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Glass for a sustainable future: How can glass scientists help meet the challenge?

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Organizing & scientific committee: S. Schuller, T. Charpentier, F. Méar, M. Lancry, L. Cormier, D. de Ligny, N. Créon, A. Goel, R. Pokorny, J. McCloy, A.C. Martins Rodrigues, Y. Yue, J. Du, D. Neuville

Book of abstract



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MONDAY

The challenges of decarbonizing the glass industry.

Erik Muijsenberg * ¹

¹ Glass Service (GS) – Rokytnice 60, 75501, Vsetin, Czech Republic

The challenges of decarbonizing the glass industry.

Erik Muijsenberg

Glass Service, Rokytnice 60, 75501 Vsetín, Czechia

Corresponding Author Email: Erik.Muijsenberg@gsl.cz

Business Development Director, Glass Service Group

Vice President, International Commission on Glass (ICG)

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The European Union has established stringent targets for CO emissions over the next 30 years. By 2030, emissions must be reduced by 55% compared to 1990 levels, with the ultimate goal of achieving climate neutrality by 2050. It is evident that these ambitious targets cannot be achieved using current furnace designs.

The International Commission on Glass (ICG) has a pivotal role in fostering collaboration and knowledge exchange across regions by organizing conferences focused on sustainability.

To achieve meaningful reductions in carbon emissions, innovative furnace designs and new technologies must be developed. Such advancements require the use of validated Computational Fluid Dynamics (CFD) tools like the GS Glass Furnace Model (GS GFM). No glass producer would risk building a new furnace concept capable of melting over 100 tons per day without rigorous analysis, calculations, and CFD modeling. Recent trends show increasing interest in reducing carbon emissions through greater reliance on electric melting or hydrogen, similar to the widespread adoption of CFD modeling during the rise of oxy-fuel technologies. Now, with the next generation of large hybrid furnaces (with over 50% electric boosting) or fully electric melters.

These complex furnaces, with multiple heat inputs, also require advanced control systems, such as Model-Based Predictive Control, to optimize the balance between electricity and natural gas usage. This approach considers fluctuating costs and aims to maximize carbon reduction.

This presentation will address the following key topics:

Introduction: The role of the ICG and the significance of glass in modern applications – the *Glass Age*.

*Speaker

- **Renewable Resources:** The importance of clean electricity for reducing carbon emissions and updates on global developments in renewable energy.
- **History of Electric Melting:** A brief overview of the evolution of electric glass melting technologies.
- **Segment-Specific Technologies:** Exploration of the most viable decarbonization technologies for various segments, such as crystal and tableware, container glass, borosilicate, fiberglass, and flat glass.
- **Case Studies:** Examples of large-scale all-electric and hybrid melters currently in operation, with a focus on the performance of a large hybrid melter.
- **Forehearth Electrification:** Insights into the potential for 70–90% energy and carbon emission reductions through electrifying forehearths.

Schotts perspectives on sustainability in the speciality glass industry

Michael Hahn * ¹, Moritz Hauf ¹, Wolfgang Schmidbauer ¹

¹ SCHOTT AG – Germany

Achieving sustainability in specialty glass production presents significant challenges that can only be addressed through technological innovation. This presentation outlines how our company addresses these challenges by implementing advanced technological solutions within clearly defined strategic frameworks. By advancing the technological readiness of these approaches, we enable a highly adaptable and efficient melting process-tailored to meet the demands of uncertain times.

*Speaker

The challenges of decarbonizing

Sousa Vasco * ¹

¹ PICVISA – Spain

Picvisa - Advanced Technology For Material Separation

*Speaker

Glass for a sustainable future: new cullet sources

Anette Zimmermann * ¹

¹ Verallia Deutschland AG – Germany

Glass is the only material infinitely recyclable without any loss of quality: it is a model material in terms of circularity.

The use of cullet in glass production reduces the need for natural raw materials such as sand, and synthetic raw materials such as sodium carbonate. It also helps reduce CO emissions, both by reducing the energy required for melting and by limiting the use of carbonate materials, whose chemical decomposition releases CO.

Today we are using mainly Post Consumer Recycled cullet, meaning glass retrieved from municipal waste collection services. To increase the cullet ratio used in our glass, we need to increase the collection, but also to find other cullet sources.

At the same time, you can see a rapidly growing number of solar panels in Europe, which are being dismantled and replaced by newer, more modern systems. These solar panels have very pure white glass, bonded with crystalline silicon, silver, aluminum and polymers. Is it possible to separate the glass in such a way that we can use it in our melt? Many start-up companies are trying to develop this recycling process. Verallia is investigating the mode of action of the various recycling options in its own company laboratory with the help of melting tests.

*Speaker

Furnace performance analysis with a focus on decarbonization strategies

Reinhard Conradt * ¹

¹ uniglassAC GmbH – Germany

The lecture starts with a fundamental analysis of thermodynamics and of heat transfer constraints in high-temperature processes in general. The consequences of the first and second law, and of finite-time heat transfer, on the performance of industrial furnaces in general are pointed out. It is true, decarbonization strategies can be based on straight-forward measures like the use of carbon-free energy input and carbon-free raw materials. But the way towards this goal needs to be supported by primary measures reducing the overall energy demand of the process, like: the reduction of process irreversibility, the reduction of the intrinsic heat demand of the batch-to-melt conversion, and an enhancement of melting kinetics.

*Speaker

Basic data on glass structure and its influence on viscosity

Daniel Neuville * ¹, Laurent Cormier ²

¹ Institut de Physique du Globe de Paris – Institut de Physique du Globe de Paris, Centre National de la Recherche Scientifique, Université Paris Cité – France

² Cosmochimie [IMPMC] – Institut de minéralogie, de physique des matériaux et de cosmochimie – France

After the initial presentation laying the foundations of the glass structure studied since the first diagram proposed by Zachariassen in 1932, using a variety of techniques, we will try to understand how structure and chemical composition influence macroscopic properties, like viscosity variations. In this presentation, we'll review the various techniques for measuring viscosities and discuss intrinsic errors, then explain the role of the various elements - network formers, network modifiers and charge compensators - and how they affect viscosity, specific heats and a number of other macroscopic properties.

*Speaker

On the Ionic Conductivity of Glass Forming Oxide Melts: A Review of the Major Trends of Compositional and Temperature Dependence

Steve W. Martin * ¹

¹ Iowa State University of Science and Technology – United States

The ionic conductivity of glass-forming oxide melts provides a critical link between the fundamental materials science of ion transport and the practical design of next-generation electrified glass-melting technologies. This lecture offers a review of the major compositional and temperature-dependent trends that govern ionic motion in oxide melts, while highlighting how these principles underpin emerging low-carbon pathways for glass production through the use of renewable electricity.

The presentation first examines the compositional factors that control electrical conductivity across silicate, borate, phosphate, and related oxide melt families. The lecture will outline how the incorporation of alkali and alkaline-earth oxides alters network connectivity, produces non-bridging oxygens, and modifies the electrochemical landscape through which ions migrate. Both monotonic and non-linear trends—such as those associated with mixed-modifier effects, coordination changes, and variations in cation field strength—are reviewed to illustrate how composition dictates conductive pathways relevant to electric-field-driven melting.

Temperature dependence forms the second major theme. Arrhenius and Vogel–Fulcher–Tammann descriptions of ionic mobility are compared to clarify how activation energies, structural relaxation, and configurational dynamics of the melt influence high-temperature electrical performance. Fragility, dynamic crossovers, and the coupling between transport and relaxation processes are introduced to connect empirical conductivity behavior to underlying structural mechanisms.

These scientific foundations are then linked to the growing industrial imperative for low-carbon glass production. The lecture will discuss how the electrical conductivity of oxide melts determines the efficiency, stability, and scalability of electric melting systems powered by renewable energy sources. Emphasis is placed on how compositional tuning can optimize conductivity profiles for Joule-heated furnaces, enabling deeper integration of wind, solar, and other low-carbon electrical inputs into glass manufacturing.

By combining structural insight, transport models, and sustainability considerations, the lecture outlines the central principles that connect melt chemistry, ionic mobility, and the transition toward electrified, renewable-powered glass-melting technologies.

*Speaker

Glass and glass-ceramics: formulation

John Stuart Maccloy * ^{1,2}

¹ Washington State University – United States

² Pacific Northwest National Laboratory – United States

Glass formulation is often viewed as a compositional exercise, but in practice it is a systems-level design problem linking composition, structure, processing, and performance. This talk surveys modern strategies for glass and glass-ceramic formulation, illustrating how the field has evolved from empirical substitutions and phase-diagram guidance to physics-informed descriptors and data-driven design frameworks.

The presentation begins with classical formulation approaches used to probe component function, including one-at-a-time substitutions, leave-one-out methods, and proxy metrics such as optical basicity, polymerization, and topological constraint theory. Examples spanning oxide, fluoride, chalcogenide, and metallic glass families demonstrate how these descriptors connect composition to viscosity, crystallization tendency, durability, optical response, and mechanical behavior. Case studies include environmentally motivated substitutions in optical glasses, parameterization of fluoride glass stability, and constraint-based design of chalcogenide systems.

The talk then highlights recent advances enabled by large glass databases and interpretable machine learning, including composition–property modeling, quantitative structure–property relations, and uncertainty-aware optimization. Nuclear waste glasses are used as a model “extreme” formulation problem, illustrating how data-centric tools complement physical insight in highly multicomponent, tightly constrained systems.

Finally, formulation challenges unique to glass-ceramics are discussed, where controlled crystallization introduces additional design variables in phase selection, thermal history, and microstructure. Overall, the talk emphasizes that modern glass formulation is a multiscale, multi-parameter design endeavor integrating classical glass science with emerging computational tools.

