Kañch

Quarterly Journal of **The All India Glass Manufacturers' Federation**

Bi-lingual

Glass is Pure or काँच जीवन है (2025)
1st Prize: Rashi Sharma (13 years)
8th class student of Bal Bharti School, Bahadurgarh HARYANA

Siliconized Vials
EVERY DROP COUNTS!

Further minimize interactions between glass surface and drug product

Less adhesion of high viscosity drug products to the inner surface of the vial

Higher restitution rates

Less residual drug volume

NIPRO PHARMAPACKAGING

NIPRO PHARMAPACKAGING INTERNATIONAL
Blokhuisstraat 42, 2800 Mechelen, Belgium | pharmapackaging@nipro-group.com | www.nipro-group.com

---

gerresheimer
innovating for a better life

Center of Glass Excellence offering

Kosamba
Mumbai

High Quality Products for Perfectly matched Moulded Glass Packaging & Tubular Glass Solution

Moulded Glass Range

Material: Borosilicate Glass, Sodalime Glass
Glass Types I, II & III in Clear & Amber Glass
State of the art facility – ISO Standard Clean Room
ISO 9001, ISO 45001 & GMP Certified Facility
Range: 2 ml – 600 ml, Type & Color wise
Injection, Infusion, Dropper, Syrup, Tablet, Sprays
Graduated, Ungraduated, DIN, Crimp & Screw finish

Tubular Glass Range

Material: Type I Borosilicate Glass
Ampoules & Vials in Clear & Amber Glass
Syringes and Cartridges in Clear Glass
ISO 9001, ISO 13485, ISO 15378, ISO 45001 &
GMP Certified Facility
Vial Range: 1 ml – 30 ml for Parental & Diagnostics
HPLC Scientific Vials, Screw Neck /
Crimp Neck Press Fit, Blowback
Ampoules: OPC, Break / Score Ring, Form:
B, C, D Printed / Non printed, treated / non treated

Syringes & Cartridges Range

Material: Type 1 Glass
Syringes and Cartridges in Clear Glass
ISO 9001, EN ISO 13485, EN ISO 15378
Syringe Range: 0.5 ml – 5.0 ml
Printed / Non-Printed, Oily Siliconized /
Baked on Silicon (BoS)
Syringes: Staked in Needle / Luer Lock /
Luer Cone / Syringe with Safety Device (InnoSafe)
Cartridge Range: 1.5 ml, 1.8 ml and 3 ml

Registered Office:
906, Windfall Off. M. Vasanji Road
J.B. Nagar Andheri (East)
Mumbai 400 059 India

Manufacturing Sites:
Plot no. 38, Village Kunvarda
Taluka Mangrol Kosamba (RS)
District Surat - 394120

Telephone +91 22 4163 2323
support.india@gerresheimer.com
www.gerresheimer.com

Order Your copy now

Contents

Excellence in Container Glass Manufacturing

An **AIGMF** Publication
www.aigmf.com

Written By **Er. Ashoka Rao Manikala**
(Former President Operations PGP Glass and AGI Greenpac)

Technical Articles

Adopt a glass bottle
100% Recyclable

Drawing Competition- Adopt a Glass Bottle (2019)
3rd Prize: Rahul Kumar Kamat (13 years)
8th class student of Govt. Co-Ed Secondary School, Sector 19G Rohini, Delhi
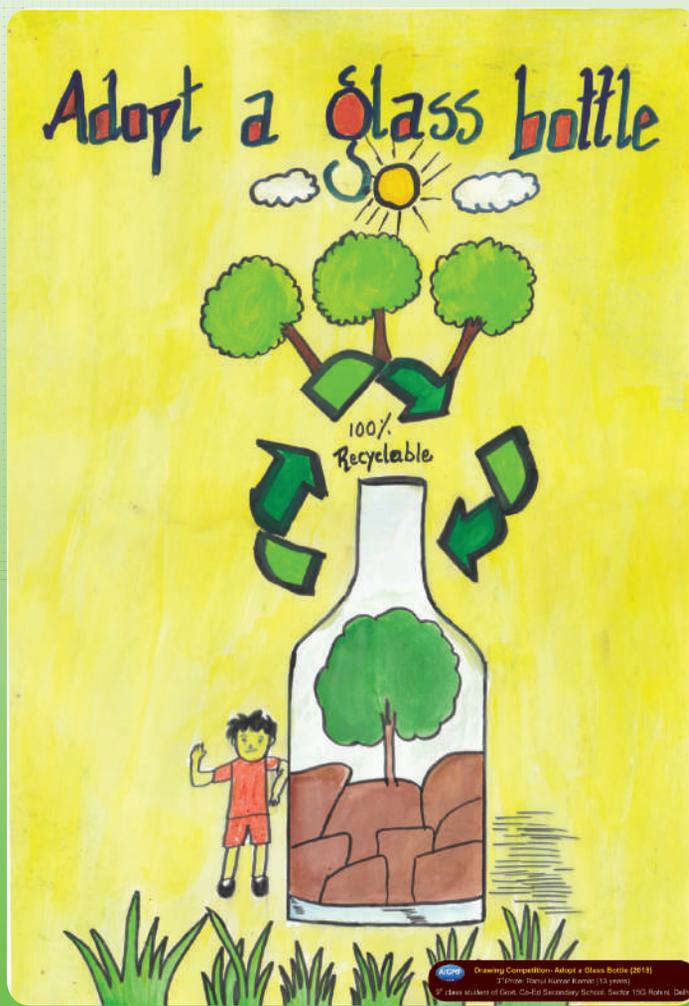
Price: INR 1000 (*within India and including postage*)
Overseas: US$ 75 (*including postage and bank charges*)

Pay via bank transfer:

Account No.	: 0411156983
Name	: The All India Glass Manufacturers' Federation
A/c Type	: Savings Account
Bank	: Kotak Mahindra Bank
Branch	: G-11 Marina Arcade, Connaught Circus, New Delhi-110 001
IFSC Code	: KKBK0000214
SWIFT Code	: KKBKINBB

GP CONSULTANTS

GLASSPOWER GLOBAL

WE CARVE PROJECTS & OUTCOMES ARE PROMISING

Client inquiry & relevant inputs

Feasibility Study & investment sizing

Plant & Technology & Equipment selection

Plant layout & Land size optimisation

Design Basis Document for Loads and Utilities

Techno-commercial negotiations & ordering

Statutory compliances & Land Development

Civil and structural design and Civil work start

Equipment delivery & Installations

Commissioning , Trials, Plant Stabilisation & Handover

✓ Float Glass

✓ Figured & Sheet Glass

✓ Container Glass

✓ Sodium Silicate Glass

Kañch

Quarterly Journal of **THE ALL INDIA GLASS MANUFACTURERS' FEDERATION**

Vol. 13 | No. 2 | July-September 2025

Contents

From the President's Desk

At the Annual General Meeting of The All India Glass Manufacturers' Federation, Youth and Industry Members were felicitated at Pride Plaza Aerocity Hotel, DELHI on August 30, 2025.

The program was organized to honour Youth of the country who participated from India-wide schools and colleges in the annual contest on 'Glass is Pure' or कांच जीवन है coinciding with the International Youth Day on August 12, 2025. Online entries were invited from the age group between 7-24 years where hundreds of entries were received from educational institutes and youth across India.

The Jury comprised of Mr. Gurmeet Singh, Chairman, Federation of Safety Glass (FOSG) and Managing Director, Gurind India (P) Ltd.; Mr. G N Gohul Deepak, Executive Director, Glazing Society of India (GSI); Mr. Dave Fordham, Member Editorial Board of KANCH (AIGMF's Glass journal), Former Publisher of Glass Worldwide magazine and Global Engagement Lead for Glass Futures (United Kingdom); and Mr. Vinit Kapur, Secretary of The All India Glass Manufacturers' Federation (AIGMF) who judged top 3 entries:

1st Prize (Rs. 25,000) was given to Rashi Sharma aged 13 years, 8th class student of Bal Bharti School, Bahadurgarh HARYANA; 2nd Prize (Rs. 15,000) was given to Avira Jain aged 13 years, 8th class student of Bhavan's B.P. Vidya Mandir, Nagpur MAHARASHTRA; 3rd Prize (Rs. 10,000 each) were given to: a) Ananya Maity aged 14 years, 9th class student of Sant Nandlal Smriti Vidya Mandir, Ghatsila JHARKHAND and b) Dakshit Sinsinwar aged 14 years, 9th class student of DPS Ranipur, Haridwar UTTARAKHAND.

The annual 'CK Somany Award for Excellence' was given to Mr. P K Kheruka, Former President AIGMF, Chairman of the Glass panel in CAPEXIL and Chairman of Borosil Ltd. The 'Balkrishna Gupta Award for Exports' was bestowed to M/s Schott Glass India Pvt. Ltd. The 2nd 'Lifetime Achievement Award' was given to Mr. Mohan Lalvani of Mascot Engineering Company.

The cash prizes for the winning students were sponsored by Schott Glass India Pvt. Ltd. Top 100 entries will get specially designed Glass Mementos.

The program also saw presentation on the Assistance in Deploying Energy Efficient Technologies in Industries & Establishment (ADEETIE) scheme initiated by the Ministry of Power, supported by the Bureau of Energy Efficiency (BEE). The main objective of the scheme is to facilitate MSMEs to upgrade with energy efficient technologies/measures through financial instruments and handholding them in carrying out investment grade energy audit, detail project report, monitoring and verification of the implementation.

On July 15, 2025 at the launch event in the august presence of Hon. Minister of Power Mr. Manohar Lal Khattar, AIGMF signed an MoU with BEE on reducing energy consumption and carbon emissions, aligning with India's commitment to sustainable development and energy efficiency covering Glass clusters in Ambala, Chirkunda, East & West Godawari, Firozabad and Jaipur.

From Oct-Dec issue, we would be starting a series of articles from the Book-"Excellence in Container Glass Manufacturing", an AIGMF publication and written by Er. Ashoka Rao Manikala, Former President Operations PGP Glass and AGI Greenpac. This book has been published with the sole intention of sharing the knowledge. The chapters have been prepared to enhance the understanding of those working in the glass industry, with no intention of making a profit. We are hopeful that this book will help everyone working in container Glass industry, the suppliers & service providers, container Glass customers and students pursuing studies on Glass manufacturing ■

Rajesh Khosla
President AIGMF and CEO/President AGI Greenpac

BECOME AN EXHIBITOR AT **GLASSTEC 2026**:

Secure your Early Bird rate until 30 Nov 2025!
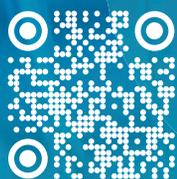
→ **glasstec.de**/registration

glasstec

INTERNATIONAL TRADE FAIR FOR GLASS PRODUCTION • PROCESSING • PRODUCTS

WE ARE GLASS

20–23 OCT 2026
DÜSSELDORF | GERMANY

→ Join us at **glasspex INDIA** & **glasspro INDIA** from September 10–12, 2025 in Mumbai

Messe Düsseldorf

Synopsis of the select papers to be presented at the 15th AIGMF International Conference at glasspex glasspro

(Sept 11, 2025)

Revolutionizing Glass Development through AI and Large Language Models: from Laboratory to Industry

Prof. N M Anoop Krishnan
Department of Civil Engineering and
Yardi School of AI (joint appointment)
INDIAN INSTITUTE OF TECHNOLOGY DELHI India
krishnan@iitd.ac.in

Professor N. M. Anoop Krishnan has made outstanding contributions to the field of glasses through multidisciplinary approaches spanning computational materials science, artificial intelligence, and experimental collaborations. He is an Associate Professor in the Department of Civil Engineering, IIT Delhi with a joint appointment in the Yardi School of Artificial Intelligence.

He has published more than 140 international peer-reviewed journal publications and has 2 granted patents. He has developed a first-of-its-kind package for glass design and discovery, namel, python or glass genomics (PyGGi). The package has more than 400 registered users and the commercial version has been sold to several glass companies across the world. He has founded a start-up Substantial AI vt. Ltd., incubated at IIT Delhi, for AI-driven glass discovery and process optimisation. He has received prestigious recognitions including Humboldt Fellowship (2023) for experienced researchers, Google research scholar award (2023), W. A. Weyl International Glass Science Award by ICG and Penn State University (2022), Indian National Academy of Engineering Young Engineer Award (INAE YAE 2020), BRNS-DAE Young Scientist Award (2021), National Academy of Science India Young Scientist Award (NASI YSA 2021), and Indian Academy of Sciences Associateship (2022).

His contributions to education and the research community are evident through his mentorship of Ph.D. students, the first of whom has gone to become a faculty member at IIT Indore. His balanced integration of fundamental science, computational innovation, and practical applications exemplifies the interdisciplinary spirit central to advancing glass science.

The Indian glass industry, valued at approximately $8.6 billion (₹70,000+ crores) in 2024 and projected to grow at over 7% annually, stands at the threshold of a technological revolution. As manufacturers grapple with evolving consumer demands for specialized properties—from scratch-resistant smart phone screens to energy-efficient architectural glass—artificial intelligence (AI) and large language models (LLMs) are emerging as game-changing tools to accelerate glass discovery and optimize manufacturing processes.

THE CHALLENGE: FROM YEARS TO MINUTES

Traditional glass development relies on the centuries-old "trial-and-error" approach, where discovering new compositions can take 10-20 years. In today's fast-paced market, this timeline is unsustainable. Artificial intelligence and machine learning approaches to materials design can accelerate the discovery
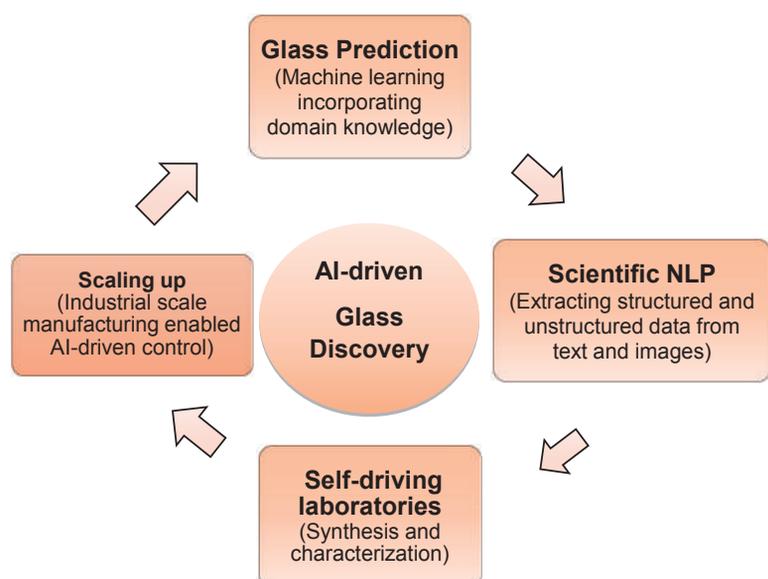

Figure 1: The cyclic process of AI based glass discovery

of new glasses in an economical fashion, offering the promise of reducing development cycles from years to months or even days.

Our research at IIT Delhi demonstrates how AI can transform glass science and research through a systematic four-step cyclic process (Figure 1). This comprehensive framework begins with data curation, where scientific natural language processing extracts information from literature to create large-scale databases. The second step involves exploiting this information through machine learning models combined with optimization to predict new materials and decode intricate patterns for tailored glass discovery. The third step focuses on actualization through high-throughput experiments using robotics and AI automation. The fourth critical step is scaling up, where successful laboratory discoveries are translated to industrial manufacturing processes, completing the cycle and feeding back into the data curation phase for continuous improvement. Data-driven approaches such as machine learning have gained a lot of interest in the recent past and can prove key to predict structure and composition of materials for tailored applications.

PYGGI: DEMOCRATIZING GLASS DISCOVERY

Our efforts toward AI-driven glass discovery have resulted in a first-of-its-kind package, namely, Python for Glass Genomics (PyGGi). PyGGi is a software package for predicting and optimizing the properties of inorganic glasses, trained on over 300,000 glass compositions encompassing more than 180 compounds and 25 different properties. This pioneering platform, commercialized through our start-up Substantial AI, embodies the complete four-step AI-based glass discovery cycle illustrated in Figure 1.

PyGGi Bank represents the data curation pillar, providing access to extensive glass property databases and allowing manufacturers to explore existing knowledge systematically. PyGGi Seer exemplifies the machine learning prediction phase, predicting properties like density, elastic moduli, and glass transition temperature from composition alone. PyGGi Zen demonstrates the optimization component for actualization, discovering compositions to meet specific property targets. The platform's industrial adoption represents the scaling up phase, enabling engineers to design glasses with precise characteristics for applications ranging from optical components to protective screens at commercial scale.

The software has already demonstrated remarkable success. PyGGi will allow researchers and companies to easily predict glasses with superior properties like scratch resistance and crack resistance at the tap of a button. Indian glass manufacturers can now access these capabilities through both desktop applications and cloud-based platforms, making advanced AI tools accessible to companies of all sizes.

LARGE LANGUAGE MODELS: THE NEXT FRONTIER

Beyond traditional machine learning, our recent work on large language models specifically trained for materials science represents the advanced data curation phase of the four-step AI discovery cycle (Figure 1). MatSciBERT, trained on a large corpus of peer-reviewed materials science publications, was the world's first materials-aware language model. We also present LLaMat, a family of foundational models for materials science developed through training on an extensive corpus of materials literature and crystallographic data.

These models can automatically extract information from scientific literature, identify patterns in vast databases, and even suggest novel glass compositions based on textual descriptions of desired properties. For glass researchers, this represents the data curation pillar of Figure 1 in action—accessing decades of global research knowledge instantaneously and systematically, enabling the complete four-step AI-driven discovery cycle that includes scaling up to industrial applications.

LEARNING FROM CEMENT: INDUSTRIAL-SCALE SUCCESS

Our recent breakthrough in cement manufacturing provides a roadmap for implementing the fourth step AI discovery cycle (Figure 1) in glass industries. Using a comprehensive two-year industrial dataset, we develop machine learning models that outperform conventional Bogue equations with mean absolute percentage errors of 1.24%, 6.77%, and 2.53% for alite, belite, and ferrite prediction respectively. X-ray-based clinker checks can take up to four hours, while our AI models deliver predictions in just 1/100 of a second—making quality control a million times faster.

glasspex
GLASS PRODUCTION TECHNOLOGIES & PROCESSES
INDIA

glasspro
PLAY GLASS PROCESSING, PRODUCTS & ACCESSORIES
INDIA

This work demonstrates all four phases of Figure 1: data curation from industrial datasets, machine learning model development for prediction, actualization through real-time quality control, and successful scaling up to full industrial deployment. Similar approaches can revolutionize glass manufacturing by enabling real-time quality control, optimizing furnace operations, and predicting product properties during production rather than after cooling. Indian glass plants can implement these systems to reduce waste, improve consistency, and accelerate product development cycles, completing the full four-step AI discovery cycle from data to industrial deployment.

IMPACT ON INDIAN GLASS INDUSTRY

For Indian glass manufacturers, AI adoption offers several immediate benefits. Cost reduction becomes possible by minimizing expensive trial-and-error experimentation through predicting successful compositions computationally before physical testing. Quality enhancement can be achieved by implementing real-time quality control systems that ensure consistent product properties and reduce rejection rates. Innovation acceleration allows manufacturers to discover novel compositions for emerging applications like flexible displays, smart windows, and advanced optical components. Finally, competitive advantage can be gained by accessing global knowledge and accelerating R&D to compete with international glass giants.

THE PATH FORWARD

The integration of AI and LLMs in glass development represents more than technological advancement—it's an opportunity for Indian glass industry to lead global innovation. With initiatives like PyGGi making these tools accessible and ongoing research developing more sophisticated capabilities, manufacturers can transform their approach to glass development from reactive to predictive.

As we move toward Industry 4.0, the companies that embrace AI-driven materials discovery will define the future of glass technology. The question is not whether AI will transform glass manufacturing, but how quickly Indian industries will adopt these revolutionary tools to maintain their competitive edge in the global market.

REFERENCES

1. https://pyggi.substantial.ai/
2. https://ceramics.org/ceramic-tech-today/deep-learning-provides-deep-help-researchers-develop-publicly-available-software-for-rational-design-of-oxide-glasses/
3. https://ceramics.org/wp-content/bulletin/2024/articles/F-Sachan_aug24.pdf
4. Zinke, L. Clinker phase prediction. Nat. Rev. Clean Technol. 1, 379 (2025). https://doi.org/10.1038/s44359-025-00077-7

Cruise Control for Glass Furnaces: Automated Furnace Control and Batch Monitoring Systems

Dr. Malte Sander
Consultant and Sales
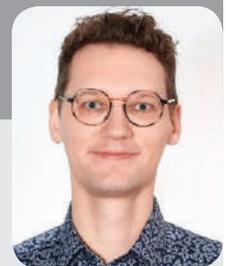GLASS SERVICE Czech Republic
malte.sander@glass-service.eu

Dr. Malte Sander studied materials engineering at the RWTH Aachen University in Germany, focusing on glass and process engineering. After investigating the batch-to-melt conversion in his master's thesis in 2017, Dr. Sander started a position as a doctoral candidate at the Chair of Glass and Glass-Ceramics in Aachen, Germany.

During his time at the chair, Dr. Sander investigated the effects of electric fields on the crystallization behavior of glass-ceramics and developed glasses for industrial applications. In 2023, Dr. Sander defended his doctoral thesis entitled "Structure and properties of thermally poled lithium alumosilicate glasses and glass-ceramics".

At the same time, Dr. Sander started his current position as business development manager at Glass Service. In his role, he supports the glass industry in solving problems, optimizing the glass melting process, and reducing carbon emissions.

Besides his work for Glass Service, Dr. Sander is Vice-Chairman of the technical committee "Glass melting technology" of the German Society of Glass. In May 2024, the German Society of Glass honoured him with the "Adolf-Dietzel Industry Price" for his valuable and ongoing contribution to the glass society.

glasspex
GLASS PRODUCTION TECHNOLOGIES & PROCESSES
INDIA

glasspro
FLAT GLASS PROCESSING, PRODUCTS & ACCESSORIES
INDIA

Furnaces are the heart of each glass factory, operating continuously to keep production running 24/7. At temperatures around 1500°C, raw materials are transformed into a viscous melt. The energy required for this chemical transformation and heating is typically provided by fossil fuels like natural gas, oil, and sometimes pet coke. Additionally, electric power supplied via electrodes directly into the melt can accelerate the melting process and reduce energy consumption.

Depending on production planning, availability of cullet, and energy supply and costs, furnace operators must control the energy input to ensure stable furnace temperatures. However, the slow response times of the melter to changes in energy input challenge operators to find efficient melting conditions.

Glass Service offers a model-based predictive control software, "Expert System III," to the glass industry to automate furnace control and address these slow response times. The software analyzes past and current production data to determine the optimal energy settings for stabilizing melting temperatures. By stabilizing the melting temperatures, the software helps reduce wasteful energy usage and lower energy costs.

Additional information about the glass level, waste gas composition, or batch coverage from our AI batch monitoring system can be integrated into the Expert System III furnace control. This integration further enhances the control behavior, optimizing furnace operations and improving the overall efficiency.

Glass melting is an energy intensive process which needs constant supervision of furnace operators for a flawless production. Glass Service provides different solutions to the glass industry to improve furnace control and monitoring. The software Expert System III uses a model-based predictive control approach to control different aspects of a glass furnace, like temperature, glass level, and combustion. The improved control reduces the energy consumption and can increase the pack to melt. Until 2025, Glass Service has installed Expert System III more than 400 times on all types of glass furnaces (regenerative fired, oxy-fuel, hybrid, all-electric).

