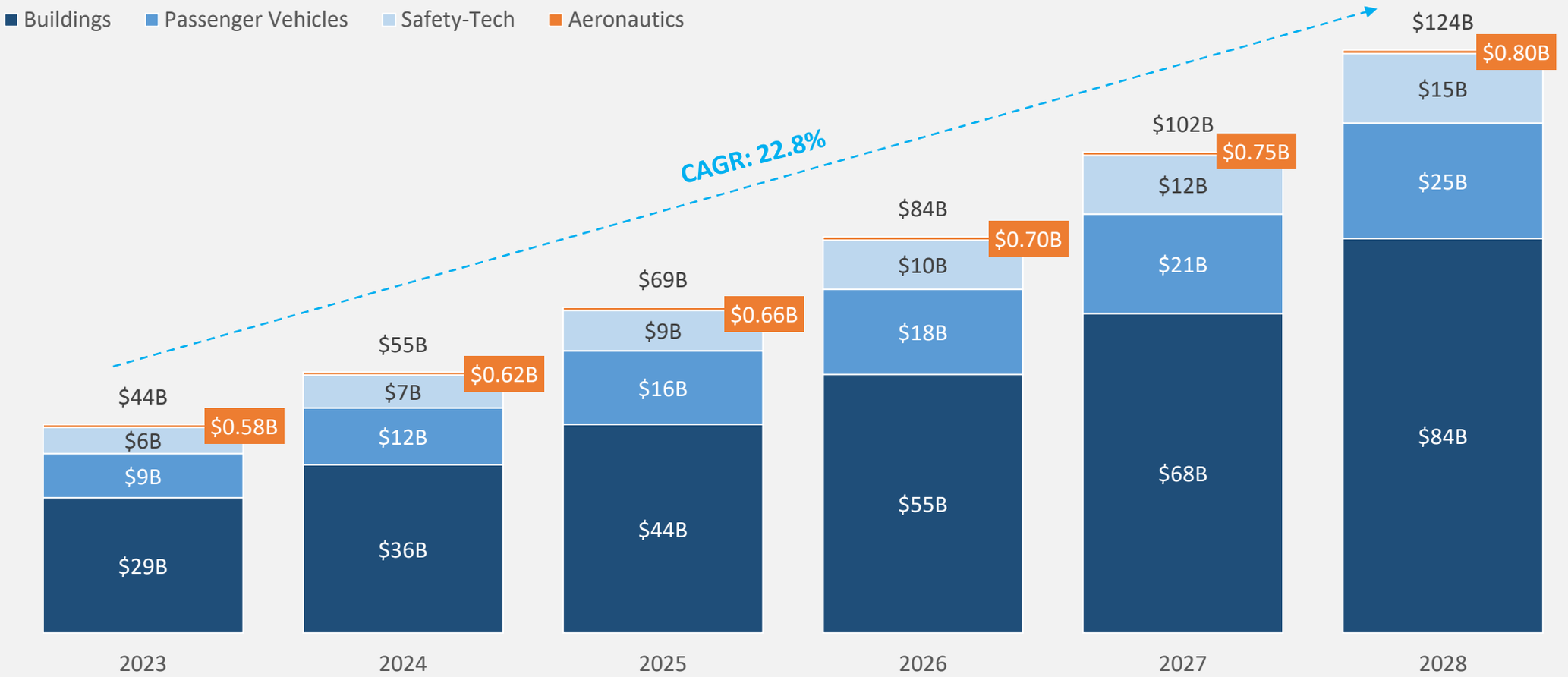


Source: Frost & Sullivan

GLOBAL TAM ANALYSIS

GLOBAL TAM: BY SEGMENT ($B)

Global TAM for Smart Glass and Safety-Tech in 2023 is expected to be around $44bn. and is expected to reach $124bn. in 2028 with CAGR of around 22.8%.



Notes

[1]For the Buildings, Passenger Vehicles, and Aeronautics segments, we consider Smart Glass

[2]For Safety-Tech (ADAS, CMS we considered Medium-Duty and Heavy-Duty Trucks and Buses; Drive Protection doors we considered buses only)

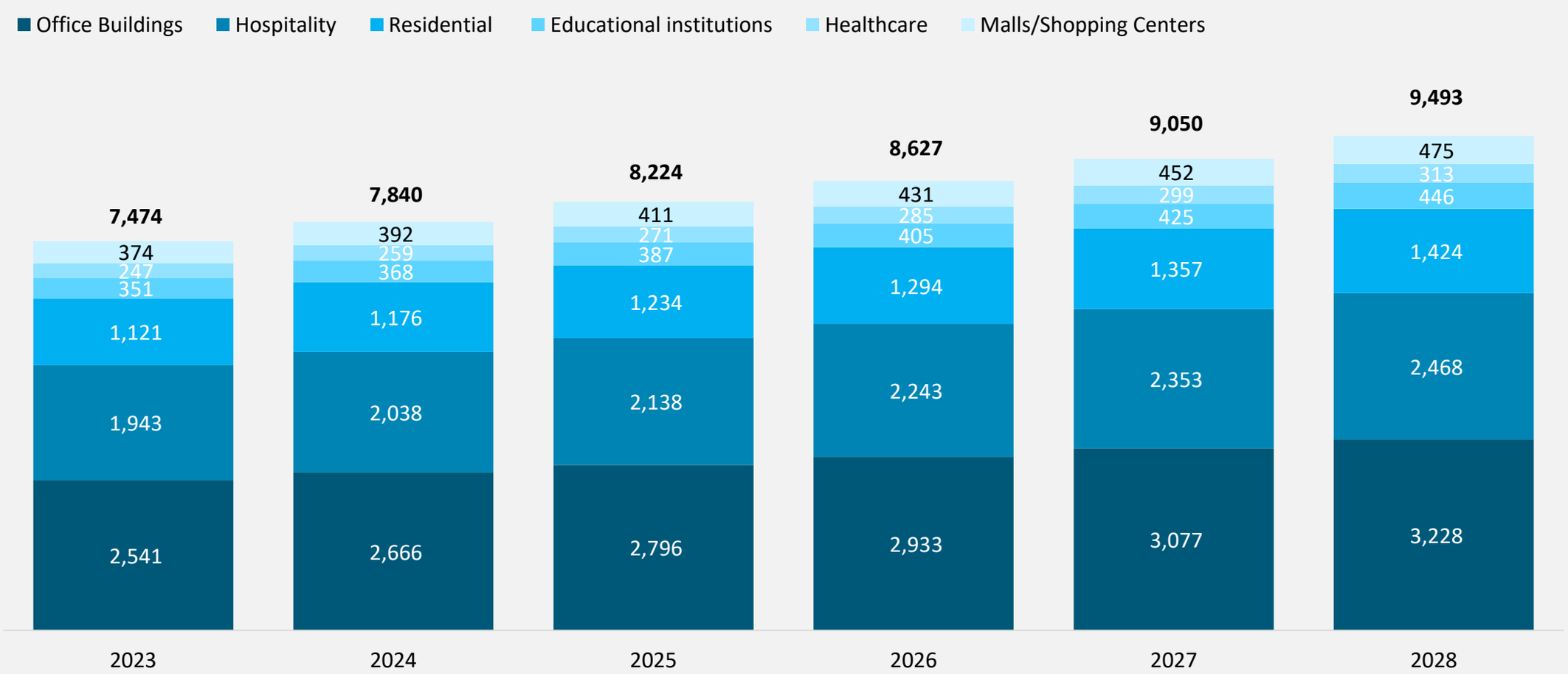
Source: Frost & Sullivan

GLOBAL TAM ANALYSIS:

BUILDINGS (Smart Glass)

GLOBAL BUILDINGS: GLASS VOLUME USED PER YEAR (million sq. mt.)

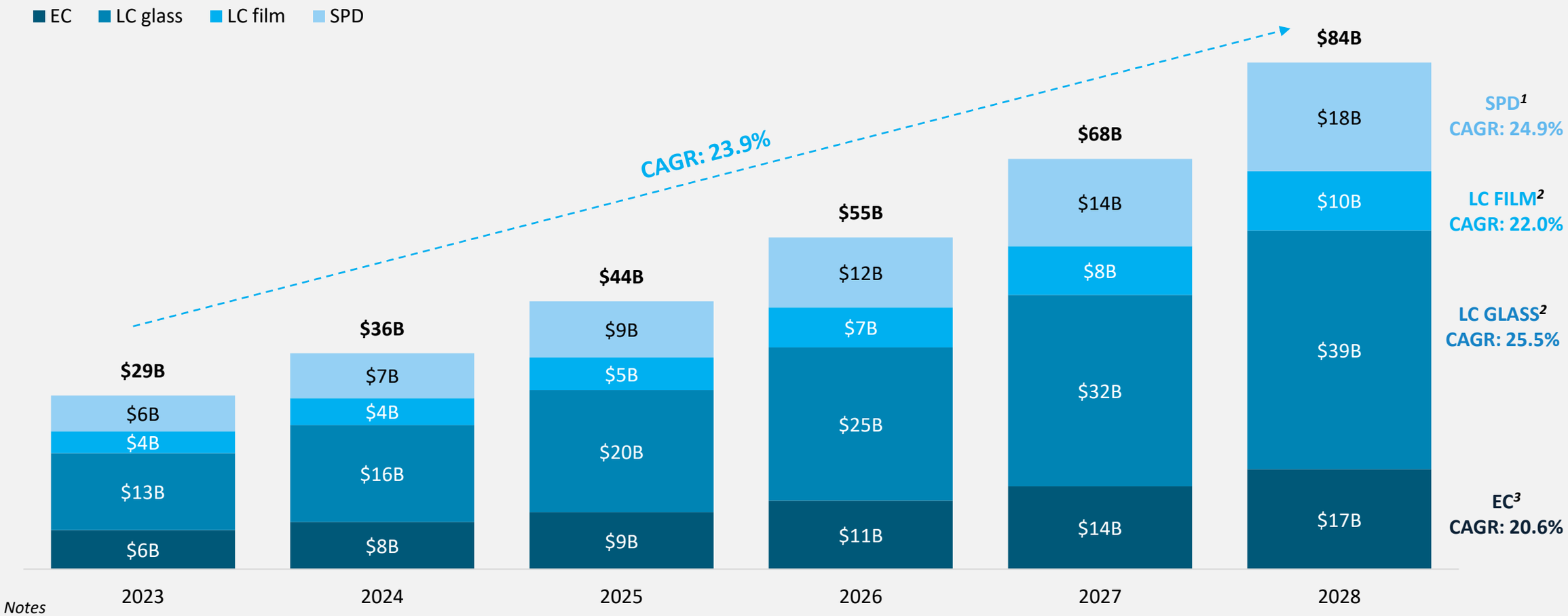
Global annual glass volume consumption in 2023 is expected to be around 7,474 million sq. mt. with Office buildings being major consumers of this market.



Source: Frost & Sullivan

GLOBAL BUILDINGS: TAM ($B)

Global Buildings smart glass (both exterior and interior) market in 2023 is expected around $29bn. with Liquid Crystal (LC) smart glass being the major contributor both in terms of TAM (with $13bn.) and growth (25.5%) from 2023-28.



