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Posted Date: 28 May 2025

doi: 10.20944/preprints202505.2201.v1

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Sustainable Development and Advanced Technologies: Properties, Perspectives and Applications of Synthetic Aerogels

Vivek Yadav [1], Karthika S [2], Anirudh Sehrawat [1], Triveni Magadum [3], Harshit Mittal [1], Vinay Shah [1] and Omkar Kushwaha [4,*]

[1] Guru Gobind Singh Indraprastha University
[2] CSIR-NIIST, Trivandrum
[3] KLE Technological University
[4] Indian Institute of Technology, Madras
* Correspondence: kushwaha.iitmadras@gmail.com

Abstract: Aerogels are novel materials that span the gap between liquids and gases because of their distinctive physical properties, such as high surface area and low thermal conductivity. Aerogels are extremely light, highly porous, and low-density materials, but they may also be made to exhibit mechanical properties like increased stiffness and strength by controlling their feature structures while keeping their relative density low. Due to excellent properties shown by aerogels, they have a lot of different applications and are used in paints, pharmacy, sensors, insulators, acoustics and tank baffles etc. In the recent times, Research and Development have contributed a lot in aerogels but it has not been as successful to industrialise and commercialise a lot of those aerogels such as synthetic and polymer-based aerogels. In this article we will discuss the past, current and future perspectives to overcome such challenges for maximum commercialisation and scale up of aerogels as well as discuss about the properties and applications of different types of aerogels for sustainability and carbon neutrality.

Keywords: synthetic aerogels; polymeric aerogels; sustainability; carbon neutrality; novel materials

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1. Introduction

Science and mankind are going through a period of transition relating to the energy, the environment, and climate change. Pollution has been one of the most critical challenges not only because it causes climate change, but also it has a negative impact on the public health as a result of increased morbidity and mortality rates. Pollution is mainly the result of releasing chemicals o the environment, which poses harmful effects to the humans and other living creatures. Of late, petroleum extracts have become exorbitantly expensive as a result of their finite dependence, which is predicted to continue as the demands grow. Apart from the monetary realm, most petroleum-based products are creating much harm to the environment. Due to the advances of modern society, there has been an increased stress in the gap of fulfilling basic requirements of clean water, air, and food. For all these, sustainability is the key parameter to minimize or mitigate the effects of environmental pollution. These potential challenges can be met by an increase in the progress of polymeric materials and technology in relation to the environmental sustainability [1,2].

From the analysis done in, Figure 1 we can observe that the total emissions are increasing from 14.38 $GtCO_2$ emissions in 2016 to 15.27 $GtCO_2$ emissions solely caused by coal, which brings concern towards an urgent replacement and substitution of such petroleum-based sources with other substitutes which reduced environment pollutions and goes forward towards sustainability and carbon neutrality. Certain alternatives in regards to the substitution of fossil fuels and petroleum-based energy sources are synthetic and polymer based aerogels.

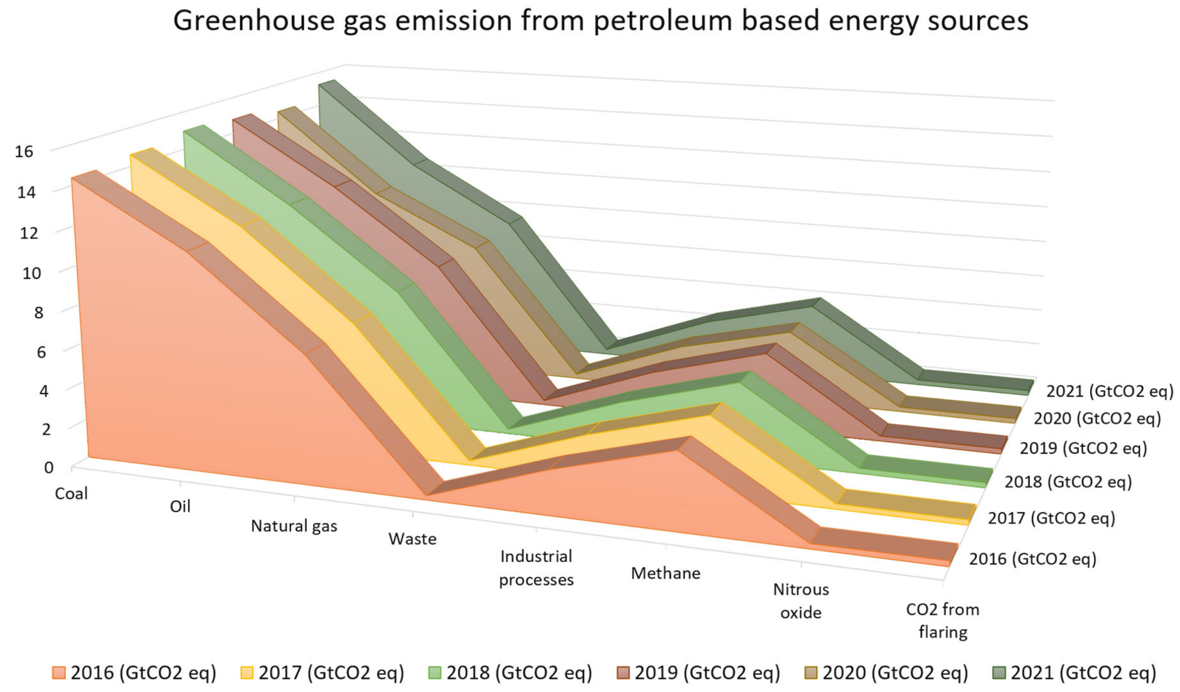

Figure 1. Greenhouse Gas Emissions from Petroleum Based Energy Sources [Calculated in $GtCO_2$ eq] (Data has been extracted from CAGR Report, 2016).

2. Aerogels

Aerogel, a novel material that bridges the gap between liquid and gas, is high because of its unique physical characteristics such as low thermal conductivity, high surface area, etc.[10]. They're made up of interlocking nanoscale filaments that form a microporous network [11]. Aerogels are the lightest solid materials with macrospores and mesoporous in a nano-scaled network with a porosity of >50% [12]. They are manufactured by substituting air for the solvent in gel network meshes. This substitution occurs during the drying process, which can be accomplished through supercritical drying or by using ambient pressure drying[13]. Placing the wet gel inside a closed container and drying the fluid beyond the solvent critical point contained within the gel pores is known as supercritical drying. The ambient pressure drying method is used to passivate the pore surface of wet gels[14]. Samuel Stephens Kistler invented aerogel for the first time in 1931 with silica[15,16]. Based on the nature of the materials utilized, aerogels are majorly divided into two groups; organic aerogels and inorganic aerogels. Aerogels made up of silica, fluoride, metal, oxides, and chalcogens are classified as inorganic aerogels. Carbon aerogels and polymer aerogels are two types of organic aerogels. Polymer aerogel is receiving increasing attention these days [13]. Various aerogel production methods towards sustainability have been showcased in Figure 2 which consists of all the modifications in the processes done in Ambient pressure drying, Rapid supercritical extraction and Aerogel beads taking into consideration the production of synthetic and bio-polymer based aerogels tending to zero carbon emissions.

