## Towards an

# International Year of Glass in 2022

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# Toward a United Nations Year of Glass 2022
# Glass for a Sustainable Society

Glass has proven to be one of the most important materials enabling the development of contemporary human civilization. Glass is an input material for key cutting edge sectors, such as energy, biomedicine, agriculture, information & communication, electronics, aerospace, optics & optoelectronics, in addition to its traditional roles in architecture, automotive, houseware & packaging; all have impacted humanity[1].

This enduring effect of glass on modern society has led some to propose that we are now living in The Glass Age[2]. The positive influence of glass on our world continues to expand as new glass products and processes are developed which address global challenges in energy, architecture, environment, healthcare, information/communication technology, photonics and more[3], all contributing to the Sustainable Development Goals of the United Nations.

In support of the perceived role of glass in meeting these goals, the history of glass is packed with milestones that have forever changed our world. While the year of discovery or the culture which first used the material cannot be identified with certainty, archaeological finds and historical texts show that glass became an object of luxury, it had an important social role in burials and its use was widespread. Ancient writers equated the glassblower's breath with the wisdom of the philosopher Seneca and the Bible[4], references glass in the Book of Job and the Book of Revelations.

The technique of blowing glass was discovered two millennia ago and changed the way the glass was regarded. Clear vessels were invaluable for stimulating transport, trade, and storage. Applications expanded when molds were introduced to control shape; artisans were free to make larger, more dynamic and intricate objects that were collected, traded and given as diplomatic gifts.

Over the last millennium, the role of glass in our shared human cultural and material heritage has swelled: church windows have miraculously spanned the length of a building allowing light to flood the interior of sacred spaces, highly decorated goblets have celebrated the reign of a dynasty, and mosque lamps have communicated a patron's generosity. In the last century float glass has come to dominate our architectural skyline and solar panels take a major role in the energy market, while in the art world it has transcended its classification as a craft material, becoming integrated into the fine arts. The twentieth century has witnessed the growth of university art programs, allowing the maker to transform from craftsperson to sculptor, using glass for artistic expression.

Over the same period scientific and technological endeavor has been underpinned by glass. The development of optics gave rise to the telescope of Galileo and his exploration of the cosmos, while the microscope has opened up the study of cells, microbes and blood. More recently, glass has been the catalyst for the high-speed manufacture of incandescent light bulbs, photo-conducting glasses have revolutionized xerography, and glass-ceramics were born from the controlled crystallization of glass. Glass optical fibers are the hidden network behind the worldwide web, stimulating a change of paradigm that has caused a global communications revolution.

In summary, glass is the transparent tool for developed and fairer societies, while compatible with a sustainable planet. It is also art, its history sharing the story and evolution of humankind.

Among the specific milestones to be celebrated in the year 2022 are:

- The 670$^{th}$ anniversary of the earliest depiction of eyeglasses in a painted work of art (frescoes dated 1352 by Tommaso da Modena in Treviso, Italy);
- The 200$^{th}$ Anniversary of the invention of the Fresnel Lens used in the seashore lighthouses that have prevented countless disasters;
- The 100$^{th}$ anniversary of the discovery of ancient Egyptian Glass in King Tutankhamun's Tomb in 1922;
- The 70$^{th}$ anniversary of the Pilkington patent in 1952 that heralded the *float glass process* and forever changed flat glass manufacture;
- The 60$^{th}$ anniversary of the Studio Glass Movement; and
- The Centennial Anniversary of the German Society of Technology (DGG).
- The 45$^{th}$ anniversary of the Nobel Prize to Anderson and Mott for their studies on glass.

**Goals of the UN Year of Glass:** The broader vision of a United Nations International Year of Glass 2022 (IYoG2022) is to celebrate the history, current state, and future of the most transformative material in the history of humankind. The IYoG2022 will underline the scientific and economic importance of glass in developing and improving the performance of the key technologies, which can help us face the challenges of a sustainable society. 2022 will be a worldwide affirmation of the Arrival of the Glass Age, showing that this transparent material can facilitate the emergence of more developed, just, and sustainable societies to meet the challenges of globalization.

Within this broader vision, we have specific goals:

- Organize glass science and glass art festivals, workshops and other activities throughout the world to promote tolerance and build bridges between people and countries.
- Highlight the intimate link between glass, art and culture and the role of glass-based technologies in preserving mankind's cultural heritage.
- Hold: early in 2022 an inaugural *Conference* in Geneva, Switzerland; a capstone mid-year *International Congress on Glass* in Berlin, Germany; and finally a World congress/exhibition dedicated to glass art and history.
- Demonstrate through joint meetings that glass science and glass arts are effective means of uniting us while respecting our diversity.
- Enhance public awareness of the critically important role glass has played in serving mankind and advancing civilization throughout recorded history be it in architecture, the arts,

communication, medicine, transportation, or other branches of science (aerospace, optics, astronomy… ).

- Stimulate international cooperation among professional scientific/technical and arts focused organizations, research institutes, universities, industry, museums, government agencies, and others involved in basic research, artistic and engineering applications involving glass and related materials.
- Promote glass as an important, inspirational and incredibly versatile platform to address some of the greatest challenges the world faces to ensure sustainable development and improving the quality of life everywhere but especially in the developing world.
- Act as a catalyst for promoting interdisciplinary fundamental and applied research in materials science and engineering with a special focus on glass and amorphous materials. Materials have been the foundation of mankind's greatest achievements and their research and development are the key to sustainable and equitable future growth.
- Build worldwide educational alliances through activities aimed at science & engineering for young people, while addressing issues of gender balance and the particular needs of developing countries and emerging economies.