*Speaker

Glass synthesis: Focus on industrial glasses

Sophie Papin * ¹, Emmanuelle Guillard ¹, Sophie Schuller

¹ Saint-Gobain Research Paris – SAINT-GOBAIN – France

Understanding of the reaction steps that occur during glass production is crucial for the optimization of the melting process and to avoid the presence of heterogeneities in the produced glasses (bubbles, undissolved grains, crystals, chemical segregation). In this presentation, we will describe the physico-chemical mechanisms that lead to the formation of a homogeneous liquid in industrial glass melting furnaces (float glass in particular). We begin by describing the reaction mechanisms involved in the production of soda lime silicate glass. We will then focus on the phenomena implied in the production of a soda-lime-silica glass made from silica and sodium / calcium carbonates. We will show what reaction paths are possible to achieve the desired liquid composition, and why it is crucial to control the properties of the precursors used (particle size, microstructure, melting and decomposition temperatures) to obtain a homogeneous liquid. These explanations will be based both on knowledge of phase diagrams and on in situ analyses at temperature, enabling us to characterize changes in compositions and morphologies (tomography, environmental SEM) and thermal effects (ATD/ATG) associated with melting and decomposition reactions.

*Speaker

Perspectives on molecular dynamic and NMR spectroscopy for glass and melt properties

Thibault Charpentier * ¹

¹ Laboratoire Structure et Dynamique par Résonance Magnétique (LSDRM) – Nanosciences et Innovation pour les Matériaux, la Biomédecine et l’Energie (ex SIS2M) – France

Since solid-state NMR allows the observation of local chemical environment of atoms independently of the existence of long range order, it has now become a key tool to resolve the structure of glassy materials. Today, the high level of sophistication of multidimensional magic-angle spinning (MAS) NMR experiments allows structural motifs to be identified both at the short range order (i.e. ~ 2 Å, such as silicate and borate polyhedra) and at the intermediate range order (2-8 Å, connectivity patterns between these polyhedra).

However, despite these achievements, the spectral broadening associated to the structural disorder of glass often limits the detailed interpretation of NMR spectra. In complement to these advances in NMR techniques, the combination of molecular dynamics simulations and first-principles calculations of NMR parameters (GIPAW method) has therefore recently emerged as a valuable tool to significantly improve the assignment, detailed interpretation and processing of NMR spectra. This new approach offers new means to address several fundamental issues (in the context of glassy materials) : i) direct comparison of MD simulations with NMR experiments, ii) linking variations of the local structure (such as bond distances or angles) with NMR signatures ; iii) improving the analysis of the NMR parameter distribution. As will be shown, the last point is essential for accurate processing (fitting) of the experimental data.

All these NMR methodologies will be illustrated through applications to various oxide glasses and in particular borosilicate glasses modeling the French nuclear waste glass. In this context, applications to key issues will be presented: i) elucidation of the incorporation mechanisms of elements such as lanthanum and lead; ii) effects of irradiation on the glass structure; iii) impact of thermal history on chemical durability; iv) structure of other industrial glasses. Our latest methodological development based on Machine Learning prediction of NMR properties will be presented. The presentation will end with a discussion on perspectives of these new methodologies for NMR studies and modelling of melts.

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Some challenges and opportunities in glass fiber science and technology

Yuanzheng Yue * ¹

¹ Department of Chemistry and Bioscience, Aalborg University – Denmark

Glass fibers play a vital role in the global green transition, particularly in applications such as structural reinforcement and thermal insulation. Continuous efforts are being made to enhance their performance through optimization of glass composition and fiberizing processes. However, achieving these improvements requires overcoming significant scientific and technological challenges. At the same time, rapid advances in characterization techniques and computational tools, including machine learning, are creating unprecedented opportunities for innovation in glass fiber science. In this talk, I will highlight some key scientific challenges and some major technological challenges in the development of high-performance glass fibers. I will also discuss emerging strategies to address these challenges, illustrated with examples from our own research. The presentation will focus on oxide glass fibers designed for reinforcement and thermal insulation applications.

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TUESDAY

Let's build a future where glass fiber is not just durable - but circular.

Anne Berthereau * ¹

¹ Owens Corning – Owens Corning - OCV Chambéry International - 767 quai des Allobroges 73009 Chambéry – France

Glass fiber, a cornerstone of modern insulation and composites, presents unique challenges & opportunities in circularity. This talk will explore the critical success factors for building a circular value chain for glass fiber, drawing insights from Owens Corning experience & benchmarking efforts. We will examine how end-of-life products recycling can be scaled across industries. Key enablers include cross-sector partnerships, best practices sharing, innovation and alignment with regulatory and customer expectations. Industrial case studies will also illustrate practical pathways. The goal is to inspire collaboration and investment in scalable circular solutions for glass fiber.

*Speaker

How the redox play for structure and properties? Implication for glass industry

Daniel Neuville * ¹, Laurent Cormier ²

¹ Géomatériaux, IPGP-CNRS, USPC – IPGP – France

² IMPMC, Sorbonne University, CNRS, MNHN, IRD, Paris – Sorbonne University – France

The first two presentations dealt with the structure and properties of glasses and liquids, but what happens at high temperatures in a furnace or a volcano?

At a time of energy transition, how does the transition from gas to electric or hydrogen furnaces affect high-temperature properties in a furnace? How do conditions of pressure, temperature and oxygen fugacity influence melting and annealing conditions, and how do they affect the properties of the final product?

In this talk, we will discuss the variability of oxygen fugacity in furnaces, and how it can influence high-temperature properties?

*Speaker

Redox control for industrial-scale vitrification of nuclear waste

Annabelle Laplace * ¹, Isabelle Hugon ¹, Luiz Pereira ², Olivier Pinet ³,
Franck Pigeonneau ⁴

¹ CEA, DES, ISEC, DPME, Univ. Montpellier, Marcoule, France – Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA) - Marcoule – France

² Department of Earth and Environmental Sciences, Ludwig-Maximilians-Universität München, Munich, Germany – Germany

³ CEA, DES, IRESNE, DER, Cadarache, F-13108 St Paul Les Durance, France – Centre de recherche du Commissariat à l'Énergie Atomique - CEA Cadarache (Saint Paul-lez-Durance, France) – France

⁴ MINES ParisTech, PSL Research University, CEMEF - Center for material forming, CNRS UMR 7635, CS 10207, rue Claude Daunesse 06904 Sophia Antipolis Cedex, France – MINES ParisTech, Center for Material Forming (CEMEF), CNRS – France

Vitrification is a method of immobilizing nuclear waste currently used on an industrial scale, particularly for highly radioactive waste. In France, the waste, which often contains several multivalent species, is incorporated into a borosilicate glass melted over 1000°C. The incorporation of such waste, into a glass-forming liquid can lead to gas releases, including those of oxygen resulting from redox reactions between dissolved species in the melt. It can have an impact on both the process and the final properties of the glass. On the other hand, a reduced glass can lead to excessive corrosion of the melting pot. Controlling redox properties is of major interest.

Thermodynamic data were acquired for various redox couples. A model was developed, based mainly on the assessment of multivalent species (in waste and vitrification additive) and on thermodynamic redox equilibrium equations. Specific vitrification additives containing relevant multivalent species have been developed in order to better control the melt redox. Besides, work has also been carried out to understand the mechanisms of oxygen bubble formation and growth, and how they are linked to redox reactions.

This talk reviews studies we have conducted and gives examples of redox control for industrial-scale vitrification of nuclear waste.

*Speaker

Experimental and Mathematical Analysis of Primary Foaming during Glass Melting – Towards improved CFD Models

Richard Pokorny * ¹, Jaroslav Klouzek ², Jose Marcial ³, Derek Dixon ³, Pavel Ferkl ⁴, Pavel Hрма ⁵, Albert Kruger ⁶

¹ University of Chemistry and Technology Prague – Czech Republic

² University of Chemistry and Technology Prague – Czech Republic

³ Pacific Northwest National Laboratory – United States

⁴ Pacific Northwest National Laboratory – United States

⁵ AttainX – Richland, 99354, United States

⁶ U.S. Department of Energy, Hanford Field Office – Richland, 99354, United States

Understanding the batch-to-glass conversion process is essential for improving the efficiency of glass melting and for developing predictive models of industrial glass furnaces. A key, yet still insufficiently quantified, phenomenon controlling heat and mass transfer during melting is the formation and evolution of the primary foam layer that develops at the interface between the reacting batch and the molten glass.

In this work, we investigate the structure, dynamics, and decay of transient primary foam during glass batch melting using a combination of high-temperature visual observation and two-dimensional X-ray radiography. Compared to earlier three-dimensional X-ray tomography studies, the applied techniques provide improved temporal and spatial resolution, allowing detailed observation of bubble nucleation, growth, coalescence, and escape. Shortly after batch charging, gas-evolving reactions generate a primary foam layer approximately 5–10 mm thick within tens of seconds. The foam is sustained by continuous gas generation and simultaneously destabilized by bubble coalescence into larger cavities that migrate laterally and escape to the atmosphere. At later stages, the remaining batch transforms entirely into foam, which gradually collapses at the melt surface. The observed foam decay rates are consistent with literature data on surface foam formed during secondary foaming.

The experimental results provide new insight into the coupling between gas evolution, foam dynamics, and batch conversion. These observations are directly relevant for the development of advanced batch-to-glass conversion models that couple reaction kinetics with heat transfer and melt properties. In particular, the presence of bubbles and cavities at the batch–melt interface modifies radiative heat transfer and thus affects the temperature history of batch particles, which strongly influences melting rates. The presented data therefore represent an important step toward physically based models capable of predicting melting behavior under realistic furnace operating conditions.