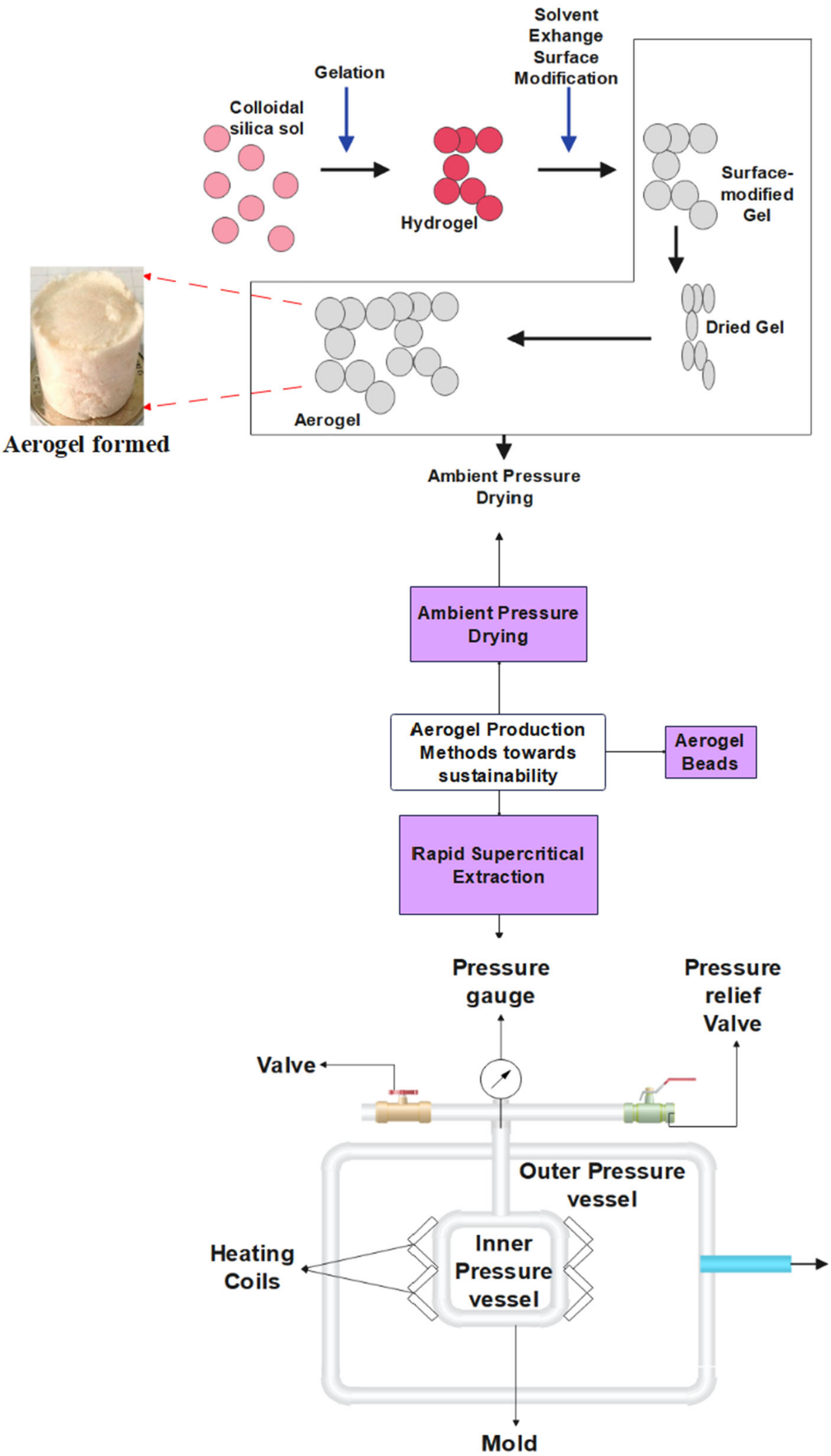

Figure 2. Aerogel preparation, production and treatment methods towards Sustainability..

2.1. Polymer Aerogels

The natural abundance of polymers has been exploited by the humans for many years in the form of oils, tars, resins, gums, and aerogel [3–5]. In the past decades, science and technological developments have resulted in a variety of synthetic polymers. Historically, plastic had a dramatic influence on the packaging industry and synthetic polymers have been widely utilized due to their durability and convenience. In recent years, the disposal of packaging plastics materials has become

 doi:10.20944/preprints202505.2201.v1

a major threat to the environment and these have now become a nuisance, damaging the natural resources such as water quality and soil fertility. During the 1990s, the plastic garbage has been tripled, which is still rising in the water, soil and air environments [6]. The most common form of polymer aerogel is a panel or thin sheet. Polyimides, polyurethanes, polyurea, polyamides, and other polymers are among those being investigated [17–20].Through the sol-gel method, polymer aerogels were created by copolymerizing several kinds of monomers, which is shown in Figure 3. Porous polymer aerogel can be made by polymerizing the successive phase of a high internal phase emulsion with an interconnected porous structure[21].

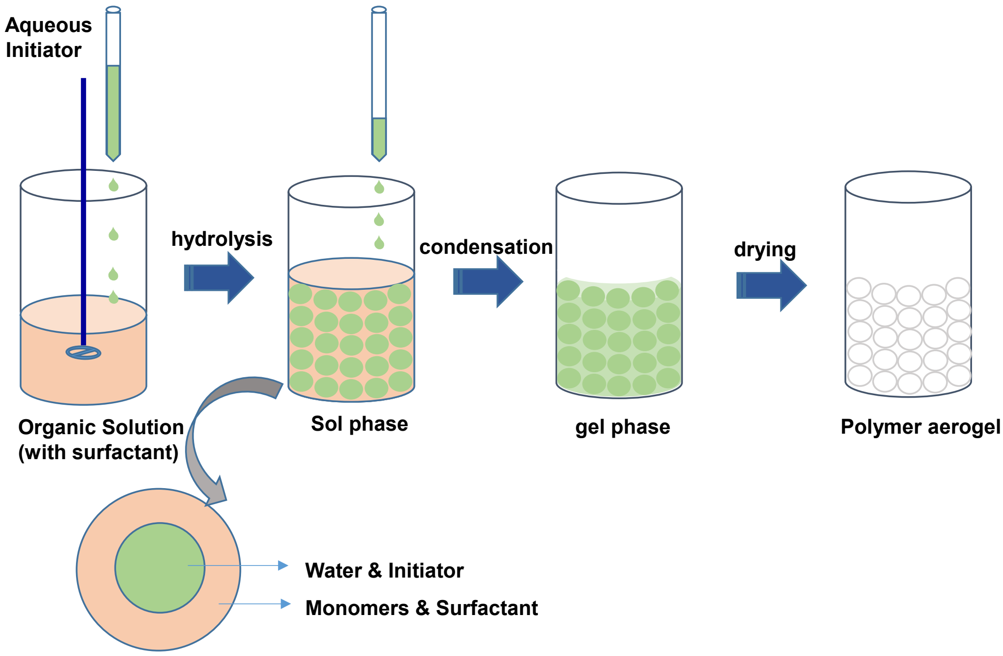

Figure 3. Manufacturing of Polymer-based Aerogels by using the green technology route.

Polymer aerogels come in two varieties: synthetic and biopolymer-based. When it comes to environmental concerns, biopolymer-based aerogels are becoming more prominent. This review discusses about various aerogels [13,22], but mainly focuses on synthetic aerogels.

2.2. Biopolymer Aerogels

Biopolymers created from sustainable resources dominate non-renewable synthetic polymers due to their excellent features such as renewability, biodegradability, and biocompatibility [7–9]..The great features of biopolymer, such as renewability, biodegradability, and biocompatibility, are now being explored in the form of aerogel. There are two major ways to make biopolymer-based aerogels: (i) by forming colloid from molecular precursors, in which the biological feedstock was reduced to its molecular state, for example, chitosan, pectin, etc. (Figure 4) (ii) by the utilization of particle-based precursors with nanoscale particle sizes, for example, chitosan nanofibril, nanofibrous cellulose, etc. [22]. Freeze-drying, gas foaming, electrospinning, and thermally induced phase separation have all been employed to create biopolymer-based aerogels [23–28].