Notes

[1]SPD: Suspended Particle Devices smart glass
[2]LC: Liquid Crystals smart glass and film
[3]EC: Electrochromic smart glass

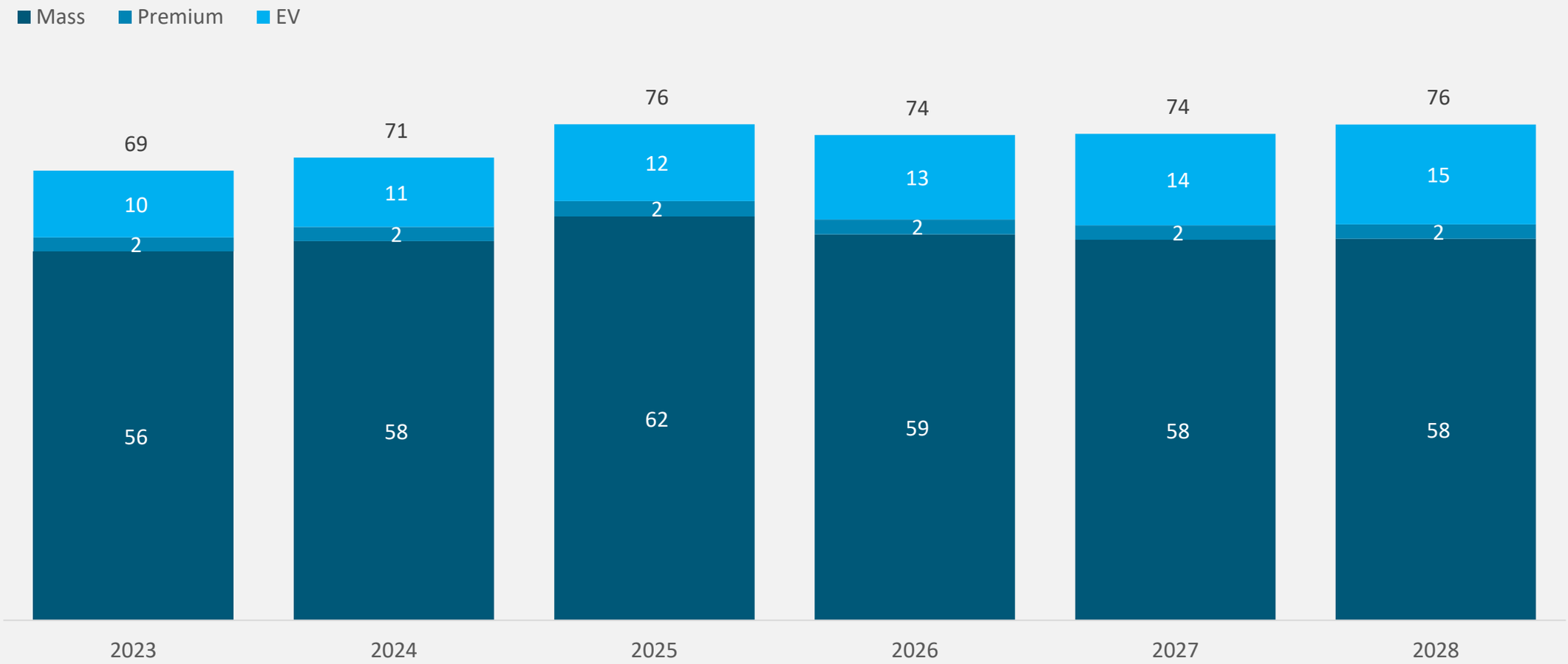
Source: Frost & Sullivan

GLOBAL TAM ANALYSIS:

PASSENGER VEHICLES (Smart Glass)

GLOBAL PASSENGER VEHICLES: NEW CARS SALES (million)

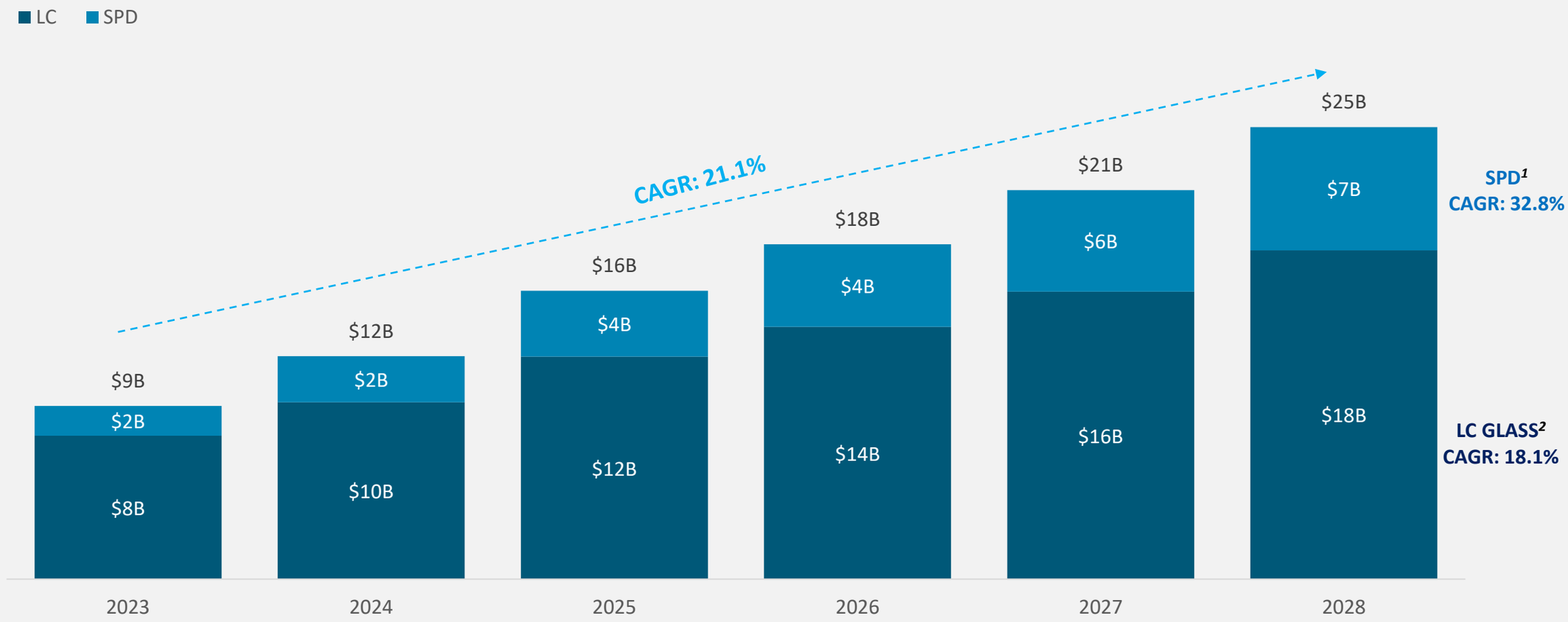
Global Passenger Vehicles (new cars) sales in 2023 are expected to be around 69 million with the mass-market segment being the major contributor (81%) to this market.



Source: Frost & Sullivan

GLOBAL PASSENGER VEHICLES: TAM ($B)

Global Passenger Vehicles smart glass market in 2023 is expected around $9bn. with Liquid Crystal (LC) smart glass being the major contributor to TAM (with $8bn.) and Suspended Particle Device (SPD) being the growth driver (32.8%) for the segment.



Notes

[1]SPD: Suspended Particle Devices smart glass

[2]LC: Liquid Crystals smart glass

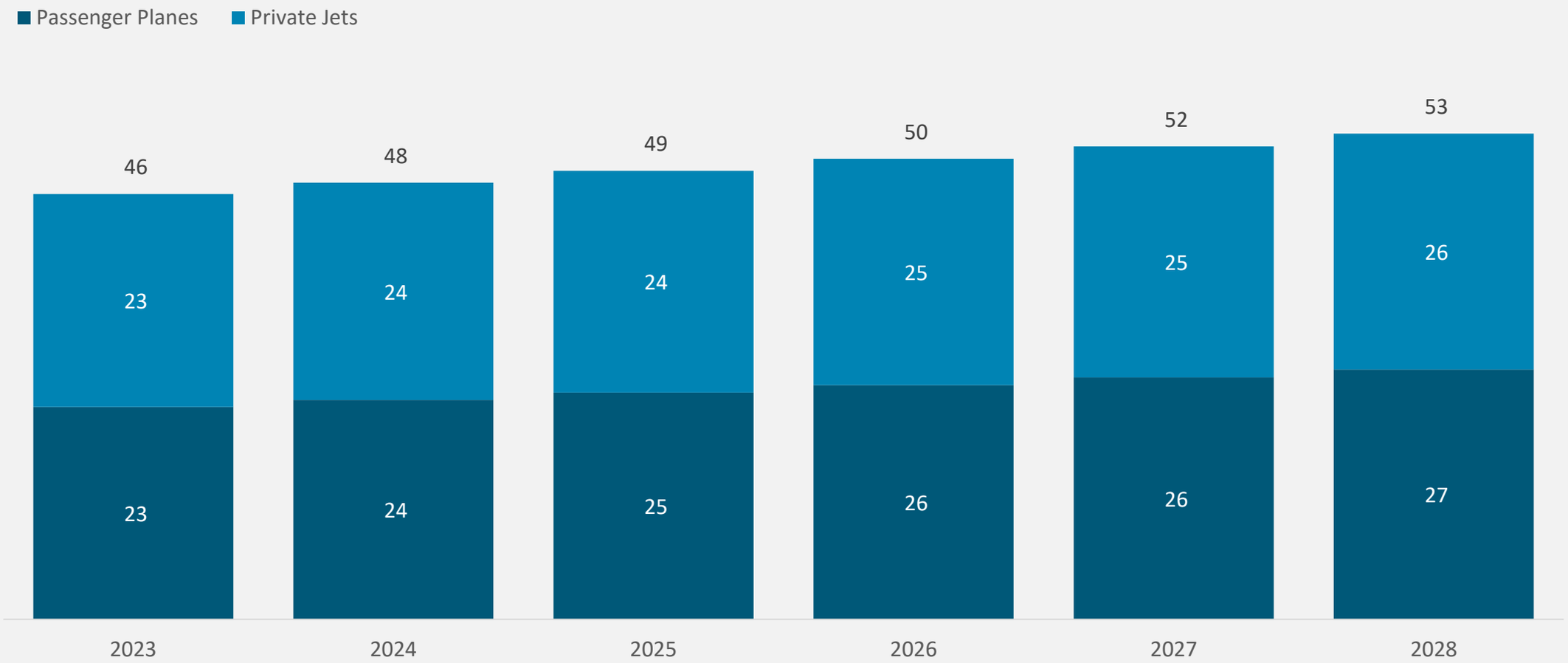
Source: Frost & Sullivan

GLOBAL TAM ANALYSIS:

AERONAUTICS (Smart Glass)

GLOBAL AERONAUTICS: ACTIVE PLANES IN SERVICE (‘000)

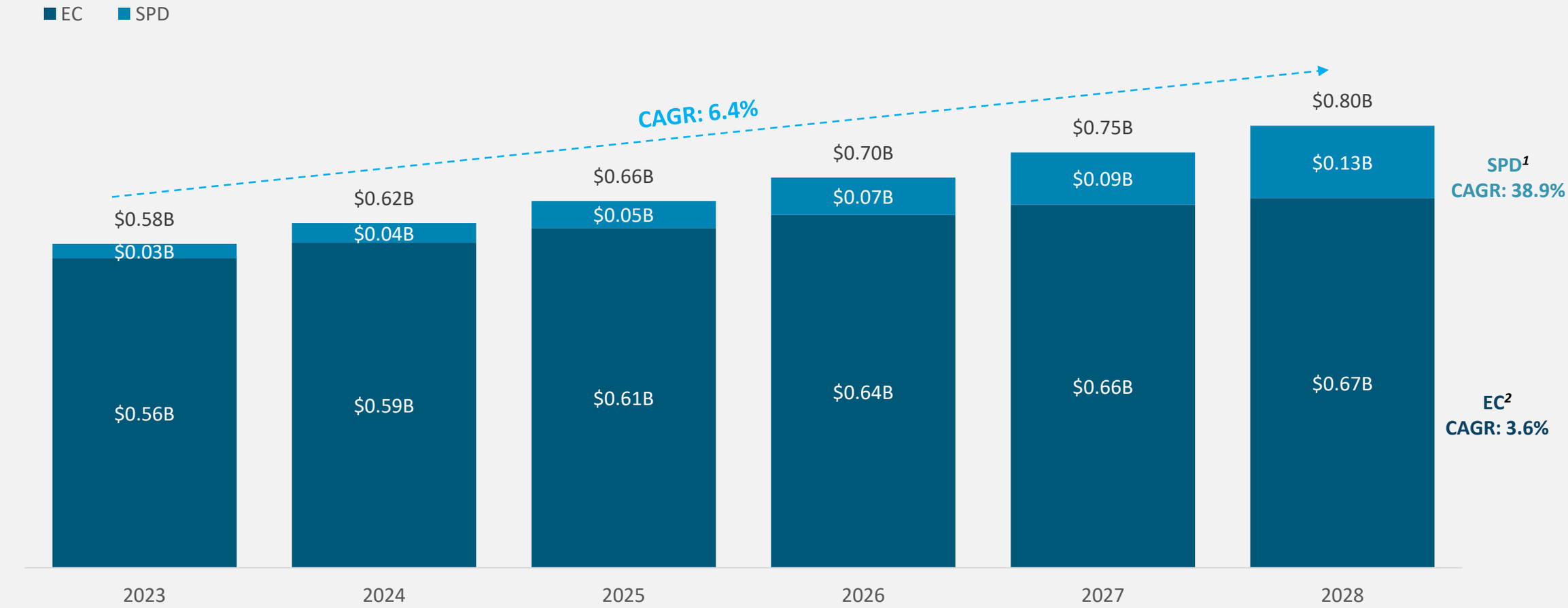
Total of passenger planes in active service globally in 2023 is around 46,000 with both commercial planes and private jets having an equal share.