Besides furnace control Glass Service is specialized in furnace monitoring. The proprietary near infrared camera coupled with an AI Batch Monitoring System helps to understand the batch movement on top of the glass melt. The integration of batch information into the Expert System III can help to further improve the melting process. For all-electric furnaces Glass Service provides a batch thickness measurement system to monitor the batch coverage.

Driving Efficiency in the Smart Plant

Mr. Michael Toelle has many years of experience in machinery and plant engineering and passion for driving customer success.

With a strong focus on building long-term relationships and understanding customer needs, Mr. Toelle together with his team enhances strategies and further elevate the level of services for the Glass industries worldwide.

Michael Toelle
Director Sales
HEYE INTERNATIONAL GmBH Germany
MToelle@heye-international.com

Glass plants are under unprecedented pressure to cut energy, curb CO_2 and bridge an ever-widening skills gap, all while increasing output and preserving glass quality.

The Heye Smart Plant concept brings proven Industry 4.0 ideas together to make this possible. Highly automated, it safeguards first-class quality at low unit cost through three interlocking pillars:

- Smart Data – integrated production and quality data
- Smart Machine Controls – intuitive user interfaces, e-timing and servo technology
- Smart Process Intelligence - closed-loop control for the forming process and lightweight containers

Advanced Digitalization in Inspection for Predictive Defect Detection

Mr. Altay Capanoglu is the Export Manager since 2021 at IRIS Inspection Machines, well experienced at all working environments after a career in manufacturers (mechanics, medical and industrial gas, energy).

Altay Capanoglu
Middle East, Africa, Central Asia and India Sales Manager
IRIS INSPECTION MACHINES France
acapanoglu@iris-im.fr

glasspex

glasspro

Wherever you look at, "Artificial Intelligence" is an overriding theme, in our daily life and of course in the industry.

But what are the main benefits of AI, for real needs of glassmakers? IRIS intelligent solutions connect each of the individual players within a value creation network.

IRIS aims at improving quality and productivity and meanwhile reducing carbon footprint and human skills dependence. IRIS pioneering use of AI technology is bringing lower costs and higher satisfaction to glassmakers around the world.

Furthermore, IRIS now offers an AI-based innovation called iBot®. iBot® does not simply monitor and manage the optimization of settings but goes beyond this, by integrating the prediction of process defects.

Reducing Glassmaking Emissions: A Gateway to the Digital Future of Process Control Technology

Mr. Magdi El-Awdan holds the position of Senior Manager – Glass & Solar at Siemens AG, Germany with 25+ years of experience, and is recognized for his leadership in automation, digitalization, and quality control processes across solar, glass, and semiconductor manufacturing environments.

Magdi El-Awdan
Senior Manager Glass & Solar
SIEMENS Germany
magdi.el-awdan@siemens.com

He oversees business development, solution innovation, and customer engagement for automation and monitoring systems that support critical infrastructure in industrial plants.

His contributions span integration of advanced digital solutions, such as digital twins, and Industrial IoT Solutions, and has spearheaded collaborations to digitally transform industrial production, enhance quality control, and minimize downtime.

Siemens will showcase its cutting-edge solutions aimed at transforming the glass industry through:

Sustainability Initiatives

- Adoption of green and clean energy
- Integration of Carbon Capture
- Promotion of cullet recycling to reduce raw material usage

Digital Transformation

- End-to-end digitalization of glassmaking processes
- Advanced process optimization for energy and resource efficiency
- Waste heat recovery technologies to minimize energy loss

Operational Excellence

- Enhanced equipment and facility efficiency
- Improved lifecycle productivity
- Development of future-ready plants aligned with evolving industry standards

AI for Mirror and Container Glass

Er. Pulkit Gaur is the Chief Technology Officer of Gridbots Technologies and drives the companies Innovation and Technological advancements. An Engineer by education and the founder of Gridbots Technologies - Robotics is his passion. He has been building robots since his childhood.

Er. Pulkit Gaur
Chief Technology Officer
GRIDBOTS TECHNOLOGIES PVT. LTD. India
contact@gridbots.com

glasspex
GLASS PRODUCTION TECHNOLOGIES & PROCESSES
INDIA

glasspro
FLAT GLASS PROCESSING, PRODUCTS & ACCESSORIES
INDIA

Er. Gaur and Gridbots Technologies have won a number of awards and accolades from many Indian and International agencies. Gridbots was awarded India's hottest start-ups award. Er. Gaur has received TED Fellowship – MIT Young Innovator Award and Rajiv Motwani Circle Fellowship for his technological innovations. Gridbots is a winner of NASSCOM Innovation Awards – 2011 under most promising technologies. In 2015, Siemens steering committee (Comprising of Nobel Laureates) invited Er. Gaur to provide inputs on their future policy on robotics. In 2017, PM Narendra Modi invited Er. Gaur for their flagship program "Champions of Change" for providing inputs of policy matters.

*In 2023, Er. Gaur won the AIGMF's prestigious annual **CK Somany Award for Innovation and Technology** for having designed and developed non-contact pattern glass thickness measurement sensors which can sample glass for thickness 100 times a second and measure it with an accuracy of 50 Microns.*

Er. Pulkit Gaur will be sharing the use of AI and modern technologies for the inspection of glass and mirrors.

He will also share how this technology is changing and evolving and is able to find defect which are impossible to find with traditional approaches.

And how through the use of advanced mathematical models and fast computers has enabled the glass companies to address challenges and reduce wastages.

AI-Driven Optimization of Glass Production: Overcoming Industry Challenges with Celfos

Dr. Oscar Verheijen received his master's degree in Chemical Engineering at the Eindhoven University of Technology in the Netherlands in 1995. Following this, he started as a Glass Technologist at the Dutch Research Institute TNO.

Dr. Oscar Verheijen
Commercial Director
CELSIAN GLASS & SOLAR BV Netherlands
oscar.verheijen@celsian.com

In 2003, Dr. Oscar finalized his Ph.D. study entitled 'Thermal and chemical behaviour of glass-forming batches'. After being active for 12 years in the field of glass melting technology, glass tank modeling, and process control, Dr. Oscar became responsible within TNO for the business development of sustainable technologies with an emphasis on thin-film solar technologies. In September 2013, Dr. Oscar joined CelSian. Currently, Dr. Oscar is the Commercial Director of CelSian and Chairman of GlassTrend, the global platform of pre-competitive R&D and knowledge exchange. Dr. Oscar's key activities are dedicated to smart sustainable glass manufacturing.

The glass industry operates in an increasingly complex environment, with rising demands for quality, energy efficiency, and cost optimization. Furnace operators play a critical role in navigating these challenges, yet they face an overwhelming volume of process variables and data points to analyze in real-time. This raises the following question: How can we provide operators with actionable insights, reducing guesswork and improving confidence?

Traditionally, furnace control systems have focused on stabilizing temperatures, yet temperature stability alone does not guarantee optimal glass quality. Aligning operational performance, reliability, and glass quality requires a deep understanding of the dynamic, time-transient behaviour of glass furnaces. The challenge lies in the broad residence time distribution, influenced by multiple variables, and the difficulty of identifying key process parameters that impact glass quality. Moreover, conventional systems struggle to adapt to sensor deterioration or replacement, leading to data inconsistencies and reduced reliability.

This presentation introduces Celfos, an AI-powered system that enhances operational decision-making by linking process settings to glass quality. By combining advanced neural network models with time-transient CFD analysis (GTM-X), Celfos provides insights into complex furnace dynamics and delivers precise quality predictions.

Celfos combines historical furnace data and real-time process parameters with qualitative GTM-X models. It works for all common glass and furnace types and is control system independent. The neural network is trained to correlate these inputs with glass quality metrics, enabling predictive quality control and adaptive decision-making, even when sensors degrade or are replaced.

Celfos is a dynamic, adaptive system that brings the glass industry closer to a future of precision and efficiency, designed to support operator expertise ∎

Transforming tiny places into larger-than-life spaces!

Create the illusion of space with the perfect reflections of Şişecam Mirror Flotal E. Its clear reflections visually expand any area, turning even capsule-sized rooms into open, airy spaces.

ŞİŞECAM

www.**sisecam**.com

Availability of Essential Spares for Container Glass Manufacturing Equipment

We are sharing the summary and other details of essential and critical spares for Container Glass Manufacturing Plant Equipment. These spares cover major equipment categories, as detailed below:

1. Glass Forming (IS Machine) Spares

Quantity : 236 items
Value   : ₹68.23 Lakhs
Make   : Bottero & Emhart

2. Inspection Machine Spares

Quantity : 126 items
Value   : ₹31.19 Lakhs
Make   : Emhart (Bottom Inspection), SGCC (Side Wall MCAL & M-Machine)

3. Utilities Spares

Quantity : 200 items
Value   : ₹20.47 Lakhs
Make   : Diatshu DG Set

4. Batch House Mechanical Items

Quantity : 44 items
Value   : ₹6.02 Lakhs
Make   : Hammer Mill, Roller Crusher, and other wear parts

5. Electrical Items

Quantity : 3 items
Value   : ₹3.87 Lakhs
Make   : Caterpillar Gas Engine

Those interested in procuring these critical spares may refer to the detailed list with part numbers and descriptions.

For further information or to request the complete list, please contact us at: Email: mrospares1@gmail.com

AIGMF

since 1944

The All India Glass Manufacturers' Federation

in partnership with:

glasstec 20–23 OCT 2026 DÜSSELDORF | GERMANY **glasspex** GLASS PRODUCTION TECHNOLOGIES & PROCESSES INDIA **G Glass Futures** **glasspro** FLAT GLASS PROCESSING, PRODUCTS & ACCESSORIES INDIA **Messe Düsseldorf India**

presents:

15th AIGMF International conference on

AI and Digitalisation - the future for sustainable glassmaking

(Sept 11, 2025)

at Bombay Exhibition Centre, Mumbai INDIA

TIME (hrs.)	TOPIC/s	ORGANIZATION	SPEAKER
0930	Registration / Tea / Coffee **Unveiling of the Touring Exhibition - 'Glass or Class'** *Featuring award-winning artwork, poetry, photography and essays by young participants (2018–2025) showcasing the role of glass in our daily life*		
1015	**Keynote Address on Artificial Intelligence** *by* **Mr. Rajesh Khosla** President AIGMF and CEO/President AGI Greenpac **Introduction of Speakers and need for Digitalisation** *by* **Mr. Dave Fordham** Global Engagement Lead, Glass Futures, United Kingdom; Member Editorial Board of AIGMF's quarterly journal 'KANCH' *(Glass)* and Former Publisher of Glass Worldwide magazine, UK		
1030	**Release of Book- Excellence in Container Glass Manufacturing** *written by* **Er. Ashoka Rao Manikala** Former President Operations PGP Glass and AGI Greenpac; and Member Editorial Board of AIGMF's quarterly journal 'KANCH' *(Glass)* **Launch of Calendar Glass Bottle 2026**		
1040	**Revolutionizing Glass Development through AI and large Language Models:** from laboratory to industry	**INDIAN INSTITUTE OF TECHNOLOGY DELHI INDIA**	**Prof. N M Anoop Krishnan** Department of Civil Engineering and Yardi School of AI *(joint appointment)*
1100	**Cruise Control for Glass Furnaces:** automated furnace control and batch monitoring systems	**GLASS SERVICE CZECH REPUBLIC**	**Dr. Malte Sander** Consultant and Sales
1120	**Driving Efficiency in the Smart Plant**	**HEYE INTERNATIONAL GmBH GERMANY**	**Mr. Michael Toelle** Director Sales
1140	**Advanced Digitalization in Inspection for Predictive Defect Detection**	**IRIS INSPECTION MACHINES FRANCE**	**Mr. Altay Capanoglu** Middle East, Africa, Central Asia and India Sales Manager
1200	**Reducing Glassmaking Emissions:** a gateway to the digital future of process control technology	**SIEMENS GERMANY / INDIA**	**Mr. Magdi El-Awdan** Senior Manager Glass & Solar

1220	AI for Mirror and Container Glass *(with live display of Robots)*	GRIDBOTS TECHNOLOGIES PVT. LTD. **INDIA**	Er. Pulkit Gaur Chief Technology Officer
1240	AI-Driven Optimization of Glass Production: overcoming industry challenges with Celfos	CELSIAN GLASS & SOLAR BV **NETHERLANDS**	Dr. Oscar Verheijen Commercial Director
1300	**Discussions / Q&A:** - **Prof. N M Anoop Krishnan** Dept. of Civil Engineering and Yardi School of AI *(joint appointment)* IIT Delhi - **Mr. Manoj Mahato** Senior Technical Architect and AIGMF Webmaster - **Mr. Dave Fordham** Global Engagement Lead, Glass Futures, UK; Member Editorial Board of AIGMF's quarterly journal 'KANCH' *(Glass)* and Former Publisher of Glass Worldwide magazine, UK - **Mr. Pulkit Gaur** Chief Technology Officer, Gridbots Technologies Pvt. Ltd. - **Mr. Tariq Kachwala** Director, FG Glass and Executive Committee Member Federation of Safety Glass (FOSG) - **Prof. A S Rao** Vice Chancellor, Vikrama Simhapuri University, Nellore- Andhra Pradesh and Member Editorial Board of AIGMF's quarterly journal 'KANCH' *(Glass)* - **Mr. Gohul Deepak** Executive Director, Glazing Society of India (GSI) - **Mr. Vinit Kapur** Secretary, The All India Glass Manufacturers' Federation (AIGMF) - **Dr. Indrajit Tah** Scientist *(Specialty Glass Division)*, CSIR-Central Glass & Ceramic Research Institute (CGCRI) - **Dr. M. Jayasimhadri** Associate Dean, School of Integrated Learning and Research (SILR), Delhi Technological University		
1315	**Wrap-up** *by* **Mr. Purvish Shah** Hon. General Secretary AIGMF and Director in Gopal Glass Works Ltd., and Gobind Glass and Industries Ltd.		
1320	**Presentation on glasstec 2026** *by* **Mr. Lars Wismer** Director of glasstec and A+A at Messe Düsseldorf		
1335	**Vote of Thanks** *by* **Mr. Pawan Shukla** Hon. Treasurer AIGMF; and President and Managing Director, Schott Glass India Pvt. Ltd. **Group Photo and Networking Lunch**		

PARTICIPATION: FREE Of CHARGE

However, those requiring a Kit Bag, Glass Memento and Lunch may register under the following:

Delegate Type	Fee *(INR)*
Main Delegate	5,000
Additional Delegate/s *(per member)*	2,500

Cheque payable to 'The All India Glass Manufacturers' Federation', at New Delhi may be sent to Secretary AIGMF, 812 New Delhi House, 27 Barakhamba Road, New Delhi – 110 001 INDIA *or* Make an online payment at:

    Account No.   : 0411156983
    Bank   : Kotak Mahindra Bank
    Name   : The All India Glass Manufacturers' Federation
    Bank Branch   : G-11 Marina Arcade, Connaught Circus, New Delhi-110 001
    IFSC Code   : KKBK0000214
    Swift Code   : KKBKINBB

Pre-REGISTRATION at info@aigmf.com in the following format:

S. No.	Company / Organization	Participant/s (Name, Designation, Address, Tel, E-mail)

INTERNATIONAL GLASS MANUFACTURING SHOW

IGMS 2026
From Sand to Hand

Media Partner: AIGMF *since 1944*

DUBAI
23–21 April

RIYADH
1–3 September

Glass is more than a material — it is the surface that shapes our skylines, brightens our homes, and drives innovation in smart cities. From timeless façades to cutting-edge technologies, glass tells the story of progress.

The International Glass Manufacturing Show (IGMS 2026) celebrates this journey. Taking place in Dubai (21–23 April) and Riyadh (1–3 September), IGMS is the only event in the Middle East that brings together the entire glass industry — from raw materials and machinery to the latest in smart and sustainable solutions.

Exhibitors from around the world will showcase innovations, while architects, developers, and buyers discover the products shaping tomorrow's projects. It is a place where business meets inspiration, and where global opportunities connect with regional ambition.

At IGMS 2026, the journey of glass — from sand to hand — comes to life.

glass-show.com

GLASS News

AIGMF SIGNS MOU WITH BEE, MINISTRY OF POWER ON REDUCING CARBON EMISSIONS

The Assistance in Deploying Energy Efficient Technologies in Industries & Establishment (ADEETIE) scheme is initiated by the Ministry of Power, supported by the Bureau of Energy Efficiency (BEE). The objective is to facilitate MSMEs to upgrade with energy efficient technologies/measures through financial instruments and handholding them in carrying out investment grade energy audit, detail project report, monitoring and verification of the implementation. The scheme provides a 5% (Small – Micro) and 3% (medium) interest subvention on loans for technology adoption.

On July 15, 2025 at the launch event

15 जुलाई 2025 को माननीय ऊर्जा मंत्री श्री मनोहर लाल खट्टर की गरिमामयी उपस्थिति में लाँच कार्यक्रम में एआईजीएमएफ ने ऊर्जा खपत और कार्बन उत्सर्जन को कम करने के लिए बीईई के साथ एक समझौता ज्ञापन पर हस्ताक्षर किए, जो भारत की सतत विकास और ऊर्जा दक्षता के प्रति प्रतिबद्धता के साथ मेल खाता है, जिसमें अंबाला, चिरकुंडा, पूर्व और पश्चिम गोदावरी फिरोज़ाबाद और जयपुर के पाँच कलस्टर सम्मलित हैं।

in the august presence of Hon. Minister of Power Mr. Manohar Lal Khattar, AIGMF signed an MoU with BEE on reducing energy consumption and carbon emissions, aligning with India's commitment to sustainable development and energy efficiency covering Glass clusters in Ambala, Chirkunda, East & West Godawari, Firozabad and Jaipur.

AIGMF
since 1944

Welcomes its New Members

Company	Products / Services
CALDERYS INDIA REFRACTORIES LIMITED Ms. Amisha Karemore / Mr. Prateek Pandey 6th Floor, Fidvi Tower, Opp Saraf Chambers Mount Road, Sadar, Nagpur- 440 001 MAHARASHTRA Tel: +91 90966 36488, +91 90289 54620 E: amisha.karemore@calderys.com, prateek.pandey@calderys.com	Refractory services, material selection and project management for Glass manufacturing units
SUBAAN LIME PVT. LTD. Dr. H.R. Dandi Unit No.17, 8th Floor, Tower-2, AIPL Business Club, Golf Course Extension Road, Sector-62, Gurugram HARYANA Tel: +91 124-4140233, +91 96190 00770 E: drhrd@drlime.in	Ultra-low iron, high grade limestone granule and powder

SEFPRO
BRIGHTER SOLUTIONS TOGETHER

SEFPRO GUARD©

• **PREDICT YOUR REPAIR TIMING TO EXTEND FURNACE LIFETIME**

• **OPTIMIZE MAINTENANCE OPERATION**

Peace of mind for your glass furnace's energy transition

EXPERT SYSTEM *ES III*™

• **OPTIMIZE ENERGY CONSUMPTION AND CARBON EMISSIONS**
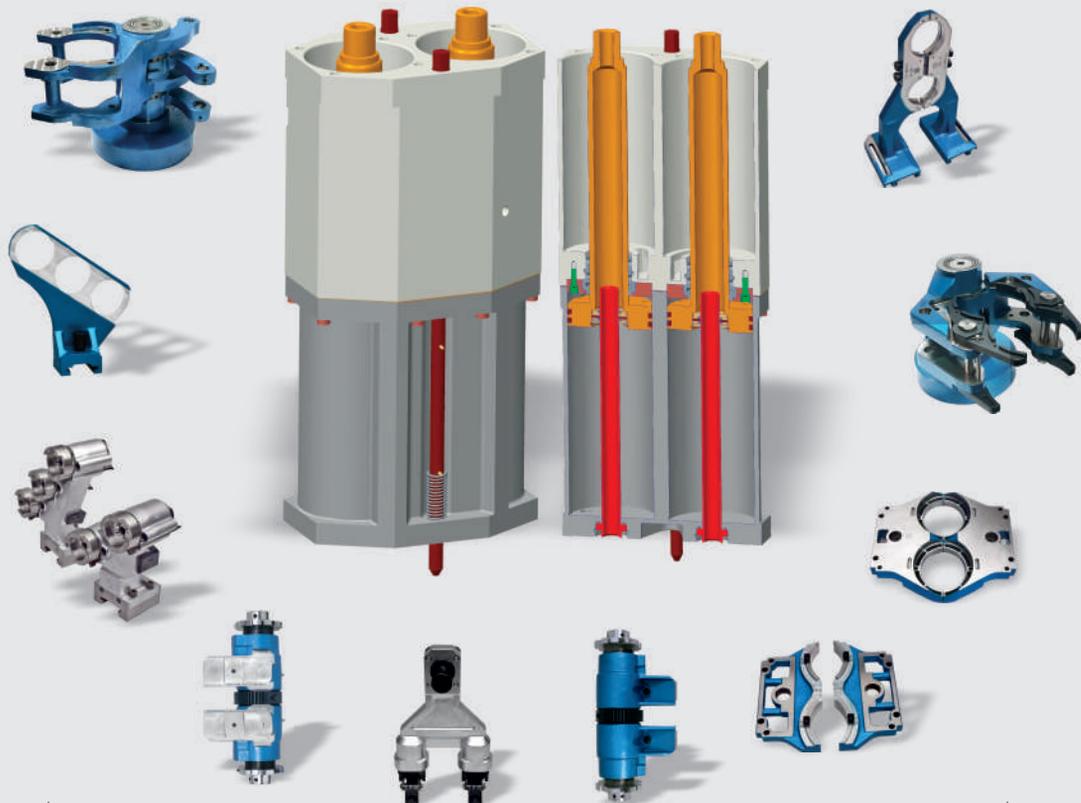
• **ACHIEVE STABLE MELTING AND FORMING CONDITIONS**

Leveraging Machine Learning: From Accelerating Glass Design to Smart Manufacturing in Glass

Satabdi Roy[a, b] and Indrajit Tah[*a, b]

[a]Speciality Glass Division, CSIR-Central Glass and Ceramic Research Institute,
196 Raja S.C. Mullick Road, Kolkata 700032, West Bengal INDIA
[b]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad- 201002 INDIA

1. INTRODUCTION

Glass is a ubiquitous material, valued for its unique optical, chemical, and mechanical properties. Its applications range from consumer products to advanced sectors like defense, telecommunications, and astronomy. However, the benefits of glass are offset by the significant environmental costs of its production. Traditional manufacturing processes are major sources of greenhouse gas emissions, waste, and air pollution. Addressing these sustainability challenges requires a multi-faceted approach. Strategies such as glass recycling, implementing oxy-fuel combustion systems, improving furnace design and insulation, and adopting electric melting have been effective in reducing the environmental footprint. Furthermore, computational methods like Computational Fluid Dynamics (CFD) [1] have become a vital tool for optimizing furnace design and process parameters, serving as a virtual testbed to minimize the need for extensive physical experiments. Despite these advancements, a major bottleneck in glass discovery remains: the reliance on time-consuming and energy-intensive trial-and-error experimentation to achieve specific material properties. The inherent aperiodic and disordered nature of glass's microstructure makes it difficult to predict its properties based on composition alone, as its behavior is governed not only by the elemental compositions, but also the arrangements of the atoms. Recent technological advancements in Artificial Intelligence (AI) and Machine Learning (ML) offer a promising solution to these limitations [2, 3]. A particularly powerful approach is Physics-Informed Machine Learning, which integrates fundamental knowledge of atomic-scale structures into ML models to enhance property prediction. This integration of AI and ML, from fundamental glass science to technological applications, holds the potential to significantly accelerate the development of new materials and optimize manufacturing processes by reducing the number of costly and resource intensive experiments. This paradigm shift will be critical for both sustainable production and the accelerated discovery of next-generation glasses.

