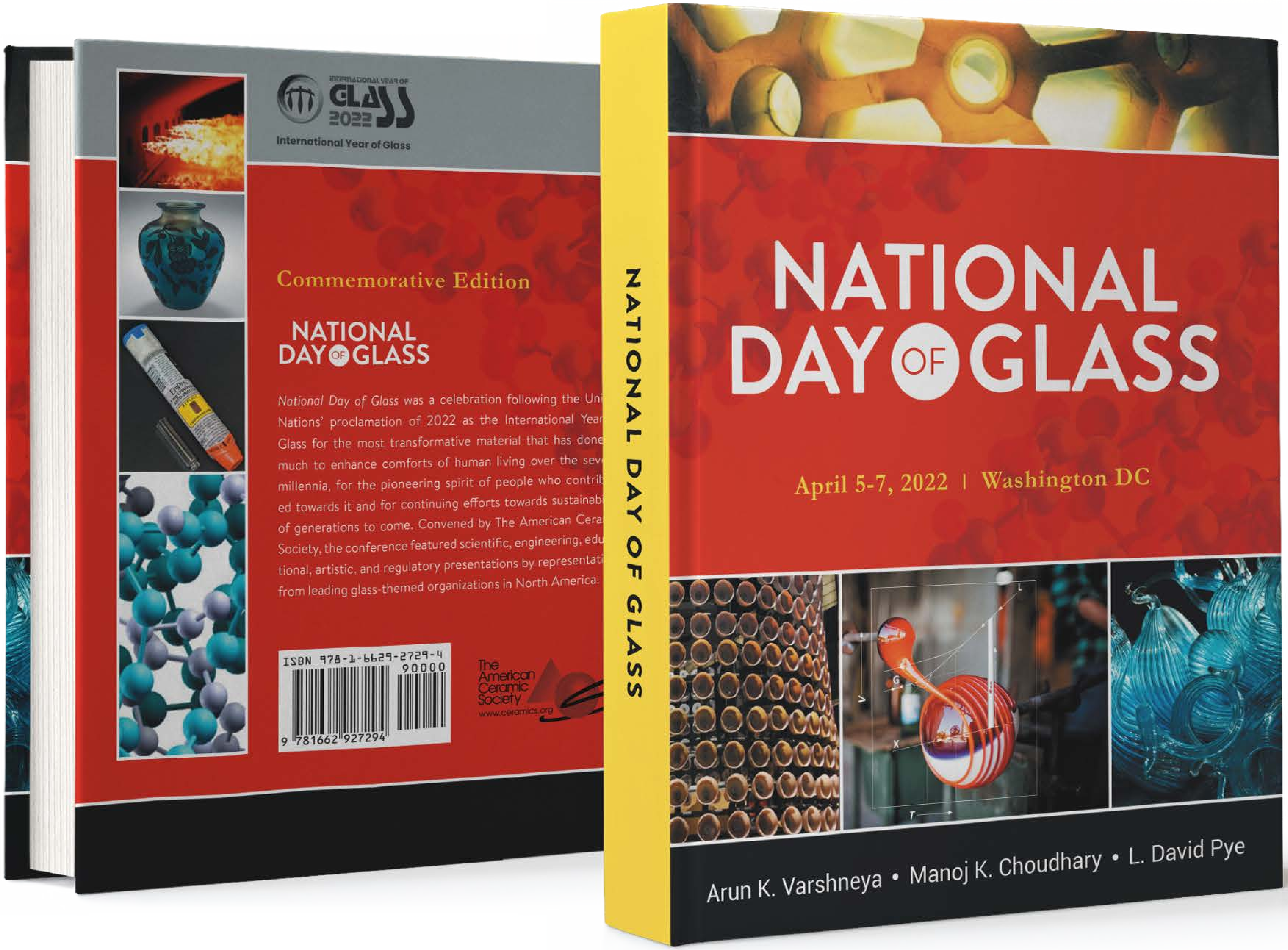
International Year of Glass
Commemorative Edition
NATIONAL DAY OF GLASS
National Day of Glass was a celebration following the Uni
Nations' proclamation of 2022 as the International Year
Glass for the most transformative material that has done
much to enhance comforts of human living over the seve
millennia, for the pioneering spirit of people who contrib
ed towards it and for continuing efforts towards sustainab
of generations to come. Convened by The American Cera
Society, the conference featured scientific, engineering, edu
tional, artistic, and regulatory presentations by representati
from leading glass-themed organizations in North America.
ISBN 978-1-6629-2729-4
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The American Ceramic Society
www.ceramics.org
NATIONAL DAY OF GLASS
NATIONAL DAY OF GLASS
April 5-7, 2022 | Washington DC
Arun K. Varshneya • Manoj K. Choudhary • L. David Pye

NATIONAL DAY OF GLASS

The American Ceramic Society
www.ceramics.org

The American Ceramic Society
Westerville, Ohio

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Westerville, Ohio

National Day of Glass

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Foreword

I want you to know that I have been reading your book National Day of Glass that you gave me in Pittsburgh.

A masterpiece. So much I could say. . .

I love the concise articles up front about various aspects of glass history, art, science and engineering. In my career I have been exposed to bits and pieces and having in one place the articles by the masters is wonderful. I feel I will get a better overall understanding and appreciation and a sense of where we are going in the future.

At the same time, I feel guilty that I did not come to the April meeting in Washington. I was still afraid of COVID. What a pity. It would have been great to hear all the masters and mingle with them. I particularly would have liked to talk to Stephen Koob and Karol Wright at the meeting. I have worked with Koob but never met Karol.

So I was thrilled with this book and cannot put it down. It is a joyful learning experience for me. I now feel that I know the masters better. Thank you so much for inviting me to contribute too.

Then I got to the end: Recent but not Forgotten Memories.
I confess that I was moved to tears as I turned page after page.
I was saddened by so many all-stars that I never got to meet (e.g., Cooper, Irwin, Shand, Roy, Preston, Ernsberger), but gratified that I had known and worked with many others: Haller, Wiederhorn, Evans, Macedo, Cahn, Van Frechette, Davis, Brill, and Hagy. I miss them all.

So, it is quite remarkable that your book elicited such an emotional response from me: joy and sadness.

Congratulations on a job well done.

George D. Quinn
Guest Researcher
National Institute of Standards and Technology

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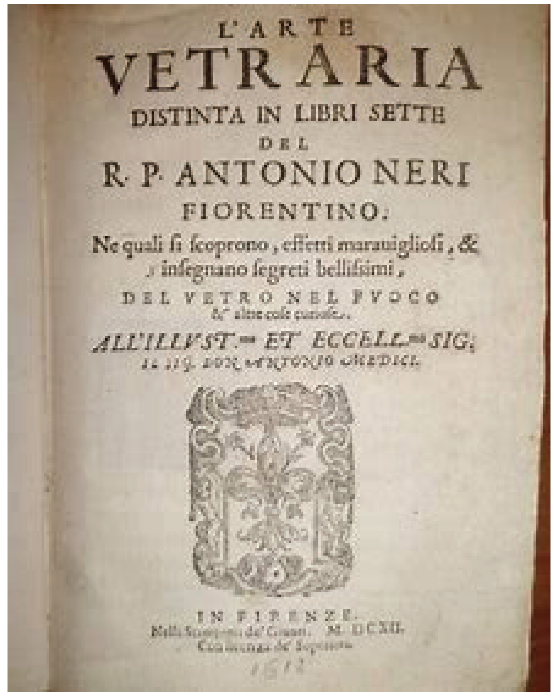
Welcome



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"*The Art of Glass*" by Antonio Neri, published 1612

Section of the Roots of Knowledge Installation by Holdman Studios. Photo courtesy of the Stained Glass Association of America and the Stained Glass Quarterly.

This volume commemorates the opening event that initiated the US celebration of the International Year of Glass (IYOG). The celebration brought together leaders from industry large and small, academia, national laboratories and the many corners of our diverse glass art community. The event reflected on the strong history of glass and its many contributions to the US and global communities, and focused on how innovation and creativity will help solve many of the challenges identified in the United Nations Sustainable Development Goals. Our historic meeting over a few days in Washington DC in early April 2022, allowed our community to define how we will support and contribute to future global opportunities and problems.

Our event resulted from the vision of its original architects, our colleagues at Corning and Prof. L. David Pye who initially conceived the idea of hosting such a 'Year', the Convening committee led by Profs. Kathleen Richardson and Mario Affatigato, our fund raising team including Robert Lipetz, GMIC Executive Director, Manoj Choudhary, past-president of ICG, and Arun Varshneya, Saxon Glass Technologies, and most importantly The American Ceramic Society (ACerS) staff, led by Mark Mecklenborg and Meetings Director, Andrea Ross and her team. Without the seamless efforts of this team, the organization, coordination and little details that made this celebration of our medium of glass, would not have happened.

We extend a huge THANK YOU and appreciation to our many sponsors of the National Day of Glass. This seminal event would not have been possible without their generous contributions. Their continuous support and partnership is truly appreciated as we celebrate the International Year of Glass.

Art Alliance for Contemporary Glass
AdValue Technology LLC
AGC USA
Corning Incorporated

Deltech Inc. and Deltech Kiln and Furnace Design, LLC
The Dow Chemical Co.
Gerresheimer Glass Inc.
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Owens-Illinois
Optica
Optimax Systems Inc.
Rochester Precision Optics
Saxon Glass Technologies, Inc.
SCHOTT AG
Verescence
Xerox Corporation
Past Presidents of The American Ceramic Society

On behalf of the Board of Directors of The American Ceramic Society.

Elizabeth C. Dickey
ACerS President, 2021-2022

Kathleen A. Richardson
Convening Chair, National Day of Glass
ACerS President 2014-2015

APPRECIATION

The recently concluded National Day of Glass (NDG) in Washington, DC was a milestone event in this very special year of 2022 as the global glass community proudly celebrates the United Nations International Year of Glass (IYOG). IYOG is an acknowledgement, the first of its kind for a material, of the transformative role of glass in advancing human civilization and its importance to achieving UN's Sustainability Development Goals. I use this space to thank individuals who played key roles in making IYOG a reality, those who organized the NDG and many others who are involved in organizing numerous celebratory events scheduled during this very special year.

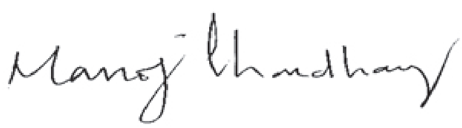
I thank Prof. David Pye and Dr. Charles Craig for their vision of a UN International Year of Glass, Prof. Alicia Duran for her energetic leadership in making that vision a reality, and Prof. John Parker for his contributions to all aspects of IYOG. I thank Profs. Kathleen Richardson and Mario Affatigato, the Convening and Technical Chairs of NDG, for organizing this splendid conference.

Finally, as the Chair of the North American Steering Committee for the International Year of Glass (NAIYOGSC), I extend my grateful appreciation to the members of this committee for their role in the organizing of NDG, and their involvement with a diverse array of celebratory events scheduled in US and Canada during 2022. The committee, constituted following the approved by the UN General Assembly of the IYOG resolution on May 18, 2021, is a forum for communication / coordination / collaboration among key glass constituencies in US and Canada. Listed below are the groups and individuals that constitute NAIYOGSC. The symbol * next to a name indicates ex-officio membership.

- **Art & Museum Coordination Committee –** Ms. Kathy Jordan (**co-Chair** of NAIYOGSC, The American Glass Guild), Dr. Karol Wight (Corning Museum of Glass), Dr. Laurence Sibrack (Art Alliance for Contemporary Glass), Ms. Brandi Clark (Glass Art Society)
- **NDG Coordination Committee** – Dr. Kathleen Richardson (Univ. of Central Florida). Prof. Mario Affatigato* (Coe College), Dr. David Pye* (NY State College of Ceramics at Alfred University)
- **American Ceramic Society (ACerS)** – Mr. Mark Mecklenborg, Ms. Sue LaBute, Ms. Andrea Ross*, Ms. Eileen De Guire*

- **Glass & Optical Materials Division (GOMD)** – Dr. Gang Chen (Ohio University)
- **Glass Manufacturing Industry Council (GMIC)** – Mr. Robert Lipetz
- **Canada IYOG Committee** – Dr. Younès Messadeq (**co-Chair** of NAIYOGSC, Université Laval), Dr. Federico Rosei (Institut national de la recherche scientifique)
- **Finance Subcommittee** – Dr. Arun Varshneya (**Chair** of the subcommittee, Saxon Glass Technologies), Mr. Robert Lipetz (GMIC), Mr. Marcus Fish (Ceramic and Glass Industry Foundation, ACerS)
- **Architectural Glass** – Ms. Urmilla Jokhu-Sowell (National Glass Association)
- **IYOG Council** – Dr. Steve Martin (Iowa State University), Dr. Li Hong* (NEG-USA), Dr. Doris Möncke* (Alfred University)

I am honored to have worked with colleagues mentioned above, in some cases over several years, on matters pertaining to IYOG. As mentioned above, while the NDG is behind us, there are numerous other IYOG events pending in US and Canada for the remainder of 2022. It is with great pleasure that I look forward to working with my colleagues in the Steering Committee on these events and extend my grateful THANKS to them all.



Manoj Choudhary, Sc.D.
Adjunct Professor of Materials Science and Engineering
Department of Materials Science and Engineering
The Ohio State University, Columbus, Ohio
Chair, North American Steering Committee for the International Year of Glass
Member, IYOG Executive Committee
President, International Commission on Glass (2015-2018)

PREFACE

Toward A National Day of Glass Conference
Convened by The American Ceramic Society
In Conjunction with the United Nations International Year of Glass
Washington, DC.
April 5-7, 2022

The road leading to a 2022 National Day of Glass Conference in our nation's capital began in 2014 when it was learned the United Nations had declared 2015 the International Year of Light. Based on this declaration, in 2015 *the International Journal of Applied Glass Science* published special issues titled "Glass and Light." About the same time in recognition of the ubiquitous role of glass in nearly every facet of modern life, a new paradigm emerged in Corning, NY, namely, we have entered the Age of Glass. Turning this page in the history of humankind was supported in part by a concurrent realization that glass is the quintessential nanotech material whose greatest contributions to the quality of life throughout the world are potentially yet to come. Additional support for the arrival of the Age of Glass was found in well received lectures given at various venues by Dr. Manoj Choudhary, President of the International Commission on Glass.

Discussion of these milestones in August, 2018 between Mr. Charles Craig, Sr. Vice President Science & Technology, Corning Incorporated, and Dr. L. David Pye, Dean and Professor of Glass Science, Emeritus, Alfred University, gave rise to the idea of a possible United Nations International Year of Glass. This concept was readily endorsed by Dr. David L. Morse, Executive Vice President and Chief Technology Officer, Corning Incorporated, who enthusiastically agreed to present this potential initiative to the Council of the International Commission on Glass. It was then presented to the respective Boards of Directors of The American Ceramic Society (ACerS), the Glass Art Society, the Stained Glass Association of America, and senior staff of the Corning Museum of Glass including Mr. Stephen Gibbs. In retrospect, this unprecedented outreach was a veritable ringing of a Giant Glass Bell heard around the world.

A major development during this period was acceptance by Dr. Alicia Duran, Research Professor, Institute of Ceramics and Glass, Spanish National Research Council, Madrid, Spain, and incoming President of the International Commission on Glass to serve as the Chair of the International Year of Glass Steering Committee charged with presenting this concept to the United Nations. Rather remarkably, Dr. Duran was a good friend of Mr. Agustin Santos Maraver, the Permanent Representative of Spain to the United Nations, a friendship that proved to be of enormous value in this undertaking. At this same time, Dr. John Parker, Professor Emeritus, the University of Sheffield, United Kingdom, agreed to help in this effort. Thus, an international team including Pye and Gibbs was formed and with the help of many others across the globe, strategies emerged how to seek declaration of a UN Year of Glass and to help plan for the celebration of this capstone year in the professional lives of so many. Following a 3-year worldwide effort and despite myriad challenges caused by overlap with the outbreak of the COVID-19 Pandemic, on May 18th, 2021 resolution A/75/L.84 was passed by the General Assembly of the United Nations declaring 2022 The International Year of Glass. This resolution was co-sponsored by 20 members of the United Nations, and endorsed by nearly 2000 glass-themed organizations from over 80 countries in 5 continents. These endorsements came from academia, industry, and government as well as museums, glass art studios, libraries, and individuals. This level of support was unprecedented in the history of United Nations declared years and played a critical role in achieving the desired declaration.

To celebrate this Year of Glass, numerous activities are planned in countries throughout the world including an opening conference in Geneva, Switzerland in February; an International Congress on Glass in Berlin, Germany in July; a National Day of Glass Conference in Washington, DC in April; a meeting of the American Glass Guild in Corning, NY in July; and a concluding International Congress in Tokyo, Japan in December. In India school children and young adults were invited by the All India Glass Manufacturing Federation (AIGMF) to submit photographs themed on "*Glass in our Lives*" as a competition. Photographs out of 7000 entries are being displayed as a touring exhibition.

To coordinate these and other International Year of Glass celebrations in North America, a steering committee chaired by Dr. Choudhary was established. This Committee was charged with hosting the planned National Day of Glass. Of exceptional importance in this undertaking, Dr. Kathleen Richardson, Pegasus Professor of Optics and Materials Science and Engineering at CREOL/College of Optics and Photonics, University of Central Florida, agreed to serve as Chair of the Convening Committee and was joined by Co-chair Dr. Mario Affatigato, the Fran Allison and Francis Halpin Professor of Physics, Coe College, and Editor of the *International Journal of Applied Glass Science*.

Due to the great interest in celebrating a National Day of Glass with the intended goal of including glass science, art, and engineering, it became increasingly clear to Co-chairs Richardson and Affatigato that the celebration was better characterized and planned as a National Day of Glass Conference with an inaugural evening reception at the National

Academy of Engineering to be organized by The ACerS. The expansion in thought and planning allowed scheduling of several panel discussions and presentations at the conference banquet by internationally renowned glass artists. Choosing the date for this seminal gathering was made with a co-aim of coinciding with the annual Cherry Blossom Festival in Washington, DC.

With these strategies in place, Dr. Arun Varshneya, Professor of Glass Science, Emeritus, Alfred University and president, Saxon Glass Technologies, Inc, Alfred NY, agreed to lead a remarkably successful effort to raise required financial support for this Conference. A listing of those giving monetary and other support is found in the Welcome by ACerS President, Dr. Elizabeth Dickey, Teddy & Wilton Hawkins Distinguished Professor and Head of the Department of Materials Science and Engineering at Carnegie Mellon University, and Dr. Richardson. Dr. Varshneya also agreed to serve as the Lead Editor of this Commemorative Edition which records for history the origin of the United Nations International Year of Glass and the subsequent *National Day of Glass Conference* convened in Washington, DC, April 5-7, 2022.

This Commemorative Edition focuses on North America. Authorship has been limited to citizens or residents of North America. Brief but authoritative updates on glass science, engineering and art and condensed versions of PowerPoint presentations are included. We pay special homage to those giants of glass science, technology and art whose shoulders we stand on and those whose memories are not yet forgotten. As a special mark of celebration, we have also included one-page reflections written by several professionals of North America who have contributed immensely to the benefit of the human race at large. Readers may enjoy their "self-assessment", their passion, their journey, and what would they wish to convey to those just beginning their careers. Finally, in the interest of historical preservation, a few photos are included that capture the celebratory atmosphere enjoyed by all at this conference.

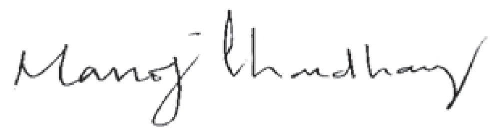
The Editors would like to express their sincere thanks to the Officers, Board of Directors, and the Staff of The American Ceramic Society for their vision, support, and help in organizing *the National Day of Glass Conference* in our nation's capital. In particular, we would like to express our sincere gratitude to Ms. Sue LaBute, Executive Office Manager, for all her hard work in compiling this edition. Thanks are also to Dr. A. N. Sreeram, Senior Vice President and Chief Technology Officer, Dow Chemical Company, Midland MI, Mr. Gary Waller, Americas Corporate President, Gerresheimer Glass Inc, Vineland NJ, Dr. Santokh Badesha, Corporate Fellow and Manager, Open Innovation, Xerox Corp, Rochester NY, Dr. George Sakoske, President and General Manager, Glass Coatings and Concepts LLC,

Monroe OH, and Kajal Varshneya, Chief Operating Officer, Saxon Glass Technologies, Inc. Alfred NY, for their generous contributions that made this historic publication possible.

In a project of this magnitude, it is likely that we missed something, or missed recognizing someone. We apologize to those who we missed inadvertently.

We sincerely hope you will enjoy and participate in the celebration of glass - the most transformative material in history - which has done so much to bring comfort and joy to humankind over the millennia.

Arun K. Varshneya
Professor of Glass Sci. & Eng., Emeritus
Alfred University
President, Saxon Glass Technologies Inc
Alfred NY



Manoj K. Choudhary
Adjunct Prof. of Materials Science
The Ohio State University
Columbus OH

L. David Pye
Dean and Professor of Glass Science, Emeritus
Alfred University, Alfred NY

NATIONAL ACADEMY OF ENGINEERING

On behalf of the National Academy of Engineering, I congratulate all the hard-working glass professionals who have contributed so much to our daily lives. I join you in celebrating 2022 as the International Year of Glass declared by the United Nations.

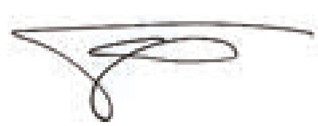
Glass is a quintessential material in thousands of engineered products that have improved comforts of human living over the past several millennia. Glass windows, light bulbs, lenses, and fiber optics for communication are just a few examples of engineered products that have advanced civilization.

The National Academy of Engineering determined in 2003 that the number one engineering feat of the 20^{th} century was electrification—which would not have been possible without Edison's light bulb. The engineering of the light bulb is simple yet complex: A tungsten filament is housed in an inexpensive glass bulb hermetically sealed to retain an inert atmosphere that allows the filament to glow and emit light without getting oxidized. The Corning Ribbon Machine that made these bulbs at an incredible speed of around 30/second is itself an engineering marvel, designated by the American Society of Mechanical Engineers as the 10th International Historical Landmark that changed history.

Beyond the humble light bulb, automobiles, airplanes, optical fibers, electronics, computers, and myriad other components of modern life all have glass in some form or another as an integral part of their functionality. For example, as engineered materials that contribute to the United Nations' mission of sustainability, glass windows, glass fiber insulation, and glass fiber–reinforced plastics are sure to rank high in the coming years. So are the engineered glass products in health care such as small borosilicate glass vials that contain lifesaving medicines with extended shelf life, chemically strengthened glass cartridges that contain epinephrine in the life-saving EpiPen, bioactive/bioinert glass and glass-ceramic materials for tissue engineering and dental implants, and bioresorbable glass stents.

Engineered glass products are thus indispensable to virtually every aspect of life—for individuals and nations, households and businesses, navigation from the bottom of the ocean to the outer reaches of space—spanning the sciences, engineering, and medicine all over the world. These and other remarkable products will continue to draw young men and women to exciting careers of exploration and development.

Again, congratulations on your amazing feats and for improving everyday life. The Age of Glass is here!



Dr. Alton D. Romig, Jr., NAE
Executive Officer

About the front and the back covers

We have chosen to bring to the reader a collage of a few glass products that have brought improvements in human living. The top photo is that of the first (1934) cast of the 200-inch Mt. Palomar mirror substrate disk supervised by George V. McCauley, now housed at the Corning Museum of Glass. The 20-ton cast was made of Pyrex® type sodium borosilicate glass. It cracked in a few places during cooling. Viewers can feel the ethereal beauty, the glass science, the glass technology, and the spirit of human endeavor that went into it. A second successful cast is mounted in the Hale Telescope Observatory, Palomar Mountain, California and has been watching the heavens since 1948. To the editors, the cast is an example of glass for the service of mankind at its best.

On the lower right of the front cover is the photo of a Dale Chihuly glass art. [© 2022 Chihuly Studio / Artists Rights Society (ARS), New York]. Again, the expression of beauty through the medium of glass art is at its best. Next to it (middle photo) shows a glass bead being wrapped around another vessel during liquid state transitioning to the solid state by cooling. The underlying science of the cooling behavior is shown in the superimposing line art of the volume vs temperature for a typical glass-forming substance. On the extreme left is the tower of glass-ceramic bakeware in its development stages including transparency, thermal shock resistance, and strength.

On the back cover, at the top left is the interior of a typical gas-fired glass melting tank. The tanks, often 30′ x 60′, can produce as much as 800-1,200 tons of glass each day. The thermal efficiency is increased immensely by firing sequentially between the two sides and allowing the heat of the exhaust gases to be extracted by passing through regenerators on the other side. Photo below is a blue aurene glass with floral design crafted by Frederick Carder between 1913-18 [courtesy, Corning Museum of Glass]. The third photo down is that of a chemically strengthened borosilicate glass cartridge, produced by Saxon Glass Technologies of Alfred NY, to contain epinephrine in the EpiPen autoinjector. The autoinjector is used to avert anaphylaxis shock in case of severe allergies to bee-stings, peanuts, shell foods and other allergens. The strengthening nearly eliminates the glass fracture probability during administration; thus, scores of human lives are saved each year by employing this strengthened glass. Photo on the extreme lower left is that of molecular dynamics simulation of a germanium-selenide glass, a non-oxide glass which is melted in much smaller tonnage than its cousins of the oxide glass family. Nonetheless, its use in a variety of optical, solar energy harvesting and computer devices makes it an invaluable member of the overall glass family. The Reader may also note the same atomic model in shaded form on both the front and back covers.

We hope you will enjoy viewing the cover art to appreciate the awesome beauty of glass, its science, its technology, and our pursuit of utilizing this material to improve comforts of human living and to capture our celebrations of the "National Day of Glass".

Arun K. Varshneya Manoj K. Choudhary L. David Pye
Susan LaBute (associate)

Conference Program

Madison Hotel, 1177 W15th St NW, Washington DC 20005 April 5-7, 2022

FINAL PROGRAM

Tuesday, April 5, 2022		
Welcome Reception	National Academy of Sciences	6 – 8:30 p.m.
Wednesday, April 6, 2022		
Opening Session	Session Chair: Kathleen Richardson, National Day of Glass Chair and University of Central Florida	8 – Noon
Opening Remarks	Kathleen Richardson, National Day of Glass Chair; Manoj Choudhary, North American Steering Committee Chair; Reinhard Conradt, President, International Commission on Glass	8 – 8:15 a.m.
"The Age of Glass - Affirmation and Celebration"	Stephen Eskilson, Eastern Illinois University	8:15 – 8:40 a.m.
"Glass – Vital to our Future"	Wendell Weeks, Chairman and Chief Executive Officer of Corning Inc	8:40 – 9:10 a.m.
"(Inspire + Transform) x Sustain = Glass"	Ludovic Valette, Vice President, Global Technology and Engineering, O-I Glass	9:10 – 9:30 a.m.
"Shaking the Etch-a-Sketch of America's Innovation Ecosystem"	Kelvin Droegemeier, Regents' Professor of Meteorology, Weathernews Chair Emeritus, and Teigen Presidential Professor, University of Oklahoma	9:30 – 9:50 a.m.

"Innovation and Invention: The Importance of Investments in Fundamental Science & Engineering	Sethuraman Panchanathan, Director, National Science Foundation	9:50 – 10:10 a.m.
"How specialty glass is energizing our future; Enabling health, energy, and sustainability"	Matthias Muller, Executive Vice President R&D and New Ventures, SCHOTT AG	10:30 – 10:50 a.m.
"Pilchuck 50 years of International Glass Art Education"	Christopher Taylor, Executive Director, Pilchuck Glass School	10:50 – 11:10 a.m.
"From University Research to Clinical Use- A Biomedical Glass Story"	Richard Brow, Deputy Provost for Academic Excellence and Curators' Distinguished Professor of Ceramic Engineering, Missouri S&T and Steven Jung, Chief Technology Officer, Mo- Sci Corp	11:10 – 11:40 a.m
"Discovering the Glasses of the Future Using Artificial Intelligence"	Mathieu Bauchy, Associate Professor, UCLA	11:40 – Noon
Session II	Session Chair: Harrie Stevens, ret., Corning Incorporated, Alfred Univ.	1:00 – 2:00 p.m.
Panel: Educating and Training the Next Glass Generation Workforce	Moderator: Christine Heckle, Corning Incorporated	
	Adelle Schade, Dean of Pre-college and Summer Programming, Albright College	
	Jacquelyn Fetrow, President, Albright College	

	Himanshu Jain, T.L. Diamond Distinguished Chair Professor of Engineering and Applied Science, and the Director of Institute for Functional Materials and Devices, Lehigh University	
	Judith Schaechter, Adjunct Professor at Tyler School of Art, Temple University, Philadelphia, PA and and Adjunct Professor of Craft at University of the Arts, Philadelphia, PA	
	Anuradha Agarwal, Principal Research Scientist, MIT Materials Research Lab; Leader, MIT-LEAP (Lab for Education and Application Prototypes); & Member, AIM Photonics Academy and MIT 's Initiative for Knowledge and Innovation in Manufacturing (IKIM)	
	Scott Cooper, Glass and Materials Science Group Leader - R&D at Owens-Illinois Corp.	
Session III	Session Chair: L. David Pye, Emeritus Prof. Alfred University	2:00 – 3:00 p.m.
"The United Nations International Year of Glass-2022: A Dream Come True"	Alicia Duran, Chair, International Year of Glass	2:00 – 2:20 p.m.
"American Glass Manufacturing - A Love Letter"	Bob Lipetz, Executive Director, Glass Manufacturing Industry Council	2:20 – 2:40 p.m.
"Glass: An Indispensable Material for a Sustainable World"	Manoj Choudhary, North American Steering Committee Chair	2:40 – 3:00 p.m.

	Session Chair: Jeff Kohli, Director of Glass Research, Corning Incorporated	3:20 – 5:00 p.m.
"Foundational Role of Non-oxide Glass to Enable Electrophotographic Printing and Creation of Xerox Corporation"	Santokh Badesha, Corporate Fellow and Manager of Open Innovation, Xerox Corporation	3:20 – 3:40 p.m.
"Igniting a Fusion Energy Future with Optics and Photonics"	Tammy Ma, Deputy Director, Lawrence Livermore National Lab	3:40 – 4:00 p.m.
"Bending Light with Glass: Images from the Cosmos to the Microbe"	Steve Feller, B.D. Silliman Professor of Physics, Coe College	4:00 – 4:20 p.m.
"The Second Decade of the Materials Genome Initiative"	James Warren, Director of the Materials Genome Program, NIST	4:20 – 4:40 p.m.
"The Art of Glass: Three Millennia of Creativity and Expression"	Karol Wight, Executive Director, The Corning Museum of Glass	4:40 – 5:00 p.m.
Session IV	Session Chair and Panel Moderator: Kathy Jordan, President, American Glass Guild	5:00 – 6:00 p.m.
Panel: Art and Glass in Society		
	Robert Schaut, Scientific Director for Pharmaceutical Packaging, Corning Incorporated	
	Ashutosh Goel, Assistant Professor of Materials Science & Engineering, Rutgers University	
	Natalie Tyler, Glass Artist	

	Megan McElfresh, Executive Director, Stained Glass Association of America	
	Urmilla Johku-Sowell, National Glass Association	
Celebratory Banquet	Theme: Glass Art in our World	7:00 – 10 p.m.
Featured Speakers		
"Sharing the Secrets: From Venice to Stanwood"	Leslie and Dale Chihuly, Groninger Museum, Groningen, Netherlands, 2018	
"Painting with Light: A New Language in Glass, a Collaboration of Science and Art"	Narcissus Quagliata	

Thursday, April 7, 2022		
Session V	Session Chair: Gang Chen, Ohio University and ACerS Glass & Optical Materials Division Chair	8:15 – 9:50 a.m.
"Research for the Glass Age"	John Mauro, Professor and Associate Head for Graduate Education in the Department of Materials Science and Engineering, The Pennsylvania State University	8:15 – 8:30 a.m.
"Breakthrough Technologies"	Stefanie Tompkins, Director, DARPA	8:30 – 8:50 a.m.
"Glass the Ultimate Sequester and Self-Sustaining Product"	Vahid Majidi, Director, Savannah River National Lab	8:50 – 9:10 a.m.
"Glass Window: Past, Present, and Future"	Naoki Sugimoto, Executive Officer and General Manager, Materials Integration Laboratories, AGC, Inc.	9:10 – 9:30 a.m.

"IPS e.max® Glass-ceramic in the Dental Industry and its Potential for the Future"	George Tysowsky, Head of Global Training and Education, Senior Vice President Technology and Professional Relations, Ivoclar Vivodent	9:30 – 9:50 a.m.
Session VI	Session Chair: Gabrielle Gaustad, Dean, Inamori School of Engineering, Alfred University	
"The Role of Fiber Glass for Contribution to SDGs"	Nomura Hiroaki, President, Electric Glass Fiber America LLC, a US-based subsidiary of Nippon Electric Glass (NEG)	10:05 – 10:25 a.m.
"A Rose Is A Rose Is A Rose: What Colorblindness Reveals about Perception"	Donald McPherson, Chief Science Officer, EnChroma	10:25 – 10:45 a.m.
"Upcycling Waste Glass into High Value Planet-saving Materials"	Phillip Galland, CEO, GlassWRX	10:45 – 11:05 a.m.
"Glass and Lasers – A Bright Future"	John Ballato, Professor of Materials Science & Engineering, Clemson University	11:05 – 11:25 a.m.
"Infrared Glass – Transforming Imaging"	Sam Rubin, CEO, LightPath Technologies	11:25 – 11:45 a.m.
"Alfred University and Glass Science and Art"	Mark Zupan, President, Alfred University	11:45 a.m. – 12:05 p.m.
"On the Shoulders of Giants"	Arun Varshneya, President and CEO, Saxon Glass Technologies	12:05 – 12:25 p.m.
Session VII	Session Chair: Doris Moncke, Alfred University	
Panel: Seeing the Future through Glass	Moderator: John Ballato, Professor of Materials Science & Engineering, Clemson University	1:30 – 2:30 p.m.

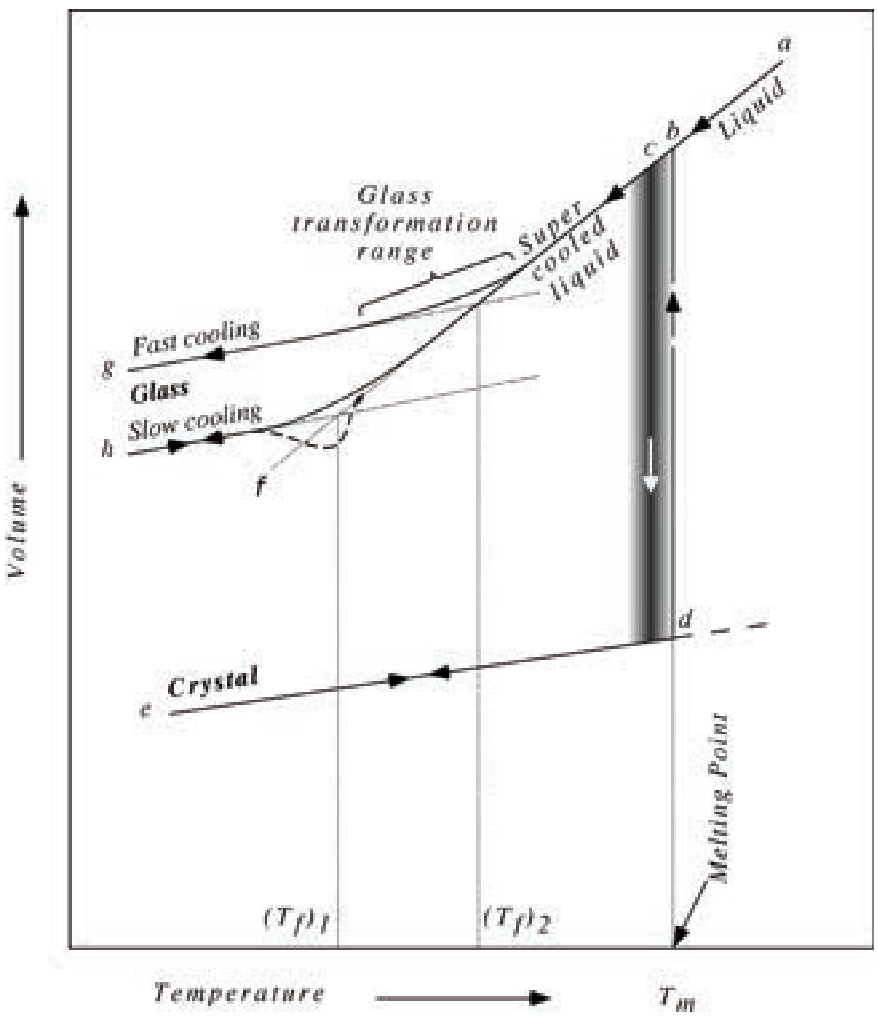
	Jeffrey Kohli, Director of Glass Research, Corning Incorporated	
	Du T. Nguyen, Lawrence Livermore National Lab	
	Collin Wilkinson, Director of Research and Development, GlassWRX	
	Alastair Cormack, Alfred University	
	Event Concludes	

Welcome at National Academy of Sciences, DC

National Day of Glass

April 05, 2022

Glass in the North Americas: Then and Now



The "most fundamental" diagram of glass science: volume-temperature relationship of a glass-forming liquid. *Courtesy: Arun K. Varshneya*

"The Answer"
by Tim Carey 2022

Where can an idea take you?

Alicia Duran
Instituto de Cerámica y Vidrio, Madrid (Spain),
President, International Commission on Glass, Chair, IYoG 2022

John Parker
University of Sheffield, Sheffield UK.
Secretary, Coordinating Technical Committee ICG

We wonder if those early technologists who noticed the small beads of a transparent material created by the heat of their furnaces imagined what could happen next? No doubt it created lively discussions over the fading embers of a wood fire. Some certainly saw the possibilities that transparency, ease of shaping and perhaps later on color could offer: for example, beads and other adornments. After all, their predecessors had already thought of arrow heads and mirrors when chipping away or, even harder, grinding away at lumps of black, shiny obsidian.

What about containers? What extra benefits might transparency offer compared with the clay-based containers that hid their contents? Certainly, the viscous characteristics of reheated glass rods gave the imaginative workers in Egypt the capacity to make hollow ware by trailing molten glass around a clay or dung based former, prized objects containing expensive perfumes for the pharaohs and families in their palaces and beads that could support an international trade around the Mediterranean basin and further afield.

It took a while before metallurgy was able to give the glass makers blow pipes and the potential to create hollow vessels, probably somewhere in what is now Syria. But the Romans imagined so many possibilities and so many ways to add value using this approach: containers, drinking vessels, prizes for the winners of chariot races; storage vessels for the bones of loved ones who had died too soon. Windows let in light and kept out cold drafts but were difficult to make without the unwanted optical distortion arising from non-parallel surfaces. While the Romans began the trend, by the time 3 digit years needed a fourth digit and life was becoming a little less tumultuous, churches, rich manor houses and castles began adopt glass windows in increasing numbers. And indeed, those responsible realized the possibilities of telling stories/passing on messages by adding artistic skills and color into the mix.

The last millennium saw major developments in glass making and imaginative applications of the glass makers art. Lenses extended the working lives of those monks creating illuminated bibles and even allowed the extension of the working day beyond the hours of daylight by focusing candlelight. Lenses led to microscopes and to telescopes, and so to an understanding of the worlds of microbes, the microstructures of rocks and the wonders of the night sky with its orderly stars and wandering planets. Telescopes allowed precise measurement of the orbits of the planets, which in turn stimulated mathematical analysis, and a fresh understanding of astronomy, giving birth to Newton's law of universal gravitation. For the alchemists the desire to create something new required glass distillation equipment so that what was grown in the apothecary's garden could be turned into healing medicines.

Next came Greenhouses and Orangeries where pineapples could be grown in cold climates. In the 19^{th} and 20^{th} century cameras, valves, radio, television, followed. Now optical fibers have taken over from the postman by delivering larger messages ever more quickly anywhere in the world.

So, in 2014, in part because of optical fibers L. David Pye, Past President of 'The International Commission on Glass and The American Ceramic Society, learned that The United Nations General Assembly had declared 2015 an International Year of Light and Light-Based Technologies. As editor of ***The International Journal of Applied Glass Science (IJAGS)*** he realized that it was an opportune moment to showcase "Glass and Light" through a special edition. I wonder if he imagined what would follow?

In 2016 a second special edition developed the idea that we have entered ***The Age of Glass***. David L. Morse and Jeffrey W. Evenson, senior administrators, Corning Inc., eloquently summarized this new thinking in their contribution "***Welcome to the Glass Age***". They argued that we are at a special moment in time where the arrival of ***The Age of Glass*** can be declared by glass scientists, engineers, educators, artists, and glass manufacturers across the globe. I wonder if they imagined what would come next?

Well, heralding the advent of ***The Age of Glass*** would certainly help to bring to the attention of the public at large the critical role glass has in our daily lives. Subsequent lectures by Manoj Choudhary, then ICG President, and David Pye given to international audiences explored the theme that glass science, engineering and art are entering new and profound chapters in their histories.

Prompted by the very positive reactions to the above, David Pye discussed the concept of an International Year of Glass (IYOG) with Charles L. Craig, Senior Vice President, Science and Technology, Corning Inc. He was strongly supportive and encouraged its pursuit. Soon thereafter Profs Choudhary and Pye introduced a motion in September 2018 at a meeting of the Council of the International Commission on Glass in Japan which read:

> ***"The International Commission on Glass, representing organizations and individuals throughout the world dedicated to the promotion of science, technology, artistry, and application of glass enthusiastically endorses the exploration of a future declaration of a Year of Glass by the United Nations."***

Following its positive reception, Prof. Pye presented the concept to the American Ceramic Society and the Corning Museum of Glass (CMoG). Both embraced the idea, the latter leading Steven T. Gibbs, a senior administrator at CMoG, to play a pivotal role in advancing IYOG 2022 to the international art community. Buoyed by this groundswell of enthusiasm, ICG's current President, Alicia Durán, took up the baton to become Chair of an International Steering Committee for the proposed IYOG. The die was cast. Based on the above remarks, a sense of history, and appreciation of a seminal idea whose time has come it is a great honor to chronicle here and affirm the advent of ***The Age of Glass***, and by extension a UN declared International Year of Glass.

We are already a third of the way through 2022. It's just 3 months since the launch in February of the United Nations International Year of Glass in the wonderful Human Rights room of the Palace of Nations in Geneva. To get this far we had to argue our case to the UN. We had to demonstrate to a more sceptical audience that glass is as amazing as we perceive it to be. But we also had to realise that the UN is focussed on its own agenda and in particular its 2030 humanitarian goals. So, our case was written around the possible contributions that glassy materials could make to issues such as climate change, pollution, food production, renewable energies, gender issues, telecommunications, health and so on.

Over a hundred people came to Geneva to hear 30 of the world's most eminent glass speakers talk on how Glass has been at the heart of so many of Society's achievements over recent millennia and how it is poised and ready to support the aspirations of all involved in bringing the United Nations 2030 goals to fruition.

Covid of course limited the size of our live audience; it may even have been the case that a desire to avoid unnecessary air travel was a factor. But, yet again glass in the form of carefully tailored/designed fibres were able to transmit the messages to a much wider international audience, some 4200 from 72 countries joined in the celebrations on the second day and several thousand listened to the recordings in the following week. We were reminded during the conference how carefully designed glass vials had given Society the means of bringing vaccination to us all. We also realised how the rapid development and improvements in face-to-face communications during the pandemic had lessened one negative impact of the pandemic – social isolation - and will bring us all closer together over coming decades without the need to spend too much time travelling and to help reduce our carbon footprints. It's perhaps as close to teleportation as we are likely to get to.

Geneva brought together people from many different parts of the glass community. Academics, architects, historians, museum curators, writers, television personalities, manufacturers, suppliers all sat together and talked, and talked. Indeed after 2 years of social isolation the flood waters of conversation overtopped any imagined barriers. Love for glass was the constant, linking all the attendants.

Following the Opening Ceremony, we have created a worldwide structure that tries in many ways to maintain these thought-provoking conversations, to challenge our preconceptions and to stimulate our imaginations. 18 regional committees covering the whole world meet regularly online. These are supported by a Museums, Art, Archaeology and History group, an Outreach team and an Education group, that work across geographical boundaries.

Our web site (iyog2022.org) has a list of planned Events which grows daily. Anyone can add to this list, although every event is vetted before it goes live. Anyone can search by country or type of event. Of course, this information gathering will also enable reporting back to the UN at the end of the year. And its existence is stimulating ideas across the whole international membership because the glass community is undoubtedly an imaginative one!

Some 90 countries endorsed the initial concept and 19 ambassadors proffered specific support for the application on its journey through the UN. So far around 50 countries have posted their activities. We aim to run a truly international event.

But is this just a flash in the pan? Will people use their imagination to create something with a life beyond the end of the year? We are already planning a reporting session to the UN at the end of the year which will address such questions.

Certainly, the glass industry is working hard to address issues such as a zero-carbon footprint. We are aware of groups that are looking at furnace design, considering the implications of using all electric furnaces, and the possibilities of replacing natural gas by hydrogen. We hope that during 2022 the construction of a furnace designed with a zero-carbon footprint will at least have begun.

Glass as a sustainable material for packaging, in architecture and transport is another area being addressed. Some of the literature stimulated by the IYOG and already in print addresses these issues. So, for example a 200 page highly illustrated book (Welcome to the Glass Age) has been published by CSIC in Spain and is available for download throughout the world. Currently in English, a translation into Spanish will be available by the middle of May and further translations are on the cards. Based on this book and other material we are also putting together posters that will be available in downloadable formats and used to inform a much wider audience.

Another area is education where we are encouraging everyone to use their imaginations. For example, leaflets are being created for a younger audience and several schools are involved in the production of targeted documentation and are participating in competitions based on writing and drawing skills. There have also been competitions for older audiences such as writing the story of the Portland Vase, the original being of Roman origin with images appropriate to the time but with multiple interpretations. Another involved the design of a Stained-Glass window for a UK church.

There are some legacy projects underway too. It has very quickly become apparent how individual towns throughout the world are enormously proud of their glass making histories. Developments include the preservation of ancient landmark buildings, the opening of new museums and the recording of the stories of glass making families. In some cases, streets are being given new names based on such history and one town in Germany is celebrating for the whole of this year its 600 year history. *Towns Twinned by Glass* is a Spanish initiative that connects artisans and ancient glass factories, from Roman to Arab, with current factories and modern glass recycling facilities and circular economy experiences. More than 50 villages are participating, and the list keeps growing. Everyone will receive a town key (made of recycled glass by artisanal processes).

One way of building on such history is to identify the Seven Glass Wonders of the World. This project has just started but is already stimulating a lively debate and will probably begin with valuable local lists that identify important tourist attractions.

Another way of promoting glass in the longer term is to team glass groups with for example gardeners. Glass objects can then be used to improve the presentation of plants at Garden shows. Such events will attract wide audiences and can also be used to promote glass recycling by introducing pre-used glass artefacts.

We are also finding that many more people with interesting stories to tell are making use of the flexibility of live-streaming to an international audience whilst simultaneously lecturing to a live audience. The evidence is that many such groups are seeing a revival/ growth in interest in their activities with new members joining – something that is generally good for our social well-being and will after all stimulate everyone's imagination.

National Day of Glass celebrated in Washington from April 5-7th was a major milestone that brought together scientists with industry champions, artists and educators. Artificial Intelligence (AI) and the upcoming challenges were discussed in depth and new ideas emerged. We are facing the future with new tools and we need to look back by reviewing the unresolved aspects of glass science and technology, looking at them with new eyes. We know that we stand on the shoulders of giants - from Turner to Zachariasen, Morey, Anderson or Mott, Mazurin or Schott. The enormous quantity of accumulated knowledge remains alive, ready to be reanalysed, to be reborn in new forms and new applications for glass.

Last, but not least, we must ask ourselves about the future of glass celebrations. We are in the Year of Glass, which will not end in December if we remember that we have only just begun the Age of Glass. a new age capable of building a more sustainable and just world.

Care and Preservation of Historical Glass

Stephen P. Koob
261 Wall Street, Corning, NY 14830

Introduction

Glass is one of our most recent technologies, with its discovery and use dating back just less than 4,000 years, and preceded by ceramics and metal production. In the United States, it only dates to 1608, with the first glasshouse at Jamestown, Virginia. This first effort was short-lived, and very little glass was made in the United States before 1750.

Utilitarian glass dominated production in America's early years, with the high demand for windows, bottles and tableware. Some luxury glass became collectibles, from candlesticks to candelabras, and were made more popular by names like Tiffany, Carder, and Bakewell. The largest and most significant American development came in 1962, when the Studio glass movement started with two artists, Harvey Littleton and Dominick Labino, who built their own furnace at the Toledo Museum of Art, and completely changed the future of glass artistry. Now, most museums proudly collect and display these modern and contemporary glass art creations, as do private collectors.

Glass composition

Early American glass production followed two major European manufacturers, those from Venice and London. Venice produced what is commonly known as silica-soda-lime glass and London started producing lead glasses in the early to mid-16th century. Early soda lime glasses were very durable and suited the production of flat glass for windows. The substitution of lead for soda produces a softer glass which is more useful for cutting and brilliant display. Both have their pros and cons for long-term preservation.

Deterioration

To most people, glass is a very strong, durable material. However, it has many liabilities in exposure, including archaeological burial, breakage, atmospheric deterioration, and over cleaning, such as by dishwasher-cleaning. One final cause of slow deterioration is outside exposure, to wind, rain, pollution, dust, etc. All of these are worth looking at to decide how best to care for and protect our glass.

Archaeological Burial

Broken or used glass was often thrown away. Discarded glass might be found years or even centuries later, when an old town or city is excavated for new buildings or roads, or as retrieved through archaeological excavation. Many of the finds are old bottles, or broken glasses from saloons or restaurants. They are often found in backyard privies or early toilets that went out of use when modern plumbing was installed. Bottles are a favorite collectible, especially if they have molded lettering such as "elixir" or some pharmacy name, and can often be found simply when digging one's garden or bought from antiques dealers. They usually exhibit an iridescent (rainbow-like) appearance from the burial environment. Alternate seasonal wetting and drying causes the glass to "weather", and layers of deteriorated glass build up on the surface. This is known as "weathering", and is prized for its historical and glittering appearance. Most of these glasses are stable and require little or no special handling or preservation.

Breakage

"Gravity happens."- A simple expression, but one that can be devastating for glass. Glass is a solid, and when it falls to a hard surface it usually breaks. The breaks result in large, and small fragments or include tiny, slivers and bits. As mentioned previously, if glass does break, it is often discarded. Glass art or luxury table items, or even sentimental heirlooms are often saved and repaired. Glass repair is one of the most difficult preservation problems, and requires not only a knowledge of the glass, but an understanding of adhesives suitable for glass and considerable skill to carry out a re-assembly. Only rarely will the damage not be visible, as glass is very unforgiving, and extremely difficult to rejoin. One should never attempt this oneself, as it requires a special laboratory set-up and an experienced glass conservator.

Atmospheric Deterioration

Glass can deteriorate by an unusual phenomenon known as "atmospheric deterioration". Also known as "glass disease", "crizzling", or "weeping"; it primarily occurs in glasses that were produced by a factory which altered the compositions of the glasses. These altered formulations first occurred in Venice and London in the late 16th, early 17th centuries, and were then spread around the world. The primary reasons for changing a glass composition are to improve the clarity or beauty of the glass, or to change its working properties and produce larger quantities faster. Altering the composition destabilizes the glass and makes it extremely sensitive to high humidity. High moisture leaches out some of the critical components of the glass and the glass turns hazy, cloudy, wet, and even slippery. As the deterioration progresses, the glass develops very fine cracks, which are microscopic at first, but then open deeper and deeper. These alterations explain the terms "crizzling" or "glass disease". Common examples are historical tableware such as bottles, decanters, candlesticks, but this phenomenon can also develop on interior windows (in churches) or on the inside of double-glazed windows. There is no cure-all preservation for these glasses. The best that is possible is to slow the process down by keeping the glass relatively dry and in an open space with air movement.

Over-cleaning

Over-cleaning whether by hand or by using a dishwasher causes irreversible damage to a glass. Glass is quite durable, but powdered detergents are abrasive and strongly alkaline, which cause a very harsh chemical attack on glass. Lead glass is even more susceptible, because it is a softer glass. Even "no-scratch" sponges will scratch these glasses. Dishwasher use is the most damaging, because of exposure to immersion in almost boiling water, abrasive and alkaline detergents and steam drying. To prevent this abuse, wash your glasses gently, by hand, using dilute liquid detergent and soft cotton towels.

Outside exposure

Already mentioned is the sensitivity of glass to moisture, but add wind, dust, sand, extreme heat and cold; it is amazing that glass can survive outdoor exposure at all! Glass does hold up to many outdoor abuses, but eventually suffers surface loss, pitting, etching, or breakage. Outdoor sculptures are primarily at risk, as they are often composed of more than just glass, and may include a frame of wood, metal or plastic- that do not survive well outdoors. In northern climates freeze-thaw often causes glass to break where it is closest to the ground. The best recommendation is not to put glass outdoors.

Recycling

Although not mentioned previously, glass has been recycled since antiquity, often re-melted and re-formed into new and more modern shapes. Evidence indicates that broken glass was recycled in Roman and Islamic times, and very likely, earlier as wel.

Conclusions

Glass is a unique and fantastic material that has changed our lives in many ways over only a few thousand years. It is a wonder to observe, use, appreciate as art, and it continually inspires new uses. It deserves our respect, care, best handling practices, and conscientious best preservation skills.

For Additional Reading

Spillman, Jane S. *Glassmaking: America's First Industry*, Corning Museum of Glass, Corning, NY, 1976.

Koob, Stephen P., *Care and Conservation of Glass Objects,* Archetype Books, London, in association with The Corning Museum of Glass, 2006.

Engineered Glass Products in Our Daily Lives and the National Academy of Engineering

Dr. Alton D. Romig, Jr., NAE
Executive Officer, National Academy of Engineering, Washington DC

Introduction

Like bronze and iron over the millennia, glass has contributed foundationally to progress and quality of life for people all over the world. Many of the engineering feats we take for granted as well as those that amaze us require glass.

You can't get through a day without glass in one form or another—from the windows in your home, office, or car to containers for food, drinks, cosmetics, and pharmaceuticals, to electronics screens, home cooktops and oven doors, tabletops, the lightbulbs that brighten our world, and the telescopes that help us see new worlds. In fact, you might be reading this with the assistance of eyeglasses, aptly named because of the use of glass in a curved frame to manipulate light to reach an exact place on your retina that presents a clear image.

This enduring and ubiquitous utility of glass led to the successful pursuit of an international goal supported by some 2000 organizations in 70 countries across 5 continents: the UN declaration of 2022 as the *International Year of Glass*.

Glass has held a meaningful place in our lives since its very early development in about 3500 BCE. But what has made glass the exceptional material it is today are the scientists and engineers who have transformed it into numerous types and forms that allow for a wealth of uses.

The NAE's History of Supporting Glass Science and Engineering

Recognizing the seminal contributions of glass through the ages, the National Academy of Engineering (NAE) was pleased to offer welcoming remarks at the National Day of Glass

Conference held April 5–7 in Washington. Organized by the American Ceramic Society, this US event of the *International Year of Glass* featured topics that aligned well with the NAE's strategic focus on people, systems, and culture. The expert speakers included NAE members—a testament to the fact that pioneers in glass engineering and applications are well represented and active among the Academy's members.