*Speaker

Sustainable glass-melting concepts – How to deal with physical limits?

Christian Roos * ¹

¹ RWTH Aachen University – Germany

Sustainable glass production means for the industry to fight at two borders. One is the challenge to make glass melting processes more energy efficient and less CO₂ emitting. The other is to also change the glass chemistry in such way that less CO₂ is emitted (directly) by the raw materials.

Sustainable glass melting processes foremost mean the development of alternative, sustainable melting concepts, such as hydrogen or ammonia fired furnaces or hybrid or fully electrically heated furnaces. But it also means to explore new sustainable glass chemistries.

By discussing both, sustainable glass chemistry approaches and approaches for a sustainable glass melting, it will be explained why it is normally not possible to tackle one problem without considering the other. In addition, it will be made clear that some physical limits hinder certain combinations of melting concepts with certain glass chemistries. Examples may be the usage of a fully electrically heated furnace with a glass composition that is sustainable and e.g. has no CO₂-emission due to the lack of carbonates but has limited electrical conductivity. Another physical limit is the efficiency of fuel fired furnaces which is bound to the Chambadal–Novikov efficiency and therefore explains quite strict limits of the efficiency η_{∞} according to the adiabatic combustion temperature.

In the lecture these limits and options are explained and the background, needed to understand and "bypass" (as far as possible) these limits is provided. Explicitly, based on soda-reduced and soda-free glass concepts for the container- and float industry it will be explained how certain glass parameters, such as electrical conductivity, crystallisation tendency, viscosity and other parameters inevitably effect the melting approach that can be taken to a more sustainable glass production. Here as mentioned above, the chemical composition *directly* determines the electrical conductivity at given temperatures. If, for sustainability reasons, soda is strongly reduced and with that the sodium content in the glass, it directly leads to consequences in the electrical heating of such a glass, especially in sections with colder temperatures, as e.g. the forehearth. In addition, alternatives to conventional soda-lime-silica mass glass compositions for e.g. container- and float-glass, such as Lion®-glass and the soda ash free ZeroCO₂Glas, are discussed. These compositions focus on CO₂-reduction and avoidance and are an integral part of a fully CO₂-free glass production. This again bridges to the other part of the game, namely and as mentioned above that a fully CO₂-free glass production can only be achieved if either hydrogen combustion or electrical melting (hybrid concepts of the two) substitutes also fossil fuels.

*Speaker

Bridging Today and Tomorrow: Industrial Furnace Design in Transition

Malte Sander * ¹

¹ Glass Service – Germany

The glass industry is navigating a period of profound change, driven by rising operational costs and increasingly stringent environmental regulations. While renewable electricity may appear to be the ideal primary energy source, its fluctuating availability presents a significant challenge. With limited large-scale energy storage in today's power grids, fossil-fuel-based base-load generators remain essential to ensure grid stability.

As solar and wind power continue to expand in the coming years, the industry faces a crucial question: how can glass manufacturers make the most of renewable energy while reducing their dependence on fossil fuels? New strategies and technologies will be needed to align production processes with the realities of renewable energy supply.

This paper explores the growing influence of renewable energy on the glass industry and examines practical solutions to support a more sustainable and resilient future.

*Speaker

NextGen hybrid furnace – Operational experience

Joris Goossens * ¹

¹ Ardagh – Germany

NextGen hybrid furnace – Operational experience Joris Goossens, Ardagh (Germany)

*Speaker

Prospects and limits for heavily boosted hybrid furnaces

Reinhard Conradt * ¹

¹ uniglassAC GmbH – Germany

The long-term future technology of industrial glass manufacturing is likely to be all-electric melting and/or the use of carbon-free fuels. Among different approaches, hybrid furnaces using fuel in combination with very high boosting levels are a promising concept. As an advantage, the concept can be applied – at least to a certain extent – to existing installations, thus supporting the transition towards a reduced CO₂ footprint on a wide scale. The lecture addresses, *part pro toto*, two typical challenges encountered with hybrid furnaces, i.e. (1) the changed boundary conditions for heat transfer between combustion space and melting space, and (2) the issue of crown refractory corrosion.

*Speaker

Decarbonisation pathways for a sustainable glass-ceramic melting tank

Emmanuel Lecomte * ¹

¹ Eurokera – Research and Development – France

Eurokera is producing cooking surfaces made of LiO₂-Al₂O₃-SiO₂ (LAS) glass ceramic. A general overview of the product offer and recent products evolutions will be provided in the introduction.

The decarbonization pathways of glass melting tanks are structured around 3 key technological and operational levers. These levers represent the practical actions and innovations that, combined, define strategic pathways to achieving decarbonisation. They will be implemented in chronological order:

- Circularity - maximize use of cullet
- Process optimization
- Hybrid glass ceramic melting tank with a new design combining high electrification rate and fuel switch

Process optimization will be highlighted through the increase of electrical boosting allowing electric energy part increase up to 40%.

Technology evolutions investigated to design a hybrid glass ceramic melting tank will be reviewed

*Speaker

Digital Twin of Glass Melting Furnaces: Architecture and Use Cases

Gökçe Yüce * ¹

¹ ŞİŞECAM – Turkey

Digital twins are emerging as a transformative technology for improving the performance, reliability and sustainability of glass melting furnaces. Growing pressure on energy efficiency, product quality, and furnace lifetime creates an urgent need for tools that provide deeper process insight than conventional monitoring and simulation approaches can offer. By combining real-time operational data with high-fidelity physical and data-driven models, digital twins enable a dynamic representation of furnace behavior that can support both day-to-day decisions and long-term strategic planning.

This work presents a comprehensive framework for developing and deploying digital twins tailored to the specific characteristics of glass melting furnaces. The study begins with an overview of furnace types, key physical and chemical phenomena and the critical performance indicators that shape design and operational priorities. Building on this foundation, the concept of a digital twin is contextualized for the glass industry, with emphasis on the distinction between digital models, digital shadows, and fully integrated digital twins. Requirements for achieving industrial grade fidelity - such as virtual sensing, robust data pipelines and hybrid modeling approaches are examined in detail.

A multi-layer architecture is proposed, covering data acquisition, model development, system integration, and user-facing visualization tools. The practical value of the approach is illustrated through a broad range of use cases across engineering, operations, maintenance and management. Examples include furnace design optimization, combustion tuning, melting efficiency improvements, emissions reduction strategies, defect risk estimation, refractory health monitoring and multi-plant benchmarking. A real-world case study highlights the outcomes of an implemented digital twin, demonstrating measurable gains in energy performance, campaign life, operational stability and cost efficiency.

The study concludes with a discussion of challenges such as data reliability, balancing model complexity with usability and ensuring successful user adoption. Future directions including AI-enhanced self-learning twins, closed-loop optimization, autonomous furnace concepts and immersive operator training are also explored. Overall, the work outlines both the current state and the future potential of digital twins as a value-creating technology for the glass industry and a promising area for continued research.

*Speaker

Electric furnace technology and control by AI

Katelyn Kirchner * ¹

¹ CelSian – United States

Buzzwords such as electrification, green energy, and artificial intelligence (AI) increasingly shape discussions about the future of glass production. But what do these concepts mean in practice for glass melting operations? This lecture explores emerging technologies that are already being implemented in industrial furnaces to improve energy efficiency and production. Particular attention is given to electric and hybrid furnace technologies, which differ fundamentally from conventional combustion-based systems in terms of heat transfer mechanisms, furnace design, and operational constraints. In conjunction, we explore digital tools being introduced in the industry, including process optimization software and AI-supported monitoring systems aimed at modernizing furnace control. Together, these developments illustrate how advances in furnace design and digitalization are shaping the next generation of industrial glass melting technologies.

*Speaker



WEDNESDAY

(free afternoon)

How can we maintain an ambitious and resilient decarbonization strategy in such a challenging environment ?

Zakaria Habibi * ¹, Francois Boland ²

¹ AGC – Belgium

² AGC – Belgium

Our strategy centers on the development of a sophisticated and adaptable toolkit of CO2 reduction programs designed to meet the unique needs of AGC's diverse plants across Europe and America. We will describe the architecture of this toolkit, which integrates our deep process knowledge to evaluate the optimal decarbonization pathways for each facility and finally reach our global goal.

Furthermore, we employ statistical tools to model the effects of uncertainties, allowing us to quantify their impact on proposed solutions for each facility.

This analysis enables AGC to prioritize its actions, determine the most crucial elements of our toolkit to deploy, and establish a clear CO2 reduction roadmap to achieve our goal.

This presentation will share the latest updates on this integrated approach to transform our industrial footprint for a sustainable future.

*Speaker

LFCM Melter Design and Testing for HLLW Vitrification in Japan

Hajime Koikegami * ¹

¹ IHI Corporation – Japan

This lecture summarizes the development of glass melter technology for the vitrification of high-level radioactive liquid waste (HLLW) in Japan, focusing on the liquid-fed joule-heated ceramic melter (LFCM) process. Vitrification is a process that immobilizes radioactive waste by incorporating it into glass matrices, making it safer for a long-term storage. In 2013, a major milestone was achieved with the successful completion of active testing at the Vitrification facility in Rokkasho reprocessing plant.