There are many arguments which support glass as the significant enabling material for building sustainable societies. In the following, we review some recent and emerging glass applications that address many of the Sustainable Development Goals of the United Nations.

**UN GOAL 3 (Good Health and Well-being):**

Ensuring healthy lives and promoting the well-being of each generation is essential for sustainable development. The development of glass and glass-ceramic materials for medical applications continues to expand.

Biocompatible and bioactive glass medical devices, including bone tissue engineering, are having a transformative effect on patients across the world. The regeneration of bone defects requires materials that can bond with bone rather than be rejected by the body's immune system. Specialty glasses and glass-ceramics have been successfully developed. Bioactive glasses can stimulate the body's natural healing process, to regrow natural bone tissue[5]. 2019 is the 50$^{th}$ anniversary of Bioglass, the first material that was found to bond to bone (and not be rejected). The first clinical products reached the market in 1994. Problems treated include bone defects in the jaw, often under/above healthy teeth or around metallic implants. Since then 1.5 million patients have been helped by Bioglass products[6], in many cases where other treatments have failed. Recently, the benefit of bioactive glasses over alternative materials has been shown to be the ions released as the glass biodegrades; they stimulate bone cells to produce new bone[7, 8]. Bioglass is the active ingredient in a toothpaste that can remineralise dentine and enamel[6]. Clinical studies have found bioactive glass has antimicrobial properties in patients with deep bone infections (osteomyelitis). Treatment with the glass not only repaired the bone but also killed the bacteria, where conventional antibiotics had failed[9,10].

Now, applications are reaching beyond bone, with new bioactive glasses that stimulate soft tissue repair. Deep, persistent wounds are a serious health concern, especially in diabetic patients. New borate glass fibers show a remarkable capacity to heal soft tissue wounds where no previous therapy had succeeded[11]. The glass fibers are packed into the wound, degrading over several days. As the glass breaks down, it releases chemicals that the body needs to enable soft tissue repair. Moreover, the fibrous morphology of the glasses provides pathways along which tissues can regrow. The glass degradation rate is a key parameter to ensure that the chemicals are delivered to the body at a rate matched to the tissue growth processes[12].

Ways to improve efficiency and bioavailability are central to targeted drug delivery. Porous or hollow microspheres offer the possibility of encapsulating fragile drugs while providing protection from biological compounds that may interfere with drug availability. Porosity offers improved loading efficiency and helps control the release of medications. Uniform microspheres can be produced that improve their delivery to a specific target site. They can also reduce dosing frequency, promoting improved patient compliance. Also, a desirable plasma concentration of a therapeutic agent can be maintained by continuous drug release from microspheres.

TheraSpheres are non-degradable glass microspheres containing radioactive Yttrium-90. They are injected through the hepatic artery and lodge in the liver to treat primary liver cancer. The high energy radiation dose they deliver could not otherwise be so effectively localised.

Surface-functionalized mesoporous silica nanoparticles (MSN) are also efficient drug delivery carriers. Their synthesis allows control of their structural properties and chemical functionalization for biotechnological and biomedical applications. They can also penetrate cell membranes in animal and plant cells. MSN-based systems have enormous potential, such as site-specific delivery and intracellular controlled release of drugs, genes, and other therapeutic agents[13].

Glass is also critical for safe storage of pharmaceuticals. The chemical inertness of glass vials, cartridges, syringes and ampoules is paramount for pharmaceutical applications to prevent the medicine from interacting with the glass during long-term storage[14]**Error! Reference source not found.**. The relatively high permeability to air and the sintering aids used in most molded plastics greatly reduce the shelf life for medicines. Likewise, oxidation and reactivity with medicine make metals unsuitable for packaging.

Over the past years the increased development of biopharmaceuticals is placing ever higher demands of the packaging components. The biologically developed drug formulations growing in the areas of therapeutic proteins, vaccines and monoclonal antibodies exhibit much higher sensitivities towards foreign substances and changes in environment than chemical drugs do[15,16,17]. All new drug delivery devices contain a glass cartridge or a glass syringe. Additionally, the liquid formulations containing surfactants, salts and chelating agents coupled with even lower drug levels placed a global focus on the interactions between the formulation and the packaging material and thus the whole container closure system[18,19,20].

Chemically strengthened glass in the EpiPen® auto-injector cartridge is used to treat emergencies caused by severe allergic reactions to, for example, bee stings. The glass used for the EpiPen cartridge must be both chemically durable and mechanically strong to withstand the high pressures associated with the injection process. Several million devices have been strengthened through this process, with no known failures, thanks to advances in glass chemical strengthening technology.

Radiation protective glasses are used for health protection in different environments and are under intense study and development.

Produced by different processing techniques, with a wide range of compositions and multiple applications, glass-ceramics have become essential materials in the health field (orthodontics).

**UN GOAL 4 (Quality Education):**

A quality education is the foundation for sustainable development. An inclusive education can also equip local communities with the tools required to develop innovative solutions to the world's pressing problems. A well-rounded education provides insights into the way society has coped with change over many millennia.