2. CURRENT APPROACH IN THE GLASS MANUFACTURING INDUSTRY

The glass industry has made significant strides in reducing its environmental impact and energy costs. From 1930 to 2010, the industry managed to reduce its energy costs and CO_2 emissions by approximately four times [4]. This was achieved by shifting away from coal and oil towards a greater reliance on natural gas and electrification [5]. In India, for example, natural gas accounts for about 95% of the total energy consumption in glass manufacturing. The sector still faces challenges, particularly within the Micro, Small, and Medium Enterprises (MSME) sector in India. These small-scale glass clusters consume around 2,76,777 tonnes of oil equivalent (toe) annually, with melting processes alone using 95% of this energy, leading to an estimated 587,225 tonnes of annual CO_2 emissions. This high energy consumption is not limited to glass; the Indian refractory industry also has a high specific energy consumption of 3.8-7 GJ per tonne of product, which is significantly higher than the global average of 3.27 GJ per tonne [6].

The strategic adoption of computational models to establish a virtual test bed is an invaluable approach to confronting industry challenges. Specifically, Computational Fluid Dynamics (CFD) [1, 4, 7] is instrumental in optimizing key design process parameters during glass melting, thereby contributing to significant reductions in energy consumption and emissions. CFD is a computational method that simulates how fluids, like molten glass, move

*Corresponding author: indrajittah.cgcri@csir.res.in

and interact within a system. In the glass industry, CFD is primarily used to analyze and improve crucial processes such as combustion, batch melting, and furnace flow. By dividing a system into a grid of small cells and solving equations for heat, mass, and momentum at each point, CFD allows engineers to: (a) virtually test new designs before they are physically built, saving time and cost; (b) optimize furnace settings to enhance product quality and manufacturing efficiency; (c) identify and investigate potential risks and hazardous conditions without real-world danger.

With the advent of faster computers and more sophisticated software, CFD has become a cornerstone of modern glass production design and optimization. The most effective approach is to first design and optimize a process using CFD simulations and then validate the results with targeted experiments, leading to substantial savings in time and cost.

3. CHALLENGES OF CURRENT APPROACH AND WAYS TO ADDRESS THEM

Detailed CFD simulations are computationally expensive, often taking days or even weeks to complete. They also require a high level of expertise to create accurate models, including the geometry, meshing, and defining proper boundary conditions. Glass manufacturing involves numerous components and control parameters. It is not feasible to vary all parameters simultaneously in a single simulation. Instead, a series of simulations is needed, with parameters being optimized one by one, which can be a slow process. The process is sequential and iterative. Finally the CFD simulations for different components with varying parameters is able to find the optimum configuration for each specific parameter.

A separate but related challenge in the glass industry is the creation of glasses with specific, tailored properties. Researchers have started using data-driven Machine Learning (ML) models to address this. These models are trained on existing data that links glass composition to its properties, aiming to predict how changes in composition will affect the final material [8, 9].

The predictive power of these data-driven ML models is inherently limited because glasses lack the uniform, crystalline structure like most other solids. Without a consistent, long-range periodic arrangement of atoms, a simple correlation between composition and properties becomes unreliable, particularly when attempting to predict the behavior of novel glass formulations outside the training data. The aperiodic nature of glass is a significant challenge to property prediction [10]. In addition, glass is a mechanically solid material while maintaining a liquid-like structure [11]. In crystals, it is well understood that the solidity arises from crystalline order at the atomic scale, which remains absent in the liquid state. So, the relationship between the structure and properties of glass is still elusive to researchers. To address the above challenges, a new approach, 'Physics-Informed Machine Learning' is being adopted, which can be promising in accelerating glass discovery [12, 13].

4. MACHINE LEARNING IMPACT ON GLASS MANUFACTURING: A ROADMAP FOR INNOVATION

4.1 Smart manufacturing

- Homogenization of the glass melt is critical for achieving the high-quality optical properties required for components in eyeglasses, telescopes, and fiber optics. The goal is a uniform refractive index throughout the glass, which is essential for its effectiveness. AI and machine learning (ML) offer a powerful way to achieve better homogenization. A thermal imaging camera can be used to monitor the temperature gradient of the melt, providing a visual representation of its uniformity. These images of well-homogenized melts can then be used as a training dataset for various ML models. Once trained, the ML model can predict the optimal conditions for achieving a perfectly homogeneous melt in a new manufacturing process, reducing the need for extensive trial-and-error. This data-driven approach allows for more precise control, leading to superior optical glass quality.

- Annealing is another important process during glass formation as it involves reducing the residual stresses in the glass. To do this effectively, there are several control parameters, such as the annealing point, annealing duration, and cooling rate, that must be carefully regulated. ML models can be trained using many thermal images of well annealed glass along with their control parameters, obtained from different experiments, and then can be used to predict the optimum control parameters for annealing. Thus, ML can be helpful in predicting the amount of time the glass needs to be held at the annealing point or the rate at which it needs to be cooled to have a better stress relief.

4.2 Integration of ML with CFD for accelerated glass production

As discussed earlier, CFD simulations can take long time for finer

understanding. AI, integrated with CFD can enhance the process in several ways. The results from CFD simulations can be used to train ML models. ML can predict results without running the full CFD simulation. AI can automatically adjust design parameters to achieve the best performance without repeated trial-and-error CFD runs.

4.3 Tailored glass with desired properties

A major challenge for glass scientists and glass industry till date is developing glasses with specific desired property. It can be achieved through a series of trial and error experimentation which is energy and time consuming. ML can be helpful in streamlining glass development by reducing this trial-and-error. By training ML models based on reliable experimental datasets containing compositions as input features and property as target output, the property of new, unknown composition for those particular materials can be predicted.

4.4 Reduction in the manufacturing energy footprint

In the glass industry, high-temperature melting and conditioning processes make it highly energy intensive. This reliance on intense heat means that energy consumption and greenhouse gas emissions are unavoidable by-products of every experiment during the traditional trial-and-error phase. However, by integrating AI and Machine Learning (ML) into manufacturing, the industry can significantly reduce its energy footprint. ML models can optimize production processes to decrease energy consumption, minimize the waste of raw materials, and lower overall emissions, making the entire operation more sustainable and efficient.
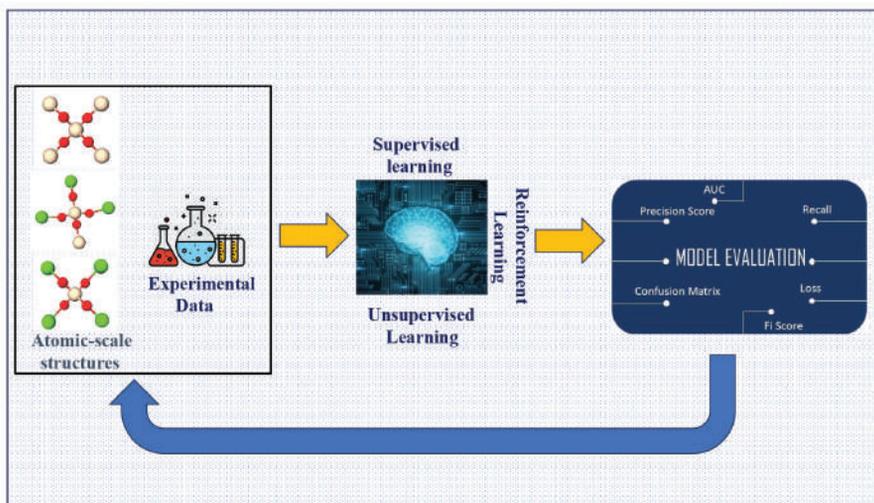
Figure 1: Physics-Informed ML for accelerating glass design

5. PHYSICS-INFORMED ML FOR COMPOSITION-STRUCTURE-PROPERTY RELATIONSHIP

The primary limitation of traditional machine learning (ML) models is their inability to predict properties for compositions they haven't seen before. They are good at interpolation-making predictions within their known data range, but they struggle with extrapolation into new, unknown compositions. To overcome this, a more powerful and generalized approach called Physics-Informed Machine Learning (PIML) [14] is being adopted. Instead of relying solely on data, PIML models are designed to incorporate fundamental physics and material science principles directly into their learning process (please see Figure. 1). This allows them to understand the underlying relationships between a material's structure, its properties, and how these factors change. By embedding these physical "rules" into the model, PIML can make more accurate and reliable predictions for new, unseen glass compositions, bridging the gap between purely data-driven and physics-based modeling. The main limitation of the formerly mentioned approach is that it can make predictions only on the similar compositions like training data that have been seen by the machine but the model remains blind on the unknown compositions. To bridge the gap, a much more generalized approach, 'Physics-Informed Machine Learning' [14] is being adopted. In this framework, several atomic scale structural information such as bond angle distribution, oxygen species such as brigding-oxygens (BO), non-bridging oxygens (NBO) etc., inter-tetrahedral connectivities, Q^n distribution etc. can be used to train the ML models to have a more generalized prediction. Figure 2 represents five SiO_4 units, the first one (a) with four bridging oxygens (Q^4 unit) and the last one (e) without any bridging oxygen (Q^0 unit). Although all of these are tetrahedral units, still they do not have the same energetic configuration. The energy depends upon the environment connected with the particular unit. So, it needs more energy to disrupt the Q^4 structure than the others, as it gives better network connectivity. Moving towards the Q^0 unit will lead to a decrease in network connectivity with increasing NBO. This highlights the importance of integrating structural information with data-driven approaches. By understanding how the atomic structure changes,
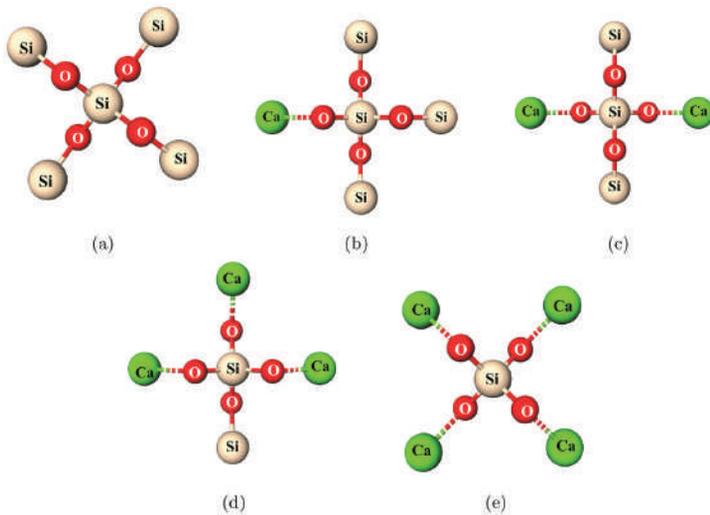
Figure 2: Q^n distribution for SiO_4 in glass structure (a) Q^4 unit with four bridging oxygens (b) Q^3 unit with three bridging oxygens and one non-bridging oxygen (c) Q^2 unit with two bridging and two non-bridging oxygens (d) Q^1 unit with one bridging oxygen and three non-bridging oxygens (e) Q^0 unit with zero bridging and four non-bridging oxygens

we can make informed decisions for glass design.

6. CONCLUSIONS

In conclusion, while significant challenges exist in glass science, particularly in manufacturing and new material discovery, the integration of AI and machine learning offers a promising path forward. These technologies can optimize critical processes like temperature control and melt homogenization in smart manufacturing. Furthermore, by combining data-driven AI with the fundamental physics of glass networks, it's possible to accelerate the discovery of new materials by exploring the vast compositional landscape more efficiently, thus moving beyond traditional, resource-intensive experimental methods. This fusion of technologies will not only improve energy efficiency in the glass industry but also revolutionize the pace of innovation.

REFERENCES

[1] Juraj Raič, Philipp Wachter, Philipp Hödl, Martin Demuth, Christian Gaber, Hannes Gerhardter, René Prieler, and Christoph Hochenauer. CFD simulation aided glass quality and energy efficiency analysis of an oxy-fuel glass melting furnace with electric boosting. *Energy Conversion and Management: X*, 15:100252, 2022.

[2] Han Liu, Zipeng Fu, Kai Yang, Xinyi Xu, and Mathieu Bauchy. Machine learning for glass science and engineering: A review. *Journal of Non-Crystalline Solids*, 557:119419, 2021.

[3] Hui Li, Pan Liu, Shaoyun Liu, and Bin Yang. Deep learning-assisted attribute prediction of chalcogenide glasses based on graph classification. *Scientific Reports*, 15(1):19360, 2025.

[4] Scott Colangelo. Reducing the environmental footprint of glass manufacturing. *International Journal of Applied Glass Science*, 15(4):350-366, 2024.

[5] Michael Zier, Peter Stenzel, Leander Kotzur, and Detlef Stolten. A review of decarbonization options for the glass industry. *Energy Conversion and Management: X*, 10:100083, 2021.

[6] Bureau of Energy Efficiency. Achieving energy and resource efficiency in glass and refractory industries: A sectoral roadmap for micro small and medium enterprises. Technical report, Ministry of Power, Government of India, New Delhi, India, 2021. ©2021 Bureau of Energy Efficiency.

[7] Ouyuan Zhang, Lin Yuan, Xurong Teng, Fangfang Zhao, Xing Fan, Changyuan Tao, and Renlong Liu. CFD-based investigation of flow field in a glass furnace reactor under an oxy-fuel electric boosting mode. *Scientific Reports*, 15(1):11037, 2025.

[8] Ravinder Bhattoo, Suresh Bishnoi, Mohd Zaki, and NM Anoop Krishnan. Understanding the compositional control on electrical, mechanical, optical, and physical properties of inorganic glasses with interpretable machine learning. *Acta materialia*, 242:118439, 2023.

[9] Saulo Martiello Mastelini, Daniel R. Cassar, Edesio Alcoba.ca, Tiago Botari, Andr/e C.P.L.F. de Carvalho, and Edgar D. Zanotto. Machine learning unveils composition-property relationships in chalcogenide glasses. *Acta Materialia*, 240:118302, 2022.

[10] John C. Mauro. Decoding the glass genome. *Current Opinion in Solid State and Materials Science*, 22(2):58–64, 2018. Materials Design of Glasses.

[11] Ludovic Berthier and Giulio Biroli. Theoretical perspective on the glass transition and amorphous materials. Rev. *Mod. Phys.*, 83:587-645, Jun 2011.

[12] Indrajit Tah, Sean A Ridout, and Andrea J Liu. Fragility in glassy liquids: A structural approach based on machine learning. *The Journal of Chemical Physics*, 157(12), 2022.

[13] S. S. Schoenholz, E. D. Cubuk, D. M. Sussman, E. Kaxiras, and A. J. Liu. A structural approach to relaxation in glassy liquids. *Nature Physics*, 12(5): 469-471, 2016.

[14] Mikkel L. Bodker, Mathieu Bauchy, Tao Du, John C. Mauro, and Morten M. Smedskjaer. Predicting glass structure by physics-informed machine learning. *npj Computational Materials*, 8:1-9, 2022 ∎

Youth and Glass Industry Awards presented

(August 30, 2025 DELHI)

At the Annual General Meeting of The All India Glass Manufacturers' Federation, Youth and Industry Members were felicitated at Pride Plaza Aerocity Hotel, DELHI on August 30, 2025.

The program was organized to honour Youth of the country who participated from India-wide schools and colleges in the annual contest

Glass mementos being handed over to the achievers in the morning assembly on Aug 30 at Sant Nandlal Smriti Vidya Mandir, Ghatsila JHARKHAND

on 'Glass is Pure' or कांच जीवन है coinciding with the International Youth Day on August 12, 2025. Online entries were invited from the age group between 7-24 years where hundreds of entries were received from educational institutes and youth across India.

Chairman of Mascot Engineering Company, Mr. Mohan Lalvani (*second from the right*) receiving the Life Achievement Award from AIGMF Office Bearers

The Jury comprised of Mr. Gurmeet Singh, Chairman, Federation of Safety Glass (FOSG) and Managing Director, Gurind India (P) Ltd.; Mr. G N Gohul Deepak, Executive Director, Glazing Society of India (GSI); Mr. Dave Fordham, Member Editorial Board of KANCH (AIGMF's Glass journal), Former Publisher of Glass Worldwide magazine and Global

Jury Member Mr. Gurmeet Singh (Chairman FOSG) presenting certificate to the 1st Prize winner

Engagement Lead for Glass Futures (United Kingdom); and Mr. Vinit Kapur, Secretary of The All India Glass Manufacturers' Federation (AIGMF) who judged top 3 entries:

1st Prize (Rs. 25,000) was given to Rashi Sharma aged 13 years, 8th class student of Bal Bharti School, Bahadurgarh, HARYANA

2nd Prize (Rs. 15,000) was given to Avira Jain aged 13 years, 8th class student of Bhavan's B.P. Vidya Mandir, Nagpur, MAHARASHTRA

3rd Prize (Rs. 10,000 each) were given to:

a) Ananya Maity aged 14 years, 9th class student of Sant Nandlal Smriti Vidya Mandir, Ghatsila, JHARKHAND

b) Dakshit Sinsinwar aged 14 years, 9th class student of DPS Ranipur, Haridwar, UTTARAKHAND

The annual **'CK Somany Award for Excellence'** was given to Mr. P. K. Kheruka, Former President AIGMF, Chairman of the Glass panel in CAPEXIL, and Chairman of Borosil Ltd. The **'Balkrishna Gupta Award for Exports'** was bestowed to M/s Schott Glass India Pvt. Ltd. The 2nd **'Lifetime Achievement Award'** was given to Mr. Mohan Lalvani of Mascot Engineering Company. The previous winners are listed at www.aigmf.com

Former President of the AIGMF Mr. P.

A presentation on International Glass Manufacturing Show (IGMS) was given by Mr. Mohamed Sherif, Business Development Manager, Strategic Management & Exhibitions and Ms. Kanika Kapoor of Trade Marketing & Events DELHI and representative of Strategic Management & Exhibitions DUBAI.

IGMS 2026 to be held from April 21-23 at Dubai Trade Centre is the flagship event of Africa and the Middle East dedicated to the glass industry and its entire value chain.

IGMS serves as a top regional meeting point bringing together leading manufacturers, traders, and decision-makers in the glass industry showcasing cutting-edge technologies in Glass Products to Glass Production Technologies, Glass Manufacturing Machinery, Glass Processing Machinery, and Glass Finishing Machinery, alongside the latest advancements in Digitalization and Automation.

AIGMF is the supporting association as well as Media partner for the event.

Select photos of the event and top 3 winners can be viewed at https://aigmf.com/past-events.php

K. Kheruka is the Chairman of Borosil Limited. He is a Commerce graduate and has over 5 decades of experience in the glass industry. He possesses a multi-faceted experience in strategy formulation and implementation, setting up of Projects, planning and execution. He has a firm grip over the technicalities pertaining to manufacturing and production of soda lime flat glass, as well as borosilicate drawn, blown and pressed glass. He has immense knowledge in marketing of glass products in the domestic and international markets.

"It has been a privilege for me to have had the opportunity to work in the field of glass! Glass is magic. God knows how much time I have spent battling a problem which has seemed unsolvable: and then the solution is suddenly found! My father has been my Guru - most of my learning, which started when I was an adolescent, has been from him. My dear uncle, Chandra Kumar ji Somany, has also been a major influence in my life. I have led an enriched life!" said Mr. P K Kheruka, recipient of CK Somany Award for Excellence.

M/s Schott Glass India Pvt. Ltd., is a 100% subsidiary of the German technology group SCHOTT AG. SCHOTT is one of the world's leading manufacturers of special glass tubing, FIOLAX® established and long-standing experience since 1911. SCHOTT has foreseen in 2018; a global 5.0 pharma tubing demand is going to increase. As

On Aug 30, parallel to the AGM of AIGMF, a presentation on ADEETIE Scheme was given by Mr. P Shyam Sundar (left), Director at the Bureau of Energy Efficiency, Ministry of Power, GoI on the Assistance in Deploying Energy Efficient Technologies in Industries & Establishment (ADEETIE) scheme.

Mr. Pawan Kumar Shukla (left), Managing Director, Schott Glass India Pvt. Ltd. receiving 'Balkrishna Gupta Award for Exports'.

already that time the supply was short compared to demand, the expected market growth offers the opportunity to increase market share by establishing incremental capacity faster than competition.

Most recently, SCHOTT, a global pioneer in specialty glass announced the addition of syringe and cartridge glass tubing reinforcing SCHOTT's commitment to the 'Make in India' initiative. This strategic action positions the company as Asia's largest producer of syringe and cartridge glass tubing.

The jury for the awards comprised of Dr. K. Annapurna, Chief Scientist, Glass Division, CSIR-Central Glass & Ceramic Research Institute (CSIR-CGCRI) and Member, Editorial Board, KANCH; Mr. Dave Fordham, Member, Editorial Board, KANCH (AIGMF's Glass journal), Former Publisher, 'Glass Worldwide' magazine and Global Engagement Lead for Glass Futures (United Kingdom); Mr. Amit Malhotra, President of Confederation of Construction Products and Services, Treasurer of uPVC Window & Door Manufacturers Association and Managing Director of McCoy Silicones Ltd.; and Mr. Pawan Kumar Shukla, Treasurer, AIGMF and Managing Director, Schott Glass India Pvt. Ltd.

"My heartiest congratulations to Shri Pradeep Kheruka for winning the prestigious C K Somany Award for

Excellence for his key R&D initiatives in developing eco-friendly solar glass formulations as well as fully tempered 2 mm thick solar panel. His contributions in the laboratory, consumer glassware and especially in the solar cover glass, have a high impact globally, including India. Further, I congratulate M/s Schott Glass India Pvt. Ltd., for receiving the esteemed Balakrishna Gupta Award for its attaining remarkable exports." said Dr. K. Annapurna, Chief Scientist, CSIR- Central Glass & Ceramic Research Institute, Kolkata.

"Not only does acknowledging the achievements of Mr. Pradeep Kheruka gives me immense personal pride having had the privilege of collaborating with him over many decades, officially honouring him with the prestigious C K Somany award provides a perfect opportunity for his outstanding achievements to be forever etched into glass industry history. Mr. Kheruka's remarkable contributions will leave a lasting impression on not only the Indian sector but on the global scale too. His name will always be synonymous with trailblazing developments in sustainable glass solutions for a greener planet. SCHOTT Glass India Pvt. Ltd., are also very worthy winners of the Balkrishna Gupta Award for Exports and fully deserve recognition for their flourishing export business despite challenging global trade conditions", said Mr. Dave Fordham, Member Editorial Board of KANCH (AIGMF's Glass journal), Former Publisher of Glass Worldwide magazine and Global Engagement Lead for Glass Futures (United Kingdom).

"The 2nd Lifetime Achievement Award was given to the Editor of KANCH

(quarterly journal of the AIGMF) Mr. Mohan Lalvani, Chairman of MASCOT Group of companies for his dedicated 4 decades in the glass industry and as an Associate Member of AIGMF since 1989. A Mechanical Engineer from ECOLE DES METIERS VERSAILES in France, Mr. Lalvani brought technical know-how to India from German and other European principals of Mascot Engineering Company representing hi-tech companies in glass industry and has contributed to the modernisation of the Indian Glass Industry", said the Secretary, AIGMF, Mr. Vinit Kapur.

The cash prizes for the winning students were once again sponsored by Schott Glass India Pvt. Ltd., producing Type 1 pharma tubing primarily meant for Glass Vials which were supplied worldwide for packaging the COVID vaccination. Most recently, SCHOTT, a global pioneer in specialty glass announced the addition of syringe and cartridge glass tubing reinforcing SCHOTT's commitment to the 'Make in India' initiative. This strategic action positions the company as Asia's largest producer of syringe and cartridge glass tubing. Mr. Pawan Kumar Shukla, Managing Director of Schott Glass India Pvt. Ltd., and Treasurer AIGMF while congratulating the students said *"sustainable packaging is the key to create a better living society for eco and health reasons; and the Youth plays a very important role in spreading these right messages".*

Top 100 entries will get specially designed Glass Mementos ∎

Mr. Shreevar Kheruka (left), Sr. Vice President AIGMF and Managing Director/CEO Borosil Ltd., receiving 'C K Somany Award for Excellence' on behalf of Mr. P K Kheruka.