The National Academies of Sciences, Engineering, and Medicine have a strong history of supporting and helping advance glass science and engineering. In fact, the modern era of glass science and engineering was arguably launched in the 1950s in part by the work of the National Academies. In 1957 the National Research Council (NRC)'s Division of Engineering and Industrial Research, which antedated the creation of the NAE, published *Windows and Glass in the Exterior of Buildings*, based on a national conference held in November 1956. Also in 1957 Frederick Seitz, future NRC chair and president of the National Academy of Sciences, asked Alfred University to convene a conference on the "Physics of Non-Crystalline Solids." It was held in 1958, with a keynote address by future Nobel Laureate Hans A. Bethe.

Building on the information shared in those conferences, the 1960s and '70s saw some remarkable discoveries and engineering advances in glass and its applications:

- Development of float glass technology
- Discovery of controlled crystallization of glass
- Discovery of glasses for use in modern xerographic photocopying, solar energy harvesting
- Development of optical glass fibers, which enabled creation of the internet
- Invention of the glass laser
- Strengthening of glass by chemical treatment of glass surfaces
- Incorporation of glass in the practice of modern medicine
- Demonstration of vitrification technology for nuclear waste disposal.

Modern Advances in Glass Science and Engineering

In the decades since then glass products and processes have been pivotal in the development of modern computers, iPhones, life-saving EpiPen autoinjectors, ultrathin flat glass sheets for television sets, advanced medical treatments, lasers for use in the National Ignition Facility program, glass-ceramic dental implants, and much more.

Glass is also critical to defense capabilities, as DARPA Director Stefanie Tompkins explained in her presentation at the Day of Glass conference. It is used in sensors and mirrors for the Space Surveillance Telescope, ballistic glass for transparent armor, and metalenses for information processing, image recognition, and precision optics.

Given the breadth of contributions over the ages, it is no surprise that glass and its associated products—such as ceramics, lasers, and fiber optics—played a key role in 15 of the 20 great engineering achievements identified by former NAE president by Wm. A. Wulf in a fall 2000 NAE *Bridge* article. In addition to the areas mentioned above, these include electrification, radio and television, household appliances, electronics, imaging and medical diagnostics, and nuclear technologies.

What's Next?

Glass has emerged as a transformative nanotech material, giving rise to what some consider the Age of Glass. New possibilities are still emerging and being refined for yet further applications as technologies, questions, and needs become more sophisticated.

In his presentation at the conference, NAE member John Mauro surveyed an impressive variety of areas and applications in which glass is integral. These include next-generation and augmented reality displays, ultra-high-purity glass for ultra-secure quantum communication, acoustic damping, and memory storage. In transportation and architecture, the Internet of Things will use glass processes for greater functionality, autonomous vehicles will rely on glass for displays, and energy-efficient glazing will be even more important as temperatures rise all over the world. In energy generation and storage, advances in fiberglass will improve the efficiency of wind turbines, glasses are integral to photovoltaics and photobioreactors, and they are being explored to enhance the storage density and safety of solid state batteries. In health care, special glasses are used for pharmaceutical packaging, antimicrobial glass surfaces in hospitals reduce the spread of infection, and bioactive glasses are being developed for the repair of heart and other tissues.

Importantly, as Mauro observed, inviting attendees to marvel at a picture of the 900-year-old stained glass windows of Sainte Chapelle in Paris, "it's not just about the science and engineering but, at a deeper level, what it means to be human…. That includes cultural and artistic aspects, and glass has played such a key role in all of them." Glass artist and entrepreneur Dale Chihuly affirmed this observation as he described the vibrant international collaboration and creativity involved in working with glass.

Celebrating 2022 as the International Year of Glass

The historic UN designation recognizes the dynamic and seminal role of glass for people, systems, and culture, and the US event in April commendably celebrated the myriad contributions of glass—past present, and future—in virtually every dimension of life.

The National Academy of Engineering joins in celebrating the *International Year of Glass* in 2022!

Congratulations!

Advances in Glass Forming

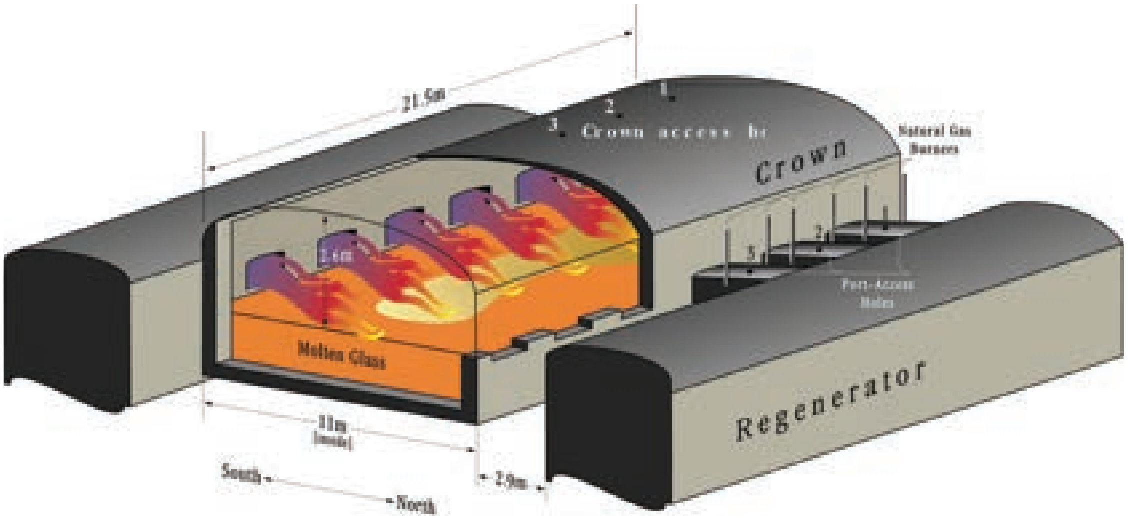
John T. Brown, Corning, NY
Aaron Huber, Johns Manville. Littleton CO 80127

In 1608 the first industrial manufacturing endeavor in the Americas occurred at the Jamestown Virginia colony followed by a second attempt at Jamestown in 1620 with Italian glassblowers; but it too failed. It would then be many years before the next glassworks was established in the Americas (Pittsburgh). The glassworks at Jamestown required large amounts of wood as an energy source to convert the sand, soda ash (burnt seaweed), potash (wood ash) and lime (oyster shells) into molten glass. The National Parks Service reports that a pile of wood as large as a two-story house was required for each small batch of glass produced. (https://www.nps.gov/jame/learn/education/classrooms/glassblowingnarrration.htm)

Many advances in the manufacturing of glass have since been accomplished over the past 400 years as the energy source proceeded from wood to producer gas to fuel oil to natural gas. Oxygen firing and electric melting have been developed in the past 80 years along with advanced controls, instrumentation, and computer modeling. The advances in manufacturing have enabled the use of more challenging glass compositions and development of a wide range of products.

Glass Melting

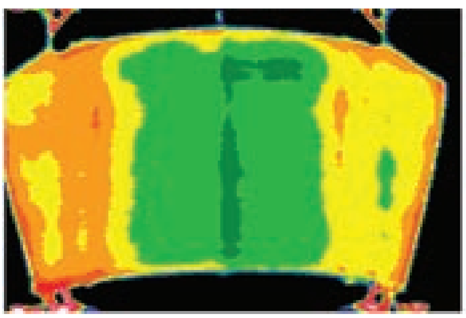
Energy to convert raw materials to glass was a major factor with the majority of energy lost in the exhaust stream. It was not until 1860 that Friedrich Siemens built the world's first successful regenerative glass furnace at Rotherham, Yorkshire. Combined with William and Friedrich Siemens' patent of gas producers (generating gas from solid fuel) and Hans and Friedrich Siemens' invention of the continuous tank furnace, this began the modern era of glass making and reduced the energy to produce glass. Modern regenerative glass furnaces preheat the combustion air to about 2200F (1200C) enabling higher glass temperatures and over 50% reduction in energy. (Michael Cable, Glass Technology European Journal of Glass Science and Technology, volume 54 number 2, April 2013).



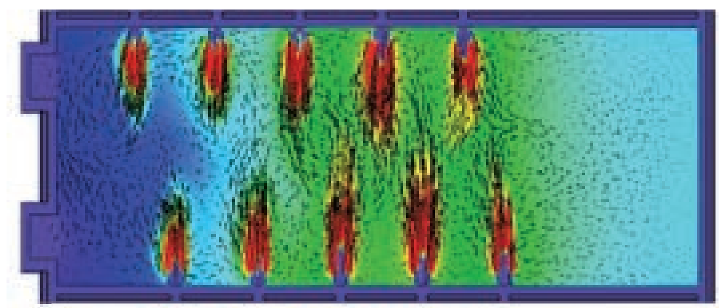
650 ton per day flat glass furnace (A. Huber graphic from 1995 USDOE proposal)

The Siemens regenerative continuous tank furnace was improved over the following 100+ years with much of the major developments occurring in the past 50 years. The lack of investment in glass melting changed with the oil embargo of the mid 1970's as energy efficiency became a major focus. Corning Incorporated was benchmarked by the USDOE to find ways to reduce energy and their 60 regenerative furnaces worldwide, over the next four years, cut energy per ton of good product by half. The Glass Industry shared things that worked, and didn't work, with their competitors through the USDOE. An industry, formerly reluctant to share, became a proponent and valued sharing of information related to energy efficiency--for survival. Multiple furnace energy balances on many furnaces began showing the pattern of energy loss through different sections of the furnace. This changed the repair strategy. Rather than remove the insulation and keep the crown cooled with fan air, it was shown to be a tremendous cost saving to replace the crown and insulation package as the savings were equal to between 6 weeks to 6 months of fuel purchases depending upon the furnace. Better insulation, better refractories such as the electrocast "AZS" (alumina-zirconia-silica), better maintenance of the furnace as well as close tracking of energy to thoughput via linear regression contributed to savings. It became an intertwined relationship between operators, management, suppliers, and the glass industry for the benefit of all.

Contributing to glass manufacturing improvements was the development of instrumentation (sensors) and advanced controls. Implementation of cameras to monitor the batch blanket, bubblers and flames became standard in the 1990's and was extended to ribbon/twill control for flat glass. The workhorse thermocouple was supplemented by infrared sensors to measure glass and process temperatures (glass ribbons, gobs, fiberizers, molds etc. as well as refractory inspections to evaluate life). Development of online stress analyzers and defect detection provided valuable information to operate and improve flat glass operations along with offline applications with containers. Online viscosity and redox sensors have been used with limited success in the harsh molten glass environment. In the 1990's advanced supervisory controls began to be evaluated for glass manufacturing and Model Predictive Control (MPC or MBC) began to be implemented on glass furnaces and forehearths. Advanced controls improved the ability to account for the long delay times in glass furnaces while combining inputs of batch feed rate, energy inputs and thermocouple readouts to adjust process setpoints over the entire process and not just one small temperature zone.



Infrared glass temperature distribution measurement 1998 (A. Huber, A Look at Controls and Sensors, 12th International Seminar on Furnace Design, Czech Republic, 26-27 June 2013)

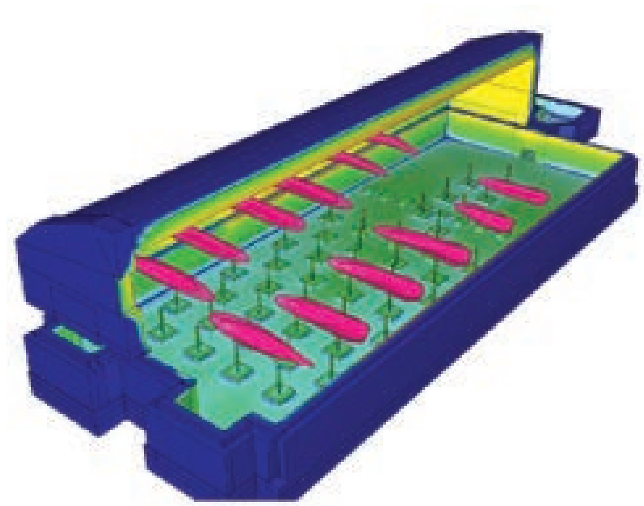


CFD model prediction of temperatures and flows in an oxygen fired glass furnace combustion space (A. Huber et.al., 14th International Seminar on Furnace Design, Czech Republic, 21-22 June 2017)

The development of computer modeling (computational fluid dynamics, CFD) for glass furnaces provided a powerful tool to improve and optimize the glass manufacturing process beginning in the 1980's. It was then possible to predict design changes and the impact of new technology on energy and glass quality along with evaluating the impact of operational changes such as burner profiles and electric boost. An early significant application of CFD glass furnace modeling was the application of oxygen/natural gas combustion to replace air fired combustion systems. CFD modeling was used to predict the impact on the glass, refractory, energy, emissions, glass throughput and optimize burner locations. Computer modeling progressed from "colorful" pictures to a tool that was used before modifications were undertaken. As CFD modeling became mainstream the term "have you modeled it" is commonly heard during discussion of proposed changes.

In the 1980's cost effective oxygen generation resulted in the development of oxygen/natural gas fired burners. Corning was the leader with development and implementation on small specialty glass furnaces through the 1980's with the first larger 110 ton per day fiberglass furnace converted in early 1990 by Johns Manville and a second in 1991. In 1991 Gallo Glass converted a 250 ton per day container furnace and publication of these conversions began rapid implementation by the glass industry. Water-cooled high momentum burners were first used followed by the development of non-cooled low momentum flat flame burners that optimized the heat transfer from the flame to the glass bath. Current state of the art burners use oxygen staging to minimize NOx while creating a larger flame area to radiate to the glass bath for improved energy efficiency while some companies have also adopted crown burners that fire vertically down on the glass bath.

Exhaust stacks of two optical furnaces, one air fired and one oxygen fired. (J. Brown, Corning)



1996 Oxygen fired reinforcement fiber glass furnace with electric boost (permission from Johns Manville)

The left photos above are of the exhaust stacks of two identical optical furnaces in Brazil using propane fuel both at 175 kg per hour fill. One on propane/air and the twin on propane/oxygen. The stack area was reduced to balance furnace pressure between the two furnaces. The air fired furnace stack was 3 inches by 60 inches and the Oxy fired furnace stack was reduced to 1 inch by 12 inches. For this application the reduction in propane fuel was 67% and reduction in exhaust combustion products was 91%. Higher temperature furnaces experienced up to 50% reduction in energy when converted to oxyfuel, but the lower temperature and better insulated container furnaces have less dramatic results with the tremendous value of combustion air preheat from regenerators. The best operating and insulated container furnace only demonstrated a 20% reduction. But the benefits don't end with just energy reduction. The 85+% reduction in combustion gases reduces the velocity of combustion gases over the glass surface, thereby reducing sulfates and particulate carry over.

Another benefit of oxygen firing was increased water content of the atmosphere above the glass. Normal regenerative furnaces experience 14 to 16% water in the atmosphere but oxyfuel is in the 64% range. This quadrupling of the partial pressure of water vapor over the glass doubles the water content of the glass. The total water absorbed is minimal and seems trivial except for research at Brockway where it was reported that a mole of water is 735 times the fluxing power of a mole of soda ash. This allows bubbles to rise faster, also to grow due to the transfusion of water vapor into the bubble increasing its size which increases the rate of rise by the cube of diameter. While better blister (bubble) quality was evident, the furnace could return to the previous blister quality by increasing pull by 20%. Most chose increased pull. All pollutants are reduced, as well as energy and this is accounting for the energy to produce oxygen. Today wide use of preheating of cullet, batch, air, and even more innovative ways are being employed to capture and return the waste heat from the exhaust back to the furnace.

With the high fuel prices in the 1970's, some companies turned to electric melting and electric boosting to decrease fossil fuel usage. Large capacity glass furnaces for float glass and containers or furnaces producing glass compositions not as compatible for electric melting, such as reinforcement fiberglass (E-glass), turned to electric boosting to increase glass throughput and quality without expanding furnace footprints. Electric boosting enabled deeper glass depths and improved designs for throughput and glass quality while also decreasing combustion energy. Much of this added electrical energy was introduced in the rear, where the batch enters the furnace to reduce particulate emissions and heat up the colder newly formed glass.

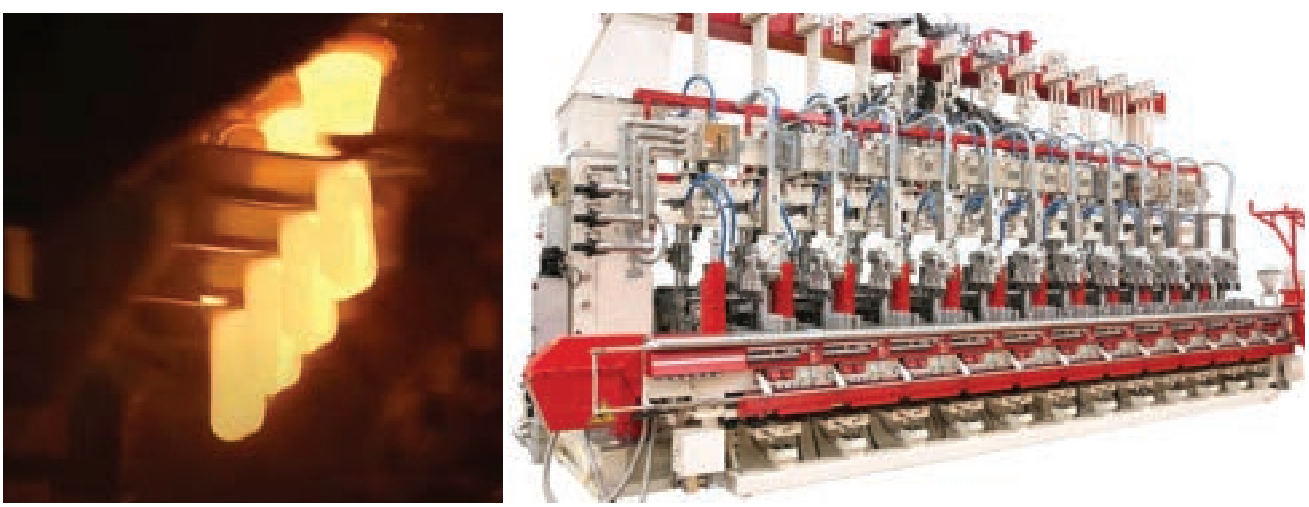
Cold top all-electric melters have the lowest energy use per ton of glass produced by the elimination of combustion exhaust losses and insulation of the glass bath top surface by the batch blanket, but historically in most locations electric costs have been 3 times the cost of natural gas due to the electric generation losses. Currently most all-electric glass melters are in the 100 or less ton per day range but there are several 200+ ton per day that have been in operation for many years. With the desire to decrease carbon emissions more efforts are focused on increasing applications of electric boost and all-electric melters.

Delivery of glass is generally through forehearths. The purpose is to condition the glass so that it is at as near a uniform temperature as possible before delivery to the forming processes. The side walls lose heat, and the chevron pattern of higher velocity flowing glass in the center of the channel contributes to a delta in temperature. Crown redesign, channel shaping and adding small oxy/gas burners has improved temperature uniformity by 30%, or delivery can be increased by 30% with the same delta in temperature across the gob or channel. Many innovations have been employed and more are being developed today but temperature uniformity continues to be a challenge. The energy to maintain molten glass has traditionally been air fired combustion but without cost effective air preheat the energy efficiency is near 20%. Thus, conversion to oxygen/natural gas combustion can result in a 60-65% reduction in natural gas and related carbon emissions with the elimination of the nitrogen in the air. Electric forehearths are also energy efficient and are common with all electric melters. Once glass is delivered to the forming area, the product such as containers, tableware or fibers is formed.

Glass Forming

Hand shops were the only method of making glass until the beginning of the 20^{th} century. Michael Owens developed a machine to manufacture containers in 1903. By 1920, the 30-ton machine made 30-35 bottles per minute. Labor of individual blow pipe forming of bottles with foot activated molds was reduced by 80%. This revolutionized the beverage industry in the US and the world. From milk bottles to beer and spirits to perfume and food products.

The individual sectioned (IS) machine by Henry W. Ingle at Hartford Empire could make a bottle every 11 seconds. With four sections operation with double gob. Triple gob on twin bowls at the end of the forehearth produced 750 bottles a minute for beer and soda pop and currently quadruple gob 12 section IS machines are state of the art.



Quadruple Gob feeding a 12 sections IS machine (BUCHER Emhart glass web site)

In 1937 William J. Woods produced the Corning Ribbon machine in 1937 making 200 bulbs a minute, initially. This was in response to Edison's popular electric light bulb. Imagine the number of glass workers blowing bulbs into molds for these light bulbs. The ribbon machine today can produce 2000 bulbs (glass envelopes) a minute.

Glass fiber insulation was invented by R. Games Slayter in 1932. Fiber glass for insulation was produced by blowing the stream of glass into gossamer thin filaments and packaged for home and building insulation. The original product was nearly abandoned due to the cost of railway transport. By changing the name from Glass to Glasfiber, German spelling for Glass, the railroads negotiated a freight billing rate that was affordable. Currently rotary spinner technology produces almost all the "wool" fiberglass insulation. Fiberglass is also a valuable material for air and water filtration.

Textile fiber glass (E-glass) and its use in Reinforced Fiberglass composites is the material of choice with widespread use in electronics, building materials, automotive, aerospace, and everyday items including boat hulls, shower stalls and windmill blades for electric generation. Windmills use over 6,000 pounds of textile fiber glass plus 6,000 pounds of resin, per blade with the size continuing to increase.

Pyroceram is pressed to form glass that is nucleated and control heated to grow crystals. This product has been used from military to home table ware plus stove to freezer use. It was invented and first used in early 1940's. It is known for its white color but can be produced in limited crystal content as a transparent product sold as Visions ware.

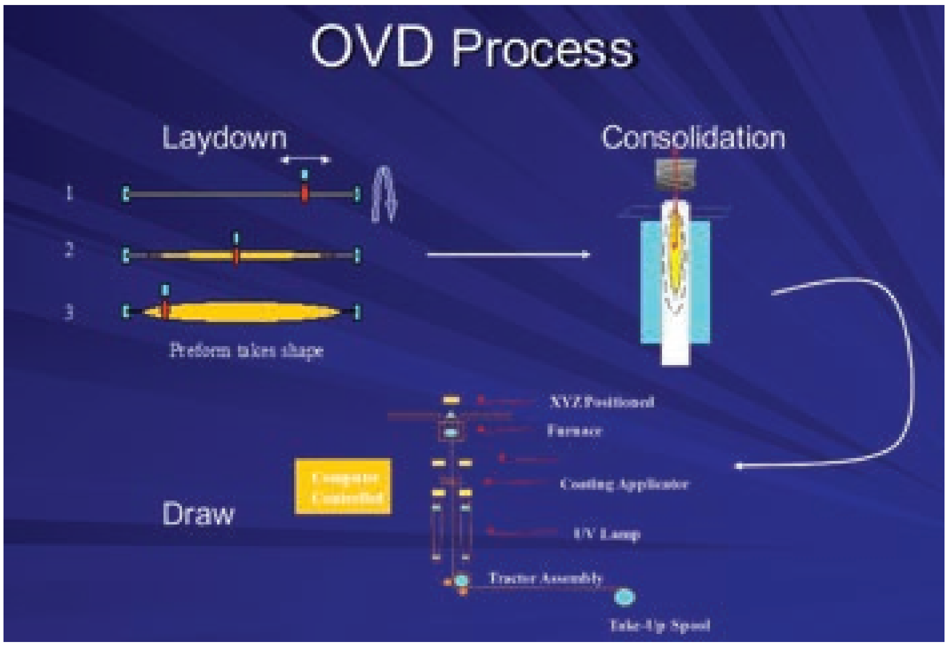
Architectural and automotive glass has had an innovative history of development from gathering by hand and pouring on steel tables followed by machine rolling to thickness then grinding and polishing. Fourcault updraw sheet process was followed by Colburn (LOF) turning the glass 90 degrees, then the PPG Pennvernon updraw with a submerged debiteuse clay block. The LOF machine gathered glass and blew it into enormous cylinders which were cut and allowed to slump into flat shapes. Melting and delivering to water cooled rollers was a method used to produce shower doors and patterned flat glass. Grinding and polishing advanced flat glass manufacture but in the early 60's this processing added another cost of 75 cents a square foot. This was the opportunity that Pilkington bet their future to develop the Float process. This process uses the properties of molten tin to float and allow molten glass to be pulled and stretched into the desired thickness for both auto and architectural uses. Thus, the terms flat, plate and float glass became interchangeable for architectural and automotive glass.

The fusion process (J. Brown, Corning)

Shortly after the success of the Float process, Corning researcher Stuart Dockerty invented the Fusion process where glass flows into a channel and uniformly flows over the sides of the pipe meeting again at the root to form a sheet of glass that is as perfectly flat as can be measured across the entire width of the pipe. It is used for display on computers, flat screen TV's and smart phones. Today, with the weight of auto's a large concern for more efficient use of fuel, the very thin (0.7mm) Gorilla® with added strength properties is being used for auto display and considered for the windshield and sidelights.

Frank Hyde produced glass from very pure chemicals through flame hydrolysis in the late 30's. His silicones were used to insulate the spark plugs on fighter planes in the second world war. Without the insulation the plane's engines would lose power. After the war the fledgling business nearly died, but consumer products saved the company. The creation of silica from chemicals like Silicon tetra chloride or tetra ethyl ortho silicate, TEOS is referred to as flame hydrolysis. Pure silicates allowed the creation of a fiber that could transmit light a distance that made optical communications possible.

Our world is connected by glass fibers, replacing up to 13,000 tons of copper a year formerly produced for telephone communications. We are enjoying the benefits of enormous data flows allowing for Dick Tracey dreamed of video watches. A fiber 125 microns in diameter is drawn from a pristine boule at a cooling rate of 20,000 degrees Centigrade per second in a controlled atmosphere to aid in heat removal. Within seconds this 125-micron fiber is coated with an organic polymer to shield from water and grows to 250 microns. Or 75% of the volume of a fiber is polymer for protection from water, the greatest threat to glass strength. Fiber is produced at the speed of sound today, or in the billions of feet produced each year. Due to the awesome advances in manufacturing, it is less expensive than filament for fishing line. Below is the process from laydown to final product on a spool for delivery.



Applications of Glass in North America

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Glass in the United States was not industrialized until the beginning of the 20th century. Michael Owens of Libbey Glass Company was the first to develop a fully automatic glass bottle making machine in 1903. After improvements, it could produce four bottles per second; as a result, the machine became a huge commercial success. The price of glass containers, particularly beverage containers, decreased drastically relative to the cost of hand-blown bottles. The automatic production of glass bottles eliminated most child labor in glass container operations. By 1912, the bottle-making equipment was used to fabricate the Mason-Ball home canning food jar. The Mason jar made a revolutionary change in safe food storage. Owens' bottle making machine has since been replaced by the more versatile Individual Section "IS" machine invented around 1925 by Henry Ingle of Hartford-Empire Company. Unlike the Owens machine which sucked molten glass from a pool, the IS machine drops a gob of glass through a chute into a mold on one side of the machine section where it is either blown or pressed into a "parison". The parison then swings over to the other side where the bottle is blown in a mold to finishing stage. An IS machine could have as many as twenty sections, each working autonomously but synchronized with the rest.

Around 1912, E. Danner of Libbey Glass Company introduced a continuous glass tube making machine which allowed glass containers to be made inexpensively for pharmaceutical ampoules, vials and cartridges. Pharmacies were permitted to sell medicines at a price that included the price of the glass container, suggesting the relative significance of the glass cost. In the 1920s, Whitall Tatum & Co. marketed an "inexpensive" soda lime silicate glass bottle that was decolorized using MnO2. In the 1930s Kimble Glass Company developed N51A medium expansion sodium borosilicate glass which was more chemically durable for containing medicines and became widely used. Another example of a chemically durable borosilicate glass is Corning Pyrex®, which was sold for laboratory glassware beginning in 1915.

Thomas Edison's goal of an affordable electric bulb was enabled by Corning Glass Works' Ribbon Machine invented by William Woods in 1926. At peak performance, bulbs were made at speeds reaching 30 per second, at costs much less than those made by hand or using semi-automatic machines. The use of an inexpensive soda lime silicate composition also reduced costs. This invention brought affordable lighting to the world. Recently, the use of glass containers for lighting applications has decreased because of the development of lower temperature LED lighting, which is more energy efficient.

Glass fiber insulation developed by Games Slayter in 1930s at Owens Corning Fiber Glass made it possible to reduce the heating costs of homes and businesses. Residential and commercial buildings account for about 40% of energy consumption in the US; about a third of the energy used in buildings is for heating and cooling. In 2020, the total energy consumption in the US was about 93×10^{15} BTU. Heating and cooling of buildings used about 12×10^{15} BTU in 2020. Fiberglass and mineral wool are the two most common choices for insulating homes and play a vital role in saving energy (and hence reducing associated greenhouse gas emissions).

Glass fibers used in insulation are discontinuous. The earliest use of significant amounts of continuous glass fibers was for electrical insulation applications. A new glass composition, known as E-glass ("E" denoting suitability of electrical insulation) was developed by Owens Corning in 1938 to meet this need. Subsequent changes were made in the composition to meet specific needs. In 1935 the first patents for thermosetting polymers appeared. These polymers could be reinforced with glass fibers to make composites and led to the creation of the glass fiber reinforced plastic (GFRP) industry. The first important application of GFRP was for making radomes for aircraft during World War II. E-glass fibers are, by far, the most widely used of all fibrous reinforcements and have applications in numerous sectors including automotive, aerospace, consumer goods, construction, ballistics, wind turbine blades, and marine infrastructure.

The onset of World War 1 cut off the supply of optical glasses from Germany to North American for gunsight scopes and triggered a homegrown industry for optical applications of glass in America. Businesses such as American Optical, Bausch & Lomb and US government laboratories such as the National Bureau of Standards developed well-homogenized and well-annealed glasses in a range of refractive indices and dispersive powers.

The float glass process to make flat glass windows is a British (Pilkington) invention. America, however, is the largest commercial market. Energy efficient glass windows which reflect heat away from the buildings during summer and gas-filled insulating layers that retain inside heat during winter have been developed by the US glass industry. Another advance is "smart" coated windows which use artificial intelligence to adjust their response to the sun while maintaining unobstructed views and eliminate the need for blinds or shades. Electrochromic windows, those coated with WO_2 film, can adjust darkness for privacy settings upon the application of electric potential. Self-cleaning windows, which are based on photocatalytic and hydrophilic behavior of specialized coatings, use sunlight to break down and loosen organic dirt, which can then be washed away by rain. Vehicle windows often have a defogger coating (In_2O_3 doped with SnO_2) which is electrically resistive and generates heat upon application of an electric potential across using coated busbars.

Many different strategies are used to increase the strength and fracture toughness of glass. One method to improve impact resistance is to build a composite material containing a polymer. For example, aircraft cockpit windshields are laminated structures made using two to three plies of chemically strengthened lithium aluminosilicate glass with polyvinyl butyral. These are designed to resist the impact of birds while flying at up to four hundred knots. The containment of the cockpit windshield has greatly enhanced the safety of air travel.

In some applications, a composite material is undesirable. Glass can be strengthened by creating a surface compressive layer, either by thermal tempering or by chemical ion exchange at the glass surface. In thermal tempering, the hot glass is cooled rapidly on the surface so the outside becomes rigid while the inside is still shrinking as it cools. This method is widely used for thick glasses but becomes difficult to apply for thin glasses because heat transferred to the glass interior decreases the thermal gradient needed to develop the stress profile. Chemical ion exchange works by replacement of a smaller ion in the glass structure with a larger ion at the surface of the glass at temperatures too low for significant stress relaxation. The replacement ions are diffused in from the surface of the glass body. An early example of ion-exchange in a commercially-available glass is Chemcor®, which was developed at Corning Glass Works in the 1960s. Ion-exchange was used to strengthen the thin glass display covers for mobile phones introduced commercially as Corning® Gorilla® Glass in 2007. The base glasses used for ion-exchanged display covers are generally alkali aluminosilicate glasses.

A lifesaving technological advancement in the application of glass for pharmaceutical applications came in 1996 when a chemically strengthened borosilicate cartridge was introduced by Saxon Glass Technologies for use in EpiPen® autoinjectors to prevent anaphylaxis shock from severe allergies to peanuts, bee stings, shell foods and the like. The chemical strengthening reduced glass cartridge fracture probability from nearly 10% down to near-zero from the applied jabbing force during the device administration. This helped save thousands of human lives each year around the globe.

The ability to obtain very low coefficients of thermal expansion in glasses such as fused silica (0.52 ppm/K from 5°C to 35°C for Corning HPFS® Standard Grade) and titanium silicate glasses (0 ±30 ppb/°C from 5°C to 35°C for Corning Ultra-low expansion ULE®) opened the door to unique applications that require exceptional resistance to thermal shock, warpage, and strain-induced optical distortion. For example, Corning's low-expansion glasses have been used as windows on the Apollo 11 lunar module, the Space Shuttle, and the International Space Station. One of the early uses of low-expansion glass was for telescopes, including the Stratoscope Telescope, which was flown by balloons and controlled from the ground. More recently, ULE® glass was used as the primary mirror on the Hubble Space telescope and for the Kepler Telescope, which discovered more than 2,600 planets.

These low expansion glasses also have useful optical properties. The high transmission of fused silica from the infrared (IR) to the deep ultraviolet (UV) led to its use as lenses for lithography in semiconductor manufacturing. The ultra-low expansion ULE® glass is used for extreme ultraviolet (EUV) lithography, where the shorter wavelength required to print features at 5 nm necessitates an all-mirror reflective design.

The low expansion glasses are unique in their method of fabrication. Fused silica can be made by a variety of processes, but one of the most interesting methods is by chemical vapor deposition, which enables high purity. The chemical vapor deposition process for fused silica was invented by Dr. James Franklin Hyde at Corning Glass Works in 1934.[1] This is a flame hydrolysis process that produces submicron molten droplets that are collected onto a blank and consolidated. Similar fabrication methods are used for ULE® glass and for optical fiber.

The development of glass-ceramic products by S. Don Stookey of Corning Glass Works expanded the horizon for ceramic applications requiring high strength. Glass products could be made by any of the established technologies and then converted to a highly crystalline ceramic by a suitable heat-treatment which allowed crystals to grow through the bulk of the glass in controlled manner. Kitchenware, missile cones, photochromic eyeglasses (that darkened in bright sunlight reversibly) were some of the key applications.

Another important contribution to modern technology is the optical telecommunication fiber. Glass is a near-ideal material for an optical waveguide application. Though the invention is ascribed to Charles Kao (Nobel Prize 2009); the practical usable technology was developed by Robert Maurer, Donald Keck and Peter Schultz of Corning in 1970. At the time, fiber attenuation losses were ~ 1000 dB/km. The optical transparency had to be increased 1000x to meet the target attenuation of <20 dB/km for being economical. This was achieved by synthesizing graded index, highly pure silica glass by a chemical vapor deposition process. Current attenuation levels of silica-germania glass fibers are as low as ~0.2 dB/km (approximately 95% transmission though 1 km of fiber). Glasses developed for displays also played a critical part in the information revolution.

The use of glass as a solid-state laser host has been an important application in the 20^{th} century. Requirements include high thermal shock resistance and low nonlinear refractive index. Some phosphate glasses can dissolve as much as 6% of Nd lasing ions as opposed to 1 to 3% in Yttrium Aluminum Garnet (YAG) crystals. Glass provides flexibility in dimensions and shape: disks, rods and fibers can be formed readily. The glass lasers can be continuous or pulsed beam and can be used at very high power levels (as much as terawatts) and high energies approaching megajoules.

The semiconducting properties of non-oxide glasses and amorphous solids, those based on group 14, 15 and 16 elements (excluding oxygen) of the periodic table, have also allowed new technologies. Photoconductivity of Se films led to the xerographic process. Photovoltaics are solar cells that convert light into electrical energy. The discovery of conductive state switching in the 1960s by Ovshinsky gave rise to the development of tiny threshold memories and switches which led the miniaturization of computers. Rewriteable CDs and DVDs are common applications of this development. These glasses are also transparent to IR which, in turn, has enabled infrared photography and night vision for military applications. Ge-Sb-Se glasses can be made transparent to the 10.6 mm wavelength of a CO2 laser. This could potentially be used in laser-assisted ablation of cardiovascular plaque to avoid open-heart surgery. The primary issue in achieving high level IR-transparency has been the purity of the glasses prepared. They need to be oxygen-free; as little as a ppm impurity of oxygen can dramatically degrade IR-transparency. Perhaps the advent of deep space melting technologies might help in this effort.

Following the discovery of the “45S5” CaO-SiO2-P2O5- based bioactive glass by L. L. Hench in the late 1960s (called Bioglass®), interest in the development of bioceramics area has exploded. Bone tissue engineering is a promising substitute in place of transplants and grafts. These materials produce 3D scaffolds which encourage regeneration of healthy tissue around the site of an injury. Newer developments in this field improve wound healing. Bioresorbable and bioinert glasses also attract attention. For example, the use of bioresorbable tapes can improve treatment of compound bone fracture by eliminating the need for additional surgery to remove the joining braces.

On the opposite end of the durability spectrum, glasses designed with a high level of corrosion resistance are used as host materials to immobilize toxic elements such as heavy metals, as well as radioactive nuclear waste to protect our precious planet. This effort began after recognition that many of the naturally-formed glasses such as tektites and microtektites discovered under deep ocean beds have remained relatively stable in the environment over millions of years. Extensive research at Pacific Northwest National Laboratory, Savannah River National Laboratory and other sites around the United States and the world has resulted in glasses which can be loaded with significant amounts of high-level waste (HLW) and remain durable. Processes for automated mixing, melting and pouring have been developed to protect plant personnel.

Glass is a transformative material. Douglas Main titled his 2018 article on glass in the Atlantic Monthly (April 7, 2018) "Humankind's Most Important Material" and wrote "Glass's influence doesn't show any signs of waning." Although the focus on the US in this article leaves out the critical contributions from scientists and engineers in other countries, glass research and development is a worldwide effort. The applications listed in the article highlight the versatility of glass, and the important role it plays products that have enriched our lives. We can be sure that glass will continue to play an indispensable role in the future.

Advances in Glass Science

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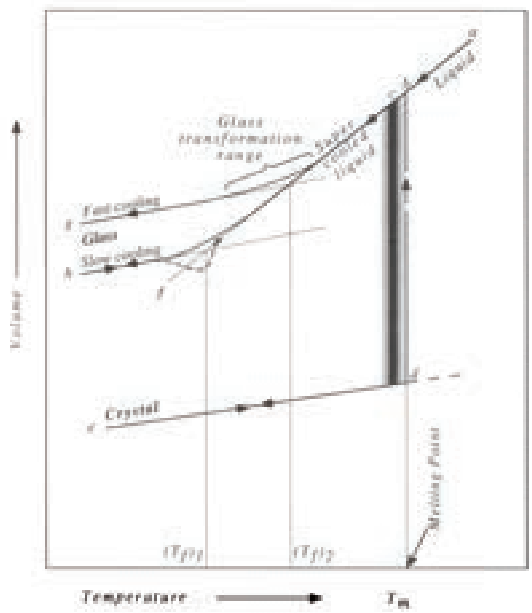
The purpose of this brief contribution is to give an overview of the current state-of-the-art in glass science, but in an intentionally broad and hopefully accessible way. Thus we will not give technical details, but rather, attempt to highlight some of the current concepts and important research areas of the field.



While the crystalline, ordered state of solid matter is (relatively) easy to define, the glassy state is a bit more subtle. That is because there are many more ways for a system to be disordered, than to be ordered. For our purposes, we will consider glass to be an amorphous (that is, disordered) material that exhibits a ***glass transition***. The glass transition is observed as a fairly abrupt change in thermodynamic variables such as volume or heat capacity, in the system as it is heated or cooled through temperatures below its equilibrium melting temperature (see figure). Thus, as a liquid is cooled below its equilibrium crystallization temperature *Tm*, it may in fact remain a liquid, if it is being cooled quickly enough. Then, at a lower temperature, it may undergo a transition to a solid form, while still retaining the amorphous structure of a liquid. This transition is the glass transition, and has several notable characteristics: although thermodynamic properties change at the transition fairly abruptly, they do not do so in the discontinuous way expected of a true thermodynamic phase transition; the temperature at which the transition happens is a function of how rapidly it is approached; and it shows hysteresis, in that it has different values for heating versus cooling. Perhaps most remarkably, the "solid" that is formed below the glass transition, that is, the glass, still relaxes in shape (like a liquid does) except now on a much longer time scale, perhaps geologically long. Thus the glass transition itself appears to be rather dominated by kinetic processes, as opposed to thermodynamic. Whether or not there is in addition a thermodynamic transition of some kind buried under the kinetics, and developing a universal explanation of why glasses form, are important open questions in the physics of glass science.

A concept that lends itself well as a framework to understanding the glass transition as outlined above, is that of the ***energy landscape***. One thinks of the energy (free energy, or potential energy) of the system as a function of the many degrees of freedom that make it up—clearly, for a macroscopic sample, say 1 gram of material, there will be an enormous number of such degrees of freedom, in that each atom can move in relation to all the others. Nevertheless, it is clear that the thermodynamically stable configuration of the atoms will correspond to the minimum energy of the landscape, and in fact, the cooling process from the liquid can be envisioned as the system randomly sampling the available configurations, but as energy is removed through cooling, it is more and more likely to be trapped in wells for longer and longer times. If the system "finds" the thermodynamic minimum well, it crystallizes; but if it is cooled quickly, it may become trapped in a well of intermediate depth. This is the landscape picture of glass formation. Moreover, this picture is consistent with the observation that even below the glass transition temperature, glasses continue to relax structurally, as the temperature is still finite, so some configurational exploration of the landscape can continue, albeit much more slowly.

The glasses described above are rather idealized, in that they have been discussed at least implicitly to be homogeneous and with liquid-like structure. Nevertheless, even such idealized glasses can show an amazing array of properties. Because they form from a liquid, they can often be cast into very complex shapes; their material strength can be surprisingly high; they can interact with light, heat, and sound in many different ways; they can show a range of fracture behavior, from brittle to ductile; they can be insulators, or metals. Certainly, "glass" is not just window glass and bottles, but to access this broad range of properties we need to go beyond the very basic description given above.

As noted, the ultimate stable form of a material upon cooling is crystalline, but during the cooling process the material may be kinetically trapped in a glassy state. At this point ***crystal nucleation and growth*** may occur in isolated regions. Ultimately the entire material may become crystalline, or, a hybrid material may result. This latter case, termed a glass ceramic, is of great importance technologically. Such materials consist of a homogeneous glassy matrix, containing isolated crystalline particles. Glass ceramics are encountered in a range of applications, from cook-tops to dental and bone restoration to architecture. From a fundamental point of view, how such materials form is an important research topic because it sheds light on the ultimate stability of glass, and the extent to which it is controlled primarily by thermodynamic or kinetic processes. Put simply, the nucleation and growth process is a competition between increasing crystalline stability as temperature is lowered, versus decreasing crystal formation rate due to slowing kinetics. Thus there is at least typically a maximum crystallization rate at a temperature a bit above the glass transition temperature, but still below the bulk melting temperature. Understanding and finding universal trends of this behavior are the fundamental problems of glass ceramic formation. The practical, technological aspects arise from determining the key processing parameters such that the resulting crystals have the optimum distribution and shape within the glass matrix, to confer the desired properties. Typically the properties observed result from a synergism between the properties of the glass matrix and those of the embedded crystals. For example, low thermal expansion glass ceramics rely on offsetting thermal expansion properties of the glass and crystalline inclusions, while high toughness glass ceramics take advantage of the crystalline phases to prevent crack propagation and ultimate breakage. Because the resulting materials are homogeneous on long length scales, large scale devices can be prepared relatively cheaply from these materials.

We described above how glass ceramics seek to enhance the properties of ideal, homogeneous glasses by embedding crystalline phases throughout the material, in a way such that the result is still homogeneous on the large scale. An alternative approach to disrupting the homogeneity of the base glass is through surface modification, which leads to internal ***stress generation and higher strength***. A variety of applications such as transparent, protective covers, high strength windows, and containers are produced by such processing. There are both physical and chemical approaches to accomplish internal stress generation. A typical physical approach is tempering, in which glass pieces are reheated above the glass transition and then rapidly cooled, such that the surfaces resolidify well before the interior. The result is a compressive surface layer. An alternative, chemical approach is to soak the glass in a molten salt bath, to exchange ions between the glass and salt. The resulting glass will then have a very thin surface layer with altered chemical composition as compared to the bulk. Typically the salt bath will be chosen to have ions larger than those in the glass, so the surface layer of the final product will be "stuffed" with ions larger than the holes in the original material. This has the effect again of generating a layer of compressed material at the surface, which is markedly more resistant to fracture than the base glass.

In the above we have explained briefly how a glass forms, and how a homogeneous glass may be further processed to introduce controlled heterogeneities and tune its properties. For both homogeneous and heterogeneous glassy materials, knowledge of its internal structure is crucial in understanding its properties and further improving its performance. The inherent disorder of glass makes ***structural study*** particularly challenging, and it is necessary to combine data from a variety of methods to arrive at a holistic view of the glass structure. The first issue, at the shortest length scales, is to determine what types of chemical bonding are present and to what extent. Here nuclear magnetic resonance spectroscopy (NMR) is a particularly powerful tool, because it is quite sensitive to interactions between neighboring atoms, while at the same time is relatively insensitive to the presence or absence of longer-range order. This method reveals the local environment of the atoms, through their magnetic interactions with their surroundings. Some of the most common atoms found in glass, namely silicon, carbon, boron, and phosphorous, have reasonable NMR sensitivities, and indeed this method has been used to determine the coordination of these atoms in a host of different glasses. An excellent complement to NMR is neutron diffraction, which involves neutron scattering from the atomic nuclei, and again reveals correlations between nearby atoms. Both NMR and neutron diffraction are highly specific to the atomic types present, but also require highly specialized instrumentation. Vibrational spectroscopies, such as Raman scattering and infrared absorption, are sensitive to the inter-atomic vibrations, and require much simpler instrumentation. However, because they are not atom-specific, the information they yield is less precise and harder to interpret. At longer length scales, structure must be measured using suitably longer-range probes, in particular, small angle neutron and x-ray scattering, electron diffraction, and, at the longest length scales, light scattering.

While the structural studies mentioned above provide data on the local and intermediate range structure, connecting that data with observed macroscopic properties requires different theoretical ideas. A particularly intriguing one is that of ***network topology***, in which broad features of the bonding network, such as average coordination number, average ring size, and so forth are used to explain and predict macroscopic properties. In this view, attention is focused on how each atom is constrained from being displaced, say by bond-stretch or bond-angle-bend forces, and so forth. Then, from fairly coarse-grained features of this network of constraints, estimates of a wide variety of properties can be made, including mechanical ones such as elastic moduli and surface hardness, and kinetic ones such as viscosity and the glass transition itself. The challenge in applying this approach is in identifying *a priori* which constraints should count, and how much.

Complementing both the experimental investigations of local structure and the topological approach relating structure to properties, are ***atomistic simulations of glass***. This approach has become effective in recent years with the advent of sufficiently large and powerful computers. The most precise method proceeds from first principles, where the quantum mechanics of the atoms with all their electrons are treated. The advantage of this approach is that highly detailed information on bond strengths and related details can be obtained, as well as properties dominated by the glass electronic properties, such as optics. The disadvantage is that only very small model systems can be treated. If the full electronic problem is replaced with average forces, then much larger model systems can be studied, using **molecular dynamics** or **Monte Carlo** methods. These studies give computational information of larger length scale structure and properties, such as elasticity. These studies also provide interesting tests for the topological approach mentioned above, as in both cases, bonding types and constraints are relatively easily identified. Finally, one can invert the problem and start from properties in order to investigate glass structure and composition—this is the approach taken by **artificial intelligence** and **machine learning**, in which training sets of data are used to try to discover new correlations, which can then be used to predict interesting new formulations to investigate.

We mention finally the ***optical properties*** of glass. The combination of a solid material, that can be made into virtually any shape, with optical properties that be tuned in myriad ways, has always been one of the most attractive features of glass. This combination has throughout the history of glass been a prized attribute, as it allows for making objects that are both highly functional, and decorative. Nowadays, this combination is being pressed far beyond the realms of art and architecture, to focus on high-tech materials including lasers, optical communications, and high performance optical systems.

We hope that in these brief pages we have inspired and encouraged the reader to delve more deeply into glass science and engineering—glass is an endlessly fascinating state of matter, which, despite its long history of human use, is only now beginning to be understood in detail.

Advances in non-oxide glass science and technology

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Chalcogenides and fluorides are the main classes of non-oxide glasses that can be easily processed in stable bulk form. Chalcogenide glasses have found greater attention due to their very broad transparency to infrared (IR) wavelengths down to 25 µm. This has historically made them excellent candidates for applications in thermal imaging and vibrational sensing. These technologies are already mature and chalcogenide IR lenses are now produced industrially by several companies such as UMICORE IR glass. While initially developed for defense applications, they are nowadays majorly used for civilian purposes like in the automotive industry for night-driving aid. Similarly, biomedical sensors for analysis of biological fluids using chalcogenide fibers are now commercialized by Diafir in France.

Gradient index optics: The newest frontier in the design of IR optical elements is the development of gradient index (GRIN) lenses for applications such as multispectral imaging. Several approaches have been investigated for the production of chalcogenide GRIN lenses including glass or powder stacking, ionic exchange and spatially resolved crystallization. *Stacking* relies on thermally induced diffusion between layers of bulk or powdered glass. Lens fabrication requires a suite of stable glasses with tailored index such as that developed by Naval Research Lab (GeAsSe/S). However, this method still results in step index patterns due to the extensive time required for long range diffusion. *Ionic exchange* is performed by immersing a GeGaSe-NaI glass in a KNO3 bath to induce K^+/Na^+ substitution and increase the index on the periphery (2 mm deep). An index change of $4.5\cdot10^{-2}$ can be achieved. *Spatially resolved crystallization* relies on the controlled nucleation of high index crystals within a low index glass matrix such as Ga2Se3 nuclei in GeGaS glass or PbSe in GeAsPbSe. The production of 1 cm diameter lenses was demonstrated in GeGaS glass heat-treated in an annular furnace to generate a higher index on the periphery. Alternatively, femtosecond laser was used to locally crystallize GeAsPbSe. One significant advantage of the laser-induced method is the ability to produce an arbitrary GRIN profile as opposed to the thermal method where the index change is dictated by the heater temperature gradient. However, laser crystallization is so far limited to thin films. A critical aspect of these crystallization approaches is that the crystal grain size must remain small enough to prevent scattering so that good transparency is retained.

Microstructured waveguides: Microstructured optical fibers (MOFs) are of much interest due to their high design flexibility which permits to control mode propagation properties. Several types of chalcogenide MOFs have been recently demonstrated in which holes are either filled with air or another glass. Fabrication of all-solid MOFs requires two glasses of different index, usually a selenide (matrix) and a sulfide (inclusions) for instance As2Se3/As2S3. All-solid MOFs designed for high power using GeAsSe/GeAsS glasses were recently shown to sustain power density up to 150kW/cm^2. MOFs based on air holes can be designed with a hollow core, a solid core or a suspended core. Guiding properties and mechanisms are dictated by the fiber symmetry. Hollow core fibers are of interest for high power delivery due to the minimal interaction of light with the material. Polarization maintaining MOFs have been fabricated using asymmetric holes and can be endlessly single mode over wide wavelength range in the mid-infrared (2-6 micron). Suspended core MOFs are of interest for controlling dispersion. They are produced with traditional glass such as As2S3 and As2Se3. Many different MOF preform preparations methods have been demonstrated including stacking capillaries, casting, extrusion and more recently 3D printing of preforms for the fabrication of hollow core MOFs. Chalcogenide MOFs are commercially available through several companies including IRflex in the USA and SelenOptics in France.

Supercontinuum generation: Chalcogenide glasses are composed of large polarizable elements which confer them high non-linear optical properties, typically three or more orders of magnitude larger than silica. These high non-linearities are beneficial for the generation of intense coherent light over broad wavelength range called supercontinuum. These novel light sources have broad and continuous emission over the IR 2-15 µm and high power up to 825 mW. They are of much interest for sensing, tomography, hyperspectral imaging etc. Supercontinuum generation has been demonstrated in chalcogenide fiber and rib waveguides typically made of GeAsSe or AsSe glasses. The supercontinuum is produced through a series of nonlinear processes using a femtosecond pulsed laser pump. Broad band supercontinuum generation over the full IR requires high-intensity pump in the mid-IR (4µm) which are not readily available. But recently, supercontinuum generation through a cascaded silica-fluoride-chalcogenide fiber system was demonstrated with a conventional 1.55 µm pump.

Phase Change Materials and Non-volatile Optics: One of the newest applications of chalcogenide solids involves phase change materials (PCMs) like GeSbTe or AgInSbTe.

They exploit the high contrast in electrical or optical properties between the crystalline and amorphous phase. Much effort has been ongoing to improve the crystallization speed and long term retention. Aging of the amorphous phase is a major issue for use in neuromorphic computing or multilevel memories where small but stable changes in resistivity are required yet tend to drift over time due to structural relaxation. More recently, PCMs have evolved into the new field of non-volatile optics including reconfigurable metasurfaces and modulated integrated photonics. PCMs play a critical role in the advent of optical computing platforms. Permanent optical memories and ultra-fast computing using GeSbTe have been demonstrated. However standard PCMs have high optical losses which impede their widespread use in photonic integrated circuits. Alternative compositions such as Sb2Se3 and GeSbSeTe have been investigated, but many challenges remain to identify PCMs with low losses that also retain high contrast and high cyclability (10^{15} cycles) for modulator applications.