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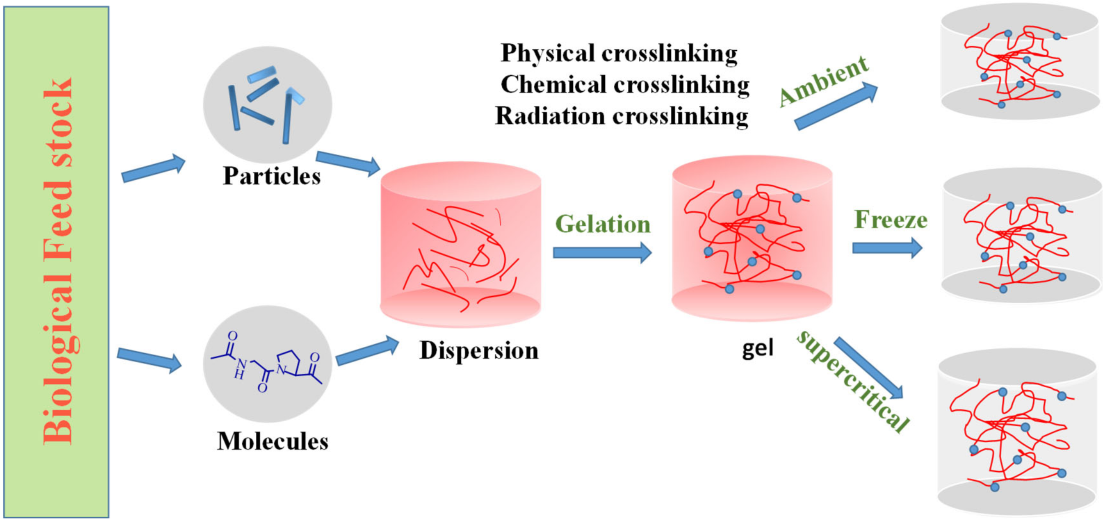

Figure 4. Schematics of synthesis of biopolymer-based aerogels and tailoring them as per the final requirement.

2.3. Synthetic Aerogels

A synthetic polymer is a macromolecule created by humans that consists of thousands of repeating units. These polymers come in both straight and branched chains. This means that nearby chains will form huge, net-like structures by bonding with one another. Crosslinking is the term for this type of chain bonding. Synthetic polymers are lightweight, durable, and long-lasting. They're pretty inexpensive to produce and uncomplicated to shape, hence such properties are used to manufacture aerogels. Various manufacturing techniques, properties and applications are shown in Table 1.

Table 1. Manufacturing techniques, Properties and Applications of Synthetic Aerogels.

Aerogels	Manufacturing Technique	Properties	Applications
Silica	Direct expansion of β-cristobalite	1.Low Thermal conductivity 2.Photoluminescence superhydrophobicity	1. shock absorbers 2. drug carriers 3. Knudsen pumps 4. thermal - superinsulation 5. space technology automotive
Carbon	Sol-gel polycondensation reaction of resorcinol and formaldehyde	1.high oil/organic solvent absorption capacity 2.good hydrophobicity electrically conductive	1.electrosorption of ions from aqueous solutions 2. rechargeable batteries 3.supercapacitors 4. broadband nonreflective materials

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Polyimides	Sol-gel confined transition	1. good mechanical properties 2. superior hydrophobicity 3. great flexibility low thermal conductivity	1.solar collectors 2. sophisticated optical elements 3. fire resistance 4. Thermal Insulation
Polyurea	Sol-gel technique	1. hydrophobic characteristics 2. Super-elasticity low thermal conductivities	1. tissue scaffolds 2. shape memory aerogels
Polystyrene	1. Solvent exchange followed by freeze-drying 2. Pickering emulsion	1. highly hydrophobic 2. oleophilic properties high sorption capacity	Oil-water separation gas storage

3. Classification of Synthetic Aerogels

3.1. Silica Aerogels

The primary class of extremely porous inorganic aerogels is silica aerogels. Since Kistler discovered silica aerogels in 1931, researchers have been working to improve their synthesis and characterization as shown in Figure 5. Mat, felt of filaments, needles, etc., forming a three-dimensional network, is the most likely structure of silica aerogel. As silica gel sets, its mechanical qualities suggest a fibrillar nature to the structure's constituents, according to his discovery. The fact that the liquid in a lump of gel at the critical temperature can be released very quickly without the outward rush of gas disrupting it, as well as the fact that diffusion and electrical conductivity in the hydrogels indicate an extremely free passage of particles the size of molecules through the solid framework [51].

It shows good transparency and good flatting efficiency [52]. In comparison to prior investigations, the suggested 192000 atoms computational silica aerogel model exhibited considerable improvements in evaluating mechanical properties [53,54]. Silica aerogel's thermal conductivity is lower than the thermal conductivity of still air [55–60].Photoluminescence and super hydrophobicity are the other two properties of silica aerogel [61–63].They can be used in a variety of contexts., including shock absorbers, drug carriers, Knudsen pumps, and thermal superinsulation. Fields of use for the latter include space technology, automotive and process technology, appliances, and buildings, as well as drug delivery [54,64–66].

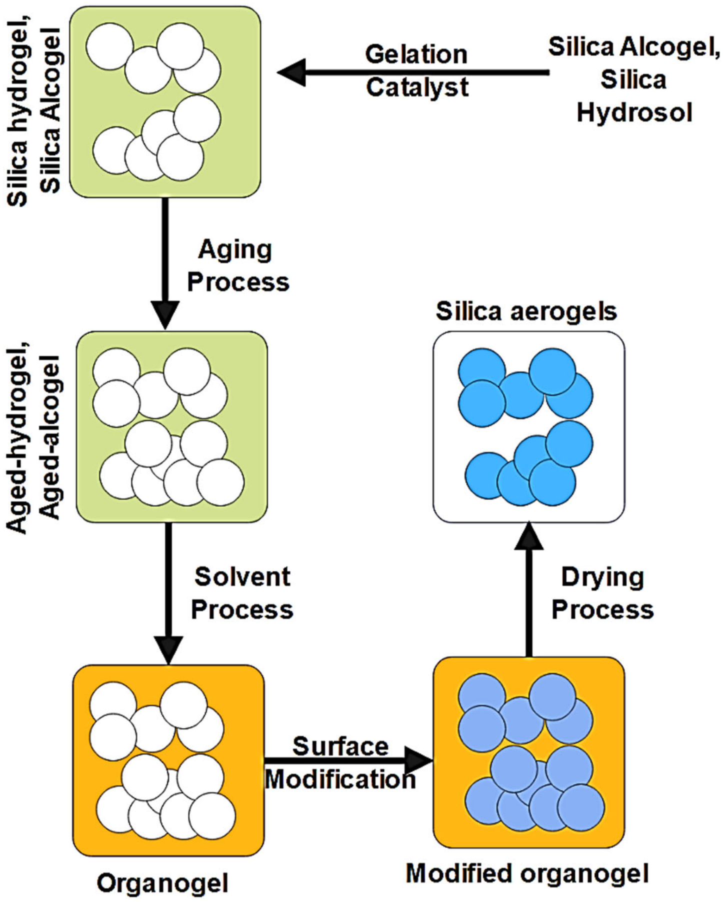

Figure 5. Silica Aerogel synthesis for Acoustic Applications.

3.2. Carbon Aerogel

Carbon aerogels (CAs) are a novel type of manufactured carbon. They are unique mesoporous materials with a variety of intriguing features, including low mass densities, continuous porosities, large surface areas. The aerogel microstructure, which is a network of linked primary particles with typical sizes between 3 and 25 nanometers, is responsible for these features.