Young brigade inks 'Glass is Pure'

(August 12, 2025, DELHI)

The Young Brigade in large numbers commemorated the International Youth Day by participating in The All India Glass Manufacturers' Federation (AIGMF) contest on 'Glass is Pure' or कांच जीवन है। The contest invited online entries from the Youth between 7-24 years by means of essays, poems, drawings, photography, etc. Hundreds of entries were received from schools and colleges across India.

1st Prize (Rs. 25,000) was given to Rashi Sharma aged 13 years, 8th class student of Bal Bharti School, Bahadurgarh HARYANA

2nd Prize (Rs. 15,000) was given to Avira Jain aged 13 years, 8th class student of Bhavan's B.P. Vidya Mandir, Nagpur MAHARASHTRA

3rd Prize (Rs. 10,000 each) were given to:

a) Ananya Maity aged 14 years, 9th class student of Sant Nandlal

Glass is Pure or कांच जीवन है (2025)
1st Prize: Rashi Sharma (13 years)
8th class student of Bal Bharti School, Bahadurgarh HARYANA

Smriti Vidya Mandir, Ghatsila JHARKHAND

b) Dakshit Sinsinwar aged 14 years, 9th class student of DPS Ranipur, Haridwar UTTARAKHAND

The Jury comprised of Mr. Gurmeet Singh, Chairman, Federation of Safety Glass (FOSG) and Managing Director, Gurind India (P) Ltd.; Mr. G N Gohul Deepak, Executive Director, Glazing Society of India (GSI); Mr.

with stand high temperature

Glass Save space in a area.

Glass Enhance the Senses of transparency and light effect of space

Diversfied designe to ehanence the level of aesthetic.

Easy to clean and mantain

Glass is a Compelitly recyclable material and coms with healthyest

Glass is Pure : For You, For Earth, Forever

100% Recyclable

Resource Saving

RESISTANT TO CHEMICAL

NON TOXIC & SAFE

VERSATILE USED

REDUCES PLASTIC POLLUTION!

WILDLIFE LOVES GLASS

RE USABLE

LONG LASTING   DURABLE   TRANSPAR...
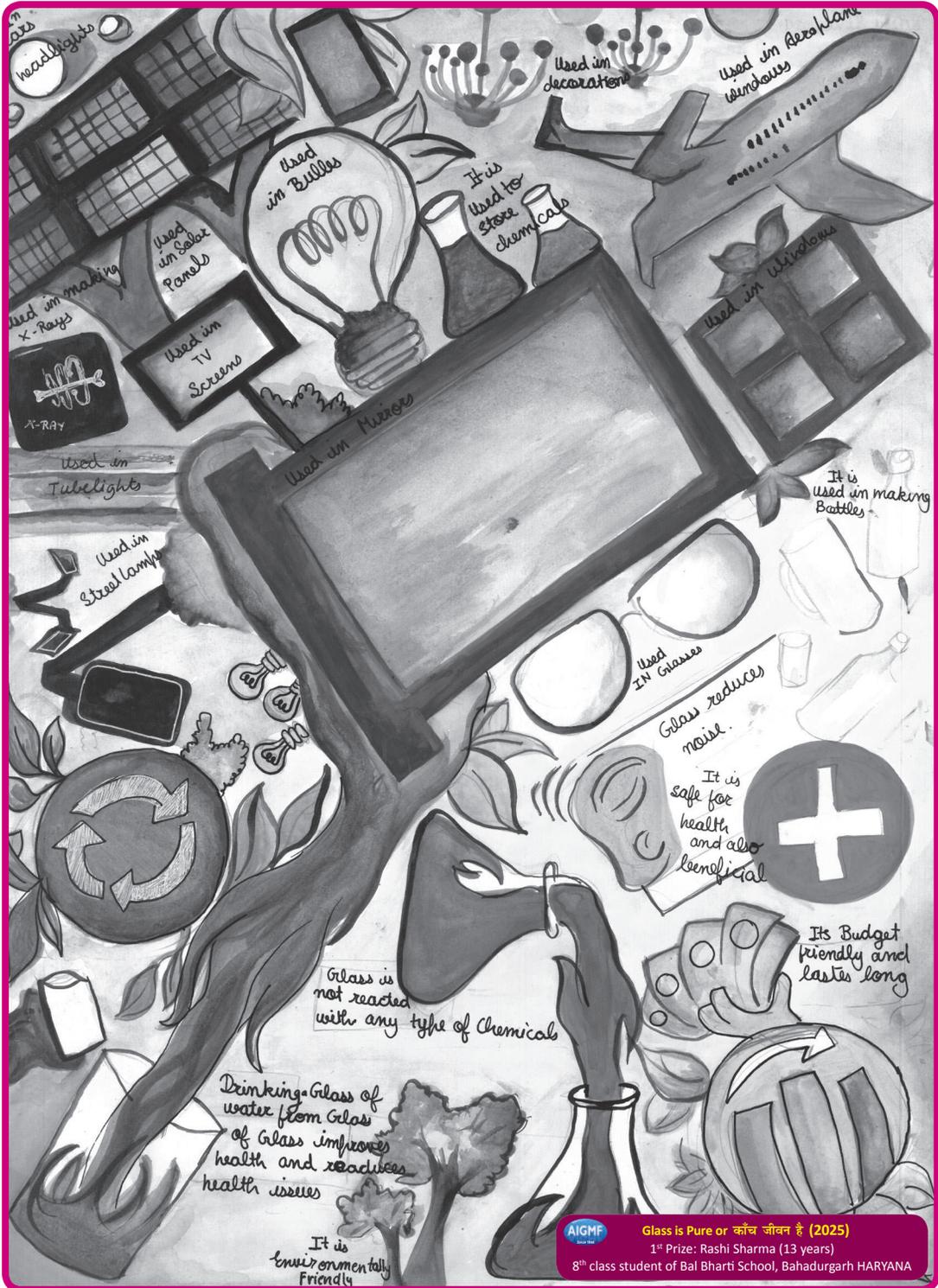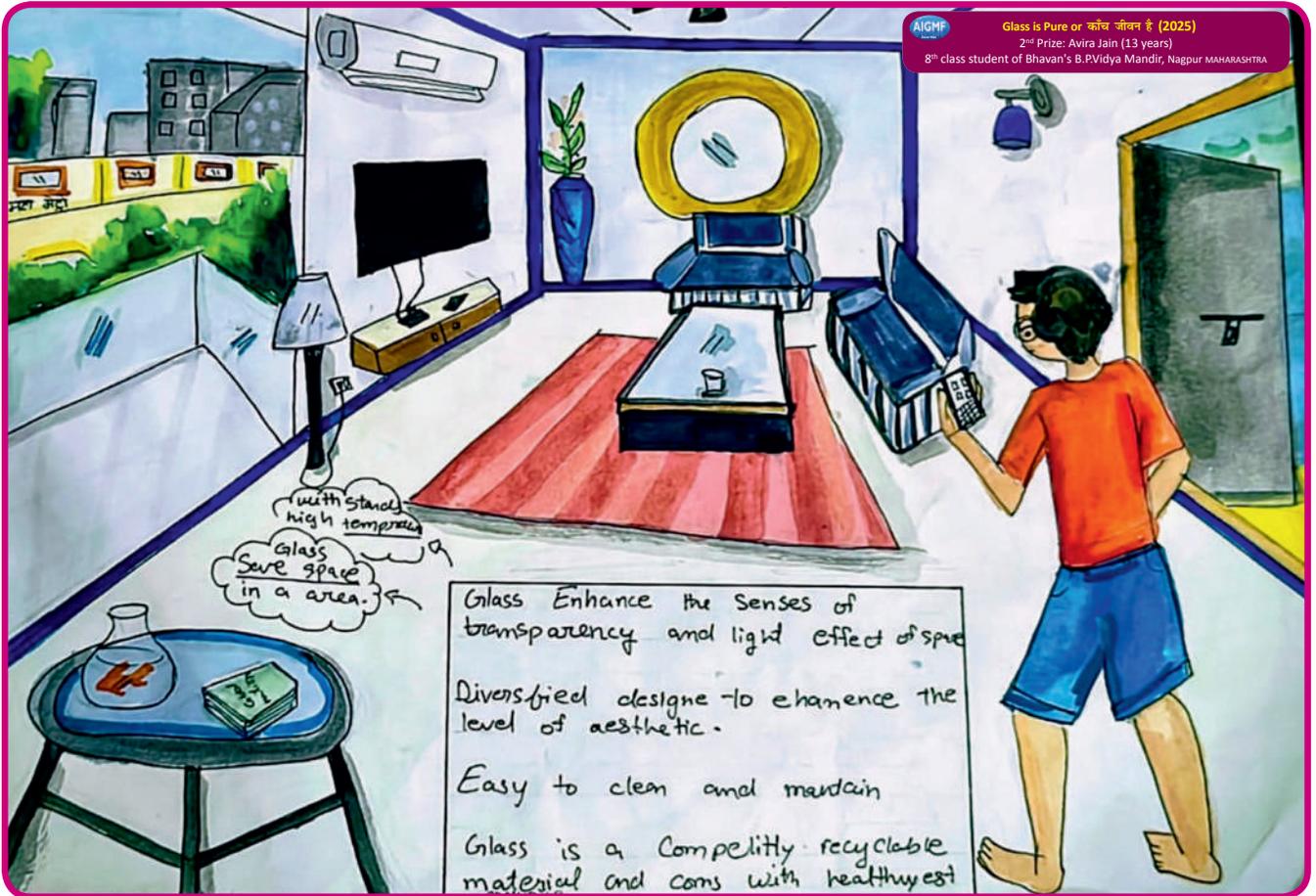
Dave Fordham, Member Editorial Board of KANCH (AIGMF's Glass journal), Former Publisher of Glass Worldwide magazine and Global Engagement Lead for Glass Futures (United Kingdom); and Mr. Vinit Kapur, Secretary of The All India Glass Manufacturers' Federation (AIGMF).

"Great continuous initiative of AIGMF unleashing the young minds into the world of Glass through art and innovation. Proud to be a part of this initiative and very privileged and enterprising to go through the sound and interesting artworks, poems and essays on pure glass. The creativity and thought process of young students on glass are splendid and thorough in all aspects. Wishing AIGMF and the student community for the successful journey in glass universe" said Mr. G N Gohul Deepak, Executive Director, Glazing Society of India (GSI).

SPARES
REPAIRS
VARIABLES
MECHANISMS

📞 **99102 49102 | 93104 93995**

✉ **pankaj@kvgindia.com**

📍 **J-87, UPSIDC-Surajpur, Site-5, Surajpur Site V,
Greater Noida, Uttar Pradesh 201310**

Beyond Glass Innovation

We are the unmatched leaders in manufacturing I.S. Machine spares, variables, and mechanisms — where precision meets perfection. Backed by world-class infrastructure and cutting-edge technology, our components deliver unmatched durability and accuracy. When it comes to quality, performance, and reliability, no one does it better than us.

"Precision in Parts,
Perfection in Glass"
~ M.D. Parsad

NEXT-GEN SERVO SHEARS
CUTTING EDGE PRECISION
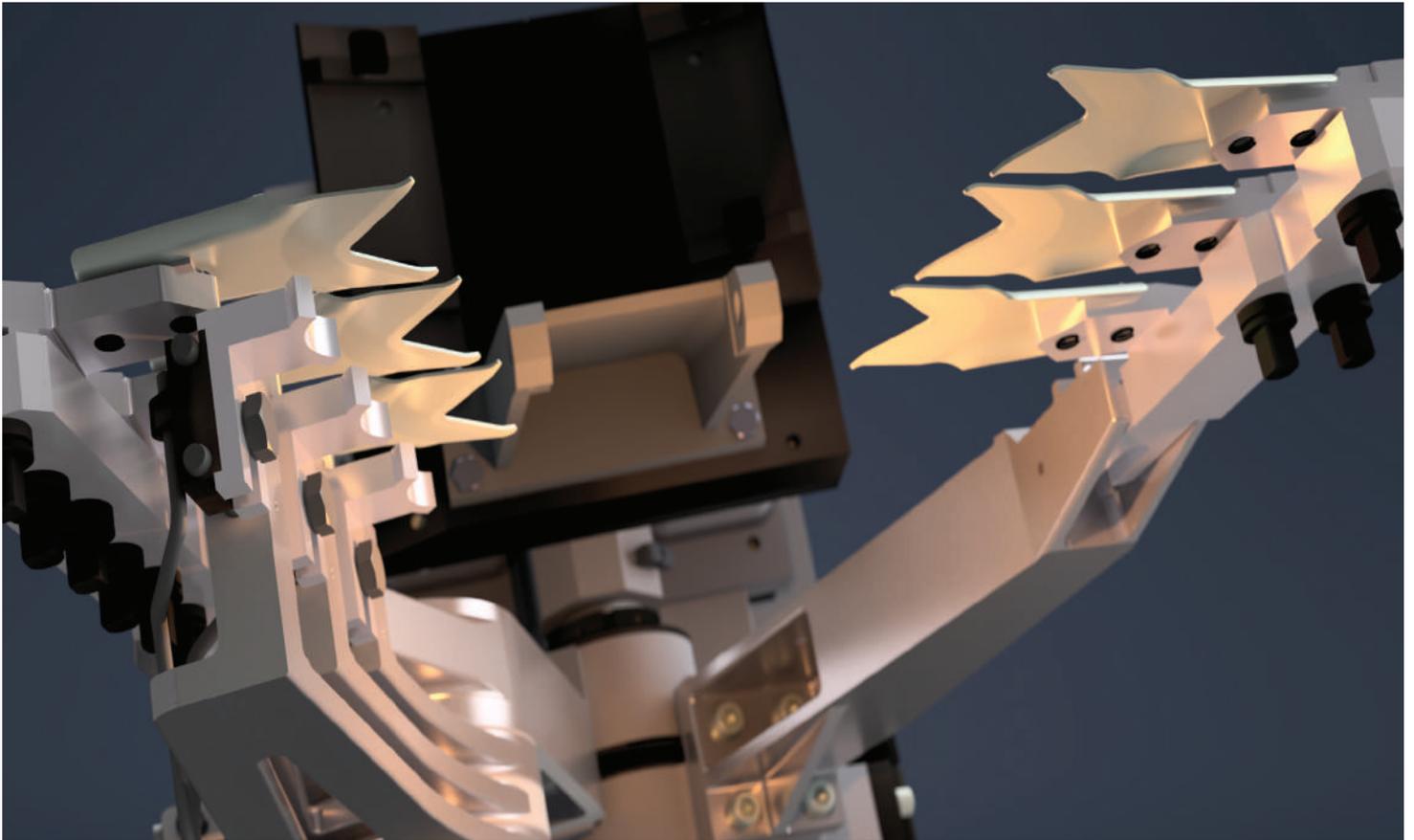
UNRIVALED PRECISION
COUPLED WITH SUPERIOR DURABILITY

HiPERFORM

+ Revolutionary new gob arm design
+ Ultra-rigid structure ensures:
    + Stable gob forming
    + Improved gob fall
    + Optimum cutting accuracy
+ Up to 250 cuts / minute
+ Almost maintenance-free operation

learn more

WE ARE GLASS **PEOPLE**

GLACERA ENGINEERS

The Backbone for Glass Manufacturers

The vision of Glacera is to apply the latest technology and its rich experience in the field of glass manufacturing towards building energy efficient and eco-friendly glass melting furnaces and provide maximum value to its customers.

■ **Turnkey Projects for glass plants involving:**

• Selection of site
• Plant layout
• Furnace design, selection of refractory & steel structure
• Furnace building, commissioning & maintenance
• Selection & commissioning of combustion system, instrumentation & allied equipment
• Selection of raw material
• Designing of fully automatic batch house and cullet handling system.
• Selection, installation and commissioning of production machinery and annealing lehrs
• Installation and commissioning of quality control equipment and packing machinery

■ **Furnace design, building, maintenance, modification and modernization**

■ **Conversion of combustion system**

■ **Furnace audits for reducing fuel consumption and predicting furnace life**

■ **Energy efficiency improvement using mathematical models**

"53 Glorious Years"
- Supporting the Glass Industry

PREM P MALHOTRA

GLACERA ENGINEERS A-2/26, Kumar Samruddhi, Tingrenagar Road, Vishrantwadi, Pune 411-015, INDIA
Tel +91-20-26681146 ■ Mobile +91-93701 46890 ■ Email: glacera@gmail.com, prempmalhotra@gmail.com

![Borosil renewables logo]

GMB | **INTER FLOAT**

Serving our customers with 1,350 Tons per day (~8.5 GW) of solar glass manufacturing capacity
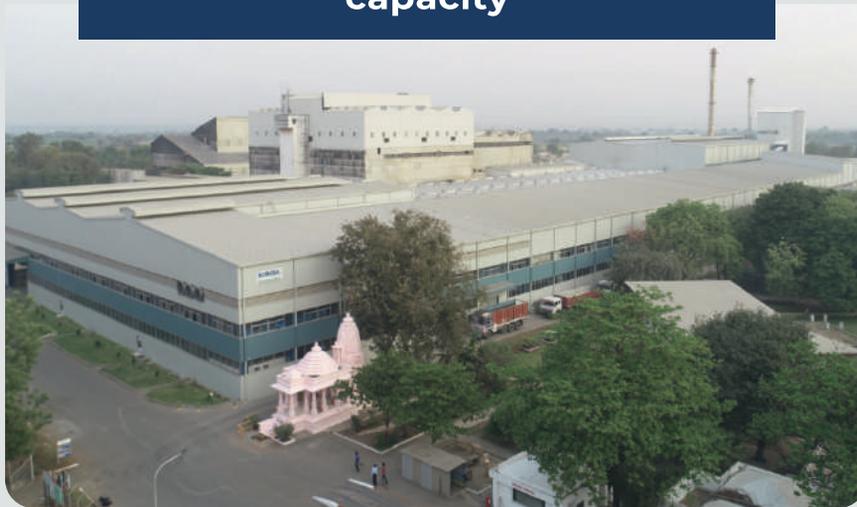
INDIA

GERMANY

Progress and Challenges in Decarbonization of Industrial Glass Melting

Dr. Manoj K. Choudhary
The Ohio State University, Columbus, Ohio, USA
Former President of the International Commission on Glass
Recipient of C K Somany Award for Excellence 2024

Achieving net-zero carbon emissions by 2050 to limit global warming to 1.5°C is one of humanity's most critical challenges. Every energy-intensive sector, including glass manufacturing, must play a part in reaching this goal. This paper, based on the AGC/Professor Michael Cable Memorial Lecture, presents a comprehensive analysis of the technical challenges and strategies for decarbonization of glass melting, the most energy-intensive process in glass production, accounting for 50–80% of the total energy used in glass manufacturing. Four key themes are explored. First, it examines the energy intensity of the glass industry within the broader context of commodity materials manufacturing. Next, it offers an overview of the glass manufacturing process, with a focus on the fundamentals of glass melting. It then highlights key technological innovations implemented by the author and colleagues that have significantly reduced the energy intensity of melting. Finally, it presents decarbonization strategies for glass melting, with a focus on energy substitution methods such as electric boosting, hydrogen combustion, and ammonia combustion, discussing their benefits, challenges, and, where applicable, providing economic projections. The paper also addresses emissions reduction through increased cullet use and raw material modifications.

1. INTRODUCTION

Over a distinguished five-decade career, Professor Michael Cable made groundbreaking contributions to all three stages of industrial glass melting: melting, refining and homogenizing. His work not only expanded our understanding of these processes but also established analytical frameworks that have driven the advancement and evaluation of innovative glass melting technologies, including those essential for decarbonization, the focus of the 2024 AGC/Professor Michael Cable Memorial Lecture and this paper.

The 2015 Paris Agreement, signed by 195 nations, seeks to limit global temperature rise to well below 2°C and emphasizes the need to cap it at 1·5°C above pre-industrial levels by the end of the century.[1]

The 2018 report by the Intergovernmental Panel on Climate Change (IPCC) and subsequent research indicate that staying within the 1·5°C threshold would significantly reduce the most severe impacts of climate change on e cosystems.[2] Exceeding this limit risks severe ecological, economic and social consequences.

Current estimates suggest that global warming will likely reach 1·5°C above pre-industrial levels between 2021 and 2040, even under very low greenhouse gas (GHG) emission scenarios.[3] This underscores the urgent need for decarbonization across all sectors – power, industry, transportation, and buildings – to achieve net zero emissions (NZE). Over 140 countries, including major emitters like China, the US, India and the EU, have set net-zero targets, covering over 88% of global emissions. However, global pledges remain insufficient. According to a UN climate report, CO_2 emissions must drop by 45% by 2030 and reach net zero by 2050 to limit warming to 1·5°C.[4] Reducing emissions from energy-intensive industries, such as steel, cement, aluminium and glass, is critical to meeting these targets.

Numerous studies addressing decarbonization of the glass industry, covering topics such as the energy and CO_2 intensity of glass production,

progress made in reducing them, and technological innovations aimed at further reductions, have been published.[5–11] This paper focuses on technical options and strategies for decarbonizing the industrial glass melting process (the conversion of a mixture of raw materials into a melt), which accounts for 50–80% of the energy used in glass manufacturing. We emphasize melting because it is the most energy-intensive stage and follows a similar approach across various glass sectors, container, flat, fibres and specialty glass. All sectors rely on thermal energy, from combustion, electricity or both, to convert raw materials into molten glass.

Discussing decarbonization strategies for melting is more straightforward, as they broadly apply across the glass industry. In contrast, forming processes (shaping the glass melt into various forms) vary significantly among segments.

Table 1. 2022 Global final energy consumption in various sectors [12]

Sector	Final energy consumption	
	EJ	%
Building	132	32
Industry	166·1	40
Transport	117·5	28
Total	**415·6**	

We begin by reviewing energy usage and CO_2 emissions in the glass manufacturing sector within the broader context of energy and capital-intensive materials production. Next, we describe the glass manufacturing process and discuss fundamental energy-related aspects of melting. We then highlight recent technological developments aimed at reducing the energy intensity of the glass melting process, which also enhance manufacturing cost-efficiency, glass quality, and environmental

sustainability. Following this, we explore the challenges and strategies for further decarbonizing the glass melting process. The paper concludes with a summary of key points.

2. MATERIALS MANUFACTURING ENERGY AND EMISSIONS INTENSITY

The global final energy consumption and CO_2 emissions in 2022 for different sectors are shown in Tables 1 and 2, respectively.[12] Final energy is the energy delivered to the end user (consumer). Direct emissions are CO_2 emissions associated with fossil fuels.

Table 2. 2022 Global CO_2 emissions from various sectors [12]

Sector	CO_2 emissions	
	Gt	%
Building	3·0	9
Industry	9·0	26
Transport	8·0	23
Power	14·8	42
Total	**34·8**	

The emissions for the building, industry and transport sectors are direct emissions associated with the use of fossil fuel (e.g. combustion of natural gas in the industry). So, the figure of 9 Gt CO_2 represents the process emissions and does not include indirect emissions from electricity used for industrial processes. Indirect emissions associated with the use of electricity are reflected in the emissions from the power sector. It is clear from Tables 1 and 2 that globally the industry sector is the largest

consumer of energy and the second largest emitter of CO_2 (next to the power sector, which includes indirect emissions from all sectors including the industry). Direct CO_2 emissions from the various industries are given in Table 3.