Source: Frost & Sullivan

GLOBAL AERONAUTICS: TAM ($B)

Global Aeronautics smart glass market in 2023 is expected around $0.58bn. with Electrochromic (EC) smart glass being the major contributor to TAM (with $0.56bn.) although going forward is expected to be replaced by Suspended Particle Devices (SPD) smart glass that will witness a growth rate of (38.9%).



Notes

[1]SPD: Suspended Particle Devices smart glass

[2]EC: Electrochromic smart glass

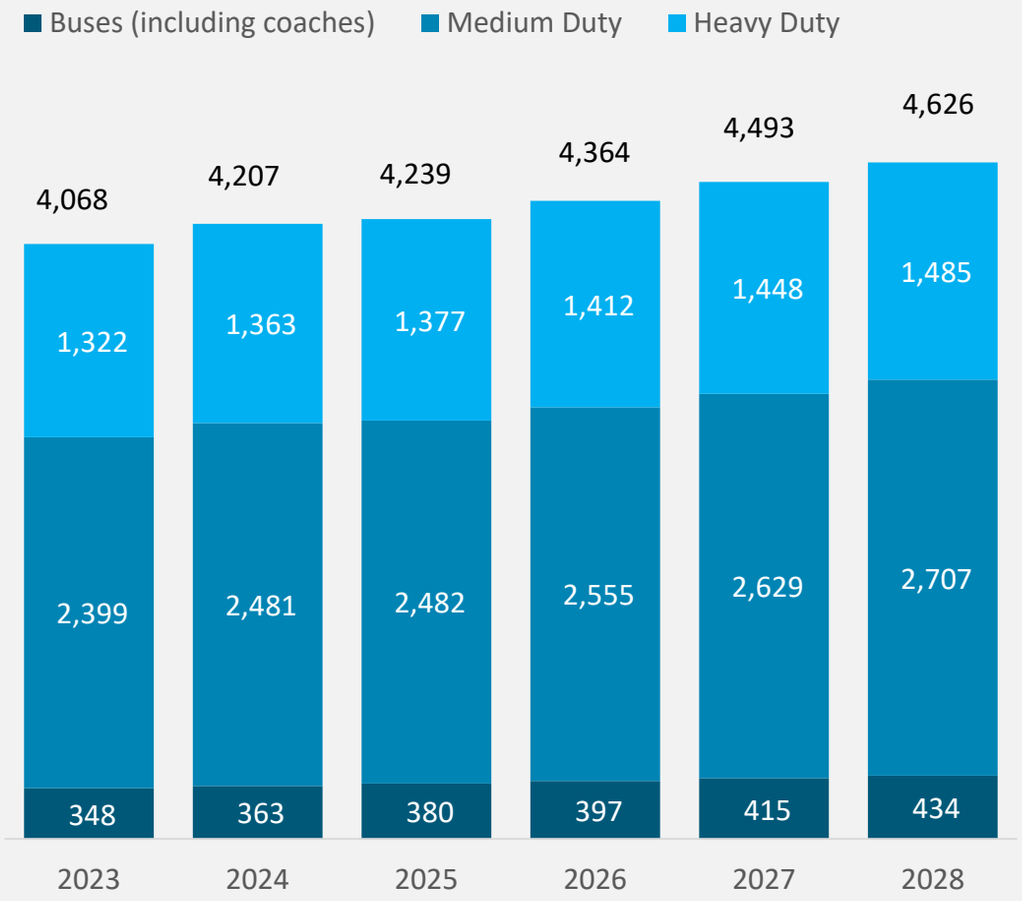
Source: Frost & Sullivan

GLOBAL TAM ANALYSIS:

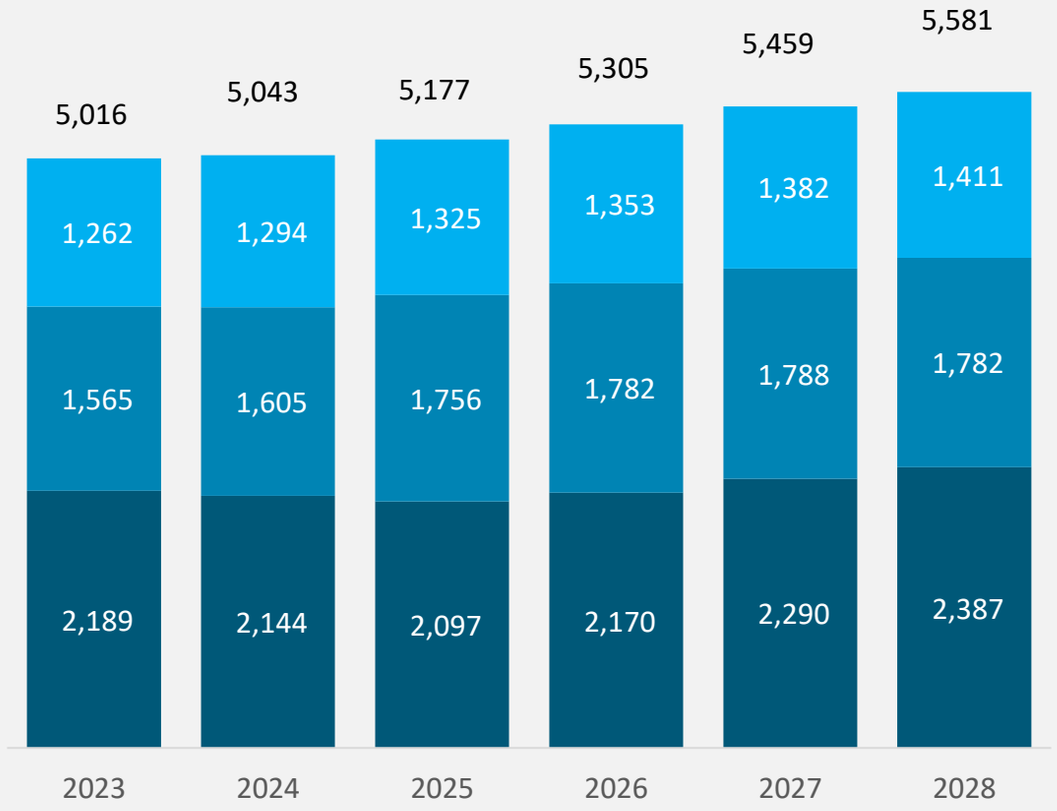
SAFETY-TECH (Advanced Driver Assistance Systems, Camera Monitor Systems, Driver Protection Doors)

GLOBAL SAFETY-TECH: NO. OF COMMERCIAL VEHICLES ('000)

Medium-duty trucks are the major contributors (59%) to new commercial vehicle sales, although it's the buses (including coaches) that have a higher share (44%) in terms of total commercial vehicle registrations on the road.



New Sales



Prior 12-months vehicle registrations[1]

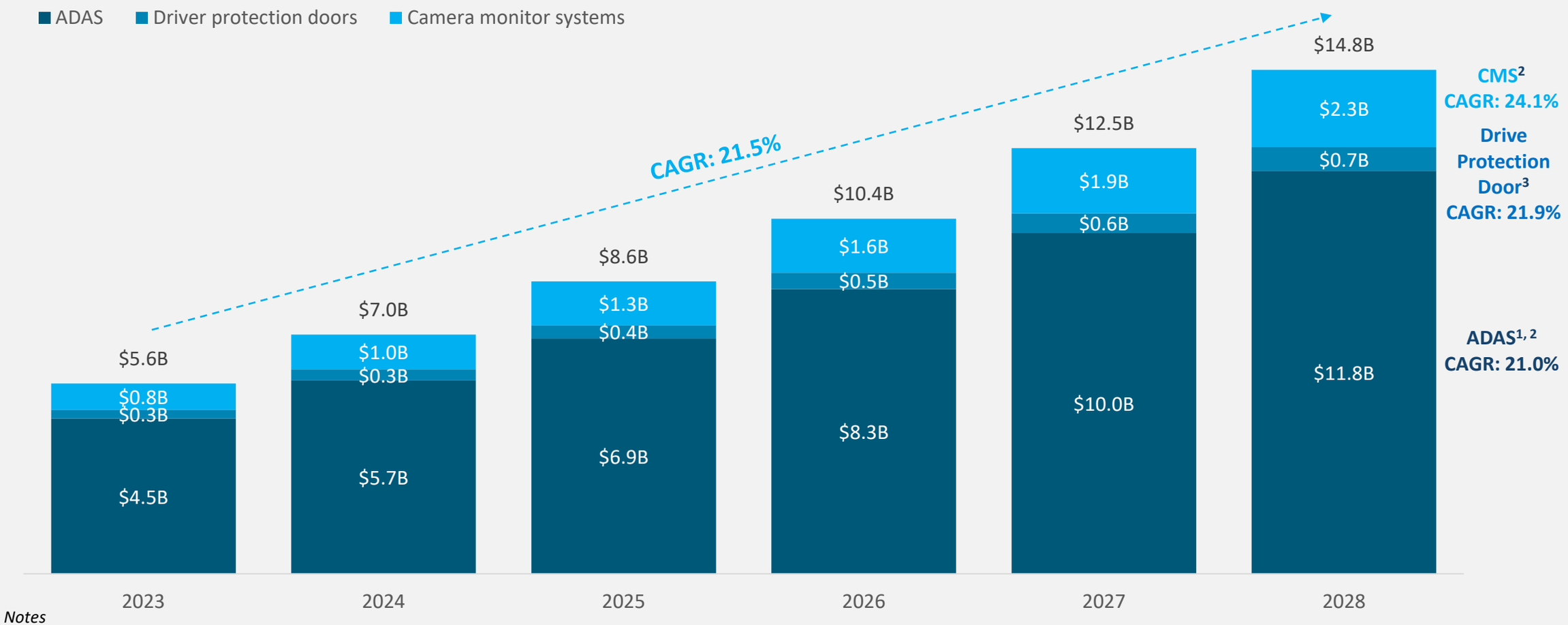
Notes

[1]Registrations are

Source: Frost & Sullivan

GLOBAL SAFETY-TECH: TAM ($B)

Global safety-tech market in 2023 is expected around $5.6bn. with Advanced driver assistance systems (ADAS) being the major contributor to TAM (with $4.5bn.), with Camera monitor systems (CMS) being the major growth driver (24.1%) for this segment.



Notes

[1]Advanced driver assistance systems (ADAS) include Blind spot detection/Side guard assist, Forward collision warning, Lane departure warning, Lane change assistance, Front and rear spot detection

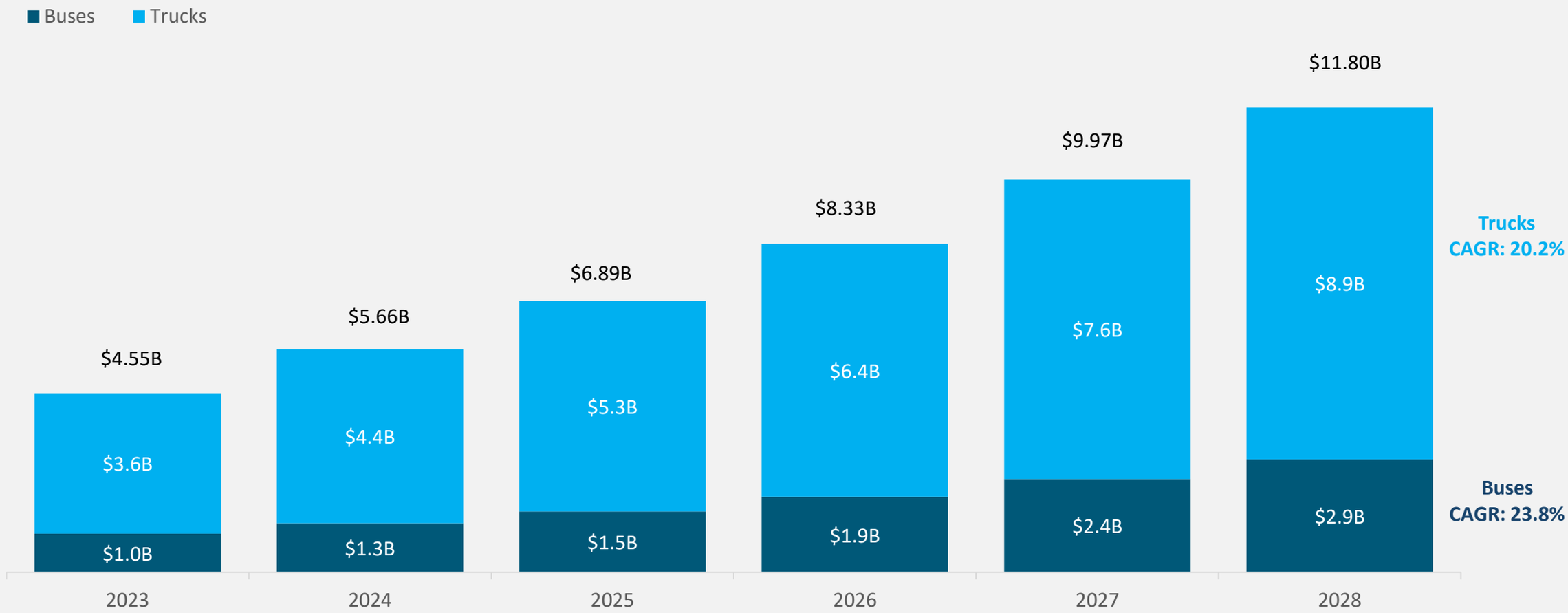
[2]For ADAS, Camera Monitoring Systems (CMS) we considered Buses (including Coaches), Medium-Duty and Heavy-Duty Trucks;