They're made by pyrolysis of organic aerogels, which are made by supercritical drying of gels produced by the sol-gel polycondensation reaction of resorcinol and formaldehyde in aqueous solutions. They may be made as monoliths, thin films, powders, or microspheres, and they are electrically conductive, unlike all other forms of organic and inorganic aerogels (such as silica aerogels), which are ordinarily insulating materials. Carbon aerogels are intriguing materials for application as electrode materials for supercapacitors, broadband nonreflective materials, electro-sorption of ions from aqueous solutions, and rechargeable batteries summarized in the Figure 6. It shows enhanced catalytic supports due to their peculiar chemical and textural features [67–69].The carbon aerogel has a high oil/organic solvent absorption capacity and good recyclability, allowing it to selectively and swiftly absorb a variety of oily pollutants.

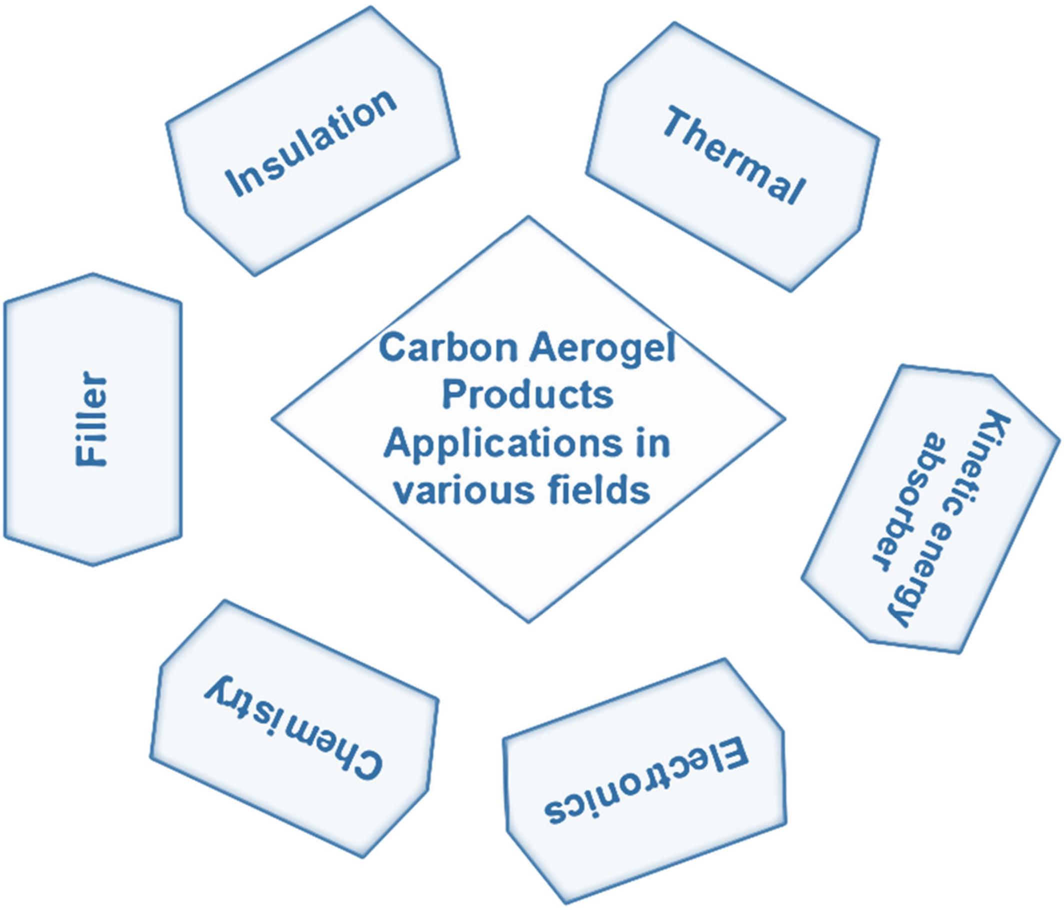

Figure 6. Applications of Carbon Aerogels in Various Fields.

As a result, this adaptable and durable functionalized carbon aerogel has promise for oil cleaning and pollution remediation. CAs have been used to explore adsorbents for the removal of organosulfur compounds from fuel [70–72]. Compressible carbon aerogels are gaining popularity as a result of their favorable electrical and mechanical properties, as well as chemical and thermal stability. Carbon nanotubes and graphene are promising choices for fabricating lightweight, compressible, and elastic carbon aerogels due to their superior mechanical strength and electrical conductivity. Improving the interaction between building units is a viable strategy for enhancing its mechanical properties. It can also be used in pressure/strain sensors and wearable devices [73]. Because of their reversible resilience and resistance to damage from external stress, carbon aerogels with outstanding compressibility and resilience are receiving a lot of interest in a wide range of applications [74,75]. Winter melon was used as the only raw material in a hydrothermal and post-pyrolysis method to create three-dimensional carbon aerogels. Winter melon carbon aerogel (WCA) has a low density of 0.048 g/cm^3, good hydrophobicity with a 135° water contact angle, and selective absorption of organic solvents and oils. WCA's ability to absorb organic solvents and low boiling point oils is about 100 percent more than its initial capability [76,77].

3.3. Polyimide Aerogel

Polyimides (PI) are a kind of engineering plastic used for high-temperature applications. Properties of polyimides are now utilized in aerogel form. The sol–gel confined transition (SGCT)-prepared polyimide (PI) aerogel fibre has a large specific surface area, excellent mechanical characteristics (with an elastic modulus of 123 MPa), superior hydrophobicity (with a contact angle of 153 °), and great flexibility (with a curvature radius of 200 m) [78].They may also be made by chemically imidizing anhydride-capped polyamic acid oligomers in solution and cross-linking them

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with aromatic triamine. Those films have tensile strengths of 4-9 MPa and are flexible enough to be rolled or folded back on themselves and recover entirely without breaking or flaking [79,80]. PI fabric woven from aerogel fibres has a low thermal conductivity (0.025 0.032 W m^{-1} K^{-1}) and provides excellent thermal insulation over a wide temperature range (165 to 250 °C).

These findings show that PI aerogel fibres might be effective thermal insulators in difficult conditions, with applications in cold protection, fire resistance, everyday insulation, and other domains [78]. PI samples were thermally stable, with breakdown beginning at 560 °C and a substantial char output in nitrogen. The CO_2 adsorption capabilities of PI aerogels, in particular, were much greater than those of prior porous materials [81]. Polyimide aerogels have a significant potential for filtration of high-temperature air due to their remarkable thermal resilience [82].Similar to silica aerogels, the relative dielectric constant changed linearly with density.

The polyimide aerogel antennas had a substantially wider bandwidth, higher gain, and lower mass than commercial substrate-based antennas, proving the viability of aerogel-based antennas as building blocks for aerospace applications [83].It was discovered that the polyimide aerogel is electrically insulating and has higher optical transmission [84–86]. Polyimide aerogel with high optical transparency and durable flexibility can be employed as an alternative for solar collectors and sophisticated optical elements. Without the usage of surfactants, pill-shaped polyimide aerogel microparticles were also created utilizing a co-flow microfluidic system [87–92].

3.4. Polyurea Aerogel

Polyurea (PUA) is a type of polymer that is formed when an isocyanate and an amine react together [93]. It is naturally hydrophilic. The water contact angle on smooth thick PUA made from an aliphatic tri-isocyanate and water was 69.1±0.2 °. However, PUA aerogels have hydrophobic characteristics, with contact angles of up to 150 degrees with water droplets [94].

Polyurea aerogel with densities of 0.19-0.26 g/cm3, high porosity (79-86 percent), and a BET surface area of 309 m^2/g were manufactured from aromatic amines and methylene diisocyanate by forming three-dimensional cross-linked networks. With a compressive modulus of 69.4 MPa, these aerogels revealed commencement of thermal disintegration at 250° C and stiffer networks at greater cross-link densities [95–98]. The mechanical features of PU aerogels, which may include super elasticity, suggest that they could be a viable approach to shape memory aerogels.