Table 3. 2022 Global CO_2 emissions from various industries [12]

Sector	CO_2 emissions	
	Gt	%
Iron & steel	2·62	29
Cement	2·42	27
Chemical & petrochemical	1·33	15
Aluminium	0·27	3
Pulp & paper	0·15	1·7
Glass	0·095	1·1[13]
Other industry	2·095	23·2
Total	**9·0**	

In Table 3, data for all industry segments except glass are from Ref. 12, the glass industry emissions are from Ref. 13. The "Other industry" category includes diverse industries including textiles, food processing, non-ferrous metals (other than aluminium), and minerals. As seen in Table 3, iron and steel, and cement together account for about 56% of direct emissions from the industry, and aluminium for 3%. Glass industry emissions constitute only about 1% of the total direct emissions from the industry sector. The scales of production of various materials listed in Table 3 are quite different. Table 4 provides the global production in 2022 for several materials.

Table 4: 2022 Global production of some materials

Material	Global production in 2022 (these are approximate numbers) (million tons)
Cement[14]	4100
Crude steel[15]	1900
Aluminium[16]	68·5
Glass [17,18] (container, flat and tableware tonnages are from Ref. 17, glass fibre tonnage is from Ref. 18)	215 (excludes specialty glasses, which are very small part of the tonnage produced)

Because of the large differences in the production levels, it is instructive to examine the specific (i.e. on a unit mass basis) energy and CO_2 emissions for various materials. The energy and the CO_2 intensities of several materials manufacturing industries are shown in Figure 1.

The energy and CO_2 intensities of glass manufacturing vary widely depending on factors like the heat source (combustion, electric, or a mix), raw materials, recycled glass content (cullet), and production scale. The values used in Figure 1, namely 7·8 GJ/t and 0·6 kg CO_2/kg glass, are values for the EU glass industry in 2007.[5] For the European glass industry, the CO_2 intensity for the year 2022 was 0·56 kg CO_2/kg glass.[13,20]

Table 3 and Figure 1 clearly illustrate that while emissions across all major industry segments must be addressed to achieve net-zero emissions, priority should be given to materials produced at massive scales, such as steel and cement, as well as those with extremely high emission intensities, like aluminium.

3. OVERVIEW OF GLASS MANUFACTURING

Although the specific manufacturing
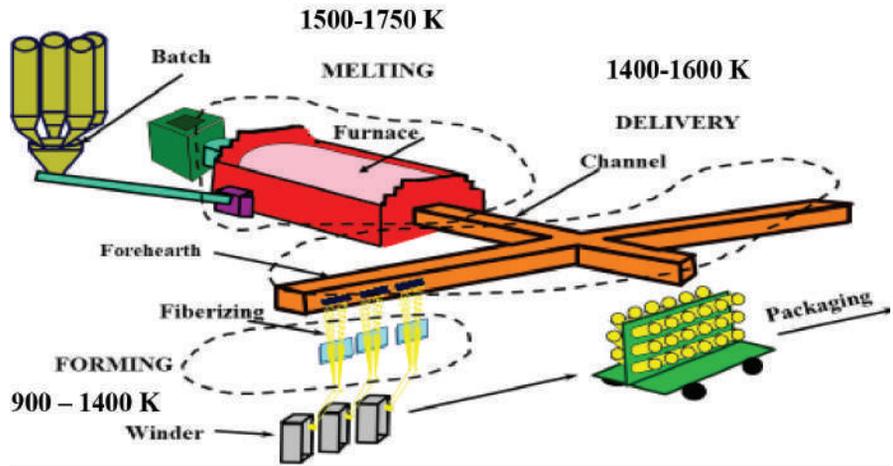
Figure 2. Simplified flow sheet of continuous glass fibre manufacturing process (the figure obtained courtesy of Owens Corning)[21]

processes vary significantly across different segments of the glass industry, they all involve three primary stages: melting, delivery and forming, as illustrated in Figure 2, a simplified flow diagram of continuous glass fibre production.

A mixture of raw materials, known as the batch, is fed into a furnace and heated to high temperatures, where several processes occur, including heat transfer, chemical reactions, gas evolution, melting, fining (removal of gases), and homogenization. Figure 2 groups these under 'melting,' all of which take place in the furnace. In some cases, such as glass bottle production, a separate refiner section removes trapped gas bubbles. The glass melt is then cooled and delivered through refractory channels to forming machines, where it is shaped into containers, sheets, fibres, etc. Afterward, the products undergo finishing treatments (e.g. annealing,

coating) and are packaged for shipping.

The glass industry uses a variety of furnaces of different designs and sizes. Some representative samples are depicted in Zier *et al.*[9] Figure 2 shows the schematics of a hybrid furnace (furnace that uses both combustion and electric heating).

As mentioned earlier, melting accounts for 50–80% of the total energy required for glass manufacturing. The energy for melting is supplied as heat, which can come from combustion, electricity, or, as shown in Figure 2, a combination of both. Fossil fuel combustion is one of the two major sources of CO_2 emissions from glass melting, with the other being the raw materials. These raw materials, including carbonates such as $CaCO_3$, Na_2CO_3 and $MgCO_3$, undergo endothermic thermal decomposition, releasing significant amounts of CO_2. On average, around 20 kg of gas, mostly CO_2, is generated for every 100 kg of glass melt produced.

Using electricity for glass melting reduces CO_2 emissions from glass manufacturing. However, if the electricity is not sourced from renewable energy (e.g. wind or solar), the CO_2 emissions are merely
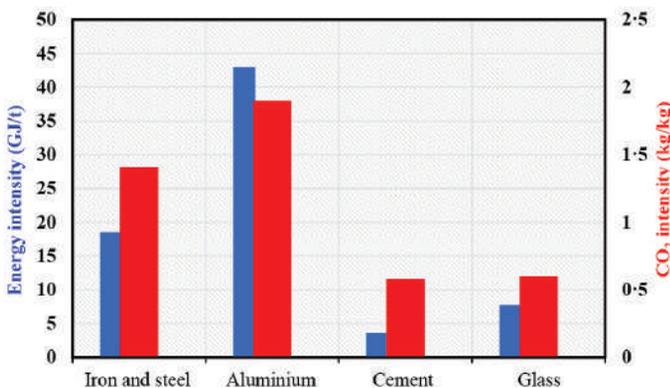
Figure 1. Energy (GJ/t) and CO_2 (kg/kg) intensities of several materials. The data for iron & steel and cement are for the year 2022 and taken from Ref. 18. The data for aluminium is for the year 2017 and taken from Ref. 19.
The sources for the glass industry information is discussed in the text
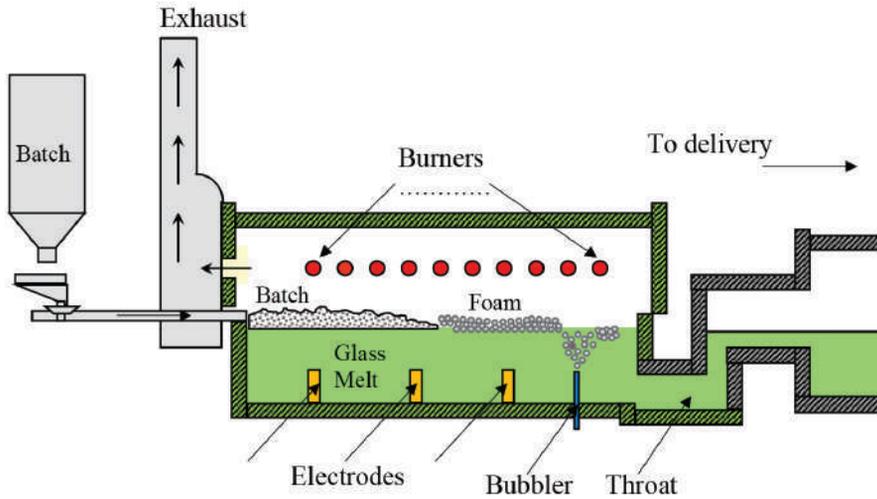
Figure 3. Schematics of a generic hybrid (gas and electric) glass furnace[21] (the figure obtained courtesy of Owens Corning)

shifted from the glass plant to the power plant. Even when electricity is generated from fossil fuels, however, electric melting is generally more energy efficient than combustion-based melting, making it a beneficial option.
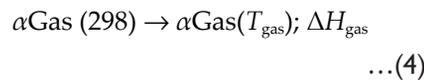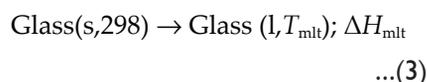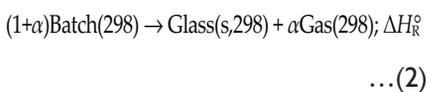
4. ENERGY REQUIREMENT FOR THE GLASS MELTING PROCESS

4.1 Theoretical energy requirement

The batch melting process may be represented as an overall reaction

$(1+\alpha)$ Batch (298 K)
$\rightarrow$ Glass melt $(T_{liq}) + \alpha$ Gas (T_{gas}); ΔH_{theor}

...(1)
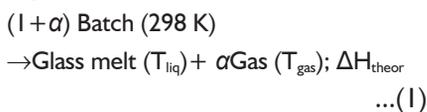
where α is the mass of gas evolved per unit mass of glass, and ΔH_{theor} is the enthalpy change associated with the above reaction, i.e. the theoretical energy demand of the batch to glass conversion process. T_{liq} and T_{gas} are the temperatures of the glass melt and the gas, respectively, and 298 K is the standard room temperature. We may represent the overall reaction, Equation (1), as consisting of three steps.

$(1+\alpha)$Batch$(298) \rightarrow$ Glass$(s,298) + \alpha$Gas(298); ΔH_R°

...(2)

Glass$(s,298) \rightarrow$ Glass (l, T_{mlt}); ΔH_{mlt}

...(3)

αGas $(298) \rightarrow \alpha$Gas(T_{gas}); ΔH_{gas}

...(4)

where s, l denote the solid (or rigid) glass and the glass melt, respectively. The enthalpy change in the first step, ΔH_R°, represents the standard heat of reaction for forming the rigid glass and gas, also known as the chemical heat demand of the batch. The enthalpy changes for the remaining processes, ΔH_{mlt} and ΔH_{gas}, account for the sensible heat needed to heat the glass and gas to their respective temperatures. The theoretical energy demand is the sum of these three enthalpy terms

$$\Delta H_{theor} = \Delta H_R^\circ + \Delta H_{mlt} + \Delta H_{gas} \quad ...(5)$$

For an E-glass with $T_{mlt} = T_{gas} = 1673$ K, Conradt[22] calculated the following values for the terms in Equation (5)

$\Delta H_R^\circ = 0.92$ GJ/t, $\Delta H_{mlt} = 1.75$ GJ/t

$\Delta H_{gas} = 0.46$ GJ/t   ...(6 a,b,c)

$\Delta H_{theor} = 0.92 + 1.75 + 0.46 = 3.13$ GJ/t

...(7)

Zier et al[9] provide a value of 2.68 GJ/t for the theoretical energy requirement for flat and container glasses. However, the glass and the gas temperature values used in the calculations are not provided.

4.2 CO$_2$ emissions and the actual energy requirement

As previously mentioned, there are two sources of CO_2 emissions: carbonates in the raw materials and fossil fuels used for combustion. For the E-glass composition studied by Conradt,[22] for which the theoretical energy was provided earlier, the CO_2 emissions from raw materials amount to 185 kg per ton of glass. The CO_2 emissions from fossil fuels depend on the quantity of fuel used, which in turn is determined by the total energy required for glass melting and the portion of that energy supplied by fossil fuel combustion. If the electricity used for melting is generated from fossil fuel-based power plants, the CO_2 emissions linked to electric boosting (where electricity provides part of the melting energy) or electric melting (where electricity supplies all of the energy) are shifted to the power plants. Table 5 presents the total energy requirements for E-glass melting under different energy source scenarios.

The numbers in Table 5 should be interpreted relatively or comparatively, as the actual energy consumption and CO_2 emissions depend on assumptions regarding the efficiency of different energy sources. In the US, CO_2 emissions from electric power generation using natural gas are approximately 122.5 kg/GJ.[23] Considering this, CO_2 emissions from all-electric melting would be around 614 kg CO_2 per ton of glass ($=185 + 122.5 \times 3.5$), which is comparable to emissions from oxy-fuel combustion but significantly lower than those from air-fuel combustion.

The key strategies for reducing the carbon footprint of glass melting and ultimately decarbonizing the process are: (1) improving the energy efficiency of the melting process,

Table 5. Specific energy required for and CO_2 emissions from melting of E-glass (on a per ton glass produced)

Energy source	Energy	CO_2 (kg/t) produced		
	(GJ/t)	Raw materials	Energy	Total
Air–CH_4	11·9	185	589	**774**
Oxy–CH_4	7·8	185	432	**617**
Electric (T_{gas}=673 K)	3·5	185	0*	**185**
Electric+10% cullet	3·4	167	0*	**167***

If the electricity comes from fossil-fuel based power plants then CO_2 emissions are shifted to the power plant and need to be accounted for at that location.

(2) utilizing electric boosting or full electric melting powered by electricity from renewable energy sources, and (3) switching to zerocarbon (or carbon-free) fuels for combustion in the glass furnace. While these measures address CO_2 emissions from energy usage, it is also important to tackle CO_2 emissions from raw materials. Incorporating cullet and biomass ash into the batch to decrease the carbonate content in the raw materials are effective ways to reduce CO_2 emissions. Lowering the carbonate content also lessens the energy required for glass melting.

5. COMPUTATIONAL FLUID DYNAMICS MODELING OF GLASS FURNACES

Flow, heat and mass transfer phenomena in a glass furnace significantly influence its energy efficiency, production efficiency,

lifespan and emissions. Computational fluid dynamics (CFD) modelling is the most effective method for analyzing these phenomena, their interactions, and their impact on furnace performance. Over the past three to four decades, CFD modelling has become essential for advancements in glass melting technology and will continue to be crucial for the future decarbonization of glass melting. Choudhary et al[21] and Choudhary[24] provide a detailed discussion on transport phenomena in glass furnaces and CFD modelling.

Figure 4 shows the CFD modelling results for a float glass furnace.[30] The isotherms in both the combustion chamber and the glass melt are presented in the central longitudinal section of the furnace. The velocity vectors are superimposed on the isotherms in the glass melt.

The glass melt circulation shown in Figure 4 represents the typical pattern in a combustion-heated furnace without electric heating or bubbling. The melt rises in the spring zone, where the temperature is highest, then splits into two circulation zones: counterclockwise toward the rear and clockwise toward the front. Modelling studies like this are used to optimize furnace design and operation, helping to reduce energy consumption and improve glass quality.

In the next section, we discuss some melting technology innovation in which CFD has played a leading role.

6. PAST GLASS MELTING TECHNOLOGY DEVELOPMENTS AND INNOVATIONS

In this section, we briefly review key technological developments that have significantly improved the energy efficiency of glass melting. These advancements have also increased furnace throughput, lowered unit manufacturing costs, enhanced glass quality and forming efficiency, reduced raw material costs, and minimized or eliminated other emissions, such as particulates. These innovations remain crucial to ongoing decarbonization efforts in glass melting, with a focus on those in
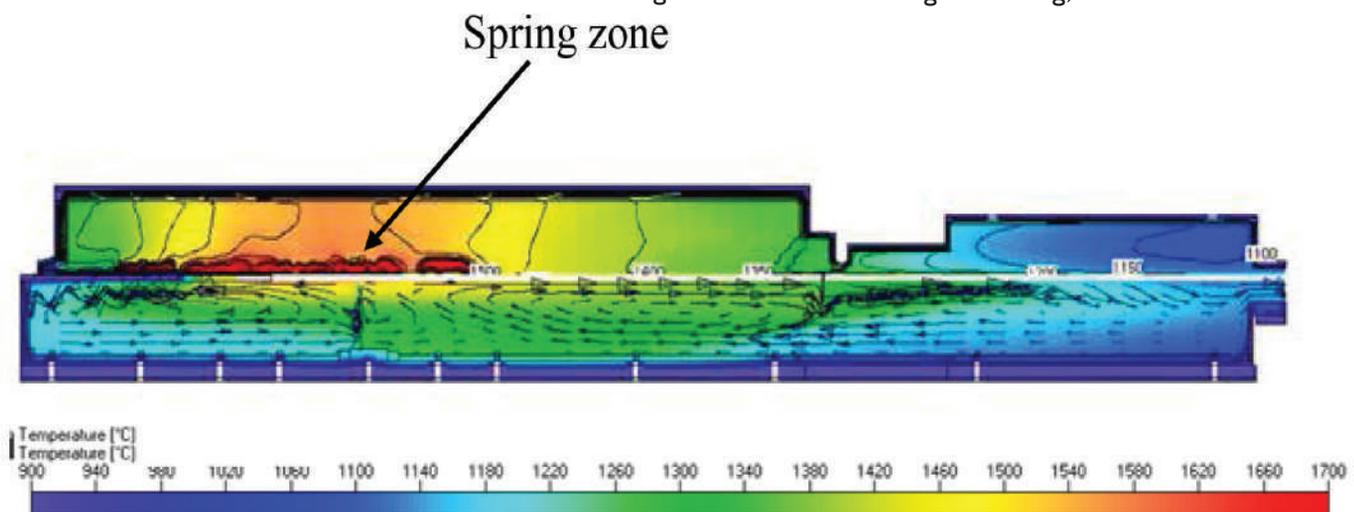
Figure 4. CFD modelling results for temperature and flow distribution in a float glass furnace (The figure obtained courtesy of J. Chmelar, Glass Service, a.s.)
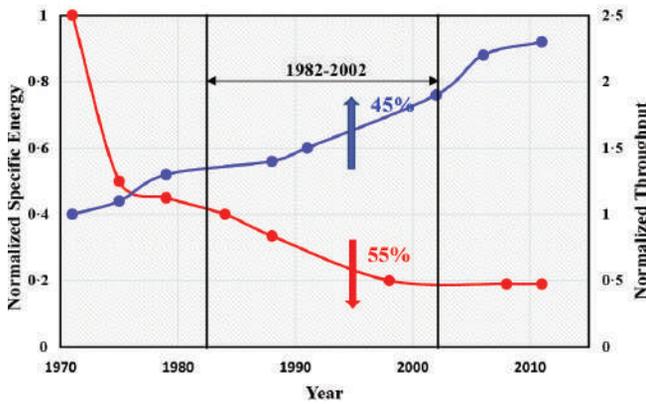
Figure 5. Normalized specific melting energy and throughput for E-glass manufacturing at Owens Corning during 1971–2011 (Base 1971=1) (The data for the figures obtained courtesy of Scott Colangelo of Owens Corning)

which the author and colleagues were directly involved.

Figure 5 illustrates the normalized (Base 1971=1) specific energy for melting and throughput of E-glass fibre production at Owens Corning (OC) over the period from 1971 to 2011. Colangelo[25] provides an in-depth review of the technological developments that contributed to the energy and environmental improvements achieved by OC during this time. We focus here on the twenty-year span from 1982 to 2002, during which the author and his colleagues were actively involved in innovations and advancements in glass melting technology.

As shown in Figure 5, significant advancements were made during this period in both energy efficiency and throughput of E-glass furnaces. Specific melting energy decreased by approximately 55%, while throughput increased by about 45%. Another notable achievement, not depicted in the figure, was the substantial reduction in particulate emissions, specifically sodium and potassium borates ($NaBO_2$, $Na_2B_4O_7$, KBO_2, $K_2B_4O_7$). This achievement eliminated the need for costly remediation measures, such as particulate capture or removal, along with the associated capital and operating expenses for environmental control systems. Additionally, emissions of gaseous boron and fluorine species (HBO_2, HF, NaF, SiF_4) were significantly reduced or eliminated.

The energy efficiency, the throughput and the environmental gains were facilitated by several factors acting in combination. The principal enabling factors were (in no particular order):

- Glass melting process fundamentals

- CFD for furnace design and operations innovations and optimization

- Electric boosting /melting

- Oxy-fuel melting

- Compositional developments to eliminate sources of some emissions

- Waste heat recovery (using the hot exhaust combustion gas to preheat the air to be used for combustion)

- Sensors (including water cooled camera for monitoring the batch) and advanced control

- Improved refractory materials

In the following section, we discuss a select few melting technology developments that illustrate some of the key factors mentioned above. It's important to note that, in addition to being a standalone factor, CFD modelling also played a critical role in advancements related to electric boosting/melting, oxy-fuel melting, and waste heat recovery.

6.1 Electric boosting for E-glass: reduced specific melting energy and enhanced throughput

In the early 1980s, E-glass melting at OC relied entirely on air/natural gas combustion. By the late 1990s, OC developed technology to supply up to 40% of the melting energy from electricity, significantly improving energy efficiency and throughput (Figure 5). While all-electric melting of fibre glass insulation had been practiced for around 50 years at OC, applying high levels of electricity to E-glass melting was a major breakthrough due to its much higher electrical resistivity, 3 to 70 times that of insulation glass at furnace temperatures (1473–1700 K) (Figure 6).

The extensive use of electricity for E-glass melting was made possible by several factors, including advances in furnace design, appropriate refractory for electrodes blocks, control of electrode immersion
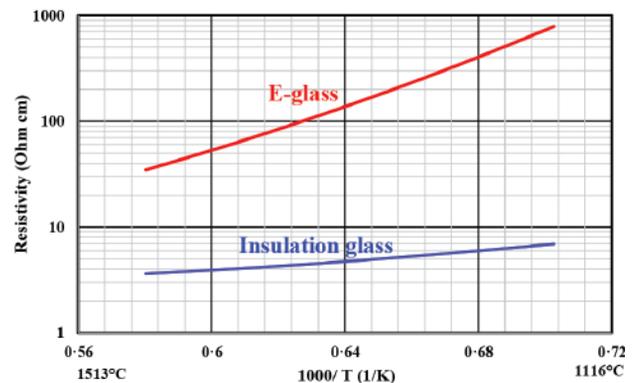
Figure 6. Electrical resistivity of an E-glass and an insulation glass melt. The plots are made using data from Varshneya et al[26]
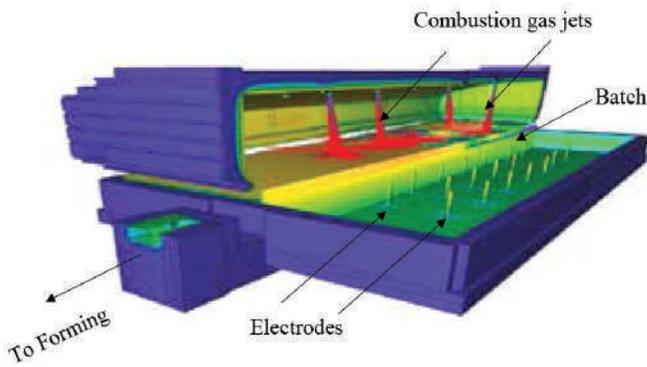
Figure 7. An E-glass furnace with impinging combustion jets and electric boost (The figure obtained courtesy of Drs Bruno Purnode and Jong Han of Owens Corning)

depth, optimal electrode placement, power distribution and electric circuit configuration. CFD modelling was essential for furnace and throat design (the glass melt exit, see Figure 3), electrode placement, and optimizing power and combustion profiles. If bubbling was used, modelling also determined the relative positioning of electrodes and bubblers. Owens Corning pioneered a fully validated 3D mathematical model for furnaces using electric or combustion heating. The first general formulation for calculating Joule heating in glass melts was provided by Choudhary.[27]

The high level of usage of electricity for E-glass melting was enabled by a number of factors including changes in furnace design, use of appropriate refractory for electrode

Figures 7–9 illustrate the use of CFD to determine the number and configuration of electrodes and the oxy-fuel combustion burners to develop melting technology for a new, lower cost, and environmentally friendly glass composition.