[3]For Drive Protection Doors, we considered Buses (including Coaches) only

Source: Frost & Sullivan

GLOBAL SAFETY-TECH: ADVANCED DRIVER ASSISTANCE SYSTEMS (ADAS) ($B)

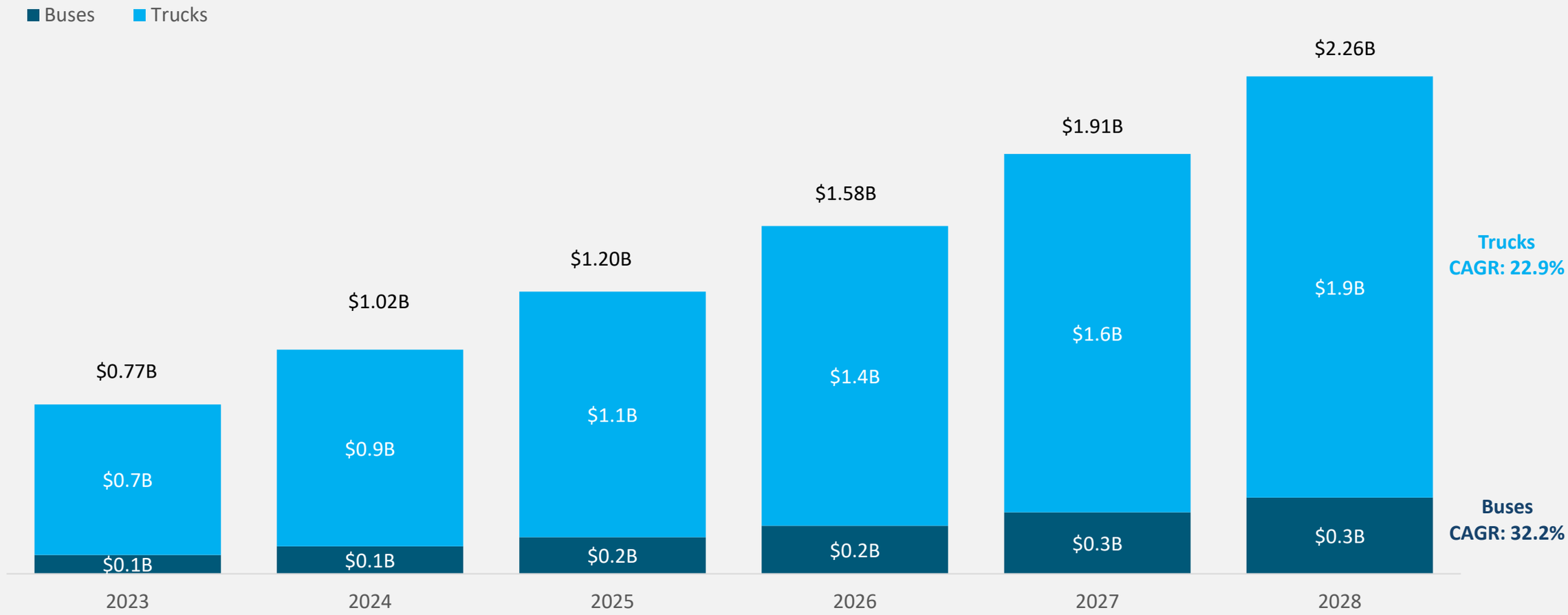
Medium-duty and Heavy-duty trucks are the major drivers of the Advanced driver assistance systems (ADAS) market TAM (with $3.6bn.) in 2023, with Buses (including coaches) being the major growth driver (23.8%) for this segment.



Source: Frost & Sullivan

GLOBAL SAFETY-TECH: CAMERA MONITOR SYSTEMS (CMS) ($B)

Medium-duty and Heavy-duty trucks are the major drivers of the Camera monitor systems (CMS) market TAM (with $0.7bn.) in 2023, with Buses (including coaches) being the major growth driver (32.2%) for this segment.



Source: Frost & Sullivan

KEY INSIGHTS

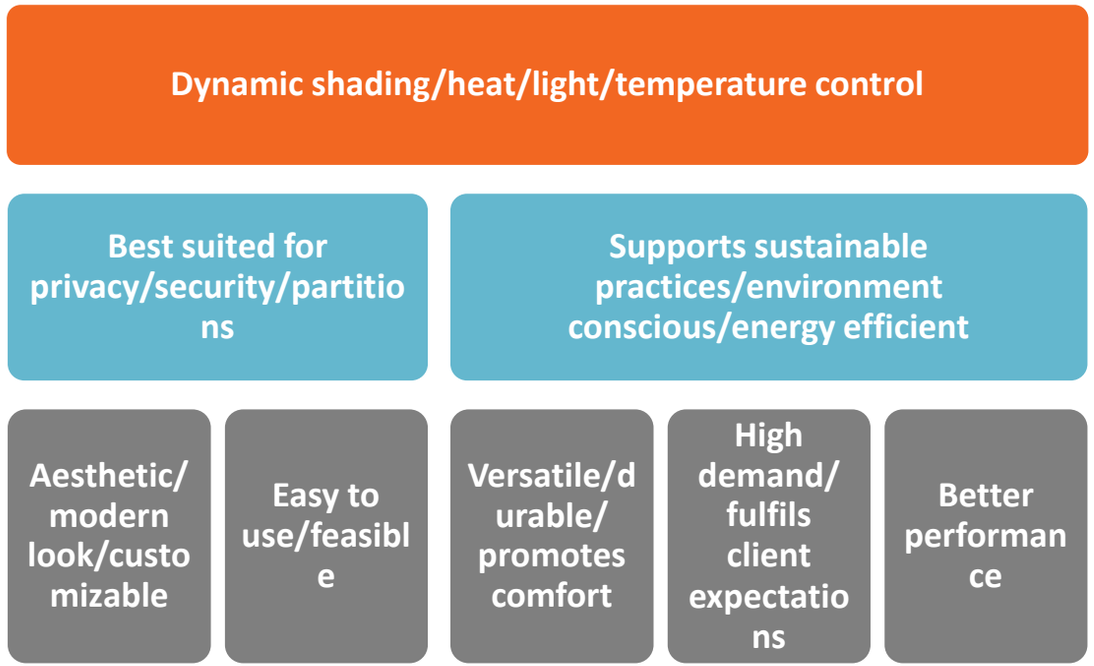
KEY INSIGHTS:

BUILDINGS (Smart Glass)

SMART GLASS USAGE

All the respondents have expressed a consensus that the utilization of smart glass is expected to grow over time. Liquid Crystal (LC) technology is anticipated to find application in interior spaces, while Electrochromic (EC) technology is projected to be predominantly employed in the exteriors of commercial buildings.

Reasons for increase in the smart glass usage



Applications to grow fast: Quotes

***I think smart glass on the external parts of the building will increase**. The reason for that is smart windows can eliminate the need for blinds, shades, or window treatments. So, the smart windows can self-adapt to heat or cool for energy conservation in the building. For instance, right now we have a building in the city of London that is on a high rise, and a lot of heat passes through it, and because of it, especially in the summer, you would have to have the AC on full. The same goes in the winter; the cold will travel through it, but if you can change the settings on the smart glass, it will definitely be a factor to consider. So, it might have a high initial cost to begin with, but over time, it is going to be easy to maintain and require less work over the next 50 or 60 years." UK*

*For **interiors, the applications will be more seen in spaces that require privacy and automation** for smart homes. **Exteriors of commercial buildings will be more popular** than those of residential homes because again, **here is the factor of cost** when it comes to designing luxury homes." USA*

*I think **both interior and exterior applications where smart glass is used will gain momentum**. Currently, it is EC glass, which is mostly used for exterior applications and facade designs, which gives a rich look, while privacy partitions with LC glass will dominate the interior spaces.." USA*

***Overall, the use of liquid crystal and electrochromic glass in building projects align with the goal of energy efficiency, occupant comfort, and sustainable design**, making them valuable additions to modern construction projects." France*

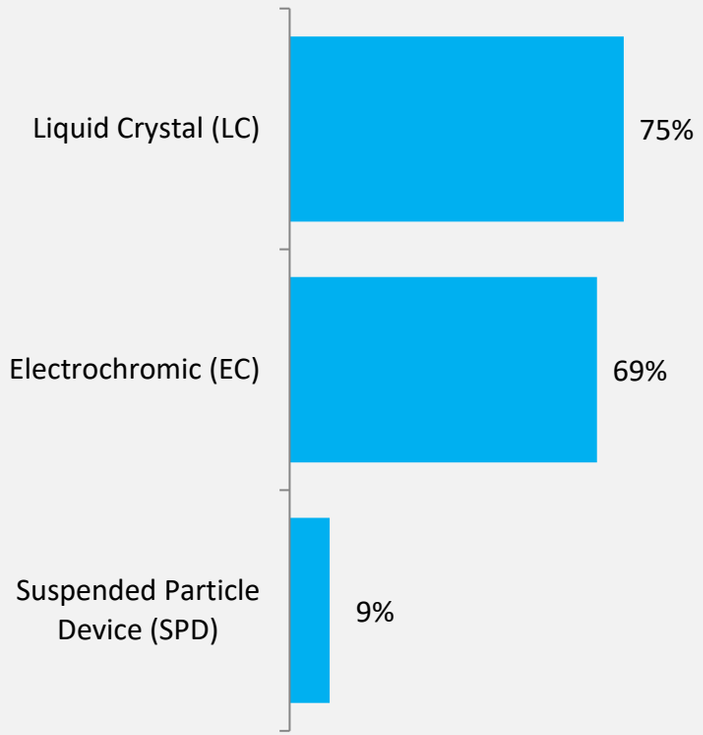
Source: Frost & Sullivan

SMART GLASS TECHNOLOGY MOST WIDELY USED IN BUILDING PROJECTS

Liquid Crystal (LC) is generally employed in interior designs for its privacy-enhancing features and energy efficiency. Meanwhile, Electrochromic (EC) is the preferred material for exterior building facades due to its adjustable transparency, effective light blocking, and aesthetic appeal.