Throughout the development, a wide range of tests were conducted - including engineering-scale, full-scale non-radioactive ("cold") tests, and laboratory-scale radioactive ("hot") tests - to optimize both the melter design and operational procedures. One key challenge addressed was the accumulation of electrically conductive noble metal deposits (such as ruthenium, rhodium, and palladium) on the bottom of the melter, which can jeopardize glass melting operation and equipment reliability. To mitigate these issues, the design improvements of the melter bottom structure and the modifications of operational methods were implemented reflecting recent progress of nuclear and glass industries experiences.

Since 2009, the advanced LFCM development programs have been in progress to further enhance the melter durability and compatibility with noble metals, as well as to increase its processing capacity. As part of this development, a full-scale inactive mock-up advanced melter (K2MOC) was designed, fabricated and installed at the vitrification technology development facility in Rokkasho. Through its test operation from November 2013 to May 2015, we successfully demonstrated the stable performance and reliability of our advanced LFCM system. Based on these results, we are planning to replace the existing melter at the Vitrification facility with the advanced melter in the near future.

*Speaker

Geomelt In Container and In Situ Vitrification Technologies : Feedback and Experience

Cyrille Véronneau * ¹, Christine Lucas - Lamouroux ¹, Brett Campbell ²

¹ Veolia – Veolia Nuclear Solutions France, 556 Chemin de l'islon, 38670 Chasse sur Rhône, France – France

² Veolia (Veolia Nuclear Solutions Federal Services , 295 Bradley Blvd, Richland, WA, 99352, USA) – United States

The GeoMelt vitrification technology was developed in the early 1980s by the Pacific Northwest National Laboratory (PNNL) under the auspices of the U.S. Department of Energy (DOE). Today, Veolia holds the worldwide exclusive rights to this technology. GeoMelt® can be implemented through various configurations, including an in-container system known as GeoMelt In-Container Vitrification (ICV™), as well as in-situ methods such as GeoMelt In-Situ Vitrification (ISV™) and GeoMelt Subsurface Planar Vitrification (SPV™).

All variants of the GeoMelt process operate on the principle of Joule-effect heating. Graphite electrodes are inserted into either the ground or a single-use refractory container. The waste material is combined with glass-forming reagents (if the waste does not inherently contain sufficient glass formers) and melted through the application of an electrical current between the electrodes. Hazardous organic compounds are destroyed via pyrolysis, while most inorganic materials are incorporated into the resulting glass matrix. Off-gases generated during the process are captured and treated in a dedicated gas treatment system. Once the power supply is terminated, the molten mixture cools to form a homogeneous, monolithic glass structure. No pouring is required, and concerns related to refractory corrosion are mitigated, thereby enhancing process reliability and enabling the treatment of a broad spectrum of waste chemistries with high waste loadings. The final waste form is an inert, dense, and mechanically stable glass-like material.

Radionuclides and hazardous metals are chemically bonded within the glass structure, forming robust interactions with the glass network components. Consequently, these contaminants are not leached, even if the glass monolith is fractured or reduced in size.

Since its inception, GeoMelt has been successfully employed to treat over 27,000 tons of contaminated soils and waste materials across multiple countries, including Japan, Australia, and the United States. For specific waste streams with limited disposal pathways, Veolia has undertaken targeted technology advancements to adapt GeoMelt® to the unique requirements of these materials. This development work has been conducted at various scales, ranging from laboratory research to industrial-scale implementations, and encompasses glass formulation studies, equipment optimization, and computational modeling to predict and enhance vitrification performance.

This presentation outlines the fundamental principles of the different GeoMelt processes, discusses their respective advantages and limitations, and provides examples of industrial applications, recent technological advancements, and ongoing research initiatives.

*Speaker

Modeling the thixotropic effect of Platinum-group element in nuclear waste glasses on the cold crucible melter

Beslay Dorian * ¹

¹ CEA / ISEC – Centre de recherche du Commissariat à l’Energie Atomique - CEA Cadarache (Saint Paul-lez-Durance, France) – France

Modeling the thixotropic effect of Platinum-group element in
nuclear waste glasses on the cold crucible melter Dorian Beslay, CEA/ISE (France)

*Speaker



THURSDAY

(Gala Dinner)

Life cycle assessment: The case of cullet use and secondary raw materials

Antonella Sola * 1,2

¹ DISMI, University of Modena and Reggio Emilia – Italy

² EnTech Interdepartmental Centre – Italy

Recycling, presently one of the pillars of the circular economy, is generally recognised as a "green practice" owing to the reduced volume of waste to be disposed of. Recycling diverts waste from landfills and incinerators, thus limiting the emission of harmful substances and greenhouse gases. Meanwhile, recycling reduces reliance on virgin materials, protecting non-renewable natural resources and preserving ecosystems by lessening extraction. Moreover, producing from recycled materials instead of virgin ones often uses less energy. As a result, recycling plays a key role in sustainable waste management practices and is valued as a strategic tool for carbon neutrality especially in hard-to-abate sectors such as the glass-making industry. However, it must be recognised that recycling, like any other industrial process, also implies relevant environmental drawbacks. Collection, transportation, sorting, and reprocessing still consume substantial energy, often from fossil fuels. Secondary materials may also require additional treatments to become usable in industrial streams. Further environmental impacts are associated with the infrastructure and machinery needed for recycling. Recycling may even compromise the quality of the materials produced. Ultimately, the effectiveness of recycling is not as obvious as it may seem.

Life cycle assessment (LCA) holds immense potential as a scientific approach to assessing the environmental footprint of recycling. LCA, which is based on international standards (chiefly ISO 14040 and ISO 14044), makes it possible to quantify the environmental impacts of products and processes across their entire life cycle. Moreover, this methodology accounts for a wide range of environmental indicators, which enables a holistic evaluation of environmental sustainability.

Among industrial sectors, the glass industry is not just a producer but a foundational enabler, providing essential materials for construction, electronics, vehicles, consumer goods, and packaging for food, beverage, and pharmaceuticals. Understanding the environmental impacts associated with glass production and recycling through LCA is crucial for implementing sustainable practices.

After a preliminary description of the basic principles of this methodological tool with reference to some aspects still under discussion in the international scientific community, some case studies focused on the use of cullets and secondary materials will be presented to explore potential recycling-related issues in the glass industry.

*Speaker

Reuse and recycling of glass mosaics in the medieval world

Nadine Schibille * ¹

¹ Institut de Recherches sur les Archéomatériaux – IRAMAT UMR7065, CNRS – France

Wall mosaics were one of the largest, most costly and prestigious forms of art in the Middle Ages. Over 360 wall mosaics survive from the Roman and Byzantine Empires, medieval Europe, as well as the Islamic Caliphates. This is but the minimum number of mosaics and it is unclear what proportion it represents of all mosaics ever created. Glass tesserae therefore present probably the largest body of coloured glass from the Roman and medieval periods and an important source of information. Chemical analyses indicate both the reuse as well as the recycling of mosaic tesserae throughout the first millennium CE. There was stock-piling for future use, and tesserae were used both as cullet or as sources of colourants such as cobalt and antimony that were no longer accessible. What is more, there is evidence that strongly coloured tesserae were used to produce virtually colourless glass, possibly exploiting the oxidising potential of the opacifiers in the tesserae. The amount of re-use and recycling is surprising and this implies that there were even more Roman glass and tesserae than had previously been realised. This presentation will discuss the reuse and recycling of mosaic tesserae in light of changing traditions and their impact on the archaeo-vitreous record of the Middle Ages.

*Speaker

Energy savings associated with the use of cullet

Katelyn Kirchner * ¹

¹ CelSian – United States

Cullet plays a central role in improving the sustainability and efficiency of glass manufacturing. Incorporating cullet into the batch reduces the energy required for melting, lowers greenhouse gas emissions, and can increase furnace productivity. However, maximizing cullet use requires careful control of raw material preparation, contaminant removal, and batch composition to prevent upsets in quality and production. This lecture quantifies the energy savings and operational implications associated with cullet use across furnace types and glass segments. It explores how cullet is currently utilized in industrial production, as well as innovative approaches being developed to further increase recycled content. Discussions will address ongoing research and development efforts related to melting dynamics, including optimization of cullet fraction, particle size distribution, redox mixing, and contamination. Practical examples illustrate both the benefits and operational limitations associated with high-cullet glass production, and highlight what will be required to further increase the use of recycled content.

*Speaker

New Pathways to Reduce the Carbon Footprint of Glass?

Daniel Neuville * ¹, Laurent Cormier ²

¹ Géomatériaux, IPGP-CNRS, USPC – IPGP – France

² IMPMC, Sorbonne University, CNRS, MNHN, IRD, Paris – Sorbonne University – France

Glass is an incredibly versatile material that has been an integral part of daily life for millennia and is poised to play a key role in future advanced carbon-neutral technologies. However, current glass production models are not particularly environmentally friendly, resulting in significant CO₂ emissions. To meet the demands of a carbon-neutral supply chain by the mid-21st century, the challenge for glass lies in developing carbon-neutral raw materials and melting processes.

When it comes to CO₂ emissions and energy consumption, several improvement strategies have already been explored. These include increasing the hydrogen proportion in gas mixtures, using electric furnaces, and incorporating cullet as a raw material in the glass and cement industries. While the use of recycled materials is already widespread and advanced protocols exist for the first two solutions, there remains untapped potential for innovation.

What has yet to be explored is the addition of varying proportions of volcanic lava to glass cullet (up to 50% by weight) to create new glass compositions. This approach could entirely eliminate carbonates—one of the primary sources of CO₂ emissions in the glass industry. Combined with recycled glass, it would significantly reduce the energy consumption of the melting process.