The furnace is equipped with seven rows of electrodes, arranged 4/4/6/6/6/6/4 from rear to front. The combustion chamber contains eight oxy-fuel impinging jet burners. Glass melt circulation patterns are illustrated in Figures 8 and 9. Figure 8 shows the flow in a longitudinal plane with four electrodes, while Figure 9 presents the flow in a cross-section of the front most row (seventh row). The colour scale indicates temperature, with blue representing the lowest and orange the highest temperatures.

The temperatures in the melt region are in the 1450–1750 K range, with much lower values in parts of the batch and at the melt/refractory surfaces.

The temperature in the combustion flame areas are typically in the 1850–2100 K range. One may observe that the melt circulation with electric boost is much more complex and significantly different from that seen

for the combustion heated furnace of Figure 4. It should be noted that Owens Corning and Corning also developed an all-electric glass melter for producing fine diameter glass fibres at low throughput rates (1200–1500 kg/h). Some modelling results for this furnace are discussed in Choudhary.[28]

The results of electric boosting for E-glass highlight potential challenges for electric melting of glass in general. While 100% electric melting of fibreglass insulation at throughputs of 250–270 t/d has been practiced for decades, achieving this for E-glass is much more challenging due to the large number of electrodes required and the high temperatures in the melter. Container and float glass, despite having lower electrical resistivity, face similar challenges due to their much larger production scales (400 tpd or more). We will address these and other challenges related to electric melting in subsequent sections.

6.2 Cost-effective, eco-friendly glass batch melting technology

E-glass melting generates particulate and gaseous emissions from the volatilization of boron and fluorine
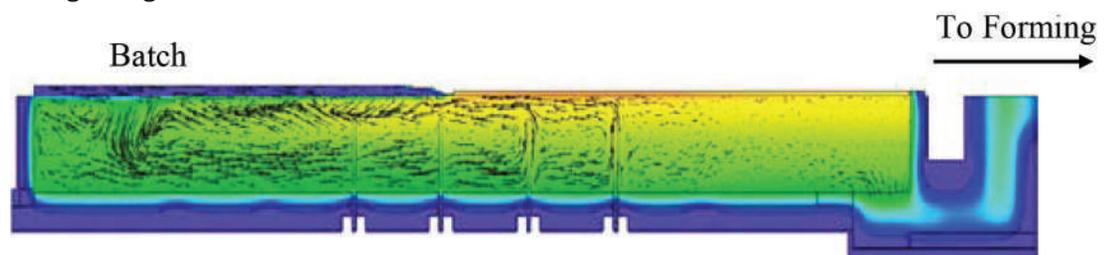
Figure 8. Glass melt flow in a longitudinal section of the furnace shown in Figure 7 (The figure obtained courtesy of Drs Bruno Purnode and Jong Han of Owens Corning)
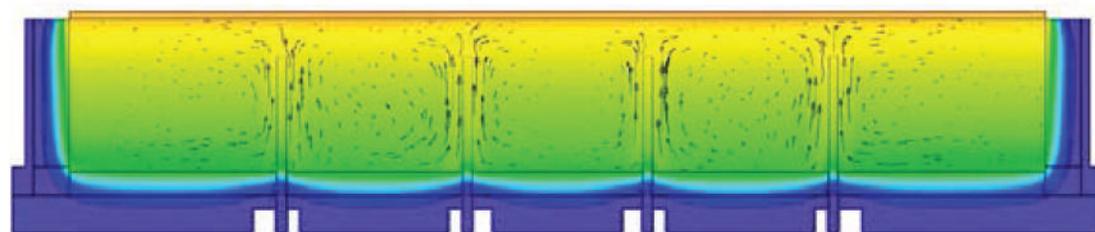
Figure 9. Glass melt flow in a cross-section aligned with the front most row of 4-electrodes of Figure 7 (The figure obtained courtesy of Drs Bruno Purnode and Jong Han of Owens Corning)

Table 6. Composition of E and Advantex glasses[25]

Oxide	Weight percent	
	E-glass	Advantex glass
SiO_2	52–62	59–62
$Al2O_3$	12–16	12–15
CaO	16–19	20–24
MgO	1–3	1–4
Na_2O+K_2O	3–6	0–2
B_2O_3	9–11	–
F	1–3	–

compounds. Boron raw materials, such as Ulexite ($NaCaB_5O_6(OH)_6.5H_2O$) and Colemanite ($Ca_2B_6O_{11}.5H_2O$), are costly and primarily sourced from Turkey, while fluorspar (CaF_2) is mined in China, Mongolia and Mexico, creating a long global supply chain. In response, Owens Corning developed melting technology for a boron- and fluorine-free glass composition, patented in 1998 and called Advantex. This technology reduces batch costs and minimizes particulate and fluoride emissions, indirectly lowering CO_2 emissions as well. Here, we briefly discuss the key features of Advantex glass melting technology.

As seen in Figure 10, the Advantex glass has significantly higher viscosity than the standard Eglass. Thus, melting this glass will require higher temperature, and that, in turn, would require higher energy unless the energy efficiency was improved.

The technology innovation was aimed at enhancing the energy efficiency. Initially, the need for higher temperatures was addressed by using significant electric boost in furnaces with side-entering air-natural gas combustion burners (schematically shown in Figure 3). However, since boron and fluorine volatilization is not a concern for Advantex glass, Owens Corning developed a melting technology that combines electric boost with oxygen-natural gas crown burners fitted through the crown, where combustion gas jets impinge on the batch and glass surfaces. This melting configuration and technology have already been discussed in the previous section and in Figures 7–9.

Figure 11 shows the isotherms on the batch/glass surface of the furnace with impinging jet burners.[21] As expected, the batch and the glass surface temperatures increase with the hot jets impinging on them, with the maximum temperature on the glass surface approaching 2100–2250 K. The use of impinging jet burners for a standard E-glass would have significantly increased volatilization of boron and fluorine and, therefore, greatly increased particulate and gaseous emissions. But, that was not a concern for the Advantex glass.

The use of the impinging jet increased heat transfer by convection. That and increased efficiency of the oxygen-natural gas combustion decreased the gas consumption by 40%.[25]
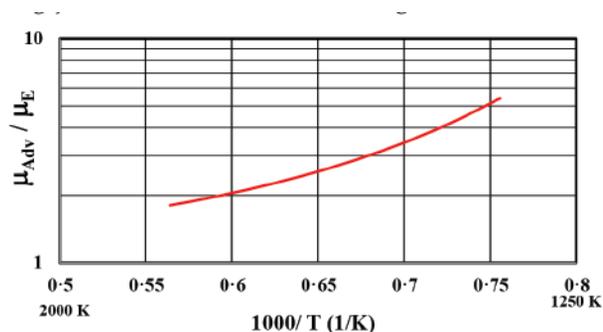
Figure 10. The ratio of the viscosities of an Advantex (μAdv) and an E-glass (μE)

The overall impact of the switch from E-glass to Advantex glass with technology described above was to lower the batch cost, reduce particulate and volatile gaseous emissions, and reduce the specific melting energy. In addition, as noted earlier, the elimination of boron and fluorine containing raw materials with long global supply chains also reduced indirect CO_2 emissions associated with the extraction and the transport of these materials.

To summarize: the reduction in specific melting energy from 1982 to 2002, as shown in Figure 5, was driven by the use of electricity, oxygen-natural gas combustion, raw material modifications and innovative energy delivery methods (e.g. impinging jets, optimized electrode and burner placement). Additional factors, such
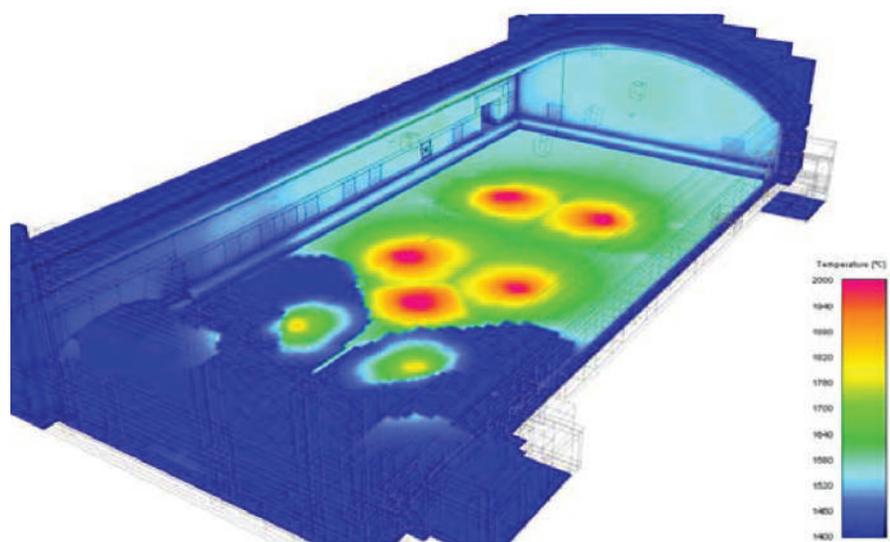
Figure 11. Temperature and flow patterns in the combustion chamber of an oxygen-natural gas impinging jet burner[21] (The figure obtained courtesy of Owens Corning)

as waste heat recovery, sensors and advanced control systems, though not discussed in detail, also played a significant role. These approaches will remain essential as we work to further lower the carbon footprint of glass melting. Next, we will explore strategies for significantly reducing the carbon footprint of glass manufacturing.

7. STRATEGIES FOR DECARBONIZATION OF GLASS MELTING

As discussed earlier, there are two principal sources of CO_2 emissions from glass melting, namely, the raw materials and the energy. So decarbonization of glass melting needs a multi-pronged approach:

1. Continued reduction in specific melting energy

2. Energy substitution

   - Increased electrification (electric melting where possible otherwise a high level of electric boost) with electricity from more renewable electric grid

   - Till non-carbon fuel sources become technically and economically viable, electric boost in combination with oxygen-natural gas combustion

   - Non-carbon fuel source for combustion, for example, hydrogen and ammonia (as a source for hydrogen or a fuel for combustion)

3. Raw materials modifications

   - Increased usage of cullet

   - Alternate raw materials (e.g. use of biomass ash to supply some of the oxides such as CaO, MgO, K_2O without having to use the carbonate raw materials, alternate raw materials that lower the chemical heat demand or the

melting temperature required in the furnace.)

4. **Carbon capture and storage (CCS)/carbon capture usage and storage (CCUS)** – It is a last resort option for addressing CO_2 emissions that cannot be avoided by the measures listed above.

We have already discussed and illustrated the reduction in specific melting energy for continuous reinforcement fibreglass (E-glass). Many of the same enabling factors (such as oxy-fuel melting, electric boost, waste heat recovery, optimized furnace design through CFD modelling, and advanced sensors and controls) have been applied to varying degrees across other glass industry segments to reduce specific melting energy. Another significant contributor has been the use of cullet in various segments, including fibreglass insulation, containers and flat glass. Using 10% cullet by weight in the batch reduces energy requirements by approximately 3% (see Table 5). In the following section, we will focus on Item 2: energy switching/substitution as a strategy for reducing the carbon footprint of glass melting.

A 2023 report from the National Renewable Energy Laboratory of the US Department of Energy concluded that a combination of reduced energy requirement, increased cullet usage and electrification (with electricity coming mainly from renewable electric grid), and hydrogen combustion, the energy demand for glass manufacturing in the US could be reduced by 75–83% and GHG emissions by 82–86% compared to the baseline values of 2010.[29]

7.1 Role of electrification in decarbonization of glass melting

Electrification will play a central role in decarbonizing all sectors of the economy. To achieve net zero emissions by 2050 (NEZ-50), the IEA projects that electricity's share of final energy consumption must increase from 20% in 2020 to 26% by 2030 and around 50% by 2050.[30] For the industrial sector, electricity consumption is expected to more than double between 2020 and 2050, meeting approximately 45% of total industrial energy demand by 2050 (72EJ out of a total of 160 EJ).[30] In contrast, hydrogen and hydrogen-based fuels (such as ammonia and synthetic fuels) are projected to supply just over 5% of industrial energy needs by 2050.[30]

There are global/societal factors to consider in meeting the massive electrification requirement. These include

- Massive need for new power transmission lines. The New York Times, quoting figures from a report by the US Department of Energy states the US "needs 47,300 GW-miles of new power lines by 2035, which would expand the current grid by 57%."[31]

- On a positive note, the levelized cost of electricity (LCOE) from renewable sources has dropped significantly in recent years,
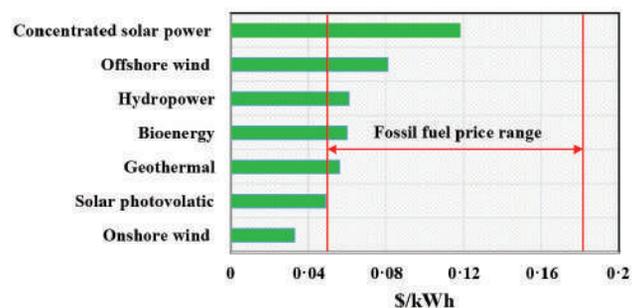
Figure 12. The global averaged levelized cost of electricity (LCOE) from various renewal resources for the year 2022[32] Also, shown is the range of LCOE from fossil fuels[33]

making it price competitive with LCOE from fossil fuels. LCOE represents the average cost per unit of electricity ($/kWh) generated over the lifetime of a new power plant. Figure 12 illustrates the global average LCOE from various renewable resources for 2022,[32] along with the low and high ends of the price range for electricity from fossil fuels.[33] Except for concentrated solar power, the LCOE from all other renewable sources is significantly lower than the mid-range LCOE for fossil fuels.

In addition the global/societal factor mentioned above, namely the need for a massive expansion of resilient and stable transmission grid, the electrification of glass melting faces several industry-specific constraints. These include:

- Certain glass compositions, such as E-glass, have high electrical resistivity (see Figure 10). Achieving all-electric melting for these glasses at commercially viable throughput levels (e.g. 250 tpd or more for E-glass) presents significant technical and economic challenges.

- Even for glass compositions with relatively low resistivity (e.g. container, flat), all electric melting at the very high throughput of these furnaces (400 tpd or more) is challenging.

- Higher levels of electric energy results in higher melt temperature and velocity, with the potential for increased refractory corrosion and shortened furnace life.

- Operating an all-electric melting system requires careful monitoring and control of key factors, including: (1) batch thickness, (2) the quantity and quality of cullet, and (3) electrode wear, with timely advancement of the electrodes to prevent increased resistance.

- All electric melting also requires significant changes in the furnace design. Electric heating "breaks up" the stratified/layered flow

seen in combustion fired furnaces (see the contrast in flow patterns of Figures 4 and 8). This may hinder the rise of bubbles to the surface from the glass melt. The course of action for the glass industry is to use:

- **All electric melting where economically and technically feasible** (all electric melting for fibreglass insulation has been practiced, as indicated earlier, for several decades.

- **Use as high as possible electric boost in combination with oxygen-natural gas combustion** in the short to intermediate term.

- **Use as high as possible electric boost in combination with hydrogen combustion** when and where economically and technically feasible.

- **In all cases use as high level of cullet as economically and technically feasible**. Given the importance of electrification in reducing the carbon footprint and achieving net zero emissions by 2050 in glass manufacturing, there is a widespread effort to develop all-electric and high-electric-boost glass furnaces. SORG's CLEAN MELTER®, for example, is a hybrid furnace for container glass melting, capable of handling up to 400 t/d with up to 80% electric boosting. It also incorporates oxygen firing and offers flexibility for substituting natural gas with hydrogen.[34]

7.2 Hydrogen combustion for glass melting

As discussed previously, electrification (with electricity from renewable resources or, in some cases, from fossil fuel with CCU/CCUS) will be a major factor for decarbonization of glass melting but all-electric melting may not be commercially and technically viable in many cases. In these cases, combustion from non-fossil fuels such as hydrogen is an

option. There is considerable interest in the glass industry in using hydrogen combustion.[35–39] There are several technical and economic challenges associated with the use of hydrogen combustion for glass melting. Table 7 shows some of the principal differences in the thermal properties and combustion characteristics of methane, hydrogen and ammonia.[40,41]

Let us first compare hydrogen and natural gas combustions.

- The wider flammability limit and the higher flame velocity of hydrogen make the control of hydrogen combustion more challenging than that of the natural gas.

- The higher adiabatic flame temperature of hydrogen may require special consideration for refractory and other materials and equipment. The higher flame temperature may also increase NOx emissions.

- While the LHV of hydrogen is about 2·4 times that of the natural gas on a per unit mass basis, it is only 0·3 times on a molar or volumetric basis. That means, the hydrogen volumetric flow rate of hydrogen would need to be about 3·3 times that of the natural gas or increase the pressure of the hydrogen supply. The product of hydrogen combustion is water vapour, while that of natural gas is both water vapour and CO_2. The higher partial pressure of water vapour in the hydrogen combustion gas may adversely impact the quality of the glass.

- Table 5 also highlights the need to address safety concerns related to hydrogen storage, transportation, and combustion. Key strategies should include using materials resistant to hydrogen embrittlement, implementing robust leak detection systems, enforcing strict safety standards and

Table 7. Thermal properties and combustion characteristics of methane, hydrogen and ammonia[40,41]

Item	CH_4	H_2	NH_3
Boiling point, °C	−161	−253	−33·4
Storage pressure at 25°C, MPa	24·82 (compressed gas)	35–70[43] (compressed natural gas)	1·03 (compressed liquid)
Flammability limits, volume % gas in air	5–15	4–75	16–30 [42]
Lower heating value LHV kJ/mol (MJ/kg)	802·3 [50]	241·8 (120)	316·2 (18·6)
Adiabatic flame temperature, °C	1950	2110	1800
Maximum laminar burning velocity, m/s	0·37	2·91	0·07
Minimum ignition temperature, °C	630	520	650

regulations, training personnel, managing ignition sources, and designing systems with adequate ventilation to ensure rapid hydrogen dispersion in case of a leak. Calabrese et al[44] provide a comprehensive review of safety challenges associated with the production, storage, transport and utilization of hydrogen.

The combination of higher emissivity of H_2O vapour compared to that CO_2, and the higher flame temperature of hydrogen may lead to higher radiative heat flux with hydrogen combustion. This appears to be the case, as shown in Figure 13. However, the absence of soot in a hydrogen flame, unlike in a natural gas flame, may reduce radiative heat transfer.

The technical challenges associated with the use of hydrogen combustion for glass melting are, as mentioned earlier, being addressed by the glass industry.[35–39] The greater challenge is the cost of hydrogen produced from renewable electricity. Hydrogen is designated by three

Table 8. The 2021 levelized cost of hydrogen produced from different sources[45]

Hydrogen source	Cost ($/kg)1·0–3
Natural gas (grey hydrogen)	1·0–3
Natural gas + CCUS (blue hydrogen)	1·5–3·6
Renewable electricity (green hydrogen)	R 3·4–12

different "colours" depending on how it is produced: (1) grey hydrogen produced from methane with no carbon capture, (2) blue hydrogen produced from methane with CCS/CCUS, and (3) green hydrogen made from renewable electricity. The levelized cost of hydrogen produced from different sources in 2021 are listed in Table 8.[45]

In the NZE by 2050 scenario projected by the IEA,[45] the solar PV-based electrolysis could become the lowest cost method of producing hydrogen ($1·6/kg) in regions with excellent solar irradiation by 2030. Locations with excellent onshore or offshore wind resources could also offer a significant decrease in the levelized cost of hydrogen ($2·1–$2·3/kg). In other words, by the end of this decade, the green hydrogen could become cost competitive with blue hydrogen in many regions and with grey hydrogen in regions with excellent solar and wind resources.

Figure 13. Measured heat transfer rates from hydrogen and natural gas burners, (the figure obtained courtesy of Erik Muijsenberg of Glass Service)

7.3 Ammonia for glass melting

Examining the ammonia column in Table 7 reveals both the advantages and disadvantages of using ammonia for glass production. The Haber–Bosch process for ammonia manufacturing has been in use for over a century, and the world has significant experience in its storage, transportation and utilization. In contrast, hydrogen storage at room temperature (25°C) requires extremely high pressures, while hydrogen liquefaction necessitates very low temperatures (−253°C). Storing hydrogen at room temperature demands pressures between 35–70 MPa. In comparison, ammonia can be stored in liquid form at room temperature at 1·03 MPa (10 atmospheres) or at −33·4°C and 0·1 MPa (atmospheric pressure).

Thus, ammonia presents potential advantages as (1) a carbon-free fuel, (2) an energy storage system, and (3) a hydrogen carrier. However, there are significant economic and technical challenges associated with the production of green ammonia (ammonia produced using green hydrogen) and its use as a zero-carbon fuel for combustion.

The fundamental characteristics of ammonia combustion have been reviewed comprehensively by

Kobayashi et al,[40] and Erdemir & Dincer[41] and the application of ammonia combustion for furnaces by Valera-Medina et al.[46] As in the case of hydrogen, we focus here on the ammonia as a zero-carbon fuel (i.e. for combustion) for potential use in glass melting, a topic that has begun to receive attention in recent years.[47,48] In the preceding paragraph we had noted the advantages ammonia offers due to its being carbon free, easy to store and transport and our long experience with it. Referencing Table 7, the principal differences between the natural gas and ammonia combustions are:

1. The LHV of ammonia is only about 40% of that of the natural gas.

2. The adiabatic flame temperature of ammonia is 150°C lower than that of the natural gas.

3. The flame velocity of ammonia is only about 20% of the value for the natural gas.

4. The flammability range of ammonia is higher and the ignition temperature is higher.

These differences, along with the nitrogen in ammonia, give rise to the following technical challenges in comparison to natural gas combustion:

1. Lower flame temperature (thus, lower radiant heat flux) of ammonia may require blending it with hydrogen or methane.

2. Achieving stable combustion with ammonia blends may be challenging, and may require careful design of the burner and modifications in the furnace design.

3. Ammonia contains nitrogen in its molecule which readily converts to NOx during combustion. Lower flame speed and narrower flammability range of ammonia

can further contribute to higher NOx emissions if not properly managed. Approaches to minimize NOx emissions from ammonia combustion need to be investigated and developed. These may involve optimizing combustion conditions and developing postcombustion NOx reduction technologies.

4. Further testing is needed to fully understand potential impact of ammonia combustion on colour, clarity and other properties of glass.

It is clear that intensive research and development is needed to overcome challenges associated with both hydrogen and ammonia combustions.

We also need to deal with the CO_2 emissions related to the production of ammonia. Ammonia production is very emissions intensive. At about 2·4 t CO_2 in direct emissions per ton of ammonia produced, it is 1·7 times as emissions intensive as crude steel production and about four times that of cement.[49] The levelized cost of ammonia (LCOA) from different sources are summarized in Table 9.[50] Different sources for ammonia mean whether hydrogen used in the manufacture of ammonia is produced from fossil fuels or renewable energy.

Table 9. The levelized cost of ammonia (LCOA) produced from different sources[50]

Ammonia source	Cost ($/ton)
Fossil fuel (grey ammonia)	110–340
Fossil fuel + CCUS (blue ammonia)	210–490
Renewable electricity (green ammonia)	720–1400

The figures in Table 9 and the following cost projections are made in a report from the International Renewable Energy Administration (IRENA) and the Ammonia Energy

Association (AMA).[49] The LCOA of green ammonia is projected to drop to $310–$610/ton by the year 2050. Co-production of fossil-based hydrogen and renewable hydrogen in existing ammonia plants will reduce the cost by using the existing assets and infrastructure and could enable the introduction of renewable ammonia sooner (by 2040 or even earlier).

The fuel substitution only addresses the CO_2 emissions related to the energy. For further decarbonization of glass melting, one still needs to address CO_2 emissions from the raw materials. Some general ways of doing that were pointed out at the beginning of this section). The residual CO_2 emissions may have to be handled through CCU for zero-carbon glass melting.