Smart Glass Technology Type (% respondents)

n=32



*"We mainly use **EC smart glass technologies for our building projects while LC usage is only applicable for interior areas** where there is more requirement for privacy. However, we majorly focus on exterior areas where there is high demand for **EC glass as it is more appealing and offers lavish look** to the building." USA, Construction Services Company*

*"We use **liquid crystal (LC) glasses for our interior architecture designs** as they are more in demand due to **its various applications and benefits** that it provides to the users such as **privacy and shielding the amount of light to be transferred in the room** due to their ultra high haze state." China, Architecture Services Company*

*"There are two design segments interior and exterior. So, for the **modern building design projects we use LC glass for the interior part and SPD glass for the exterior part.** Since both technologies are paired with glass or other transparent material their application areas are different.*
*Based on the type of projects that I worked on to date and the knowledge that I have gathered, **LC glass is used in interior applications where on-demand privacy or transparency is a top priority and SPD glass is used in exterior applications because of their tinting and shading capacities**." Italy, Architecture Services Company*

*"We use several different types of glass on every building project, as it depends on the segment, such as office building, residential, education, etc. **We mainly prefer to use electrochromic (EC) and liquid crystal (LC) for building projects.** I believe these applications improve the comfort, energy efficiency, and functionality of buildings while offering innovative solutions for architecture and design." France, Architecture Services Company*

*We are a construction company and **mostly we work with electrochromic glasses** in our building process. We are mainly working in the commercial segment and have our projects in commercial segment such as offices, shopping malls, and the hospitality segment which has the major demand for these glasses in the market." China, Architecture Services Company*

Source: Frost & Sullivan

SMART GLASS USAGE: QUOTES

It will definitely increase in the long term *because one of the problems in terms of smart glass usage in the year 2000 was the cost and today, it is feasible for projects and companies as well because now we have a better understanding of the carbon emissions and the energy performance of buildings. So, whatever helps to achieve better building performance and a better channel comfort will be in high demand in the market.*
As per my experience, ***electrochromic offers flexibility for various projects, so I think electrochromic is going to be the leading cutting technology for smart glass applications.*** *The LC and SPD glass are very similar technologies to each other, but the electrochromic glass I think has a better value in the market and maybe it is going to be more feasible in terms of cost." UK*

It will be a ***major contributor in renovating and building spaces and there is a growth we see towards them****. We will certainly use it in our planning in the future as well because we need to go with the trend. I* ***would probably say the fastest-growing application is privacy, followed by thermo-control and dynamic shading and the slowest growth would be the convertible window*** *that can be used as a projection screen." Germany*

It will definitely increase in the coming years. *Currently, the smart glass sector is highly in demand in the market due to the modern technological advantages that it provides to its users. If we think that 5 to 10 years ago, it was not possible to adjust the light or the shade of the glass except for curtains, but now we can adjust and control light and heat, leading to reduced energy consumption and cost savings.* ***I think building facades will be the fastest growing area*** *and it will find new possibilities in changing the outlook of the building because facades represent you or your building and clients want to have it designed in a way that will support the building codes and provide a modern look to it with a welcoming environment." USA*

Looking at the range of benefits that smart glass offers, I would say that its usage will increase. *It is a technology that is helping us achieve our desired goals and plans in terms of meeting sustainability goals, achieving carbon reduction goals, and fulfilling client expectations.*
The fastest-growing application area is building facades, energy-efficient windows, and integration with building automation systems. *The slowest will be the usage of smart glass in residential windows and low-rise buildings due to the major factor of cost and I personally do not think there is any need for it." Italy*

The market will expand for new products and technologies in coming years, and ***there will be demand for liquid crystal and electrochromic glass****. As we can see, day by day the construction industry is* ***moving towards the carbon neutral goal or the companies are trying to achieve their sustainability targets****, so we are trying our best to include the sustainable materials in planning. Privacy walls and building facades would be more popular in the market." UK*

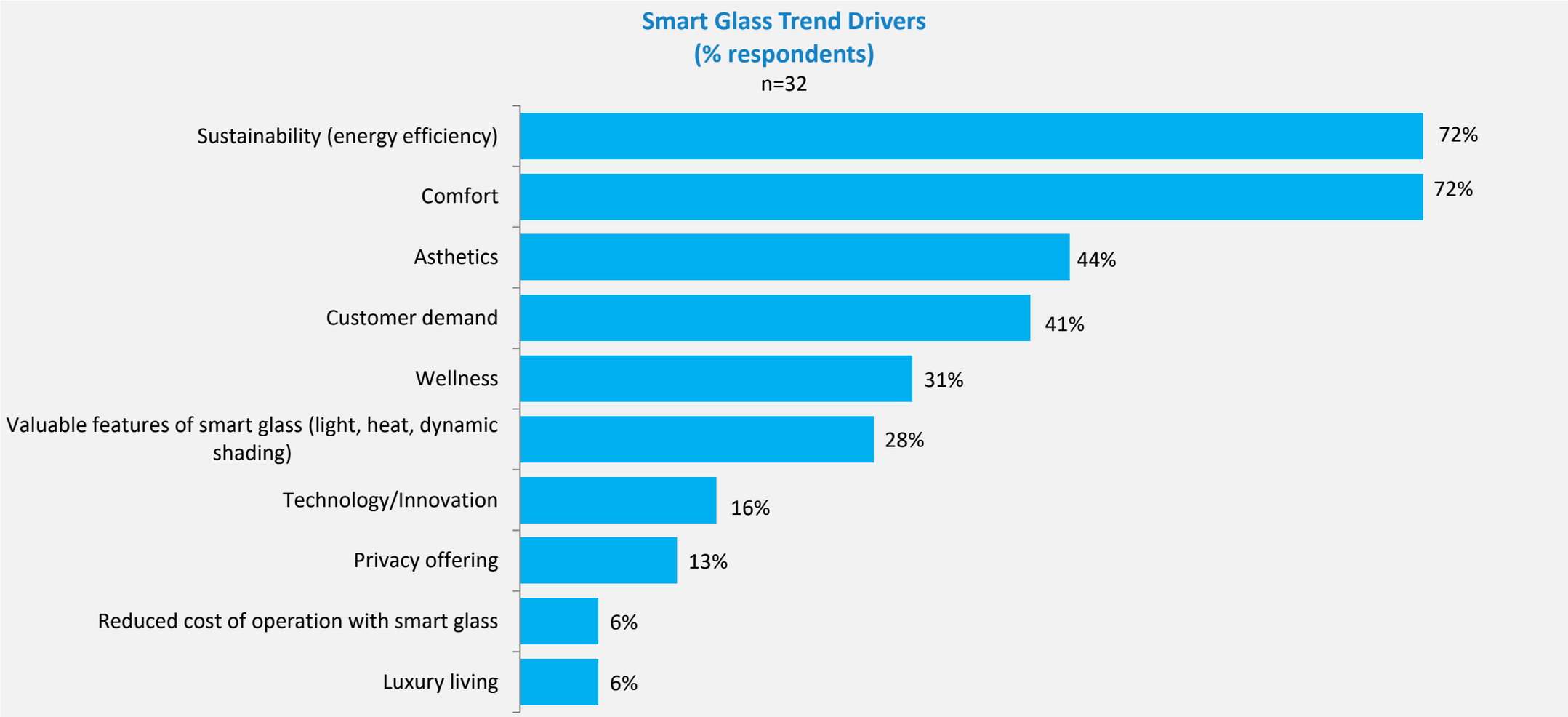
In my opinion, it will increase in the coming years*. I believe these glasses are famous for its exterior usage as they are used highly in offices and other commercial buildings* ***with shading and tinting applications, thermo-control and dynamic shading****. So, it will have a good growth in the exterior segment of the building. Also, the maximum growth for these glasses in the interior segment has been seen in the residential sector due to its looks and aesthetic that it provides to the interiors of the homes." China*

I would say that before using it, we have observed that smart glass technology ***contributes to sustainable building practices****. As it help to reduce the carbon footprint of a building by conserving energy and improves overall environmental performance. Overall, the use of liquid crystal and electrochromic glass in building projects align with the goal of* ***energy efficiency, occupant comfort, and sustainable design, making them valuable additions to modern construction projects****." France*

Source: Frost & Sullivan

DRIVERS OF SMART GLASS TREND IN BUILDING AND CONSTRUCTION

The key factors steering the advancement of smart glass technology include enhancing customer comfort, advocating for sustainability, implementing energy-efficient building practices, and emphasizing aesthetics



Source: Frost & Sullivan

DRIVERS OF SMART GLASS TREND IN BUILDING AND CONSTRUCTION: QUOTES

*In terms of health and wellbeing, we have done some research in which **whenever we are able to maximize the natural daylight, the productivity of the employees increases from 15% to 20%, and whenever we utilize these technologies, it reduces carbon emissions significantly** and optimizes building performance." UK*

***I believe it is sustainability, energy-efficient building practices, and utilizing smart technologies that will drive the comfort of customers**. For the construction industry, we are more aligned to promote energy-efficient construction practices and build homes that have aesthetic designs rooted in smart construction. Although luxury homes will require most automation, we also need to deal with costs that need to go down." USA*

*I would say **building style, comfort, luxury living, and aesthetics are driving this trend.** Sustainability is the most common word for architects because, again, with changing climate conditions, just having fancy designs will not work; it need to be sustainable enough to support green construction practices as well as control indoor temperature." USA*

***Comfort and the level of privacy** because people are more interested in using smart technologies that will benefit them. Curtains and blinds have left the trend and are not used at least in commercial spaces because we have smart glass that is mounted on the exteriors or interiors. **Again, having energy-efficient buildings is the main objective of the government and with these advanced materials coming to the market, we are surely interested in making the best use of them**." Germany*

***The smart glass industry is driven by comfort, client desire, aesthetics, sustainability, and well-being.** With smart glass, we can achieve almost 30 to 40% of costs and I think for most of the buildings, it is an everyday feature today. So, I would say, that cutting on electricity costs, offering privacy, and rapidly customizing a space that takes less space are the major factors to drive these trends today." USA*

***The customer base is very demanding today** and glass-based products are on a high surge today we talk about the current market whether it is glass houses, glass buildings, office views with glass, or hotels and restaurants covered in lavish glass is the new age trend. This trend is driven by the factors of comfortable living which every individual wishes to have in their homes or office. **So, comfort and wellness will always be the driving factors** because no individual will prefer to have a spacious glass view with zero temperature control in the building. **Sustainability is built with comfort** because, with a controlled environment, we would surely think of increasing costs, but this is not the case with smart glass as here we save on energy over costs." Italy*

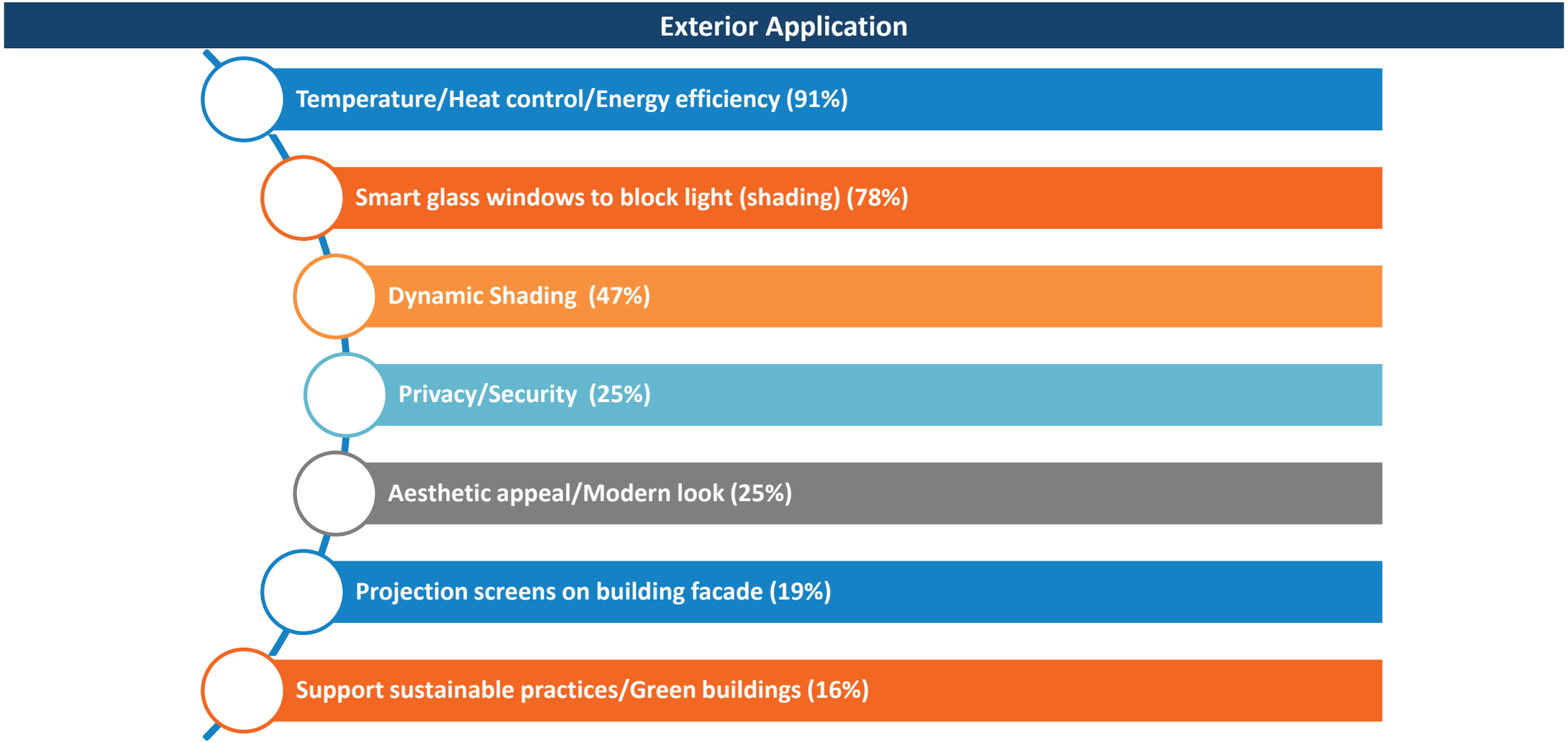
***The smart glass industry is driven by all these trends i.e., comfort, client desire, aesthetics, and sustainability**. Customers want adaptable solutions, sustainability, energy efficiency, and improved wellness. It minimizes natural light, decreases energy use, and prioritizes indoor well-being. Our company is also working on green buildings to reduce the carbon emissions by 2030." USA*