Glassy Solid Electrolytes: From Fundamental Glass Science to New Solid State Batteries

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Introduction – The Ionic Bond in Otherwise Covalent Network Glasses

Common alkali silicate glasses such as windows and lenses, which have had tremendous impact on both the quality of life and the exploration of many fundamental scientific questions, owe their favorable processing ease, yet amazing properties, to the delicate balance between the formation of network breaking alkali (and alkaline earth) ionic bonds to form non-bridging oxygens, that lower the viscosity of the melt from which they are formed, and the remaining covalent network forming bridging oxygens.[1] The weaker ionic bond strength of the alkali ion – non-bridging oxygen pair, in particular, creates a subset of ions, the alkali ions, that are inherently less strongly bonded to the network of the glass and as such can exhibit decoupled independent motions from the glassy network.[2] The covalent glass network exhibits motion only at temperatures in and above the glass transition temperature range of the liquid. These weakly bonded mobile alkali ions were observed more than 100 years ago to create an ionic current when an electric field, or an electrochemical potential, was applied to the glass.[3] While the alkali ion – oxygen ionic bond is significantly weaker than the covalent Si-O-Si bridging oxygen bond, it is never-the-less is sufficiently strong such that the measured responding ionic currents to the applied voltages as measured by the ionic conductivity, $\sigma_{d.c}$, are quite low and typically ~10^{-9} $(\Omega cm)^{-1}$ at room temperature.[2]

New Mixed Oxy-Sulfide-Nitride Based Glasses as "Fast Ion Conducting" (FIC) Solid Electrolytes

The low ionic conductivities are 6 orders of magnitude lower than that required, ~10^{-3} $(\Omega cm)^{-1}$, see Figure 1a, below, at room temperature for use in typical Lithium ion batteries

(LIBs). The fundamental break through that was discovered by the author and others more than 30 years ago was that by substituting the oxygen in these typical oxide glasses for sulfur to create a new class of sulfide glasses loosened the inter-ionic bond strength between the Li^+ ion, for example, and the sulfide anion to such an extent that as shown in Figure 1a, the $\sigma d.c$ increased dramatically and into the required range ~10^{-3} $(\Omega cm)^{-1}$.[3]

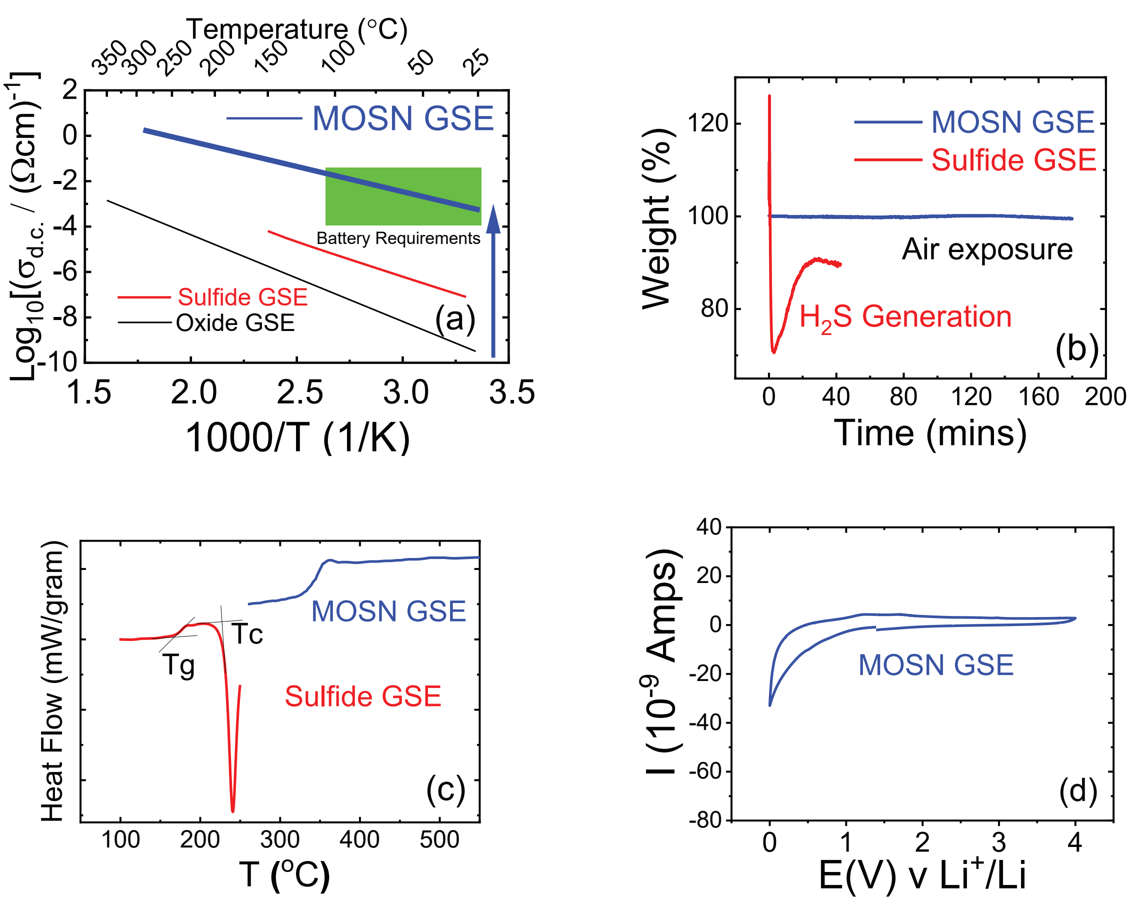
However, high conductivity, alone is not sufficient for application as a solid electrolyte (SE) in an all solid state lithium battery (ASSLB). The SE must be electrochemically stable against reduction in contact with lithium metal (LM) anodes. It must be electrochemically stable against oxidation in contact with high voltage cathodes such as cobalt oxide. It must be sufficiently resistant to crystallization so that it can be formed into very thin 20 micron thick sheets. It must be sufficiently mechanically strong to resist failure during charge and discharge processes inside the battery. And finally, it must be sufficiently chemically stable in air so that it can be easily assemble into ASSLBs in dry room atmospheres.

This is where the authors 40+ years of experience with these highly decoupled FIC Glassy SEs (GSEs) has been able to use the nearly infinite compositional turnability of glass to create next generation Mixed Oxy-Sulfide-Nitride (MOSN) GSEs that are beginning to meet each of these demanding yet required physical property attributes. By mixing back in a small amount of oxygen into the glass, the author and his students have discovered the surprising result that not only are the mixed oxy-sulfide (MOS) glasses more chemically and electrochemically stable than the parent pure sulfide glass, they also have even higher Li^+ ionic conductivities. Further, by mixing in a small amount of nitrogen into the MOS glass, these new MOSN glasses are even more chemically and electrochemically stable, they have even higher ionic conductivities, and are more resistant to crystallization.

Figure 1a shows the dramatic increase in Li^+ ionic conductivity of the Lithium MOSN GSEs into the range, ~ 10^{-3} $(\Omega cm)^{-1}$ at room temperature, required for SEs in ASSLBs. Figure 1b shows the dramatically improved chemical stability of the Lithium MOSN GSEs, where no significant weight change for nearly 200 hours in air is observed. Figure 1c shows that while typical pure sulfide based FIC GSEs rapidly crystallize above their glass transition temperatures, Tg, certain of the MOSN GSEs exhibit no crystallization events even when heated more than 250°C above their Tg. Figure 1d shows an electrochemical cyclic voltammogram of a MOSN GSE that shows essentially no electronic current flows up to 4 V vs Li/Li^+ and demonstrates that these MOSN GSEs can be electrochemically stable against high voltage cathode materials. Figure 1e shows that with the strong resistance to crystallization that these MOSN GSEs exhibit, they can be drawn into the thin films that are required for high power applications such as electric vehicles. Finally, Figure 1f shows a battery cycling experiment on a MOSN GSE where increasing voltages are applied to a symmetric battery cell formed by placing two identical thin sheets of LM on the two sides of a MOSN GSE disc ~ 1 mm thick. The responding Li^+ ion current is then measured. In the case of these new MOSN GSEs, Li^+ current densities up to 1.75 mA/cm^2 can be achieved without failure or non-ohmic (non-linear) behavior developing in the glass. Such current densities are those typically needed for high current applications such as electric vehicles.

Summary – New MOSN GSES are a New Functionality in Glass Enabling New High Energy Density ASSLBs

While a full detailed description of these new MOSN GSEs is beyond the scope of this modest report here, the data and results provided do suggest that these new MOSN GSEs may represent a new application for glass. The high Li^+ ion conductivity of these new glasses combined with their many other advantageous properties, enabled in part by the near infinite variability of glass composition, may create a new functionality of glass that may have a dramatic impact in opening new avenues of research and development to create new kinds of ASSLBs with dramatically higher energy densities, high power densities, safer operation, and all at a potentially lower cost.



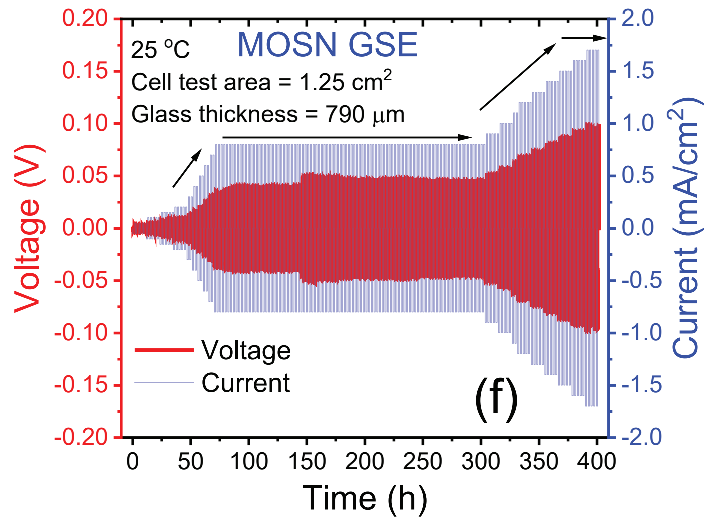


Figure 1 shows the Li^+ ionic conductivity of the Lithium MOSN GSEs are in the range, ~ 10^{-3} $(\Omega cm)^{-1}$, at room temperature required for SEs in ASSLBs. Figure 1b shows the improved chemical stability of the Lithium MOSN GSEs in air over that of a reactive pure sulfide glass. Figure 1c shows that certain of the MOSN GSEs exhibit no crystallization events even when heated more than 250°C above their Tg. Figure 1d that MOSN GSEs have essentially no electronic current flows up to 4 V vs Li/Li^+. Figure 1e shows that these MOSN GSEs can be drawn into the thin films. Figure 1f shows that Li^+ current densities up to 1.75 mA/cm^2 can be achieved without failure or non-ohmic (non-linear) behavior developing in the glass.

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Atomistic Simulations of Glass Materials

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In the past few decades, the field of atomistic simulations of glass has developed into an indispensable part of glass research and complements experimental and other modeling methodologies to understand the fascinating but inherent complex glass materials. The problems that can be addressed by atomistic simulations range from complex glass structures, composition design and refinement, ion-exchange strengthening, surface modifications, pressure effect, to glass corrosion. With ever increasing computing power and wider adoption of simulation as a valuable research method, atomistic simulations have become more integrated in glass science and glass research like other fields in material science and engineering. In this section, I will introduce the most common atomistic simulation methods including molecular dynamics, Monte Carlo, and reverse Monte Carlo. A few representative examples of applications of atomistic simulations ranging from solving complex structural issues, understanding key processing induced structural and property changes in glasses, and glass-environment interactions are briefly summarized. Lastly, challenges and outlooks of the field will be presented. For more detailed information, there are several good reviews[1] and, particularly, the readers are encouraged to refer to a new book titled "*Atomistic Simulations of Glasses: Fundamentals and Applications*" edited by the author and Dr. Alastair N. Cormack and published by Wiley and the American Ceramic Society.

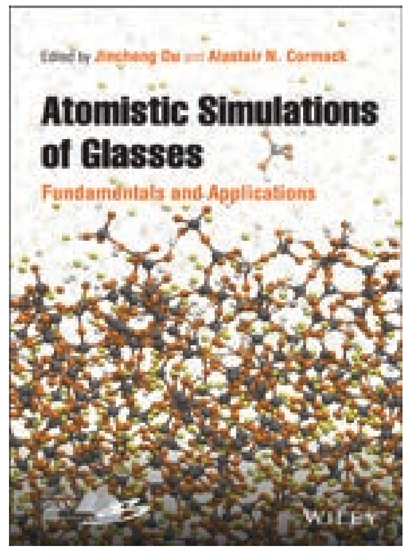

Fig. 1 Book cover of "Atomistic Simulations of Glasses: Fundamentals and Applications" by Wiley. The cover image shows sodium silicate glass-water reaction interfaces from reactive potential based MD simulations.

Atomistic simulation methods

Molecular dynamics (MD) is the most common atomistic simulation methods for glass simulations.[1] MD simulation is based on solution of Newton's equation of motion of an assembly particles, usually atoms or ions, in a simulation box with periodic boundary conditions to model solids or liquids. This is done iteratively at a time step usually in the scale of femto-second to provide accurate description of atomic motion in these systems. The process is highly iterative, as well computational and memory intensive, hence suitable for computer simulations. Control of temperature and pressure is achieved by applying a thermostat and barostat. Evolution of the atom positions are recorded and called trajectories that can be used for further structural analysis. Various thermodynamic properties can be calculated based on statistical mechanics. A number of algorithms to solve the equation of motion have been proposed and tested. Nowadays, MD algorithm has been implemented in several general usage simulation packages such as Lammps, DL_POLY and Gromacs that lead to widespread usage of the method on simulations of glass, melt, and other materials. MD simulations usually employ interatomic (or empirical) potentials to describe interactions between particles hence is called classical MD simulations. The interatomic potential consists of the most important input in any MD simulations. Active development in the past decades enable MD simulations of different glass systems ranging from silica and alkali silicates to more complex aluminosilicate and borosilicate multicomponent glasses. The accuracy of the potential has also increased tremendously. For example, latest potential for borosilicate glasses can reproduce the boron coordination changes in wide composition ranges that are consistent with experiments or models. Recent development of reactive potentials also enabled the simulations of glass-water interfaces and glass-environment interactions.

When the interaction energies and forces are calculated from first principles methods such as density functional theory, this is usually called first principles MD or *ab initio* MD (AIMD),[2] although the motion of particles are still considered classically and governed by Newton's equation of motion. Different flavors of AIMD have been developed. AIMD is computationally much more expensive than classical MD and can handle only relatively small number of particles and shorter times. However, AIMD provides accurate energies and forces hence the trajectories of atoms are not biased by the interatomic potentials as in classical simulations. AIMD is very suitable for simulations of glass melt as less time is required to reach equilibrium due to faster dynamics. These trajectories and structural info can then be used as input for fittings of interatomic potentials through force matching or providing accurate melt structural info such as partial pair distribution functions. Another important application of AIMD is for systems where interatomic potentials are not available or too complex. A good example is chalcogenide glasses. AIMD has been applied to simulations of various chalcogenide glass structures and amorphous to crystal transformation in phase change chalcogenide materials.

Monte Carlo (MC) is another atomistic simulation method that can be used to generate glass structures. MC algorithm follows the Markov chain by using total potential energy of a system. MC favors equilibrium structures of a system at certain temperature and pressure and does not follow the normal dynamic trajectories. As a result, MC is commonly used to explore liquid or melt structures but due to its lack of dynamic information hence is less commonly used in glass structure generations. However, MC has be combined with MD in the cooling process to generate glass structures. The kinetic MC (KMC) method adds time scale to the simulation by using the rate of reaction or processes of events as input. KMC or related method has been successfully applied to simulate glass corrosion or glass etching.[3] One common approximation applied in these simulations is to adopt simple lattices on which cations are added to the lattice sites to mimic the network structure of glasses. These simplifies simulations but might lose some important structural features hence the latest KMC method for glass corrosion is built up "real" glass structures generated from MD simulations.[3]

Another type of MC simulation that is commonly used for glass structure generation is Reverse Monte Carlo (RMC). RMC uses experimental structural information such as structure factors or pair distribution functions from diffraction experiments as target and move atoms to best reproduce those results. Other experimental data such as those from Extended X-ray Absorption Fine Structure (EXAFS) can also be used as input, while additional structural information such as coordination number from Nuclear Magnetic Resonance (NMR) or chemical intuition can be used as constraints in the simulations. RMC can also be combined with MD simulations and one example is Empirical Potential Structure Refinement (EPSR) in which the interatomic potential parameters are adjusted so the best match with experimental data is achieved. Another flavor of RMC is force enhanced atomic refinement (FEAR), in which the potential energies from either first principles or classical potentials are used as an additional criterium for RMC structure refinement. These modifications enhanced the original RMC method by addressing the limitations of pure stochastic nature of the MC moves that can lead to unphysical atomic arrangements.

Applications of atomistic simulations in glass science

Atomistic simulations have become a mature method that find wide applications in glass science. The widespread usage is not only shown from large number publication in the literature but also from ever increasing number of practitioners and adoption as a research tool from university laboratories to industry research and development units. This section gave examples of applications of atomistic simulations in three areas.

1. Solve complex structural problems in glasses

One of the main applications of atomistic simulations is to obtain realistic glass structure models and solve changing structural issues in glasses.[4,5] With the 3-dimension coordinates as a result of simulations, short and medium range structures can be elucidated in detail. Despite the much faster cooling rate than experiments during glass formation in MD simulations, the structures generated with effective potentials and reasonable procedures still show large resemblance to the real glass structures when compared with variable available experimental data. Here are a few examples of structural issue or mystery that were elucidated by using atomistic simulations. Polyamorphism is an interesting phenomenon in glass science where amorphous solids possess the same composition but different densities. A few glass systems such as yttrium aluminate glasses are one of the first glass systems to show such behavior. By combining MD simulations and diffraction characterizations, the high density and low density yttrium aluminate glasses and melts were investigated in detail. It was found that the high density phase has more higher coordinated Al which form edge-sharing than normally corner-sharing polyhedra in the low density phase.

Silica and other network forming glasses possess strong peak in short Q range in their structure factors from neutron or X-ray diffraction. This peak is usually called first sharp diffraction peak (FSDP) and considered to correlate to the medium range order of the glass. With addition of modifier oxide such as alkali oxides, the FSDP intensity decreases indicating a decrease of medium range order when network is gradually broken due to formation of non-bridging oxygen.[4] This is generally true for most alkali oxides except lithium oxide. The FSDP of neutron structure factor actually increases with addition of lithium oxide. Does this mean that lithium silicate glass has higher degree of medium range order than other alkali silicate glasses? Lithium ions are relatively small and have close to four-fold coordination. Would lithium ion enter the network structure to increase medium range order? MD simulations were performed in a wide range of lithium, sodium and potassium silicate glasses. Their structures characterized and structure factor calculated. Despite the similar modified glass structure in terms of non-bridging oxygen formation and ring statistics, the calculated neutron structure factor of lithium silicate glass shows unusually strong FSDPs. Examining the partial structure factors and swapping the neutron scattering length show that the unusually strong FSDP in lithium silicate glass is originated from the negative neutron scattering length and not due to its high medium range orders.[4]

The structures of chalcogenide glasses are usually more complex than oxide glasses due to the potential formation of homonuclear bonds.[2] The complex bonding in chalcogenides also prevents reliable interatomic potentials to be developed for the simulations of these glasses. As a result, AIMD simulations are used to model the structures of these glasses. AIMD simulations of GeGaSe chalcogenide glasses show the tendency of formation of Ge-Ge and Se-Se homonuclear bonds,[2] but Ga is mostly coordinated by Se and rarely form homonuclear bonds with other cations (Fig. 2). This is explained by the higher ionic bond character of Ga as reflected by their larger atomic charges than Ge. One advantage of AIMD simulations is that the access to various electronic properties such as electronic density of states and atomic charges.

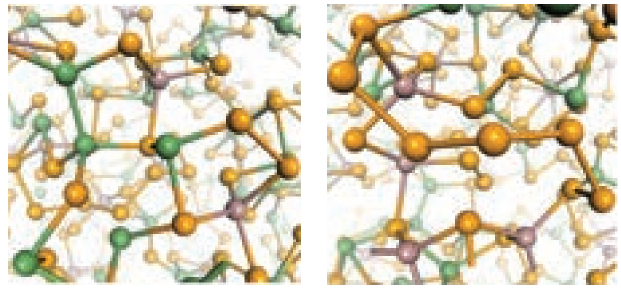

Fig. 2 Structure of GeGaSe chalcogenide glasses from AIMD simulations.[2] Left figure shows the Ge-Ge homonuclear bonds and the right figure shows the Se-Se chain structures. Ga forms GeSe4 units but does not bond directly to Ge.

2. Understand structure-property relations and structural origin of properties

Atomistic simulations are also often used to elucidate origins of peculiar property changes. Based on the glass structure generated, various properties such as dynamic, vibrational, mechanical, and others can be calculated. Ion-exchange or chemical strengthening is now a widely used method to improve the mechanical behaviors of glasses and find applications from aerospace, pharmaceutics, to consumer electronics. MD simulations have contributed significantly to understand the mechanisms of chemical strengthening as a result of swapping of larger cations with the smaller ones that lead to the formation of surface compressive layers. A number of papers on utilizing MD simulations on the surface layer strength have been published. Fig. 3 shows an example of one of the latest studies on MD simulations of soda lime boroaluminosilicate glasses where K^+ for Na^+ substitutions have been investigated.[5] The structures and properties of ion exchanged

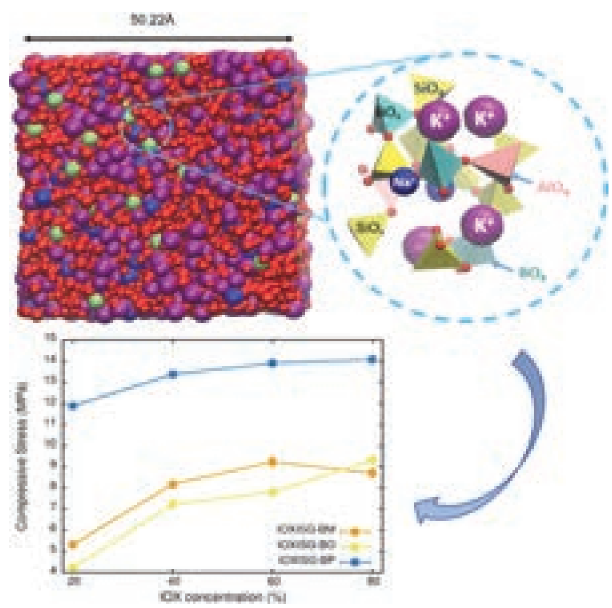

Fig. 3 MD simulations of ion-exchange strengthening in boroaluminosilicate glasses.[5] Some glasses show much larger level of strengthening in terms of surface compressive layer formed than others. The underlining mechanisms were explained on the structures of the glasses from MD simulations.[5]

and melt-quenched glasses with the substitution were investigated, and the properties were correlated by using the Quantitative Structure-Property Relation (QSPR) analysis.[5] Two series of glasses were investigated with one series found to be more suitable for chemical strengthening than the other.

Another area of glass property change is on the pressure and pressure history effect on glass properties. Pressure has been used as a new approach to modify glass properties. Pressure induced structural and property changes were investigated in detail by using MD simulations. These results provided insights on which structural changes led to the densification and associated mechanical and diffusional property changes. These simulation work, together with experimental characterization such as NMR and diffraction studies to gain insights of pressure and pressure quenching induced property changes in glasses.

3. Elucidate glass surface structures and reactions with the environments

Glass products will inevitably interact with the environment either during the processing or in applications. Glass surface-environment interactions and glass corrosion hence are of great importance to glass production, architecture, display, pharmaceutical, nuclear waste disposal and biomedical applications. MD simulations have contributed to the understanding of glass surface structures and the glass-water interfacial reaction mechanisms. With recent development of reactive potentials, simulations of glass-water interfacial reactions of silicate and aluminosilicate become possible. The fundamental steps and the reaction mechanisms of glass corrosion from hydration, hydrolysis and ion-exchange reactions to alternation layer formation can be described by atomistic simulation in detail (Fig. 4). Although MD is limited by the shorter time scales accessible, direct simulation of corrosion rate is difficult. However, alternative methods have been

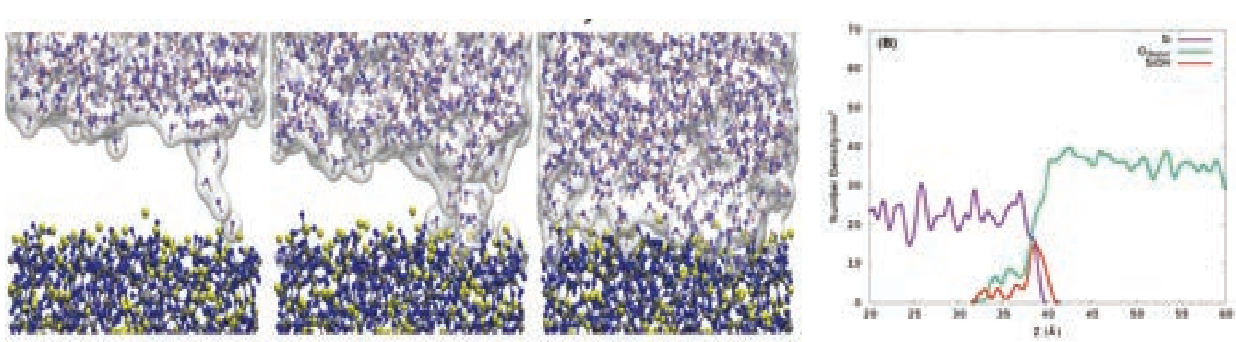

Fig. 4. Reactive potential based MD simulations of hydration and interfacial reaction of sodium silicate glass surface.[6] Left two figures show snapshots of the hydration process. The right figure shows the Z-density profile at the glass-water interface.

developed to study longer term corrosion behaviors. We have combined MD and QSPR analysis to study the corrosion rate of a series borosilicate and aluminosilicate glasses. With well-designed descriptors, the corrosion rate of over various glass compositions can be related by linear regression analysis. MC or KMC methods have also been developed to predict glass corrosions in longer time scales.3 These models can provide surface microstructural changes such as dissolution and gel layer formation and the insights on alteration of glass materials that are of great importance in long term nuclear waste disposal and durable glass vials for vaccines and other biomedical applications.

Outlook and closing remarks

In summary, atomistic simulations have evolved into an important approach for studying glass and related materials. With development of simulation methodologies including effective interatomic potentials and simulation algorithms, a wide range of glass systems (e.g. silicate, borosilicate, aluminosilicate, chalcogenide, mixed anion glasses) can now be modeled. Furthermore, the interaction of glass with the environment can also be modeled by using reactive potentials. ICG TC27 Atomistic simulations focuses on these methods and their applications. With the recent surge of machine learning and artificial intelligence, ever increasing computing power, and the development of quantum computing, further expansion of atomistic simulations and related modeling methods in glass science and technology are expected. It is possible that fully atomistic simulations with cooling rate close to realistic values can become a reality in the foreseeable future.

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Finding Needles in Haystacks: Discovering New Glass Compositions by Machine Learning

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Discovery of new glass compositions

Discoveries of new glass products (e.g., windows, lenses for microscope or telescope, optical fibers, or smartphone screens) have fundamentally been enabled by the discovery of *new chemical compositions* for glass [1]. Initially, Egyptian glasses in 3000 BC featured a Na2O–CaO–SiO2 composition. Since then, refinements in the proportions of these oxides or the addition of new oxides have enabled new functionalities for glass. For instance, the addition of MnO2 in glass has played a pivotal role in the discovery in 1450 of the Cristallo Venetian glass—the first transparent, colorless glass. The addition of PbO led to the design of flint glasses in 1675, whose high-refractive index accelerated the development of optical lenses. In 1830, the stoichiometry of the initial soda-lime silicate formulation was refined into the "magical" 1:1:6 composition (that is, wherein 1 mol of Na2O is combined with 1 mol of CaO and 6 mol of SiO2), which is the base composition for window glasses. In 1915, the addition of B2O3 enabled the discovery the Pyrex glass and modern glassware. In 1971, the addition of P2O5 enabled the discovery of the Bioglass, which can stimulate bone growth after fracture. Today, much research is still conducted to discover new glass compositions (i.e., new types of oxides to add into glass, or new optimal stoichiometries) that would feature new functionalities—e.g., to discover new types of glasses that are unbreakable, that can conduct electricity, or can resist dissolution for millions of years.

Need to accelerate the discovery of new glass compositions

Discovering a new glass composition then consists of navigating this space (that is, by iteratively adjusting the chemical composition) until a glass featuring the target performance is found. To this end, various approaches have historically been used.

Clearly, although they have enabled the discovery of many glasses over the past centuries, glass discovery methods based on trial-and-error, serendipity, or high-throughput systematic exploration are not fast and efficient enough (see **Fig. 1**)—one cannot afford to wait for another century to discover the new glass(es) that will address today and tomorrow's pressing grand challenges, e.g., in environment, energy, communications, and health. Traditional discovery approaches rely on important aspects (e.g., empirical methods can leverage human intelligence and intuition, while high-throughput simulation-based methods leverage the power of computers) but are unlikely to fundamentally accelerate the pace at which new glasses are discovered. In that regard, machine learning offers a promising option as it combines the *ability to learn* (typically displayed by humans) with the unparalleled *speed of computers*. This is why artificial intelligence and big data have been identified as a new paradigm of materials science [3].

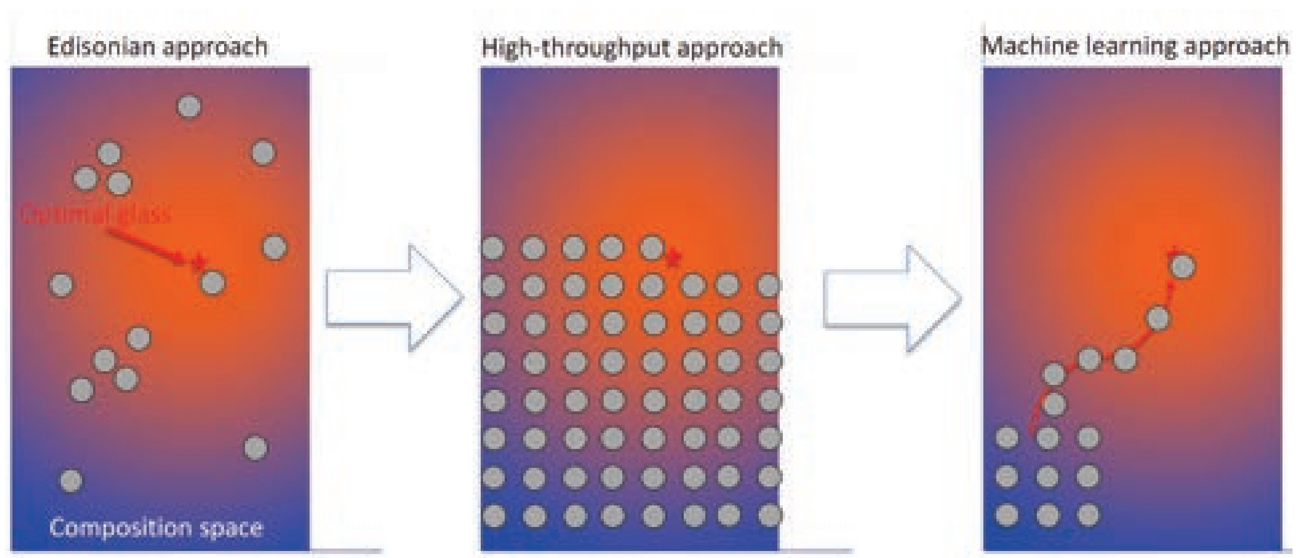


Fig. 1: *Illustration of different glass discovery schemes. The rectangular box represents an accessible compositional space (wherein each available oxide is a degree of freedom). Within this space lies an optimal glass (indicated as a red star) that features optimal properties. The grey circles illustrate the different glass compositions that are synthesized and tested until the optimal glass is found. From left to right, the three boxes represent the (i) trial-and-error Edisonian approach, (ii) high-throughput approach, and (iii) machine learning approach.*

What is machine learning?

Machine learning can be defined as the science of getting a computer to learn how to perform a given task (e.g., discovering a new glass) *by example*, without being explicitly programmed on how to perform this task. As such, machine learning offers a completely new paradigm in computing. Indeed, before the age of machine learning, computing used to rely on explicit programming—wherein, to teach a computer how to perform a task, a person needed to provide some inputs and write a series of instructions (i.e., an algorithm) that explicitly describes how to perform this task. Then, thanks to its speed, the computer can extremely quickly execute this algorithm and offer the outcome of the calculation as an output (in terms of the inputs). Machine learning offers a completely reversed computing paradigm as it makes it possible for computers to learn how to perform a task simply by example, that is, by observing how this task is being perform. As a key difference with explicit programming, machine learning does not require any premade algorithm specifying how to perform this task but, simply, a series of previous observations—that is, a dataset of inputs (e.g., glass composition) and associated outputs (e.g., glass properties). Machine learning then "learns" from the dataset to infer a relationship mapping the inputs to the output—a process called training. Once the training is complete, machine learning offers as an outcome the recipe on how to transform the inputs into the output—that is, machine learning provides the algorithm. This algorithm can then be used by the computer to perform the task (just like in the explicit programing paradigm) but without have been explicitly taught how to perform this task.

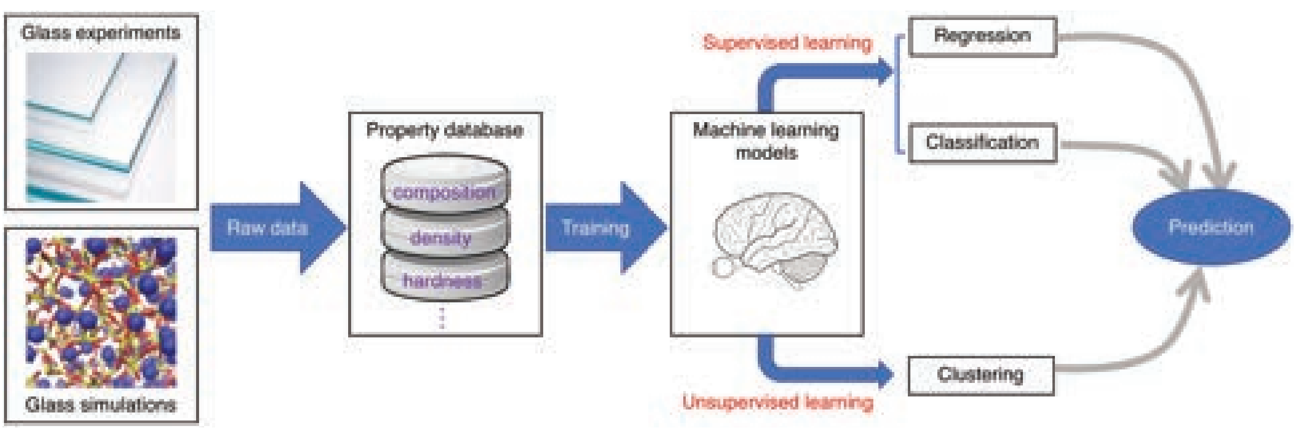
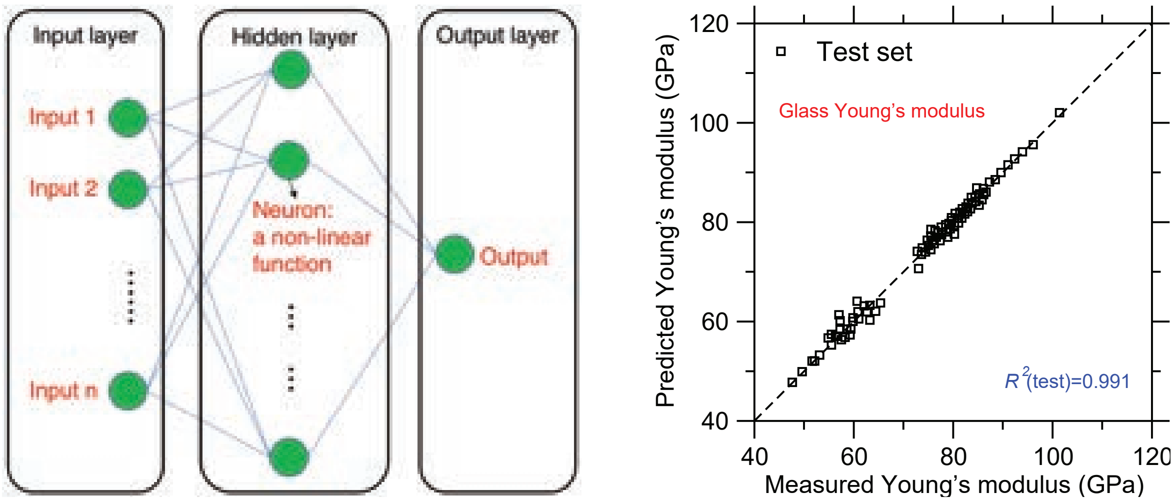


Fig. 2: *Illustration of a typical machine learning pipeline for glass discovery. A dataset is used to train a machine learning model to map the composition of glasses to their associated properties. The trained model is then able to predict the properties of new glasses that are yet to be tested.*



(a) **(b)**

Fig. 3: (a) *Illustration of an artificial neural network model, which comprises an input layer, hidden layer, and output layer. Here, the input variables refer to the glass composition (fractions of each oxide), while the output refers to the associated predicted property.* **(b)** *Comparison between predicted (i.e., the output of the model) and measured Young's modulus for calcium aluminosilicate glasses [3]. The correlation coefficient R^2 is indicated as a measure of the model accuracy.*

Using machine learning to quickly screen new promising glasses

In the context of glass discovery, the first "task" of interest is usually to predict the properties of a glass based on the knowledge of its chemical composition. This can be performed by considering a large dataset comprising (i) the composition of various glasses and (ii) the associated properties of each of these glasses. By learning from this dataset, machine learning would then offer as an output a property prediction algorithm, that is, a mathematical function that can map the chemical composition of a glass to its properties (see **Fig. 2**). If properly trained, this machine learning model would then be able to predict the properties of brand-new glasses, even if such glasses have never been synthesized or tested before. An example of such predictions is provided in **Fig. 3**, which shows a comparison between the true (measured) Young's modulus with the value that is predicted by an artificial neural network machine learning model—wherein the predictions are performed on glasses that were not used to train the model (i.e., test set). Such predictive models make it possible to extremely quickly screen glass compositions in a high-throughput fashion—that is, by systematically considering different glass compositions, predicting the associated properties with the machine learning model, and determining whether or not this glass meets the performance or constraints requirements.

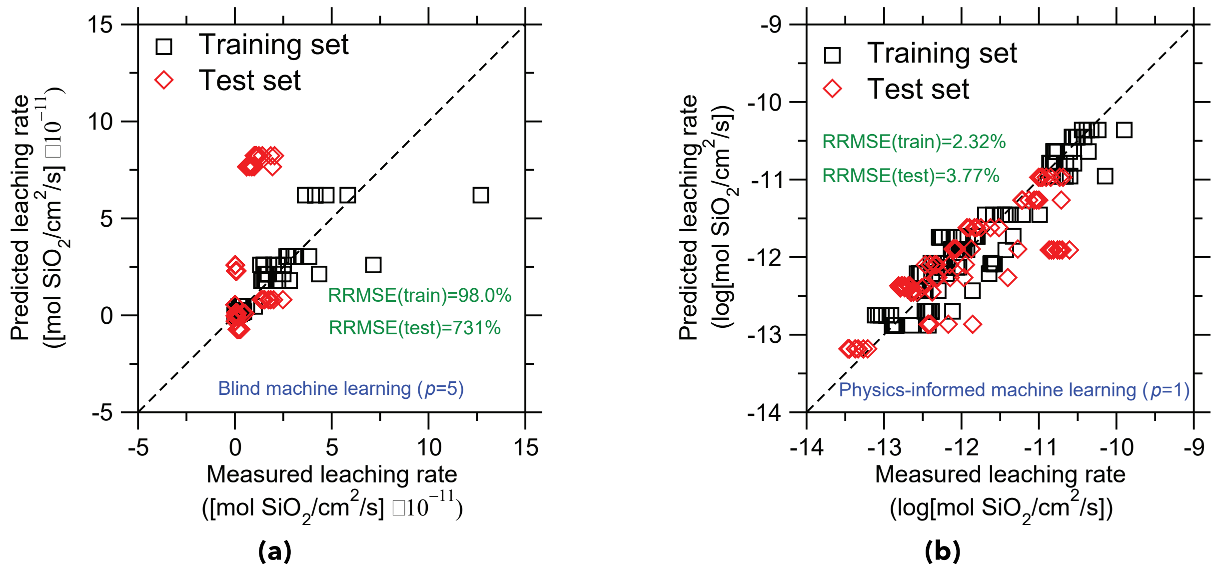


Fig. 4: *Comparison between predicted and measured glass dissolution rates values, as offered by* **(a)** *"blind" machine learning and* **(b)** *"physics-informed" machine learning using polynomial regression models [3].*

Challenges in machine learning for glass discovery

Although machine learning typically excels at "interpolating" (that is, inferring the properties of a glass that is in between two previously tested glasses), it usually fails at "extrapolating" (that is, predicting the properties of glasses that are very different from those used to train the model). This is a serious limitation since the glasses that need to be discovered to address future grand challenges are likely to be very different from those that are already known and characterized. This challenge can be overcome by embedding some knowledge within machine learning models (that are otherwise purely data-driven and, hence, "blind" to physics or chemistry). Indeed, physical or chemical knowledge can "guide" machine learning models and prevent them from offering unrealistic extrapolations. This can be accomplished by (i) using some physics- or chemistry-based descriptors as inputs to the model, (ii) enforcing some constraints based on existing knowledge during the training of the model, or (iii) using knowledge to guide the choice of the functional form of the inputs-output mapping. As an example, **Fig. 4** illustrates the improved ability of a "physics-informed" machine learning model to predict the dissolution rate of a series of sodium aluminosilicate glasses (that are in a different compositional space than the glasses used to train the model) as compared to a conventional, purely data-driven "physics-blind" machine learning model. This type of hybrid approach—that combines the power of machine learning with the robustness of physics-based models—holds many promises to accurately predict the properties of new exotic glasses, which is key to go beyond the range of glass families that have presently been explored.

Efficiently discovering new glass compositions by Bayesian optimization

The potential of machine learning goes beyond the task of simply predicting glass properties based on the knowledge of composition. Specifically, machine learning also has the potential to guide a user on how to explore the composition envelope—that is, given an accessible compositional space, some performance target, and some previous examples of glasses and their properties, *what should be the next most promising glass to be synthesized and tested*? This "task" is complex as it requires to both "exploit" existing knowledge (e.g., glasses are compositionally similar to a glass that performs well are also likely to perform well) and "explore" the compositional envelope (i.e., to investigate new compositional domains that are yet to be sampled). Clearly, an ideal search strategy should combine exploration (to have a chance to identify the ideal optimal glass) and exploitation (to avoid randomly and inefficiently exploring the compositional envelope forever). The balance between exploration and exploitation is a tradeoff—since both pure exploration (random trial-and-error search) and pure exploitation (simply fine-tuning existing glasses) are inefficient strategies. In that regard, various optimization methods are available to achieve an ideal balance between exploration and exploitation.

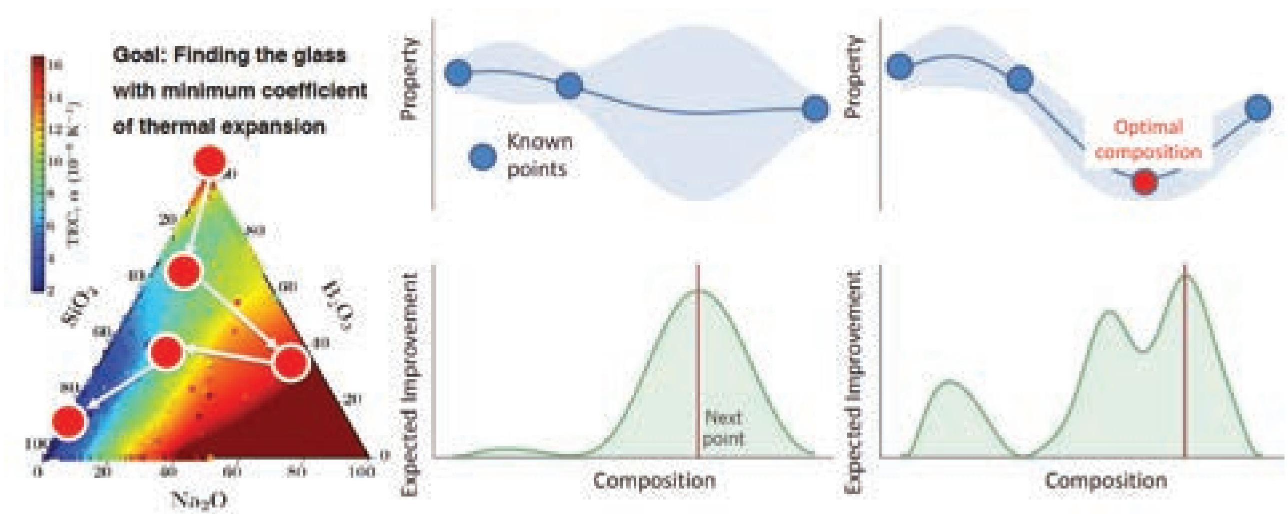


Fig. 5: *Illustration of a glass discovery task by Bayesian optimization. As an example, the goal is here to discover a glass featuring the lowest coefficient of thermal expansion (CTE) within the Na2O–B2O3–SiO2 ternary compositional domain. Starting from a series of glasses with known composition and CTE (blue circles), a Gaussian process regression machine learning model is trained—which predicts the compositional dependance of the CTE (blue curve) and confidence interval of the prediction (blue shaded area). Based on these two pieces of information, the expected*

improvement function (green curve) predicts what should be the next glass composition to try (i.e., the composition that exhibits the maximum probability of featuring a minimum CTE value). Once this new glass is synthesized and tested, it is added to the dataset (red circle) and the machine learning model is retrained. The expected improvement function is then recalculated to identify the next glass composition to try. This iterative process is repeated until convergence (i.e., until an ideal glass with low CTE is discovered).

For material discovery, the most common approach is probably Bayesian optimization (see **Fig. 5**). This approach consists of the following steps. Assume that the goal is to identify the glass composition *x* that exhibit a minimum coefficient of thermal expansion (CTE,). Based on a dataset of glass compositions (*x*) and associated CTE, a machine learning model is first trained to map the composition of a glass to its CTE and uncertainty thereof (). This can be accomplished by training a Gaussian process regression model, which intrinsically embeds an estimation of the accuracy of the property prediction—for instance, the model is aware that it exhibits a large uncertainty (large confidence interval) when predicting the CTE of a glass that is very different from the glasses used to train the model. One then calculates an "expected improvement" function, which combines the knowledge of (i) the predicted evolution of the CTE as a function of composition and (ii) the uncertainty thereof . The goal of this function is to prescribe the next most promising glass that is the most likely to exhibit a decrease in CTE as compared to the previously tested glasses. This is achieved by finding the best balance between (i) considering the glasses that are predicted to exhibit minimum CTE (by exploiting the maxima of the predicted function) and (ii) considering the glasses that are located in poorly-sampled compositional domains (by exploring the regions featuring large values). The glass composition prescribed by the expected improvement function is then synthesized and tested, which, in turn, offers a new datapoint that is appended to the dataset. The machine learning model is then retrained based on this new dataset, before a new promising glass composition is prescribed again by the expected improvement function. This process is then repeated until the optimal glass is discovered. This type of search is efficient since, at each step, it focuses on the most promising glass (without wasting any time on considering non-promising glasses) and allow the model to learn from its own mistakes or get comforted in its successes (since the "true" properties of the prescribed glasses are added back to the dataset after being tested). As such, machine learning and Bayesian optimization make it possible to accelerate the discovery of new glasses by minimizing the number of glasses that need to be tested before the ideal glass is identified (see the right panel of **Fig. 1**). Thanks to this powerful discovery paradigm, one can only hope that it will not take long before the discovery of a new glass formulation that will change the world, again.

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Advances in Glass for Optics and Photonics

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Being able to see cells on a microscopic scale or contemplate the universe through the lenses of Hubble telescope was possible thanks to the ability of researchers to understand the complex properties of vitreous materials. Such an impressive and overwhelming development has been only possible because of new advances in technical characteristic measurement, allowing a better understanding of the structural, optical, and thermal properties. Further, in the last 20 years, we assisted a great competition in exploring new glass compositions leading to new applications, particularly in optic and photonics. One of the keys enabling glass materials in various spheres of optic and photonic applications is the ease of molding into different forms ranging from thin films to microstructure fibers. Here we discuss a series of future opportunities in glass for optic and photonic devices.

Smart Glass

The fourth industrial revolution is happening now, involving a paradigm shift from glasses to "smart glasses". Smart glasses are glassy that respond (active) in a controllable and reversible way, under determined conditions, front external stimuli, and nowadays are employed in diverse technological applications. For instance, since 2012 many companies have launched their smart glass products, among those is Google with its "Google Glass" and others such as Sony, Microsoft, and Epson. Smart glasses are used also in buildings, for instance, electrochromic smart windows ("green" nanotechnologies)[1], which are able to vary their throughput of visible light and solar energy by the application of an electrical voltage and are able to provide energy efficiency and indoor comfort in buildings, represents a key element in the energy and environmental performance of the buildings. Many projects have demonstrated the advantages of the use of smart windows, such as saving, approximately, 60% of the need for artificial light, a reduction in the cooling load by up to 20%, and peak power up to 26%[2]

Another field of smart glasses is the clinical practice through bioactive glasses are a special subset of oxide-based biocompatible glasses that can bond to hard and soft tissues and stimulate new tissue growth while dissolving over time, making them highly attractive materials for healthcare and regenerative medicine[3].

Augmented reality with smart glasses is today a powerful technology supporting shop-floor operators undertaking various responsibilities such as assembly, maintenance, quality control, and material handling, with the finality of improving the performance and product quality. This enables users to conduct tasks without extensive physical effort, for example, information visualization, image, data processing, internet navigation, information transmission, sharing, risk detection, and warning). Here, the overlaying of virtual information on the real worldview is called ``augmented reality,'' and applying this concept makes it possible to enhance a human's perception of reality. In order to enable the user to see the virtual objects and interact with the environment, there are three devices: (i) head-worn devices, (ii) hand-held devices, and (iii) spatial devices[4]. These devices implement diverse types of optics to visualize information to the user, but all those are based on smart glasses. In addition, augmented reality on mobile devices is dominated by smartphones. The shift in mobile devices from smartphones to smart glasses will happen early. Hence, smart glasses have great potential to become the main platform for augmented reality. So far, it is obvious that this gap represents an immense opportunity to researchers to develop comprehensive approaches to interaction in a hybrid user interface employing smart glasses.

Glass for Infrared region

The development of glass composition with heavy metals oxide glasses having optical transparency in the mid-infrared region has stimulated several researchers to explore different families of glasses. This includes fluoride, germanates, tellurites, antimonates**,** tungstates, and germanates. The most developed in the form of fiber are fluoride, germanate, and chalcogenide as optical fibers. Specifically, by using appropriate process of purification, Le Verre Fluoré company in France achieved optical losses (1dB/km) at 2.5 μm. Such results allowed researchers at Laval University to develop IR-fiber laser operating in the window range of 2.7 to 3.4 μm with good stability and higher out power with applications for dentistry and cosmetics[5]. Another family of glasses operating in the mid-infrared is the gallo-germanate glasses doped with barium named BGG. These glasses are thermally and mechanically more stable compared to fluoride or chalcogenide, allowing the manufacture of a high-efficiency laser. Also, such glasses have been used as domes for military applications[6]. Remarkable progress has been achieved in the development of these glasses as host media for rare-earth ions for optical amplification or as non-linear media. Nevertheless, their production as optical fibers still a great challenge because of surface crystallization during drawing process.

In the form of film minces, chalcogenide glasses have been used as waveguides enabling propagation losses of 0.7 $dB \cdot cm^{-1}$. Recently, a hybrid chalcogenide-silicon microresonator with a Q factor of 6.02×10^5 has been produced[7]. Further improvement in the fabrication process should enable higher Q-factors and open the way to new non-linear optical sources such as Raman or Brillouin lasers and Kerr soliton combs. A promising solution for low-cost, compact non-linear photonic devices with applications in various fields such as telecommunications and spectroscopy is undergoing.

Glass in Neuroscience

Thanks to the advent of optogenetics in back 2005[8], it became capable of manipulating the neural circuit using light with high precision in targeting specific groups of neurons. To underline how the brain encodes information and guides behavior, it is essential to develop a method to deliver light into the deep brain region of freely moving animals without loss. Silica fiber has been spotlighted and has become an invaluable tool in optogenetics as a waveguide into the deep grain region due to its high transmission, biocompatibility, and easy accessibility in the market. The first demonstration of optical fiber for in vivo optogenetic stimulation was performed in 2007 using a flat-cleaved multimode silica fiber with a fiber core diameter of 200 μm.[9] The silica fiber performed its duties well in delivering light for deep brain optogenetic stimulation, which could lead to distinguishable behavioral change in early study. As the individual even within the same type of neurons exhibits different response patterns[10–12], scaling down the simulation volume from genetically identified neuronal groups to individual neurons is necessary. It prompts the fiber photometry to evolve to satisfy the high spatial specificity in photostimulation in completely contradictory two approaches: (1) enlarging the fiber diameter for fiber-optic imaging[13,14] or (2) reducing the fiber diameter to spatially restrict the illumination volume[15,16].

Fiber-optic bundles consisting of several thousands of individual cores enable us not only to stimulate selective stimulation of individual neurons but also to image and record neural activity simultaneously with a high spatial resolution in combination with genetically encoded activity sensors. Either graded-index[13,17] or convex lens[14] is assembled with the fiber bundles to create the focal plane at the tip of the fiber and to enhance the collection efficiency of the fiber . On the other side, numerous attempts have been made to reduce the fiber tip dimension and thereby increase the spatial resolution, taking advantage of the minimal invasiveness of the fiber.[15,18] Although the approach in the direction of decreasing the fiber dimension demonstrated manipulating and recording of neural activity from only a single cell yet, it can evolve for a multiple-neuron stimulation and recording by adopting the fiber array scheme. In the scheme, the spatial resolution is determined by the density of the fiber arrays. Therefore, a further study on the fabrication process must be performed in a way to improve productivity and reduce the fabrication cost.

There have been revolutionary advances in neuroscience, which was ignited by optogenetics and genetically encoded activity sensor. However, such advances could have been realized in combination with advanced fiber optics. To understand the fundamental operating principle of the brain network, there is still a long way to go, and further advances in illumination and collection schemes with optical fiber are prerequisites. There are ongoing questions for the two approaches about how to reduce the invasiveness and fabrication costs, respectively. Future studies should answer the two questions to continue the advances in neuroscience.

Optical Tweezers (OT)

In 1986, Ashkin developed a single-beam particle trapping system via a highly focused laser beam, i.e., optical tweezers invention[19]. Such contribution to science was recognized with a Nobel Prize in Physics in 2018. From this invention, the ability and capability to manipulate particles are of big interest in science and technologies fields. In an OT, the particle's motion is controlled due to the optical field, more specifically in a photophoretic trap, the particle motion is due to the interactions of the trapping optical field with the particle via gas kinetics of air molecules and thermal exchange. But, if the trapped particle is in an anisotropic means, it can be challenging to design a system to trap the particle for a long time. Because prolonged laser light illumination of a specific spot could modify the means. In this framework, glass-fiber optical tweezers (GF-OT), based on optical fiber tips, have been developed with various structures for different applications[20]. It is important to mention that there are several types of optical fiber tip geometries. GF-OTs simplify the setup of optical tweezers removing the microscope objectives from the working space. In addition, GF-OT gives new advantages such as flexible shape, robustness against disturbance, and highly integrative. One other important development from GF-OTs is the combination with advanced laser spectroscopic techniques (fluorescence, absorption and Raman spectra, time-resolved Raman spectra among others) to achieve on-trap single-particle studies or sensing.

New advances in fabrication techniques have led to the development of plasmonic tweezers in which plasmonic waves amplify the optical force[21]. In general, a plasmonic wave is an evanescent wave highly localized at a metal/dielectric interface. Such dielectric can be glass with a gain optic. Hence, a robust enhancement and localization of an electromagnetic field at a certain point called a plasmonic hotspot could induce deeper trapping well allowing nanoparticle trapping. In this case, such hybrid tweezers benefit from the advantages of optical resonators coupled to the plasmonic units in an amplifier glass.

Although the addressed application fields here need to be further investigated, GF-OTs have a key role in several different application fields, with special emphasis on Biology and Medicine. Hence, is not so unreasonable to envision, that in a near future, a miniaturized optical device based on GF-OTs, controlled remote, is able to simultaneously guide light, sense, trap, and manipulate micro-sized cells.