A key challenge in using these natural materials is the thermal working range of the glass, which must remain compatible with its physical and chemical properties. These constraints apply equally to ancient glassmakers (and today's artisans) as well as to industrial-scale production at the tonnage level. Specifically, processes such as assembly, blowing, and tempering are consistent across scales and are limited by the high-temperature working range of glass.

We have developed new glass compositions by blending cullet with varying amounts of volcanic lava. Initial results are promising and could pave the way for producing bottles or other containers.

*Speaker

Investigation of melting and fining/foaming behaviors in E-Glass batches with alternatives raw materials

Gülin Demirok * ¹, Ezgi Sözen ¹, Deniz Gürler ¹, Melih Üstün ¹

¹ Şişecam Science, Technology and Design Center – Turkey

Understanding the melting behavior and foam formation of glass batches is critical when alternative raw materials are introduced into E-glass batch recipes. In this study, the effects of selected alternative raw materials on batch melting characteristics and foaming behavior were systematically investigated.

High-alumina kaolin was evaluated as an alternative to low-alumina kaolin, Al(OH)₃ was used in place of pure alumina, wollastonite was assessed as an alternative CaO source and slag was introduced as a combined CaO, MgO and AlO source. The melting behavior of the modified batches was first examined using the batch free time method to compare melting kinetics and overall melting performance.

In addition, selected alternative raw materials were further analyzed using High Temperature Melting Observation System with Evolved Gas Analysis (HTMOS-EGA), allowing a detailed assessment of melting progression, gas release behavior, and foam formation under simulated real furnace atmospheres. The comparative evaluation provided insight into the influence of each alternative raw material on batch reactions, melting efficiency, and foaming tendency.

Based on the experimental results, the suitability of the investigated alternative raw materials for potential use in E-glass production was assessed, supporting decision-making regarding their applicability in industrial glass manufacturing.

*Speaker

Chemo-structural drivers controlling molybdenum solubility in aluminoborosilicate glasses

Ashutosh Goel ^{*} ¹, Nedgine Joseph ¹, Hrishikesh Kamat ², Rajan Saini ¹, Grégory Tricot ³, Kun Wang ⁴, Randall Youngman ⁵

¹ Rutgers, The State University of New Jersey [New Brunswick] – United States

² James R. Glidewell Dental Ceramics, Inc. – United States

³ LASIR UMR CNRS 8516 – lille – France

⁴ Alfred University – United States

⁵ Corning Incorporated – United States

Borosilicate glasses are widely regarded as benchmark materials for the immobilization of nuclear waste because of their exceptional ability to incorporate a broad spectrum of fission products within their disordered network. However, the solubility of molybdenum oxide (MoO₃) in conventional borosilicate glasses is severely limited (≤ 1 wt.%), which constrains the achievable waste loading. When MoO₃ concentrations exceed this solubility limit, phase separation occurs, leading to the formation of a yellow, poorly durable phase—commonly referred to as *gall*—composed primarily of alkali molybdates (e.g., Na₂MoO₄ and CsMoO₄), along with minor chromate and sulfate species. Consequently, developing glass compositions capable of accommodating substantially higher MoO₃ contents remains a critical challenge in nuclear waste management. Recent studies have demonstrated that systematic optimization of the alkali/alkaline-earth-to-Al₂O₃ ratio enables the design of alkali/alkaline-earth aluminoborosilicate glasses with MoO₃ solubilities approaching ~ 14 wt.%. This presentation will examine the underlying chemo-structural drivers governing MoO₃ solubility in alkali/alkaline-earth aluminoborosilicate glasses engineered across a broad compositional space.

*Speaker

Challenge of the self-healing glass seal for hydrogen fuel cell

Francois O. Mear * ¹

¹ Lille University – Catalysis and Solid State Chemistry Unit – France

Glass and glass-ceramics have shown potential as sealants materials for solid oxide fuel cell (SOFC) and solid oxide electrolysis oxide (SOEC). To achieve these objectives, vitreous seals must meet several requirements such as low hydrogen permeation, physicochemical stability at operating temperature over several thousand hours and a thermal expansion coefficient close to those of interconnectors. The joints can be of two different technologies: compliant or rigid. Both have advantages and disadvantages.

SOFCs are subjected to different thermal cycles, which required that the sealant materials have long term thermal stability and are able to repair the damages due to long term operation. It is reported these damages can be repaired by the flow of glass in the micro-cracks.

In this lecture is presented our work both on formulation of glass seal and on self-healing processing in glassy materials. It will be illustrating with some examples of self-healing involving glasses in the high-temperature sealing of SOFC/SOEC.

*Speaker

Challenge for lightweight glass - Glass strengthening methods

Dominique De Ligny * ¹

¹ Freidrich Alexander Universität Erlangen-Nürnberg – Germany

Weight-lightening of glass leads both on lower consumption of raw materials and less energy is required for the melting. It also significantly lowers transportation cost. However, this mass lost needs to be compensated by an external strengthening to reach the required mechanical properties and crack residence. Different strengthening methods will be presented. First ultrathin glass can be coated, thermal or chemical reinforcement. An alternative solution is to associate to the thin glass an exoskeleton that will be needed to be soldered or attached. In all these cases it is key to observe residual stress in situ in glass. During the last part of the presentation, new development of Raman, Brillouin and optical spectroscopies will be presented to directly estimate the residual stress and the gained mechanical properties.

*Speaker



POSTERS

Assessing Chemical Homogeneity in Glasses Through Statistical Analysis of Spatial Crystal Distributions

María Helena Ramírez Acosta *¹, Lorena Raphael Rodrigues², Edgar David Guarín Castro², Edgar Dutra Zanotto²

¹ BAM Federal Institute for Materials Research and Testing – Germany

² Federal University of São Carlos = Universidade Federal de São Carlos – Brazil

Ensuring chemical homogeneity is critical not only for the fabrication of commercial glasses and glass-ceramics with reliable performance, but also for fundamental studies in glass science, where this property is often a core assumption. Therefore, the development of simple procedures to assess the chemical homogeneity of glasses is of significant interest to the glass community. In this context, we implemented and evaluated, for the first time, a statistical method to determine the microstructural uniformity of partially crystallized glasses using the aggregation index (R), a parameter derived from the Poisson distribution. The R -index quantifies deviations of an observed spatial distribution of objects from a perfectly homogeneous (random) distribution, enabling the identification of clustering or periodic patterns indicative of inhomogeneity. Since crystal nucleation in glasses is strongly influenced by the chemical composition of the parent glasses, particularly the local distribution of constituent elements, the spatial distribution of crystals in derived glass-ceramics can be used as an indirect measure of chemical homogeneity. To test this approach, we conducted a nearest-neighbor statistical analysis of the spatial crystal distribution in partially crystallized $\text{Li}_2\text{Si}_2\text{O}_5$ and $\text{Ba}_5\text{Si}_8\text{O}_{21}$ glasses, using optical micrographs acquired at different magnifications. The resulting R -indices indicate a high degree of homogeneity in the experimental crystal distributions, reflecting a uniform distribution of chemical elements in the parent glasses. These results demonstrate that the R -index is a valuable and easily implemented tool for assessing the chemical homogeneity of internally nucleating glasses.

*Speaker

Chlorine Incorporation in Iron Phosphate and Borate Glasses for Nuclear Waste Immobilization

Yanis Daoud * ^{1,2,3}, Daniel Neuville ², Laurent Cormier ³, Cyrille Véronneau ¹

¹ VEOLIA NUCLEAR SOLUTIONS – VEOLIA NUCLEAR SOLUTIONS FRANCE – France

² Institut de Physique du Globe de Paris – Institut National des Sciences de l'Univers, Institut National de l'Information Géographique et Forestière [IGN], Université de la Réunion, Institut de Physique du Globe de Paris, Centre National de la Recherche Scientifique, Université Paris Cité – France

³ Propriétés des amorphes, liquides et minéraux [IMPMC] – Institut de minéralogie, de physique des matériaux et de cosmochimie – France

Chlorine is a volatile element commonly found in various types of waste, including legacy radioactive waste and waste generated by molten salt reactors. The presence of chlorine in these wastes represents a significant challenge for long-term immobilization, as its vitrification in conventional borosilicate glasses is hindered by the low solubility of chlorine, leading to volatilization losses and potential degradation of the glass matrix.

In this context, iron phosphate glasses have emerged as a promising alternative for nuclear waste immobilization due to their ability to accommodate a wide range of elements and their favorable chemical durability. This study focuses on the mechanisms of chlorine incorporation in P₂O₅ - Al₂O₃ - Fe₂O₃ - X (X = CaO, Na₂O, SrO) and B₂O₃ - Al₂O₃ - Fe₂O₃ - X glass systems.

The effects of the nature of alkali and alkaline-earth elements, synthesis routes, and chlorine precursors were systematically investigated in order to enhance chlorine solubility in the glass matrices. The objective is to identify the key parameters governing chlorine incorporation and retention, thereby contributing to the development of durable glass formulations for the immobilization of chlorine-bearing nuclear wastes.