Education has always been a central goal of the International Commission on Glass (ICG), a body which offers a global platform for international cooperation across the world of glass. The ICG has an important mission to stimulate an understanding of glass and promote interaction among experts in glass science and technology, art, history, and education. The consolidation of industry over the last century has reduced the numbers employed even though output has continued to rise. To revitalize worldwide glass education in a shrinking but nevertheless vibrant jobs market, a series of ICG Summer and Winter Schools have been held, starting in 2009. The Montpellier Summer School reached its 11th edition in 2019 and audiences continue to grow; in 2018, to celebrate the first ten years of these ICG Schools, the volume Teaching Glass Better[21] was published. It summarizes the course contents and captures the historical development and philosophy of the schools, explaining the lessons learned and offering a framework for others to follow. The Wuhan ICG Winter School in China achieved its 5th anniversary in October 2019 and this year a new school, the NASSPM (North America Summer School on Photonic Materials) was held in Quebec with great success. India has hosted a similar event and plans another, probably in 2022. The overlapping of staff across the schools and even students has helped to propagate and stimulate best practice in teaching methods.

The commitment of ICG to education and outreach is also highlighted by its Youth Outreach Committee, whose goal is to organize events and mentoring programs aimed at attracting and retaining the future talents of the glass world. The idea is to provide them with the tools and the network for a successful career, where they will impact on industry and on society by developing and improving sustainable manufacturing methods and expand the applications of glass.

Education is not only important at the highest levels but also for primary and secondary students, and for young technicians. Active programs targeting such groups are taking place in for example Brazil and India. We hope that a Year of Glass will encourage the wider sharing of existing practice and the stimulation of new ideas. Education is the best way to reach and instruct younger generations, raising their awareness of sustainable development goals and how to achieve them, starting from small changes in everyday life. Multiple examples need to be incorporated at every level, from elementary schools to colleges and university, to demonstrate the potential of glass in different applications and as an essential material to face the challenges of climate change and a sustainable society.

Glass recycling is currently used as the perfect model of a circular economy, "from cradle to cradle". Applications in health, ICT, photonics, architecture, energy, can demonstrate the crucial role of this material for constructing new and sustainable societies in a living planet.

Many other national and international organizations have similar aims. ICG is in contact with the British Glaziers and GlaaS, its equivalent in Australia. Another goal of the IYoG2022 will therefore be to encourage the sharing of aspirations and to expand the scope of courses available. This will include reviews of standards and how these are maintained and even improved, a sharing of educational experiences across different sections, and the setting up and publicizing of a database of the courses and educational material available internationally.

**UN GOAL 5 (Gender Equality)**

While the world has achieved progress towards gender equality and women's empowerment under the Millennium Development Goals (including equal access to primary education between girls and boys), women and girls continue to suffer discrimination and violence in every part of the world. Gender equality is not only a fundamental human right, but a necessary foundation for a peaceful, prosperous and sustainable world.

Following Donald J. Johnston, General Secretary OECD, "*Half of the brainpower on Earth is in the heads of women. Today, the difficulty is to move from the acceptance of equal rights to the reality of equal opportunity. This transition will not be complete until women and men have equal opportunities for occupying position in power structures throughout the world*."

Feminist economists and sociologists have developed two powerful metaphors to explain the employment situation of women. The ***Glass Ceiling*** explains the difficulty many women experience to access the highest professional levels, the very limited presence of women in positions of power and the lack of recognition of the work of many female professionals. The ***Sticky Floor***, on the other hand, refers to the large number of women condemned to occupy the lower ranks of the occupational pyramid: temporary, part-time, low-wage jobs, considered "unskilled". This is a floor from which women cannot easily escape during their working life and which daughters usually inherit from their mothers.

The scientific world has historically mistreated women, and discrimination continues to be present. On March 8th, 2019 there was still only one woman for every nine men in the elite of European/Western science. European women scientists occupy very few decision-making positions; their jobs are often worse evaluated; they receive less funds and fellowships for their research; and their salaries are lower than those of their male colleagues.

The European Technology Assessment Network (ETAN) report, published in 2001 by the *Helsinki group* reviewed the position of women in science and technology in Europe, concluding that *the "under-representation of women threatens the goals of science in achieving excellence, as well as being wasteful and unjust".[22].*

A statistical review of the position of women in higher education, research institutes and industry shows that, despite variations in systems and structures in different countries, the proportion of women in senior scientific positions is extremely small everywhere, demonstrating gender segregation in the scientific field. The gender imbalance in R&D institutes is similar to that of Universities. Moreover, the proportion of women in top positions as CEOs in industry is around 3%. To ignore these patterns is to accept discrimination. The report provides a shocking picture of exclusion and segregation, a common feature all over the world, and which is duplicated in the glass field and ICG.

Following the UN Beijing Conference on women in 1995, different reports have highlighted the importance of ***"mainstreaming"***, or ***integrating gender equality***, as a main policy to be implemented in Sci/Tech fields. The arguments in favour of having more women in research decision-making positions are abundant, from human rights and ethics to economics. The arguments for social justice and fairness are obvious, but there are also functional arguments:

***Diversity increases creativity***, providing a substantially broader point of view, with more sensitivity and respect for different perspectives, which is invaluable within any organization.

***Diversity increases quality***. The closer to reality the research is, the better it can produce results and products that people actually need and use.

***Gender equality improves efficiency*** as is confirmed by the recent orientation of universities towards business strategies.

It is difficult to achieve female equality in a single institution or a field, because this is a goal to be achieved across all fields, from academia to industry. But we can use a variety of tools to help women to achieve their full potential, and this applies in the glass field and ICG.

Gender equality is a must in all ICG and Year of Glass activities to be achieved by recruiting top glass-women for committees, for plenary and invited talks, as well as positions at the CEO and Management Board level. The International Year of Glass 2022 will propose and support committees chaired by women, and every committee should be highly diverse - from congress organising committees to every team running an activity. Educating companies and other platforms for talent in how to manage diversity and make it an engine for innovation and creativity is the best way to build a brighter, more diverse future.