Glass lasers

Doped glasses with rare-earth ions (REI with 3^+ valence) remain the most heavily utilized method for laser gain in laser glass. The 4f electrons are the responsibilities to the optical emissions and couple weakly to the glass structure. The presence of multiple structural sites in the glass creates a range of dipole environments, which is ideal for engineering broad bandwidth REI-doped photonic device materials, suitable for laser and amplifier devices. Therefore, REI-doped glasses are transparent, which can amplify light by the stimulated emission of radiation, i.e., a source of solid-state laser. For a good laser glass performance emission, the identification of the glass composition goes through the find the REI-doping concentration ideal and the solubility glass for the REI[22]. Here, two factors must be considered: the wavelength for a uniformity pumping while avoiding the phenomenon called concentration quenching of the REI. Moreover, the performance of the laser glass is also influenced by residual hydroxyl (O-H) groups within the glass structure introduced by conventional melt quenching techniques, hence, it is important to consider purification techniques in the fabrication process of the glass in order to optimize the laser glass performance. The best example is the materials science and technology organization at Lawrence Livermore laboratory that supplies optics for high-energy and high-power laser systems. This laboratory is mostly focused on fourth major areas: optical fabrication, laser-matter interaction, Chemical, and laser post-processing, and bulk materials allowing to produce the most advanced doped glass in the world.

For active devices, high REI-doping concentrations are usually required for integrated optic circuits, therefore, it is required glasses with high solubility to REI. This is because REI clustering effects become important leading to a low emission performance. For instance, the low solubility of REI in silica or chalcogenide glasses due to the mismatch in size, valence, or ion covalency between the REI and the constituents of the glass network is an issue to overcome, but other glasses overcome such issue[23].

The development of optical telecommunication is based on the growth of technologies of fiber fabrication and of laser diodes. Nonetheless, the insatiable need for high-capacity communications results in a permanent reconsideration of the glasses to employ as well as a new manner of transmission of information. In this context, optical fibers are most often used to transmit information between two points a with high velocity of transmission and low loss, this can also be used as an active medium for amplification purposes and laser development. In these cases, REI-doped fibers are used for their light-emission properties (gain and amplification). Dense wavelength division multiplexing (DWDM) technique was developed to meet the demand for multichannel transmission, which is until today supported by Er^{3+}-doped fiber amplifiers (EDFAs). The installation of EDFAs in DWDM networks has led to increases in the speed of data communication, and over the last 25 years, the speed has increased from 100 Mb/s to more than 5 terabits (Tb/s). However, as the data speed approaches several Tb/s, there is a bandwidth limitation in the traditional EDFA[24]. With the development and installation of special optical fiber, the opportunity for extended bandwidth can get over the C-, L-, and U-bands via co-doping of the REIs which have efficient optical transitions inside and outside these two bands[25] To recall, the gain per unit fiber length depends on the concentrations of dispersed REI in the fiber. Those ions act as the emission centers in the medium for light amplification. Therefore, to design the emission spectra of REI-doped glass, consequently of optical fiber, it is of vital importance to understand the relationship between the local ligand field and the optical properties of specific 4f-levels (radiative transition probability, the decay probability, and quantum efficiency of amplification transitions).

Plasmonics may join electronics and photonics at the nanoscale by providing an actual solution to the problems of integration and data transfer rate to the nanoscale. Such a new approximation is so-called Nanophotonics and is dedicated to nano optoelectronic components, offering extended bandwidths and high processing speeds. However, remains a challenge to use plasmonic circuits in on-chip configurations due to the required precise control over the plasmonic modes and their properties, particularly those related to their loss. In this context, REI-doped glasses can be employed as substrates, plasmonic-nanostructure + gain-medium, i.e. hybrid materials, have shown great potential for applications in photonics, fuel cells, among others, thanks to their unique optical properties[26].

Finally, the increase in the demand for new temperature sensors gave rise to REI-doped glasses as new material for optical thermometry due to their temperature dependence on the emission properties of RE-doped materials[27]

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Fiber Optics for Communications

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Where Were We?

In 1956, Larry E. Curtiss, a junior year physics student at the University of Michigan developed the first practical method of making all-glass flexible fiber optics when he used a rod-in-tube method to combine commercially available high index core glass rods with low index cladding glass tubes and draw the composite into fibers. Although quite lossy, enough light was transmitted to open the door to a medical device business using bundles of these fibers for endoscopes, a business that still thrives today.

In 1960, Theodore Maiman, at Hughes Research Laboratories in Malibu, CA demonstrated the first solid-state laser when he pumped light from a xenon flash lamp into a single crystal ruby rod doped with chromium to create 694nm wavelength pulsed light, ushering in the enormously successful laser industry. Communications companies of the day, such as AT&T, IT&T, British Post Office and others realized the significance of using high frequency laser beams for high-capacity transmission of information, but it was quickly realized that transmission of these light beams through air was impractical and conventional fiber optics were much too lossy.

Charles Kao, a physicist at Standard Telecommunications Laboratories in Harlow, UK measured various glass fibers transmission and concluded in 1966 that if impurities could be significantly reduced, the intrinsic light scattering of glass might be low enough to reach a signal loss of just 20dB/km (or 1% transmission through a one-kilometer-long glass fiber), equaling the transmission of electricity through copper wires. However, the very best quality optical glasses at that time had losses of ~1000dB/km or 10^{98} too high for fiber communications! Kao encouraged numerous glass researchers to try to surmount this almost inconceivable hurdle. Corning Glass Works assigned physicists Robert Maurer and Donald Keck, and chemist Peter Schultz to "see what they could do". After four years of effort, in 1970 the team made a titania-doped silica core single-mode optical fiber with a loss of 17dB/km using vapor deposition methods to purify the glasses (called flame hydrolysis). In 1972, using a germania-doped silica core and pure fused silica glass cladding and an improved vapor deposition technique called outside vapor deposition (OVD for short), they announced a record-breaking loss of just 4 dB/km (or

40% transmission over one kilometer) and in a paper published soon after predicted that if hydroxyl (water) impurities could be eliminated, the loss could be as low as 0.2 dB/km at 1550nm wavelength (95% transmission over one kilometer). This breakthrough opened the door to practical fiber optics for telecommunications.

Corning built a pilot production facility in 1975 (as one executive said: "it was like building a gas station before the automobile was invented") and in 1977 General Telephone and Electronics (GT&E) successfully deployed the world's first "live" fiber optic cable link (containing Corning fiber) into their Long Beach, CA network.

Where are We Now?

Over the next 25 years, many engineering hurdles were overcome to improve fused silica-based optical fiber performance and strength, to economically mass produce them, cable them, connect/splice them and deploy them on land and under the sea. Light-emitting diodes (LED's) were first used with multimode fiber designs and replaced in 1984 by laser diodes using single mode fibers, thereby greatly improving their information carrying capacity. Single mode fibers have a core size of ~ 9 microns inside a 125-micron OD cladding (approximately the diameter of a human hair). Multiple wavelengths were transmitted simultaneously (called wavelength division multiplexing), each carrying its own information stream without crosstalk. Complex and costly electronic signal regenerators (repeaters) were replaced by fiber laser amplifiers spliced into the network, and fiber designs were improved to minimize signal distortion due to intrinsic glass material dispersion, modal dispersion and chromatic (emitter) dispersion, allowing longer distances between repeaters. Variations on the OVD vapor deposition process were developed to produce the doped fused silica core glass rods including vapor axial deposition (VAD), modified chemical vapor deposition (MCVD) and plasma vapor deposition (PCVD).

All these improvements led to deeper and deeper penetration of fiber optic cables into the telecommunication network: first in long haul "trunk" lines (crisscrossing continents city-to-city) and interconnecting continents under the sea, then into "middle mile" links between city central offices and local area networks. By the mid 1990's the stage was set for a true information revolution. Worldwide fiber-based high-capacity communication networks combined with the advent (and computing power) of the laptop personal computer (1981) and user-friendly software(~1985) and the "mouse" inexorably led to the formation of….*the internet*! Suddenly, everyone could be easily interconnected through e-mail ("You've got mail" in 1993) and the demand for more and more information carrying capacity soared, a demand that could best be met by optical fiber.

Another surge in demand for bandwidth occurred with the introduction of the smart phone in 2007 and app store in 2008. Today, 7 billion people own a cell phone accounting for 90% of the global population. Cell phones are transmitting wirelessly to a cell tower and from there the signals are typically routed through hard-wired (fibered) networks. Without fiber optics, cell phone communications as we know it today would not exist.

It is estimated there are now 4 billion email users worldwide sending and receiving 300 billion emails every day. Undeleted emails, attachments, historical files and "selfies", etc. are typically archived (stored) in The Cloud: huge Data Centers located around the world, each containing tens of thousands of computers, storage devices, routers, servers and switches, all interconnected via optical fiber allowing seamless storage and nearly instantaneous retrieval of all this information via powerful search engines.

Today, over 4 billion kilometers of fiber are deployed worldwide (equivalent to 100,000 times around the equator) and the demand for more seems almost insatiable. The first fiber "preforms" (the rod containing the core and cladding glass made by vapor deposition) were the size of pencils and when drawn at ~2000°C in towers just a few meters tall yielded just a few kilometers of fiber. Today these preforms are the size of telephone poles and yield over 6000 km of fiber with a loss of 0.182 dB/km at 1550 nm (touching the intrinsic limit). The lion's share of these fibers is single-mode design and are still based on the germania-doped silica cores invented in 1972. Fiber draw speeds are >50 m/sec draw towers are six stories high, and all fiber are proof tested at 150 kpsi tensile strength (guaranteed to last 25 years).

Where are We Heading?

June 2022 will mark 50 years since the first 4 dB/km germania-doped fused silica core fiber was made. The technology has clearly stood the test of time and no obvious substitute material or communication technology is in sight for use in typical applications. However, specialty fibers, such as ultra-low loss pure silica core fibers are now being developed and deployed for long distance undersea links (to limit the number of amplifiers needed). Hollowcore fibers (air cores with specially designed silica glass cladding) are also under development for use in very low latency applications. A myriad of fiber optic sensors are constantly being developed to take advantage of the sensitivity of optical fibers and coatings under pressure, temperature and other extrinsic forces. Last, but not least, fiber optic lasers are now capable of delivering more than 100 kW of power. Lower power fiber lasers are used in applications such as steel cutting and welding where the flexibility and low maintenance of these systems outshine conventional gas lasers.

Finally, the “last mile” or fiber-to-the-home and fiber-to-the-premises (FTTH and FTTX) are being deployed in earnest. When the first fibers were deployed, the wild dream was to have one day “video phones” to see the caller. That dream has been met and surpassed many times over. What will come next? It is impossible for me to predict, but I do know that optical fiber based on fused silica glasses will continue to play a critical role in global communications infrastructure for many years to come.

Glass in High Power & Energy Lasers

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After its invention more than 70 years ago, lasers are in so many aspects of our lives including barcode scanners, laser printers, medical treatments, and laser machining to name a few. The laser light is created, directed, and manipulated by optics such as by increasing its energy, reflecting, and focusing. Glass is a go-to material for optics because of its high transparency, bulk clarity (homogeneity), and stability (mechanical, chemical & thermal) as well as because of the ability to control its bulk properties through changes in composition and its surface topology with precision via optical fabrication.

This is especially the case for glass optics used in high power & energy lasers. A great example is the world's most powerful and energetic laser, the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (Figure 1). The NIF laser is an experimental facility which creates extreme temperatures (100 million degrees) and pressures (100 billion atmospheres) used to study conditions relevant to our nuclear stockpile in the absence of further underground tests including the fusion process (also relevant to fusion energy) and other high energy density science research. The NIF has 192 laser beams with an aperture size of ~35 cm housing >7000 ~0.5m scale optics.[1, 2]

Figure 1. *Photo of one of the two laser bays of the NIF.*

Figure 2 shows two specific glass optical components used in the NIF. The first one is Nd-doped phosphate laser glass, which is the heart of the laser system where the Nd atoms within the glass (which leads to its beautiful purple color) aid in stimulated emission resulting in laser gain (i.e., increase the fluence (energy/area) of the laser light). The NIF contains over 3000 slabs of Nd-doped laser phosphate glass.[3] The second one is the grating debris shield optic made from fused silica glass. This optical component experiences the highest laser fluence at an ultraviolet wavelength of 351 nm, and hence is the most prone to laser damage by tiny absorbing imperfections on its surface. The surface of the grating debris shield has a repeating surface structure called an optical grating (similar to that on a CD or DVD) which results a small portion of the transmitted laser light to be diffracted into a sensor to diagnose the laser beam.

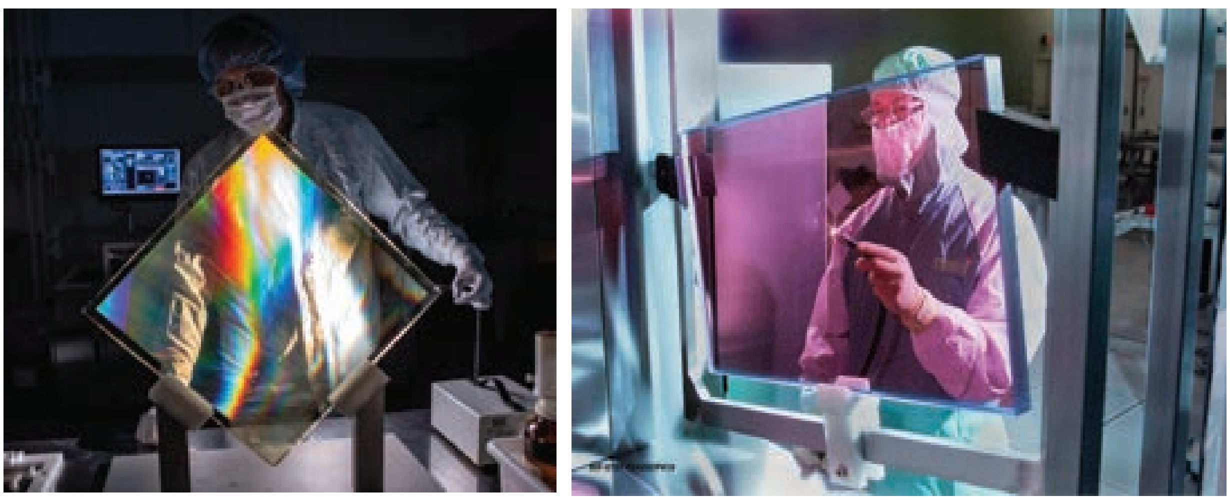

Figure 2. *Photo of two large optics used in the NIF laser: Nd-doped phosphate laser glass (46 x 81 x 4 cm^3) (top) and fused silica glass grating debris shield (43 x 43 x 1 cm^3) (bottom).*

The quality level needed for these optics is demanding, including: bulk uniformity (i.e., homogeneity) <5 parts per million (ppm); surface shape control <200 nanometers (~1/3 of the wavelength of visible light) across the length of the optic; surface roughness <5 angstroms (which is just a few atomic bonds); and laser damage resistance that is record breaking to ensure optic survivability. This demanding quality level has been achieved with these glass optics and the other NIF optics. In addition, this has been an enabler for NIF to routinely operate at these high power & energy levels (500TW/1.8MJ). *Recent NIF shots at these levels have provided experimental results that fusion ignition (i.e., more energy generated relative to the input laser energy) is within reach, opening doors for the possibility clean fusion energy in our future.*

The ability to tailor the glass composition aided tremendously in optimizing properties to maximize the laser characteristics (i.e., ability to extract the laser energy), to improve the manufacturability, and to improve the durability of the Nd-doped phosphate laser glass. First, phosphate glass was chosen over the more common silica-based glass because of its superior laser properties. In addition, the specific multi-component phosphate glass composition was chosen after a comprehensive study. Figure 3 illustrates this using a 3 component (ternary) composition diagram, which show the various glass compositions synthesized. Having the right combination of laser, mechanical, and chemical properties, the resulting commercial laser phosphate glasses used on NIF are LHG-8 (from Hoya Corporation) and LG-770 (from Schott Glass Technologies). Notice that these commercial glasses lie along specific ratio of O/P=3 (referred to as metaphosphate) which provide the ideal glass atomic structure for these properties. Other key technical challenges that were overcome for fabricating this glass include: 1) minimizing Pt inclusions in the glass that can cause laser damage; 2) reducing the water (OH) content in the glass to maximize laser gain; and 3) reducing fracture during processing to improve manufacturing yield.[4]

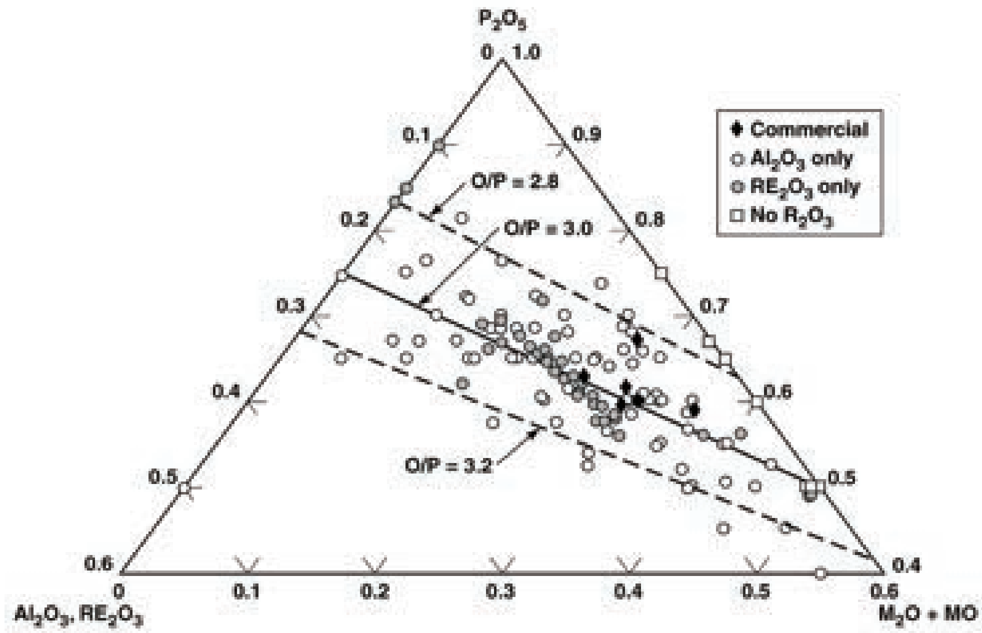

Figure 3. *Ternary P2O5 - Al2O3,RE2O3 – MO+M2O composition diagram showing both research and commercial laser glass compositions. RE=rare earth atom (e.g., Nd); M=modifier atom (e.g., K, Mg, Ba) (after [3])*

The ability to alter and improve the surface shape and quality of the fused silica glass optics (like the one shown in Figure 2 bottom) aided to improve both how precisely the laser light propagated through the optic and how much laser light can pass through without it damaging. Figure 4 shows the progression of how these improvements in surface quality over the years have led to four orders of magnitude reduction in the number density of laser damage sites. Many of these advances can be linked to an improved fundamental understanding of the glass materials science behind optical fabrication and the physics of laser–matter interactions. More specifically, the precursors that lead to laser damage were identified (such as scratches/digs, chemical impurities, and depositing precipitates) and significantly reduced via improved grinding/polishing, cleaning, and chemical etching methods. Again, these advances have enabled the NIF to operate at high power and energy.[2, 5]

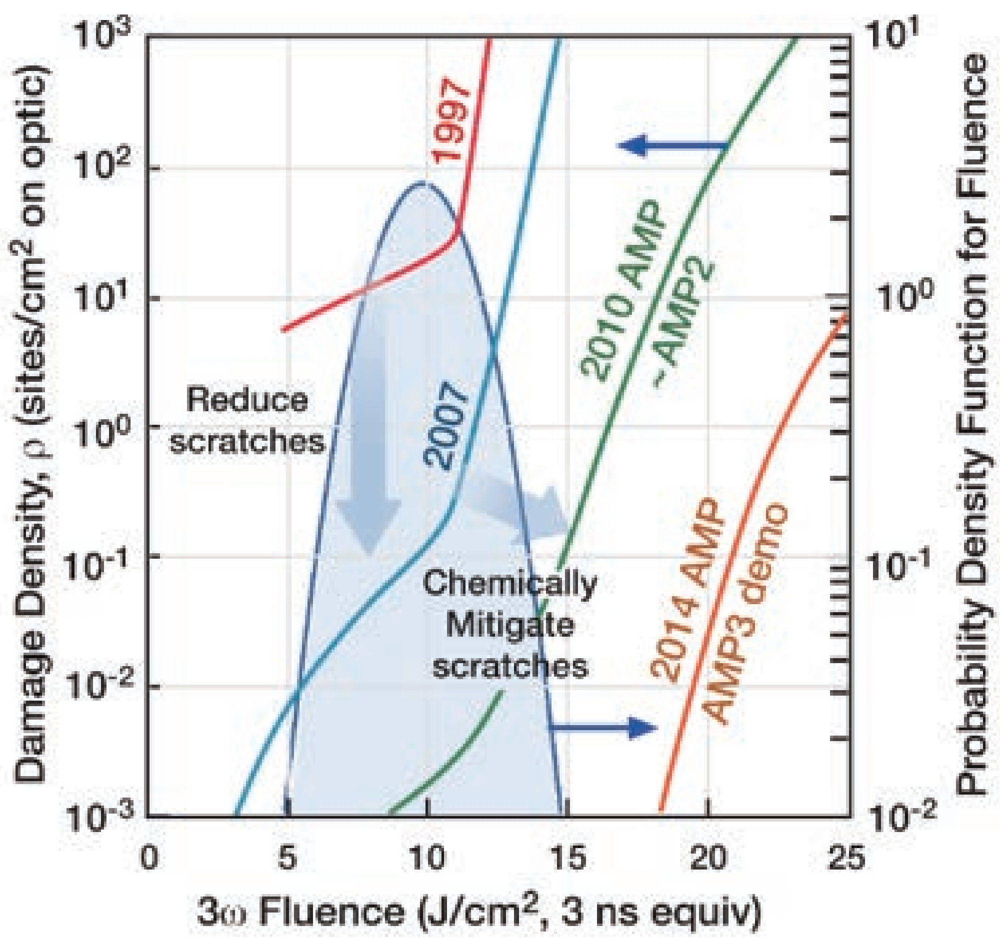

Figure 4. *Laser damage density on a fused-silica optic surface as a function of 351 nm laser fluence. The lines represent the quality level of the optics at various times and the shaded region indicates the relative fluence distribution expected on a 1.8-MJ NIF laser shot. (after [2, 5])*

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Vitrification: Using Glass to Stabilize Radioactive Wastes

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Vitrification as a method to treat hazardous and radioactive waste involves the conversion of the waste to a stable glassy matrix. In the context of the long history of glass making, the development of waste vitrification is relatively recent, dating back to work in the 1950s in the US, Canada, the UK, and France that investigated the ability of melts of various minerals and glazes to incorporate nuclear waste constituents. The essential idea is that molten glass is a very powerful solvent that is capable of dissolving wastes of diverse compositions, whereby their constituents first become part of the glass melt and, ultimately, part of the solid glass product. The waste constituents are thus incorporated into the glass structure at the atomic scale and are therefore very effectively bound in the glass matrix. Glasses, and particularly silicate glasses, can be extremely resistant to aqueous corrosion, as evidenced by the fact that man-made and natural glasses have survived in the environment for thousands to millions of years, respectively. Thus, while glass may seem to be a strange choice as a material in which to immobilize dangerous radioactive wastes, these and other features make it very well suited for that role. Glass is an amorphous material and is able to incorporate numerous elements over wide composition ranges. The amorphous nature also makes glass properties relatively insensitive to the effects of radiation and radioactive decay, which can include significant atomic displacements in the structure. Finally, the basic glass making process is relatively simple and robust, making it well-suited for use in radioactive production environments. For these and other reasons, vitrification has become the international method of choice for the treatment of the most dangerous radioactive wastes and particularly those that are generated from the reprocessing of spent nuclear fuels, often referred to as high-level nuclear wastes (HLW). That application has been the primary driver for development of waste vitrification technologies over the past several decades.

The technology for reprocessing spent nuclear fuels was developed for defense programs, dating back to the Manhattan Project, where the objective was to extract plutonium for weapons production; in its modern form, it is used for reprocessing some spent fuels from commercial power generation. While the wastes from both of these applications are typically treated by vitrification, defense wastes are much more chemically diverse and are present in much greater volumes and therefore represent a very different challenge. The first reprocessing facility – and indeed the first production reactor – was operated at the Hanford site, the largest of what became more than 130 sites in the US nuclear materials production chain for which the US Department of Energy (DOE) now has cleanup responsibility. As the cold war drive for plutonium production increased, so too did defense HLW generation. At Hanford, from 1943 to 1964, 149 underground carbon steel single-shell tanks were constructed to store these wastes, followed, beginning in 1968, by 28 double-shell tanks with capacities of up to 4400 m^3; the tanks have design lives of 20 and 50 years, respectively. Together, the tanks contain about 210,000 m^3 (56 million gallons) of waste and about 195 million curies of radioactivity, about 60% of the reprocessing wastes in storage in the US. The Hanford tank wastes reflect the history, and full chemical diversity, of the development of modern reprocessing technology. Sixty-nine of the tanks are known to have developed leaks. In view of the location of these facilities along the banks of the Columbia River, treatment of these wastes – the world's largest nuclear waste vitrification project – represents one of the most pressing and challenging environmental remediation issues.

Unlike commercial reprocessing wastes, the acidic wastes at Hanford were neutralized with sodium hydroxide to prevent corrosion of the carbon steel tanks used for storage. In fact, the roughly 50,000 metric tons of sodium that was added constitutes the majority of the solids in the waste that now needs to be treated. Since the vast majority of the atoms in the waste are not radioactive, the waste will be separated into a large stream that contains most of the mass but as little as possible of the radioactivity (the low-activity waste (LAW) fraction), which is cheaper to treat, and a much smaller stream into which most of the radioactivity is concentrated (the HLW fraction), as shown in Figure 1. The HLW sludge is formed by precipitation of most of the heavy metals and long-lived transuranics that occurs upon neutralization of the acid wastes. The residual high-sodium salt solution (supernate), and crystallized supernate (saltcake) contain most of the radionuclides that are soluble at high pH, such as cesium and technetium. In the Hanford Tank Waste Treatment and Immobilization Plant (WTP) that is under construction, the HLW and LAW fractions will be separately vitrified. The LAW glass product is designed for on-site shallow-land disposal while the HLW glass is designed for disposal in a National geologic repository. The WTP consists of a Pretreatment Facility to perform the separation, LAW and HLW vitrification facilities, a laboratory, and more than 20 support buildings. The WTP is by far the world's largest nuclear waste vitrification facility. The WTP Pretreatment Facility alone is 12 stories tall and the size of four football fields.

A variety of technical issues have delayed completion of the Pretreatment and HLW Vitrification facilities. The focus has therefore shifted to startup of the LAW Vitrification facility, which is planned for 2023 (HLW is now planned for 2035). This requires bypassing

Pretreatment and adding new facilities for cesium removal (the Tank Side Cesium Removal (TSCR) system, which employs ion exchange) and for secondary wastes (the Effluent Management Facility (EMF)) in the so-called Direct Feed LAW (DFLAW) approach. The TSCR system is up and running and has already treated several hundred thousand gallons of LAW that is now staged for vitrification.

The basic components of a vitrification system typically include a feed preparation and delivery system, a glass melter, an exhaust gas ("off-gas") treatment system, and a glass product handling system. The Hanford WTP includes four such processing lines, two each for LAW and HLW, each with the most complex off-gas treatment systems ever used for vitrification due to the unique regulatory requirements. The wide range of glass melting systems that has been explored for waste vitrification can be broadly categorized in terms of the method by which energy is supplied to effect the feed-to-glass conversion. These include joule-heated ceramic melters (JHCM), hot-wall induction melters, cold-wall induction melters ("cold-crucible"), indirect resistance-heated melters, plasma torch melters, electric arc melters, microwave melters, and various types of combustion melters including commercial glass melters, cyclone melters, and submerged combustion melters. Combustion melters are generally not practical for nuclear waste applications where electric-fired melters are preferred for safety and simplicity.

As with other nuclear waste vitrification plants in the US, the Hanford WTP melters are based on JHCM technology, developed in the 1970s. A JHCM consists of a ceramic refractory-lined cavity that contains a pool of molten glass and submerged plate electrodes that are typically located on opposite walls. The molten glass is an ionic electrical conductor due primarily to the presence of alkali elements in the formulation. An alternating voltage applied to the electrodes causes current to flow through the melt. Resistive heating occurs and power is dissipated throughout the volume of the melt. As a result, in contrast to systems where heat is supplied at the surface, this system is, in principle, infinitely scalable, which is a crucial feature for the very large scale US nuclear waste applications. The feed, an aqueous slurry formed from waste that is pre-blended with the chemical additives (at the WTP) or glass frit, is pumped onto the surface of the molten glass where it forms a floating layer of reacting material known as a cold cap. The cold cap is highly stratified in both temperature and composition and many complex processes that convert feed to glass occur in this layer. Progressively deeper into the cold cap, water and other volatiles are evaporated, salts are decomposed and melted, various transient phases are formed and consumed, and finally, new glass is formed.

The first production scale application of slurry-fed JHCM technology to HLW vitrification was the joint German-Belgian PAMELA facility (0.72 m^2 melt surface area) that operated in Mol, Belgium from 1985 to 1991. In the US, JHCMs have been used at the former spent fuel reprocessing site at West Valley, NY (2.2 m^2), and at two facilities at the Savannah River Site (2.6 m^2 and 5 m^2), and also in Japan, and India; China has been developing and testing defense HLW vitrification systems based on German JHCM technology since the early 1990s. Vitrification facilities at Mayak in Russia have employed distinctly different JHCM designs, more closely resembling those used in commercial glass manufacturing.

The feed-to-glass conversion reactions are governed by the substantial flows of heat and mass through the cold cap region, which can be rate determining. Historically, JHCMs have relied on slow natural convection to produce mixing in the viscous glass pool. In melter bubbler technology invented at the Vitreous State Laboratory (VSL) in the early 1990s, gas bubbles rising from organized arrays of outlets transfer momentum to the molten glass, which increases mixing and the rate of heat and mass transport to the reacting feed material in the cold cap on the glass surface. The result is an enormous boost in glass production rates, up to about a factor of five. The first production-scale deployment of melter bubbler technology was in the M-Area Melter at the Savannah River Site, which is still the largest radioactive waste melter to have operated in the US. It is also incorporated into all of the melters at the Hanford WTP and was successfully retro-fitted into the Savannah River Defense Waste Processing Facility (DWPF) melter in 2010, resulting in a doubling of the melter throughput compared to prior operations since startup in 1996.

The Hanford WTP has two 10-m^2 LAW melters and two 3.75-m^2 HLW melters, all of which include bubblers, each with nominal glass production rates of 15 metric tons (MT) per day and 3.75 MT per day, respectively (Figure 2). The LAW melters – each about 9 m x 6.5 m x 5 m, weighing 330 tons – are the largest of their kind ever built. To achieve the same throughput without bubblers, the melters would either need to be five times larger or ten melters would be needed, with concomitant many-fold increases in capital and operating costs, which are already in the many tens of billions of dollars.

By comparison to US JHCM systems, in France and the UK, where the vast majority of commercial spent fuel is reprocessed, the resulting high-level nuclear waste is vitrified using hot-wall induction melters. In these melters, heat is supplied by inductively coupling to the metal wall of the melter. Consequently, the wall is the hottest part of the system, which limits melter lifetime to a few thousand hours due to metal corrosion and creep, as compared to five years or more for JHCMs. Since energy is supplied through a surface (the melter wall) to heat a volume, the practical size of such melters is limited by heat transport considerations, so higher throughput requires multiple melters in parallel (six lines at the La Hague facility in France and three lines at the Sellafield vitrification facility in the UK). Each melter has a glass production rate that is about one twenty-fifth that of one Hanford

LAW melter. Hot-wall induction melter vitrification of nuclear wastes has been ongoing in France since 1978.

Of the many possible glass-forming systems, silicate glasses are by far the most widely used for waste vitrification and that is also the case for Hanford LAW and HLW. The primary reason for the use of silicate glasses is their resistance to aqueous corrosion and, although their compositions differ in detail, natural silicate glasses provide a useful connection to the geologic record in terms of understanding potential modes of degradation over the time scales for decay of the longest-lived radionuclides. Such natural analogs include volcanic and meteoritic glasses and range in age from recent to hundreds of millions of years. More specifically, borosilicate glasses are used since the addition of boron reduces the melting temperature (~1050 – 1200 °C is typical) and improves the chemical durability. Lower melting temperatures reduce corrosion of vitrification equipment and increase their lifetime. Phosphate glasses have also been investigated extensively for nuclear waste vitrification but have found much more limited use. At the Mayak facility in Russia, nuclear wastes from weapons production have been vitrified using sodium aluminosilicate glasses. While these glasses have relatively low processing temperature (~1000 °C), they are prone to devitrification, have much poorer chemical durability than silicate glasses, and are much more corrosive in the melt, which challenges the selection of materials for melter construction and reduces melter lifetime. The more recent development of iron phosphate glasses for waste vitrification has mitigated some of these issues. However, like other phosphates, the melts and melt vapors are still very corrosive to the typical metal alloys that have been successful for use with silicates, which remains a challenge for practical applications.

An important aspect of the design of appropriate glass compositions for treatment of a given waste stream is optimization with respect to the solubilities of the most limiting constituents in the waste, since that determines the "waste loading" in the final product; waste loading is the fraction of the mass of the final glass product that originates from the waste, rather than from chemical additives. Chemical additives are used to tailor the feed composition so that the melt and glass product have the desired properties. For example, many high-level nuclear wastes contain very little silicon, which therefore is supplied as a chemical additive, either in raw form as silica or in the form of a non-radioactive glass frit or cullet. Waste loading is an important factor in the overall treatment economics since it determines the amount of glass that is produced from a given amount of waste, which drives processing and disposal costs, and the amount of additives used. Melting rate, another important economic factor, is also affected by glass composition and additive selection. The glass melt also must be compatible with the selected glass melter technology, which typically involves melt viscosity, electrical conductivity, phase behavior, corrosivity, etc. Finally, the glass product must perform its intended function in immobilizing the constituents of concern against aqueous leaching. Glass formulation development is therefore a problem in constrained multivariate optimization (meeting property constraints by varying glass composition), where the desired solution is a viable and robust operating envelope for the process. To the extent that quantitative relationships and correlations between the key glass properties and the glass composition are available, this is, in principle, merely a mathematical problem; in practice, however, development of such relationships for glass compositions with dozens of components is a very substantial undertaking and is an active area of research. Examples of such models for Hanford LAW and HLW glasses are shown in Figure 3.

Advances in glass formulation can also lead to improved process efficiency and simplification. For example, the WTP Pretreatment Facility is designed to separate the HLW solids from the supernate by filtration; remove cesium from the supernate by ion exchange; wash the solids to remove interstitial supernate; remove aluminum and chromium from the solids by caustic and oxidative leaching, respectively; and combine the ion-exchanged cesium with the HLW solids for immobilization in HLW glass. However, breakthroughs in glass formulation at VSL have significantly reduced the need for several of those steps. For example, higher aluminum capacity in the HLW glass means that the need for aluminum removal from the HLW solids by caustic leaching is reduced; this also reduces the amount of added sodium, which decreases the amount of LAW glass. Similarly, higher chromium capacity in the glass reduces the need for its removal by oxidative leaching. Such performance improvements through glass formulation optimization and process chemistry have the advantage of being essentially transparent to the engineered facility and are therefore easy to retrofit. A program that the VSL began for DOE in 2003 to apply this approach to Hanford has to date led to projected 30 – 50% reductions of the amount of glass and near-doubling of melt rates. These gains have come through departures from more traditional nuclear waste glass formulations and have included lower-silica, higher-boron glasses as well as the addition of components such as V, Sn, Zr, Zn to increase sulfur incorporation and reduce glass leaching and refractory corrosion (Table 1). Waste loadings in glasses for Hanford high-sodium LAW are limited either by molten sulfate salt formation (liquid-liquid phase separation) for high sulfate wastes or refractory corrosion and aqueous leach resistance when the alkali content is limiting.

The glass from nuclear waste vitrification processes is typically poured into metal canisters that are designed for disposal in engineered repositories. The performance of these repositories must be assessed over the time scales characteristic of the decay of the relevant radionuclides, which typically extend to tens of thousands to millions of years. Such assessments typically employ reactive chemical transport modeling that takes into account the coupled effects of fluid flow and glass-water reactions on the chemistry of fluids percolating through the disposal facility. An essential component is therefore knowledge of the mechanisms and rates of the glass-water corrosion reactions and their variation with solution composition and other environmental factors. These complex processes are the subject of active research. The early stage of glass corrosion is characterized by alkali-hydronium ion exchange and hydrolysis of the silicate matrix. The latter is often modeled in terms of first-order kinetics proportional to the residual reaction affinity (essentially, the departure from saturation with respect to an assumed pseudo-phase); the rate is also assumed to be Arrhenius and dependent on the solution pH. In principle, all species affect the reaction affinity but typically only silicic acid is used. Although ion exchange is often assumed to be a short-term transient, it has been argued that since the reaction affinity rapidly approaches zero, alkali release by ion exchange actually controls the long-term rate via dissociation of silicic acid, which increases the affinity and thereby causes more glass to dissolve.

As the glass continues to dissolve, the combined ion exchange and hydrolysis of the silicate network leads to the formation of a multi-layered reaction zone including a hydrated porous gel layer that is depleted in the more soluble glass components (e.g., alkalis, boron) and enriched in the less soluble components (e.g., Al, Fe, and Si), and crystalline phases that precipitate on the surface. The rate of dissolution then continues at a relatively constant residual rate that in some cases is consistent with a process controlled by diffusion through the hydrated surface layer. The key alteration phase is often a clay mineral, such as a smectite or chlorite. Finally, depending on the type of alteration phases that form, the glass-water reaction can increase from the residual rate and return to an elevated rate. This is due to a reduction in reaction affinity caused by the onset of the formation of certain secondary phases, which drives the solution away from saturation and causes the glass corrosion rate to increase. Various zeolite phases have been identified to form during this process and tests that are seeded with such zeolites have been shown to transition to the higher rate of glass corrosion. Thus, while there is good evidence for glass passivation in the reaction process, the stability of such passivation can be affected by secondary phase formation. While there has been great progress in characterizing and analyzing these processes in general, and the nature of the glass alteration layers in particular, the behavior is very complex and strongly dependent on glass compositions and environmental conditions. Somewhat paradoxically, these requirements are actually more stringent for Hanford LAW glasses than for HLW glasses since, whereas the latter are designed for deep geologic disposal, the former are designed for disposal in a shallow-land engineered facility.

Vitrification has been used successfully to treat a variety of nuclear wastes and progress continues to be made to improve performance and better understand the long-term behavior of nuclear waste glasses in disposal facilities. The impending startup of the Hanford WTP LAW vitrification facility will provide a crucial step forward in addressing a major threat to the environment.

Table 1. Examples of Representative High Waste Loading Glass Compositions Developed for Hanford WTP LAW and HLW Vitrification (Source: VSL).

Component, wt%	LAW Glasses		HLW Glasses	
	High Sodium	High Sulfur	High Bismuth	High Aluminum
Al2O3	9.00	7.58	11.66	23.97
B2O3	11.00	9.82	11.30	15.19
BaO	0	0	0.01	0.05
Bi2O3	0	0	6.71	1.14
CaO	1.95	10.02	0.84	6.08
CdO	0	0	0	0.02
Cl	0.26	0.41	0	0
Cr2O3	0.34	0.50	0.52	0.52
F	0.04	0.04	0.82	0.67
Fe2O3	0.34	0.24	6.96	5.90
K2O	0.54	0.55	0.46	0.14
Li2O	0	2.49	0.16	3.57
MgO	1.00	1.04	0.43	0.12
Na2O	24.00	16.00	15.74	9.58
NiO	0	0	1.93	0.40
P2O5	0.12	0.14	4.99	1.05
PbO	0	0	0.25	0.41
SO3	0.60	1.50	0.48	0.20
SiO2	39.35	41.19	36.26	30.50
SnO2	1.02	0	0	0
TiO2	0.34	0	0.16	0.01
V2O5	1.55	1.74	0	0
ZnO	3.00	3.21	0.16	0.08
ZrO2	5.55	3.53	0.21	0.39
Total	100	100	100	100

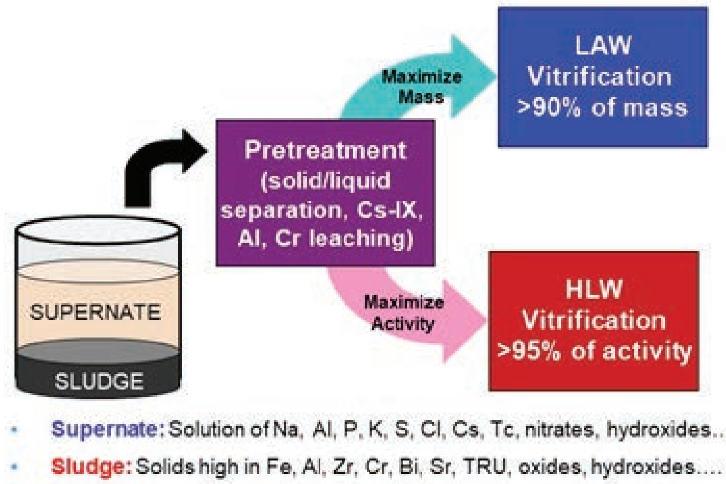

Figure 1. Schematic overview of tank waste treatment at the Hanford WTP.

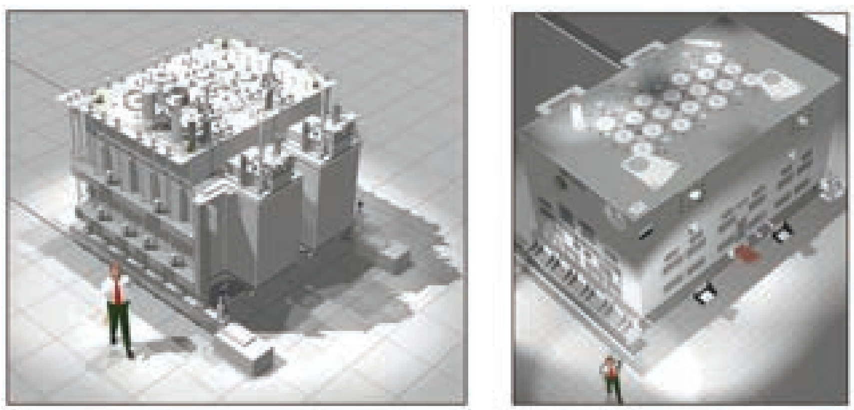

Figure 2. Hanford WTP HLW (left) and LAW (right) melters (Courtesy Atkins Nuclear).

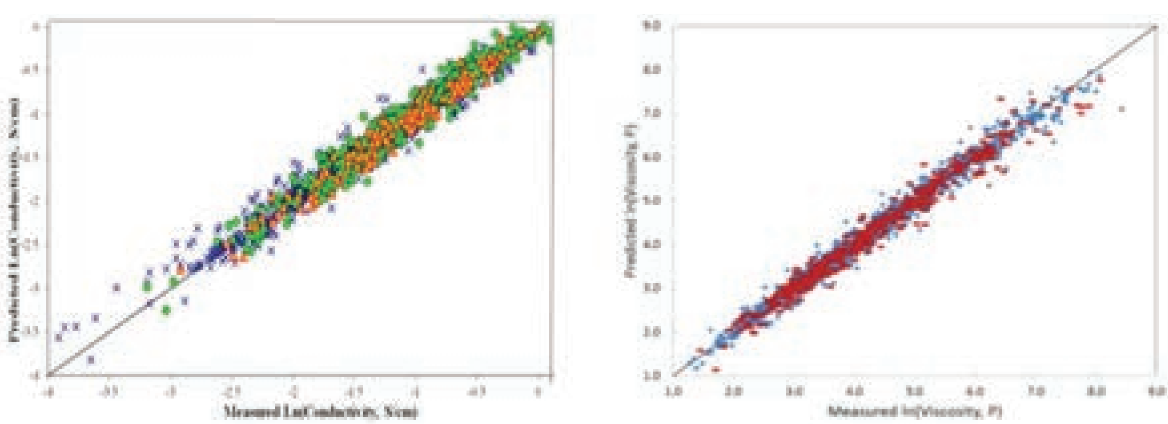

Figure 3. Predicted-versus-measured plots for models for melt electrical conductivity of WTP LAW glasses and viscosity of HLW glasses (Source: Data and models from VSL).

Nuclear Waste Vitrification

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Background

High-level nuclear waste (HLW) is the highly radioactive biproduct of reprocessing of irradiated nuclear fuels originally for weapons production and later for recycling of fissile/ fertile content of the fuel (legal definitions vary between countries).

Table 1. Nuclear waste vitrification facilities examples

Plant[(a)]	Location	Waste[(b)]	Melter[(c)]	Startup
AVM	Marcoule, France	HLW	HWIM	1978
WIP	Trombay, India	HLW	HWRM	1985
WIP	Tarapur, India	HLW	HWRM	1985
Radon	Moscow, Russia	ILW	LFCM CCIM	1985 1999
Pamela	Mol, Belgium	HLW	LFCM	1985
MCC	Mayak, Russia	HLW	LFCM	1987
R7	LaHague, France	HLW	HWIM	1989
			CCIM	2010
WVP	Sellafield, UK	HLW	HWIM	1990
T7	LaHague, France	HLW	HWIM	1992
TRP	Tokai, Japan	HLW	LFCM	1995
DWPF	Savannah River, US	HLW	LFCM	1996
WVDP	West Valley, US	HLW	LFCM	1996
VICHR	Bohunice, Slovakia	HLW	HWIM	1997
AVS	Tarapur, India	HLW	LFCM	2008

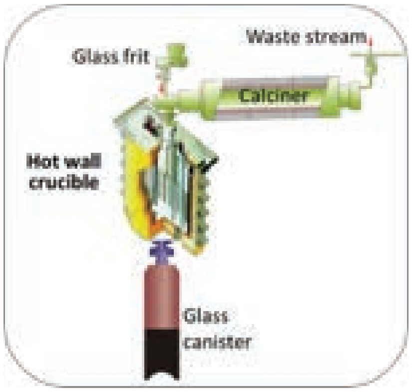
UVF	Ulchin, ROK	ILW	CCIM	2009
VEK	Karlsruhe, Germany	HLW	LFCM	2010
WIP	Kalpakkam, India	HLW	LFCM	2012
GVP	Guangyuan, China	HLW	LFCM	2021
WTP	Hanford, Richland, US	LAW HLW	LFCM LFCM	2022 TBD
RRP	Rokkasho, Japan	HLW	LFCM	TBD

[a] AVM: Atelier de Vitrification de Marcoule, WIP: Waste Immobilization Plant, MCC: Mining and Chemical Combine, WVP: Waste Vitrification Plant, TRP: Tokai Reprocessing Plant, DWPF: Defense Waste Processing Facility, VICHR: vitrification process-Chrompik, AVS: Advanced Vitrification System, UVF: Ulchin Vitrification Facility, VEK: Verglasungseinrichtung Karlsruhe, GVP: Guangyuan Vitrification Plant, RRP: Rokkasho Reprocessing Plant, WTP: Waste Treatment and Immobilization Plant

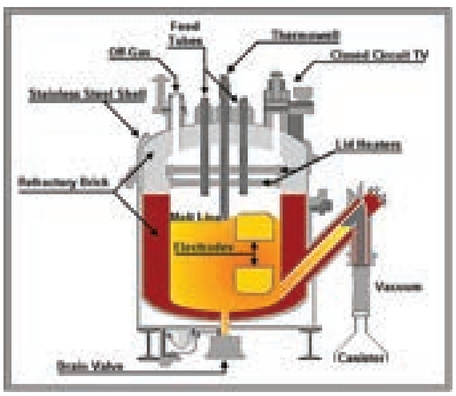
[b] HLW: high-level radioactive waste, ILW: intermediate-level radioactive waste, LAW: low-activity waste

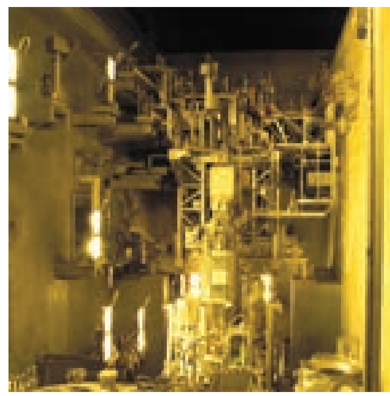
[c] CCIM: cold-crucible induction melter, LFCM: liquid-fed ceramic-lined melter, HWIM: hot-walled induction-heated melter, HWRM: hot-walled resistance-heated melter

The HLW contain long-lived fission products and actinides that require immobilization from the environment for extended periods. Vitrification, the transformation of a material into a glass, is the technology of choice for immobilizing HLW around the world. Waste glass research began in the 1950's along with other candidate nuclear waste forms. Glass was selected as the primary nuclear waste form for its high tolerance to waste composition variation, fast continuous processing, and high chemical durability. It quickly became the most technically mature technology with industrial-scale waste vitrification beginning in 1978 at the *Atelier de Vitrification de Marcoule* (AVM) plant in France. Since that time over 20 facilities have started, and several completed, nuclear waste vitrification (see Table 1 for examples). A specialized set of melter technologies were developed to meet the challenges of high-radioactive environments, liquid or slurry waste feeds, and radioactive gas generation. Figure 1 shows three examples of the commonly deployed waste glass melter technologies.

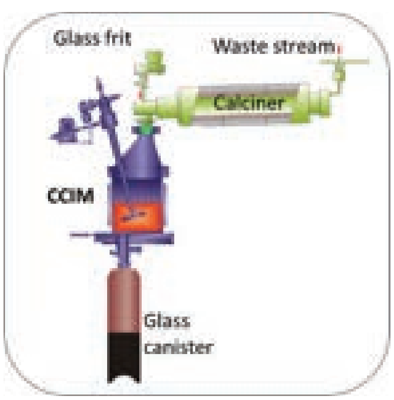


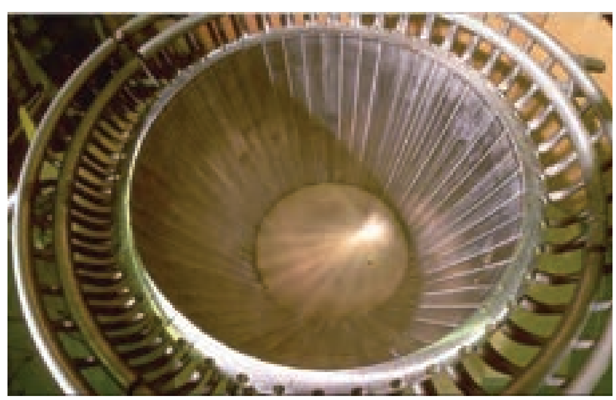
Hot-walled induction-heated melter (HWIM, images courtesy of Orano)





Liquid-fed ceramic-lined melter (LFCM, images courtesy of the Savannah River Remediation)





Cold-crucible induction melter (CCIM, images courtesy of CEA-Marcoule)

Figure 1. Nuclear waste melter technology examples

Nuclear waste glass compositions have been developed to satisfy a challenging set of constraints. First and foremost, the long-term release of radionuclides to the environment must be minimized by designing chemically durable glasses. Efficient processing of nuclear waste into glass through the melter and associated systems adds significant constraints, for example viscosity near 5 Pa-s at processing temperatures of 1100 to 1200°C. There are also constraints driven by the waste characteristics, such as waste incorporation and radioactive decay heat management. Originally, these constraints were met by glasses designed through an Edisonian process of glass composition changes and testing. More recently, the science of glass composition-structure-property relationships have progressed to the state that numerical glass composition design is possible. The focus of this review is on those advancements. A number of excellent reviews are available for further details.[1-9]

Composition of Typical HLW Glasses

With the notable exception of Russia, HLW glasses fall in the alkali-alumino-borosilicate composition family. Figure 2 shows a representation of the compositions of typical HLW glasses. Note that the composition region of Hanford HLW is significantly broader than those from other US and international waste glasses. The primary reason for this disparity is the range of Hanford HLW is significantly broader than at other sites since nuclear fuel reprocessing was first deployed there during World War II and many different processes and process variations were deployed. The culmination of these processes was the Plutonium-Uranium Reduction Extraction (PUREX) process from which the processes at all other large-scale reprocessing facilities were derived.

Some key differences between the glass compositions include higher lanthanide oxide concentrations in some of the international waste glasses which are offset in US waste glasses by higher concentration of three valent transition metals. Hanford waste also contains higher concentrations of Al2O3, B2O3, high-valent transition metals and halogen than the other waste streams. Alumina concentrations are from Al-cladding dissolution and the B2O3 replaces SiO2 for high alumina glasses. The four valent oxides are dominated by ZrO2 primarily from cladding dissolution; the five-valent oxides are dominated by V2O5 added to improve sulfate solubility; and the halides are dominated by F added to assist in zirconia cladding removal.

Recent Advances in Waste Glass Composition-Structure-Property Relationships

In recent years many detailed studies have been conducted to evaluate the structure of multi-component waste glasses. These include neutron and high-energy x-ray diffraction, nuclear magnetic resonance (NMR), x-ray absorption spectroscopy (XAS), and optical spectroscopy techniques. For examples, oxygen coordination number, Q-speciation and second nearest neighbor distributions, and bond-lengths and angles have all come into sharper focus. One interesting observation from a compilation of these data is that the range in variation of these parameters in typical waste glasses is significantly narrower than observed for other glasses reported in literature. This relative uniformity is attributed to the constraints placed on nuclear waste glasses. Despite broad ranges of single component concentrations in waste glasses, the ratios of similar components (e.g., modifiers) are relatively narrow. Some notable exceptions include the boron coordination between trigonal planar and tetrahedral (ratios being N3 and N4) which varies significantly from glass-to-glass.

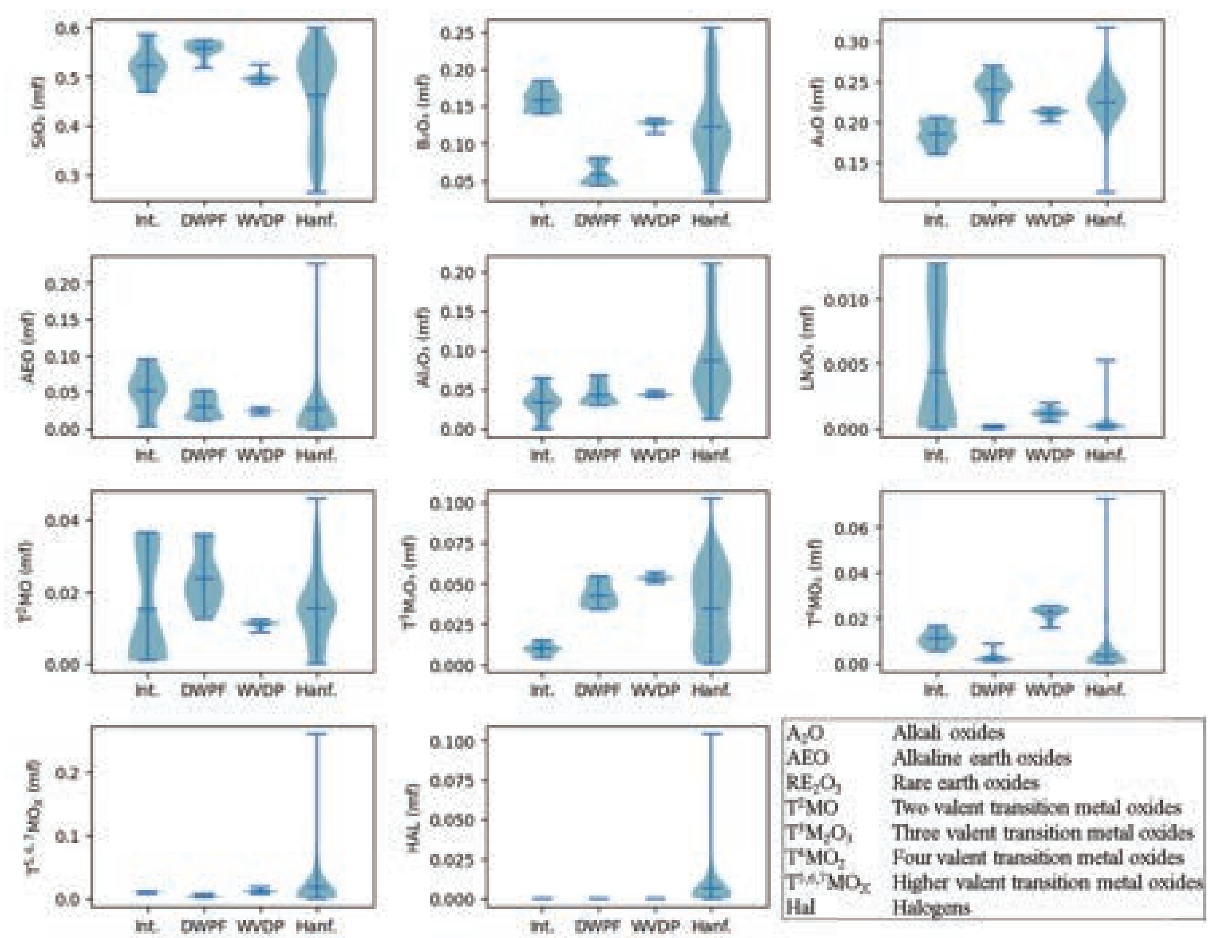


Figure 2. Distribution of major HLW glasses (international, DWPF, WVDP and Hanford) oxide concentrations in mole fraction.