***Health and well-being are the driving attributes**. So, basically the concept of smart glass is to drive the occupant comfort and then save on electricity usage. No matter what time of the year it is, we cannot really get consistent comfort with the traditional glass, and this is the reason we have smart glass in the market. So, yes, **increased comfort, increased customer satisfaction, reduced glare, aesthetic indoor environment, sustainable performance and health are the major attributes for me**." China*

***Energy efficiency regulations, environmental consciousness, and the desire to lower operational costs are driving the adoption of technologies** like smart glass that can optimize natural lighting and reduce the need for artificial lighting and HVAC s." Italy*

Source: Frost & Sullivan

SMART GLASS APPLICATIONS: EXTERIOR



Source: Frost & Sullivan

SMART GLASS APPLICATIONS, EXTERIOR: QUOTES

*"The **exteriors of the building** are the main areas of attraction and the **main reason behind adopting smart glass technologies was to enable sustainable practices and take a step ahead in green building construction initiatives**. Since the exterior of the building offers a smart and lavish look, we use EC glass for external purposes in our projects because these glasses aid in improving energy consumption, provide us with instant light control features, and give us the ability to control the direct exposure of UV light and transparency as per our needs. Also, it can be operated on a very low voltage, which eventually leads to savings in energy as well as cost. As mentioned, the push to use EC glass was towards having a high-energy performance building, and with changing climatic conditions, these glasses provide the best solution to meet all the demands as they reduce the energy consumption cost of commercial buildings." Construction Services, USA*

*In our exterior architectural designs, we have included all the mentioned applications for the buildings that we currently use for our customers. We have **smart windows for thermal comfort and the amount of light coming in is in controlled conditions**. Also, **dynamic shading is preferred** over glass which automatically enhances the indoor environment, and most people likely prefer **having a controlled environment** and avoiding glare which directly hits the eyes." Architecture services, USA*

*We are already using electrochromic smart glass windows in our projects. They work the best to **block extreme sunlight and provides thermal comfort** to the users sitting inside the room. It has **vibrant shading properties** and eliminates glare, and it works the best for high-rise buildings which are vulnerable to extreme weather conditions." Building Design, USA*

*I would say smart glass windows have the adjustable tint that **can control the amount of sunlight and heat entering in the building**. This helps to regulate indoor temperatures and reduce the need for heating or cooling. **Dynamic shading is a new technology** glass that uses technology to tint the glass as per the light and heat conditions. **We do not deal with projection screens yet, but this technology can help build artistic display on the building's facade**. Offices can have presentations on the glass as well and so the benefits are more for commercial buildings and retail spaces.." Building Design, UK*

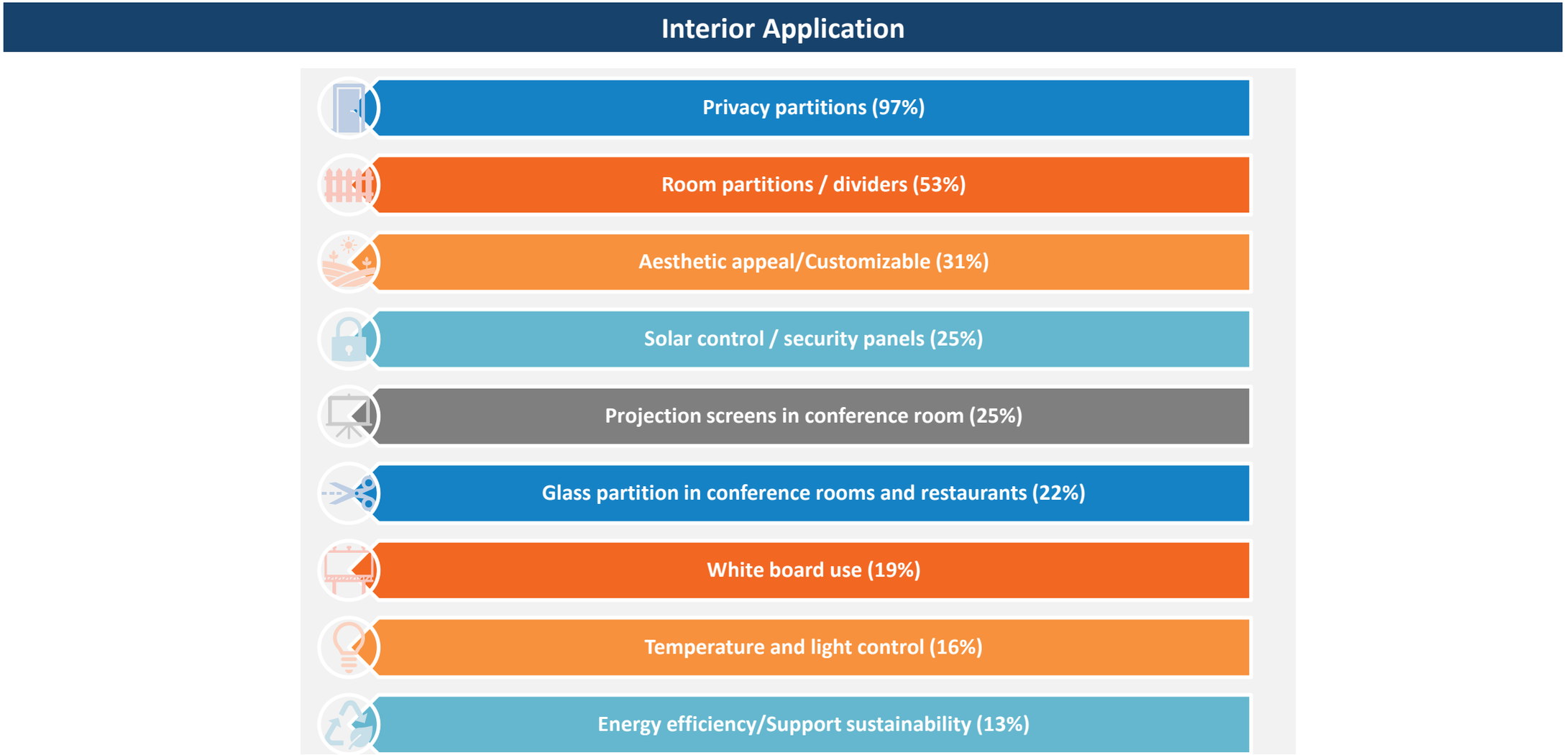
*"We use electrochromic glasses for **applications like sunlight, thermos control and glare control which is currently in demand** in the market. The electrochromic glasses are switchable glasses that can be adjusted and controlled by the user as per the need, they provide shading and tinting capabilities which can change the darkness of these glasses to avoid excessive sunlight or heat to enter through them because of the multilayer adjusting capabilities present in them. Also, **they are energy efficient** and only use electricity when it is turned-on which is very minimal providing you a comfortable and soothing internal environment that is a must for big offices and shopping malls." Building Design, China*

*"Switchable glass has so many features and is used in the exterior of the building. We are already **using electrochromic glass for dynamic shading**, which helps maintain the interior temperature, along with dynamic-tinted, which changes its transparency level in response to external conditions and block excessive light from the outside.." Architecture Services, China*

*Yes, our **main requirement is to regulate the amount of sunlight and heat that enters a building**. For instance, in summer or in hot weather, it can be tinted to reduce glare and heat gain that is entering the building. It also helps to keep the interior cooler and reduce the need for air conditioning. In cold weather, it can become transparent to allow more sunlight and heat in the room. Additionally, while planning for the building's exterior, we can consider smart glass applications to improve **energy efficiency, occupant comfort, the overall functionality of the building, and the aesthetics of the overall structure.**" Architecture Services, France*

*The thing is we need to put big ideas to enlarge the spaces, **so controlling the light and heat is an important parameter** here and we do so by using smart glass technology. **Dynamic glazing is popular as well and is currently used in our projects**. These glasses are tinted i.e., the SPD glass which comes with a dark tint to cover the shading parameters. We have not yet discovered the technology of using smart glass on building facades for projection screens but would love to include it in the future." Italy, Architectural services*

SMART GLASS APPLICATIONS: INTERIOR



Source: Frost & Sullivan

SMART GLASS APPLICATIONS, INTERIOR: QUOTES

*Typically, it is just to have **privacy to have this smart glass installed at home and secondly, it would be due to temperature control features**. Because homeowners are more focused on having their home designed on the interior part mostly bathrooms, doors, dining areas, living room, and even partitions, or wherever we see the potential to install blinds or curtains rather than exterior areas. Also, as I said, home theatres are designed in a way that uses smart glass like projection screens, but almost 70% of usage is seen in interior areas." Building Design, USA*

*We have used both LC glass and film for the interiors, wherever applicable to form a neutral or opaque tint. For **office building projects, mostly for privacy partitions, doors, or windows,** we use LC glass or sometimes films, while for **residential homes, most of the usage is for bathrooms or partition walls to give a unique style and appearance to the interior space**. For the retail and hospitality sectors, again, the applications are similar i.e., to have privacy without compromising on style." Architecture Services, USA*

*We have designed most of the spaces with LC glass and clients require customization in every nook and corner to adjust their level of privacy requirements and how they can match the interiors of the space. The first application **where smart glass is popular is for privacy and comfort**. In office spaces, we have designed areas with LC glass **superior for wall partitions** and we have also used **glass partitions in meeting rooms**. People do use it as a **whiteboard and for screen projection** to showcase their presentations, while some of them prefer to have their window views blocked from another room. I would say interior designing changes the whole perspective of smart glass and no doubt it does provide a finished look to the spaces." Architecture Services, Germany*

*We can include smart glass in various applications inside the building which includes windows, glass partitions, doors as well as in the flooring. **All the applications intend to have privacy in the required area and LC glass is the best-suited option** for interior spaces." Architecture Services, Italy*

*Liquid crystal glass or what we typically call privacy glass which is mainly intended for **discretionary projects and partitions, or privacy offering is the main feature of it**. So, all the application areas such as door, windows, privacy walls, restaurant areas, office spaces and **along with presentations on the glass are possible features with one click**. We can also **control solar radiation through LC glass**, and which is an important parameter in energy control as well." Architecture Services, China*

***Typical application areas include interior windows and partitions**, conference rooms, and reception areas. **Privacy partition is an important application** which requires significant use of LC smart glass." Architecture Services, France*

*These smart glass technology can reduce the **amount of heat entering a space and improve energy efficiency and occupant comfort.** Any commercial or high-end buildings will demand for these type of technology, that **helps in sustaining the building for the longer period**. "Architecture Services, Poland*

*I would say smart glass technology has versatility that makes it a valuable solution in interior of building design, **it also offers flexibility and innovative options to create more comfortable, efficient, and visually appealing spaces**. It can be used as **privacy portions, room dividers, security panels etc.**" Building Design, Italy*

*In our interior designs, we have all the applications for our customers. We use LC glass for **room privacy and room separation** as it provides them to use the entire space and decorate their places as per their requirement such as an extra room or an extra partition. LC glasses are hi-tech glasses and can turn from transparent form to opaque form whenever needed as well as **control the amount of light that can transmit which makes them more in demand in the market** in the residential homes." Architecture Service, China*

Source: Frost & Sullivan

SMART GLASS: NAVIGATING THE PATH FROM HIGH-END BUILDINGS TO MASS MARKET ADOPTION

Smart glass technology is currently more prevalent in high-end buildings but there is an optimistic outlook for its increased adoption in mass markets in the coming years. The predictions emphasize a shift driven by factors such as cost reduction, technological advancements, and changing consumer preferences.

Current Market and Demand

- Smart glass technology is currently in high demand in high-end buildings rather than the mass market
- Current high demand is observed in high-rise buildings, hospitality, and commercial sectors etc.
- Initial costs are high, but high-end projects can afford them

Challenges and Opportunities

- Challenges include initial high costs, lack of knowledge, and limited adoption in mainstream markets.
- Opportunities lie in innovations, cost reductions, and increased awareness leading to broader market acceptance.