The limits to the participation of women in sci-tech are not professional, but social; they derive from a sexist educational model, which forces women who decide to work in science to identify themselves with models that pretend to be neutral but are subliminally masculine. In addition to implementing diversity and mainstreaming gender policies, the contradictions generated between quality and professional values, on the one hand, and expectations and social image of women on the other must be overcome. A commitment is needed to build another science from women themselves, another way of approaching scientific work - already inherent in Nature - which combines real options and does not require a choice between professional and personal life.

Gender matters. Because women are half of the world, we must become half of the glass world, beginning with the main world association related to glass (ICG).

This task transcends the world of research and industry because it must begin with the transformation of education into a co-educational project. With teaching that transmits transformative knowledge, that recognizes and incorporates the social relations of sex and constitutes a step towards a more complete culture, made by men and women. This is the challenge, because this is the future.

**UN GOAL 6 (Clean Water and Sanitation):**

Clean, accessible water for all is an essential aspect of the world we want to live in and there is sufficient fresh water on the planet to achieve this. However, due to damaging economics or poor infrastructure, millions of people including children die every year from diseases associated with inadequate water supply, sanitation and hygiene. Water scarcity, poor water quality and inadequate sanitation negatively impact food security, livelihood choices and educational opportunities for poor families across the world.

While the past century has seen an unprecedented rise in living conditions for billions of people, many hundreds of millions still live in abject poverty with no or little access to clean water. The development of porous filter materials offers opportunities to sanitize water for safe consumption. Porous glasses for such applications include foam glasses or glasses that have been separated into two phases by spinodal decomposition. Typically one phase has a lower chemical durability and can be leached out by appropriate treatment. This leaves an interconnected network of pores, where the pore width can be controlled. Such filters can also be utilized for air purification, an especially urgent issue in many countries.

On other side, the main causes of surface water and groundwater contamination are industrial discharges, excess use of pesticides, fungicides, fertilizers (agrochemicals) and landfilling domestic wastes. Wastewater treatment is based upon various mechanical, biological, physical and chemical processes. This is a combination of many operations like filtration, flocculation, sterilization or chemical oxidation of organic pollutants. During recent decades, the photocatalytic degradation of various toxic organic compounds has been proposed as a viable process to detoxify drinking water. So sunlight shining on coated glass immersed in solutions containing organic pollutants, creates a redox environment able to destroy the pollutants. Most organochloride compounds and many pesticides, herbicides, surfactants and colorings are completely oxidized into non-toxic products.

The best results have been obtained by the combined use of porous glass filters along with glass/glass-ceramic coatings of titania and solar photo-catalysis and they constitute a cost-effective solution for implementation in developing countries.

**UN GOAL 7 (Affordable and Clean Energy):**

Energy is central to nearly every major challenge and opportunity the world faces today. Be it for jobs, security, climate change, food production or increasing incomes, access to energy for all is essential. Working towards this goal is especially important as it interlinks with other Sustainable Development Goals. Focusing on universal access to energy, increased energy efficiency and the increased use of renewable energy through new economic and job opportunities is crucial to create more sustainable and inclusive communities, and resilience to environmental issues like climate change.

As the worldwide demand for energy increases, new technologies are required to enable renewable energy generation and more efficient energy storage. One of the most promising sources of renewable energy is the sun. Solar energy is the largest carbon-neutral source of energy of global disposability. More energy from sunlight strikes the Earth in 1 h ($6.3 \times 10^{20}$ J) than all the energy consumed on the planet in a year ($4.7 \times 10^{20}$ J in 2004). The current exploitation of renewable energy is ≈7% (2004) of global energy consumption. The huge gap between our present use of solar energy (0.04%) and its enormous undeveloped potential defines a grand challenge in future energy research and materials technology.

Energy from the sun can be harvested via a variety of technologies, including photovoltaics, solar thermal energy generation, and photo-bioreactors. Glassy materials play a key role in each of these technologies for enhancing the solar energy conversion efficiency and enabling the overall functionality of the device[23].Photovoltaic technologies are based on the photoelectric effect, where photons are absorbed by a material to excite electrons from the valence band to the conduction band. A variety of photoelectric materials can be used in photovoltaic solar cells, including crystalline and amorphous silicon, as well as thin film semiconductors such as CdTe and copper indium gallium sulfide (CIGS). Glass design plays an important role in improving the solar energy conversion efficiency by increasing the fraction of solar energy that can be imparted to the semiconductor, e.g., through increased transparency, light trapping, or anti-reflective coatings. Glasses also provide mechanical and chemical protection for ensuring the long-term functionality of the photovoltaic cells.

Solar thermal devices offer an alternative method for harvesting energy from the sun. With solar thermal energy, parabolic glass mirrors reflect the sun's rays, directing the light onto a glass tube along the focal path of the mirrors. The solar energy heats a fluid inside the glass tube, which then powers a generator for production of electricity. Glasses for solar thermal collectors must have high mechanical strength, chemical durability, and dimensional stability with respect to large changes in temperature.

Photo-bioreactors are another approach for harvesting the sun's energy. With this approach, phototrophic microorganisms such as green algae are grown inside glass tubes. When the microorganisms are exposed to solar radiation, they convert the solar energy into chemical energy through natural photosynthesis. The conditions of the photo-bioreactor, including the optical transmission and temperature, are optimized to maximize the rate of solar energy conversion by the microorganisms.

Beyond solar energy, glass also plays a critical role in enabling efficient conversion of wind energy to electricity. The efficiency of windmills increases with longer turbine blades, which are made from fiberglass-reinforced composites. Longer blades require the development of fiberglass compositions with higher stiffness. The strength of the fiberglass-reinforced composite is also a critical property to enable larger, more efficient and more reliable windmills.