Advances have been made in the ability to simulate the structure of multi-component waste glasses. Self-consistent sets of molecular-dynamic (MD) force-fields (FF) have been developed including a dozen of the most significant waste glass components. Ab-initio calculations of glass structure have also progressed to higher fidelity and more oxide components. These models, benchmarked with precise structure measurements, enable a detailed view of the glass structure including component coordination, second nearest-neighbor distances, bond lengths and angles, ring/cage size distributions, in addition to several physical properties. Reaction processes such as glass dissolution have been simulated using combinations of reactive FF MD and Monte-Carlo (MC) techniques. An interesting new advance in that arena was the MC simulation of corrosion using a classical MD glass structure which included both forward reaction and back reaction to an amorphous alteration product.

The enhanced structural data from closely coupled theory, experimentation, and simulation has led to a range of new quantitative structure-property relationships (QSPR). Most of these relationships are based on bond counting techniques which are further enhanced by bond vibration assumptions (i.e., topological constraint theory, TCT) or bond energies (i.e., Fnet). These QSPR models require prior knowledge of some of the key structural parameters. A model for boron coordination (N4) in complex glass compositions was recently published. This model extends the previous work on sodium borosilicate and sodium-aluminoborosilicate composition-N4 relationships to 20+ component nuclear waste glasses.

The properties of prime importance to nuclear waste glasses include viscosity, electrical conductivity, liquidus temperature, crystallization on slow cooling, and chemical durability. The viscosity and electrical conductivity of waste glass have been modeled as a function of the non-bridging oxygen concentration in the waste glass. Current work is ongoing to predict viscosity using physics constrained machine learning. Liquidus temperature of multicomponent glass melts was found to be related to bond lengths through an ion potential model with surprising precision – higher precision than empirical models. Liquidus temperature has also been modeled using quasi-chemical methods, octahedral site preference energy, associate species models, and quasi-crystalline methods.

As waste glasses cool in the canister, the centerline of the canister cools much slower than the outer edges and typically doesn't cool below the transition temperature for over 18 h. This slow, canister centerline cooling (CCC), may result in crystallization of unwanted phases. In US waste glasses the sodium alumino silicate – nepheline—is the primary concern. Nepheline formation typically degrades the chemical durability of the glass. The formation of nepheline as functions of glass composition and cooling schedule are highly complex leading to a range of non-linear models. Eventually models incorporating structural features of the initial melt were developed. The most successful models for prediction of nepheline in glass are based on machine learning techniques.

Chemical Durability of Glass

The effects of composition and structure on chemical durability of glass have been well researched. Early efforts correlated glass durability to the free energy of hydration of a mechanical mixture of glass constituents. Recent advances have shown that chemical durability is not a single material property that can be uniquely measured. Instead, it is the response to a host of coupled material and environmental processes whose rates are estimated by a combination of theory, experiment and modeling. The durability is typically divided into three primary regimes: 1) the fast initial rate regime that occurs when glass is initially contacted with water under specific temperature and pH conditions; 2) a slow, nearly constant rate of corrosion that develops when glass is corroded for long periods in static or slow moving conditions; and 3) a potential acceleration of rate that occurs when solution composition changes typically due to precipitation of glass components from solution. The first stage is the most related to glass structure and has been successfully modeled using TCT and Fnet models. The second stage is considered the most practically important for waste glass performance due to the slow water infiltration rates and long time horizons. Two chemical processes have been found to control corrosion rate during this stage: 1) solution saturation which reduces the driving force for dissolution (and under some circumstances can cause dissolution and reprecipitation) and 2) the formation of a dense passive layer that slows the migration of water into and glass components out of the glass. Geochemical models are therefore added to initial-rate models to predict the performance of glasses in this regime. The prediction of the sudden acceleration has received intense study over the last decade. Most recent efforts are focused on phase field boundaries in aqueous solution driving precipitation of zeolite phases.

Glass Composition Design

Waste glass design began, as did most materials design, using an experimentally intensive Edisonian process. This process took years to decades to develop each waste glass composition and associated processing envelope. These methods were and are sufficient for design of waste glasses when the waste composition remains relatively constant. However, that is not the case for WTP or, to a lesser extent, DWPF. Starting at roughly the turn of this century, numerical optimization techniques began to become popular. These processes had two major advantages: 1) the design time for new glasses shrank to months (for DWPF) to minutes (for Hanford); and 2) the glass compositions are better optimized and with higher waste loading. With the concurrent advent of machine learning techniques in materials science and expansion of nuclear waste glass property-composition databases, a new era of nuclear waste glass design is beginning in the 2020's. Both traditional and physics constrained machine learning techniques are being applied along with real-time materials discovery techniques to develop the next generation of waste glass compositions. The fruits of this exciting new frontier are yet to be understood.

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Glass: The Perfect Material For Managing Waste(S) From The Global Materials Cycle

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Glass has the ability to accommodate an array of chemical elements within its structure. This has made glass one of the perfect mediums for the stabilization of hazardous, toxic, and even nuclear wastes.[] Sometimes the vitrification process creates glasses that can be land disposed and/or reused/recycled. Other glasses, that retain their hazardous or toxic characteristics after vitrification, have to be buried safely.

Think about the "global materials cycle" (Figure 1) for just a minute. Every day commodities and engineered materials are made by a variety of synthesis and processing techniques that use one or more raw materials taken from the earth. These commodities or "things" have many applications as shown in Figure 1 as applications. However, when the "things" are used up, spent, no longer needed, or no longer working, they need to be disposed of and are considered by many as "wastes." Rather than accumulate wastes there are many options that allow a waste or trash material to be recycled and not to be disposed of in landfills or other specialized burial environments.[] Wastes that can be recycled can often be (1) engineered into new end uses (think about aluminum cans being recycled to make aluminum airplane parts) or (2) "things" that can be recycled into more of the same product (recycled paper being made into new paper products) so that the raw materials, trees, are conserved.

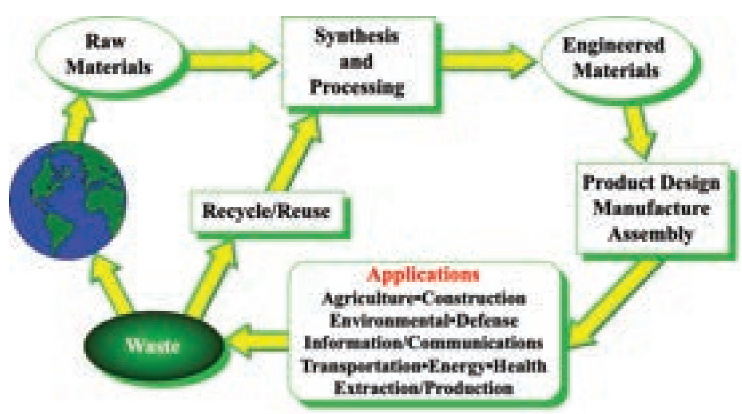

Figure 1. The global materials cycle

Why Use Glass ?

Why is glass the “the perfect material” for recycling while, at the same time, glass is also the safest minimal volume material for disposal back into the earth, if that is the only option available?

Glass is an attractive medium as it atomistically bonds the hazardous species in the solid glassy matrix. The structure of glass is flexible because it possesses short and medium range order (SRO, MRO) to bond the hazardous species to several different oxygen bonds. Thus, glass is flexible to composition variation in the waste(s) being vitrified. Often, once the hazardous species are atomically bonded in glass they pass the Environmental Protection Agencies (EPA) durability tests whereas the raw waste was not able to pass the EPA tests. Moreover, vitrification is a high temperature process that destroys organics. Many organics exist on the EPA Resource Conservation and Recovery Act (RCRA) lists of hazardous species.

The list below contains many unusual types of wastes that have been vitrified and rendered non-hazardous, i.e. New York harbor sludge, Pb paint, mining industry wastes, asbestos. Also, in this list are uses for domestic waste glass (wine and beer bottles, glass jars, broken window glass, and/or cooking ware) that is not hazardous but winds up in landfills. Much of the domestic waste can be “**upcycled**”…meaning a waste or a recycled glass product that can be reused in such a way as to create a product of higher quality or value than the original. Examples are discussed further below the table.

What Can be Vitrified ?	**What are the Uses for the Reclaimed/ Upcycled Glass ?**
Industrial wastes (examples follow) Wastewater treatment often involves filtering aids, after filtering the materials are contaminated with hazardous species and the "filter aid" can be vitrified [3,4] Waste sludges and/or liquid supernates [3,4] Ni plating line wastes [,] Harbour sludges contaminated with hydrocarbons and heavy metals [] Mining industry waste sludges [] Mining industry mill tailings [6,] Cathode ray tube (CRT) recycling [] Foundry sand and electric-arc-furnace dust [,] from metallurgical processing and ore refining [] Lead paint on tanks or bridges [,18-20] Failed cement formulations used for hazardous waste stabilization Ion-exchange resins and zeolites [] Asbestos-containing material (ACM) or inorganic fiber filter media [] Incinerator ash and slag [,] Upcycling of coal fly-ash from power plants (currently AARPA funded at SRNL with GlassWRX) Upcycling of wine, beer, glass jars in the CaO-Na_2O-SiO_2 system from domestic sources (currently AARPA funded at University of Utah, SRNL with GlassWRX) Diatomite soil waste from the brewing industry[18] Sludge from the pulp and paper industry[18] Radioactive applications (from nuclear fuel reprocessing, transuranic, plutonium, and other actinide materials	Roofing shingles Glassphalt (crushed glass is added to asphalt to improve its rigidity and enhance non-skid properties) for construction of roads (Hollywood Blvd – the reason that it sparkles is glass), highways (VA and NY), parking lots, airport runways, and driveways (see www – in use since the 1970's) Glasscrete (general term for crushed glass used as an aggregate in concrete) used for construction of highways, parking lots and airport runways (see www) Glasscrete® is a foam glass product that is made of 100% recycled glass (no concrete). Uses are lightweight aggregates for flooring and buildings, as well as, for insulation (see www) Engineered Cellular Magmatics (ECM's) - synthetic stone made of 100% glass that has been foamed and often contains ceramic/ mineral phases, many of which can be zeolitic. Manufactured by GlassWRX. ECMs are designed for specific chemical reactivity and structural properties not generally considered the domain of foam glass. ECM's are used for air and water filtration, bio and chemical remediation, microbial habitat for sequestering hazardous species from ponds and lakes, soil and cementitious amendments. Recent applications include sea wall construction of Roman type concretes made from mixtures of lime and ECM's to protect low lying communities due to sea level rise.

Spent Filter Aids from Wastewater Treatment and Water Filtration

Wastewater treatment to remove heavy metals involves filtration through high surface area (>50 m^2g^{-1}) silica based media such as perlite, perflo, diatomaceous earth, or rice husk ash (RHA). Perlite is used as a filtering aid before bottling beer and as a commercial pool filtration technology.

Perlite is a volcanic glass formed by the hydration of obsidian. When perlite is heated to temperatures of 850–900 °C, water trapped in the structure vaporizes. The escaping water causes the silica rich material to expand which provides the high surface area.

Diatomaceous earth (DE) consists of fossilized remains of diatoms (microscopic single-celled algae) that exist in lacustrine and oceanic sediments. DE is used as a filtration aid. Diatomite forms by the accumulation of the amorphous silica (opal, $SiO_2 \cdot nH_2O$) from the remains of the dead diatoms. Tubular filters filled with DE (known as filter candles) were successfully used during the 1892 cholera epidemic in Europe for water filtration.

DE has a high porosity because it is composed of microscopically small, hollow exoskeleton particulates of the diatoms. Diatomite and DE are also used to filter water, particularly in the drinking water treatment process and in fish tanks, swimming pools, and for beer and wine before human consumption. Rice husk ash (RHA) is from pyrolyzed rice husks. The rice plant absorbs pure SiO2 from the soil while growing. The rice husks are a farming (agricultural) waste byproduct.

Perlite contains between 74-76 wt% silica, while Perflo Super Cel (a certain type of perlite) contains ~73 wt% silica.[17] Diatomaceous earth (DE contains 67-68 wt% silica.[] Once ashed, or pyrolyzed, the RHA is 90% pure silica.

While waste waters and other liquids can be readily cleaned up by the use of reactive high surface area silica, the "used" or "spent" silica, which now contains the hazardous constituents, can be vitrified. The spent filter aids can be mixed with other wastes such as done in the Ni plating line example in the table above, or vitrified alone with some glass fluxes such as alkali oxides. It was determined by researchers at the SRNL, that the presence of the reactive filter aids in a waste glass greatly enhanced the solubility and retention of hazardous, mixed (radioactive and hazardous), and heavy metal species in glass.[3] The filter aids also lowered the melt temperatures.

Decontamination of Lakes, Ponds, and Streams With Glass Made From Wastes

Researchers from Spain have fabricated glass-ceramic Raschig rings from industrial and urban wastes, e.g. mixtures of glass bottles, pieces of animal bones, diatomite soil, waste from the brewing industry, and sludge from the pulp and paper industry. The glass ceramic Raschig rings encourage biofilms of microorganisms to developed on the surfaces and these microorganisms remove Cd and Pb from aqueous solutions such as lakes, ponds and streams. []

Decontamination of New York Harbor Contaminated Soil/Sludge With Glass

Sludge from harbors needs to be routinely dredged to maintain navigability. The soil/sludge is contaminated with oil, and other hazardous hydrocarbons and heavy metals from boats, ships, and cars going across bridges. Routinely, the sludge is dredged and then barged back into the deep ocean offshore without any treatment. This cleans up the harbor but just moves the contamination further off-shore.

Figure 2. Carol and Ronald Jantzen on the R.V. Manning taking sediment/sludge cores in Raritan Bay, NJ (~1968).

Vitrification is a viable means to immobilize the harbor sediment/slludge and render it nonhazardous. [5] Sludge loadings of 85 wt% have been demonstrated in the Na_2O-CaO-SiO_2 glass system at temperatures of ~1350°C. This temperature was chosen to be compatible with the Westingouse Plasma Vitrification System in which further scale-up testing was performed.

The vitrified harbor sludge could be recycled into products such as fill for asphalt roadways and other applications given in the table above. These options had been examined and deemed practical.

Thermal Spray Vitrification (TSV) for Removal of Pb Paint on Bridges and Tanks

Red-lead based primer is used to control corrosion of steel on bridges, ships, water storage tanks, military tanks, metal buildings, fire hydrants world wide. The TSV process was developed by the U.S. Army Corps of Engineers Construction Engineering Laboratory (CERL) to remove and stabilize the lead paint on steel structures by spraying molten glass onto the metal surface using a thermal spray gun (Figure 3).[] The hot glass vaporizes the organics and the glass bonds the Pb, Cr, and Cd. The glass spalls off the steel surface because of the thermal mismatch stresses that occur during cooling. In TSV there is no human uptake of Pb, Cr, Cd as there is during sandblasting, which is the most common technology to remove Pb paint from steel. A glass composition was developed [,] for use in the TSV process that accommodates high lead loadings and results in a glass product that passes the EPA characteristically hazardous release limits. Field tests have been conducted on a bridge, on an air- craft hangar door, and on fire hydrants: Over 300 fire hydrants have been remediated at Tyndall AFB.

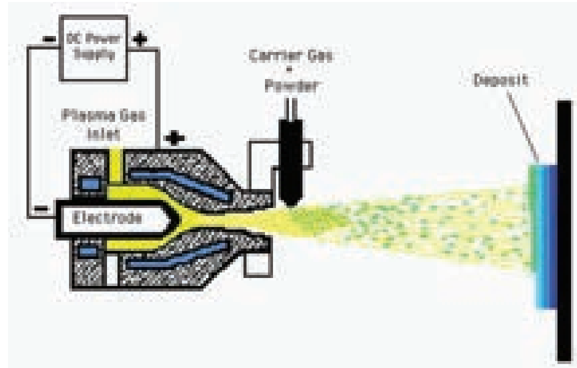

Figure 3. Schematic of Plasma Spray Apparatus where crushed glass powder or frit is mixed with a carrier gas.

Asbestos Containing Materials (ACM) Remediated with Glass

Currently, asbestos-containing materials (ACM) are disposed of by an involved process of sealing water-soaked asbestos in plastic for safe transportation and disposal into regulated landfills. The “wrap and bury” technology (Figure 4) results in large waste volumes, precludes recycle of the asbestos, and precludes the recycling of pipe for situations where asbestos covered pipe (used for carrying steam) is being disposed of.

Figure 4. Typical disposal of Asbestos covered steam pipes.

A hot caustic-bath process has been developed to safely remove ACM from metal pipes and structures [14,] which facilitates recycling of the asbestos and the metallic components. Glasses have been developed to stabilize asbestos and the associated filler materials which can be plaster of Paris, gypsum, etc.[14] Palex glasses (alkali magnesium silicate glasses) are tolerant of the high magnesium and calcium contents from the ACM and filler materials. Vitrification of ACM destroys the asbestos fibers and renders the asbestos nonhazardous. The resulting glass/glass-ceramic is suitable for many reuses.(see Table above.)

Mining Wastes Remediated with Glass

Wastes emanating from the mining industry also represent a significant environmental challenge both in the mining techniques and in the refining operations. Vitrification has been evaluated as a means to immobilize wastewater treatment sludge [6] and mill tailings [7] from mining operations that fail EPA characteristic hazardous leaching limits for cadmium. The use of a cement waste form is the current treatment route.

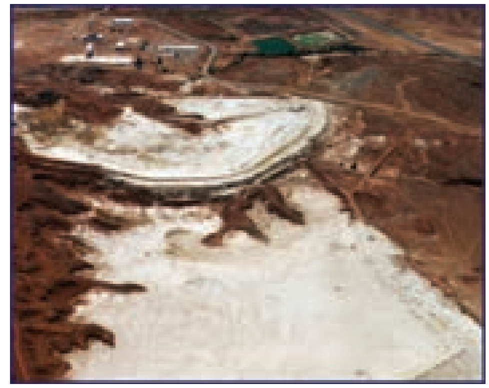

Figure 5 Generic mining industry above ground waste sludge ponds

Although the cement product passes the characteristic hazardous leaching limit for cadmium, little or no volume reduction is obtained by grouting the waste, and there is always a legal liability regarding disposal. The waste was made into three different types of glass: the Na_2O–CaO–SiO_2 glass system, the borosilicate glass system, and the basalt glass system at waste loading of 35-50 wt% on a dry oxide basis. The Na_2O–CaO–SiO_2 readily stabilized the mining waste and rendered it recyclable, which eliminates the legal liability associated with disposal. Homogenous glasses were formed with volume reductions up to 93% compared to the wet waste basis.

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Mathematical Modeling of Transport Phenomena in Industrial Glass Melting Furnaces

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1. INTRODUCTION

The computational fluid dynamics (CFD) based modeling of glass melting processes is used extensively in the glass industry and has become an important tool for furnace design and operation, and to a limited extent, for the process control. Choudhary et al.[1] have provided a comprehensive review of the theory and practice of mathematical modeling of flow and heat transfer phenomena in industrial glass melting, delivery, and forming processes. A recent book chapter by Choudhary[2] builds on the earlier publication and goes considerably beyond it to make it suitable for practitioners of mathematical modeling of glass melting processes at all levels; beginners to adepts. It includes sections on modeling related thermodynamics and transport properties of commercial glass melts and extended discussion on numerical solution, model validation, and secondary or post-processing models that transform the primary model outputs of velocity and temperature distributions into parameters (referred to as quality or performance parameters) that are meaningful to glass furnace designers, process engineers, furnace operators, and plant managers.

In this brief article we will present a synopsis of key developments in the CFD based modeling of industrial glass melting and delivery processes. Melting and delivery processes used across different segments of the glass industry (e.g. container, fibers, sheets, tubes, tableware) share common attributes and can be treated in a combined way. The forming processes, on the other hand, are segment specific and it would not be possible to cover them in detail here. We will, however, briefly note some forming modeling developments mentioned in Choudhary et al[1].

2. HISTORICAL PERSPECTIVE

The foundations for mathematical modeling of transport phenomena in industrial glass melting processes were laid in the 1970's. The computational limitations of those days necessitated the use of grossly simplifying assumptions for modeling of batch melting and linking the flow and heat transfer phenomena in the batch region to those in the glass melt and the combustion chamber of furnaces. Flow and heat transfer phenomena in glass melting processes are accompanied by and coupled with many other chemical and physical phenomena (e.g. combustion, batch reactions, evolution of gases, dissolution of silica grains in the melt, and volatilization). In the early days of mathematical modeling, it was not possible to properly account for this complex set of phenomena. One also had to use simplified geometries, the models were often two-dimensional, and modeling of electric boosting /melting was rudimentary. To have a proper perspective, let us note that even now, some 40- 45 years later, although glass furnace models are much more comprehensive and sophisticated, one still has to make many assumptions and approximations.

Serious interest in and use of mathematical modeling in the glass industry began in 1980's and accelerated in 1990's with astounding advances in digital computing along with the development of user-friendly computational fluid dynamics (CFD) software with extensive pre- and post-processing capabilities. Since the early 2000's and especially in the last decade, mathematical modeling has grown in sophistication in its ability to integrate the three main domains in the furnace (glass melt, batch, and combustion chamber), linking the melting and delivery sections, and incorporating improved (though still far from realistic) formulation of batch melting. Modeling has also benefited from the availability of more accurate and comprehensive information on transport properties and with an improved understanding of batch/glass surface movement generated by cameras. Further, the relevance and effectiveness of mathematical modeling to the practical issues of glass furnace operation and design has been enhanced by the development of post-processing parameters mentioned above.

Modeling of glass forming operations started in 1980s. Although initially very primitive, forming modeling has improved significantly over the last few decades. Most of the early studies in glass forming involved the simulation of hollow container production. Simplified mathematical models for glass bulb, tube, fiber, TV and sheet glass began to appear in the 1990s and in the second half of this decade several studies which investigated the drawing of single glass fibers were published.

The pre-2000 studies on mathematical modeling of glassmaking processes (melting and forming) are described in a wide ranging publication by Schott Glass describing.[3]

Mathematical modeling, with varying degrees of sophistication, is now common place in the glass manufacturing industry. Many large glass companies have in-house modeling capabilities or work with organizations that specialize in modeling of glassmaking processes, especially of melting and delivery, and to a limited extent, forming.

Mathematical modeling is used in the glass industry for a variety of purposes including solving production problems, improving production and energy efficiencies, enhancing furnace life, and reducing environmental emissions. It is also used to screen significant furnace design and operational changes before implementing them. Real time incorporation of transient three-dimensional modeling of flow and heat transfer into process control schemes is not feasible but attempts have been made to incorporate knowledge derived from modeling into control strategies. The economic benefits of using mathematical modeling have been widely recognized by the glass industry and many, especially large glass manufacturing companies have integrated modeling and affiliated tools into their manufacturing practices.

3. KEY PHENOMENA IN INDUSTRIAL GLASS MELTING

We provide below an abbreviated description of glass manufacturing and the phenomena that are modeled with the help of two figures. Fig. 1 shows the flow diagram of a typical industrial glass fiber manufacturing process and Fig. 2 is the schematic diagram of a glass melting furnace that uses both combustion and electricity to supply energy for heating and melting.[1]

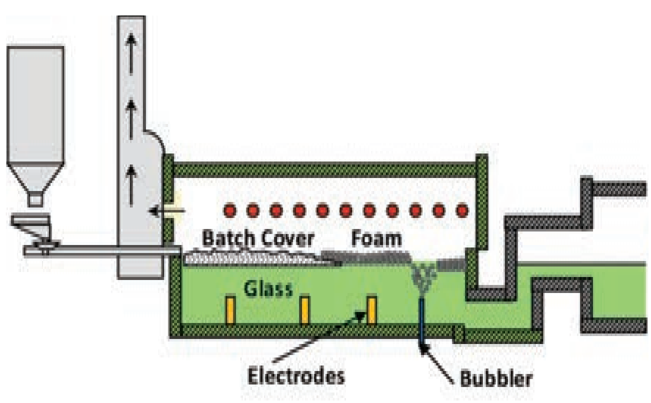

Fig. 1. Flow diagram of continuous glass fiber manufacturing. (The figure obtained courtesy of Owens Corning).

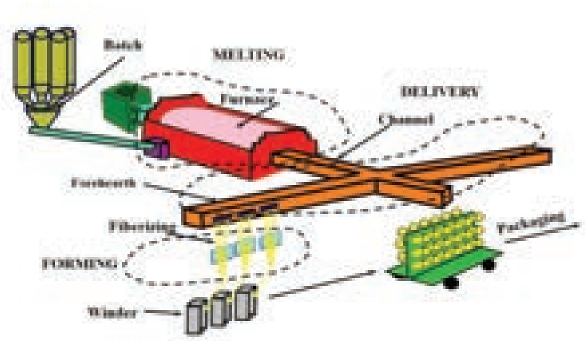

Fig. 2. Sketch of a generic glass furnace. (The figure obtained courtesy of Owens Corning).

Mathematical models of furnaces incorporate fluid flow and heat transfer and affiliated phenomena either in the melting section alone, and increasingly now in both the melting and delivery sections shown in Fig. 1. As can be seen from Fig. 2, the furnace models include the combustion chamber, the batch (the mixture of raw materials), the foam, and the glass melt and, depending on design and operation, electric boosting and bubbling.

The flow in the melt is due to thermal buoyancy (and in some cases also bubbling) and is laminar. The flow in the combustion chamber is highly turbulent. The rheology of batch (solid-liquid mixture) is complex and not adequately modeled. All the principal heat transfer media in a glass furnace (glass melt, combustion gases, batch, foam) are participating in nature, i.e., they modify thermal radiation by emission and absorption. The scattering of radiation in the glass melt and also usually in the combustion chamber is ignored. The phenomena of flow and heat transfer are coupled because the transport and thermodynamic properties are temperature dependent and also because, as mentioned earlier, the flow in the glass melt is due to thermal buoyancy. Listed below are important physical and chemical phenomena that take place in the four domains of a glass furnace. Many of these, especially in the batch and foam regions, are not modeled rigorously and represented at best through empiricism.

- **Combustion Chamber**

  Turbulent convective and radiative heat transfer accompanied by combustion reactions and heat effects associated with them.

- **Batch**

  Heat transfer accompanied by formation of melt layer (and its flow), dehydration and chemical reactions (with their heat effects), gaseous flow through the porous batch, heat exchange between gas and solid and gas and melt (unless assumed to be in thermal equilibrium).

- **Foam**

  Heat transfer in a cellular matrix containing gas bubbles enclosed in liquid lamella.

- **Glass Melt**

  Laminar, thermal buoyancy driven flow. Additional driving forces for flow may be present due to bubbling and surface tension gradients near the refractory walls. Conductive, convective and radiative heat transfer with heat generation in case of electric or electrically assisted melting. The modeling of physical phenomena of flow and heat transfer in the delivery section involves the same basic concepts and uses the same techniques as those in the melting section. But the delivery section does not contain batch and is much simpler to model than the melter.

The conservation equations for momentum and energy, of course, apply to forming also. However, forming entails different geometric scales and regimes for flow and heat transfer than those encountered in the glass furnace. Although the forming steps differ dramatically among different segments of the glass industry, mathematically the issues faced are quite similar. All forming models require methods to handle large free surface deformations, complex heat transfer boundary conditions, and, generally, a more elaborate treatment of internal radiation (e.g. the banded semi-transparent radiation exhibited by glass at temperatures typical of forming conditions) than the models for the glass melts in the melting and delivery sections. Also, the non-Newtonian behavior (i.e. the dependence of the viscosity on the shear rate) often cannot be ignored in forming models.

4. NUMERICAL SOLUTION OF TRANSPORT EQUATIONS

Transport equations governing mass, momentum, and heat transfer may be expressed as particular cases for the following general transport equation.

$$\frac{\partial}{\partial t}(\rho\Phi) + \nabla \cdot \rho v \Phi = \nabla \cdot \Gamma \nabla \Phi + S \qquad (1)$$

[rate of change convection diffusion source]

In the above equation, Φ is the general dependent variable (e.g. velocity component, enthalpy, electric potential), Γ is the generalized diffusion coefficient and S is the volumetric rate of generation or source term.

The recognition that the transport equations have the general form given by Eq. (1) greatly facilitates the development of generalized numerical approach and the associated computer code. Briefly, the numerical solution of Eq. (1) involves subdividing the modeling domain (e.g. furnace, channel, or the object being formed) into smaller volumes and applying the conservation laws in each of these volumes. This process of dividing the modeling domain into smaller volumes is called mesh/grid generation. The dependent variables (velocity components, pressure, temperature, electric potential, turbulence parameters, etc.) are assumed to vary in a presumed functional form within these volumes and the conservation laws are reconstructed. This results in one algebraic equation per discrete volume per conservation equation. The set of algebraic equations thus obtained are solved in a direct or iterative fashion to calculate the value of the dependent field variables in each of the discrete volumes.

The most commonly used numerical modeling techniques fall into three categories as follows: finite difference method (FDM), Finite volume method (FVM) and finite element method (FEM).

5. MODEL VALIDATION

Even the most comprehensive glass furnace models do not adequately capture some essential details of glassmaking processes, especially those taking place during the batch to glass melt conversion. Also, several input parameters to the model (e.g. transport properties of the melting batch layer, foam thermal properties, bubble dynamics, boundary conditions) are not known with much accuracy. For these reasons, it is vital to establish some degree of validation for the model and fine-tune it with respect to a reference or base case operating furnace. The fine-tuned model may be used in the directional sense, i.e. to look for trends predicted by the model rather than use the model for absolute predictions of temperature and velocity distributions. This is well recognized by the glass furnace modeling community and modeling is typically used to predict directional impact of changes in the design or operation of a reference furnace. The most detailed validation involves measuring temperature profile along the depth of the glass melt. This is not always feasible because of the challenges associated with temperature probing in the melt region of an operating glass furnace. Sometimes, tracer studies are performed to measure the residence time distribution (RTD) in the furnace and used to validate the model.

6. SECONDARY OR POST PROCESSING MODELS

The primary outputs from the CFD based models, namely, pressure, velocity, and temperature distributions, especially the first two, are in themselves not of great practical interest to furnace designers, process engineers, and furnace operators. The primary results need to be transformed into parameters that convey, in some cases directly but typically through inference, information on energy efficiency, production efficiency, glass quality, furnace life, and environments emissions. These are collectively referred to as the quality or performance parameters. The transformation of primary results (i.e. the results obtained by the numerical solution of governing conservation equations and boundary conditions) into performance indicators is achieved through the use of post processing or secondary models.

The commonly used secondary models include the models for calculating the RTD, sand grain or silica dissolution, melting index (an alternative or in addition to sand grain dissolution), the removal of gas bubbles from the melt (fining), and evaporation from the glass melt surface, and the corrosion of superstructure refractory by alkali vapors (e.g. NaOH) arising out of evaporation from the melt surface.

7. ILLUSTRATIVE MODELING RESULTS

The general nature of flow and temperature distribution in a combustion heated glass furnace (with oxygen being the oxidant, hence the term oxy-fuel furnace) is illustrated in Fig. 3. The figure shows, in a longitudinal cross section, the calculated isotherms in both the combustion chamber and the melt regions together with the circulation pattern in the melt region. The circulation pattern shows the spring zone (the location of the maximum glass surface temperature) and the two recirculation cells that constitute the now well recognized characteristic flow pattern in a glass tank without bubblers and/or electric heating.

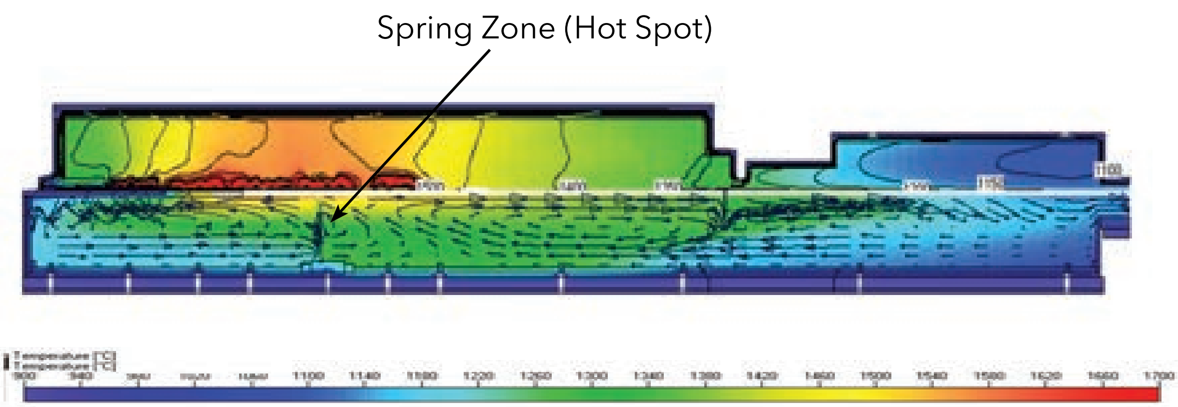

Fig.3. Flow and temperature distribution in the longitudinal cross section of a float glass furnace. (The figure obtained courtesy of J. Chmelar, Glass Service, A.s.)

Fig. 4 illustrates the use of modeling to develop innovative melting technologies. It shows the isotherms on the batch and glass surfaces of a fiberglass furnace with combustion burners firing from the top of the furnace (the crown). [1] *Fig. 5 shows the glass melt circulation in an electric furnace with top entering electrodes.* [2]

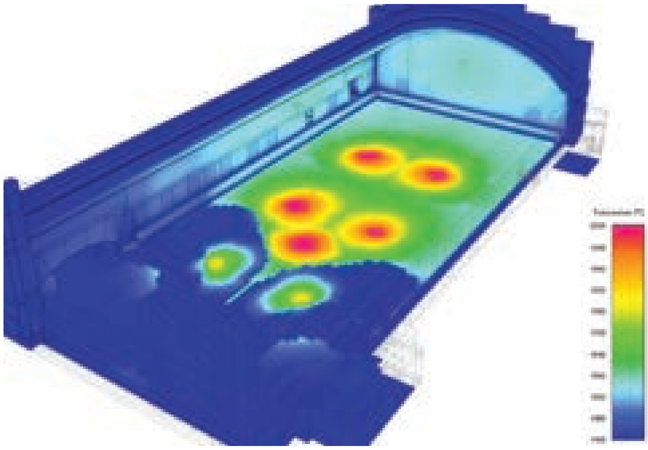

Fig. 4. Isotherms on the batch /glass surface of a fiberglass furnace (the figure obtained courtesy of Owens Corning).

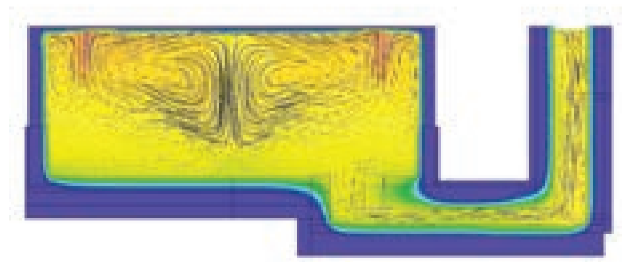

Fig. 5. The circulation pattern in the central plane of an electric furnace with top entering electrodes (the figure obtained courtesy of A. M. Huber of Johns Manville)

8. CONCLUDING REMARKS

In recent decades, the computational fluid dynamics (CFD) based modeling of glass melting and delivery processes has become commonplace in the glass industry and become an important tool for furnace design and operation, and to a limited extent, for the process control. Nevertheless there remains the scope for improvement in several areas as identified by Choudhary et al.[1] and Choudhary. [2.] The complexity of phenomena taking place in the melting batch pile makes the batch sub-model the weakest link in the furnace models, especially those for the combustion heated furnaces. The batch models need to incorporate more first-principles based elements in combination with judicious use of empiricism. The formation and decay of foam on the melt surface is another area that needs more first-principles based development and experimental data is. Although the situation has greatly improved regarding the availability of high temperature melt properties data. There is always scope for more accurate thermodynamic data such as the vapor pressure and chemical activities of volatile species, and transport data such as the diffusion and mass transfer coefficients. When dealing the modeling of a complex array of phenomena such as that involved in glass melting, it is crucial to validate the model. Finally, the development of fast and reliable algorithms that can help incorporate CFD modeling based information /knowledge for process control is desirable.

The paper focused on the CFD based modeling of glass melting and delivery processes with brief incursions into the modeling of forming processes. The quality of formed glass products (e.g., fibers, containers, sheets) can be highly dependent on the processes taking place upstream of the forming process. Developing comprehensive models that span from furnace to final product would provide means to determine the source of defects and final product variations. This is a challenging task but worth pursuing.

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Glass Recycling in the United States

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Glass, theoretically, is completely recyclable. Over 12 million tons of glass are produced each year in the United States, but experts estimate that less than 25% is recycled (Jacoby 2019). The low recycling rate in the US may surprise some, as using recycled cullet is a win-win for the glass industry; it reduces the amount of post-consumer glass going into landfills and also has the potential to reduce energy use of producing glass by up to 20% (Dyer 2014). Cullet, glass that has been crushed into small pieces, requires a lower melting temperature compared to primary materials. Experts estimate that for every 10% of cullet substituted for primary glass making materials, roughly 5% of greenhouse gas emissions are saved (Kovacec, Pilipovic et al. 2011).

The United States lags the European Union where container glass consists of 80-90% recycled cullet compared to only 30-40% in the US (Cooper and Swiler 2019). Close geographic proximity of sources and sinks is one reason the EU outpaces the US, where destinations for recycled cullet have decreased from roughly 40 container glass companies with 112 plants in 1967 to about 17 companies operating 54 plants in 2018.

(left) Modern partners with Bella Rose Winery to divert glass from landfills (credit Julie Berrigan, VP Communications and Public Relations)

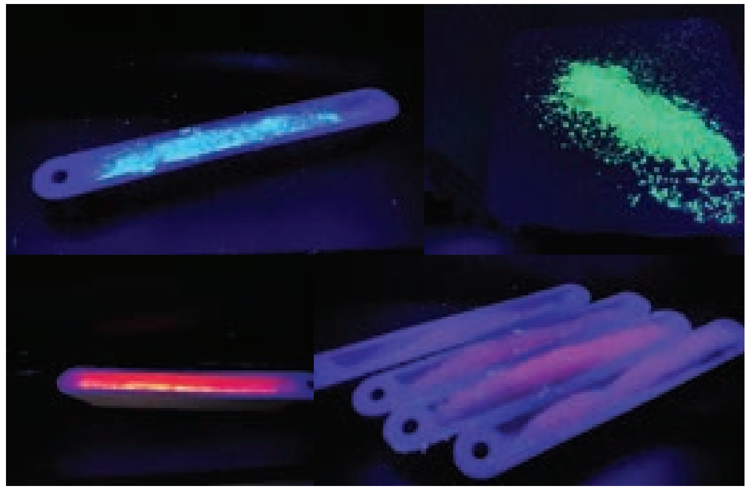
The economics of glass recycling are a growing challenge for Material Recovery Facilities MRFs). As more collection turns to single-stream, creating high quality cullet becomes harder. Single stream recycling is required in most areas in the US due to the dynamics of population density, waste management, and the costs of transportation and shipping. Very little of glass that ends up in municipal solid waste single stream ends up being recycled (Rogoff and Ross 2016, Damgacioglu, Perez et al. 2018).

Quality of the glass cullet is the leading driver of glass recycling economics. Higher quality cullet is worth more and can be used in a higher number of product sinks. The largest issues impacting quality are impurities, color composition, moisture content, and the redox state. Impurities are the biggest source of contamination and include ceramics, stone, and porcelain/chinaware (referred to as CSP), ferrous and non-ferrous metals, special glass types such as quartz glass/vitreous silica glass, glass ceramics, lead glass, and opal glass, and organic wastes which can include paper, plastic, sugar, and fats from food residues. Landfill cover is often the only option for cullet with 80% purity or less. At greater than 95% purity, including color sorting, the economics improve somewhat. However, distance still drives overall cost and potential locations for recycling.

The challenge in recycling non-soda lime silicate glass compositions is even greater. Many products make use of more compositionally diverse glasses like boro-, and alumino-silicates, leaded glass, and surface treated glasses. Cathode rate tube (CRT) monitors are a major problem as the funnel glass contains lead. Photovoltaic modules have semiconductor based cells sandwiched between the glass panels making high yield recycling challenge (Goe and Gaustad 2014).

These issues and others are being addressed in a $1.8M project funded by the New York State (NYS) Dept. of Environmental Conservation at the Center for Glass Innovation (CGI) in the NYS College of Ceramics at Alfred University. A significant emphasis of the CGI is developing new high-performance materials, low-cost feedstock alternatives, and energy efficient manufacturing processes that will result in a reduction of the glass manufacturing industry's carbon footprint.

As opposed to extensive processing of glass waste to obtain the high quality required for container glass and other sinks, the CGI approach relies heavily on "repurposing" glass waste "as-is". Ideal characteristics of these applications are: a) less sensitivity to color and composition so that a wider range of cullet quality can be used, b) local use to minimize transportation, c) high volume or high value added, d) stable or growing markets, and e) not requiring large scale re-melt facilities. Team is exploring a large number of sinks that satisfy this criteria.



One approach is developing value added sinks that utilize lower quality glass cullet, generally after crushing to particle sizes from 30–500μm (2022 Bellows et. al.). Such particles can be compositionally modified at temperatures 500–700 °C below normal glass melting temperatures. Luminescent/phosphorescent glass has been produced. High durability glass can be produced via dealkalization of high (surface area}/(volume) particles by water leaching at ~ 100 °C or at 500-600 °C with water + HCl or H2SO3 vapor. Low temperature sintering can produce colored, luminescent, and phosphorescent glass powders for glass frits and microbeads. Rapid growth applications include specialty solid and hollow microbeads, (CAGR 6-9%) and "foam glass" (CAGR ~ 7%). (right – example phosphorescent glass rods and beads produced by AU. Credit: Charles Bellows)

Perhaps the most promising of all uses is the use of crushed glass cullet (< 1000 μm) a substitute in the production of cement and concrete (Bueno, Paris et al. 2020). Such a sink could demand vast quantities of recycled glass in thousands of local concrete manufacturing destinations. Current issues that limit use include the Alkali Silicate Reaction (ASR) in which Na and K is leached from the glass causing a continuing elevated pH and swelling of the cement. Although safe usage of small glass particles has been demonstrated in several studies, the CGI work will provide detailed data on effects of total glass content, particle size, reduction of alkali content by use of dealkalized glass particles, and use of low density high strength insulating foam glass.

Another active research area is in sensor technology paired with machine vision and learning to improve sorting and separation processes available to waste processors. Others are working on in-melt technologies that remove impurities to create glass for use further up the value chain, for example, in float glass facilities.

Stay tuned! Research in recycling is increasing and progress is being reported at increasing rates as more and more states and smaller private companies with novel technologies enter the game.

Center for Glass Innovation

New York State College of Ceramics

Alfred University

Alfred University
INAMORI SCHOOL OF ENGINEERING
AT THE NEW YORK STATE COLLEGE OF CERAMICS

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National Glass Association Hosts Glass & Glazing Advocacy Day

Urmila Jokhu-Solwell, NGA, Vienna VA 22180

Industry leaders, Congressional members, and agency officials convene in Washington, DC to discuss the architectural glass industry's top priorities April 4-5

NGA's staff and members advocating for the glass industry

"Use this year to tell your story" – United States Representative Debbie Dingell, quoted at NGA Glass & Glazing Advocacy Day, an event of the International Year of Glass 2022.

Industry leaders from National Glass Association (NGA) member companies, Congressional members and agency officials convened in Washington, DC on April 4-5, 2022, for the association's first Glass & Glazing Advocacy Day featuring meetings face-to-face with legislative leaders from all over the United States.

Policy priorities important to the architectural glass and glazing industry were at the forefront of the event: high-

NGA Advocacy and Technical Director, Urmilla Sowell and Representative Debbie Dingell of Michigan performance glazing and building resiliency; bird-friendly glazing; recycling and circular economy; school security; and registered apprenticeship programs.

The event was held just prior to the American Ceramic Society's National Day of Glass, which took place April 5 - 7, to build upon the spotlight on the glass industry in Washington, DC.

In her opening remarks, NGA President & CEO Nicole Harris referenced the International Year of Glass by stating, "With momentum building across the globe, we wanted to take this opportunity to amplify our message here at home, with leaders in Washington, DC, to share how glass is an adaptable, sustainable, energy-efficient, strong, beautiful, safe, and essential building product."

NGA's members advocating for the glass industry

Executives from 20 NGA member companies representing primary glass manufacturers, fabricators, suppliers, and installing companies from across the country were invited to advocate on behalf of their businesses, NGA, and the architectural glass and glazing industry. The event was held at the offices of K&L Gates.

The Congressional members, legislative staff and agency officials who met with NGA members were:

- Rep. Neal Dunn (R-FL-02)
- Nena Shaw, Acting Director, Resource Conservation and Sustainability Division
- Rep. Debbie Lesko (R-AZ-08)
- Rep. Kurt Schrader (D-OR-05)
- Caius Willingham, Legislative Assistant (Rep. Pramila Jayapal D-WA-07)
- Rep. Debbie Dingell (D-MI-12)
- U.S. EPA's Doug Anderson, ENERGY STAR Program Windows Project Manager
- Rep. Morgan Griffith (R-VA-09)
- Wesley Whistle, Legislative Assistant (Senator Bob Casey D-PA)
- Luis Reyes, Deputy Legislative Assistant (Senator Tim Scott R-SC)

- Rep. Bill Johnson (R-OH-06)
- Kevin Petroccione, Legislative Assistant (Rep. Scott Fitzgerald R-WI-05)
- Brennan Barber, Educational Policy Advisor (Senator Tina Smith (D-MN)
- Shannon Frede, Gray Maxwell, Katie Corr (Senator Ben Cardin D-MD)
- U.S. Dept. of Energy's Marc LaFrance, Windows Technology Manager on the Emerging Technologies team and Bruce Lung, Senior Technical Advisor

NGA's members advocating for the glass industry

The National Glass Association represents America's building glass manufacturers, suppliers, fabricators, and installers. NGA's 1,700 member companies employ 71,000 workers in 49 states who produce and install glass for homes and commercial buildings, demonstrating glass is a viable career path for all. NGA promotes and defends the use of glass in the built environment. NGA provides business, technical, building code, and educational resources for the architectural glass industry. Our advocacy and technical initiatives respond to the relentless, ever-changing challenges to our industry.

The architectural glass industry was represented by an amazing mix of people including company CEO's, engineers, technical experts, Building Code Consultants and more. From the largest organizations in our industry to single location entities- all had a voice in front of some of the most influential people in the country.

Glass industry participants included:

- Courtney Little of Ace Glass
- Guy Selinske of American Glass and Mirror
- Tino Amodei of Armoured One LLC
- Bill Sullivan of Brin Glass Company
- Stanley Yee of Dow
- Julia Schimmelpenningh and Julia Farber of Eastman- Saflex

- Darijo Babic, Jon Griggs and Tuan Tran of Guardian Glass
- Jeremiah Watson and Patrick Elmore of Infinite Recycled Technologies LLC
- Vaughn Schauss of Kuraray America, Inc.
- Stephen Weidner, Kyle Sword, and Kayla Natividad of NSG Pilkington
- Richard Braunstein, Billy Strait and Rick Wright of Oldcastle BuildingEnvelope
- Carl Newhouse of SageGlass (Saint-Gobain)
- Helen Sanders of Technoform
- Rob Carlson of Tristar Glass, Inc.
- John Korff of Virginia Glass Products
- Ricardo Maiz and Paul Bush of Vitro Architectural Glass
- Tom Culp of Birch Point Consulting, NGA Energy Code Consultant
- Nick Resetar of Roetzel & Andress, NGA Structural and Fire Code Consultant

High Performance Glazing: According to the U.S. Energy Information Agency, in 2020, the combined total energy consumption by buildings in the residential and commercial sectors represented about 40% of total U.S. energy consumption. Energy efficient glass can help reduce the amount of energy needed for residential and commercial buildings. NGA members are continually developing new kinds of high-performance glass, and we urge the Department of Energy, Environmental Protection Agency, General Services Administration, Department of Defense and Congress to incentivize continued use of energy efficient glass.

Building Resiliency: Construction of buildings that are resilient to hurricanes and other severe weather events is becoming more and more important, particularly in coastal communities. NGA companies continue to develop weather resilient glass. The federal government should invest in resilient buildings and Congress should incentivize private sector investment in resilient buildings.

Recycling and Circular Economy: Currently building glass recycling is not generally done in North America. NGA members believe window glass recycling will eliminate a significant amount of landfill waste and help develop other industries. They are committed to educating EPA and Congress about opportunities and technologies to recycle architectural glass.

Registered Apprenticeship Programs: NGA Glazier Apprentice Curriculum is used as a part of U.S. Department of Labor-approved, registered apprenticeship programs for glaziers. Students who complete the curriculum earn a credential from the NGA and National Center for Construction Education and Research (NCCER).

School Security: NGA members have developed protective glazing including forced entry, blast and bullet-resistant glass that is designed to resist penetration from a variety of firearm ammunitions. U.S. building glass manufacturers stand ready to help make schools and other buildings safer.

Bird-Friendly Glazing: NGA members have developed solutions for bird collisions with buildings. For consistency in implementation, we encourage referencing NGA's Best Practice for Bird Friendly Glazing Design Guide, as GSA Facility Standard P-100 has already done.

Read a recap of NGA Advocacy Day on glassmagazine.com, and see social media coverage on Twitter and LinkedIn.

Glass: An Indispensable Material for Sustainable Development

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ABSTRACT

On May 18, 2021 the United Nations General Assembly formally approved a resolution declaring the year 2022 "The International Year of Glass" (IYOG). This is a seminal and celebratory moment for the global glass community. This is the first time that United Nations has accorded such a recognition to a specific material and represents an acknowledgment of the vital role glass has played and will continue to play in the advancement of human society. The proposal to UN for IYOG focused on the vital role of glass in achieving many of the UN Sustainable Development Goals (UNSDGs). It also emphasized the commitment of the global glass community to these goals, which include good health and wellbeing, quality education, gender equality, clean water and sanitation, affordable and clean energy, industry, innovation, and infrastructure, sustainable cities and communities, and climate action. In this brief paper we discuss the critically important role of glass as an enabler of sustainable growth. In particular, we highlight the role of glass in energy savings and renewable energy generation, and reduction in greenhouse gas emissions.

1. INTRODUCTION

Choudhary et al[1] have provided the historical background on the international effort to have the United Nations General Assembly (UNGA) approve the resolution to declare the year 2022 as the "International Year of Glass". As described in that earlier publication, the criticality of glass for the sustainable development was the key element of the IYOG proposal to UN. In particular, the proposal highlighted how glass as a material and the global glass community are and will be involved in promoting and helping achieve many of the seventeen UN Sustainable Development Goals (UNSDGs) for UN's 2030 Agenda for Sustainable Development.[2] In Section II, we discuss the alignment of glass and the glass community (including but not limited to industry, academe, arts, museums, and end users) to the 11 of the 17 UNSDGs. Section III focuses on the vital role of glass in addressing climate change by being a key enabling material for energy savings and renewable energy generation. We end the paper with some concluding remarks.

2. IYOG2022 AND THE UN SUSTAINABILTY DEVELOPMENT GOALS

The 17 UN Sustainable Development Goals were set up in 2015 to be "a universal call to action to end poverty, protect the planet and improve the lives and prospects of everyone, everywhere".[2] These goals were set-up in 2015 and are intended to be achieved by the year 2030. The principal strategy for getting the UN support for IYOG was to demonstrate IYOG's alignment with 11 of the 17 UNSDGs. The IYOG mission, given below, explicitly stated this alignment.

"…to pursue a United Nations International Year of Glass for 2022 which will underline the technological, scientific and economic importance of glass —…material underpinning many of our technologies and which can facilitate the development of more just and sustainable societies to meet the challenges of globalization."

The IYOG proposal submitted to UN General Assembly specifically address the 11 UNSDGs listed below.

UNSDG 3: Good health and wellbeing
UNSDG 4: Quality education
UNSDG 5: Gender equality
UNSDG 6: Clean water and sanitation
UNSDG 7: Affordable and clean energy
UNSDG 9: Industry, innovation, and infrastructure
UNSDG 11: Sustainable cities and communities
UNSDG 12: Responsible consumption and production
UNSDG 13: Climate Action
UNSDG 14: Life below water
UNSDG 17: Partnership for the goals

For specific details on IYOG's alignment with the above goals, please refer to Choudhary et al.[1]

3. ROLE OF GLASS IN ADDRESSING CLIMATE CHANGE

Glass is an enabling material in several sectors intimately linked with sustainable development. Some of those areas are listed below. Also included are some products and/or attributes that allow glass to play indispensable roles in these areas. The list is by no means exhaustive.

- Energy Savings
  - glass fiber insulation, glass fiber based light weight durable composites, smart windows, efficient lighting
- Renewable Energy Generation
  - glass fiber based composites for wind turbine blades, solar panels and concentrators
- Energy Storage
  - glass based solid state batteries
- Environmental safety
  - recyclability of most glasses, use of glass for nuclear waste immobilization, glass media for filtration
- Healthcare
  - biocompatible glasses, bioactive glasses, bioresorbable glass, and glass for pharmaceutical packaging
- Information and communication
  - Optical glass fiber, other oxide glass and non-oxide glass devices used for transmission and display of information, visualization, and data storage.
- Infrastructure
  - glass panels (strengthened laminate glass) used for transport hubs (e.g., airports, train stations), and residential & commercial architecture.

We will now discuss the first two items on the list, namely glass's role in energy savings and renewable energy generation. Energy generation and consumption are intimately linked with greenhouse gas emissions. By enabling energy savings and playing an important role in renewable energy generation, glass plays a significant role in addressing the climate change. This role is going to become even more significant in the future.