8. CONCLUDING REMARKS

Glass melting, the most energy-intensive step in glass manufacturing, accounts for 50–80% of total energy consumption. This paper focuses on decarbonizing this critical phase, addressing four key themes. It begins by discussing the need to decarbonize major energy-use sectors, including electric power, industry, and buildings. It then analyzes the energy and CO_2 emissions intensity of glass manufacturing, placing it in the context of other commodity materials like steel, cement and aluminium. The second theme covers the fundamentals of glass melting, including thermodynamic energy requirements, flow, and heat transfer in furnaces, along with specific energy use and CO_2 emissions estimates, particularly for E-glass melting.

The third theme of the paper highlighted key glass melting technologies implemented by the author and colleagues that significantly reduced energy intensity and increased throughput, lowering

per-unit costs. Innovations such as electric boosting, oxygen–natural gas combustion, eco-friendly glass compositions, and process improvements, supported by CFD modelling, were discussed. These advancements are crucial for the ongoing decarbonization of glass melting, the focus of the fourth theme.

The paper outlined decarbonization strategies for the glass melting process, focusing on reducing CO_2 emissions from energy consumption. It provided an in-depth analysis of energy substitution methods, including electric boosting, electric melting, and hydrogen and ammonia combustion technologies, evaluating their benefits and techno-economic challenges. Additionally, it emphasized the need to reduce emissions from raw materials by increasing cullet use and modifying raw material compositions.

The key conclusions from this study are as follows:

- Glass manufacturing is moderately energy-intensive. Direct CO_2 emissions from glass production are significantly lower than those from industries like crude steel and cement, which operate at much larger scales, and also less than emissions from primary aluminium production.

- Over the past few decades, specific melting energy (energy used per unit mass) in all major glass segments, container, flat, fibre and specialty glass, has significantly decreased. This reduction has resulted from various factors, including waste heat recovery, electric boosting and melting, oxy-fuel combustion, improved thermal insulation, increased cullet use, compositional modifications, optimized furnace design,

enhanced burners, and the integration of sensors and advanced control systems. Notably, many advancements, especially in optimizing furnace design and operation, were facilitated by computational fluid dynamics (CFD) modelling.

- It is widely acknowledged that electrification will play a critical role across all major energy sectors, electric power, industry, transportation, and residential and commercial buildings, in achieving net-zero CO_2 emissions by 2050 to limit global warming to no more than $1·5°C$. By 2050, electricity is projected to meet about 45% of total industrial energy demand, necessitating substantial investment in a stable and clean electric grid. On the positive side, the levelized cost of electricity (LCOE) from renewable sources has, on a global scale, become competitive with LCOE from fossil fuels.

- Fully electric melting may not be economically or technically feasible for many glass manufacturing plants due to a range of factors, including the high electrical resistivity of certain glass types, high production throughput, concerns about furnace lifespan, electrode maintenance requirements, cullet quality concerns, electricity costs, and the lack of a resilient renewable energy grid.

- The decarbonization strategy for glass melting will have the following elements:

  - **All electric melting where economically and technically feasible.**
  - **Use as high as electric boost in combination with oxygen-natural gas**

  combustion in the short to intermediate term.

  - **Utilize high levels of electric boosting in combination with hydrogen combustion** where economically and technically feasible. By 2030, green hydrogen is projected to become cost-competitive with blue hydrogen (produced from renewable electricity) in many regions, and with grey hydrogen (produced from fossil fuels with carbon capture) in areas with abundant solar and wind resources.

  - **In the long term, ammonia may also be considered as a carbon-free fuel for combustion**. By 2050, or possibly sooner, the levelized cost of green ammonia (produced using green hydrogen) is expected to become competitive with that of grey ammonia (produced using hydrogen from fossil fuels). Notably, the glass industry is actively exploring both hydrogen and ammonia combustion for glass melting.

  - All the measures indicated above only address CO_2 emissions associated with the energy usage for glass melting. There is also the need to deal with CO_2 emissions from the carbonate raw materials. This will require a combination of remedies.

  - Use as much cullet as economically and technically feasible

  - Use carbon neutral raw materials (e.g. biomass ash) to supply some of the constituent oxides in the glass composition

  - For complete decarbonization of glass melting, any remaining CO_2 emissions would need to be

handled through carbon capture, usage or and storage (CCU/CCUS).

Achieving complete or deep decarbonization of glass melting presents significant economic and technical challenges. While reductions in specific melting energy have largely stemmed from incremental improvements over the years (typical in a mature, capital-intensive and competitive industry) rapid decarbonization necessitates substantial R&D, technological innovation, and collaboration among industry, government, and academic institutions, and government incentives. A recent World Economic Forum report underscores the crucial role of public-private collaboration in accelerating industrial decarbonization.[51] It presents strategies for uniting leaders from industry, government, academia, and civil society to advance a coordinated and sustainable path to net zero, offering a practical framework for action. The glass manufacturing industry can also leverage these insights to support its decarbonization efforts.

The United Nations recognized the importance of glass to sustainable development by declaring 2022 the International Year of Glass.[52] Throughout history, glass has played a transformative role and continues to be vital across numerous industrial and consumer sectors. Decarbonizing its manufacturing process will further elevate its significance in a low-carbon, more sustainable world.

REFERENCES

1. https://unfccc.int/process-and-meetings/the-paris-agreement

2. https://www.ipcc.ch/sr15/

3. https://www.climate.gov/news-features/features/whats-numbermeaning-15-c-climate-threshold

4. https://www.un.org/en/climatechange/net-zero-coalition

5. Schmitz, A., Kaminski, J., Scalet, B. M. & Soria, A. Energy consumption and CO_2 emissions of the European glass industry. *Energy Policy*, 2011, **39**,142–155.

6. Brinckerhoff, W. P. Industrial decarbonisation and energy efficiency roadmaps to 2050: Glass. (Report prepared for the UK Department of Energy and Climate Change and the Department for Business, Innovation and Skills), 2015.

7. Springer, C. & Hasanbeigi, A. Emerging Energy Efficiency and Carbon Dioxide Emissions-Reduction Technologies for the Glass Industry. Lawrence Berkeley National Laboratory Report, 2017.

8. Griffin, P. W., Hammond, G. P. & McKenna, R. C. Industrial energy use and decarbonisation in the glass sector: A UK perspective. *Adv. Appl. Energy*, 2021, **3**, 1–14. https://doi.org/10.1016/j.adapen.2021.100037

9. Zier, M., Stenzel, P., Kotzur, L. & Stolten D. A review of decarbonization options for the glass industry. *Energy Conv. Manage. X*, 2021, **10**, 1–31. https://doi.org/10.1016/j.ecmx.2021.100083

10. Furszyfer Del Rio, D. D., Sovacool, B. K., Foley, A. M., Griffiths, S., Bazilian, M., Kim, J. & Rooney, D. Decarbonizing the glass industry: A critical and systematic review of developments, sociotechnical systems and policy options. *Renew. Sustain. Energy Rev.*, 2022, **155**, 1–29. https://doi.org/10.1016/j.rser.2021.111885

11. Sinton, C. W. Deep decarbonization of glassmaking. *Am. Ceram. Soc. Bull.*, 2023, **102**(4), 24–29. 12. https://www.iea.org/energy-system/

13. https://www.statista.com/statistics/1071205/carbon-dioxide-emissions- from-glass-production-worldwide/

14. https://www.statista.com/statistics/1087115/global-cement-production- volume/

15. https://www.statista.com/statistics/267264/world-crude-steelproduction/

16. https://www.statista.com/statistics/1372840/worldwide-primaryaluminum- production/

17. https://www.iyog2022.org/images/files/77-economicsiyog-200925.pdf

18. https://www.statista.com/statistics/1177580/global-glass-fibercapacity/#

19. https://www.iea.org/reports/material-efficiency-in-clean-energytransitions

20. https://www.statista.com/statistics/1154296/glass-production-eu

21. Choudhary, M. K., Venuturumilli, R. & Hyre, M. R. Mathematical Modeling of Flow and Heat Transfer

Phenomena in Glass Melting, Delivery, and Forming Processes. *Int. J. Appl. Glass Sci.*, 2010, **1**(2), 188–214.

22. Conradt, R. Thermodynamics of Glass Melting. In: F. T. Wallenberger & P. A. Bingham (Eds), *Fiberglass and Glass Technology*, Springer, New York, 2010, 385–412.

23. https://www.eia.gov/tools/faqs/faq.php

24. Choudhary, M. K. Mathematical Modeling of Rate Phenomena in Glass Melting Furnaces. In: H. Li (Ed.), *Fiberglass Science and Technology*, Springer Nature, Switzerland, 2021, 483–539.

25. Colangelo, S. Reducing the environmental footprint of glass manufacturing. *Int. J. Appl. Glass Sci.*, 2024, **15**, 350–366.

26. Varshneya, A. K., Vascott, T., Karuppanan, R. & Jones, J. M. Electrical Resistivity. In: T. P. Seward & T. Vascott (Eds), *High Temperature Glass Melt Property Database for Process Modeling*, American Ceramics Society, Westerville, 2005, p 173–186.

27. Choudhary, M. K. Three-dimensional Mathematical Model for Flow and Heat Transfer in Electric Furnaces. *Heat Transfer Eng.*, 1985, **6**, 55–65.

28. Choudhary, M. K. Mathematical Modeling of Flow and Heat Transfer Phenomena in Electric Glass Furnaces. *Proceedings of the Julian Szekely Memorial Symposium on Materials Processing*, H. Y. Sohn, J. W. Evans & D. Apelian (Eds), TMS, Warrendale, PA, 1997, 341–364.

29. Avery, G. & Carpenter, A. Supply Chain Energy and Greenhouse Gas Analysis Using Materials Flows through Industry (MFI) Tool: Examination of Decarbonization Technology Scenarios for the US Glass Manufacturing Sector. Technical Report NREL/TP-6A20-8370. February 2023. https://www.nrel.gov/docs/fy23osti/83730.pdf

30. https://www.iea.org/reports/net-zero-by-2050

31. https://www.nytimes.com/2023/05/04/opinion/nepa-permittingreform.html

32. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2023/Aug/IRENA_Renewable_power_generation_costs_in_2022

33. https://ourworldindata.org/grapher/levelized-cost-of-energy

34. https://sustainablemelting.sorg.de/hybrid-melting/

35. https://www.thechemicalengineer.com/features/energy-usinghydrogen-for-glass/

36. https://furnaces-international.com/news/neg-successfully-melts-glasswith- hydrogen

37. https://ceramics.org/ceramic-tech-today/ceramic-video/videohydrogen-trials-show-promise-at-glassmaking-plants/

38. https://www.glass-international.com/news/agc-successfully-useshydrogen-as-fuel-in-glass-production-test

39. https://www.airliquide.com/stories/industry/hydrogen-alternativereduce-carbon-footprint-glass-industry

40. Kobayashi, H., Hayakawa, A., Kunkuma, K. D., Somarathne, A., Ekenechukwu, C. & Okafor, E. C. Science and Technology of ammonia combustion. *Proc. Combust. Inst.*, 2019, **37**, 109–133.

41. Erdemir, D. & Dincer, I. A perspective on the use of ammonia as a clean fuel: Challenges and solutions. *Int. J. Energy Res.*, 2021, **45**, 4827–4834.

42. Fu, W. Y., Zhou, Y., Wu, J., Zhang, K. & Meng, X. Flammability Limits of Ammonia in Air from 298 to 423 K at Elevated Pressures. *Energy Fuels*, 2024, **38**, 10168–10182.

43. https://www.energy.gov/eere/fuelcells/hydrogen-storage#

44. Calabrese, M., Portarapillo, M., Di Nardo, A., Venezia, V., Turco, M., Luciani, G. & Di Benedetto, A. Hydrogen Safety Challenges: A Comprehensive Review on Production, Storage, Transport, Utilization,and CFD-Based Consequence and Risk Assessment. *Energies*, 2024, **17**, 1–26.

45. https://www.iea.org/reports/global-hydrogen-review-2023

46. Valera-Medina, A., Vigueras-Zuniga, M. O., Shi, H., Mashruk, S., Alnajideen, M., Alnasif, A., Davies, J., Wang, Y., Zhu, X., Yang, W. & Cheng, Y. B. Ammonia combustion in furnaces: A review. *Int. J.Hydrogen Energy*, 2024, **49**, 1597–1618.

47. https://www.agc.com/en/news/detail/1203960_2814.html

48. Yamamoto, H., Nakatsuka, N., Hori, S., Kikuchi, K., Matsunami, T., Suzuki, K., Tomoda, T. & Akamatsu, F. Effect of ammonia-air combustion melting on the color and physical properties of soda lime silicate. *Ceram. Int.*, 2024, **50**, 13237–13249.

49. https://www.iea.org/reports/ammonia-technology-roadmap/executive-summary

50. IRENA-AMA Report. Innovation Outlook: Renewable Ammonia. International Renewal Energy Agency, Abu Dhabi, Ammonia Energy Association, Brooklyn, 2022. (https://www.irena.org/-/media/ Files/ IRENA/Agency/Publication/2022/May/IRENA_Innovation_Outlook_Ammonia_2022.pdf)

51. https://reports.weforum.org/docs/WEF_United_for_Net_Zero_Public_Private_Collaboration_to_Accelerate_Industry_Decarbonization_2025.pdf

52. Duran, A. & Parker, J. M. (Eds.) *Celebrating Glass, achieving sustainability, inspiring transformation*, Consejo Superior de Investigaciones Científicas (CSIC). 2024.

Originally published in Glass Technology: European Journal of Glass Science and Technology ∎

CLARITY, QUALITY & SERVICE IS THE FUTURE

Haldyn® Glass Limited
CIN: L51909GJ1991PLC015522

GLASS made WITH CARE

Chalcogenide glasses: A vision beyond Visible (Part-2)

Dr. K Annapurna

Chief Scientist, Speciality Glass Division

annapurnak.cgcri@csir.res.in

& Dr. Pritha Patra

(CSIR-Senior Research Fellow)

CSIR-Central Glass & Ceramic Research Institute (CGCRI), Kolkata

patrapritha06@gmail.com

Single-crystal germanium (Ge) is the globally used commercial material for the fabrication of focusing lenses in thermal imaging cameras. The transparency window of Ge covers both the second and third atmospheric windows, at 3-5 μm and 8-12 μm, respectively. However, Ge is a costly material that must be grown as a larger single-crystal material for lens fabrication, which is a challenging process. Also, fabrication of an aspheric or diffractive lens from single-crystal Ge is quite an expensive method, which needs diamond tip turning. If Ge crystal is used as the IR optics maximum workable temperature range is up to 80^0C, and hence, the device needs to be cooled during operation. Further, to minimize chromatic dispersion (abbe no of single crystal Ge is ~400), special multielement anti-reflective coatings are used on the lens to minimize the reflection and to increase the transparency. This is why a thermal imaging camera is much more expensive than an optical camera. Other than Ge, zinc selenide (ZnSe), zinc sulfide (ZnS), calcium fluoride (CaF_2), barium fluoride (BaF_2), Silicon (Si) are also used as lens material. However, each of them has their own limitation. Some are limited by their transparency window; some are difficult to mould because of their polycrystalline nature. Henceforth, current interest in this field is drawn towards the development of a suitable material that fulfills all the technical criteria, as well as allows low-cost

mass production, additionally does not exhibit any barrier to complicated shaping in lenses. In this context, the article aims to demonstrate how chalcogenide glasses offer a more suitable and cost-effective alternative to germanium for the fabrication of IR lenses.

Chalcogenide glasses are a unique category of non-oxide, semiconducting glasses with low phonon energy (~350 cm^{-1}), primarily composed of group 16 elements from the periodic table, including sulfur (S), selenium (Se), and tellurium (Te). Their internal structure typically features covalent bonds, including homo-molecular bonds (S–S, Se–Se, or Te–Te) and hetero-molecular bonds (S–Se or Se–Te). Among

the three chalcogen elements, only selenium can independently form glasses. Other electropositive elements like Ge, Ga, In, Sb, As, and Pb are added as modifier elements to enhance the glass formability. Further, in some cases halides of alkaline metals and alkaline earth metals or silver halides (LiX, NaX, KX, CsX, AgX, where X= Cl, Br, I) are also added into the glass compositions for structural modification and optical properties tailoring. Presence of heavy elements (high reduced mass) and strong covalent bond (large bond strength) made these glasses low phonon (~300 cm^{-1}), thereby their transparency window extended up to the Far-IR region. Depending upon the composition of S, Se, and
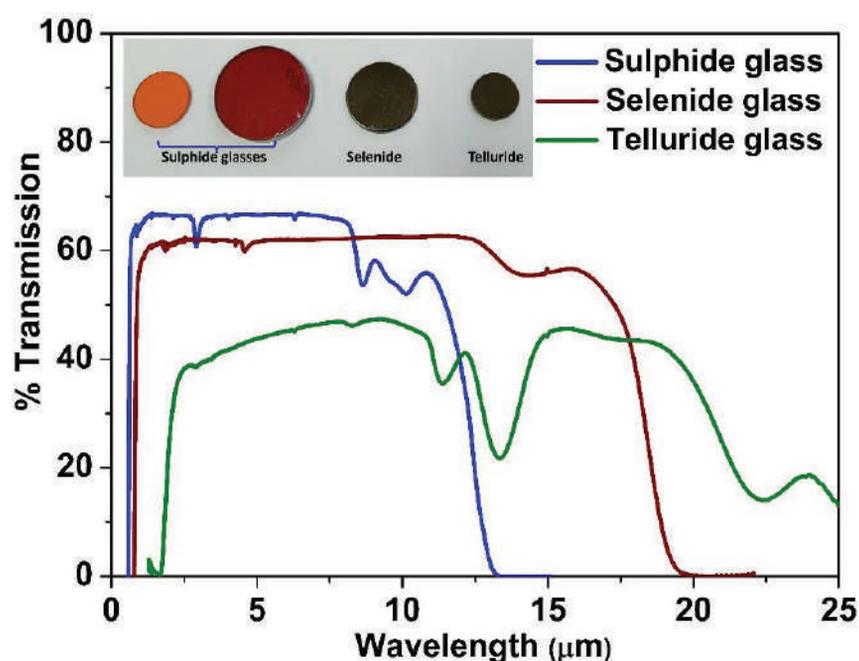
Fig. 1. Transmission window of sulfide, selenide, and telluride glasses exhibiting IR edge up to 12 μm, 20 μm, and 20 μm, respectively.
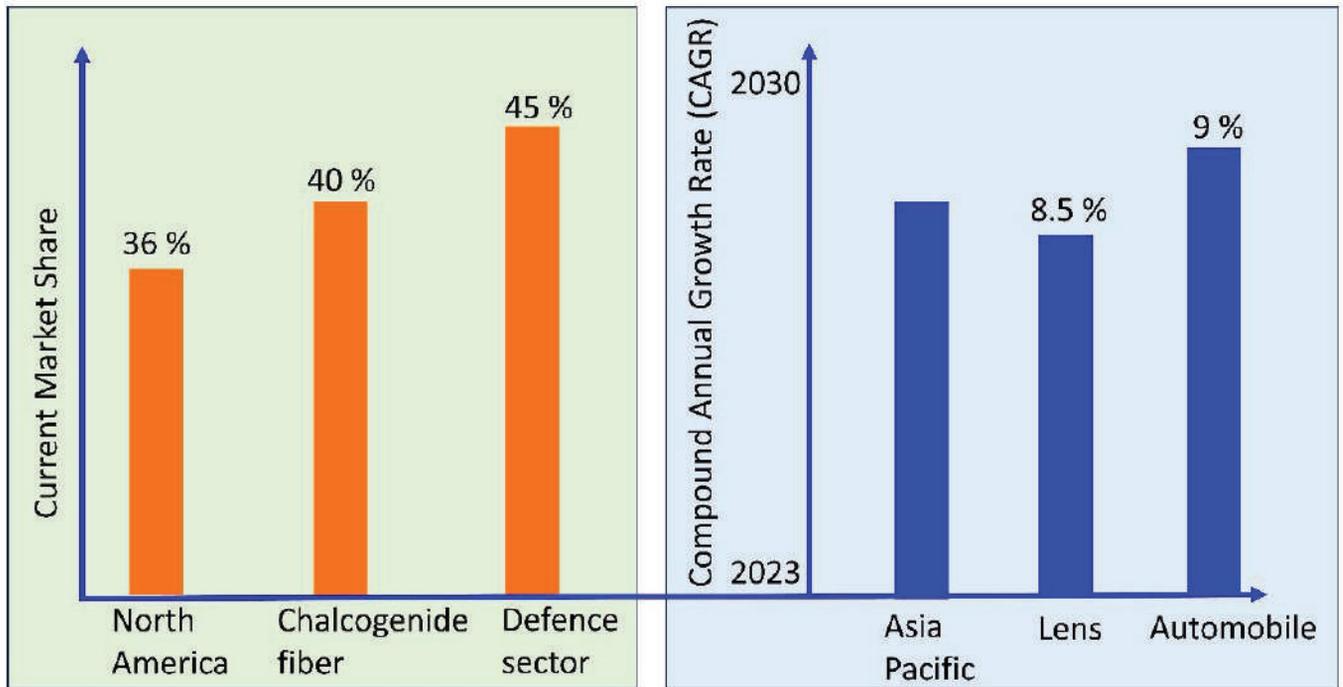
Fig. 2 (a) current maximum market share (b) expected CAGR of chalcogenide glasses, for different applications, with projection of the leading region

Te glasses (molecular mass increases S→Se→Te) exhibit an IR transparency cutoff/edge up to ~12 μm, ~18 μm, and beyond 20 μm, respectively. The images of some S, Se, and Te-based chalcogenide glasses fabricated at CSIR-CGCRI are shown in Fig.1, along with their transmission window.

In the current global scenario, the chalcogenide glass is one of the fastest-growing markets due to continuous demand and advancements in the field of infrared technologies. The sectors like defence, aerospace, automobiles, telecommunication, healthcare show huge demand for infrared lenses, fibers, amorphous semiconductors, and infrared detectors. Particularly, with the progress of IR- imaging technology in many different fields like thermal imaging, night vision, missile guidance, and surveillance in power supply systems or thermal industries, chalcogenide glass manufacturing is significantly impacting the market. Considering the geopolitical conflicts, most of countries are increasing their defence budget to improve their border security surveillance. Overall,

chalcogenide glass market expected to show a sharp uprising from ~319 to ~574 USD million in the next nine years (2025 to 2034), projecting a compound annual growth rate (CAGR) of ~ 8%. According to the survey, three factors are categorizing the chalcogenide glass market based on subsegment of glasses/components (fiber/lens/detector), application fields (defence, automobile, aerospace etc.), and marketing region (countries/subcontinents). As per the 2023 report, among all subsegments chalcogenide fibers hold maximum market share of 40%. However, fastest growing subsegment is chalcogenide lens, with expected CAGR of 8.5%. Application wise, defence sectors project maximum share of 45%, while automobile industries shows fastest CAGR future growth of 9%. Regionally, North America region is currently holding the largest share of 36% in chalcogenide market, followed by Asia Pacific (currently 32%, with expected fastest growth). Maximum current market share of different regions, subsegment and application fields of chalcogenide glasses are

shown in Fig. 2a, and the categories which is expected to show largest growth (CAGR) in upcoming year is given in Fig. 2b. The key technological advancement that can further boost the chalcogenide market is focused on lowering production cost, and high purity glass preparation in large scale maintaining the optical performance.