New glassy materials are also being developed for energy storage, including glass-based solid-state batteries. Here the goals are to improve energy storage density, reduce charging time, and increase the number of possible recharging cycles (i.e., improved cycling performance). The long-term safety of solid-state batteries is also of paramount concern. The performance of solid-state batteries requires a charged species with sufficiently high mobility. Typically, $Li^+$ or $Na^+$ ions are used as the conducting species. Both glass-based and glass-ceramic-based materials have been proposed as appropriate solid-state electrolyte materials[24, 25, 26,, 27].

Glasses also play a critical role in nuclear power generation, which results in both high- and low-level radioactive waste that requires geological time scales to decay fully. Hence, the safe long-term storage of nuclear waste is of critical concern for protection of our environment and to ensure the safety of humans and wildlife living near the waste disposal sites. One effective technique for storing liquid nuclear waste is to immobilize it through vitrification in a glassy matrix[28]. Of course, the glass must be stable and chemically durable over thousands of years to ensure the long-term safety of the waste storage. New glasses are currently being designed to develop glass chemistries that can both enable higher solubility of the radioactive waste, while simultaneously ensuring a sufficiently high durability. Glass-ceramics have also been proposed for nuclear waste immobilization and may support an even higher density of waste storage compared to glasses[29].

Glass may play a role even in the development of hydrogen-powered vehicles. One of the challenges is to realize the hydrogen storage in a small volume and light weight; a possible solution is offered by hollow glass microspheres (HGM), with diameters in the range 1 to 100 µm. One can exploit the rapid diffusion of hydrogen through the thin wall into an HGM at elevated temperatures and pressures; the gas is then trapped upon cooling to room temperature. A rapid release of the stored hydrogen is possible, for instance, by photo-induced outgassing, in which an infrared light lamp is used to accelerate the release rate[30].

**UN GOAL 9 (Industry, Innovation and Infrastructure):**

Investments in infrastructure – transport, irrigation, energy and information and communication technology – are crucial to achieving sustainable development and empowering communities throughout the world. It has long been recognized that growth in productivity and incomes, and improvements in health and education outcomes require such capital spending. Manufacturing is an important driver of economic development and employment but the $CO_2$ emissions during fabrication must also be considered.

Technological progress is the foundation of efforts to achieve environmental objectives, such as increased resource and energy-efficiency. Without technology and innovation, industrialization will not happen, and without industrialization, development will not happen. More investment is needed to increase efficiency in the high-tech products that dominate manufacturing and a focus should be given to information and communications services (ICT) that increase connections between people. Glass products have a key role in many of these fields, especially ICT technologies.

The invention of low-loss glass optical fibers was essential in the development of the Internet, enabling exponentially growing levels of communication across the globe[31]. Optical fibers are the physical support that allowed the paradigm shift leading to the global communications revolution. They are the indispensable elements on which the process of globalization of the economy and industry is based, being the main support of a knowledge society.

As the demand for bandwidth continues to grow, new fiber optic technologies are being developed to enable more data to be transmitted over longer distances, while minimizing the need for signal amplification. This will involve further reductions in fiber attenuation, which may be achieved through improved material design or process optimization. Photonic crystal fibers may also enable lower-loss optical transmission, although significant process challenges must be overcome before this technology becomes viable for long-haul transmission[32]. New glass fibers are also being developed to enable quantum communication, which can lead to secure communication via quantumly entangled photons[33]. Glass fibers will play a critical role in facilitating the "Internet of Things," i.e., the interconnection of everyday appliances and objects, such as stovetops, refrigerators, etc., within buildings. This connectivity will enable such appliances to send and receive data, and perhaps even include built-in smart displays.

More generally, photonics is nowadays a broad technology enabling a vast diversity of applications, and many advances in photonics rely on the use of glasses and glass-ceramics. On one side, the photonics industry relies on many components having optical glass at their heart: indeed, glass is critical for the fabrication of spherical lenses, aspheres, prisms, beam splitters, optical fibers, axicons, and other optical components. Similarly, the optical communications industry relies on glass components and devices: linked to optical fibers, the addressing and filtering of the information flux is largely performed by integrated optical circuits. These circuits are fabricated in glass, owing to the very low losses guaranteed by glass optical waveguides, or in hybrid material structures, where one can exploit the different properties of glass, glassy materials (such as many polymers), and semiconductors. Recent advances concern the area of wireless communications, where radio signals can be carried over a fiber-optic cable (RoF, Radio over Fiber), e.g. to facilitate wireless access, such as 5G and WiFi simultaneous from the same antenna. The radio frequency generation at millimeter wave frequency and beyond, needed for photonic RoF systems, may be performed by glass lasers, using Er-Yb doped glass waveguides[34].

Fiber lasers, too, exploit the unique characteristics of glass doped with rare earth ions. They benefit from superior performance, compactness, versatility compared to other commercial lasers and are therefore used as a standard in many industries over the world for a huge range of applications. Their use in clinical surgery and therapy is also expanding. Besides being a technological application tool, fiber lasers constitute an excellent platform for investigating a wide range of nonlinear phenomena and to advance our understanding of nonlinear processes[35].

LED sources, which are based on the light emission from crystalline semiconductors, often require the integration of a phosphor to produce white light or to suitably tune the emitted color, and this is often a solid glass artefact or a glass thin film doped with rare earths. One-dimensional photonic crystal structures, which allow manipulation of the passage of light, may be realized by the deposition of glass layers with different refractive indices (e.g. using a sol-gel process) . 2D and 3D photonic crystals are fabricated by self-assembling ordered arrays of glass nanoparticles. Their application to sensing is attracting a growing interest, but glass micro- and nano-spheres may also offer solutions to many other problems[36].