*Speaker

Expansion of viscosity models for US Hanford site radioactive waste glass melts

Casey Walsh *¹, Jaime George², Pavel Ferkl², Alex Scrimshire¹, Pavel Hrna³, Anthony Bell¹, Robin Smith¹, Paul Bingham¹, Albert Kruger⁴

¹ Sheffield Hallam University – United Kingdom

² Pacific Northwest National Laboratory – United States

³ AttainX – Richland, 99354, United States

⁴ U.S. Department of Energy, Hanford Field Office – Richland, 99354, United States

Glass viscosity is a compositionally dependent property that is critical in many glass processes, especially nuclear waste vitrification. Glass viscosity in nuclear waste vitrification processes must sit between certain limits when inside the melter to ensure an efficient melting process. Although Hanford nuclear waste can be high in alkali content, mixed alkali effects and their combined effect on properties of the vitrified products have received relatively little attention. Additionally, oxides found in nuclear waste that can occur in more than one oxidation state (Bi, Cr, Mn) are often assumed to be in one oxidation state, and if present in a small quantity are often grouped together in an ‘others’ category rather than their contributions being analysed. Several series of alkali aluminoborosilicate glasses with varying contents Bi₂O₃ (0-1 mol%), Cr₂O₃ (0-1.5 mol%), MnO (0-5.75 mol %), Li₂O and Na₂O (0-22 mol%) were made and their viscosities measured across a wide range of temperatures. Results of these measurements will be presented and compared with existing models and literature.

*Speaker

From Waste to Glass: Beneficiation of Biomass Ash and Slag for Sustainable Glass Production

Sabrin Abdus Samad ^{*}, Anthony Bell, Wei Deng ¹, Feroz Kabir ¹, Hywel Jones ¹, Paul Bingham ¹

¹ Sheffield Hallam University – United Kingdom

The global glass industry faces challenges from high energy use, CO emissions, and material competition. In the GIFFT project, biomass gasification ash and slag were investigated as potential alternative raw materials to support further glass decarbonisation. This study evaluates beneficiation routes to improve their suitability for industrial glass production. Ash and slag were characterised by XRF, XRD, and CHNS analysis, showing high carbon (20–30%) and moderate levels of chlorine, sulphur, and heavy-element contents in ash, while slag contained lower impurity levels. Both samples were then subjected to water leaching at 90 °C, 75 °C, 50 °C and room temperatures for 1, 2 and 3 hours, followed by analysis of leachates using ICP-MS, pH and conductivity measurements. XRF and ICP results confirm that the leaching process significantly reduced chlorine and sulphur levels, indicating high solubility and effective removal. The samples were then subjected to combustion, followed by sieving and magnetic separation. TGA-MS analysis validated the removal of carbon to < 1% post combustion process, and XRF analysis confirmed the reduction of iron content after magnetic separation. The sized fractions were incorporated into green soda-lime-silica glass at 5% substitution. XRF and optical analysis showed that beneficiation removed impurities and improved homogeneity. Overall, the approach enables resource-efficient, economically viable use of gasification residues in sustainable glass manufacturing.

*Speaker

From waste to valuable products: vitrification of Air Pollution Control Residues

Giulia Tameni * ¹, Julie Padgett ², Ian Martin ², Paul A. Bingham ¹

¹ Sheffield Hallam University – United Kingdom

² FCC Environment – United Kingdom

Air pollution control residues (APCr) are hazardous wastes (19 10 07* of European Waste Catalogue) generated during the treatment of gaseous emission at energy-from-waste (EfW) facilities handling municipal solid waste. APCr are characterized by elevated concentrations of volatile heavy metals (such as Pb, Zn, Cd, Cr, Cu, Hg) and soluble salts, particularly leachable chloride (i.g. sodium and/or potassium chlorides), as well as trace amounts of organic compound, including dioxins and furans. The production of in the UK APCr is projected to rise from 574000 tonnes in 2022 to 770000 tonnes by 2028 ((i), (ii)). This growth highlights the urgent need for environmentally sustainable disposal and management strategies. Current stabilization strategies primarily focus on landfill disposal rather than on valorisation of the final product. In the valorisation strategy adopted in this study, APC residues originate from different sites are used for glass production, mainly focused on the SiO₂-CaO system. This is achieved by blending the residues with other by-products, such as foundry sands and dolomite, which provide components beneficial for glass formation. Several compositional ratios among the raw materials are systematically investigated, resulting in the production of glasses fully derived from waste materials. The final glasses are characterised by using XRF, XRD, TGA-MS and FT-IR. Further analyses and new glass batches are underway to minimize the volatilisation of components during melting stage.

(i) <https://www.augean.co.uk/wp-content/uploads/2024/02/Brochure-Renewable-Energy-Sector.pdf>

(ii) <https://www.tolvik.com/published-reports/view/uk-energy-from-waste-statistics-2024/>

*Speaker

Structural Effects On The High Temperature Density Of Sodium Borosilicate Glasses Doped with Aluminium

Miu Onaru * ¹, Paul Bingham ¹, Alex Scrimshire ¹, Anthony Bell ¹, Robin Smith ¹, Albert Kruger ²

¹ Sheffield Hallam University – United Kingdom

² U.S. Department of Energy [Washington] – United States

Boron is an essential component in most nuclear waste glasses, since it enhances chemical durability while reducing the thermal expansivity of the final product and reducing melt viscosity (1). Its unique characteristic to transition from trigonal to tetrahedral coordination with increasing temperature governs certain structure-property relationships in borosilicate glass systems (2). However, the effects of boron coordination on the high-temperature density of molten glass remain largely unexplored, despite high temperature density being a key physical parameter affecting glass melt behaviour in melter furnaces (3).

This poster will discuss the motivation for investigating high-temperature density of simplified Hanford nuclear waste glasses, present high temperature density data for simple SiO₂-Al₂O₃-B₂O₃-Na₂O glasses, broadly representative of Hanford nuclear waste glass matrices, with varying Al₂O₃ contents, and the limitations in current high temperature density experiments. The poster will also discuss high-temperature Raman spectroscopy results aimed at investigating how temperature-driven structural changes, particularly boron coordination, influence melt density.

(1) M. I. Ojovan, W. E. Lee, and S. N. Kalmykov, "Immobilisation of Radioactive Wastes in Glass," *An Introduction to Nuclear Waste Immobilisation*, pp. 319–368, Jan. 2019, doi: 10.1016/B978-0-08-102702-8.00019-4.

(2) O. Majerus, L. Cormier, G. Calas, and B. Beuneu, "Temperature-induced boron coordination change in alkali borate glasses and melts," *Phys Rev B*, vol. 67, no. 2, p. 024210, Jan. 2003, doi: 10.1103/PhysRevB.67.024210.

(3) T. Sugawara *et al.*, "High-temperature heat capacity and density of simulated high-level waste glass," *Journal of Nuclear Materials*, vol. 454, no. 1–3, pp. 298–307, Nov. 2014, doi: 10.1016/j.jnucmat.2014.07.055.

Author e-mail: Miu.Onaru@student.shu.ac.uk

*Speaker

Role of Crystal Content and Aggregation in Processing Behavior of HLW Glasses

Tomas Pipota *¹, Mei Hosokawa², Petra Cincibusova¹, Miroslava Vernerova¹, Jaroslav Klouzek¹, Richard Pokorny¹

¹ University of Chemistry and Technology Prague – Czech Republic

² Institute of Science Tokyo – Japan

High-level waste (HLW) glasses with increased crystal contents are of growing interest due to their potential to relax current crystallinity limits and increase waste loading. In this study, the feed-to-glass conversion process was investigated for HLW glass feeds containing 2–4 vol.% crystalline phases (after 72h at 950 °C). A series of feeds was prepared with increasing Fe content in target glass compositions previously processed in the VSL DM100 melter. Two of these compositions were known to cause operational issues, including the formation of rigid, bridging cold caps that disrupted feeding and reduced melting rates.

High-temperature visual observations revealed that primary foam formation and maximum foam volumes were similar across all tested feeds and consistent with typical HLW behaviour. However, pronounced differences were observed during foam collapse. Glasses with higher crystal contents exhibited significantly slower foam decay, with incomplete collapse and persistent bubble entrapment at temperatures up to 1150 °C. Severe effect was observed for the composition with the highest crystal content, which retained a substantial foam volume and visible bubbles in the final melt.

Optical microscopy of quenched glasses showed extensive crystal presence and aggregation, particularly in samples exhibiting delayed foam collapse. While isolated crystals are expected to have a limited effect on melt viscosity, crystal aggregation can strongly influence melt rheology. In addition, crystals were observed to preferentially associate with gas bubbles, promoting the formation of a highly viscous, crystal-rich foam layer at the melt surface. This layer impedes gas percolation, stabilizes foams, and contributes to bubble retention and cold cap rigidity. Subsequent measurements of effective melt viscosity aim to quantify the impact of undissolved crystals and their aggregation, directly affecting glass processing and melter operation.

*Speaker

Vitrification of Radiological Asbestos-Containing Wastes (ACW): A Disposability Toolbox

Hannah Blystra * ¹, Anthony Bell ¹, Wei Deng ¹, James Stevens ², Paul Bingham ¹

¹ Sheffield Hallam University – United Kingdom

² United Kingdom National Nuclear Laboratories – United Kingdom

This project aims to contribute to improvements in the following three key categories. One, exploring reductions in large volumes of the Very Low-Level Wastes (VLLW), Low Level Wastes (LLW) and Intermediate Level Wastes (ILW) further contaminated by asbestos (1). Two, increase the availability of quality research into the management of radiological asbestos-containing wastes (Rad-ACW). Finally, three, assist evaluating alternative immobilisation methods for Rad-ACW with lower environmental impact. Vitrification of Rad-ACW seems a promising answer to all three of these categories, as vitrification creates a leach resistant product while lowering the volume of waste and immobilising radionuclides efficiently (2). This study further meets the needs of these three categories by establishing suitable chemical and morphological simulants for asbestos, allowing safer laboratory-based experiments, and utilizing thermal treatment methods.