3.1 Glass and Energy Savings

We limit our discussion to role of glass in saving energy in residential and commercial buildings and the automotive sector. Glass saves energy in buildings through its use as insulation and windows. It saves energy in the automotive (and transportation sector in general) by fuel savings through the use of glass fiber containing light weight composites.

3.1.1 Glass and energy savings in buildings

The total energy usage in U.S. in 2020 was about 92.94 quad (1 quad = 10^{15} BTU = 1.055 × 10^{18} joules). The energy consumption by end-use sectors is shown in Fig. 1.

Total usage = 92.94 x 10^{15} BTU

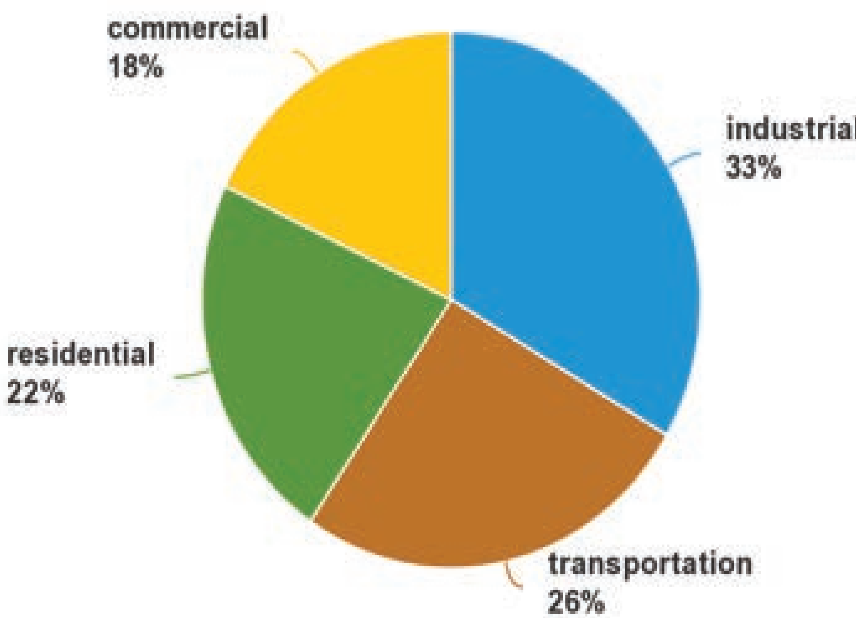

Fig. 1 *Energy usage in US in 2020 by sectors*
(Source: https://www.eia.gov/energyexplained/use-of-energy/*)*

As seen in Fig. 1, about 40% of total energy usage is in residential and commercial buildings. It is estimated that about a third of that is used for heating and cooling of buildings. Associated with energy usage are the greenhouse gas (GHG) emissions. Emissions are expressed in million metric tons of carbon dioxide equivalent (MMTCDE). The MMTCDE of a gas equals million metric tons of it multiplied by its global warming potential (GWP). The GHG emissions from buildings are of two kinds – direct and indirect. Direct emissions are produced from the usage of energy in buildings for purposes such as heating, and cooking. Indirect emissions are associated with the generation of electricity that is used in the buildings. Direct emissions from residential and commercial buildings in US in 2019 were about 852 MMTCDE. This represented about 13% of the total GHG emissions of 6,558 MMTCDE in U.S. in 2019. Indirect emissions associated with use of electricity in buildings were about 1148 MMTCDE. The MMCTDE figures cited here are from reference[3].

It is clear from the figures given above that buildings are significant users of energy and contributors to GHG emissions. Also, as noted before, heating and cooling account for about a third of the energy usage. Thus, insulation has a major role to play in saving energy and reducing GHG emissions. Fiberglass and mineral wool insulation (many fiberglass insulation manufacturers also manufacture miner wool insulation) account for about 40% of the insulation used in buildings. The impact of fiberglass insulation on energy savings may be assessed by noting that a typical fiberglass insulation product saves about 12 times as much energy in its first year in place as the energy used to manufacture it.[4] In other words, the energy consumed during manufacturing of fiberglass insulation is saved during the first four to five weeks of its use.

Windows, doors, and skylights are significant components in a buildings envelope and impact energy usage in buildings. It is estimated that heat gain and heat loss through windows account for 25%–30% of residential heating and cooling energy use. Use of coatings, glazes, and other techniques are used to tailor the light transmission properties of glass to save energy and provide comfort. The light transmission altering techniques are used in “Smart Windows” and can reduce energy loss through windows by 30 - 50%. Smart windows use electro-, thermo-, and photo-chromatic effects, and suspended particles to modify the transmission of light through the glass panes. Low emissivity coatings are used to lower the solar gain (increase in thermal energy of a space due to solar radiation) while maintaining high visibility.

3.1.2 Glass and energy savings in the automotive sector

Glass plays an important role in increasing the fuel economy (miles per gallon) of automobiles while maintaining safety. It is estimated that a 10% reduction in the vehicle weight can result in a 6%-8% improvement in fuel economy.[5] Replacing cast iron and steel components in an automobile with lightweight materials such as carbon fiber, and glass fiber containing polymer composites reduces the weight resulting in a reduction in the automobile’s fuel consumption. The use of glass fiber reinforced composites can reduce the vehicle weight by 25 to 35%, thereby improving the fuel economy by 12 to 25%. Lightweight materials such as the glass fiber composites are important in all vehicles including hybrid electric, plug-in hybrid electric, and all-electric vehicles. Lightweight materials in the all-electric and hybrid vehicles helps offset the weight of power systems such as batteries and electric motors, improving the efficiency and increasing their all-electric range.

The use of lightweight materials and the resulting benefit in fuel economy is not limited to the automotive sector. These materials also have applications in other sectors including aerospace, marines and high speed trains.

3.1 Glass and Renewable Energy

Fig. 2 shows the distribution of 2020 U.S. energy consumption by the energy source.

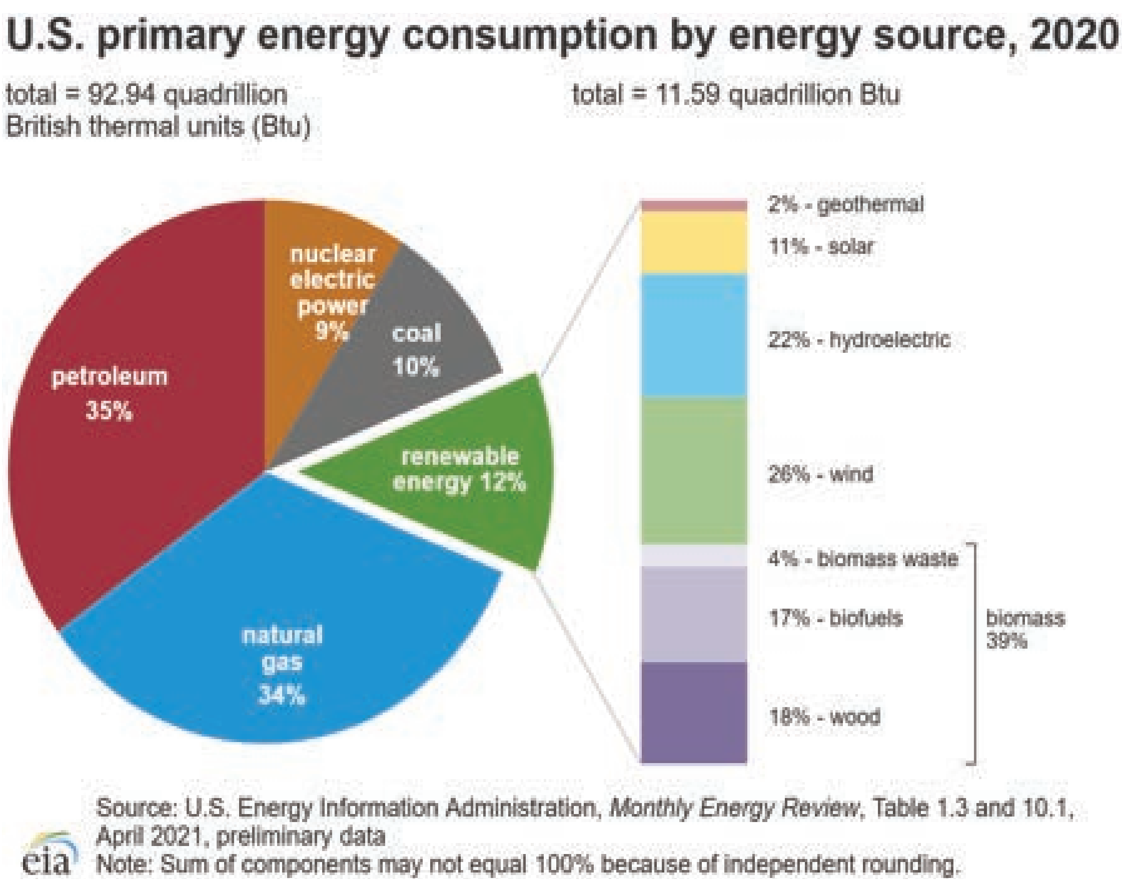

Fig. 2 *U.S. Primary Energy Consumption by Energy Source Distribution for 2020 (Source:* https://www.eia.gov/energyexplained/renewable-sources/*)*

As seen in Fig. 2, energy usage from renewable sources surpassed that from coal and this trend is likely to accelerate. Wind and solar constituted about 37% of the renewables. During 2010-2020, the costs for wind and solar power generating systems have decreased dramatically – by about 85% for solar photovoltaic (PV) and 56% for onshore wind.[6] In the same period the global installed capacity of solar PV (utility scale and roof top combined) has increased from 42 GW to 714 GW; and that of onshore wind has gone up from 178 GW to 699 GW.[6]

Glass fiber reinforced composites with their high strength and stiffness and low density are very attractive for wind turbines. The Wind Turbine Composite Materials Market is forecast to grow at the compound annual growth rate (CAGR) of 10.3% during 2021-2026 and reach a value $18.9 billion by 2026.[7] The glass fiber reinforced plastic (GFRP) had the largest share (more than 55%) of the wind turbine composite market in 2020 and is expected to grow at a significant rate during 2020-2026.[7]

Glass being a durable, highly transparent material is the obvious choice for solar power. It finds its application for solar power generation in the form of photovoltaic panels and as solar thermal collectors. The global solar market was valued at $ 52.5 billion in 2018 and is forecast to reach $223.3 billion by 2026 at the CAGR of 20.5% from 2019 to 2026.[8]

3. CONCLUDING REMARKS

The year 2022, the UN International Year of Glass (IYOG) is a seminal and celebratory year for the international glass community. The approval on May 18, 2021 by the UN General Assembly (UNGA) of the resolution to declare 2022 as the International Year of Glass is a matter of great joy and pride for everyone associated with glass. We know glass is "humankind's most important material"[9] and are grateful that that this is the first time that United Nations has accorded such a recognition to a specific material. It represents an acknowledgment on the part of the international community of the vital role glass has played and will continue to play in the advancement of human society. The keys to getting the UNGA approval were the proposal to align IYOG with UN's sustainable development goals (UNSDGs) and the enthusiastic endorsement the proposal received from organizations, institutions, and people from across the globe.

In this short paper, we focused on glass's indispensability for sustainable development since, as noted above, that was a key factor in getting the UNGA approval for IYOG. After describing the alignment of IYOG with 11 of the 17 UNSDGs, we discussed glass's critically important role in energy savings and renewable energy generation from wind and solar radiation.

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Contemporary Glass in the Year of Glass 2022

Jan Mirenda Smith,
AACG/IYOG2022 Steering Committee Co-Chair

Glass as a 5,000-year-old transformative material has brought a global celebration endorsed by the United Nations as the International Year of Glass 2022 in recognition of its use in science, history, technology, industry, and art. Additionally, the year marks the 60th anniversary of its use as an art material, referred to as the Studio Glass Movement, which began in 1962. Although 1962 marks a major milestone, it is important to acknowledge the centuries of development that led to this creative juncture.

Glassmaking was America's first industry, brought to New Jersey by the German glassmaker, Caspar Wistar in the 1700s and reached a crescendo by the 19th century. Many ancient processes and glass formulas were rediscovered and applied to a highly specialized and competitive industrial environment. Art glass was also in production in Europe and in the United States using the designer and craftsman relationship. Louis Comfort Tiffany, Emile Galle, and Rene Lalique, were among many designers throughout Europe and the United States making unique exquisite works.

Harvey K. Littleton *at a hand-built kiln, c. 1949. Photo courtesy the Littleton Family.)*

Maurice Marinot and Jean Sala were among several Europeans distinguishing an individual style in blown glass in small studios in the early twentieth century. Maurice Heaton, Frances and Michael Higgins, and Edris Eckhardt, among others, were individually exploring kiln-formed directions. Harvey K. Littleton met these presenters in 1957 at the First Annual Conference of Craftsmen at Asilomar in California, who confirmed his vision that artists could use glass for sculpture.

In 1951, the University of Wisconsin-Madison hired Littleton to teach ceramics. However, an interest and exposure to glass began at an early age, visiting Corning Glassworks with his father, Jesse Littleton, employed in 1913 as one of their first scientists. Among his credits is the invention of the formula for Pyrex, glassware widely used for cooking. Littleton also lived within blocks of Frederick Carder, founder of Steuben Glass in Corning. Therefore, since his youth glass had an allure which he had the opportunity to explore in his first casting during the summer of 1942 while he was employed at the Corning Vycor Fabrication Division. He made a mold from his previously sculpted clay torso to cast the figure using the Vycor glass formula. He pursued that vision for the next twenty years.

Harvey K. Littleton, *American, Vycor Multiform Cast Torso, 1946, Photo courtesy the Littleton Family*

Educational Programs

In 1962 Otto Wittman, Director of the Toledo Museum of Art gave Littleton the opportunity and garage space to explore his vision suggesting he offer two workshops in glassblowing: one in March and another in June. Littleton supplied a furnace, some glass tools and an assistant, Thomas McGlaughlin. His friend and former ceramics student Dominick Labino, who was Vice President of Research and Development for Johns Manville Corporation, contributed his knowledge of furnaces and glass formulas by supplying 475 marbles. The 475 marbles were later the cornerstone of Littleton's 1963 University of Wisconsin studio with Johns Manville supplying 2400 lbs.. The serendipitous arrival of Harvey Leafgreen, a retired Libbey glassblower, who offered an impromptu blowing demonstration for each participant on the last day of the first workshop added to the success, and he was invited back in June. These workshops were fundamental to Littleton's pursuit, but it was formalization of the educational programs that followed in 1962 that were the foundation of the Studio Glass Movement.

Littleton began a graduate independent study program at the University of Wisconsin-Madison in fall of 1962, after a summer of European travel resulting in lifelong friendships with Sybren Valkema of the Gerrit Rietveld Academie in Amsterdam, Netherlands, and Erwin Eisch of Frauenau, Germany. The program entered the campus curriculum in fall of 1963, with the support and expertise of Labino.

These lasting friendships foreshadowed the exchange of expertise fundamental to the extraordinary growth of the Studio Glass Movement over the next twenty years. Much of this was due to the proselytizing by Littleton's students that brought forth new glass education programs in such rapid succession that the Glass Art Society Journal listed eighty-five educational programs across the country by 1978. Littleton retired in 1977 yet, the influence he set in motion spread globally and a new infrastructure supporting it was taking shape. Harvey Littleton traveled through Europe frequently and many of his students followed benefitting from his initiative, studying on Fulbright scholarships. Sam Herman was among the earliest who studied at the Edinburgh College of Art and became a research fellow rebuilding the glass furnaces at the Royal College of Art and also began a glass program in Australia. Other Littleton students or their students traveled abroad to the Royal College of Art, Sweden, Germany and Austria. Marvin Lipofsky, who started the glass program at the University of California at Berkeley in 1964, traveled frequently eventually collaborating with glassblowers in factories in many other countries. Fritz Dreisbach traveled extensively, teaching, demonstrating, and creating several programs. This lineage was so extensive that Lipofsky, Dreisbach and McGlaughlin attempted to draw a glassblowing family tree by 1974 tracing most of the instructors back to students of Harvey Littleton or his students. Simultaneously, another glass program was forming at Alfred University where Andre Billeci invited workers from Corning to offer summer programs in the early 1960s.

Dale Chihuly is the most acclaimed Littleton student who studied in Italy as a Fulbright Fellow in 1968. He returned in 1969 to teach glass at the Rhode Island School of Design, (RISD), while simultaneously founding the prominent Pilchuck Glass School in 1971 in Washington State, eventually with Benjamin Moore, bringing Italian Maestro Lino Tagliapietra to the United States to share Italian techniques with so many.

Documentation and Writing

Although the information was swiftly crossing the country, it remained undocumented, and efforts continued as mostly trial and error until the formation of an artists' resource: The Glass Art Society (cleverly termed GAS) was formed in 1971 by a small enthusiastic core of several young glass artists and former Littleton students: Fritz Dreisbach, Marvin Lipofsky, Audrey Handler, as well as Mark Peiser and William Bernstein from Penland School of Crafts, with Henry Halem, also a student of Littleton, as the first president. This was a critical association that shared knowledge of tools, equipment, and techniques to advance the medium, supporting its growth as well as access to materials and suitable glass formulas that would advance the artists' ability to create art.

GAS documented their annual conferences by publishing an informative journal, as there was little information published thus far on the medium. Littleton published an early book in 1971, *Glass Blowing: A Search for Form*[iii]*;* Labino published a paperback in 1968, *Visual Art in Glass*[iv]; and Ray and Lee Grover published *Contemporary Art Glass* through Crown Publishers, New York in 1975[v]. Stained glass remained a smaller segment of the contemporary art glass trend, although, it was becoming part of this new narrative with one of the first monthly publications. *Glass Art Magazine* was started in 1973[vi] dedicated to stained glass and contemporary art glass. Artists like Narcissus Quagliata and Judith Schachter have brought new light to this centuries old art. Additionally, new installations in the 21st century have come forth by artists previously not associated with glass, like Kehinde Wiley, using a contemporary narrative emulating social platforms through this traditional format[vii].

Artists Driving an Industry

The needs of the artists drove the glass industry and expanded on the artist driven studio environment originally taught by Littleton. Former students like Roland Jahn, Andrew Magdanz and Michael Boylen were among those presenting artist driven solutions for larger and more efficient furnaces; more sophisticated annealing equipment; improved and more compatible glass formulas with compatible colors which allowed for the creation of new work not possible with the 475 marbles. Access to color in the 1970s in sheet and bar form from Kugler in Germany, or color formulas developed by artists like Daniel Schwoerer, who formed Bullseye Glass in 1974 initially for making stained glass, greatly expanded the artistic boundaries. Additionally, a new generation of artists trained in glassmaking moved from the self-made and built mantra taught by Harvey Littleton to the next tier: an industry that manufactured furnaces and annealers for this burgeoning market. Several furnace and equipment manufacturers founded by artists emerged to supply new product designs addressing the changing needs of glass artists, including moving from gas to electric operations. Green innovations have been examined by artists running studios that operate on methane gas rather than propane or natural gas and using recycled glass material[viii]. Additionally, some have been working with equipment running on biofuels[ix] such as recycled vegetable oil, collected from fast food venues[x]. These were among many necessary technical innovations that supported mastering the material and the advancement of new work on a larger scale that continues today.

While education of artists became the first element of creating this movement, exhibitions facilitated the exposure of this exciting art as the early pioneering participants mastered techniques. The Corning Museum of Glass organized the first prominent international contemporary survey exhibition *Glass* 1959, featuring the newest designer-craftsmen works from many of the leading manufacturers. Individual artists exploring the medium also exhibited: Edris Eckhardt, Michael and Frances Higgins and Maurice Heaton were among them.[xi]

The *Toledo National* in 1966 was the next important glass exhibition highlighting the work of the new artists producing glass, followed by the important craft exhibition *Objects USA* in 1969. In 1978, '81 and '84, David Huchthausen curated three touring contemporary glass exhibitions called, *Americans in Glass,* which exposed cutting edge new work to a broader public by focusing the tour on smaller cities and institutions: Corning opened *New Glass Now, 1979,* this time, showcasing current work from individual artists. This led to the annual publication of *New Work,* a juried selection of contemporary work, bringing the most current to the forefront. Prominent exhibitions exposed "new glass" to a broad public, inspired more active collecting of glass, built important collections, and supported the artists.

Growing popularity and support encouraged the formation of glass only commercial galleries. On a small scale, Edgewood Orchard opened in Wisconsin in 1969, and in 1982 began a series of summer glass educational weekends to augment their glass exhibitions. These introduced collectors to the art and artists through a congenial outdoor atmosphere with demonstrations continuing until 1994. Habatat in Michigan, opened in 1971 and Heller Gallery opened in New York in 1973, and later, Ivor Kurkland Glass Gallery opened in California in 1981[xii]. Each setting displayed new glass artists exclusively in socially poised opening receptions to mingle with the patrons. This winning combination of art, artist and social exhibition space catapulted the appeal and beauty of this glistening art form to a more sophisticated level of organization, along with a new level of virtuosity, scale, and technically astounding work.

Collecting

With such a rapid expansion of artists and opportunity, glass art reached a crescendo in the early 1990s. The collecting community organized in 1989 to form the Art Alliance for Contemporary Glass (AACG) and the gallery spaces became united under the brilliant showcase of large-scale art fairs. In 1993, Sculptural Objects and Functional Art (SOFA) opened in Chicago showing three-dimensional art from approximately one hundred galleries in a four-day period at Navy Pier in Chicago forming a model for similar fairs in other parts of the country. This forum provided one impactful event center with galleries putting forth their best stable of art stars, all exhibiting in one place, offering simultaneous educational events, soirees, and sales.

Modest collections that began through direct contact with the artists were now overshadowed by this new marketplace where large prominent private collections were being built in an encyclopedic fashion, recognized for their excellence, and accumulated knowledge of artists and techniques. Glass was transformed from its humble beginnings with lumpy greenish forms that could hardly be identified even by the maker, to now, when artists could truly distinguish themselves through style, command of this magical material, and virtuoso technique.

Harvey K. Littleton, *American Amorphic Vase, 1962; Blown Glass Photo courtesy the Littleton Family*

As this generation of supporters/collectors examines the future of glass in the twenty-first century, they also contemplate its destiny they worked so hard to establish. A current dilemma to address in documentation is the resting place of many of these established collections that were so diligently stewarded. As museums grappled with accepting the art, collectors have worked to legitimize it by acceptance into museum fine art collections, particularly when their next generation is not driven with the same passion[xiii].

Techniques expanded through Technology

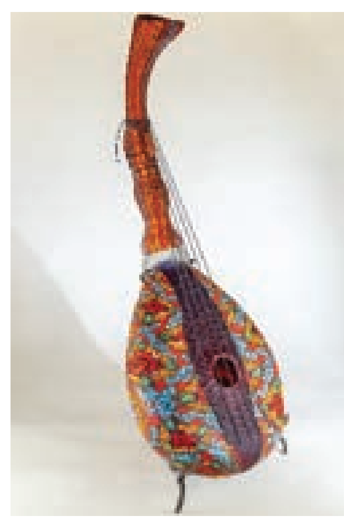
In thirty years from 1962 to approximately 1992, glassblowing was the dominant technique of the pioneering students. Exposure to and reinvention of historic techniques combined with contemporary innovations expanded the artists' technical toolbox. Littleton instilled a self-sufficiency that carried the artists to innovative exploration, but also innovative blended thinking. Dale Chihuly was among the first to reinvigorate the team concept in the artistic studio, taking advantage of multiple skills inspired by the Italian model. The crossover between art and science was apparent to make innovations possible. Creation of new glass formulas, compatible colors and successful adhesives and large-scale casting technologies brought astounding capabilities in scale and visual reference. Revisiting ancient methods brought traditional functional

Stephan Dam *Glass Panel, 2008 / painted Metal stand, 22 x 40 x 8"* forms into a contemporary dialogue. Flameworking is among the oldest methods of shaping glass from the middle east. It was used for the bead industry in Venice in the 14th century, and the scientific community later trained flameworkers for creating laboratory equipment. Flameworking methods allowed for detail not capable in blown forms, as well as the crossover of industry from the scientific lampworking studios to intricate art, such as in the work of Paul Joseph Stankard. In contemporary studio glass, it offered accessibility to the material in a more intimate and immediate process compared to furnace work. From beadwork to large sculpture flamework allows for detailed expression, or scale such as the work of Lucio Bubacco, or the socially powerful work expressed in the voice of Joyce C. Scott.

Lucio Bubacco *Not All Devils Are Bad 1996 Hand Blown and Flame worked colored glass 23.25 x 14 x 9"*

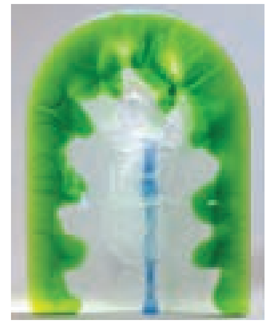
Neon found a renewed path in the contemporary glass world from its kitsch origin of the 1940s in signage to explorations in the 1960s in light sculpture and Paul Seide's light structures of the 1980s. The continued contemporary exploration reshapes darkness and uses language to convey social commentary. Artists combine the use of science in contemporary plasma sculptures such as in the work of Wayne Strattman.

Casting, kiln forming, cutting, polishing, laminating, engraving, and carving methods provided new structural options, scale, and surfaces. Additional techniques shared by the Italian maestros brought to Pilchuck, reinvented the historic methods of murrine, entrapped bubbles such as in masterful reticello techniques and the lace forms of latticinio into a contemporary language such as the work of Davide Salvatore.



Davide Salvadore, *Italian Mandalino 2015, Blown and sculpted glass with murrine, 38 x 15.5 x 8"*

The casting knowledge of Czechoslovakian artists Jaroslava Brychtova and Stanislav Libensky expanded the potential of scale, paving the way for new work in large solid sculpture and use of facilities in the Czech Republic for the expertise necessary to create these works. The combined knowledge and access to various methods to achieve the final outcome has provided artists with the tools and skilled assistance to execute their ideas such as the work of Karen LaMonte.

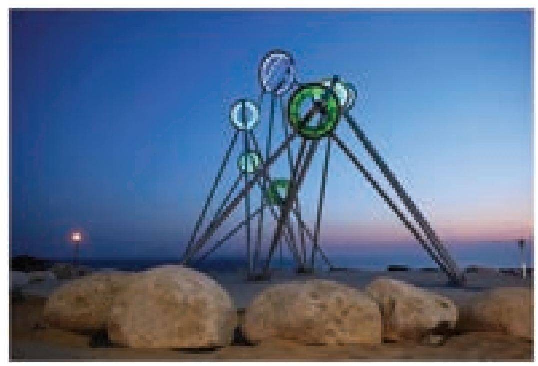


Petr Hora, *Czech*
#27 (Green Gravestone Form w/ inclusions) 2004
Cast Glass with inclusions, 20 x 15 x 4"

Transitions to the 21st Century

With the mastery of technical abilities and introduction of mixed media, new tantalizing ideas and narratives were forming into more mature artistic statements. Although Littleton and his followers emphasized the making of art, and glass was initially exhibited by museums, establishing museum collections raised curatorial questions about its legitimacy as art, categorizing it as craft. The advances in technology and mastery of techniques spawning new capabilities in making glass art carried it from its humble beginnings in the 1960s to the turn of the twenty-first century, and ultimately delivering a new powerful artistic medium.

Technology was also driving partnerships and innovations in glass developing new opportunities for artists in partnership and collaboration with once restricted factory settings. Partnerships with science, technology and industry allowed for materials knowledge and access needed to construct large scale outdoor public works by artists like Howard Ben Tre, Martin Blank or John Littleton and Kate Vogel.



John Littleton and Kate Vogel,
American, Celebrating Muskegon, Michigan, 2021
Glass, steel, led lighting. Outdoor installation. Photo courtesy of the artists.

Innovation has driven artists to develop new industries for their unique abilities such as upscale handmade lighting, thus employing artists with glass blowing skills. Architecture and art merge with James Carpenter's structures, who began his architectural firm in 1979. His structures are environmentally aware, fundamentally innovative, impactful intersections of science and light, using glass as the vehicle. Christopher Ries broke the boundaries of factory and studio, by working inside Schott Glass Factory as a resident artist to create sculptural works from pure optical crystal, exploring the purity of its reflective qualities and operating at an 800-pound scale only a factory setting could establish with control of the pure cast crystal.

Access and availability to glass, coupled with ease of working methods beyond blowing techniques has opened creative opportunities for hobbyists and community education. Successful community impact can be found in beadmaking, fused methods, stained glass, or mosaics. The creative experience provides a successful positive outcome for marginalized youth or adults while also capitalizing on such metaphorical qualities of glass as fragility, strength, transparency, opacity, and resiliency.

Several nonprofit studios have emerged to provide a meaningful experience to underserved communities: Hilltop in Seattle; Glassroots in New Jersey; and Firebird Arts Community in Chicago are just a few examples. Glass continues to be a transformative material. Like its use in medicine and innovations in bandaging, reconstruction, and healing. Artists select glass as a medium to elevate the distressed dialogue of social injustice and create change. One twenty-first century outcome is the discussion emerging online through GEEX Glass organized by artists/educators Helen Lee and Kim Harty. Their mission is to address issues pertinent to glass artists of color and the LGBTQ community.

Dale Chihuly was among the first to change scale in a modular fashion in the 1970s by using the fundamental collaborative process of a glass blowing team to make multiple works that could build scale by installing a framework for the structural support some of the first multi-media installations in unsuspected locations globally. Other artists continue this practice to create environments constructed from glass or using glass as an effective part of the statement. Glass becomes a metaphorical material for change, strength, fragility, and beauty. Artist Michael Meilahn with Nick Nebel has created immersive environments of sound, video and hanging glass objects involving the viewer in the dialogue of change regarding food production globally.

Michael Meilahn, *American, Primordial Shift, 2013, Suspended Blown Glass, Cast Bronze, Audio/Video, 30'H x 30'W x 25'D)*

In the twenty-first century, artists continue to pursue the expansive potential of glass by exploring previously defined art forms such as performance art through the choreography so evident in a hot shop, frequently presented by the Doug and Pat Perry Studio at the Chrysler

The Nautica Team, 2019, photo courtesy of the Doug and Pat Perry Studio, Chrysler Museum of Art)

Museum of Art. Glass' spontaneity, immediacy, improvisational nature, lends itself to performance. Its fragility suggests ephemeral existence and its malleability provides movement through manipulation.

Tim Tate *21st Century Guernica 2017 Glass, Mirrors, 3D Printed vitrolite, steel frame, LED Lighting, 36" in Diameter*

As a material for change, exploration, and the merging of the future with the present, glass continues to be an innovative and transformational material. Newly explored work in 3-D printing of glass allows for innovation of a new process, one that can replicate a form and one that has technology as the intervention device. Tim Tate, an artist driving a dialogue on 21st Century Glass, has employed 3-D printed forms in his work.

Interestingly, as the beginning of the movement sixty years ago worked to place this material into the hands of the artists, its collaboration and continued innovation has allowed it to move into a coalesced realm of existence between industry, science, art, and innovation. Its future is being created as this transformational material, again finds new direction.[xiv]

Endnotes:

i Frantz, Suzanne K., Contemporary Glass: A World Survey from The Corning Museum of Glass, Harry N. Abrams, Inc. New York. P.11-17.

ii Frantz, p.56

iii Littleton, Harvey K, Van Nostrand Reinhold Company, New York, Cincinnati, Toronto, London, Melbourne, 1971

iv Labino, Dominick, Wm. C. Brown Company Publishers, Dubuque, Iowa, 1968

v Lynn, Martha Drexler

vi Frantz, p.

vii https://mymodernmet.com/contemporary-stained-glass-art/

viii https://bittersoutherner.com/southern-perspective/2021/captured-and-converted-howmethane-powers-art-in-western-north-carolina-jackson-county-green-energy-park

ix Email information from Tim Muth, Green Energy Park, North Carolina, 5/12/22 x Text conversation with artist Tracy Kirchman, 5/2022.

xi Exhibition Catalogue: Glass 1959, The Corning Museum of Glass, Corning Glass Center, 1959.

xii Lynn, Martha Drexler, American Studio Glass 1960-1990, Hudson Hills Press, New York and Manchester, p.103

xiii https://bmmglass.com/2017/09/museum-hosts-glass-symposium/ Ganis, William, In Perpetuity, lecture

xiv All Images unless otherwise noted, are taken from The Larry and Rita Sibrack Collection: A Passion for Art, photography by Steven Coffin, Blurb.

Education, Books, Societies, and Outreach in Glass in the United States

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I. Introduction.

Glass science is a mature, ever-interesting, and is growing in knowledge. It has a plethora of learned societies, more books than ever before, and still more volumes coming out often. We perform outreach to the general public in numerous ways that is culminating in 2022 with the *International Year of Glass*. In this chapter I will briefly review education, books, professional societies, and outreach in glass science. These have the crucial common link of transmitting knowledge within our field from one generation to the next.

II. Education

There are excellent, but perhaps too few, educational opportunities in glass science and technology throughout the United States. Since glass is inherently an interdisciplinary subject it takes place in a plethora of departments of many specialties. These include, most commonly, chemistry, geology, materials science and engineering, chemical engineering, electrical engineering, physics, data and computer science, and more.

A typical university, with glass research taking place, will have up to a few professors working with a few undergraduates and more graduate students. The funding is mostly external and is mostly federal in origin in these departments. Excellent research and education occurs at these venues. Among several examples is the following sampling: *Missouri Institute of Science and Technology, Iowa State University, RPI, Pennsylvania State University, Rutgers University, Duke University, Cornell University, University of California at Davis, University of Michigan, MIT, University of Central Florida, University of Arizona, University of Florida, Lehigh University, Clemson University*, *Arizona State University, Creighton University*, and more.

A singular exception to the usual case is the *New York State College of Ceramics at Alfred University*. Joined to a liberal arts college this is the most focused program in glass science in the United States. Its website proclaims:

The Inamori School of Engineering is one of only two institutions in the US that offer a BS in Ceramic Engineering and the only institution in the US that offers degrees in glass science. We offer undergraduate and graduate degrees in Biomaterials Engineering (BS and MS), Ceramic Engineering (BS through PhD), Glass Engineering Science (BS through PhD) and Materials Science and Engineering (BS through PhD).

Some four-year liberal arts colleges also encourage undergraduate students to do research on glass. A notable example is Coe College. The glass science research program began at Coe College in 1979 with the arrival of Steve Feller. The initial effort was to measure physical properties in glasses extended in composition using home-made roller quenchers. Today there are four faculty, Mario Affatigato, Caio Bragatto, Ugur Akgan, and me who actively engage several dozens of undergraduate students per year in publishable research in glass. We have published well over 250 papers in glass science. A key to our program is the use of a four-year research program for our undergraduates.

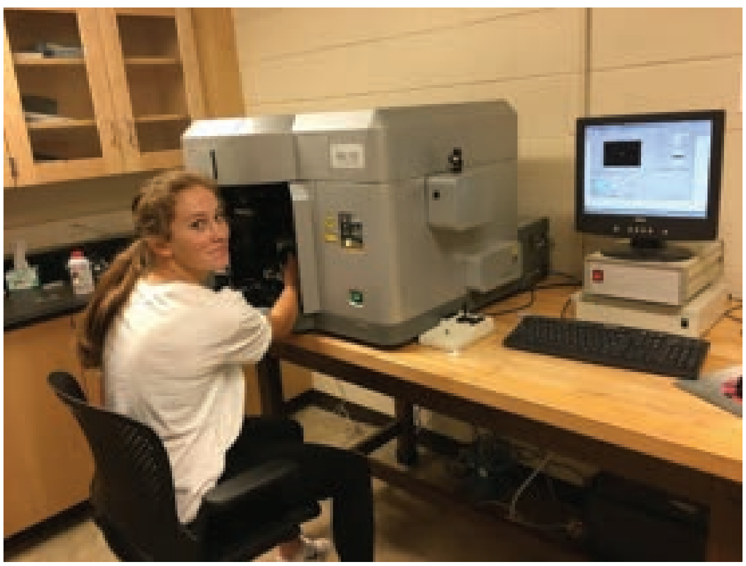

Figure 1: Martha Jesuit performs Raman spectroscopy at Coe College.

Several other mostly undergraduate colleges participate in research on glass. These include *New College in Florida, Ursinus College in Pennsylvania, William Jewell College in Missouri, and Austin Peay University in Tennessee*.

A significant amount of education in the form of research on glass takes place at national labs, as well. For example, many glass group study atomic structure using neutron scattering at Oak Ridge National lab. Others do x-ray work at the *Advanced Photon Source (APS)* at Argonne National Lab. Still other use high energy protons at beamlines to test particle detectors made of glass at Fermi National lab.

III. Books and Journals

There are numerous books and journals devoted to glass science. In many respects this is the golden age of these sciences and book titles are being released in growing numbers. A major source of books is the American Ceramic Society (AcerS) and its publishing arm Wiley Publishing.

IIIa. Books

Some examples of recent book titles on glass and authors include these important titles: *Glass-Ceramic Technology, 3rd Edition* by Wolfram Holand, and George H. Beall *Modern Glass Characterization.*by Mario Affatigato, and *Successful Women Ceramic and Glass Scientists and Engineers: 100 Inspirational Profiles* by Lynnette Madsen, Cristina Amon, and Shirley M. Malcom. Certainly, much valuable information is contained within the phase diagram volumes published by the American Ceramic Society. Today, these are maintained and sold in an online form by the society.

There are excellent books by Larry Hench, the inventor of bioglass. He produced more than 30 books on glass and ceramics. Included in this creative output are six interesting and popular titles for children that are in the *Boing Boing the Cat* series:

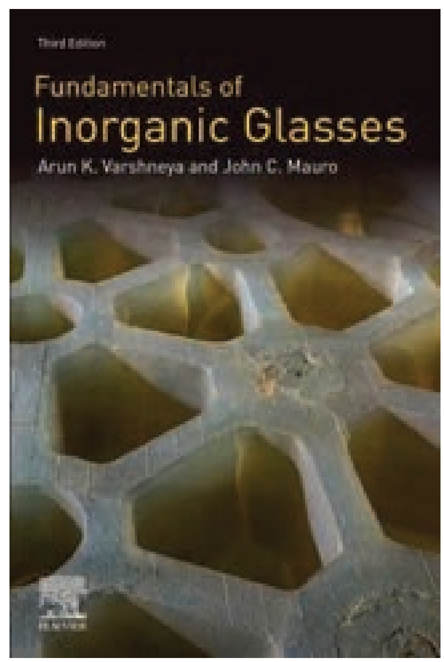

Fig.2: Varshneya's book cover

There are excellent texts for students to learn about the field. Arun Varshnaya's classic *Fundamentals of Inorganic Glasses* was recently revised and issued with new coauthor John Mauro: This is now its third edition. Also, in its third edition is another fine text *Introduction to Glass Science and Technology* by Jim Shelby.

A few classics volumes are: *Glass Engineering Handbook* by G. McLellan and E. B. Shand and *Properties of Glass* by G. W. Morey. This is a classic book of the 1960s Also, *Sol-Gel Science* by C. J. Brinker and G. W. Scherer is worthy of mention.

III b. Journals

Like books, journals have never been more popular and thus voluminous. New titles continue to appear. Noted peer-reviewed journals on glass that American glass scientists publish in include (but are not limited to): the *Journal of the American Ceramic Society, the International Journal of Applied Glass Science, The Journal of Non-Crystalline Solids, Physical Review, the Journal of the American Chemical Society, Solid State Ionics, Physics and Chemistry of Glasses –European Journal of Glass Science Part B, Acta Materialia, The Journal of Physical Chemistry C, The Journal of Physical Chemistry Letters, Phys. Chem. Chem. Phys., and the Journal of Solid State Chemistry*.

Many conference proceedings arise from the plethora of international conference held yearly on glass. An example is the joint Borate (nine proceedings in print) and Phosphate conference (two sets of proceedings are now out). Many professional societies publish their own journals, see section IV below on examples of such societies.

IV. Professional Societies

The principal professional society for glass in the United States is the American Ceramic Society. The society runs professional meetings, publishes journals, books and the online phase diagrams, honors practitioners, and supports students. Much additional information may be found at http://ceramics.org. Within AcerS are a number of divisions. The main one for glass is the *Glass and Optical Materials Division (GOMD)*.

Members of the GOMD routinely join and attend meetings of other societies including, within the United States, the Materials Research Society (MRS), the American Physical Society (APS), and the American Chemical Society (ACS). American scientists also join international ceramic organizations such as the *Society of Glass Technology or SGT* (UK), The *Japanese Ceramic Society*, the *German Ceramic* or DKG, and the Brazilian Ceramic Society. There is also the *International Commission on Glass* as the world-wide umbrella group linking the world societies together.

V. Outreach

Universities do much outreach on glass to the general public through programs of the American Ceramic Society, the American Institute of Physics, and the American Chemical Society. AcerS has numerous opportunities for outreach laid out in detail on its website (https://ceramics.org/tag/outreach): Some examples are:

Free Materials Science Lessons Download free lessons from The American Ceramic Society website for teacher demonstrations and small group student lab lessons. *K-12 Outreach from The American Ceramic Society Information and resources for K-12 students.*

DiscoverE (formerly the National Engineers Week Foundation) This program helps unite, mobilize, and support the engineering and technology volunteer communities. This site celebrates K-12 education and promotes the value of engineering education and careers. There is a lot of great information for students and teachers alike!

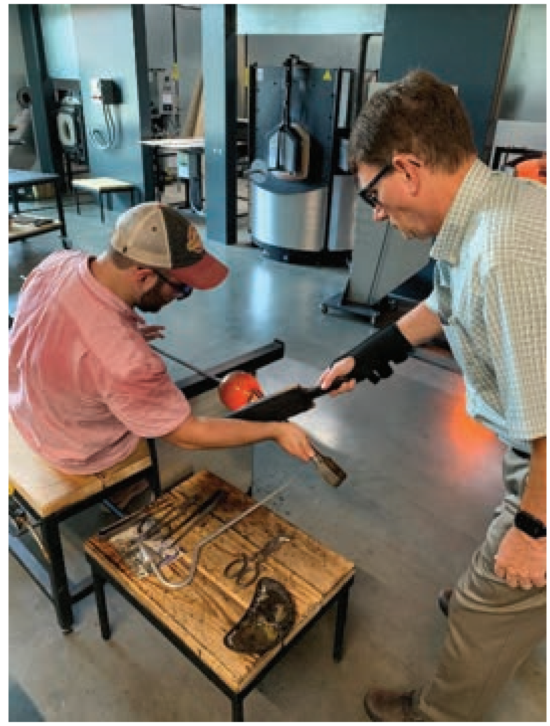

Figure 3: Prof. Steve Martin and Dr. Steven Kmiec of Iowa State University make a glass vase in their demonstration glass lab.

SciGirls from PBS SciGirls is designed to spark girls' curiosity in science, technology, engineering, and math (STEM) through activities that promote knowledge and discovery. This program—including the TV show, website, and educational outreach—is all about hands-on science inquiry. Participants learn the scientific process, work collaboratively to investigate meaningful questions, and see how STEM helps people solve problems, achieve goals, and help others.

The Society of Physics Students (SPS), a part of the American Institute of Physics, has an activity meant for classrooms for all ages of school children on making boron oxide glass. It maybe found at: https://www.spsnational.org/programs/outreach/borate-glass

It was developed by Ariel Crego of Coe College. It is described by SPS as follows:

Students learn about glass, how glass is formed, and under what conditions that can occur.Glassy materials form a cornerstone of the study of material sciences—with leaps and bounds made in recent years, a full understanding of amorphous materials has never been so important. With this experiment students will learn how phase changes occur, how that affects atomic placement, and structure affects the material properties.

Many colleges and universities have outreach programs; too many to list here. A few examples are given below.

Iowa State University is active in demonstrating glass blowing and related arts. Their brand new facility, shown in Figure 2, is much used in glass demonstrations.

Coe College has an annual *Playground of Science* that includes glass making. This event typically brings to campus more than 1200 students and parents.

VI. Acknowledgements

The National Science Foundation is thanked under grant number NSF DMR-1746230.

A perspective of graduate education of glass science and engineering in the United States

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1. Background

Graduate education leading to a doctorate (or Master of Science with research) in STEM disciplines is expected to advance the frontiers of discovery, and contribute to the growth of the economy, national security, and the health and well-being of the public. It should contribute to innovation and push forward the cutting edge of technology, thereby creating opportunities for the employment of a much larger technical workforce, trained through bachelor's and associate degree programs. Thus, an appropriately trained graduate research workforce is crucial for remaining competitive in today's global economy.

Most recent data from 2020 indicate that 90% of doctorates in engineering and 84% in physical and earth sciences seek employment outside academia, mostly in industry. Employment opportunities are gradually trending away from academia. Therefore, it is natural to ask: are we preparing our PhDs sufficiently well in glass science and engineering for their subsequent professional careers? I had posed this question to the leaders of the glass industry during the 2004-2015 period of International Materials Institute for New Functionality in Glass (IMI-NFG). A response that I heard more than once stuck with me: "*you have very smart students coming out of your university but they don't think like us*". That is, there seemed to be a disconnect between the way academia was training glass doctorates and the expectations of the predominant employment sector. The first comprehensive analysis of doctoral training reported in 2018 by the National Academies of Sciences, Engineering and Medicine established that this problem of workforce development was widespread across all STEM fields, not just in glass science and engineering.

The cause of this systemic problem appears to be a lack of communication between the academia and the major employers, including corporate R&D companies, national labs, defense and health research organizations, etc., besides universities and colleges. To address this malaise, a comprehensive model of doctoral training in STEM fields, called

Pasteur Partners PhD (P3) has recently been developed through collaboration between academia (Lehigh University) and glass industry (Corning) with support from NSF's Innovation in Graduate Education program.

A new track for doctoral education based on this model was established at Lehigh in 2021. It is now available to students in all STEM Departments, as discussed below.

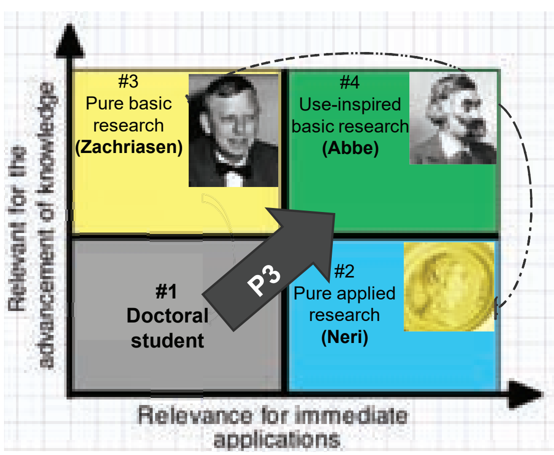
2. Scope of doctoral training in USA

The present form of STEM PhD education was shaped 70+ years ago following WWII, when Vannevar Bush laid the foundation of science policy for the country and establishment of the National Science Foundation. It was based on the experience from the most impactful technological development at the time: the atom bomb. It asserted that when the country invests in fundamental research driven by curiosity to explore nature, there will be others who will find ways to exploit the new knowledge to develop applications, which a company would take up and turn into products to benefit society. This linear model of society's progress originating in curiosity driven research was evaluated five decades later by Donald Stokes, who argued in his book, *Pasteur's Quadrant*, that for optimum benefit the society should focus on use-inspired research that falls in the fourth quadrant of two orthogonal approaches to research – the curiosity driven basic research and empirical research driven by the need to solve an immediate problem at hand (see Fig. 1).

These approaches have been personified in Niels Bohr and Alva Edison. The former was interested in understanding the constitution of matter without being concerned about the use of a given material, whereas the latter wanted to solve technical challenges presented by a particular application that would benefit the user. As pointed out elsewhere in the present book, the progress of glass science and engineering has been replete with empirical observations that were highly protected by the inventors for much of its history of several thousand years. The first account of this Edisonian approach to research by numerous makers of glass was compiled by Antonio Neri in the first book on glass, L'Arte Vetraria. For the field of glass, the work of William Zachriasen, who published the first atomic structure model in 1932 at the age of 26, may be considered as representing curiosity driven basic research about the constitution of glass.

With glass becoming a widely used material in consumer products as well as high-tech devices, it has supported a large number of companies that have been in operation successfully over centuries. Among them several large companies across the globe such as Corning, Schott, Asahi, NEG, Saint Gobain, etc. have pursued use-inspired research driven by the market. Their continued success can be attributed to the commitment to innovation made possible by discoveries and the role of composition, processing, and the understanding of structure-properties correlations. Thus, there are numerous excellent examples of scientists who have pursued use-inspired research and contributed to the advancement of society, thereby befitting the fourth quadrant in Fig. 1. From this list, Ernst Abbe conducted the first systematic study of optical properties of glass in order to produce superior optical devices that led to many advances in physics, microbiology, and materials science. Thus, Abbe personifies the use-inspired approach of Louis Pasteur, the father of microbiology, who conducted in-depth fundamental studies to treat specific disease processes.

Overall, the field of glass has progressed reasonably well in the US by pursuing use-inspired research. However, that mode has been largely confined to corporate research with little attention given to involving graduate students and their training. The lack of involvement of industry in graduate training that introduces young researchers to use-inspired research, and thus to a mindset of solving complex problems is not unique to glass, but pervasive across various industries in varying degrees. The P3 model is designed to provide a uniform platform to prepare the student with a mindset of research that can successfully address complex socio-technological problems of today. We argue that P3 students will also be successful as well-rounded faculty mentors. At the same time, we note that whereas the P3 program attempts to train the majority of students by taking them from the origin into the fourth quadrant in Fig. 1, some students should be allowed



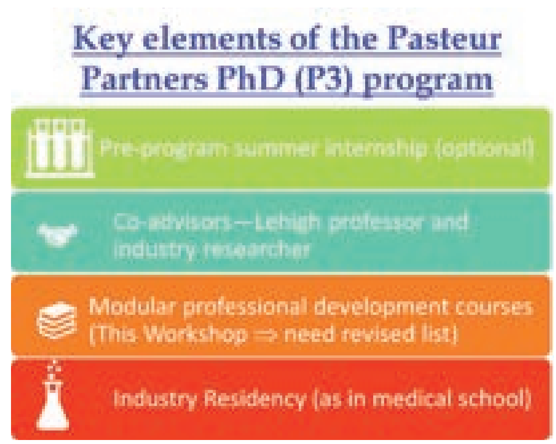


Fig. 1 (Left). Stoke's model of research with curiosity driven fundamental approach indicated on the vertical axis (third quadrant), and application driven empirical approach on abscissa (second quadrant). Pasteur's quadrant (#4) represents use-inspired research.

Fig. 2 (Right). The four key elements of Pasteur Partners PhD (P3) model of student-centered graduate training that is designed to train the mindset of the student to solve complex problems in an industrial environment realistically.

to pursue curiosity driven, blue sky research in the third quadrant, to be able to explore problems 'outside the box'.

Figure 2 summarizes the key components of the P3 track as established at Lehigh University, and several other institutions are considering adapting this model for their programs. Fortunately, the glass community is well placed to lead this effort with its history of use-inspired research in industry. Although significant hurdles remain to establish industry-university partnerships required for P3 training, Corning has taken the lead along with companies from other sectors in supporting the P3 model.

3. Delivery of graduate education

The field of glass is a small part of the materials science and engineering discipline that itself is usually a relatively small department in most engineering colleges at US universities. There are hardly any institutions that have a degree program in glass science and engineering. Also, during the last couple of decades, the education of glass science and engineering has been affected adversely as the distribution of faculty with expertise in glass has changed from being concentrated at very few universities to being distributed at many universities. This often results in just one solo faculty member who is knowledgeable in glass science, at most institutions. This person typically teaches just one glass course, which ends up being an introduction to the whole field. Even when the lone professor of glass wants to offer an advanced course, there are too few students in any given term who sign up for such a specialized course; it is difficult for the university administration to approve courses that have fewer than half a dozen students. The result is a larger number of students exposed to glassy materials, but with relatively shallow, cursory knowledge that does not prepare them to pursue graduate degrees and become professional glass scientists or engineers.

A solution to the problem of training graduate students in glass science and engineering under the above described circumstances was pioneered under IMI-NFG in 2007 by professors from nine universities (Alfred, Arizona, California-Davis, Coe College, Florida, Iowa State, Lehigh, Michigan, and Missouri Sci. Tech.). They introduced the concept of multi-institute team teaching (MITT), which could be extended to other disciplines with a similar distribution of learners and teachers. It combined advanced distance learning technology with unprecedented cooperation among faculty from multiple universities to share the teaching as well as their students. Altogether IMI-NFG offered eight semester-length courses free of cost to the participants, the last of which was on glass processing. It was taught in 2015 by 21 lecturers, and had 275 students registered, representing 45 universities and 25 companies from 25 countries. In spite of the tremendous success of the MITT approach for training graduate students, it did not continue beyond the tenure of IMI-NFG, mainly due to the lack of management resources and a sustainable financial model. There is renewed interest recently in offering at least some of these courses on a regular basis. Perhaps a professional organization like the American Ceramic Society or the International Commission on Glass can administer their offerings and assure continued training of students in advanced topics of glass science and engineering.

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Women In Glass –
beyond the glass ceiling

Christine Heckle, Corning Inc. Corning NY
Carol Jantzen, Savannah River National Laboratory, Jackson SC
Denise M. Krol, University of California-Davis
Kathleen A. Richardson, University of Central Florida, Orlando FL

The International Year of Glass (IYOG) provides an opportunity to evaluate the progress made on diversifying the face of Glass across the world in general, as well as here in the US. To do this, we have assembled a multi-generational perspective of leaders within the US glass community. While not meant to be all encompassing, it is meant to offer a benchmark on how far we have come, and how far we have yet to go in the inclusion of women and minorities that make up the US Glass community.

If you Google *"Women in Glass Science"* the first thing that comes up is an advertisement for pint beer glasses with photos of *Great Women in Science*! [1] Sadly, this top search result is not indicative of the numerous studies and global initiatives that have focused on the issue of Women in Science However it requires much deeper digging to find hard data on *Women in Glass Science* in general and more specifically, in the US. There have been numerous publications on gender as summarized in a most recent review which discusses penetration of women in science careers in Europe as compared to other countries [2], women in science in both academia [3] and those gaining footholds in diverse scientific fields since the first world war in the US [4]. More recently, Lynnette Madsen, a program director at the US National Science Foundation, wrote a book on Women in Ceramics and Glass [5], where she identified 100 leaders in our field who have made inroads into diverse careers. These publications while varied in their publication dates, all come to similar conclusions: that while progress is being made in gender parity in industry and academia, women still trail men in publications and citations related to their scientific work, as well as their pay levels.

Perhaps the first comprehensive summary on *Women in Glass* was reported by the team leading the compilation of a special issue of the International Journal of Applied Glass Science (IJAGS) on *Women in Glass* in 2020 [6]. This issue of IJAGS not only featured seasoned women researchers, but was structured to pair senior and junior co-authors working in the same field to co-author a joint publication. Beyond a snapshot of the state-of-the-art in diverse technical areas, the effort led to new collaborations and networks, going far beyond simply 'another' journal special issue. We've done a bit of digging to identify some relevant historic perspectives of the co-authors and their various histories and disciplines, to illuminate this story. We share here, across decades and disciplines of industry, academia and national labs, some of our findings on various **firsts** or **only's** trying to capture a few examples where there were more than one or two women 'in the room' for a given event.