Another emerging field is that of flexible and stretchable photonics: it is envisaged that the fabrication of integrated optical circuits in thin films deposited on top of ultra-thin glasses may lead in the near future to a breakthrough similar to what is happening with flexible electronics. Wearable photonic monitors and sensors will be soon within reach[37].

Glass has also played a revolutionary role in information display, from early televisions based on cathode ray tubes to more recent flat panel displays[38]**Error! Reference source not found.**. As the resolution of these displays improves by using smaller pixel sizes, the requirements on the high-tech glass substrates become more and more stringent[39]. New glasses must be developed to improve dimensional stability during the display fabrication process, that is to minimize the magnitude of volume relaxation as the thin film electronics constituting the display are deposited onto the glass substrates. New ultra-thin glasses are also being developed to enable bendable or even foldable displays[40]. Advanced glasses are also being developed for visualizing information through augmented and virtual reality devices, which perhaps represents the next revolution in information display technology[41].

In addition to their critical role in the transmission and display of information, glasses have also revolutionized data storage. Chalcogenide-based phase change memories have enabled rewritable data storage by toggling localized regions between glassy and crystalline states, which represent either 1 or 0 bits[42]. High-density magnetic memory disks are built on high-strength, high-stiffness glass substrates to enable faster rotational speeds and higher-density memory storage[43]. Glasses are also promising materials for next-generation holographic memories, which could enable exceptionally high data storage densities[44].

Among new glass processing techniques, Sol-gel plays an important role. This is a liquid phase, wet chemistry-based technology interest in which has grown steadily for the past 50 years and has recently gained momentum for applications in optics, optoelectronics and photonics. Sol-gel is a low temperature, energy-saving, low-cost technology, especially suitable for glassy coatings and membranes. Such coatings are used for: mechanical and corrosion protection; anti-reflection; hydrophobicity; photocatalytic self-cleaning and fuel cells; optic and optoelectronic functionalities in solar cells, solid-state lighting and optical communications; and from discrete devices such as optical filters, switches and waveguides to integrated optical circuits.

Glass plays also a key role in transport technologies, leading the design and production of smart windscreens that are revolutionizing vehicle safety. Flat glass is used to make windscreens, backlights, windows and sun roofs for a wide range of automobile and transport applications, from cars to cruise ships, trains, aircrafts or buses.

Innovative high-tech glazing solutions have been developed to minimize heat gain in vehicles and offer thermal comfort all year around, to reduce vehicle weight through the use of lightweight glazing, to provide maximum visibility for optimum driving conditions, to integrate new features that enhance the driving experience and to safeguard the vehicle occupants in case of accident. Glazing solutions for the automotive industry need to offer the highest possible performance in terms of safety, security and durability, as well as style and comfort for vehicle manufacturers and for their passengers[45].

The crucial role of glass products in clean and renewable energy were just described in Goal 7.

**UN GOAL 11 (Sustainable Cities and Communities):**

Cities are hubs for ideas, commerce, culture, science, productivity, social development and much more. At their best, cities have enabled people to advance socially and economically. With the number of people living within cities projected to rise to 5 billion people by 2030, efficient urban planning and management practices must be in place to deal with the impact of urbanization. Common issues include congestion, lack of funds to provide basic services, a shortage of adequate housing, declining infrastructure and rising air pollution. Challenges linked to rapid urbanization, such as the safe removal and management of solid waste, must be overcome in ways that allow cities to continue to thrive and grow.

Following the discussions in Goal 9, it is worth repeating that glass technologies are essential in the development of modern transportation. For example, chemically strengthened glasses are essential for the safety of airplane cockpit windshields. New lightweight, high-strength glasses are being developed for automotive windshields to improve fuel efficiency and passenger safety[46]. Glassy materials will also play a more prominent role in automotive interiors, especially with the development of self-driving vehicles. With humans expected to play a less active role in driving the vehicle, glass displays and touch screens will provide new options for entertainment and connectivity on the road. However, the glass and glazing industry are increasingly going beyond this by offering innovative products that dramatically reduce fuel consumption and $CO_2$ emissions. Thus, they are taking an active role in contributing to innovative and technological competitiveness as well as to the greening of the transport sector. Weight reduction, solar control glazing and the development of electric vehicle-specific glazing notably achieve this.

The flat glass industry is also actively developing new energy efficiency technologies for buildings; newly developed glass and glazing units can significantly reduce the need for heating and cooling, reducing energy consumption and the associated emission of carbon dioxide. Advances in glass coatings will enable the development of energy neutral buildings, or even buildings that contribute to the energy grid.

Contemporary residential and commercial architectural design increasingly incorporates more and larger window areas. This design trend is supported by the evolution of energy-efficient glazing, the most effective being capable of dramatically reducing heat gain and heat loss. Many of these energy-efficient glazing options also provide some measure of UV protection[47]. A recent TNO study quantifies the energy savings and $CO_2$ emission reduction potential from high-performance glazing[48] across the 28 EU Member States for both 2030 and 2050 horizons. In addition to the maximum potential, whereby all windows are equipped with high-performance glazing across all EU buildings, it also simulates the impact of various window replacement rates, all compared to a baseline scenario. The study draws on recent scientific sources to define input parameters such as today's European building stock and performance, the evolution in the energy mix, the penetration of high-performance heating and cooling equipment and so on.