Two primary methods were used, method 1 was glass frit plus simulated waste loading melted at 1450°C, and method 2 explored lower temperature melts by using simulated waste plus flux and modifiers. Method 1 included using one of three glass frits (e-glass, soda-lime-silicate (SLS), or Mixture Windscale (MW)) plus one simulated asbestos wastes, and radiological simulant doping at 0%, 1%, and 5% before heating. Method 2 included simulated asbestos wastes plus additives Na₂O, Li₂O, and B₂O₃ in a ratio to each other consistent with that of full lithium MW Frit (3). All materials were also evaluated for their suitability as immobilisation and denaturing hosts through characterisation of their composition-structure-property relationships.

By integrating materials science, process engineering, and regulatory frameworks, this study will aid in addressing critical waste management challenges in the nuclear sector, contributing to a safer, more sustainable approach to ACW management, aligning with industry objectives, enhancing long-term environmental stewardship and developing the foundation of a disposability toolbox.

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*Speaker

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Rheological Modeling of Thixotropy in Noble Metal Enriched Nuclear Glass

Dorian Beslay * ¹, Emilien Sauvage ¹, Sébastien Castel ¹, Sophie Schuller ¹

¹ CEA – Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA) - Marcoule – France

High-level radioactive waste (HLW) is processed by vitrification for long-term deep geological disposal. While the glass matrix can incorporate most radionuclides, platinum group metals (Pd, Rh, Ru) remain insoluble and form platinoid particles (1,2). These particles significantly modify the physical properties of the glass melt, inducing non-Newtonian behavior, specifically shear-thinning and thixotropy (3,4). To date, these complex effects have not been integrated into numerical models of the industrial process. Therefore, the objective of this study is to develop a predictive viscosity model that accounts for these rheological phenomena. To achieve this, a data acquisition campaign was conducted using a high-temperature rotative rheometer in a working temperature comprised between 1050 °C and 1250°C. A specific protocol composed of successive steps at various shear rates was used to record material's response for different initial states in isothermal conditions. The influence of various parameters was explored including temperature and platinoid concentration. These data are the basis for a mathematical modeling stage, where rheological equations were fitted to the experimental results, as described by Moore (5). The developed model describes the viscosity with an average relative error of 20% compared to experimental measurements. For a first approach integrating thixotropy into such a complex system, these results show a strong correlation with the observed behaviors. This work represents a major step forward in simulating the behavior of high-level waste glasses. A subsequent validation step under real scenarios is planned to confirm the model's industrial robustness.

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Optical performance in mechanically improved multicomponent oxide glasses

Ricardo Santos Baltieri ^{*} ¹, Marco Holzer ², Robert Maaß ^{2,3,4}, Andrea S. S. De Camargo ^{2,5}

¹ BAM Federal Institute for Materials Research and Testing – Germany

² BAM Federal Institute for Materials Research and Testing – Germany

³ Department of Materials Engineering, Technical University of Munich – Germany

⁴ Department of Materials Science and Engineering, University of Illinois at Urbana-Champaign – United States

⁵ Otto Schott Institute of Materials Research, Friedrich Schiller University – Jena, Germany

Oxide glasses play a central role in advanced materials, both in cutting-edge research and in widely available commercial technologies. They stand out due to their wide chemical flexibility, stability, and relatively simple fabrication routes, which make them suitable for large-scale and cost-efficient production. Their tunable refractive index and ability to combine high optical quality with chemical durability have already enabled applications ranging from lenses and optical fibers to displays and biomedical devices. Furthermore, as emerging technologies demand improved performance and security, oxide glasses continue to attract interest as materials capable of providing mechanical resistance while preserving desirable optical properties.

Despite their relevance, traditional oxide glass families face important challenges, especially regarding brittleness and the need to expand their functional capabilities without compromising transparency, processability, or stability. Recent research to overcome these limitations has focused on exploring chemically complex compositions to unlock improved optical and mechanical behaviors. By tailoring composition through multiple network-forming oxides, it is possible to enhance structural compactness and charge density, ultimately achieving higher refractive indices, an essential feature for many modern optical design.

In parallel, incorporating trivalent rare-earth dopants enables further optical functionality by means of characteristic electronic transitions suitable for sensing, luminescence, and energy-related applications. Rare-earth-doped oxide glasses have shown improved emission efficiencies when embedded in highly polarizable networks, emphasizing the importance of composition engineering. In this work, we investigate multicomponent oxide glasses containing more than five network-forming oxides, focusing on their mechanical behavior and optical viability. Special attention is given to the incorporation of rare-earth ions such as Sc³⁺, Er³⁺, Yb³⁺, and Eu³⁺ to explore their influence on structural and optical behavior. The motivation is to advance the understanding and development of glass systems that combine enhanced optical performance with mechanical robustness, paving the way for durable, high-index materials suitable for next-generation photonic and sensing applications.

*Speaker

Influence of Melter Operating Conditions on Subsurface and Melt-Line Corrosion of High-Chromium Refractories

Radek Pezl *¹, Jaroslav Klouzek^{2,1}, Miroslava Vernerova^{1,2}, Petra Cincibusova^{1,2}, Pavel Hрма³, Pavel Ferkl⁴, Richard Pokorny^{1,2}

¹ University of Chemistry and Technology Prague – Czech Republic

² Institute of Rock Structure and Mechanics of the Czech Academy of Sciences – Czech Republic

³ AttainX – Richland, 99354, United States

⁴ Pacific Northwest National Laboratory – United States

Monofrax® K-3 high-chromium alumina refractory is the preferred lining material for nuclear waste glass melters due to its high chemical durability. However, melter lifetime is often limited by accelerated corrosion at the melt-line (neck) and subsurface regions during vitrification of nuclear waste and glass making in general.

Corrosion kinetics were studied using static and rotating crucible experiments to simulate forced convection. Subsurface corrosion increased linearly with melt velocity (~10% per mm·s⁻¹), consistent with diffusion-controlled mass transfer. In contrast, melt-line attack showed little dependence on bulk velocity, indicating a different governing mechanism.

At the melt-line interface corrosion is not governed by bulk flow but by local surface phenomena. Marangoni convection, driven by surface tension gradients from dissolving refractory components, generates intense flow patterns within the meniscus. Preliminary surface tension measurements suggest the formation of dynamic gradients directly associated with high-chromium refractory dissolution.

Corrosion behavior was quantified as a function of temperature and glass composition revealing a correlation between melt viscosity and dissolution rate. The measured rates follow Arrhenius behavior, yielding an apparent activation energy consistent with the temperature dependence of viscosity. This indicates that corrosion is primarily governed by viscous-controlled mass transport. Derived diffusion coefficients support diffusion-controlled corrosion modeling, coupled with CFD to optimize melter design and operation.

*Speaker

Impact of Fluorine on Silicate Glass Structure and Diffusivity

John Bussey *¹, Daniel Neuville², John Mccloy³

¹ Washington State University, Institut de physique du globe de Paris – Institut de Physique du Globe de Paris, IPGP, Paris, France – France

² Institut de physique du globe de Paris – Institut de Physique du Globe de Paris, IPGP, Paris, France – France

³ Washington State University – United States

The incorporation of fluorine plays a crucial role in determining the behavior of silicate melts across geologic, industrial, and nuclear waste vitrification systems. In addition, there are several outstanding scientific questions regarding the interconnected structural role and diffusivity of fluorine. The speciation and diffusion of fluorine is underexplored across many glass systems and is also important for transport and crystallization processes. It should be noted that fluorine is of recently renewed focus in Hanford Site vitrification efforts due to new regulation changes regarding the lack of pre-treatment. Fluorine addition to three classes of glasses will be discussed: soda-lime silicate glasses, sodium aluminosilicate glasses, and more complex aluminoborosilicate nuclear waste glasses. The impact of F on glass structure will be explored through F K edge X-ray Absorption Spectroscopy (XAS), ¹⁹F Magic Angle Spinning Nuclear Magnetic Resonance (MAS-NMR), Raman Spectroscopy, and other nuclei MAS-NMR. The importance of Al-F moieties as well as the presence of controversial moieties such as Si-F will also be discussed. The drastic impact of F on diffusivity will be discussed in the context of viscosity measurements, glass transition temperature changes, and crystallization behavior, as well as in relation to the glass structure. The tendency for immiscibility in high fluorine silicate melts will additionally be covered. Finally, the potential to explore diffusivity through temperature-dependent conductivity and NMR measurements will be mentioned.

*Speaker

Investigating the Effect of Sulfur Sources on the Structural Polymerization and Viscosity of Silicate Glass

Sara Aqdim ^{*} ¹, Shashank Prabha-Mohan ², Ioana Nuta ³, Etienne Médard ⁴, Daniel R Neuville ¹

¹ Geomat Lab – Institut de Physique du Globe de Paris, IPGP, Paris, France – France

² Laboratoire Magmas et Volcans – Université Clermont Auvergne, CNRS – France

³ CNRS SIMaP laboratory – Université Grenoble Alpes – France

⁴ Laboratoire Magmas et Volcans – Université Clermont Auvergne, CNRS – France

Understanding sulfur behavior in silicate glasses is a major challenge for both industrial glass production and the stabilization of complex waste forms. While sulfur solubility is often studied, the influence of the chemical nature of the starting precursor on the final physical properties of the glass remains poorly understood. Specifically, the role of the counter-cations introduced with sulfur and their subsequent impact on network connectivity remains a key question for predicting melt behavior.

This study investigates the incorporation of sulfur into a soda-lime silicate glass composition using different precursors: elemental sulfur and sodium sulfate. By systematically adjusting the sulfur loading up to its solubility limit, we evaluate how the choice of the starting reagent influences the final glass structure and its macroscopic response, even when a single oxidation state is achieved in the final glass. Structural characterizations, primarily through Raman spectroscopy, are correlated with low-temperature viscosity measurements and density variations. This approach aims to identify the structural trade-offs between sulfur integration and the availability of network-modifying species.