Low shrinkage, low thermal conductivities, and great thermal stability were all observed in the polyurea-based aerogel. A sol-gel technique is used to create porous materials made of polyurea with three-dimensional, chemically cross-linked solid networks and liquid-filled meso and macropores created through an oil-in-oil (O/O) emulsion, and these materials are good for transporting nutrients and could be used as tissue scaffolds [99–105]. Structural features of some significant polymers are given in the Figure 7.

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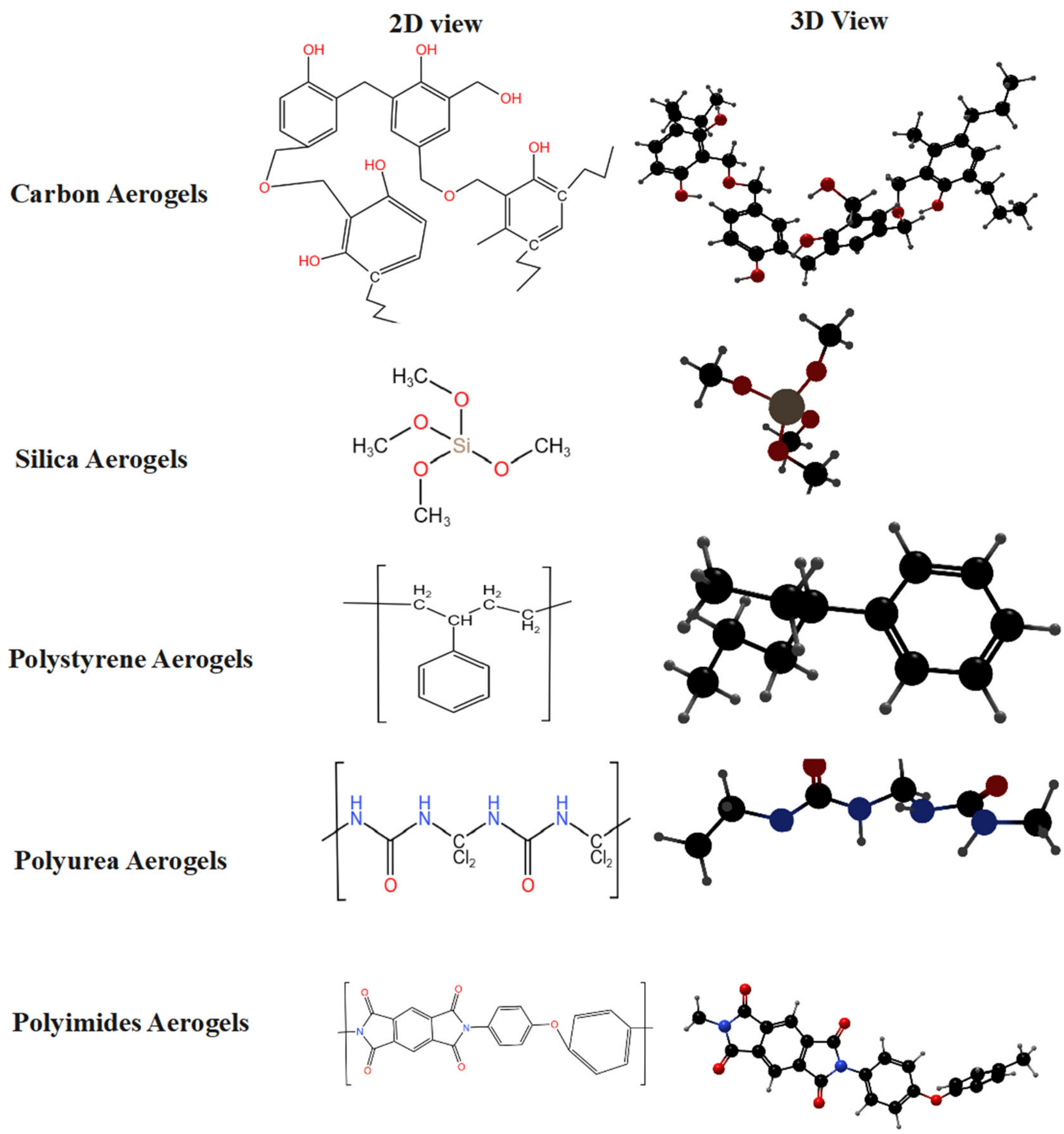

Figure 7. Formulations of various types of Synthetic Aerosols.

3.5. Polystyrene Aerogel

Polystyrenes are amorphous, high-molecular-weight linear polymers containing monomer styrene. Syndiotactic polystyrene (s-PS), a novel semicrystalline polymer, was synthesized and preliminarily characterized in 1986. s-PS has a polymorphic behaviour that is primarily based on four crystalline forms: α, β, γ, and δ. α-form s-PS aerogels have a high sorption capacity, quick kinetics, and accessible handling properties, making them particularly ideal as a sorption medium for removing residues of pollutants from water and wet air [106–109].

Long organic molecules can be detected and removed from water using ε-form aerogels [110–112]. Xylene was used to prepare s-PS gel, which was then exposed to solvent exchange with ethanol and water. Samples were freeze-dried to make the aerogel. As an alternative to traditional brittle aerogels, the generated s-PS aerogel with ultra-low dielectric constant, hydrophobicity, and mechanical strength can be employed [113]. Because nitrogen has a high sorption capacity at 77 K, microporous s-PS aerogels could be helpful for gas storage [114,115]. The Pickering emulsion approach was also used to make s-PS aerogel. When the s-PS chains are cooled to room temperature, they form thermo-reversible gels that trap the water droplets inside [116]. The s-PS aerogel's dielectric constant and porosity have a linear relationship. Also, its highly hydrophobic and oleophilic properties allowed it to be used in oil-water separation [117–119].

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3.6. Synthetic Aerogel Composites

Two or more constituent materials combine to form a composite material, having significantly different physical or chemical properties that, when combined, generate material with qualities that are distinct from the individual components. Reinforcement (fibers, particles, flakes, and/or fillers) is incorporated in a matrix (polymers, metals, or ceramics) in a composite material. The matrix keeps the reinforcement in place so that it may create the required shape, while the reinforcement enhances the matrix's overall mechanical qualities. Composites show high strength, corrosion resistance, dimensional stability, low thermal conductivity, and excellent mechanical behaviour [120,121]. Many studies have been conducted to enhance aerogel qualities by utilizing these attributes (Table 2).

Table 2. Composites of Aerogels Features.

Materials	Composite Aerogel	Method of synthesis	Characteristics
	Silica-Titania	Chemical liquid deposition of titania onto silica	Photocatalytic property
	Graphene oxide-Silica	In-situ-Sol -gel reaction	Stable Piezo- resistive behavior
Silica			Mechanical Property
	anatase–silica	co-gelation of nanoparticles	Better compositional and structural property
	C/Al_2O_3	sol-gel process	good strength
			low thermal conductivity
Carbon	organic fiber-reinforced organic aerogel	co-pyrolysis	Superior property than pure Carbon aerogel
	polyimide (PI)/graphene	Unidirectional freezing	Anisotropic conductivity
			EMI shielding
			compression performance
Graphene	graphene/ZIF-8	two-step reduction procedure and a layer-by-layer assembly method	high CO_2 uptake capacity
			variable mechanical robustness

Chemical liquid deposition of titania onto nano porous silica scaffolds was used to create silica-titania composite aerogels. The photocatalytic properties of the resulting silica-titania composite aerogel are remarkable. This feature is aided by small particle size, high specific surface area (425 m^2/g), and improved crystallinity after heat treatment at 600 °C [122].For the manufacture of graphene oxide(GO)/silica-based composite aerogels, an in-situ sol-gel reaction of organo-silanes in the presence of surface-functionalized GOs was established, followed by an ambient-pressure drying technique. The piezo-resistive behavior of GO/silica-based composite aerogels is stable. It exhibits intriguing uses under several hard and extreme circumstances due to its superior mechanical characteristics, thermal stability, and multifunctionality [123]. By co-gelation of prepared nanoparticles, create an anatase–silica composite aerogel.