The two scenarios studied show that windows equipped with high-performance glazing have the potential to deliver up to 75.5 Mtoe of energy savings in 2030 and 67.3 Mtoe in 2050. This correspond to annual $CO_2$ emission avoidance of up to 94.2 Million tons and 68.5 Million tons in 2030 and 2050 respectively. The study shows an energy saving potential in 2030 equivalent to a reduction of 30% in the energy consumption of buildings, showing windows to be key components in the energy performance. The European Union is targeting the objective of becoming the first climate neutral economy by 2050. To achieve this ambitious goal, reducing drastically energy consumption from buildings is a necessity even if Europe succeeds in decarbonizing its energy production.

The contribution of glazing to a climate neutral Europe could potentially be even higher. New glazing products, such as switchable/ electrochromic glazing, glazing-integrated photovoltaics or other novel technologies, not considered in the TNO study, could generate additional $CO_2$ savings.

**Glass containers** are also key players in the route to reducing solid urban waste (SUW). The "*Reduce, Reuse, Recycle"* Waste Hierarchy constitutes the main rule to reduce the amount of waste generated, and to improve overall waste management processes, offering guidance for creating a sustainable life. More than 60% of SUW is containers and packaging, mostly single use, usually manufactured from non-renewable raw materials, or which, if renewable, are nevertheless being exploited faster than their regeneration rate.

Reduce is possible by consuming durable goods with long warranties and avoiding disposable items. In the case of containers, returnable glass bottles are consumed in hotels and restaurants while single-use containers are preferred by supermarkets. Glass containers, mainly jars and pots, are often reused to store items in the kitchen though. The third R, recycling, implies the transformation of the object into a raw material that can be shaped into a new item. Glass is the only container recyclable in the hard meaning of the concept: one glass bottle produces another glass bottle. Glass can be infinitely recycled thus being a perfect example of “circular economy” expressed as “from cradle to cradle”. Moreover, glass containers are the only ones with the GRASS and Food Safety stamp in Europe and US.

The ever expanding use of clean and renewable energies, especially PV-solar energy for housing along with the use of low-energy LED lighting offer other ways to reduce energy consumption, lowering $CO_2$ emissions and pollution in cities.

From greener transport to efficient architectural glazing, from the installation of PV panels to the use of glass containers that respect the 3R rule, glass is essential to improving the use of natural resources, lowering $CO_2$ emissions and pollution while enhancing the life of citizens.

Culture in all its expressions is an essential element in improving and developing the life of cities and the well-being of its inhabitants. Among cultural institutions, museums play a strategic role in making cities and communities inclusive, safe, and sustainable.

Museums are places where the tangible and intangible heritage of humanity and its environment is preserved, studied, and exhibited for the purposes of education, study and enjoyment. Communities identify museums as spaces for sharing ideas in a safe, inclusive, and accessible environment[49].

Being multidisciplinary institutions open to people and embedded in the community, museums can play a strategic role in enhancing the knowledge of glass among citizens. They are crucial for dissemination, educational activities, and hands-on experience.

Even if the origin of museums is rooted in western society and culture, most communities worldwide host museums and recognize them as a tool for empowering people, giving them resources for learning and developing skills, while enhancing their quality of life and wellbeing.

Art, science, archaeology, history, and social sciences find their meeting point in specialized glass museums and museums with collections of glass. They display glass objects from the antiquity to the present-day, not only works of art but also glass for everyday use, as well as specialized glass for industry and science.

Museums have plenty of stories to tell, describing raw materials and techniques needed for producing glass and glass objects along the centuries, and giving insight into the life of the people who created and used them.

Glass museums have educational programs for children and adults aimed at raising knowledge about glass, its history and use. They ensure inclusive and equitable quality education and promote lifelong learning opportunities for all (see also goal 4).

Many glass museums are equipped with hot and cold workshops and studios which can provide invaluable opportunities for learning. Glassmaking activities are also tools which create inclusivity.

**UN GOAL 12 (Responsible Consumption and Production):**

Sustainable consumption and production are about promoting resource and energy efficiency, sustainable infrastructure, and providing access to basic services, green and decent jobs and a better quality of life for all. Currently, consumption of natural resources is increasing, particularly within Eastern Asia. Countries are though addressing challenges regarding air, water and soil pollution.

Since sustainable consumption and production aims at “doing more and better with less”, net welfare gains from economic activity can increase by reducing resource use, degradation and pollution along the whole life cycle, while increasing the quality of life. There also needs to be significant focus on the operation of the supply chain, involving everyone from producer to final consumer.

Glass is an environmentally friendly material in many ways. Most glasses are made from safe, readily available raw materials such as sand, soda ash, and limestone. Also, glasses can be reused and recycled any number of times. In addition to using more recycled materials, the glass industry is currently developing more energy efficient melting technologies to reduce the carbon footprint of glass manufacturing. One approach to reduce the environmental impact of glass manufacturing is the development of alternative glass compositions with lower melting temperatures compared to traditional soda lime silica glasses. The ultimate goal is to achieve carbon-neutral manufacturing.

As discussed in Goal 11, the glass industry offers recyclable goods, from glazing to containers and vehicle windscreens. Glass is the only material which is infinitely recyclable.

Educating consumers on sustainable consumption and lifestyles is essential, by providing them with adequate information through standards and labels and engaging in sustainable public procurement. The concepts of a “circular economy” have to be understood by citizens to commit to the challenges of global change; explaining how it will be possible to maintain lifestyle without damaging the planet.