Future Market Trends

- Predictions suggest that in about 10 years, smart glass technology will become more affordable and widespread in mass markets
- Growth expected in the usage of smart glass in residential construction, including villas and apartments
- EC glass may find a place in high-end buildings, but adoption in mass markets may be slow
- The applications of smart glass are varied and evolving, with potential for more applications in the future

*"**Currently, we have seen a high demand for smart glasses in high-rise buildings,** and I believe it will remain the same for the next 2–3 years. However, **we will definitely see growth in the usage of smart glass in villas and apartments** i.e., residential construction, mainly because of the functionality and modern architectural look it provides to the homes." USA*

*"**EC glass will surely find a place in high-end buildings and not sure about the mass markets because the adoption rate is slow** and people find it convenient to place blinds or shades rather than smart glass." UK*

*"**No, it will definitely find its way to the mass market as well, but it will take some time**. I do agree that it has more usage in high-end buildings; however, because of its ultra-modern features and luxury look, it will find its way in market for common man as well." Germany*

*"**Definitely, it will find its own way in the next 5 years in the mass market** and will be the most used as well as implemented technology in the industry. Applications such as **liquid crystal and electrochromic will be in high demand.**" China*

*"I would say these smart glass technology will **influenced by a various factors, including technological advancements, demand in different sectors, regulatory changes, and economic conditions,** with such demand and growth these smart glass technology will definitely find its way in the mass market." France*

*"Currently, **as per the latest trend, majority of the smart glass are used in high-end buildings** but surely, **it will find its place into the mass market** because of the increased demand from the consumers and increased government regulations towards its usage.." France*

Source: Frost & Sullivan

SMART GLASS BENEFITS

Smart glass technology offers a wide range of benefits, including energy efficiency, privacy control, aesthetics, and sustainability, making it a preferred choice in modern building design.

Smart Glass Benefits

Aesthetics and Style
- Aesthetically pleasing design is a major factor in the adoption of smart glass technology.
- The style and look of smart glass contribute to its appeal, especially in modern architecture.

Ease of Operation and Low Maintenance
- Simple on/off mechanism for smart glass activation through switches, apps, or voice commands.
- Low maintenance requirements, making it a convenient and user-friendly technology.

Versatility and Customization:
- Smart glass technology is versatile, offering benefits across various industries.
- Provides flexibility in exterior design and can be customized for specific applications.

Privacy and Temperature Control:
- Smart glass provides privacy control with options for controlled daylight.
- It helps in temperature control, preventing overheating of indoor areas.

Commercial vs. Residential Applications:
- More benefits are seen in commercial external buildings, including radiation reduction and energy savings.
- In residential use, the emphasis is often on aesthetics and style rather than extensive functional benefits.

Comfort and Wellness:
- Enhances comfort through controlled privacy, light, temperature and and minimizes the need for artificial lighting.
- Supports well-being and a more pleasant living or working experience.
- Smart glass blocks harmful UV rays, protecting occupants and interior furnishings

Energy Efficiency:
- Smart glass contributes to increased energy efficiency by controlling light and heat.
- It aids in reducing the need for additional HVAC systems, leading to long-term energy savings.

Cost Savings and Sustainability
- Initial higher costs are often justified by long-term energy and maintenance savings.
- Contributes to green building certifications and aligns with sustainability targets.

Sound Insulation
- Some smart glass technologies offer sound insulation properties, reducing external noise when in opaque state.
- Particularly useful in commercial, healthcare, and education buildings.

Source: Frost & Sullivan

BARRIERS TO SMART GLASS ADOPTION

The high cost of smart glass remains a topmost persistent challenge across various industries and applications.

Barriers to Smart Glass Adoption

1. **High Initial Installation Cost:**
   - The high upfront cost of installing smart glass, makes it less financially viable for many individuals and companies.
   - The initial expense acts as a significant barrier for adoption, particularly in residential settings.
2. **Limited Awareness and Knowledge:**
   - Slow adoption rate due to the novelty of the technology and the need for knowledge sharing within the industry.
   - Lack of awareness about the benefits and applications of smart glass technology, especially among residential owners and clients.
3. **Energy Consumption Concerns:**
   - There are concerns about the energy consumption of smart glass because of lack of awareness leading to slow adoption
   - Energy-related factors being perceived as a challenge that needs to be addressed.
4. **Reliability and Performance Variability:**
   - Concerns about the reliability of the technology, with worries about potential malfunctions and out-of-control situations.
   - Concerns regards the variability in performance among different smart glass manufacturers.
5. **Market Standardization and Competition:**
   - Lack of standardization and competition in the emerging smart glass market affecting pricing and availability.
6. **Resistance to Change:**
   - Internal resistance to change, particularly in convincing stakeholders within organizations to adopt smart glass, often tied to cost factors.
7. **Limited Availability in Some Regions:**
   - Limited availability of smart glass products in certain regions, hindering the overall adoption rate.
8. **Limited Aesthetic Design Options:**
   - Limited options for aesthetic design with smart glass, posing a challenge for architects and design teams trying to meet client preferences.
9. **Skills and Training:**
   - The need for specialized skills and training for workers dealing with smart glass technologies, contributing to installation complexities.
10. **Quality and Availability of Smart Glass:**
    - Concerns about the availability of quality smart glass in the market, potentially limiting options for users

Source: Frost & Sullivan

KEY INSIGHTS:

PASSENGER VEHICLES (Smart Glass)

USAGE OF SMART GLASS IN PASSENGER VEHICLES

The adoption of smart glass in passenger vehicles is expected to rise gradually. Areas such as windshields, sunroofs, sun visors, side windows, and side mirrors are projected to see increased growth.

Areas of increased application of smart glass in Passenger cars

1. Anticipated accelerated growth in rear door windows, sunroofs, windshields, and sun visors due to features like on-demand privacy, improved visibility, and increasing customer demand.

2. Expected expansion of advanced smart glass with color-changing and shading features, extending beyond rear and side windows to include doors and entertainment systems within vehicles.

3.Identified potential growth area in the integration of smart glass into steering wheels for screen monitoring and temperature control.

I think it's probably going to increase because there is more need for SUVs. It's very difficult to sell an SUV without a sunroof for instance, so I think it is going to increase in the next coming years." UK

I believe it will increase because as per our current experience, our industry keeps on evolving with new technology and trends. I anticipate faster growth in applications like sunroofs and windshields due to their larger glass coverage and exposure to significant heat and light. Additionally, I foresee technological evolution centered around smart steering wheels, where smart glass can monitor screen levels and provide temperature control features." Germany

The usage of smart glass will increase in our organization and as I mentioned earlier, we are trying to utilize smart glass into application areas like windshields, sunroofs, and sun visors. The applications that will grow faster are the rear door windows area, sunroof, windshield and sun visors due to features that they can offer like on-demand privacy, better visibility, and increasing customer demand." China

The application areas that would grow and will gain high demand remains same i.e., sunglass roofs, windshields, rear door windows and back windows. China

"We are adopting the technology, and I am sure the growth will be strong and will surely increase in upcoming future. Also, I have seen a lot of usage of LC glass in luxury cars and EC glass would probably be the slowest adoption in the automotive market." USA

The usage of smart glass will gradually increase and improve compared to the current usage. The application areas like windshields, sunroofs, sun visors, side windows and side mirrors will experience higher growth along with its integration technologies like ADAS, and intelligent assist will experience a slower growth." USA

Source: Frost & Sullivan

SMART GLASS TRENDS PATTERN AND DRIVERS IN PASSENGER VEHICLES

Smart glass technology remains well-know in the automotive sector, and overall trends are comparable across regions, albeit with slight variations. For instance, certain markets prioritize smart glass application in windshields, while others emphasize its use in sunroofs.

Drivers of Smart Glass Usage

- **Competition and Affordability:**
  - Increasing competition among major OEMs is propelling the trend.
  - Affordability of smart technology contributes to its widespread adoption.
- **Customer Design Preferences:**
  - Growing global preference for SUVs.
  - Customer demand for spacious interiors and ample light inside vehicles, shaping window designs to meet these preferences
  - It's a customer-driven technology influenced by a desire for both quality and adherence to current trends.
- **Entertainment and Information Needs:**
  - Significant demand for in-vehicle entertainment driven by screens and information.
  - Cockpit designs evolving to accommodate larger screens and more information.
- **Energy Recovery for Electric Vehicles:**
  - Focus on recovering energy, especially with the shift toward electric vehicles.
  - Windows being explored as a source to recover energy for powering batteries.
- **OEM Innovation:**
  - Innovation from OEMs is a key driver.
  - Focus on bringing new technologies to vehicles.
- **Awareness and Benefits:**
  - Increased awareness of smart glass technologies.
  - Growing recognition of the benefits and integration capabilities.

Source: Frost & Sullivan

BARRIERS TO SMART GLASS USAGE IN PASSENGER VEHICLES

The primary obstacles to the adoption of smart glass in passenger vehicles are elevated expenses, raw material availability, and the need for seamless integration with existing systems to avoid compromising vehicle safety.

Barriers to Smart Glass Usage

- **Raw Material Challenges**
  - Geopolitical situations affect the availability of raw materials.
  - Ongoing geopolitical issues, such as the Israel-Palestine conflict and potential future conflicts, especially in Taiwan, a major semiconductor producer, pose challenges to produce smart glass due to the need for increased semiconductor usage in car control systems.
- **Cost Barrier:**
  - The primary obstacle for smart glass in passenger vehicles is its high cost compared to traditional glass.
  - Amidst the significant investment in electric car production, manufacturers may be hesitant to incur additional expenses on smart glass
- **Integration Challenges:**
  - Ensuring seamless integration with existing systems is crucial to prevent issues affecting vehicle safety and functionality, such as malfunctions or technical errors
  - Additionally, incorporating smart glass in vehicles contributes to or raises the vehicle's weight, impacting the fuel efficiency of gasoline and diesel-powered vehicle

*"**Cost is going to be one factor** and I don't think the manufacturers are going to go into additional expenses on smart glass if you must spend billions in producing electric cars.*
***The second one is raw materials;** there were obviously some challenges of raw materials in the last years and that will continue based on geopolitical situations." UK*

***The main barriers of using smart glass in passenger vehicles is the cost as these type of glasses are expensive** compared to the traditional glass, **another barrier is its integration ability** with existing system is critical because it is important to ensure that the technology does not affect the vehicle's safety and functionality i.e., issues like malfunctioning of the electric system or technical errors." USA*

***The only barrier that I would like to mention is the cost** as they are quite expensive compared to the traditional glass due to the specialized manufacturing process that they require. **Ultimately, it increase the overall budget as well as it requires special expertise and equipment for its assembly in a vehicle."** China*

***The integration of smart glass** in a vehicle adds or increases the vehicle weight that **affects the fuel efficiency** especially of gasoline and diesel-powered vehicles. So, reducing vehicle weight while maintaining durability of the glass is a challenge." China*

Source: Frost & Sullivan

KEY INSIGHTS:

AERONAUTICS (Smart Glass)

SMART GLASS USAGE TRENDS AND ITS DRIVERS

The incorporation of smart glass is seen widely across the aviation industry as it serves the dual purpose of enhancing safety measures for pilots and significantly improving the overall comfort and satisfaction of passengers, aligning with the evolving expectations of travelers.

Smart Glass Usage Trends

- **Industry-Wide Adoption:** The use of smart glass is a trend observed across the global airline industry. All major airline companies are currently in the process of upgrading their fleets and services. Over the next five years, a significant growth and increased utilization of smart glass in the airline industry are anticipated.
- **Predicted Growth of Electrochromic Glass:** Electrochromic glass is expected to see increased usage in the outer windows of aircraft. This type of glass offers tinting and shading applications, and advanced design features, aligning with the industry's focus on improving the overall passenger experience. The growth of electrochromic glass is predicted not only for cockpit and passenger windows but also for potential applications in the interior of the aircraft to enhance design aesthetics.
  - Currently, electrochromic glass is primarily utilized in the cockpit windows and passenger windows of commercial aircraft. However, there is potential for expansion into other areas within the aircraft's interior for a more advanced and aesthetically pleasing look.
- **Customer Comfort as Priority:** The priority in adopting smart glass technology is stated to be the enhancement of customer comfort. Electrochromic glass applications are seen as fulfilling the specific requirements and functionalities that the aviation industry demands to prioritize the comfort of passengers.