Aerogels with a high titania content may be made using this method. Aerogels with pre-defined compositional and structural properties may be accessed in a flexible and modular manner using nanoparticle-based techniques, significantly expanding the capabilities of interesting materials [124].Reinforcing the aerogels using electro spun nanofibers improves and modifies the mechanical properties of low-thermal-conductivity silica aerogel composites [125,126].The sol-gel process has also been used to effectively synthesize a lightweight (carbon/alumina) C/Al_2O_3 composite aerogel with good strength and low thermal conductivity. The fracture toughness, bend strength, and heat conductivity of an organic fiber-reinforced organic aerogel composite generated by ambient drying and co-pyrolysis are all greater than the pure CA, implying that CAs will be used more in thermal management applications [127–129]. Unidirectional freezing was used to create anisotropic polyimide (PI)/graphene composite aerogels. Anisotropic conductivity, EMI shielding, heat transfer, and compression performance were all demonstrated in the PI/graphene composite aerogels [130,131].

4. Properties of Synthetic Aerogels

The structure of synthetic aerogels is unique among conventional materials, and it confers a variety of peculiar characteristics. These aerogels are solids with high porosity (100 nm), and, as a result, they have very low density, conductivity, sound velocity, and refractive index etc. which are summarized in the Figure 8. Such aerogels are one of the most promising high-performance thermal insulation materials available today for construction applications. They have a low thermal conductivity, which distinguishes them from standard thermal insulation materials.

Extraordinary dielectric characteristics and electrical behavior are also due to their nanostructure and extremely high porosity. The enormous volume fraction of trapped gas in the pores and the high concentration of adsorbed molecules on the numerous surfaces dictate the dielectric characteristics of such aerogels.

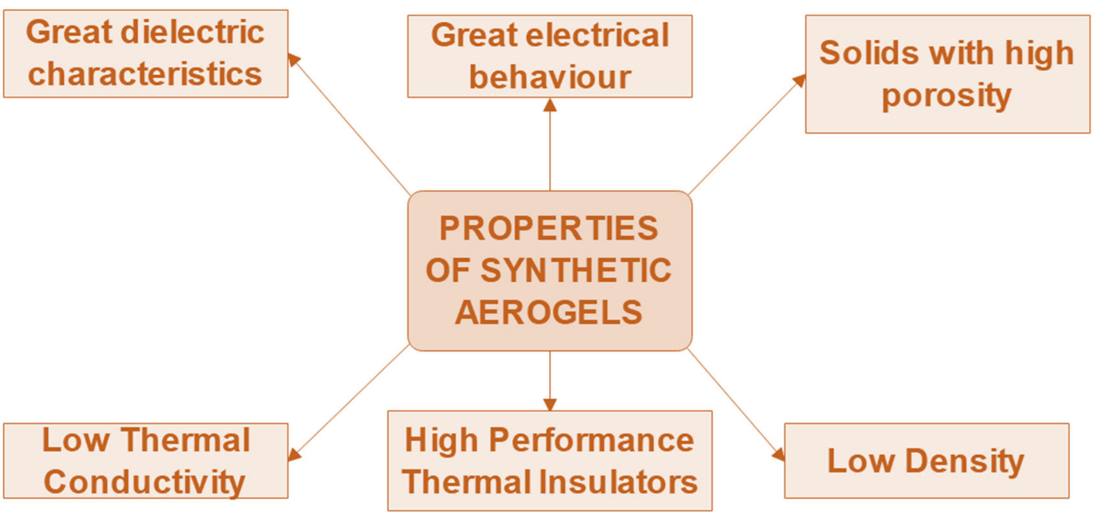

Figure 8. Several Properties of Synthetic Aerogels.

5. Applications of Synthetic Aerogels

One of the additional benefit of aerogels is their visual transparency for insulation applications, allowing them to be used in windows and skylights, helping architects and engineers to innovate architectural solutions. Biopolymer-based aerogels have a noticeable antibacterial activity. It has the potential to be employed in wound healing applications, which is a high-demand medical solution.

Silica aerogels are load-bearing and have a high compression strength of up to 3 bar, but their tensile strength is relatively low, making the material highly brittle [27,29–32]. Even though aerogel has low mechanical characteristics due to its lightweight, superior mechanical properties such as increased stiffness and strength can be achieved by controlling the feature structure of aerogel while maintaining a low relative density [33–36].

The other applications which aerogels and most particularly the recent aerogels which are the biopolymeric and most importantly synthetic aerogels hold are in areas of acoustics, shock absorption, tank baffles, carrier materials, paints, varnish, pharmacy, sensors, insulators, catalysis, adsorbents, nano vessels, extracting agents and many more shown in Figure 9.

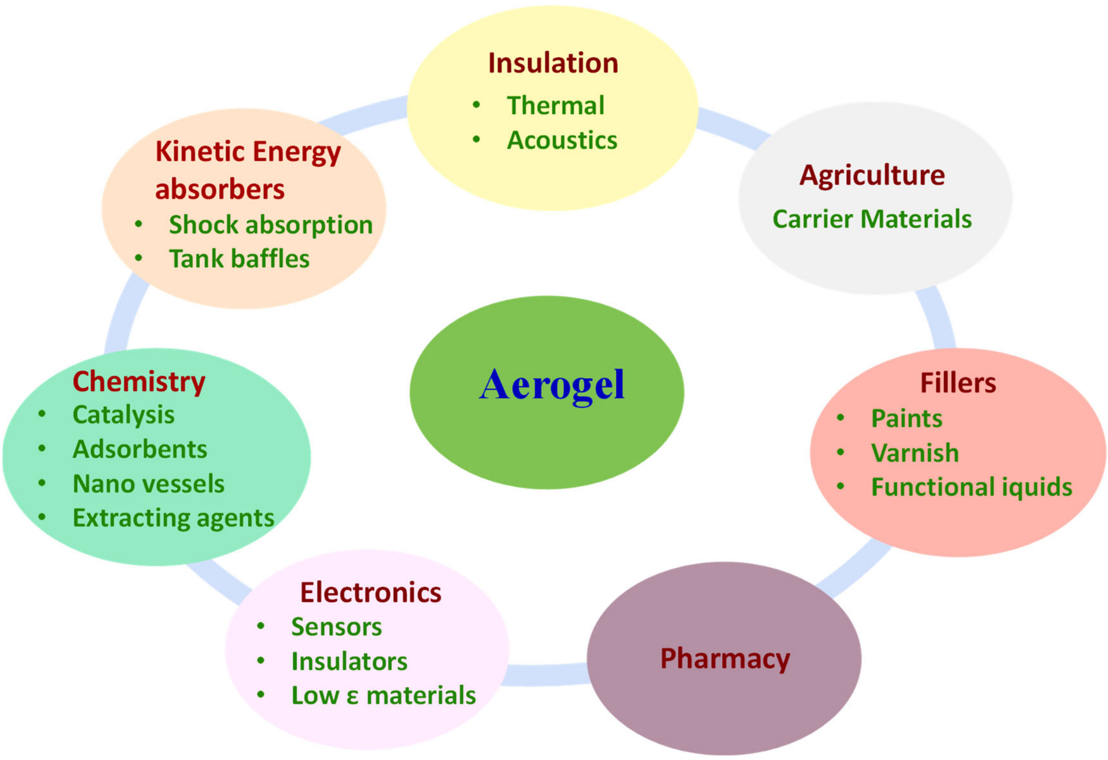

Figure 9. Broad spectrum of Applications of Aerogels.