Carol Jantzen highlights her experience in the late 1960's when in 1969 she was one of the first 5 women admitted to the PhD program at Penn State. At that time, there were fewer role models (Della Roy was the only professor at the PSU Materials Research Lab) available to provide inspiration and advice when male professors didn't want to take women students fearing they'd leave to marry or have children. Carol graduated from SUNY Stony Brook (1976) and following a post-doc in Europe (where she found much more acceptance of women in materials science), she went on to be a pioneer over a 37 year career at Savannah River Lab (now, Savannah River National Laboratory). Carol recalls upon her joining SRL in 1980, that she was one of 3 women in a group of 500-600 male PhD's (of about ~ 1000 MS and PhDs) at the site. While there were a lot of women technicians, there were very few female scientists. Carol received numerous awards for her technical contributions of glasses used in the nuclear waste area, and in 1996, became the first President of the American Ceramic Society in 100 years, one of many firsts for *Women in Glass*.

Many of the *Women in Glass* in the 70's and 80's were affiliated with the Optics field, as recounted by Denise Krol who following her PhD at Utrecht University (1980) spent her early career at Phillips Laboratory in the Netherlands, prior to coming to AT&T Bell Labs in 1986. She was fortunate to be among other 'first women' (see Figure 1), who like Denise, had challenges in laboratories that had previously been dominated solely by men. Denise blended industry and government lab experiences, followed by academia where she mentored countless women. During the 1980's, Kathleen Richardson joined the optics field as well, working in Optical Materials at the University of Rochester's Laser Laboratory (LLE) prior to returning to Alfred University for her PhD (1992) in non-oxide chalcogenide glasses. At LLE she was the only woman engineer, though her lab was next door to that of then Institute of Optics grad student Donna Strickland, who went on to receive the Nobel Prize in Physics in 2018. One of very few women at optics conferences in the mid-late 1980's (with Denise Krol), she went on to be an academic at the University of Central Florida (UCF) and Clemson University, committed to directing research for more than 50 Bachelors, Masters and PhD women, 2 dozen high school interns and 15 post docs and engineers in Optics, Chemistry and Materials Science and Engineering. Many of her graduates have gone onto industry, national labs and academia. Kathleen served as ACerS president in 2014-2015. She continues to be highly cited in the area of infrared glass and glass ceramics, along with her diverse team of collaborators. Christine Heckle, also an Alfred University PhD (1998) was the first graduate of Alfred's Glass PhD program, formalized in the early 1990's and made official by the State of New York in 1994. This program at last count has graduated close to 30 PhDs, with ~30% women. Since joining Corning, Chris has made significant inroads in the technical management ladder at Corning Incorporated, leading a broad range of technical programs. As research director, Chris has done much to highlight diversity in Corning's facilities, which now boasts an almost 30% level of women within their workforce within the US. Industry as discussed below, has far outpaced national labs and academia in this effort towards gender parity. We summarize here a few of the other histories where women made contributions that have paved the way for us and others. While not exhaustive, it does show the diversity of disciplines that have found their way to glass and have served as important examples of progress.

Industry

Initially turned away because "women were disruptive in the lab" Mary Purcell Roche became the first woman scientist in Corning Glass Works in 1942 with a MS in Biochemistry. In 1955, Ellen Lunn Mochel became the first woman with a PhD to work at Corning. Ellen's husband had been hired at Corning earlier, left and was recruited to return. His requirement was that she be hired also, after completing a PhD in chemistry at the University of Louisville. Ellen investigated the reaction of sulfur dioxide with glass which led her into Project Muscle, advancing ion exchange to strengthen glass. Ellen discovered that alkali aluminosilicate glasses containing greater than 5% alumina had especially good strength after surface abrasion, a key building block for the future Gorilla Glass. Corning launched "Women's Issues" Corrective Action Team in the 80s, followed by the formation of the Corning Professional Women's Network. In 1988, Corning was named in Working Mother magazine as one of 100 best companies to work for. Linda Pinckney was Corning's first woman Research Fellow, named in 2002. In 2008, Lina Echeverria was named the first woman Vice President in the Science & Technology division. In 2022, one third of Corning's workforce in the US is women, but more work remains. Less than 10% of the top leadership in the technology community are women.

Figure 1: (left to right) Denise Krol, Eva Vogel and Suzanne Nagel at the GOMD conference in 1995.

In the 1980s AT&T Bell Labs was one of the key players in glass science and technology. While at the time there were only few technical women at Bell Labs, those that were there made serious efforts to welcome, support and mentor new women hires. For example, there were regular meetings held by and for women in research, where they could talk about specific gender-related issues that they ran into. Maybe at the time Bell Labs was not only leading the way in science, but also, in highlighting the role women could play in cutting edge optical science. Summarized in the January 1986 edition of Lasers and Applications [7], Suzanne Nagel, a 1972 PhD graduate of University of Illinois, served as a leader in the Labs' quest for low loss optical fiber technology. In 1992 she was appointed a Bell Labs Fellow, the highest technical level of recognition in Bell Labs, becoming the first woman to achieve this distinction. Nagel credited her career success to establishing a mentor system, and she set out to use her visibility to help create mentoring opportunities for other women in science, speaking to organizations across the country. In her honor the 2018 Optical Fiber Communication Conference and Exhibition (OFC) introduced a new networking space, the *Suzanne R. Nagel* lounge, focused on improving gender equity at OFC and the field of optical communications. Suzanne often attended the Glass Division meetings. On those occasions she also encouraged other women scientists to pursue their career goals and led by example by speaking her mind. And she showed us that you can be a serious scientist and have some fun after work at the same time.

As discussed in [5] another notable woman glass scientist from the early days at Bell Labs is Eva M. Vogel, who was hired as one of very few technical women in 1970 in the materials research department. She was active in both glass and ceramics research and became the first woman chair of the ACerS Electronics Division in 1993–1994. After she joined Bellcore in 1984 she became one of the leading scientists on nonlinear optical properties of glasses [8]. Eva was also keenly aware of the difficulties that women in glass science faced in the early days. Having arrived in the US in 1969 from the former Czechoslovakia, she did not initially have a network of former professors and friends from college or graduate school in the US and she decided that she wanted to play her part in providing a more inclusive climate for other women. She acted as a mentor and an adviser to a number of young women scientists.

Academia

Figure 2 – current Women Glass researchers (courtsey, E. Zanotto, IYOG Opening Ceremoney

As of the 1980's, there were only (3) PhD programs worldwide granting degrees in Glass Science. While early programs offered Glass Technology programs, programs in Glass were often found associated with Ceramics departments. Russia (Institute of Silicate Chemistry, St. Petersburg), the UK (Sheffield University) and the US (Alfred University) were the first to offer glass-related degree options. Alfred University graduated its first woman with a Bachelors in Glass Technology in 1937. Sylvia Gailar went onto be one of the first women to join the US Army designing lenses for military systems, a position she later gave up in opposition to the military effort prior to moving to Europe. These institutions and others had some of the first women faculty teaching glass science and leading research efforts in their Universities. These have included Profs. Natalia Vedishcheva, Inst. Silicate Chemistry

(Russia), Doris Ehrt at Friedrich Schiller University (Germany), Angela Seddon at Sheffield University, now at the University of Nottingham (UK), and Alexis Clare at Alfred University (US). These women served as the mentors that inspired many of those women featured in the Women in Glass IJAGs article, as depicted in Figure 2 [9]. Many of these women, Doris Möncke, Liping Huang, Delia Bauer, Alicia Duran, Kathleen Richardson, Heike Ebendorff-Heidepriem, Annie Pradel, Ana Candida Rodriguez, Laeticia Petit, Madoka Ono, and others, now teach in materials, optics, physics or glass programs around the world, inspiring students that they too can be glass researchers and/or educators. As the face of educating the next generation of glass scientists and engineers is evolving, so too are the methods being used to excite and motivate students in glass, as discussed in [10]. Women are involved in all of these important activities, transforming the face of glass education and training.

Figure 3. Attendees at the 1990 Gordon Conference on Glass, Tilton NH

One of these long-time educators illustrates an ongoing challenge in our academic communities, the number of female faculty. Prof. Lisa Klein, best known her sustained efforts in sol-gel processing of glasses, earned her PhD in Ceramics from MIT in 1976 and has been a professor covering glass topics at Rutgers University. She was the lone woman faculty member in Materials Science and Engineering for 32 years. Sadly, while numbers have grown, in many cases these women remain one of only a few women (if not the sole woman) in their various academic departments.

Figure 3 illustrates the attendees at one of the last Gordon Conferences on Glass, held at Tilton NH in 1990 which shows several of the (then) female graduate students from Alfred who were in the pipeline for the new PhD in Glass Program. In addition to the Glass Division meetings of the American Ceramic Society, the Gordon Research Conferences gave us 'early glass women' the opportunity to bond and support each other in the pursuit of our careers, and for students to see and speak with leaders in our field.

Others from this photo (beyond Krol, Richardson and Vogel) who were leading the optical glass research activities during this time, include Susan Houde-Walter who also spanned glass and optics in the 1980s. Susan earned her PhD in Optics from the University in Rochester in 1987 evaluating ion-exchange processes for gradient refractive index (GRIN) applications. She is now CEO of LaserMax Defense a company making hardened and miniaturized optical systems. She served as a past-president of the Optical Society of America (now Optica) and was elected as a Fellow of ACerS in 2000. Also shown in the photo is Martina Sabourin, one of the first Asian women who supported the Bell Labs team in their initial activities in prototyping and transitioning solutions in the flat panel display area in the early 1990's. Following her departure in the mid-90's from Bell Labs, Martina went on to lead quality and compliance activities at Owen's Corning, Tyco Communications and her current position now at ThorLabs.

The future of Glass and STEM

The next generation of researchers and educators is indeed diverse and making inroads into to the new problems and opportunities in glass. As has been shown, many of these advances in both topic areas and opportunities for improvements in diversity in the glass workforce, will likely occur at boundaries of disciplines. Educators are recognizing that more efforts are needed to not only attract this diversity into STEM-related academic programs, but to retain them and translate them forward, towards their careers. These efforts are making inroads, and while still slow, are starting to bear fruit as shown in the gender diversity now seen at conferences and meetings where there are now many more 'women in the room.'

As we co-authors have learned individually and as a cohort, such initiatives start at the grass roots, by showing aspiring girls, the faces of young women scientists that look like them and who can describe how to do such things and where a range of resources and networks can help. Shown in Figure 4 are just a few of the next generation, a snapshot from a Women in STEM day at the University of Central Florida from 2015 when the Richardson group was made up solely of women. Shown in Figure 4 (left to right), are Dr. Charmayne Smith, now at Pacific Northwest National Labs, Prof. Casey Schwarz, now in the Physics Department at Ursinus College, and Dr. Rashi Sharma, a post-doc at UCF. These women, like so many before them, are changing the way we teach and train young students today, to tackle the many challenges confronting our field in energy, waste and recycling, biomaterials and beyond. These are the efforts, as well as those made by the many women before us, who will continue to blaze a *widening path*, of Women in Glass.

Figure 4. UCF post-docs at a Women in STEM day in 2015, supporting recruiting of middle school students into glass science and engineering

Acknowledgments

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Women attendees at the NDoG

Front Row (Left-Right):
Kathy Jordan, Stephanie Tompkins, Jaquelyn Fetrow, Anuradha Agarwal, Alicia Duran

Standing (Left-Right)
Natalie Tyler, Kim Ma, Urmilla Jokhu-Sowell, Megan McElfresh, Ellen Rogers, Elizabeth Dickey, Anne Mullins, Adelle Schade, Tammy Ma, Doris Moncke, Eriko Maeda, Kathleen Richardson, Lisa Lamberson, Jessica DeGroote Nelson, Marina Pascucci, Christine Heckle, Elizabeth Sturdevant, Jennifer Rygel, Pam Strollo, Irene Peterson

A Future of Glass

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Glass has proven to be one of the most important materials enabling the development of modern human civilization. Glasses are key components in cutting edge industries, including energy, medicine, architecture, information, communication, electronics, automotive, aerospace, optics, houseware, and packaging. In each of these sectors, glasses have provided an enormous positive impact on humankind, leading some to propose that we are now living in the Glass Age. The positive influence of glass on our world continues to expand as new glass products and processes are developed that address global challenges in each of the above areas.

In the healthcare sector, new biocompatible and bioactive glasses will have a transformative effect on millions of patients, including drug delivery and hard/soft tissue repair. Glasses with high mechanical and chemical durability are also essential for use as pharmaceutical packaging for the safe storage and delivery of critical medicine.

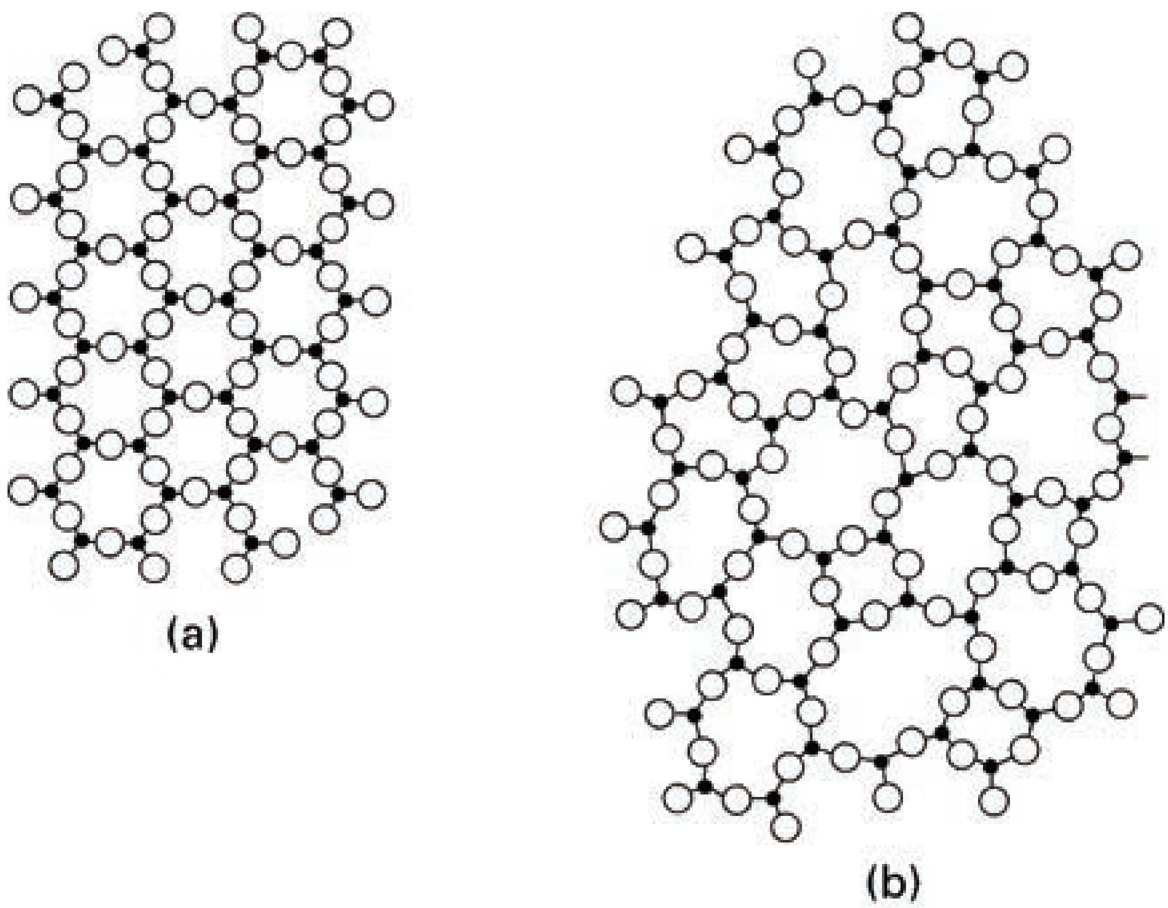
The role of glass in energy production and storage continues to grow. Glasses are key components for a variety of solar energy harvesting technologies, including photovoltaics, solar thermal energy, and photo-bioreactors. Ultra-stiff fiberglass is a critical component for wind energy harvesting. Glassy materials will also be used as energy storage media for solid-state batteries with improved safety, energy storage density, and cycling performance. These improvements in energy harvesting/storage will be complemented by new glazing technologies to reduce energy consumption.

New fiber optic technologies will be developed to enable higher bandwidth communication, while minimizing the need for signal amplification. Advanced glass fibers will also be developed for quantum communication. Glass fibers will also play a key role in facilitating the "Internet of Things," i.e., the interconnection of everyday appliances and objects. Another emerging field is that of flexible and stretchable photonics, including wearable photonic sensors. Glasses are also promising materials for next-generation holographic memories, which could enable exceptionally high data storage densities.

Glass has also played a revolutionary role in information display, from early televisions based on cathode ray tubes to more recent flat panel displays. As the resolution of these displays improves by using smaller pixel sizes, the requirements on the high-tech glass substrates become more stringent. New glasses for high-resolution displays will be developed to minimize relaxation during the display fabrication process as thin film electronics are deposited onto the glass substrates. New ultra-thin glasses are being developed to enable bendable or even foldable displays. Advanced glasses are also being invented for visualizing information through augmented and virtual reality devices, which perhaps represent the next revolution in information display technology.

Selected Presentations
at the
National Day of Glass

Washington DC April 5-7,2022



Glass science at its best: Atomic arrangements in glass (b) compared to those in crystals (a). *After W. H. Zachariasen, J. Amer. Chem. Soc. 54(1932) 3841.*

The Art of Glass: Three Millennia of Creativity and Expression
Dr. Karol B. Wight, President and Executive Director
The Corning Museum of Glass

CORNING MUSEUM OF GLASS

Early Glass: 1400-330 BCE

The process of making glass was developed during the Bronze Age, sometime before 2000 BCE, in Mesopotamia. The remains of this earliest glass are a few small fragments, mostly from beads. The ‘how’ and ‘why’ of glassmaking are not known, but because beads and other objects made at that time were decorated with vitreous glazes it may have been a happy accident that then changed the world.

While glassmaking began in Mesopotamia, the technology quickly spread first to Egypt and then elsewhere throughout the Mediterranean. By the 1300s BCE, glass ingots were being transported as a commodity to be reheated and formed; thus, the manufacture of raw glass and the making of glass objects were already distinct processes. The quantities of glass produced at this time were small, and glass was considered a luxury material. The colors developed for the earliest glass objects were opaque and intentionally resembled precious natural materials like turquoise, lapis, carnelian, and other colored stones.

One of the earliest ways it was shaped was by casting, melting powdered glass or chunks of glass in molds to form pendants and inlays.

Cast Portrait Inlay of Pharaoh Akhenaten, about 1353-1336 BCE. Egypt.
2012.1.2

Flameworked “Seven Star” Eye Bead, 475-221 BCE. China.
51.6.552

Another early technique was core-forming, in which a core made of a material like clay or mud is wrapped around a metal rod. Hot glass was applied over the core, most likely by trailing thick ribbons of glass, and then marvering it to consolidate the material. Additional trails could be added to create decorative stripes, which were then dragged to create zigzag or feathered designs. Once cooled, the core was removed from the glass to reveal an interior cavity.

Flameworking was another early technique for shaping glass, and quantities of beads and pendants were made, worn, and traded across vast distances, even from the Mediterranean World to Asia along the Silk Route.

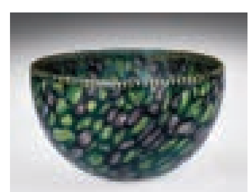
Hellenistic Glass: 330-33 BCE

The mosaic technique of combining small pieces of glass to create a decorative effect is one of the earliest glassmaking processes known. Hemispherical bowls were manufactured by first placing segments of patterned glass rods into a design and fusing them into a disc shape. The edge was finished by adding a segment of a cane. The disc was then sagged over a hemispherical mold to form the final shape.

The use of glass was not limited to vessels and jewelry but was also used in architectural decoration, including windows, walls, and floors. The mosaic technique was used to create revetments that were inlaid into plaster walls.

Core-Formed Vase, probably 1400-1300 BCE. Egypt.
66.1.213

Mosaic Glass Bowl, 125-1 BCE. Probably Eastern Mediterranean.
55.1.2



Mosaic Revetment with Fish, 99 BCE-25 CE. Roman Empire.
61.1.6

Roman Glass: First century BCE – 500 CE

The development glassblowing caused a seismic shift in how glass was made and used. Processes evolved from being laborious and multi-stepped to a swift choreography of skill and creativity. Glassblowing allowed glassmakers to create entirely new shapes and designs, breaking free from the conventional forms and patterns used in the past.

Cameo glass was designed to imitate precious layered stones and was carved in such a manner to showcase the contrasting colors. The creation of the multi-layered blank took great skill and involved combining opaque and transparent glass that had compatible colors; this assured successful annealing. Once annealed, the blank was handed off to a craftsman to carefully carve away the outer layers of glass and complete the design.

Blown objects require less glass to make, a reality that turned them into an affordable item. The rising demand for glass vessels required the makers of raw glass to design furnaces with a greater capacity for melting thus the tank furnace was developed. And from this early period, glass was also recycled with broken glass shards reheated and reshaped into new wares.

Cameo Glass Cup, 1-50 CE. Roman Empire; probably Italy. 52.1.93

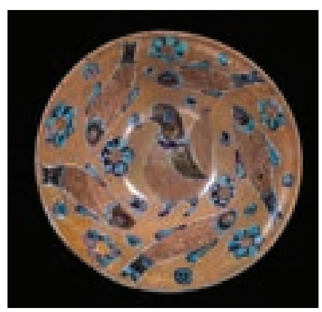
Mold-blown Cup, 30-70. Ennion, Eastern Mediterranean; possibly Lebanon, Sidon. 66.1.36

Medieval and Islamic Glass: 600 CE – 1400 CE

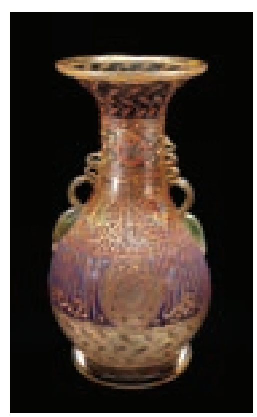
The majority of techniques used to shape and decorate glass were developed before and during the Roman period, and they continue to be used today. But there were also new developments.

Staining is achieved by applying a paste of silver or copper particles suspended in a binder to the surface of a glass object. Once decorated, the piece is then fired at a low temperature in a reducing environment. Once the glass has cooled, the paste is wiped off leaving behind the metallic particles that have migrated into the body of the glass and colored it shades of brown, yellow, red, white, or green.

Enameling was a technique that developed from the Roman tradition of painting glass. Enamel is made from powdered glass and is suspended in an oily material that is painted onto a cold glass object and fired at a low temperature. This allows the enamel to melt onto the surface without deforming the glass object. Unlike earlier painted decoration, enamel does not wear off the surface.



Stained Bowl, about 800-899. Probably Egypt. 99.1.1

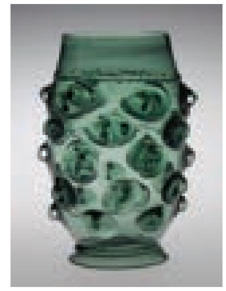


Enameled Vase, about 1310-1330. possibly Egypt; possibly Syria. 55.1.36

Renaissance Europe: 1400-1600

Much of the late medieval and Renaissance glass produced in Europe was made of a green glass called 'forest' glass. The coloration was caused by the iron impurities present in the sand from which it was made. Such vessels were made in small glasshouses located in forests, close to the source of fuel. During this period, authorities all over Europe became concerned about the consumption of wood. As a result, the quantities of glass that could be made was closely regulated so as not to consume too much timber. Eventually these restrictions led to the use of coal for glass furnaces instead of wood.

Prunted Barrel, 1500-1599.
Germany.
53.3.2



The most storied glass industry is that of Venice, centered on the island of Murano. Venetian glassmakers are best known for the creation of cristallo, a clear, long-working colorless glass that allowed them to create fragile and elegant glassware. The recipe's secret centered on the use of quartz pebbles from the Ticino and Adige Rivers. The plant ash used as a flux was imported first from Syria and Egypt, and later, from Sicily and Spain. The final key ingredient was manganese dioxide used as a decolorizer.

The secret of cristallo was closely guarded, and Venetian glassmakers worked under strict regulations including restricting their movements, to protect the recipe and the industry. Venice dominated the glass world from about 1500 to about 1700.

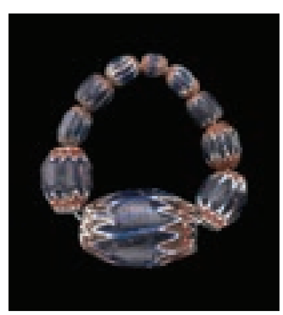
Wineglass, about 1650-1700.
Italy, Venice.
51.3.118

Eventually the secrets of colorless glass made their way to other parts of Europe. As a result, distinctive regional glassmaking styles emerged to compete in the marketplace.

One technique used to decorate clear vessels was diamond point engraving, a light cutting technique that first made its appearance in antiquity.

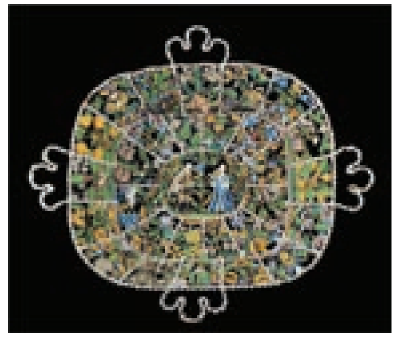
Venice was a center of glass bead production beginning around 1500, and the rediscovery of how to draw hollow canes transformed the industry. The chevron, or rosette bead was among the most famous. Made of multiple layers of glass, the bead's ends are ground away to reveal layers of color. This type, and many others, were exported to Africa, where they were considered by many cultures to be highly valuable. It is important to acknowledge that beads were traded for human lives as part of the African slave trade. But they also stimulated a domestic bead making tradition across the African continent that continues today.

Covered Goblet, about 1570-1590. Court Glasshouse, Austria, Tyrol, probably Innsbruck.
68.3.1



Chevron Beads,
about 1600-1700.
Italy, Venice.
62.3.9

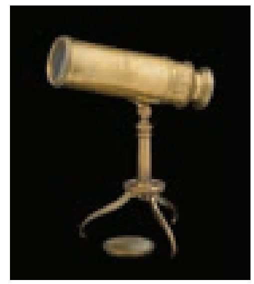
Small seed beads were used to decorate a variety of beaded wares across Europe. They were manufactured primarily in Venice and Bohemia. Seed beads were widely distributed as trade goods. As the continent of North America began to be explored by Europeans in the early 16th century, they brought quantities of seed beads with them to trade. Because a beading tradition already existed among the American Indian tribes, glass seed beads began to be incorporated into the production of items that were traditionally decorated with beads made from natural materials.



Beaded Basket Depicting a Couple, about 1660-1670. England.
53.2.4

Early Modern Glass: 1700-1800

Throughout the history of glassmaking, there has been a strong relationship between those who make the recipes for glass, and those who fashion that glass into decorative and functional objects. One example can be seen in England where George Ravenscroft worked to improve the clarity and brilliance of glass used for fine tableware. He experimented with the addition of lead oxide to the raw materials and by 1676, he succeeded in making crystal-clear lead glass that did not deteriorate. And while his goal was to improve tableware, lead glass had additional applications.



Miniature Tabletop Refracting Telescope, about 1800. Peter Dollond, England.
2018.8.10

Six major scientific instruments were invented during the 17th century: the telescope, microscope, barometer, thermometer, air or vacuum pump, and pendulum clock. And all but the clock employed glass in a fundamental way. Instruments like the telescope and the microscope enabled the user to go beyond the domain of the everyday and into new, unexplored realms. Peter Dollond is co-credited with the development of the achromatic lens, in which colorless lead (flint) glass and soda-lime glass are combined to show refraction without net dispersion.

Mirror in Carved and Gilded Wood Frame, about 1760. Probably William Mathie (carver), Thomas Chippendale (design based on), probably England, London (glass); Scotland (frame).
2018.2.8

Many technical advances in glassmaking occurred during the 1700s that had a direct impact on how we live our lives today and experience the world around us. Large cast plate glass was now made by pouring molten glass onto a large metal tableand rolling it out evenly using a copper rolling pin. This was perfect for windows and for mirrors. Interior lighting was provided by small tabletop fixtures placed in front of mirrors to reflect light into a room.

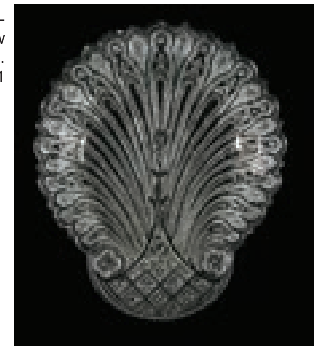
Pocket Flask, 1765-1774. Henry William Stiegel, United States, PA, Manheim.
50.4.22

In the American colonies, glassmaking was among the earliest European industries undertaken in America. Ultimately these attempts were not successful and for nearly a century, glassware was imported from Europe. Eventually glassmaking industries were established along the eastern seaboard. The shapes and styles of early North American glass closely resembled European types.

Industrial Era Begins: 1800-1900

Progress in engineering and manufacturing in the 19th century led to even further developments in glassmaking. The introduction of the hand press in the 1820s, when combined with molds, resulted in the manufacture of glass multiples of the same size and decoration. With a press, a team of two operators could produce four times as many glasses as a team of three or four glassblowers, and affordable pressed items became commonplace.

Cut and engraved glass continued to be as well, and one of the central places for producing cut glass in the latter-19th century was Corning, New York. The Houghton family had relocated the Brooklyn Flint Glassworks from Brooklyn to Corning in 1868, and after being rechristened Corning Glass Works, the company began to focus their production on tableware and technical glasses. One of their products was thick-walled blanks that were then sold to companies that specialized in glass cutting. One of the leading companies in the United States at that time was J. Hoare and Company, also located in Corning. The pattern of this brilliantly cut bowl is called the Crystal City pattern in honor of the manufacturing town.



Pressed Tray, about 1830-1845. United States, New England.
68.4.501

Bowl in "Crystal City" or "Wedding Ring" Pattern, 1891-1895. J. Hoare & Company, United States, NY, Corning.
83.4.149

The stylistic opposite to cut glass was art glass, and the one of the leading American manufacturers was Louis Comfort Tiffany. His distinctive art nouveau style included unique glass recipes and designs that were deployed in a variety of ways.

Studio Glass: 1962-2000

Harvey Littleton was a child of Corning, the son of research physicist Dr. Jesse Littleton who worked for Corning Glass Works. Harvey pursued a career as a ceramic artist, but also wanted to create artistic works in glass. In 1962, he teamed up with Dominick Labino, a glass research scientist at Johns-Manville near Toledo, to hold a workshop to demonstrate that glassblowing could be achieved outside of a factory by building a small furnace for glassworking. The next year, Littleton introduced the first university program for glass in the United States at the University of Wisconsin in Madison, and the American Studio Glass movement was born.

Dragonflies and Water Flowers Lamp, 1899. Louis Comfort Tiffany, Clara Pierce Wolcott Driscoll, Tiffany Glass and Decorating Company, Stourbridge Glass Company (glass, bronze), United States, NY, Corona.
2013.4.4

Upward Undulation, 1974. Harvey K. Littleton, United States, WI, Verona.
79.4.145

Contemporary Glass: 2000-present

The American Studio Glass movement is nearly synonymous with the name of Dale Chihuly. He is known for his exuberant approach to color and form. One of the founders of Pilchuck Glass School, where many of today's glass artists have had an opportunity to study and create, Chihuly is regarded as an icon and visionary.

Another icon in the contemporary glass world is the Venetian maestro Lino Tagliapietra. His works are a fluid demonstration of the technical mastery of Venetian technique and an enthusiastic approach to color and form. Tagliapietra was invited by Dale Chihuly and Benjamin Moore to come to teach at Pilchuck in 1979, and this became a trip that changed his life. After that first trip, he returned to the United States every year to teach and work.

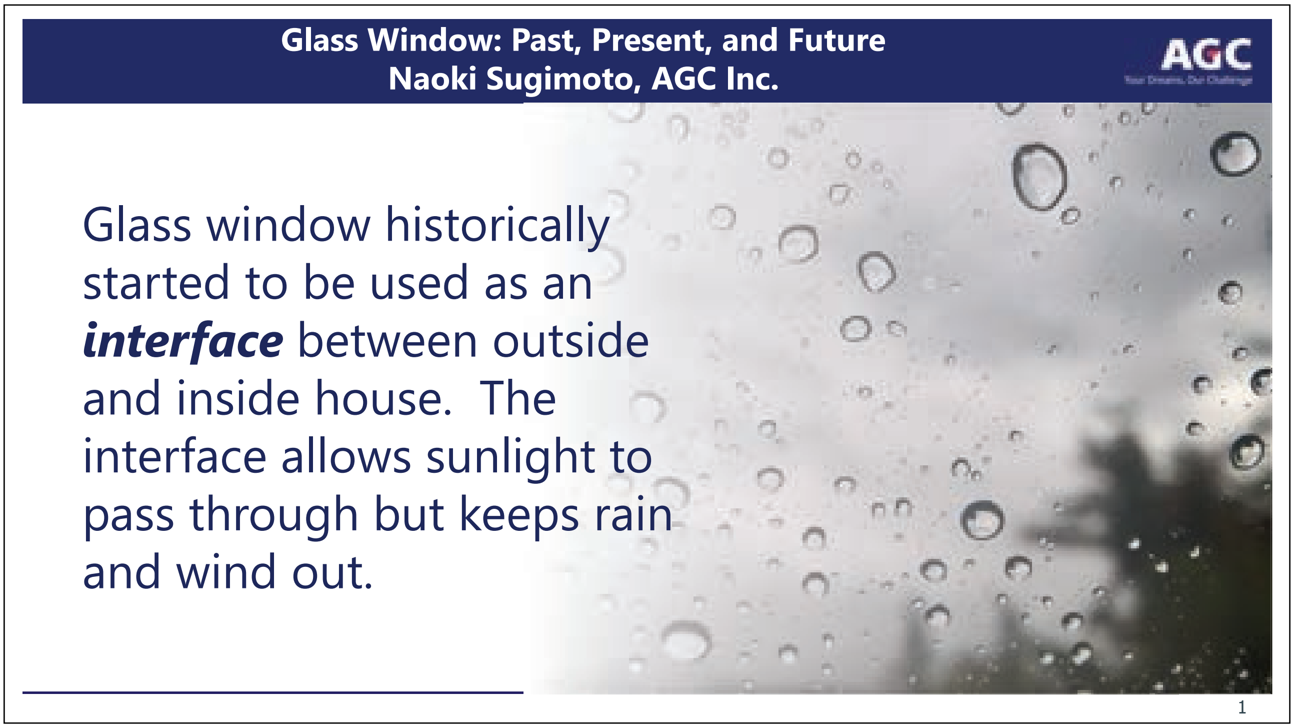
Fern Green Tower, made in 1999; reconfigured in 2013. Dale Chihuly, United States, WA, Seattle. 2000.4.6

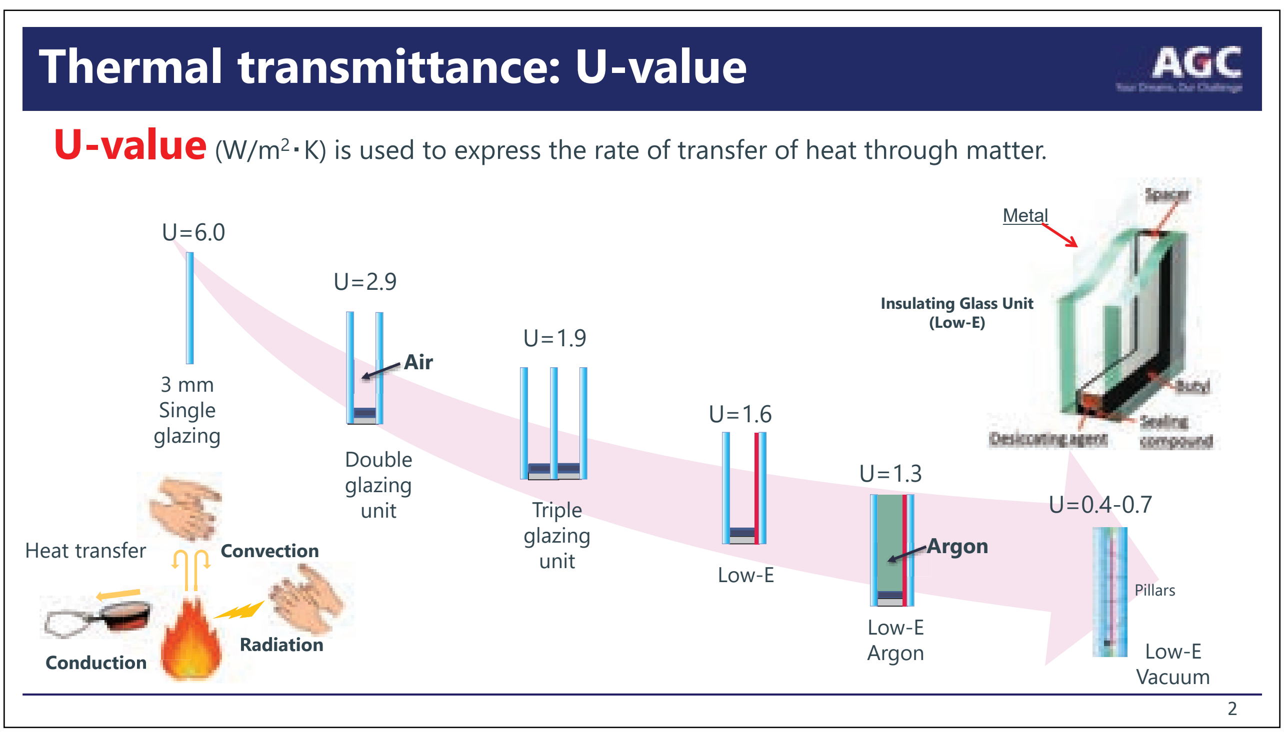
Endeavor, 2004. Lino Tagliapietra, United States, WA, Seattle. 2005.4.170

One of the most recent additions to the collections at The Corning Museum of Glass is called *The Secret Life of Glass* by Spencer Finch. It is composed of sixteen glass panels, fused together to create a multicolored wave-like composition. The pattern was derived from a heat map made of the glass curtain wall in front of which this work is now installed, created by taking the temperature of the glass façade at various points on February 24th, 2017. When the temperature variations were plotted into this pattern, Finch determined which color to assign to which temperature. The result is the contemporary equivalent to a stained-glass window, but without the traditional leading as the glass from which it is made, created by Bullseye Glass, is completely color compatible. This has allowed the different colors to be fused together into panes. The Secret Life of Glass has become one my favorite pieces in our collection, and as you can see from this image, encountering it in the late afternoon can be a soul-lifting experience, exactly what a beautiful work of art can be in our lives.

The Secret Life of Glass, 2017-2020. Spencer Finch, Bullseye Glass Company (glass), United States, NY, New York City, Brooklyn (designed); United States, OR, Portland (glass manufactured). 2020.4.1

All images used with permission from The Corning Museum of Glass

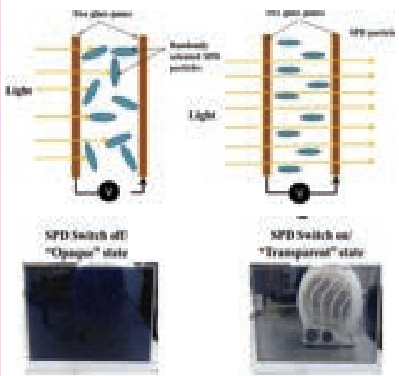

Glass Window: Past, Present, and Future
Naoki Sugimoto, AGC Inc.
AGC
Glass window historically started to be used as an ***interface*** between outside and inside house. The interface allows sunlight to pass through but keeps rain and wind out.
1


Thermal transmittance: U-value
AGC
U-value (W/m²･K) is used to express the rate of transfer of heat through matter.
U=6.0
3 mm Single glazing
U=2.9
Air
Double glazing unit
U=1.9
Triple glazing unit
U=1.6
Low-E
U=1.3
Argon
Low-E Argon
U=0.4-0.7
Pillars
Low-E Vacuum
Metal
Spacer
Insulating Glass Unit (Low-E)
Butyl
Sealing compound
Desiccating agent
Heat transfer
Convection
Radiation
Conduction
2

On demand Switchable technologies

AGC

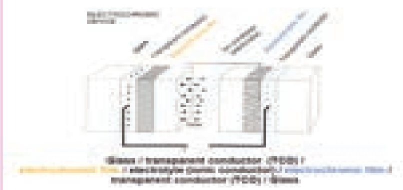
Suspended Particles Device (SPD)



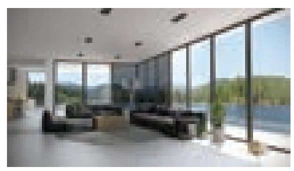
https://www.researchgate.net/publication/282701862_Measured_overall_heat_transfer_coefficient_of_a_suspended_particle_device_switchable_glazing

Switching speed: Several sec.

Electro Chromic device (EC)

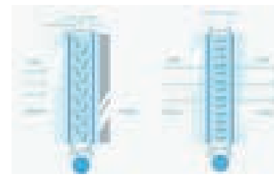


https://www.sciencedirect.com/science/article/abs/pii/S0040609003009830



Switching speed: Several min.

Polymer Dispersed Liquid Crystal (PDLC)



https://www.gauzy.com/how-pdlc-technology-works/

Switching speed: milli-sec.

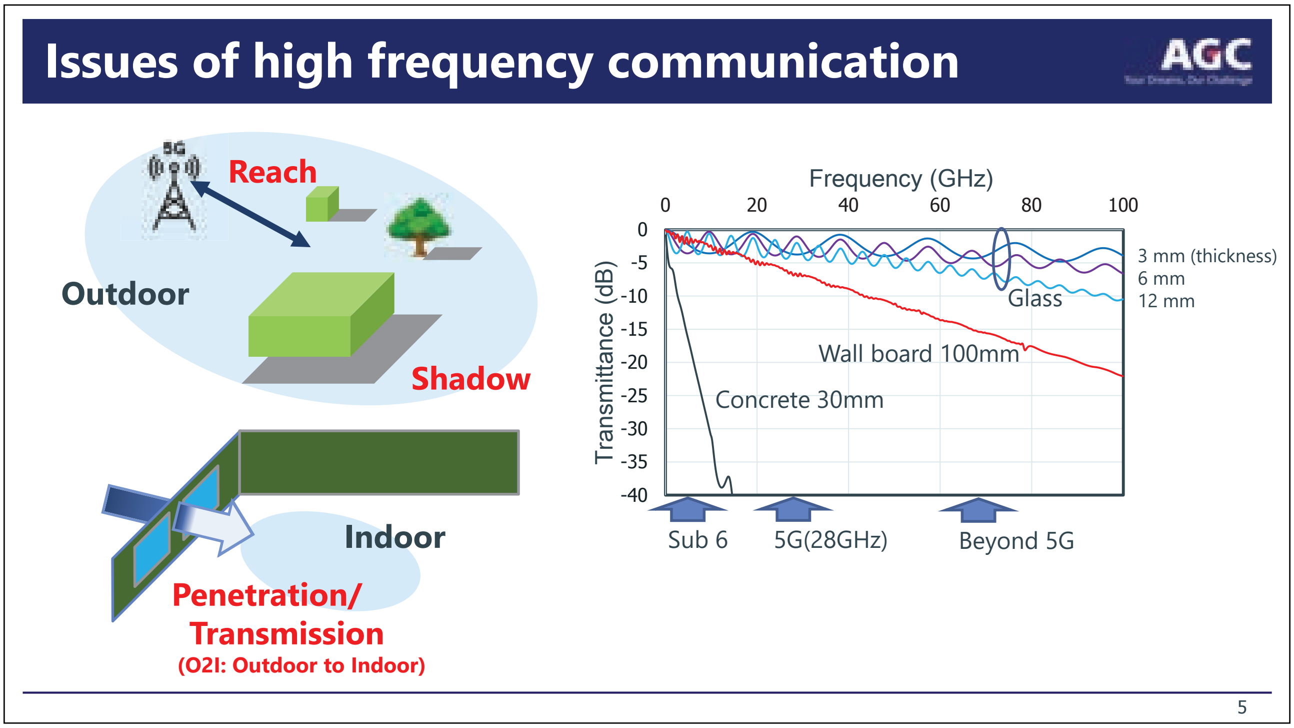
3

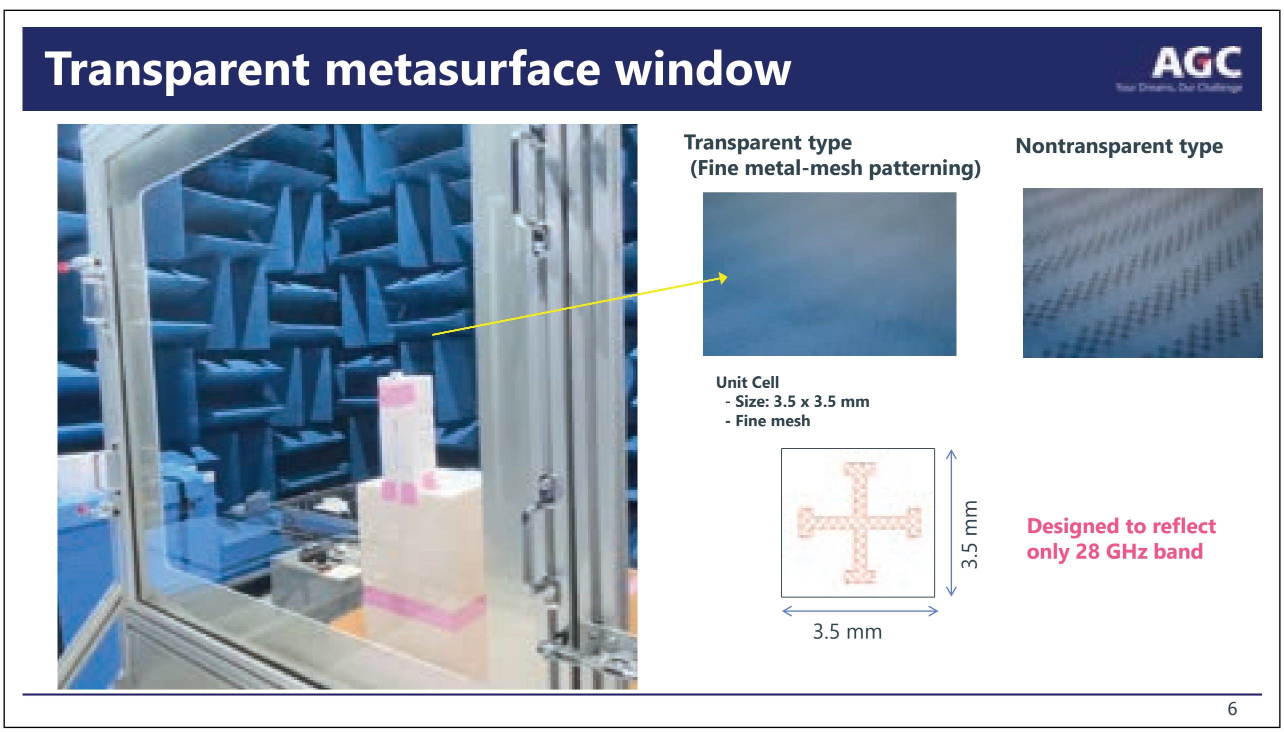
Light and Heat manageable window

AGC

Modern window minimizes heat loss and increases the comfort of the occupants. The window contributes to energy savings of buildings and reduction of GHG emissions.

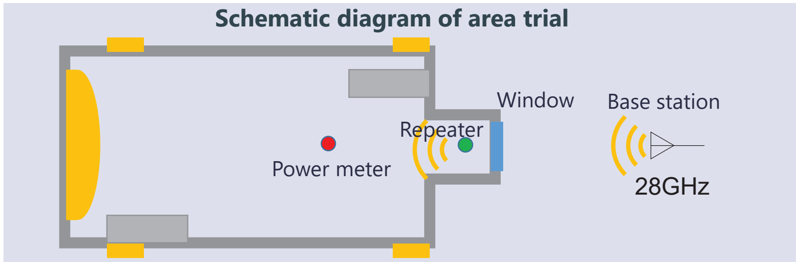
4

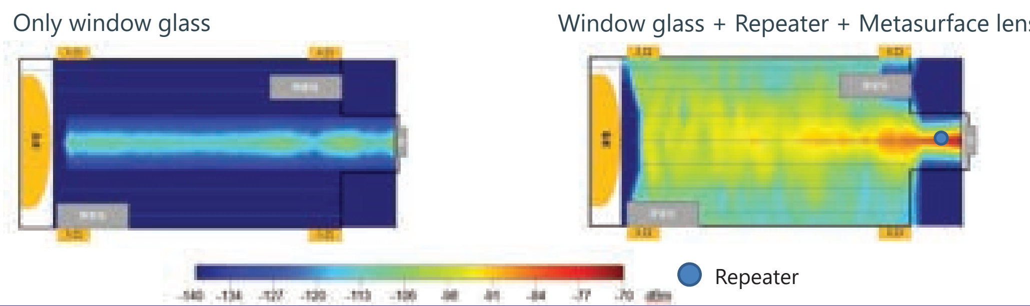

Issues of high frequency communication
AGC
Reach
5G
Outdoor
Shadow
Indoor
Penetration/
Transmission
(O2I: Outdoor to Indoor)
Frequency (GHz)
0
20
40
60
80
100
Transmittance (dB)
0
-5
-10
-15
-20
-25
-30
-35
-40
3 mm (thickness)
6 mm
12 mm
Glass
Wall board 100mm
Concrete 30mm
Sub 6
5G(28GHz)
Beyond 5G
5


Transparent metasurface window
AGC
Transparent type
(Fine metal-mesh patterning)
Nontransparent type
Unit Cell
- Size: 3.5 x 3.5 mm
- Fine mesh
3.5 mm
3.5 mm
Designed to reflect
only 28 GHz band
6

Improvement of Blind zones

AGC





J. Tsuboi, K. Motegi, O. Kagaya, D. Kitayama, K. Miyachi and T. Asai, pp.63-68, RCS2021-187, Technical Committee on Radio Communication Systems (RCS), IEICE

7

Summary

AGC

- **Glass window** has been historically contributed to human life as an interface which allows light and heat to pass through but not rain and wind.
- Modern window manages light and heat, so that it contributes to the **comfort** of the occupants and passengers.
- It also contributes to energy savings of buildings and **reduction of GHG emissions**.
- It becomes the **best gateway** and interface for 5G communication.
- Glass window evolves continuously with development of a sustainable society.

8


(INSPIRE + TRANSFORM) x SUSTAIN
= GLASS
The American Ceramic Society
celebrates
INTERNATIONAL YEAR OF
GLASS
2022
LUDOVIC VALETTE, O-I GLASS – APRIL 7, 2022


GLASS IS UNIQUE AND HOLDS A
SPECIAL PLACE IN OUR LIVES
GLASS – Engineering EMOTIONS
and creating MEMORIES!