Trend Drivers

- **Customer Comfort and In-Flight Environment:** The key factors motivating the trend of adopting smart glass technologies in aircraft are identified as customer comfort and the overall in-flight environment. By incorporating these technologies, airlines aim to offer a better and more comforting travel experience to passengers, aligning with the expectation of value for money.
- **Enhanced Safety and Pilot Guidance:** The smart glass technologies can enhance aircraft safety by providing pilots with crucial flight information, aiding in situational awareness, and assisting in challenging conditions such as low visibility or complex scenarios.
- **Continuous Upgrades for Improved Services:** To meet the expectations of passengers seeking value for their money, the aviation industry is consistently upgrading its flights and services. This commitment to improvement reflects the industry's dedication to providing the best possible services to customers.

Source: Frost & Sullivan

BENEFITS OF SMART GLASS USAGE IN AVIATION

Smart glass integration in passenger aircraft brings benefits such as improved privacy, reduced glare, enhanced aesthetics, and a competitive edge for airlines. Its capacity to enhance overall flight experiences, especially during long-haul journeys, positions it as a valuable asset in the aviation industry.

Smart Glass Benefits

- **Privacy Control:** Smart glass in passenger aircraft offers a significant benefit in terms of privacy control. Passengers can personalize window settings to achieve the desired level of privacy during the flight.
- **Glare Reduction:** The technology provides advanced shading and tinting applications, enabling passengers to control glare and sunlight. This contributes to a more comfortable and enjoyable flight experience by reducing discomfort caused by excessive light.
- **Aesthetic Appeal:** Smart glass enhances the aesthetic appeal of the aircraft interior. The ability to dynamically adjust window transparency adds a modern and sophisticated touch to the cabin, contributing to an overall positive passenger experience.
- **Competitive Advantage:** Utilizing smart glass technology provides a competitive edge over rivals in the aviation industry. The innovative and passenger-centric features differentiate airlines and attract customers seeking a more personalized and advanced travel experience.
- **Improved Flight Experience:** Passengers benefit from a better flight experience as they gain control over window settings. This control allows them to tailor their environment, making long flights more comfortable, especially when they wish to rest or work without disturbances.
- **Long-Haul Flight Suitability:** The value of smart glass technology becomes particularly evident in long-haul flights. Passengers on extended journeys can leverage the personalized privacy settings to enhance their comfort and create an environment conducive to relaxation or work.
- **Personalization:** The ability to personalize smart windows according to individual preferences adds a layer of convenience for passengers. This feature aligns with the growing demand for personalized services in the travel industry.

*The main benefit of utilizing smart glass in passenger aircraft is to provide benefits in terms of **privacy control, glare reduction, and to provide the aesthetic appeal**. Another benefit which I mentioned is the **competitive advantage** that it provides from the competitors. " USA*

*It is the same as I have mentioned earlier, it **provides comfort and a more better flight experience** to the passengers with its **advanced shading and tinting applications** which can control the glare and sunlight during the flight to **give the passengers the control to personalize the smart windows** as per the light they want during the travel." China*

*I would say, passengers can have control over the windows, that allows the **personalized privacy settings**. These smart glass technology **particularly beneficial and valuable in long flights, where passengers want to rest, or they might have to work without any disturbances**." UK*

Source: Frost & Sullivan

BARRIERS TO SMART GLASS USAGE IN AVIATION

The successful adoption of smart glass in aviation faces challenges related to technological integration, cost considerations, potential operational disruptions, economic accessibility for passengers, and meeting stringent certification requirements for high-pressure environments

Barriers to Smart Glass Usage

- **Integration with Aviation Technologies:** The ability of smart glass to seamlessly integrate with existing and emerging aviation technologies, such as augmented reality and advanced communication systems, is a key barrier.
- **High Initial Cost:** The high initial cost of smart glass technology is a significant challenge. This cost factor includes not only the technology itself but also the necessary certifications and installations, contributing to the economic challenges faced by airlines.
- **Operational Disruptions:** The installation of advanced technologies like smart glass may cause operational disruptions. Problems in the implementation phase can impact the efficiency of airline operations.
- **Economic Accessibility:** The increase in ticket prices due to the adoption of smart glass technology may make it economically inaccessible for some passengers. This economic barrier could hinder the widespread adoption of the technology.
- **Certification for High-Pressure Environments:** Smart glass technologies need certifications to ensure they can withstand the pressure conditions of the aircraft environment. Meeting these certification requirements is crucial for the safe and reliable use of smart glass in aviation.

*The only barrier that I would think of is the **ability of smart glass to converge with the existing or emerging technologies** in aviation like augmented reality and advanced communication systems.“ USA*

*I would say the **cost is a major factor along with time,** respectively. These technologies take a lot of time for the installations and can cause some problems in our operations. Also, **with the increase in cost there is an increase in the ticket prices** as well which is sometimes a problem for few passengers, and they tend to not go for it.“ China*

*I would say the pressure of the atmosphere, as these **smart glass technology need to have certifications to installed** on the aircraft that they can handle high level of pressure. Another thing is that I think the cost as the it has **high initial cost**.” UK*

Source: Frost & Sullivan

KEY INSIGHTS:

SAFETY-TECH (Advanced Driver Assistance Systems, Camera Monitor Systems, Driver Protection Doors)

DEMAND FOR SAFETY-TECH SOLUTIONS IN MEDIUM-DUTY AND HEAVY-DUTY TRUCKS/BUSES

The adoption of Safety-tech systems in trucks and buses is anticipated to rise over time, driven by several factors such as improved safety, enhanced overall efficiency, and a heightened awareness among customers etc.

Elements driving the surge in demand for Safety-tech solutions

- **Safety Improvements:** The demand for Safety-tech is expected to increase due to the improvement in safety features. The integration of technologies like drive-off assist and drowsiness detection in trucks reflects a commitment to enhancing overall safety.
- **Regulatory Compliance:** The growing number of government rules and regulations related to Safety-tech is identified as a significant factor contributing to increased demand. Compliance with safety standards and regulations is cited as a driving force behind the adoption of Safety-tech solutions.
- **Efficiency and Overall Driving Experience:** The adoption of Safety-tech is expected to enhance overall efficiency and provide a smoother, more efficient, and safer driving experience. Advanced technologies are viewed as highly demanded by drivers for a better driving experience, suggesting a positive impact on driver satisfaction.
- **Autonomous Driving Evolution:** The anticipation is that over time, Safety-tech technologies will become more adaptive, eventually leading to complete autonomous driving solutions. This reflects a forward-looking perspective on the evolution of technology within the organization and the industry.
- **Truck Segment Focus:** There is a specific emphasis on the truck segment as a primary beneficiary of increased demand for Safety-tech solutions. This is attributed to the belief that advanced technologies are essential for smooth, efficient, and safe driving experiences, aligning with the unique challenges and demands of the trucking industry.
- **Accident Reduction and Liability Mitigation:** The integration of Safety-tech solutions is expected to contribute to accident reduction and liability mitigation. This aligns with the broader objective of improving safety, complying with regulations, and addressing the growing awareness of the importance of road safety.
- **Growing Customer Awareness:** Customer awareness plays a crucial role in the increasing demand for Safety-tech solutions. The market is experiencing a shift where people are becoming more aware of the benefits of these technologies, particularly in improving safety through features like blind spot detection and automatic emergency braking systems.

Source: Frost & Sullivan

DRIVERS OF SAFETY-TECH INTEGRATION

Safety-tech systems are being implemented in various commercial vehicles all over the globe as they play a pivotal role in elevating vehicle safety, optimizing driving performance, and offering added convenience to drivers.

Key drivers

- . The key driving factors include
- **Increased Emphasis on Safety Features:**
  - Manufacturers are placing a greater emphasis on safety features in vehicles.
  - Customer demand for safe transport and government regulations mandating safety systems in commercial vehicles are key drivers.
  - Advanced technologies in trucking not only enhance safety but also provide real-time data for better efficiency and cost reduction.
- **Changing Customer Purchase Patterns:**
  - Customers are now prioritizing vehicles that assure the safety of passengers.
  - Changing customer behavior and government regulations are driving factors in this shift.
- **Digital Shift in Services:**
  - People are shifting from traditional approaches to digital-enabled services.
  - Digital features not only reduce manual work but also contribute to safer travel environments and lower accident rates.
- **Government Mandates for Vehicle Safety Systems:**
  - Governments in many countries mandate the inclusion of safety systems in vehicles. This is contributing to the adoption of safety technologies and reduces accidents.

*"**Increased emphasis on safety features** from manufacturers as well as increased number of safety norms and government rules and regulations are driving these trends." USA*

*"Safety-tech is expanding due to a number of factors, **including the growing need to increase driver safety, rising consumer demand and the government rules and regulations** towards implementation of safety practices." UK*

*I believe, the purchase **pattern of customers is now changed,** and they are now **investing in vehicles that provides assured safety** of the passengers or the people they are riding with. So, changing customer behavior and increasing regulations are the driving factors." China*

*"The main driver for this trends are people **shifting their interest from traditional approach to the digital enabled services**, which can reduce their manual work and provide them ease while travelling. This features also help in reduce the accident rates and provide the safe as well as secure environment within the buses. Another driving trend for this is **government, in many countries it is mandatory** to have such systems in vehicles to have safe traveling and reduce the accidents." UK*

Source: Frost & Sullivan

BARRIERS TO EXPANSION OF SAFETY-TECH

Although there is a recognition of the benefits of Safety-tech technology in enhancing road safety, the key challenges include the high upfront and operational costs, concerns about data privacy, and the technical complexity of implementing these systems in both new and existing vehicles.

Barriers to expansion of Safety-tech

- **High Cost and Maintenance:**
  - Safety-tech technology involves the integration of sensors, cameras, and software systems, making the overall system costly.
  - The high initial installation cost and ongoing maintenance expenses can be significant barriers.
- **Data Privacy Concerns:**
  - The collection and processing of large amounts of data by Safety-tech systems raise concerns about data privacy and protection.
  - Consumers and regulators are worried about how the data is used and protected.
- **Technological Complexity:**
  - The technological complexity of Safety-tech systems, including sensors, actuators, cameras, and computational software, can be a barrier.
  - Upgrading or integrating these systems with older vehicles poses challenges.
- **Challenges for Small OEMs:**
  - The upfront cost and complexity of Safety-tech technology may cause small OEMs to lag in implementing these solutions in their vehicles.
- **Integration with Older Vehicles:**
  - Upgrading or changing current safety systems in older vehicles to incorporate Safety-tech solutions can be challenging.
- **Technical Challenges:**
  - Technical challenges, such as the need for proper maintenance, can be a significant issue if timely maintenance is not provided.

*"Safety-tech technology works with the integration of components like sensors, cameras and software system so, **the whole system is costly and requires high maintenance.** The second thing, I believe is the data privacy and its protection can be one of the barrier as Safety-tech system collects and process large amount of data so, the consumers or regulators are concerned about its privacy and protection as well as how it is being used." USA*

*The **main barriers are the upfront cost and the technological complexity** of the system. These systems require use of sensors, actuators, cameras and computational software which increases the overall cost and this make it equally challenging in terms of gauging its performance." UK*

*The **cost is the major barrier** and because of this, the small OEMs are lagging in implementing these solutions in their vehicles. **The other barrier is to upgrade or change the current safety systems with these new systems** so, it is difficult integrating these solutions with the older vehicles." China*

*I think **cost will be the major concern, it has high initial installation cost which can be significant barrier for small commercial fleets**. Another would be technical challenges, as any advanced technology needs a proper maintenance, if we are not able to provide the overall timely maintenance then it can become the huge issue." UK*

Source: Frost & Sullivan

TAM METHODOLOGY

TAM METHODOLOGY

Annual Volume of Glass used by building type[1] (sq. mt.)	X	% buildings using smart glass	X	% type of smart glass[2]	X	Average (sq.mt.) price ($) of smart glass	=	BUILDINGS TAM
New annual passenger vehicle sales	X	% passenger vehicles using smart glass	X	% type of smart glass[3]	X	Average (sq.mt.) price ($) of smart glass	=	PASSENGER VEHICLE TAM
No. of registered planes[4]	X	% planes using smart glass	X	% type of smart glass[4]	X	Average (sq.mt.) price ($) of smart glass	=	AERONAUTICS TAM
Number of registered commercial vehicles	X	% commercial vehicles using safety-tech solutions[5]	X	Average (sq.mt.) price ($) of safety-tech solutions	=	SAFETY-TECH TAM		

Notes

[1] Building Type: Office Buildings, Hospitality, Residential, Educational institutions, Healthcare, Malls/Shopping Centers

[2] Building Smart Glass: LC glass, LC film, EC, and SPD

[3] Passenger Vehicle Smart Glass: LC glass and SPD

[4] Aeronautics Smart Glass: EC and SPD

[5] Safety-tech solutions: ADAS, CMS, Drive Protection Doors

Source: Frost & Sullivan

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