6. Characterization Techniques of Synthetic Aerogels

One of the most critical parameters in controlling physical, mechanical, and thermal qualities is density. Aerogel is a material with low density. Normally, the displacement technique determines density using the ASTM D 1622 standard. To determine real density, an automated density analyser is also utilized.

6.1. Electron Microscopy

The microstructure, surface, pore size, and cross-section morphologies of synthetic aerogel fibres were studied using scanning electron microscopy (SEM), shown by the schematic Figure 10. The electron beam in an SEM produces high-energy electrons, some of which are backscattered by elements with a high atomic number, resulting in a negative image that allows the material structure to be detected. SEM can also be used to characterize the nanostructure and cell geometry of an aerogel [37–46]. Transmission electron microscopy (TEM) was also used to examine the microstructure of the aerogel. These aerogel samples were dispersed in ethanol, and TEM was performed on the suspensions in an ultrasonic bath. The dilute suspensions were then dropped on a carbon-coated copper grid with holes and evaporated dried at ambient temperature [42,44]. The interaction of radiation with matter is used to characterize the structures. The atoms contained in a sample can be determined using energy-dispersive X-ray spectroscopy (EDX).

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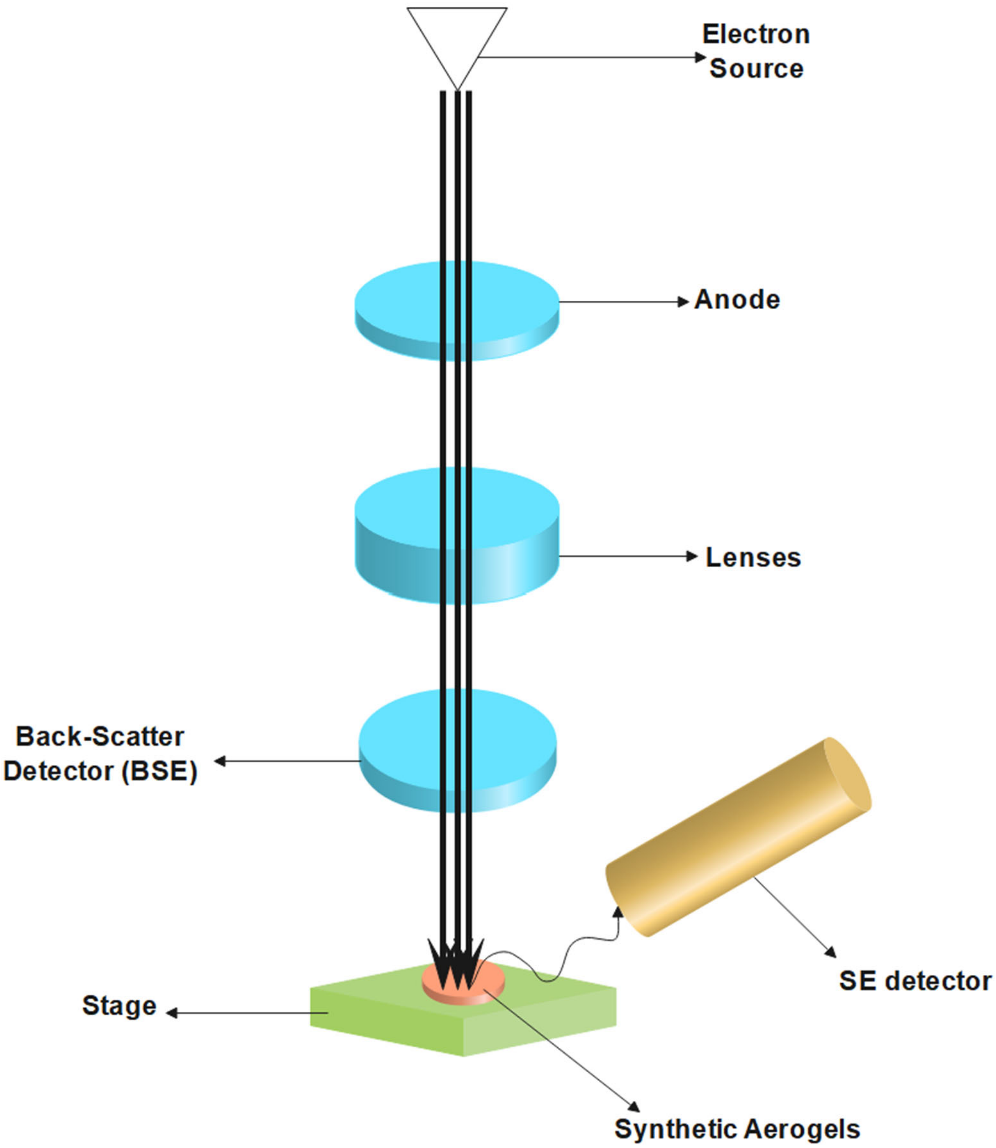

Figure 10. Scanning Electron Microscopy for Synthetic Aerogels.

6.2. Fourier-Transformed Infrared Spectroscopy (FTIR)

The chemical bonds and structure can be identified using Fourier-transformed Infrared Spectroscopy (FTIR). These techniques were utilized in silica aerogel to study the mat-aerogel interface for composite materials and to investigate graft reactions [40,42].The impacts of dissolution and protonation processes on the chemical structure of KNF aerogel fibres were also studied using FTIR technology. FTIR technology is utilized to determine not just the chemical compatibility of aerogels but also their hydrophobicity.

6.3. X-Ray Diffraction Patterns

X-ray diffraction (XRD) patterns, was used to confirm the dissolution and crystal structure of the aerogel [37,41,42,44]. X-ray photoelectron spectroscopy (XPS) is a surface-sensitive quantitative spectroscopic technique based on the photoelectric effect that can identify the elements present in a material as well as their chemical states and the overall electronic structure of the material. This technique is also used in chitosan aerogel characterization [39].

6.4. Raman Spectroscopy

Another valuable approach for determining the structural properties of aerogels is Raman spectroscopy. This is a non-destructive chemical analysis technique that offers precise information on chemical structure, phase and polymorphism, crystallinity, and molecular interactions without destroying the sample [46].

6.5. Other Characterization Techniques for Synthetic Aerogels

Different approaches may be used to validate the hydrophobic behaviour of an aerogel, mainly by estimating the water contact angle. The angle is formed by a liquid (usually water) colliding with a solid surface. When the contact angle is more than 90, the surface is considered to be hydrophobic, and when it is greater than 150, it is said to be highly hydrophobic. The hydrophobicity of the aerogel was additionally confirmed by FT-IR and TG-MS analyses [37,39,40,43,44]. Electronic universal testing equipment was used to test mechanical characteristics such as tensile, compression, etc. [41]. A dynamic mechanical analyser (DMA) is also used to analyse the mechanical property of aerogel [47].The main reason for using aerogel-enhanced material is their exceptionally low heat conductivity. The literature mentions flux meters, hot plates, transient plane source sensors, hot discs, and heat flowmeters for measuring thermal conductivity [37,40,42,45,46].

The thermal stability of the aerogel fibres was determined by thermogravimetric analysis (TGA). The mass of a sample is measured over time as the temperature varies in this method of thermal analysis. The phase change enthalpy of aerogel is determined using the differential scanning calorimeter (DSC) curve [39,41].In this thermos analytical technique, the difference in the amount of heat required to raise the temperature of a sample and a reference is calculated as a function of temperature. The waveguide transmission measuring method and the vector network analyser were used to test the permittivity of aerogels [48,49].The rheological characterization of aerogel was performed using a rheometer [50].