It has been found that Se glasses with IR transmission window up to 16 μm are particularly suitable for thermal imaging lens preparation. Fabrication of bulk chalcogenide glasses is much easier as well as inexpensive than growing single crystal Ge. Initially, 'Umicore' USA commercialized arsenic (As) based chalcogenide glasses with the composition $Ge_{22}As_{20}Se_{58}$ (GASIR1®), which match all the criteria of thermal imaging and also obtained high resolution image. Later, due to the hazardous nature of arsenic, researchers became interested in the fabrication of As-free chalcogenide glasses. 'Umicore' replaced As with Sb and developed non-arsenic glass with the composition $Ge_{20}Sb_{15}Se_{65}$ (GASIR2®). 'Vitron' developed IG5® glass having
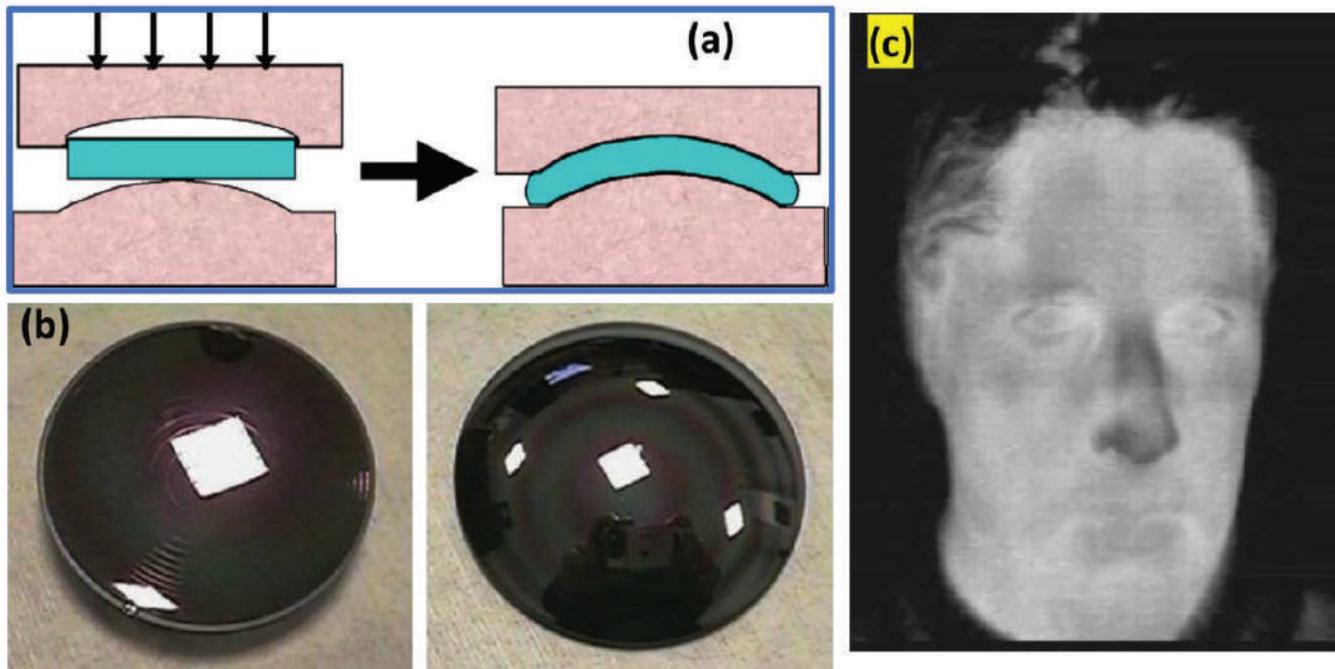
Fig. 3. (a) sketch of chalcogenide lens preparation (b) moulded diffractive surface and spheric surface lens (c) thermal image captured with GASIR ($Ge_{22}As_{20}Se_{58}/Ge_{20}Sb_{15}Se_{65}$) glass lens. Represented with permission [1,2]

the composition $Ge_{28}Sb_{12}Se_{60}$. Popular optics manufacturing company 'Schott' Inc., Germany offers both As-containing and As-free compositions IRG3® ($Ge_{30}As_{13}Se_{32}Te_{25}$) And IRG5® ($Ge_{28}Sb_{12}Se_{60}$) respectively.

All these commercial glasses exhibit much lower thermo-optic co-efficient (dn/dT) than single crystal Ge, which is beneficial for good quality imaging. Other than these well-known manufacturers of IR optics, several lab scale research works are going on worldwide to develop more appropriate chalcogenide glass compositions for thermal imaging. Those compositions should follow certain important criteria as given below:

1. Glass should exhibit excellent transparency up to 16 μm or beyond (Se or Te based glass). Impurity presence should be at minimum particularly at 2-16 μm wavelength region.

2. High resistance towards devitrification or crystallization, else presence of any crystallites would be difficult for moulding and unfavourable for optical properties of the lens.

3. Linear temperature vs viscosity profile so that to make the moulding process easy.

4. Glasses should exhibit suitable thermal and mechanical stabilities. Glass transition temperature (T_g) should be higher than 250^0C, so that should outstand some relatively high temperature during processing.

These chalcogenide glasses are also having advantage of direct compress moulding to ready to use lenses because of their low softening point temperature. This will make them suitable for making moulded optics, which is economically viable process for mass production as well as limiting the material loss. Figure 3 represents a schematic of the lens moulding technique and a developed lens, respectively, at the Universite' de Rennes and Vertex under French Defence contracts, which had been used as a thermal imaging camera lens. In a simple moulding procedure, a glass block is heated under moderate pressure until it reaches the appropriate viscosity first and then

attains plasticity in order to duplicate perfectly the surface of the mould. Thermal image taken by an aspheric and diffractive lens prepared from $Ge_{22}As_{20}Se_{58}/Ge_{20}Sb_{15}Se_{65}$ (GASIR) glass composition [1, 2] is also shown in Fig.3.

Part 3 of this article will be continued with the activities of CSIR-CGCRI in the field of chalcogenide glass production and its application in thermal imaging and other infrared applications.

REFERENCES

(1) Zhang, X. H.; Guimond, Y.; Bellec, Y. Production of Complex Chalcogenide Glass Optics by Molding for Thermal Imaging. *J. Non. Cryst. Solids* **2003**, *326-327*, 519-523. https://doi.org/ https://doi.org/10.1016/S0022-3093(03)00464-2.

(2) Bureau, B.; Zhang, X. H.; Smektala, F.; Adam, J.-L.; Troles, J.; Ma, H.; Boussard-Plèdel, C.; Lucas, J.; Lucas, P.; Le Coq, D.; Riley, M. R.; Simmons, J. H. Recent Advances in Chalcogenide Glasses. *J. Non. Cryst. Solids* **2004**, *345-346*, 276-283. https://doi.org/https://doi.org/10.1016/j.jnoncrysol.2004.08.096 ∎

OPIS A DOW JONES COMPANY

CHEMICAL MARKET ANALYTICS

Media Partner: **AIGMF**

World Soda Ash
Conference

Building Momentum, Adapting to Shifting Demand.

7 – 9 October 2025 | Palma de Mallorca, Spain

Join us at the World Soda Ash Conference, your premier destination for all things related to the soda ash industry.

Hosted by Chemical Market Analytics, this conference brings together industry experts, thought leaders, and key stakeholders for two days of insightful discussions, networking opportunities, and market analysis.

Highlights include:

In-depth presentations on technological advancements and sustainability initiatives

Access to exclusive market reports and research findings

Expert-led panel discussions on market trends and forecasts

Networking sessions with industry peers and potential collaborators

Opportunities to showcase your products and services to a global audience

For more information, visit out site: **chemicalmarketanalytics.com/wsa**
or contact: events@chemicalmarketanalytics.com

MITIGATE
volatile energy price risk
Choose
PRICE HEDGING
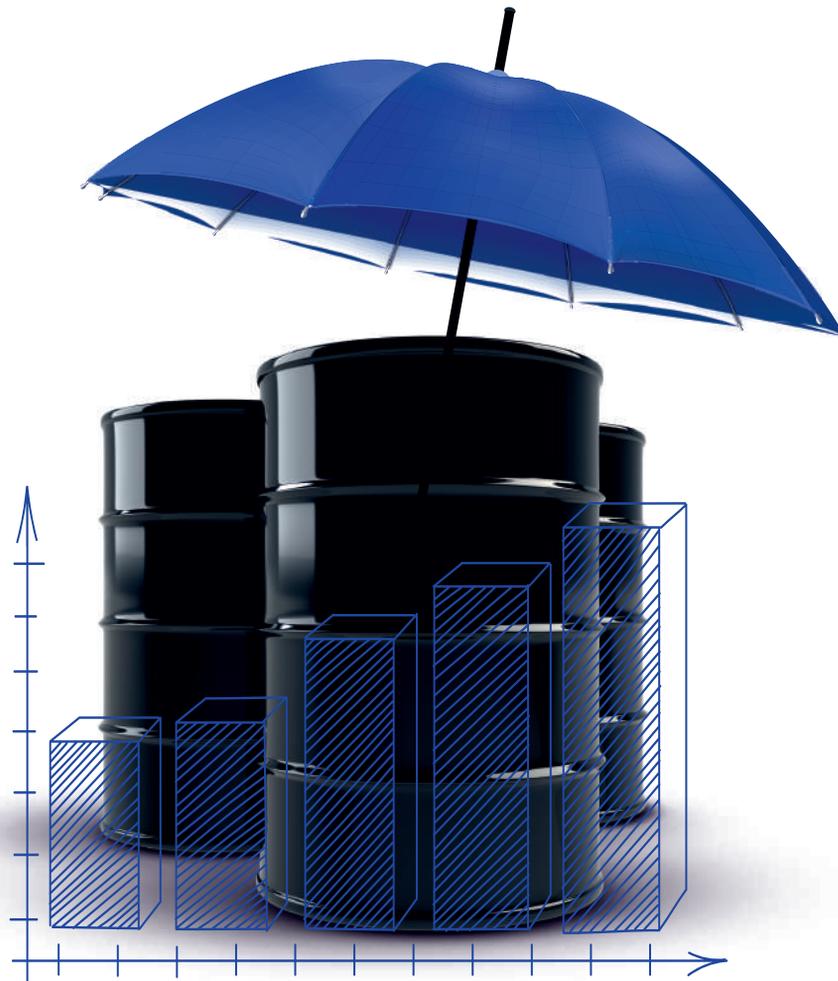
- A cushion against volatile energy price movements
- Hedging with Energy Derivative contracts helps in safeguarding the budgeted input cost
- Protecting the Profitability margin of the company

MCX
METAL & ENERGY
Trade with Trust

MCX INVESTOR PROTECTION FUND

Laminated Safety Glass in Vogue: How Researchers are now Recycling it

The topic of 'safety glass' seems relevant: Many glass manufacturers are strengthening their laminated safety glass production, developing thinner laminates to save raw materials, energy and weight in façades or advancing to the highest safety classes. Bulletproof, explosion protection, etc. appear to be attracting more interest in unpredictable, volatile times, especially for system-relevant infrastructure. On behalf of glasstec, the author asked Mr. Steffen Schäfer, Technical Director at the German Flat Glass Association (BF, Bundesverband Flachglas) and Dr. Miriam Schuster, Head of the Glass and Polymers Research Group at the Institute of Structural Analysis and Design at the Technical University of Darmstadt, whether the 'feeling' of increased activity in the field of safety glass is appropriate and what research is being conducted in the field of safety glass.

B+L Marktdaten GmbH has been regularly analysing the markets for windows and façades in all global markets relevant to German companies on behalf of the Bundesverband Flachglas e.V. (BF) for 20 years. This includes monitoring production volumes and sales of the different 'types' of float glass, coated glass, toughened safety glass, laminated safety glass and insulating glass. Unsurprisingly, the persistently low level of construction activity is also having a negative impact on sales in the glass industry. The

Cullet saves raw materials, energy and CO_2 emissions.

Photo: AGC Glass Europe

weakening construction sector does not appear to be a singular problem, but rather the result of an economic, political and social crisis: interest rate increases and higher borrowing costs, high construction costs due to rising energy prices, building materials, transport and tradesmen's services – first due to supply bottlenecks caused by the COVID-19 pandemic, then due to inflation. At the same time, there is a shortage of skilled labour, meaning that construction times are being extended, costs are rising and planning reliability is suffering. Increased uncertainty is also included in this due to political and geopolitical developments that are difficult to predict, insufficient state subsidies and the much-described basic problem of strict German building regulations and correspondingly long approval processes. Finally, there is the demographic and social change with declining construction activity in shrinking regions and increasing requirements in growing urban centres.

The German Flat Glass Association provides an insight into the new B+L figures on the market data for windows and façades: *"While all types of glass have been affected by declining sales since 2022, laminated safety glass has stagnated at a relatively high level, and sales are even forecast to increase slightly year-on-year in 2025. This is partly due to a growing interest in safety glass applications and the very active work on DIN 18008 in recent years. Fortunately, laminated safety glass products are being favoured on the market, especially in comparison to basic glass"*, explains Mr. Schäfer. One of the major challenges facing the flat glass industry – but also one of its opportunities – is the increasing demand for greater cost-effectiveness and sustainability in safety glass: *"The glass industry is already making a lot of progress here – manufacturers are increasingly using renewable energy, saving resources, developing products with a lower carbon footprint and*

effective ways to close their cycles. They know that if they invest here, they will create a good competitive position for themselves in global competition in the future".

IN PROGRESS: RECYCLING LAMINATED SAFETY GLASS

Sustainability is now also a competitive advantage in economic terms – but laminated safety glass has been in a difficult position up to now, as it is difficult to recycle due to the film bond. Dr. Miriam Schuster, head of the Glass and Polymers research group at the Institute of Structural Analysis and Design at the Technical University of Darmstadt, reports: *"We are researching new ways to separate and recycle laminated safety glass by type, as it is now an integral part of modern architecture, both in the interior and the façade. While the glass is theoretically fully recyclable and PVB as a thermoplastic material can also be recycled in principle, the reality is sobering: The majority of old laminated safety glass elements are shredded and the glass fragments are transferred to other industries, for example for the production of glass wool or hollow glass. The majority of PVB residues are landfilled or incinerated. The separation of glass and interlayer has so far been the biggest obstacle to a genuine recycling or reuse cycle".*

A team of researchers led by Dr. Miriam Schuster and Prof. Dr. Johannes Kuntsche from the Department of Structural Engineering

The so-called "daisy effect" occurs when laminated safety glass is heated and indicates the beginning of bubble formation in the PVB. It is a key indicator for the optimum separation time.

In Fig. 1-d and Fig. 1-e (bottom row), you can also see that the film thickness has increased due to the daisy effect.

Figures: Maximilian Düwel, master's thesis "Circular economy of laminated glass – investigations into the unmixed separation of glass and interlayer" (2024)

at Darmstadt University of Applied Sciences has taken up this challenge. At the "CircuClarity One" conference, which took place at glasstec 2024, they presented preliminary investigations into an innovative process that allows laminated safety glass to be separated by type without glass breakage and without PVB contamination. The aim is to enable the reuse or closed-loop recycling of the glass sheets as well as the recycling of the PVB film.

THEIR SEPARATION METHOD IS BASED ON A FOUR-STAGE PROCESS

1. Heating: The glass samples are heated to approx. 170-220°C until the so-called "daisy effect" (formation of bubbles in the film) has fully formed.

2. Mechanical separation: The laminates are sheared and pulled apart in a manually guided device. Crucial: The interlayer

is separated cohesively without damaging the glass.

3. Water treatment: Heat treatment in water leads to improved separation.

4. Peeling: Finally, the remaining intermediate layer is removed mechanically.

Freshly produced samples of different types of structure, different PVB adhesion levels (high, medium), different interlayer moisture contents (0.32-0.66%), different lamination processes – and, of course, aged samples – were analysed. In addition, different temperatures were analysed for step 1. The result: The lower the temperature is, the longer it takes for the daisy effect to fully develop. The adhesion of the PVB significantly influences the separation process during peeling in step four, but not significantly during mechanical separation in the second step.

After the separation process, intact glass panes and large pieces of film free of glass dust are obtained.

Photo: Dr Miriam Schuster, TU Darmstadt

The successful separation of LSG enables closed-loop recycling as cullet in float glass plants and even reuse, e.g. glass sheets in secondary applications.

However, Dr. Schuster believes that further steps are required for successful, practical and industrial implementation, such as an in-depth analysis of the daisy effect during the heating of LSG, the industrial scaling of the heating process or automated peeling, the optimisation of the process parameters and an evaluation of the material quality after separation. A corresponding research proposal for further development has already been submitted.

On 20-23 October 2026 in Düsseldorf, glasstec 2026 will once again be the central and impulse-giving leading trade fair for the exchange of ideas on future topics in the glass industry. With the special show "glass technology live" and the associated "glasstec conference", the trade fair will bring together research, manufacturers and users who want to help shape the future. In this context, visitors can also look forward to a follow-up event on the topic of circularity: "CircuClarity Two"∎

More information at glasstec.de

DUKHIRAM MAURYA

Engineering and Refractory Services, Quality Craftsman and Workmanship

Our Clients across the Continent

Malaysia, U.A.E, Egypt
Saudi Arabia, Kuwait,
Lebanon, Uganda,
Nigeria, Tanzania,
Kenya, Sri Lanka, Oman

Glass to Glass Services Offered

FURNACE STEEL FABRICATION AND ERECTION
Structural, Piping, Ducts and Equipmet Installation

BATCH HOUSE
Modification, Erection, Fabrication

REFRACTORY INSTALLATION SERVICES
Cosmetic, Pharmaceutical, Oxy Fuel, Container, Tubing, Float, Sheet, Tableware, Lighting, Opal, Fibre etc Glass Furnaces

SODIUM SILICATE FURNACE
Design and Installation

DRILLING, DRAINING AND HEAT UP
Furnace

HOT REPAIR SERVICES
Online Checker Replacement including Regenerator Crown, Division Wall, Overcoating, Tile Patching etc

B-304, Universal Business Park, Kamani Oil Mill Road, Chandivali, Mumbai - 400 072, Maharashtra, India.
Phone: +9122 - 2857 5411 / 2857 9788
Email: info@dukhiram.in

DUKHIRAM MAURYA ENGINEERING AND REFRACTORY WORKS (I) PVT LTD

Membership of the Federation

Members of the Federation are classified into two categories; manufacturers of primary glass articles are enrolled as **Ordinary Members** of the Federation and suppliers to the glass industry viz., suppliers of machinery, raw materials, consultants and others connected with the glass industry are enrolled as **Affiliate Members**.

Foreign Companies supplying machinery etc., to the glass industry are also enrolled as **Affiliate Members**.

Membership forms can be downloaded from www.aigmf.com/membership.php

Members of the Federation are enrolled on the recommendation of Zonal Associations viz.:

- Eastern India Glass Manufacturers' Association (EIGMA)
- Northern India Glass Manufacturers' Association (NIGMA)
- South India Glass Manufacturers' Association (SIGMA)
- Uttar Pradesh Glass Manufacturers' Syndicate (UPGMS)
- Western India Glass Manufacturers' Association (WIGMA)

ADMISSION FEE / ANNUAL SUBSCRIPTION

Ordinary Members:

- Admission fee ₹ 5,000/-
- Annual subscription: Single Unit: ₹ 40,000 + GST as applicable
- More than one Unit: ₹ 1,60,000 + GST as applicable
- Applicants for enrollment for a period of five years may pay an amount of ₹ 1,80,000 for a single Unit and ₹ 7,50,000 for more than one Unit + GST as applicable

Affiliate Members:

- Admission fee ₹ 5,000/-
- Annual subscription: ₹ 16,000 + GST as applicable
- Applicants for enrollment for a period of five years may pay an amount of ₹ 70,000 + GST as applicable

Affiliate Members from countries other than India:

- Admission fee US $ 200
- Annual subscription: US $ 500 + GST as applicable
- Applicants for enrollment for a period of five years may pay an amount of US $ 1,800 + GST as applicable ■

List of Advertisers

GLINDCO
PROJECTS | CONSULTING | EQUIPMENT

COMPLETE SOLUTIONS TO GLASS INDUSTRY

PROJECTS & CONSULTING SERVICES

- Turnkey Supply of Glass Plants
- Turnkey Project Management
- Project Consulting
- Design and Engineering Services
- Installation Services
- Feasibility Studies
- Take-over Assistance
- Revival of Sick Units

SERVING SEGMENTS

- Glass Container Plants
- Float Glass Plants
- Sheet Glass Plants
- Patterned Glass Plants
- Pharma Glass Vials Plants
- Neutral Glass Tubing Plants
- Tableware Glass Plants
- Opal Glass Plants
- Glass Bricks Plants
- Glass Frit Plants
- Silicate Glass Plants
- Glass Processing Plants

EQUIPMENT SUPPLY

- Batch Plants
- Glass Melting Furnaces
- Fore-hearths
- Combustion Systems
- Batch Chargers
- Reversal Dampers
- Flue Control Dampers
- Cullet Processing Plants
- Sand Processing Plants

PLANET CERAMICA PVT LTD
502, Concourse House, Ameerpet, Hyderabad-500016 | Contact: Ph:+91 8341761484
Email: contact@glindco.com | Website: www.glindco.com

HAL
HEAT APPLICATIONS INDIA
MEMBER OF H*twork INTERNATIONAL

+91 820-0196577 | +91 98255 11685
HAL@HEATAPP.IN
WWW.HEATAPP.IN

80+	300+	3000+
Expert Personnel	Sets of Equipment	Projects Over 3 Decades

With an extensive experience spanning over three decades in this domain, Heat Applications India Pvt. Limited (HAL) has gained the trust of industries worldwide. We are providing specialised services such as refractory dry out and heat up solutions for all industries.

- Controlled Furnace Heat up
- Furnace High speed Draining with Water Recycling
- Controlled Furnace Cool down
- Refractory Dry Out
- Refractory Expansion Control & Cullet Charging
- Combustion Technology

- Hot & Cold Refractory drilling service for installation of bubbler / thermocouples and electrodes
- Thermal Decongestion of Regenerators
- Oxy-fuel Burner | Boosting Systems
- Air - Fuel Burner

Mr. M.D. Farooq
(Founder)

Manufacturer Of Energy
Efficient **Lehrs**

Belts

SHREE LAXMI GLASSTECH

www.shreelaxmiglasstech.com

SLG

ISO 9001:2008
Certified Company

YOUR PARTNER FOR THE GLASS CONTAINER INDUSTRY

Innovative. Reliable. Global.

At **SLG**, we are more than manufacturers-we are architects of precision, engineering the future of glass container technology. With a legacy of excellence and a forward-thinking mindset, we are revolutionizing the industry by delivering high-precision, export-quality glass solutions that exceed international standards.

Who We Are

SLG has earned its place as a globally recognized specialist in the glass manufacturing sector. For years, we have served as a reliable partner to some of the most respected glass producers worldwide-delivering performance-driven components, mechanisms, and inspection systems that power the modern glass production line.

EXCEPTIONAL GLASS ENGINEERING BEGINS WITH SLG

REDEFINING GLASS EXCELLENCE

OUR EXPERTISE SPANS ACROSS

- S.G., D.G., T.G., and Q.G.
- I.S. Machine mechanisms and variable equipment
- High-performance spare parts for a wide range of machines and operations
- State-of-the-art Bottle and mold inspection gauges for quality assurance
- Advanced furnace burners, components, and spare parts
- Cullet scraper systems that enhance recycling efficiency
- Printing machine parts designed for longevity and precision
- All-encompassing plant maintenance solutions for continuous uptime
- Our Promise: Precision. Performance. Progress.

SLG – PRECISION-MADE ● GLOBALLY DELIVERED ● UNMATCHED IN PERFORMANCE

Export More than **50 Countries**	Since **2005**	Exports Account for **Over 95%** of Total Sales

Corporate Office

SHREE LAXMI GLASS TECH

H1-163, V.K.I. Area Ext., Jaipur, Rajasthan-302013 (INDIA)
www.shreelaxmiglasstech.com ● Email : sales@shreelaxmiglasstech.com

Suresh Jangid : +91 9829063816 **C. Shekhar Jangid** : +91 9829260816 **Dikshant Jangid** : +91 9116127919