The results provide new insights into the mechanisms governing melt rheology and network stability. By comparing different sulfur sources, this work clarifies how the chemical path of sulfur incorporation dictates the physical properties of the glass, offering a better understanding of sulfur's role as either a passive dopant or a structural driver in silicate systems.

*Speaker

Iron phosphate-based oxide glasses: promising materials for positive electrodes in Li-ion and Na-ion batteries

Maxime De Araujo * ^{1,2}, Taos Guyot ^{3,4}, Julia Agullo ³, Loïc Simonin ⁴,
Sébastien Martinet ⁴

¹ CEA, DES, ISEC, DPME, Univ Montpellier, Marcoule, France – CEA, DES, ISEC, DPME, Univ Montpellier, Marcoule, France – France

² Université Grenoble Alpes, CEA-Liten, Grenoble, France – Université Grenoble Alpes, CEA-Liten, Grenoble, France – France

³ CEA, DES, ISEC, DPME, SEME, LFCM – CEA Marcoule 30207 Bagnols sur Ceze – France

⁴ CEA, DES, LITEN, DEHT, STB, LM – Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA) - Grenoble – France

The development of new active materials for positive electrodes is a major challenge in order to improve the performance of Li-ion and Na-ion batteries. Currently, commercial positive electrodes are crystalline (LFP, NMC, etc.). However, interesting performances have been reported with vanadium-containing glass positive electrodes, reaching around 1,000 Wh/kg after 10 cycles. The advantage of glass lies in its disordered network, which can incorporate a large quantity of transition metals. The flexibility of the amorphous network induces a theoretically unlimited number of vacant sites for the insertion and deinsertion of alkali ions. So, these two advantages confer a potentially very high specific capacity to glass positive electrodes, as well as a better stability during charge/discharge cycles.

The majority of research focuses on oxide glasses containing vanadium, due to its ability to form a glassy network and its numerous oxidation states. Nevertheless, vanadium is a critical and toxic element, and the literature remains limited on vanadium-free glass positive electrodes.

In our study, we formulate vanadium-free oxide glasses as active material for positive electrodes. These glasses are synthesized by the melt-quenching technique, then characterized via different techniques such as XRD, DTA, SEM-EDS, ICP, SFX, to determine their physicochemical properties. Chronoamperometry and electrochemical impedance analyses are also carried out to study the electronic and ionic conductivity of the bulk glass. The micrometric glass powder is then used as the active material for the positive electrode in coin cells configured for Li-ion and Na-ion systems. The electrochemical performances are evaluated by galvanostatic cycling at different rates, to analyze the electrochemical mechanisms more precisely.

This approach, combining elaboration, characterization and electrochemical tests, is used on different transition metals, alkalis and network formers. The study seeks to establish the relationships between glass composition, structure, and electrochemical performance, in order to identify the most promising systems for amorphous positive electrodes.

A family of glasses with the composition $29A_2O - 29Fe_2O_3 - 42P_2O_5$ (with $A = Li$ or Na) turned out to be interesting, thanks to their promising electrochemical performances and their stability during cycles.

*Speaker

Modeling viscoelastic behaviour of a nonequilibrium glass

Uliana Karaseva * ¹, Alexander Freidin ¹

¹ Institute for Problems in Mechanical Engineering of the Russian Academy of Sciences – Russia

Two processes related to the relaxation of the structure of a glassy material are discussed: the relaxation of the structure to the equilibrium state described with the use of internal variables which evolve to the equilibrium values;

corresponding stress relaxation since the viscosities depend on above variables.

A viscoelastic material is modeled as the Maxwell material consisting of an elastic element and two viscoelastic elements. The viscosities of dashpots in the second and the third Maxwell elements depend on the internal variables which characterize how far the material is from the equilibrium state. It is assumed that the free energy of the first element is a quadratic function of the elastic strain equal to the total strain, while the energies of the second and the third elements are the quadratic forms of elastic strains and the internal variables with cross effect.

The dependencies of the total stress on the total strain and kinetic equations for the internal variables are formulated based on the Clausius-Duhem inequality. The cross-terms in the free energies make additional contributions to the stresses induced by the nonequilibrium structure represented by internal variables and have the meaning of internal stresses. Then the internal variables were specified as fictive temperatures. Finally the derived system of equations for the internal variables and viscous strains was solved to describe the stress relaxation and evolution of the viscosity to the equilibrium value in the case of uniaxial tension.

Two sets of material parameters were chosen for which it was shown that:

The stress relaxation and structure relaxation characteristic times can be the values of the same order. In this case one can observe the direct dependence of the viscosity on stress, i.e. so called nonlinear viscosity;

If the stress relaxation time is much less than structure relaxation time then the influence of stress on viscosity and structure relaxation is noticeable only at short times, while the relaxation of the structure and, thus, the viscosity to equilibrium values continues after stress relaxation.

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*Speaker

Modeling of Calcination in Rotary Kilns for Nuclear Waste Vitrification

Louis Martin *¹, Caroline Michel¹, Alain Ledoux¹, Huynh-Duc Nguyen¹, Loïc Favergeon²

¹ CEA, DES, ISEC, DPME, Univ. Montpellier, Marcoule – CEA – France

² Centre SPIN, Laboratoire Georges Friedel – Ecole Nationale Supérieure des Mines de Saint-Etienne – 158 cours Fauriel 42023 Saint-Etienne, France

High-level radioactive waste (HLW) vitrification relies on a calcination step to convert fission product solutions into a stable oxide powder suitable for glass incorporation. Although widely implemented at the industrial scale, continuous calcination remains a complex process involving strongly coupled chemical reactions, heat transfer, and material flow (1,2).

This work aims to improve the understanding and modeling of calcination in rotary kilns in order to support the simulation and optimization of vitrification processes. The study combines experimental investigations and modeling approaches. Calcination mechanisms are analyzed using differential thermal and thermogravimetric analyses (DTA-TGA), complemented by X-ray diffraction (XRD), scanning electron microscopy (SEM), and infrared spectroscopy (FTIR) (3). A design of experiments is used to identify the main effects and key interactions between fission product and calcination additives such as sucrose (4).

The results reveal distinct thermal domains associated with dehydration, denitration, and high-temperature decomposition, and highlight the chemical species and interactions governing reaction enthalpies, kinetics and mass losses. These findings form the basis for the development of a simplified thermodynamic model, intended to be coupled with material flow and thermal models (5,6).

This approach contributes to a more predictive description of calcination and its impact on downstream glass melting operations.

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Mechanistic Study of Crystallization in Alkali Aluminosilicates: The Role of Ti, Zr, and PO as Nucleating Agents

Mohamed Belaabd * ^{1,2}

¹ Daniel Neuville – Institut de Physique du Globe de Paris, IPGP, Paris, France – neuville@ipgp.fr, France

² Laurent Tapie – Université de Paris – France

Glass-ceramic materials offer a wide range of applications, from military to biomedical fields (Fu et al., 2020). Among them, alkali aluminosilicate glass-ceramics (Li, Na, K) exhibit mechanical properties very similar to those of natural teeth. Since the 1980s, they have been employed as dental restorative materials (Zhang et al., 2023), providing more reliable alternatives to composite resins (Malament et al., 2001).

The aim of this study is to assess the feasibility of developing a multilayer material by co-fritting ternary aluminosilicate glasses (Li, Na, K) and to investigate the physicochemical behavior at the interface after sintering at temperatures close to the glass transition temperature (T_g). The glasses were synthesized with the following compositions: 70 mol% SiO₂, 10 mol% Al₂O₃, and 20 mol% MO (M = Li, Na, K), corresponding to three glass families-LAS (lithium aluminosilicates), NAS (sodium aluminosilicates), and KAS (potassium aluminosilicates). These oxide ratios are comparable to those found in commercial glass-ceramics (Lubauer et al., 2021).

In addition, equivalent base compositions incorporating the nucleating agents ZrO₂, TiO₂, and PO at concentrations of 0.5 mol%, 0.5 mol%, and 1 mol%, respectively, were synthesized and co-fritted to investigate their influence on crystallization behavior. These glasses were subsequently characterized by differential scanning calorimetry (DSC) to determine the glass transition (T_g) and crystallization (T_c) temperatures. Raman spectroscopy was also conducted, and the effects of Ti and Zr were further investigated using X-ray diffraction (XRD).

*Speaker

List of participants

- Agnes German
- Aqdim Sara
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- Berthereau Anne
- Beslay Dorian
- Blystra Hannah
- Boland François
- Bussey John
- Charpentier Thibault
- Cuvelier Pierre Antoine
- Daoud Yanis
- De Araujo Maxime
- De Ligny Dominique
- Demirok Gülin
- Goel Ashutosh
- Goossens Joris
- Hahn Michael
- Karaseva Uliana
- Kirchner Katelyn
- Klouzek Jaroslav
- Koikegami Hajime
- Laplace Annabelle
- Lecomte Emmanuel
- Lindberg Pontus
- Martin Steve

- McCloy John Stuart
- Melscoet Isabelle
- Muijsenberg Erik
- Neuville Daniel
- Onaru Miu
- Papin Sophie
- Pezl Radek
- Pipota Tomas
- Pokorny Richard
- Rodrigues Ana Candida M
- Roos Christian
- Sá Teles Sanches Isabella
- Samad Sabrin Abdus
- Sander Malte
- Sauvage Emilien
- Schibille Nadine
- Schuller Sophie
- Sola Antonella
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