**UN GOAL 13 (Climate Action):**

Climate change is now affecting every country on every continent. It is disrupting national economies and affecting lives, costing people, communities and countries. Weather patterns are changing, sea levels are rising, weather events are becoming more extreme and greenhouse gas emissions are at their highest levels in human history.

Affordable, scalable solutions are now available to enable countries to leapfrog to cleaner, more resilient economies. The pace of change is quickening as more people are turning to renewable energy and a range of other measures that will reduce emissions and increase adaptation efforts. Climate change, however, is a global challenge that does not respect national borders. It is an issue that requires solutions that need to be coordinated at the international level to help developing countries move toward a low-carbon economy. Paths towards decarbonization are being developed by the glass industry, for a low-carbon economy[50]

Glass artefacts have a major role in combating climate change due to their energy saving functions and despite the relative high energy demand for batch melting and the generation of $CO_2$ during glass production. The energy efficiency of glass melting itself has increased substantially in the last decades via the use of recyclable post-consumer waste glasses and the reduced weight of glass products, e.g. for container glasses by 25% (≈300 kg $CO_2$/1000 kg glass).

Although often taken for granted, glass windows allow light into homes and offices while also protecting the occupants from harsh weather conditions[27]**Error! Reference source not found.**. Today, glass is widely used in architecture for both its practical functionality and its appealing aesthetics. Some newly developed architectural glasses include photochromic[51] and electrochromic[52] materials, which enable windows to adapt dynamically to sunlight conditions so improving energy efficiency.

Vacuum insulated glazing is another technology which has improved energy efficiency[53]. Traditional double-pane windows are filled with a noble gas such as argon between the two panes, which reduces the transfer of heat. With vacuum insulated glazing, a vacuum replaces the noble gas to reduce heat transfer further. The strength of the glass panes becomes more critical with vacuum insulated glazing, since small spacers are required to maintain the plane parallel geometry of the two glass panes, and localized stresses are generated near the contact points of the glass with these spacers. Also, the panes must be perfectly sealed to prevent the diffusion of air into the vacuum.

In architectural spaces, laminated glasses are being developed which increase acoustic damping to reduce "noise pollution" in homes and offices. For example, a recent patent includes a viscoelastic acoustic damping layer between two panes of glass to increase sound absorption[54].

The energy saving glass products, including low-emissivity double glazing in buildings, mineral wool and foam glass for insulation and continuous filament glass fiber for production of wind turbines, lighter vehicles, etc. compensate several times over during their service life for the energy consumption of their production. For example, the replacement of single with double-glazed windows will save 60 kg $CO_2$/year due to heat insulation compared to approximately 25 kg $CO_2/m^2$ emissions for their manufacture, i.e. the energy payback time is 5 months. Similarly, the promotion of glass containers is important not only because they fulfil the 3R' rule but because the use of recycled glass reduces the energy consumption in glass furnaces. Indeed, the energy necessary to melt glass is reduced by 2,5% for each 10% of batch replaced by cullet; for 100% green bottle recycling this means a reduction above 20% and 15% for amber glass.

**UN GOAL 14 (Life Below Water):**

The world's oceans – their temperature, chemistry, currents and life – drive global systems that make the Earth habitable for humankind. Our rainwater, drinking water, weather, climate, coastlines, much of our food, and even the oxygen in the air we breathe, are all ultimately provided and regulated by the sea. Throughout history, oceans and seas have been vital conduits for trade and transportation. Careful management of this essential global resource is a key feature of a sustainable future.

Plastic waste is currently polluting the world's oceans and other bodies of water. The ingestion of plastic by fish and other marine animals also causes health problems in humans consuming fish and seafood. The toxins found in plastics can lead to numerous health problems, including immune disorders, birth defects, and several types of cancer.

Glass packaging can be used as a safe and clean alternative to plastics to address this problem and eliminate plastic waste. Glasses are made from natural, safe, and abundant materials such as sand, soda ash, and limestone. Glasses are also infinitely recyclable as described previously. Elimination of plastics will promote the health of life below the water and the health of humans who consume fish and seafood as part of their diet.

**UN GOAL 17 (Partnerships to Achieve the Goal):**

A successful sustainable development agenda requires partnerships between governments, the private sector and civil society. These inclusive partnerships built upon principles and values, a shared vision, and shared goals that place people and the planet at the center, are needed at the global, regional, national and local level.

Urgent action is needed to mobilize, redirect and unlock public and private resources to deliver on sustainable development objectives. These include green energy, infrastructure and transport, as well as information and communications technologies.

The main goal of an International Year of Glass 2022 is to activate partnerships between governments, R&D and academia, companies and civil society. This is the key to this application – the many arguments supporting the significance of glass as an enabling material for building a sustainable society. With its unparalleled versatility and technical capabilities, glass material has fostered numerous cultural and scientific advancements in communications, optics, energy, and medicine. But glass involves much more than science. Glass is also art, the history of this material sharing the history and evolution of humankind.

A UN Year of Glass in 2022 will underline the technological, scientific, economic, historical and artistic role of glass in our societies. It will emphasize the rich possibilities of developing technologies and their potential contribution to meeting the challenges of a sustainable and fairer society. It will bring together the multicolored threads of technology, social history and art through educational programs and museum exhibitions.

To achieve these ambitious aims the key will be to promote networking among: every type of glass association; universities, colleges and schools; R&D centers, and industry, including producers and suppliers; and museums and civil society. This great mobilization will require activation of national governments, industry, academia and cultural centers to support the initiative and promote a wide range of activities related to this IYoG2022. All our effort will focus on demonstrating that glass is the transparent tool able to build a sustainable planet based on more developed and fairer societies.

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