7. Current Perspectives

The current synthesis methods consist of precursor mixing in the first step leading to sol which is converted into hydrogel which is then converted into alcogel as shown in the Figure 11.

These alcogels are then consisting of three parts: i) cryogel, ii) synthetic aerogel, iii) xerogel. With the help of supercritical drying, alcogels are converted, and with the help of Freezing/drying, they are converted into synthetic Aerogels and finally with the help of evaporation, alcogels are converted into Xerogel. Therefore, it may be concluded that from one Synthesis, three products are formed with different applications, properties and perspectives.

Taking into account the current market of aerogels in 2023 which is approximate $2 billion USD which is projected to reach $3 billion USD in 2025 with the compounded annual growth rate of ~25 percent which is very large increase, also proving the potential substitution of conventional energy sources and previous technologies with aerogels and more specifically synthetic aerogels. The current research interests and the investments oriented towards the aerogels due to being one of the most promising materials, providing the lowest possible density along with the other high end special properties, as summarized in Figure 12.

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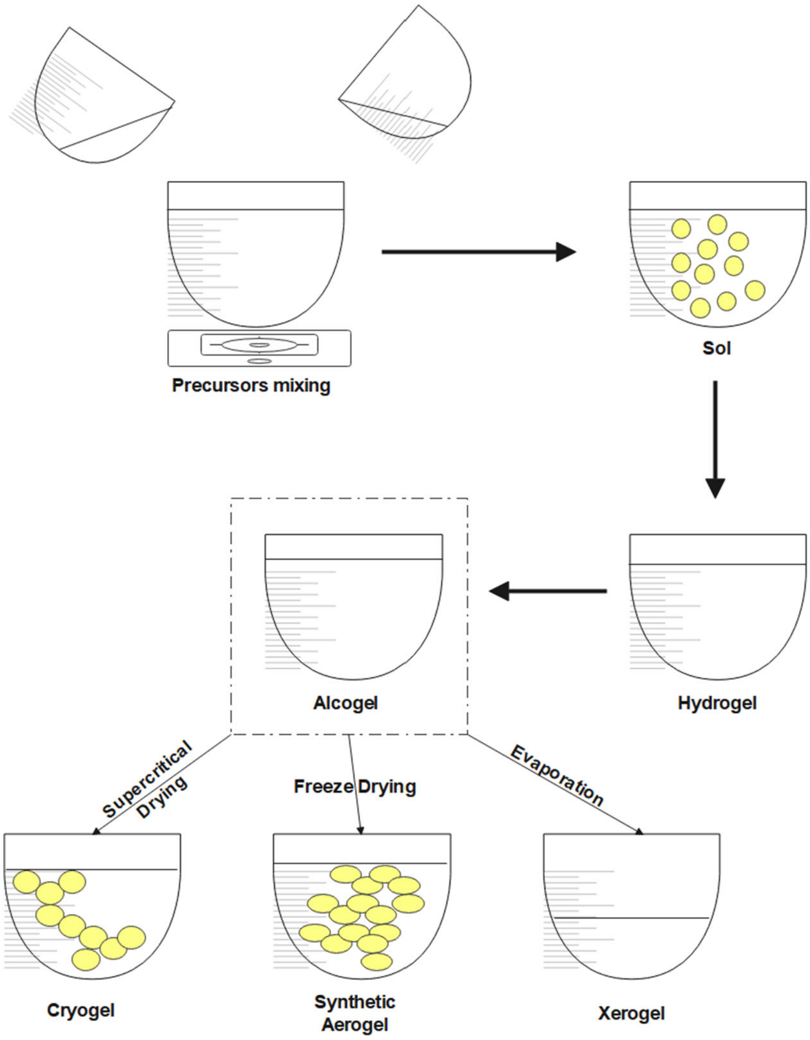

Figure 11. Current Synthesis Methods of Aerogels.

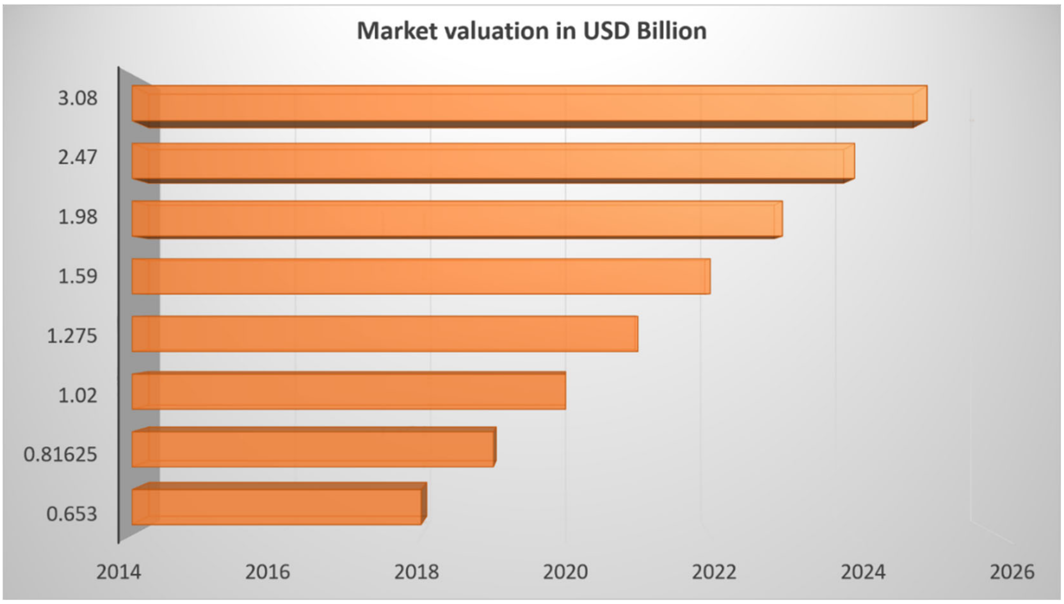

Figure 12. Current market valuations and future projections of aerogels in USD billions.

8. Conclusions

Aerogels are one of the most promising and high-performance materials due to their high porosity and low density. Aerogel made of synthetic materials satisfies all of the requirements. One of the main reasons why synthetic aerogels should get a lot of attention is because of their excellent properties at the same time not harming environment like the conventional energy sources, when we looked at the synthetic aerogels, we discussed their characterization techniques, classifications, properties, applications and perspectives of such aerogels, and these are some of the conclusions:

- Silica Aerogels have low thermal conductivity and photoluminescence super hydrophobicity and have applications in vast number of fields like drug carriers, thermal insulation, space technology and Knudsen pumps.
- Carbon Aerogels has promising properties with high oil/organic solvent absorption capacity and very good hydrophobicity. Such materials also have showcased incredible properties in rechargeable batteries, supercapacitors and broadband non reflective materials.
- Polyimides Aerogels are one of the most important and crucial aerogels as they also overcome the weak mechanical properties which aerogels usually and in addition showcase superior hydrophobicity, great flexibility and low thermal conductivity with applications in solar collectors, sophisticated optical elements, thermal insulation and fire resistance.
- Polyurea and Polystyrene both have high hydrophobic characteristics and high sorption capacity and low thermal conductivities. The properties of Polyurea aerogels help in the tissue scaffolds and shape memory aerogels whereas polystyrene have their applications in oil-water separation gas storage.

Acknowledgements: OSK, KS and HM would like to acknowledge Indian Institute of Technology, Madras, CSIR-NIIST, Trivandrum and Guru Gobind Singh Indraprastha University for providing a healthy research atmosphere and required facilities. The authors would also like to acknowledge The MOKSH Research and Development for providing relevant support to ease this research.

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