GLASS IS MADE OF SAND, SODA ASH, LIMESTONE, AND RECYCLED GLASS
Glass is reusable
Glass is 100% and infinitely recyclable
Glass is inert and won't contaminate food & beverages
A TRUSTED PACKAGING SOLUTION FOR THOUSANDS OF YEARS


GLASS:
Earth friendly & brand building


GLASS INDUSTRY:
UNMET NEEDS &
NEW REQUIREMENTS
Reinforce competitive position
Follow demand
Upgrade sustainability profile


THE NEED FOR FLEXIBILITY AND SCALABILITY
PROVIDING CAPACITY WHERE AND WHEN NEEDED


SUSTAINABLE PRODUCT & PROCESS
PLANET
PEOPLE
COLLECTIVE PROSPERITY
Infinitely recyclable
Reduced logistic
low-carbon and renewable energies


GLASS IS CONSTANT SOURCE OF INSPIRATION...
...TO TRANSFORM EVERYTHING WE DO AND HOW WE DO IT
...IN PURSUIT OF A MORE SUSTAINABLE WAY OF LIFE

GLASS FOR FUTURE Nippon Electric Glass

The Role of Fiber Glass for Contribution to Sustainable Development Goals

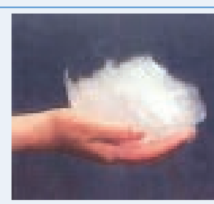
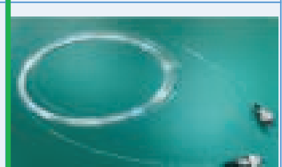
Hiroaki Nomura
Nippon Electric Glass

National Day of Glass
American Ceramic Society
Washington D.C.
April 5-7, 2022

1

GLASS FOR FUTURE Nippon Electric Glass

Fiber Glass

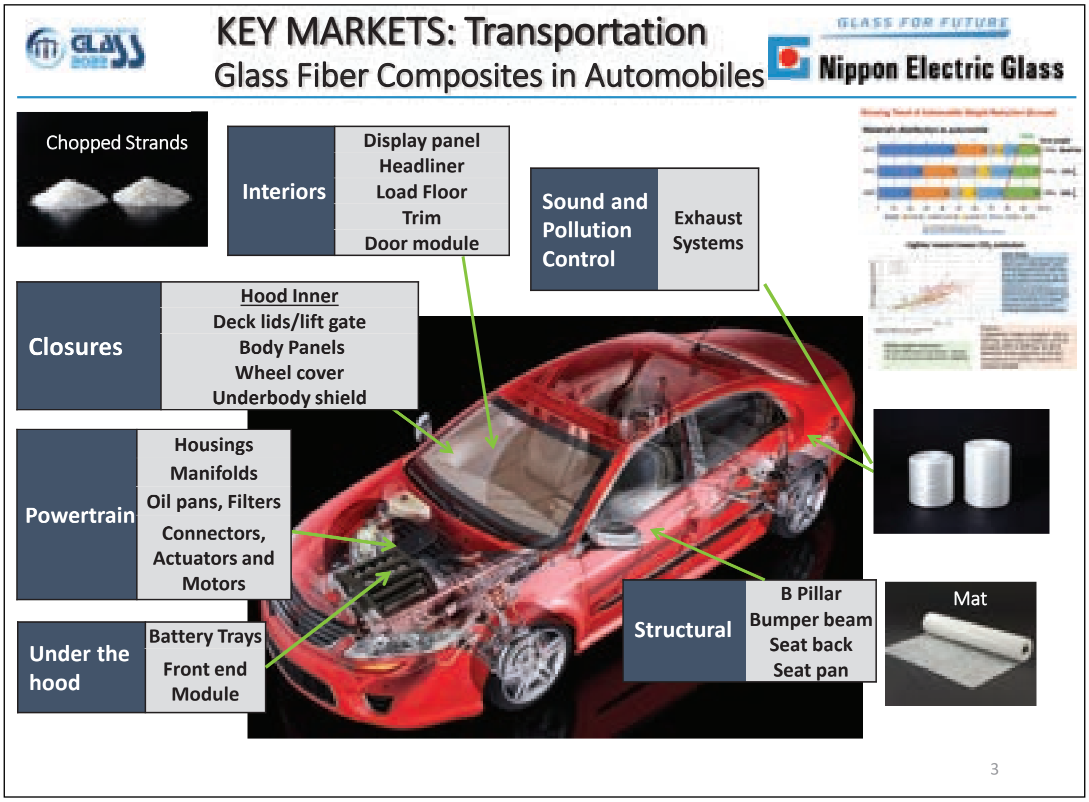
Category	Continuous Filament	Vitreous Wool	Optical Fiber
Process	Melting & Fiber Spinning	Flame attenuation /Air-blowing or Centrifugation	Draw from preform
Main Application	Reinforcement (FRP, FRTP)	Insulation & Filtration	Telecommunication
Appearance			

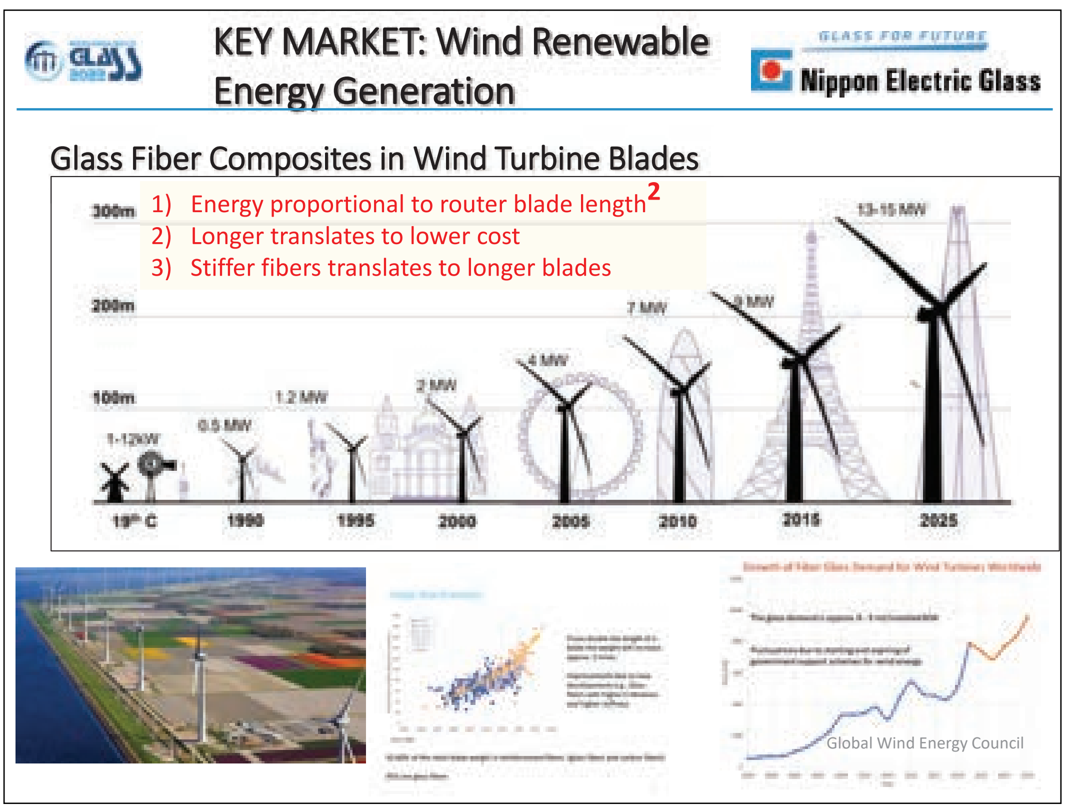
Attractive property

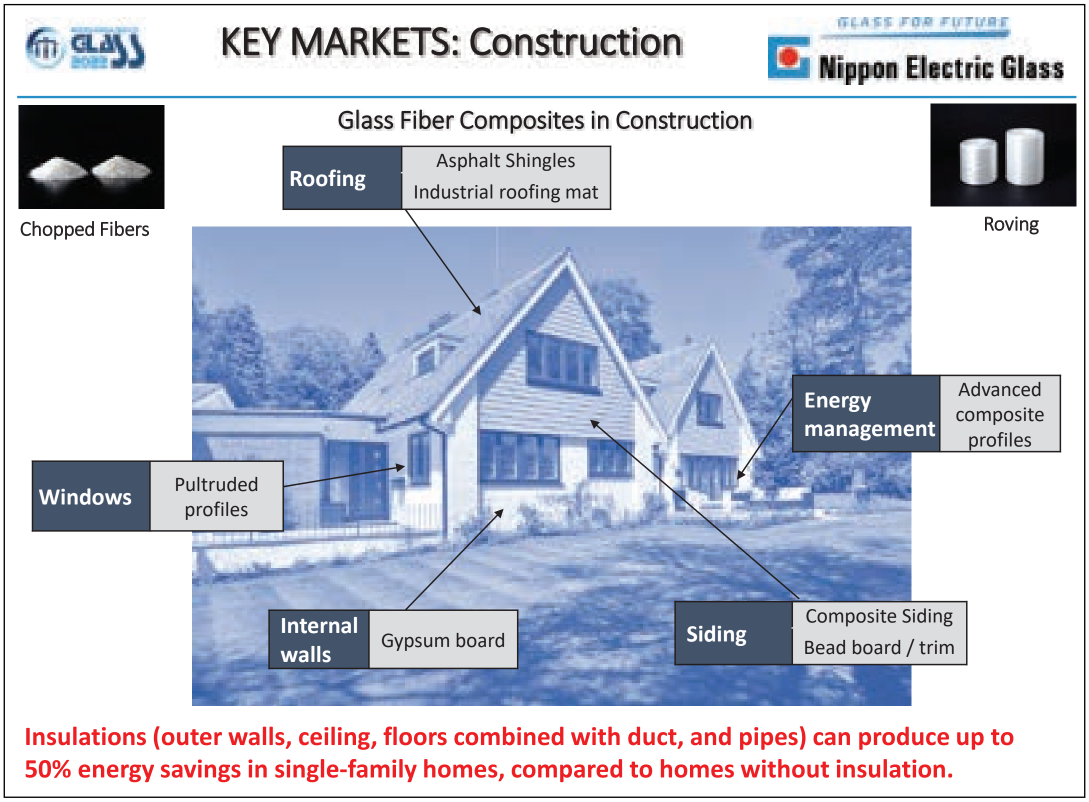
High elasticity
High mechanical strength
High heat resistance
High electrical resistivity
High chemical durability

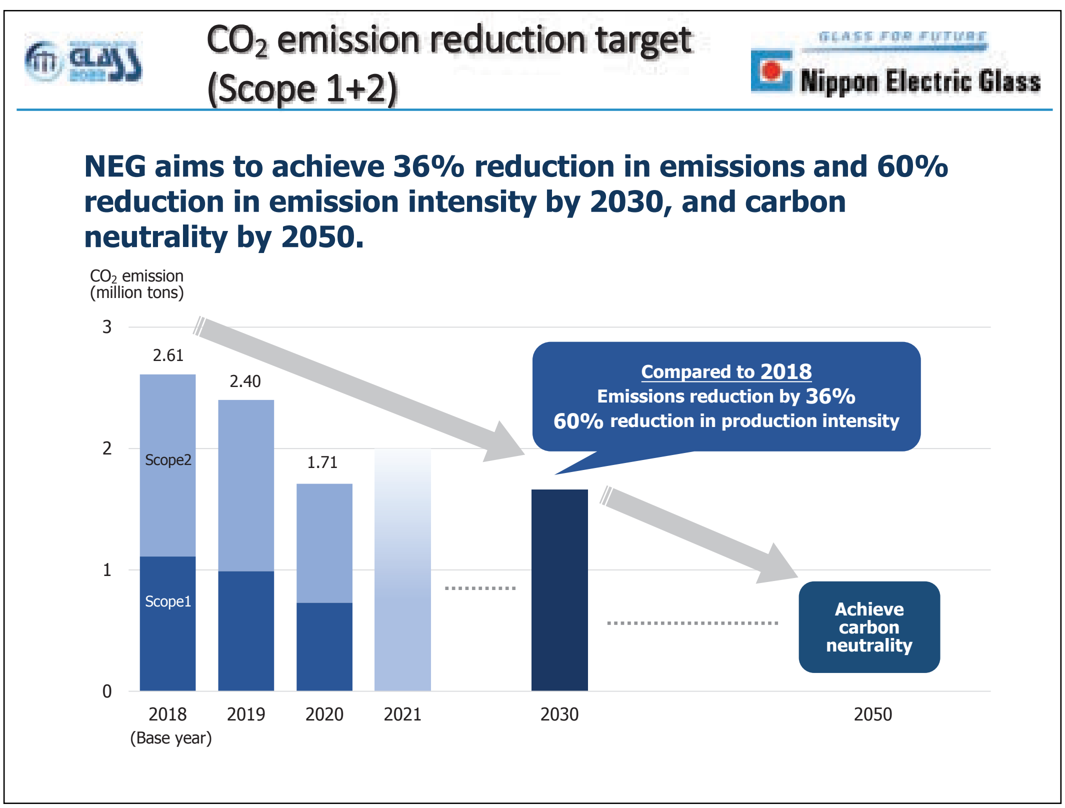
Major markets (example)

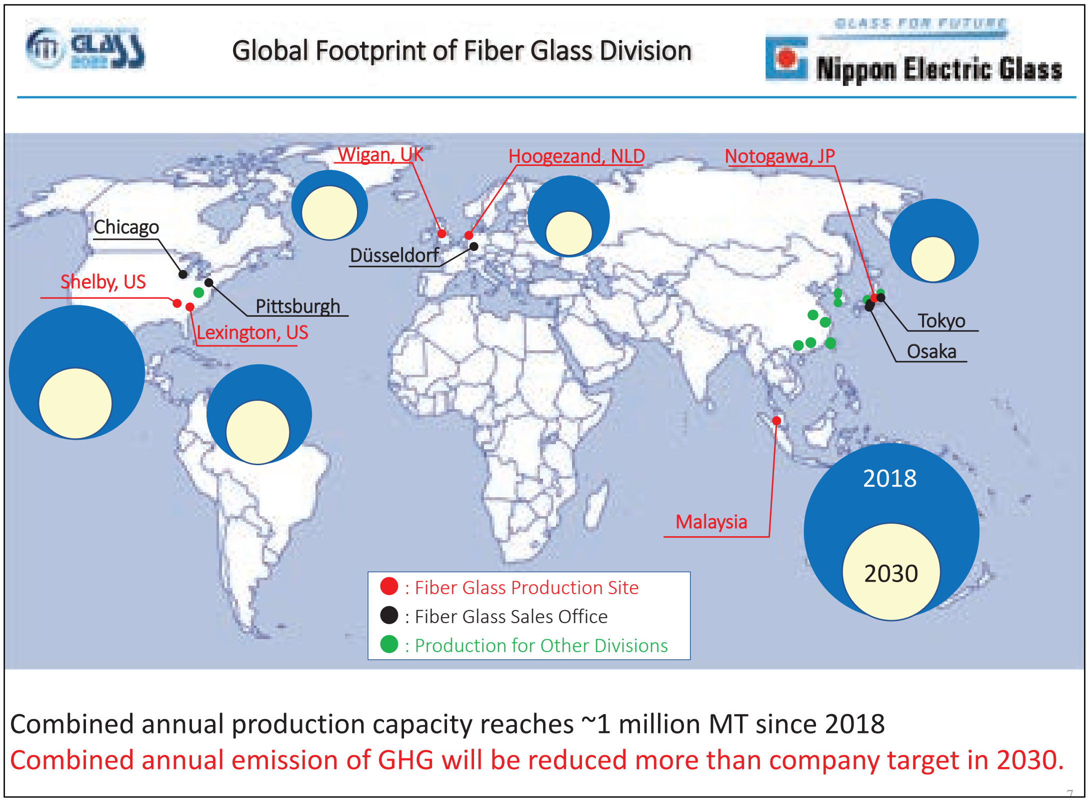
Transportation
Wind renewable energy
Construction


KEY MARKETS: Transportation
Glass Fiber Composites in Automobiles
GLASS FOR FUTURE
Nippon Electric Glass
Chopped Strands
Interiors
Display panel
Headliner
Load Floor
Trim
Door module
Sound and Pollution Control
Exhaust Systems
Closures
Hood Inner
Deck lids/lift gate
Body Panels
Wheel cover
Underbody shield
Powertrain
Housings
Manifolds
Oil pans, Filters
Connectors, Actuators and Motors
Under the hood
Battery Trays
Front end Module
Structural
B Pillar
Bumper beam
Seat back
Seat pan
Mat
3


KEY MARKET: Wind Renewable Energy Generation
GLASS FOR FUTURE
Nippon Electric Glass
Glass Fiber Composites in Wind Turbine Blades
1) Energy proportional to router blade length[2]
2) Longer translates to lower cost
3) Stiffer fibers translates to longer blades
300m
200m
100m
1-12KW
0.5 MW
1.2 MW
2 MW
4 MW
7 MW
9 MW
13-15 MW
19th C
1990
1995
2000
2005
2010
2015
2025
Global Wind Energy Council


KEY MARKETS: Construction
GLASS FOR FUTURE
Nippon Electric Glass
Glass Fiber Composites in Construction
Chopped Fibers
Roving
Roofing
Asphalt Shingles
Industrial roofing mat
Energy management
Advanced composite profiles
Windows
Pultruded profiles
Internal walls
Gypsum board
Siding
Composite Siding
Bead board / trim
Insulations (outer walls, ceiling, floors combined with duct, and pipes) can produce up to 50% energy savings in single-family homes, compared to homes without insulation.


CO_2 emission reduction target (Scope 1+2)
GLASS FOR FUTURE
Nippon Electric Glass
NEG aims to achieve 36% reduction in emissions and 60% reduction in emission intensity by 2030, and carbon neutrality by 2050.
CO_2 emission (million tons)
3
2
1
0
2.61
2.40
1.71
Scope2
Scope1
Compared to 2018
Emissions reduction by 36%
60% reduction in production intensity
Achieve carbon neutrality
2018 (Base year)
2019
2020
2021
2030
2050


Global Footprint of Fiber Glass Division
Nippon Electric Glass
Wigan, UK
Hoogezand, NLD
Notogawa, JP
Chicago
Düsseldorf
Shelby, US
Pittsburgh
Lexington, US
Tokyo
Osaka
Malaysia
2018
2030
: Fiber Glass Production Site
: Fiber Glass Sales Office
: Production for Other Divisions
Combined annual production capacity reaches ~1 million MT since 2018
Combined annual emission of GHG will be reduced more than company target in 2030.

Foundational Role of Non-Oxide Glass to Enable Electrophotographic Printing and Creation of Xerox Corporation

xerox™

Making everyday work better.

Objectives

- Introduction some historical aspect
- Role of Chalcogenide glass in printing systems @Xerox
- Chemical processes for chalcogens reclaimation, alloying, and tailoring electrical properties

Dr. Santokh Badesha, Corporate Fellow and Manager Open Innovation.
santokh.badesha@xerox.com Phone: 585-422-3428 (Xerox)
sbadesha@purdue.edu Phone 765-496-5936 (Purdue)

Xerox History

OTD in 1938, Chester Carlson and Otto Kornei put a glass slide with writing on it on a zinc plate coated with sulfur and exposed it to light. They then managed to transfer the image to wax paper. It was the 1st photocopy-a process which Carlson called Xerography that led to @Xerox

Xerography

Xero **Graphy**

Greek

Xeros → **Dry**

Graphic → **Writing**

xerox™

Xerox History

1939	Chester Carlson files the original xerographic patent
1947	Haloid enters agreement to develop a product
1950s	Haloid CEO Joe Wilson seeks manufacturing and distribution partner (IBM, GE, Kodak). IBM engages Arthur D. Little and Co. (ADL) to "value xerography"

ADL Conclusion: *"Although it may be admirably suited for a few specialized copying applications, the Model 914 has no future in the office copying equipment market"*

"How could ADL get it so wrong?"

xerox™

Xerox History – Cont'd

ADL Conclusion:
"Although it may be admirably suited for a few specialized copying applications, the Model 914 has no future in the office copying equipment market"

1950's	Haloid "bets the company" and develops the 914
1959	Haloid launched the 914
1959-1972	914 drives revenue from $30M to $2.5B in 13 years

"How could ADL get it so wrong?"

XEROX CORPORATION

xerox™

Xerox History – Cont'd

Office Copying Competitive Landscape (circa 1950s)

Existing technology
- Wet or thermal based process
- Messy & low quality
- Equipment list price ~$300
- Special inks, papers, supplies
- Average output = 15-20 copies per day
  - fraction of max output

Xerox 914
- Dry process
- High quality
- Equipment COGS ~$2000
- Special supplies and service
- Speed = 7 copies/minute

ADL & others "valued" the new technology through a traditional business model
- Charge for equipment & supplies as needed
- Template valuation models
- High price of 914 severely limits number of sales & future consumables annuity
  - Niche application

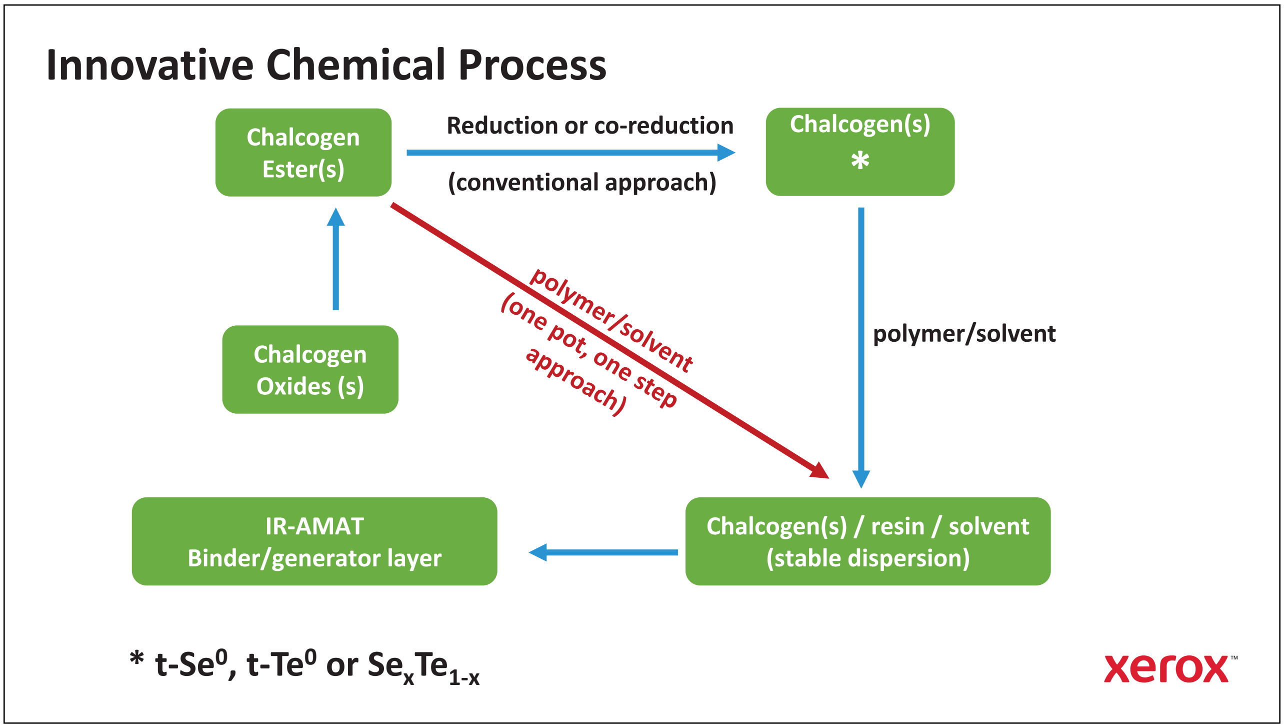
xerox

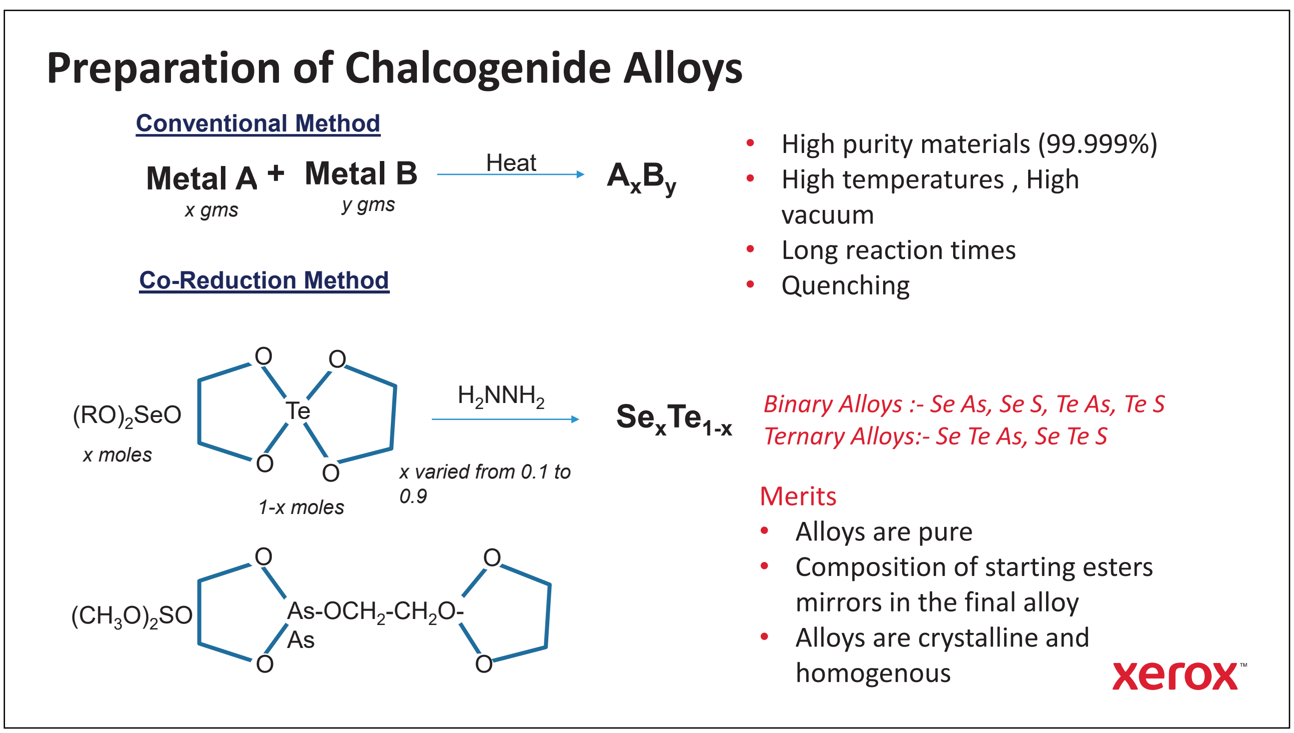
Xerox History – Cont'd

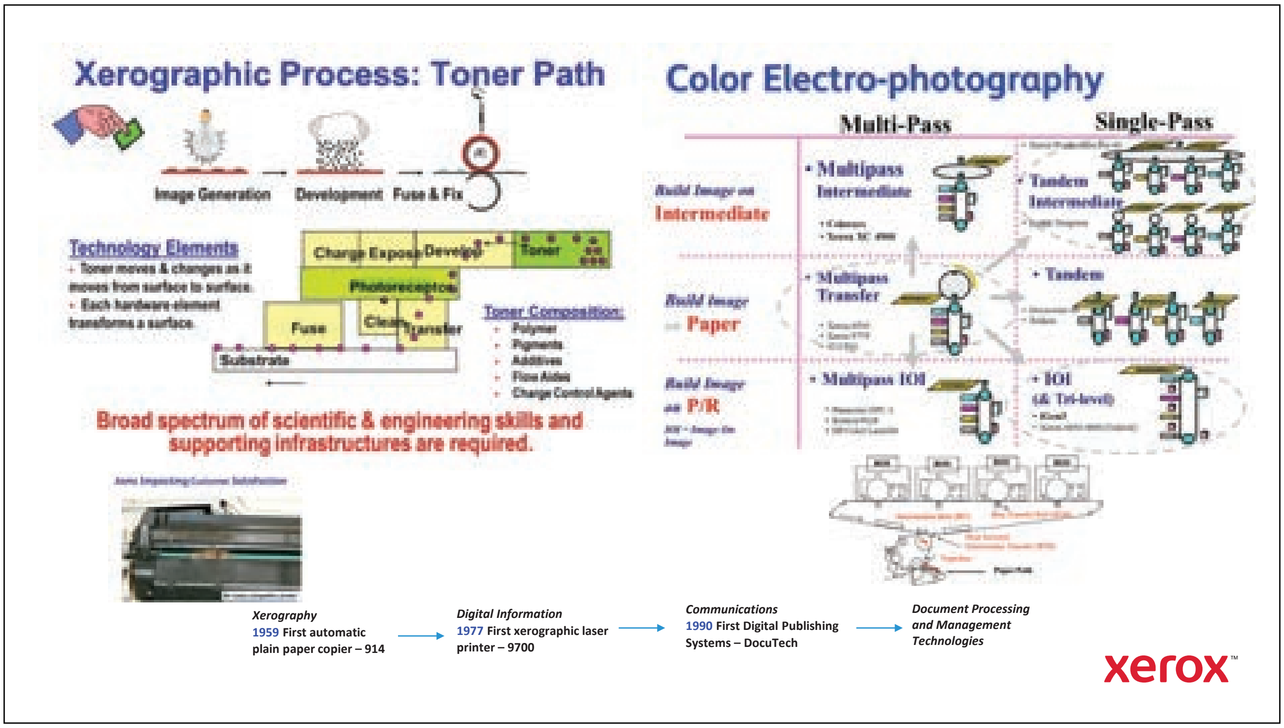
- Joe Wilson ignored ADL valuations
  - Changed the business model
    - $95 per month to lease the machine
      - includes 2000 free copies per month
    - $0.04 per additional copy above 2000 per month
    - Xerox provided required service & support
    - Lease could be cancelled after 15 days
- New business model lowered barrier for customer trial
  - Haloid/Xerox bore the risk
- Enormous Usage : averaged > *2,000 copies per day*

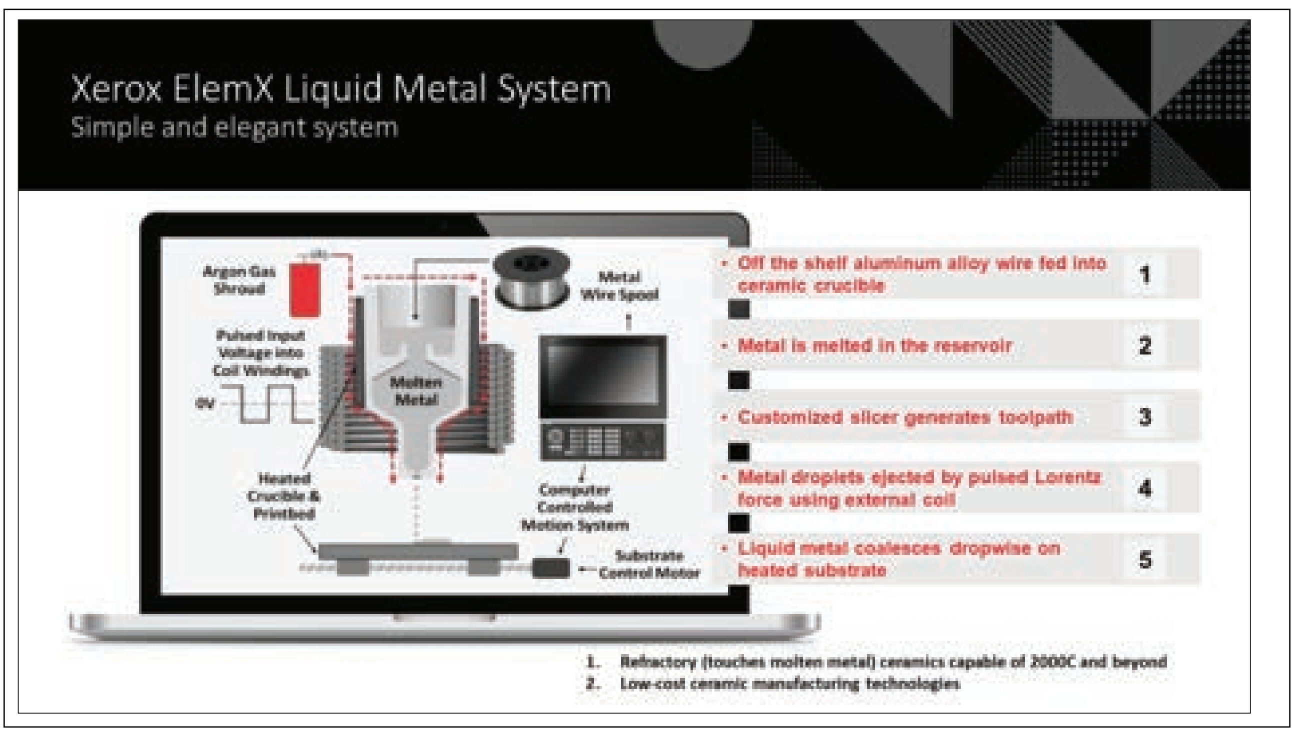
What led to success?
- Great Invention
- Strong Customer Value Proposition
- Required Investment
- Appropriate Value Chain
- Innovative Business Model!

xerox


Innovative Chemical Process
Chalcogen Ester(s)
Reduction or co-reduction
(conventional approach)
Chalcogen(s) *
Chalcogen Oxides (s)
polymer/solvent (one pot, one step approach)
polymer/solvent
IR-AMAT Binder/generator layer
Chalcogen(s) / resin / solvent (stable dispersion)
* t-Se^0, t-Te^0 or Se$_x$Te$_{1-x}$
xerox


Preparation of Chalcogenide Alloys
Conventional Method
Metal A + Metal B
x gms
y gms
Heat
A$_x$B$_y$
High purity materials (99.999%)
High temperatures , High vacuum
Long reaction times
Quenching
Co-Reduction Method
(RO)$_2$SeO
x moles
Te
O
1-x moles
H$_2$NNH$_2$
x varied from 0.1 to 0.9
Se$_x$Te$_{1-x}$
Binary Alloys :- Se As, Se S, Te As, Te S
Ternary Alloys:- Se Te As, Se Te S
(CH$_3$O)$_2$SO
As-OCH$_2$-CH$_2$O-As
Merits
Alloys are pure
Composition of starting esters mirrors in the final alloy
Alloys are crystalline and homogenous
xerox


Xerographic Process: Toner Path
Image Generation
Development
Fuse & Fix
Technology Elements
• Toner moves & changes as it moves from surface to surface.
• Each hardware element transforms a surface.
Charge
Expose
Develop
Toner
Photoreceptor
Fuse
Clean
Transfer
Substrate
Toner Composition:
Polymer
Pigments
Additives
Flow Aides
Charge Control Agents
Broad spectrum of scientific & engineering skills and supporting infrastructures are required.
Color Electro-photography
Multi-Pass
Single-Pass
Build Image on Intermediate
Multipass Intermediate
Tandem Intermediate
Build Image on Paper
Multipass Transfer
Tandem
Build Image on P/R
Multipass IOI
IOI (& Tri-level)
Xerography
1959 First automatic plain paper copier – 914
Digital Information
1977 First xerographic laser printer – 9700
Communications
1990 First Digital Publishing Systems – DocuTech
Document Processing and Management Technologies
xerox


Xerox ElemX Liquid Metal System
Simple and elegant system
Argon Gas Shroud
Metal Wire Spool
Pulsed Input Voltage into Coil Windings
0V
Molten Metal
Heated Crucible & Printbed
Computer Controlled Motion System
Substrate Control Motor
• Off the shelf aluminum alloy wire fed into ceramic crucible 1
• Metal is melted in the reservoir 2
• Customized slicer generates toolpath 3
• Metal droplets ejected by pulsed Lorentz force using external coil 4
• Liquid metal coalesces dropwise on heated substrate 5
1. Refractory (touches molten metal) ceramics capable of 2000C and beyond
2. Low-cost ceramic manufacturing technologies

Xerox Wins 2005 The National Medal of Technology

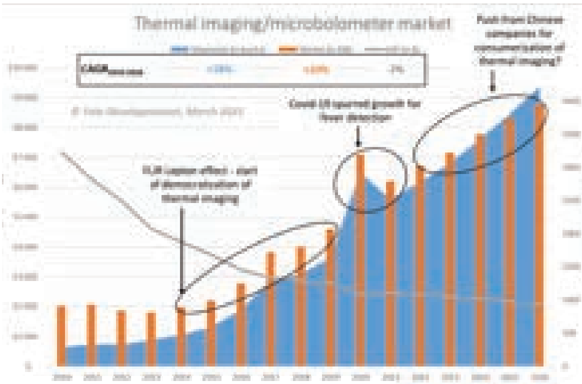
The National Medal of Technology honors the thousands of Xerox people who create, collaborate and contribute to every aspect of our technological success

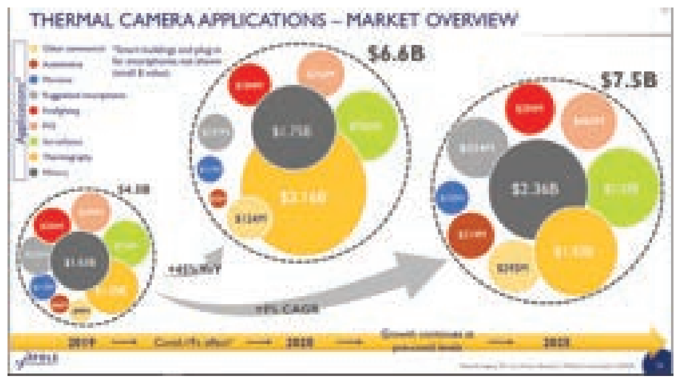
"In recognition of over fifty years of innovation in marking, materials, electronics and communications that created the modern reprographics, electronic printing, and print on demand industries".

Infrared Materials
Resilience of US Supply Chain

LightPath Technologies

Sam Rubin, CEO





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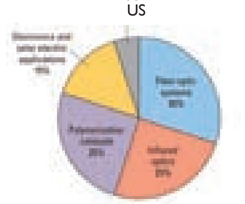
Optical Materials for Infrared Applications

LightPath Technologies

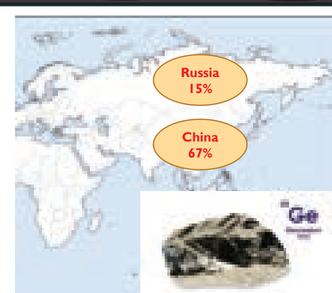
- Very few materials available for use in Infrared
- Incumbent materials are Crystalline
- Germanium is most used material
  - **US Imports 95% of its Germanium**
  - strong dependance on materials coming from outside the US (China and Russia)
  - Limitations on size of Optics
  - Optical properties are constant
  - Finite resources
- Significant price fluctuations +104% 2009-2014
- Complex component fabrication methods
- Key material for Defense use, Identified as critical mineral that the US depends on

1. "Germanium and Indium", USGS professional paper 1802-I
2. 2019 Report to Congress US-China Economic and Security Review Commission

Germanium Applications in the US



30,000 Tons of Germanium imported into the USA Annually



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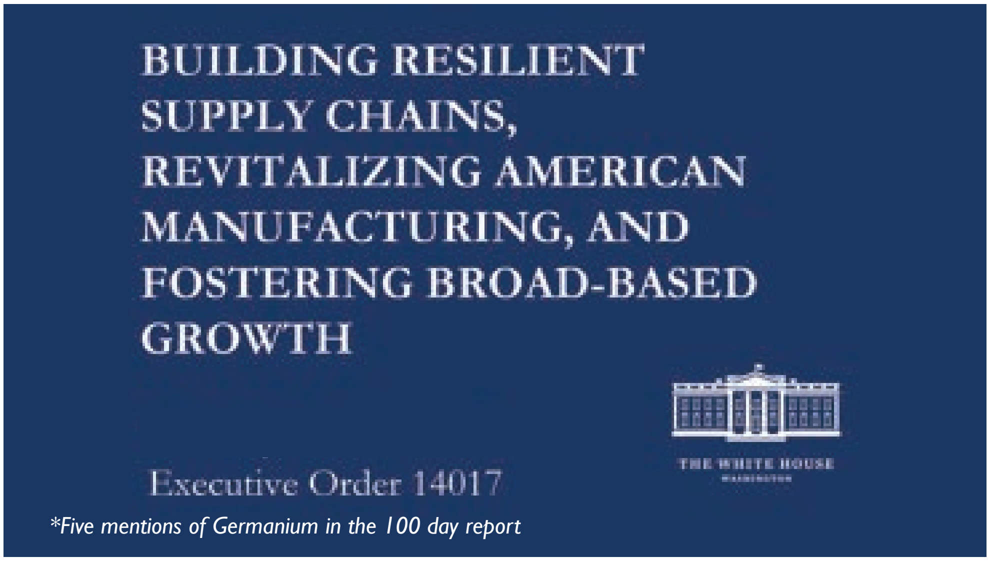
Executive Order 14017 – America's Supply Chain

LightPath Technologies



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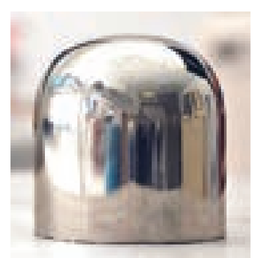
Chalcogenide Glass – Alternative to Germanium

LightPath Technologies

- Synthetically Produced
- Stable cost
- Made in the USA
- Synthetic glass → Lends itself for mass production technologies (molding to shape)
- Parameters can be Optimized for different Uses (refractive index, thermal behavior)
- Transmits over wide range of Wavelengths
- Other benefits: a-thermal, lower density (weight)

Current Status

- Only five types of Chalcogenide currently exist commercially, <u>more are needed</u>
- Limited manufacturing capacity in the US
- Work required to ensure manufacturing readiness, stable production, and commercial acceptance
- Low market adoption, long product life cycles in Defense industry
- Glass recycling technology needed



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LightPath's Chalcogenide Production

LightPath Technologies

Glass Production
- Located in Orlando, Florida
- 9 years of experience in producing infrared glass
- Current capacity up to 10 Metric Tons a year
- Vertically integrated, glass used to produce final lenses and assemblies
- Recently awarded exclusive license for a portfolio of Chalcogenide materials developed at the Naval Research Labs
- Focused on transitioning the new materials to production

Lightpath Technologies Inc
- 35 years of Optics manufacturing
- ~$40m annual Revenue, 300 employees in three continents
- Publicly traded on Nasdaq (Ticker LPTH)
- Developer and leader of precision molded optics technology
- Began pivot towards infrared optics in 2016
- Vertically integrated, from glass production to final assemblies and infrared imaging sub systems
- Focused at enabling customers to make the most of infrared imaging, through technological and operational leadership

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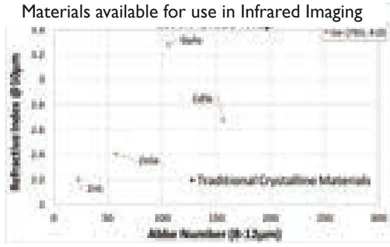
Replacement for Germanium. And?

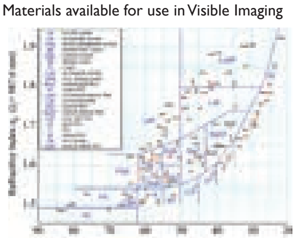
LightPath Technologies

Materials available for use in Infrared Imaging

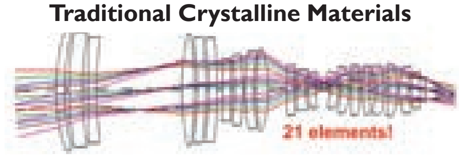


Vs.

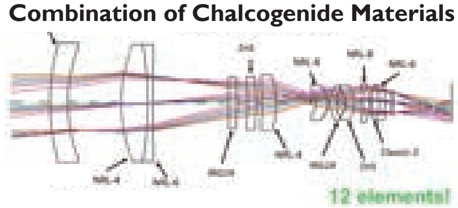
Materials available for use in Visible Imaging



3X Zoom Lens Designed with
Traditional Crystalline Materials



Same 3X Zoom Designed with
Combination of Chalcogenide Materials



1) J.L. Ramsey et al, Proc SPIE, 10998-0M (2019)

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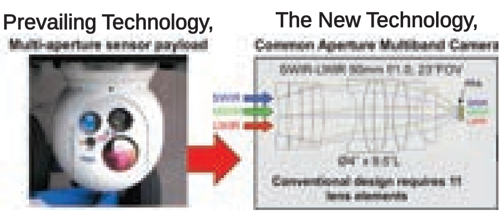
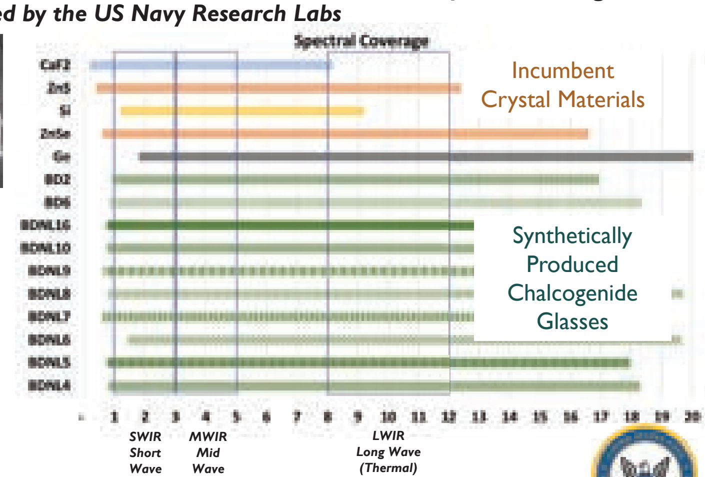
Multispectral Imaging

LightPath Technologies

November 2021, LightPath Technologies receives the exclusive License to commercialize Infrared Chalcogenide glasses developed by the US Navy Research Labs





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What's Next?

LightPath Technologies

Current Status

- One composition produced by multiple manufacturers:
  Schott, Vital, LighPath, Umicore, AMI
- Range of Optical Coatings Developed
  - Low temperature Anti Reflective
  - Protective DLC (Diamond-Like Carbon)
- Space qualification in progress
- Diverse and Stable Supply Chain for raw Ingredients
  - Selenium – Philippines, Mexico, Germany, China
  - Arsenic – China, Morocco, Belgium
  - Sulfur – Canada, Mexico, Russia, Spain

Challenges Ahead

- Production Readiness – Incumbent (Germanium) has a 60+ years of use, data, measurements, etc.
- More Materials are a must
- Full glass characterization
  - Refractive index data under varying conditions
  - Thermal properties
  - Mechanical Properties
  - Homogeneity
- More optical Coatings
- Adoption by Design Engineers (Design in)
- Less waivers for materials coming from China and Russia
- Capacity. US imports 7,500 Metric Tons a year of Ge for use in Imaging alone

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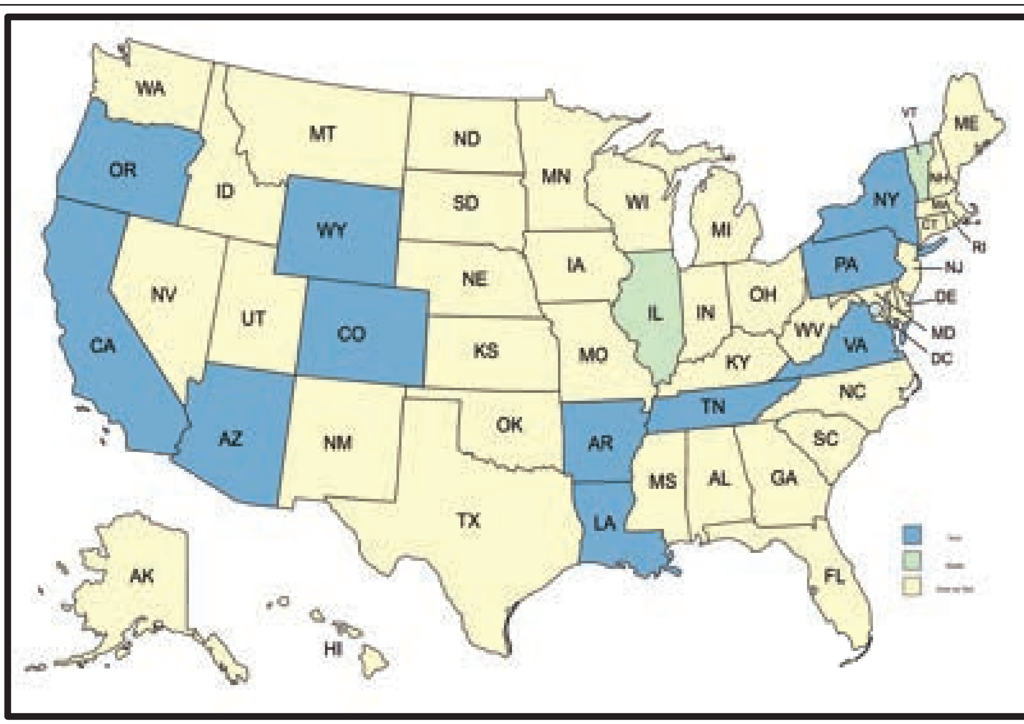
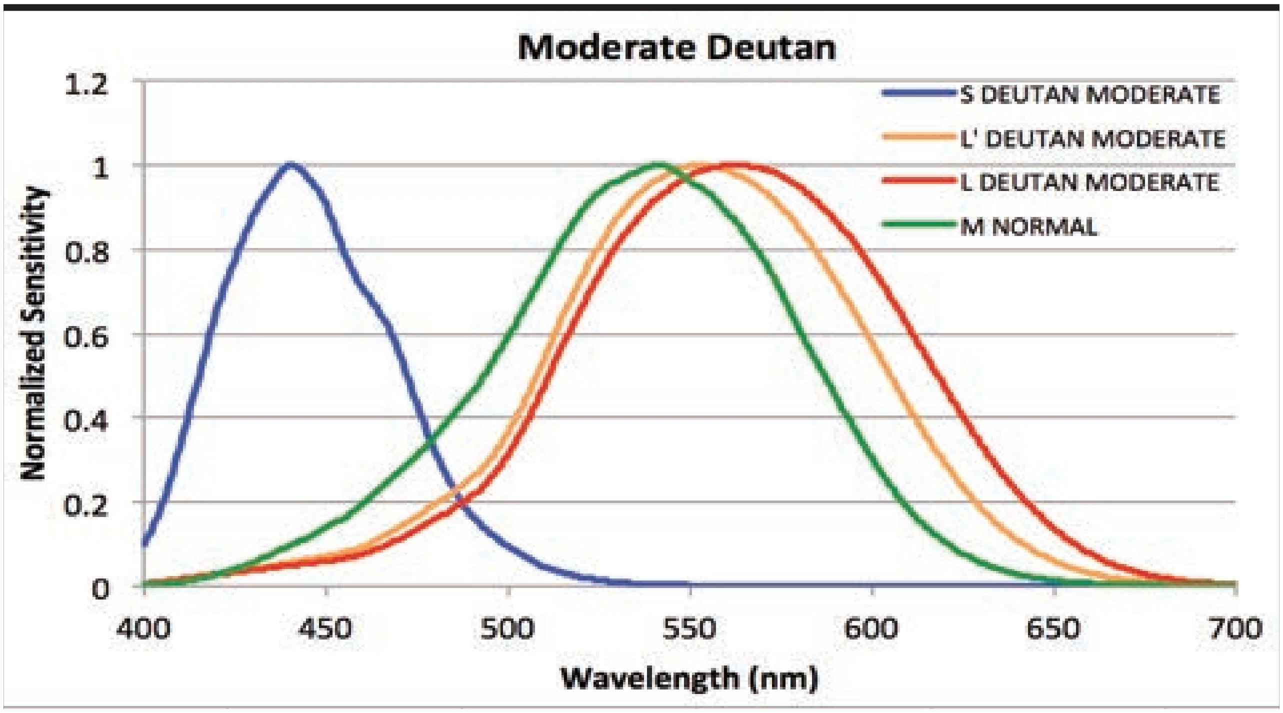
A Rose Is A Rose Is A Rose:
What Colorblindness Reveals about Perception

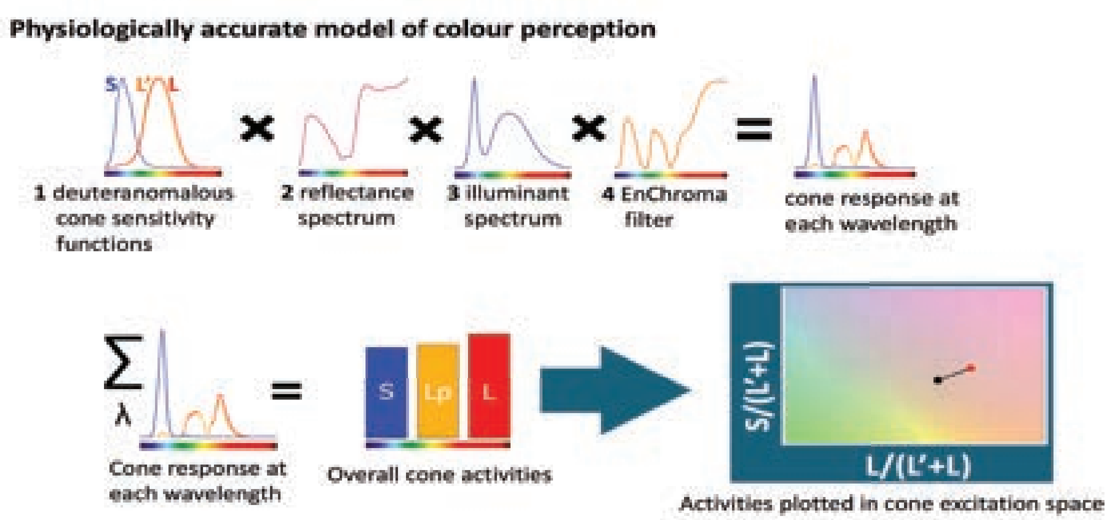
Donald McPherson, PhD

Founder & CSO, EnChroma
Berkeley, CA





The effectiveness of EnChroma's notch filter in enhancing deuteranomalous colour vision. L. Somers, A. Franklin, J. M. Bosten (Somers, et al., ICVS 2019)



(Current Biology 30, 3011-3015, August 3, 2020)

Current Biology

Report

Adaptive Changes in Color Vision from Long-Term Filter Usage in Anomalous but Not Normal Trichromacy

Highlights

- Long-term use of color notch filters increases chromatic response in color anomals
- No such effects are observed in normal trichromats or a placebo condition
- Spontaneous comments of observers suggest that the effects mav endure

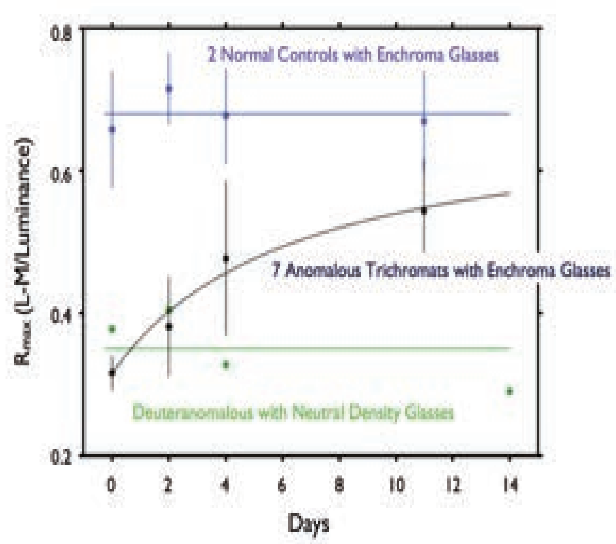
Authors

John S. Werner,
Brennan Marsh-Armstrong,
Kenneth Knoblauch

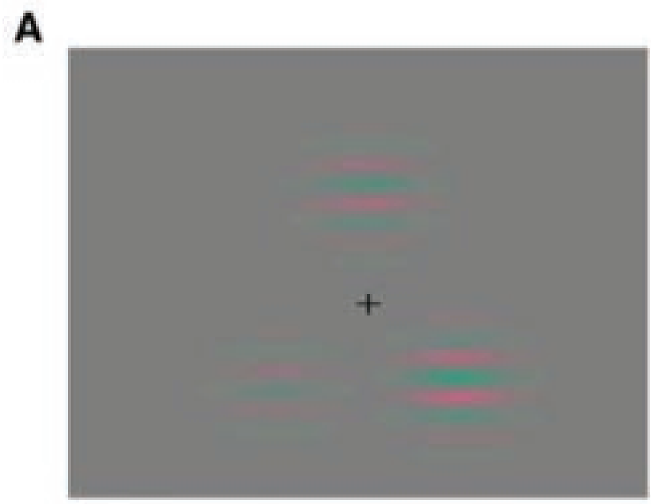
Correspondence

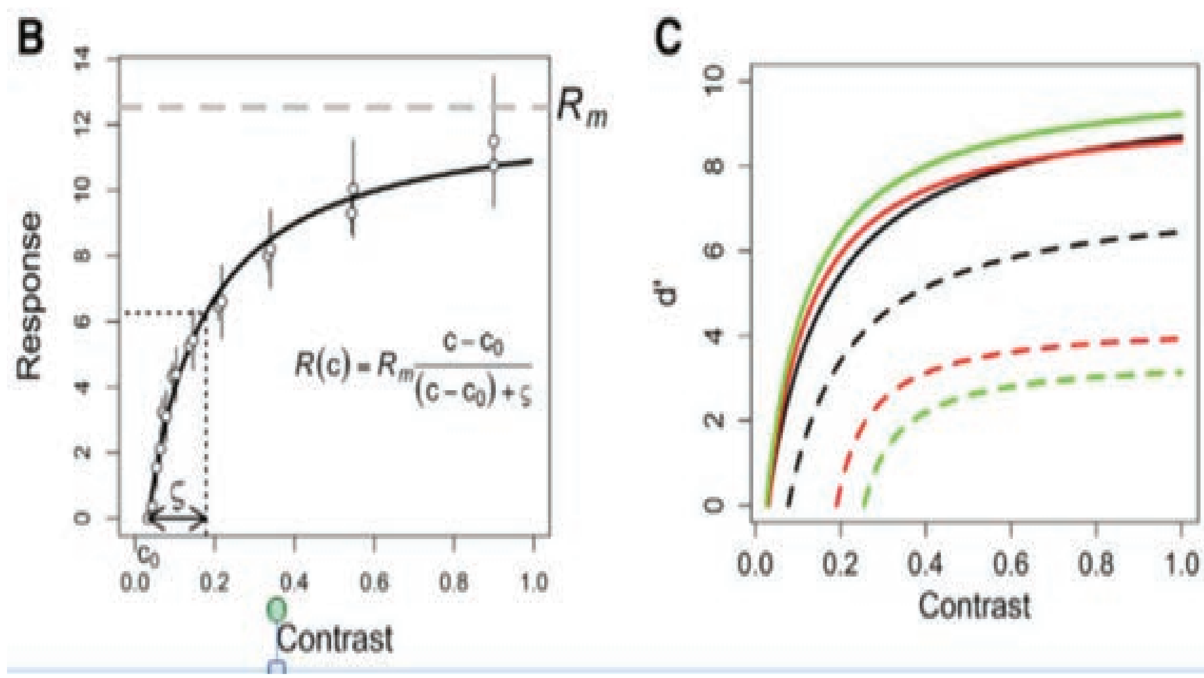
jswerner@ucdavis.edu

- ALL TESTING PERFORMED WITHOUT ENCHROMA EYEWEAR
- NO IMPROVEMENT FOR NORMALS ANDNO EFFECT WITH PLACEBO EYEWEAR
- PERCEPTUAL LEARING LEADS TO IMPROVED RESPONSE GAIN



An ordered triplet of Gabor patterns varying in chromatic contrast. The observer selected which of the lower two was most similar to the standard on top.





Eye (2022): Brief Communication/Published 08 January 2022

Performance enhancement in color deficiency with color-correcting lenses

Jeff Rabin, Frances Silva, Natalie Trevino, Harper Gillentine, Liqing Li, Loary Inclan, Gary Anderson, Erica Lee & Harrison Vo

University of the Incarnate Word Rosenberg School of Optometry

L, M, and S cone-specific checkerboard patterns used for pattern-onset VEPs.

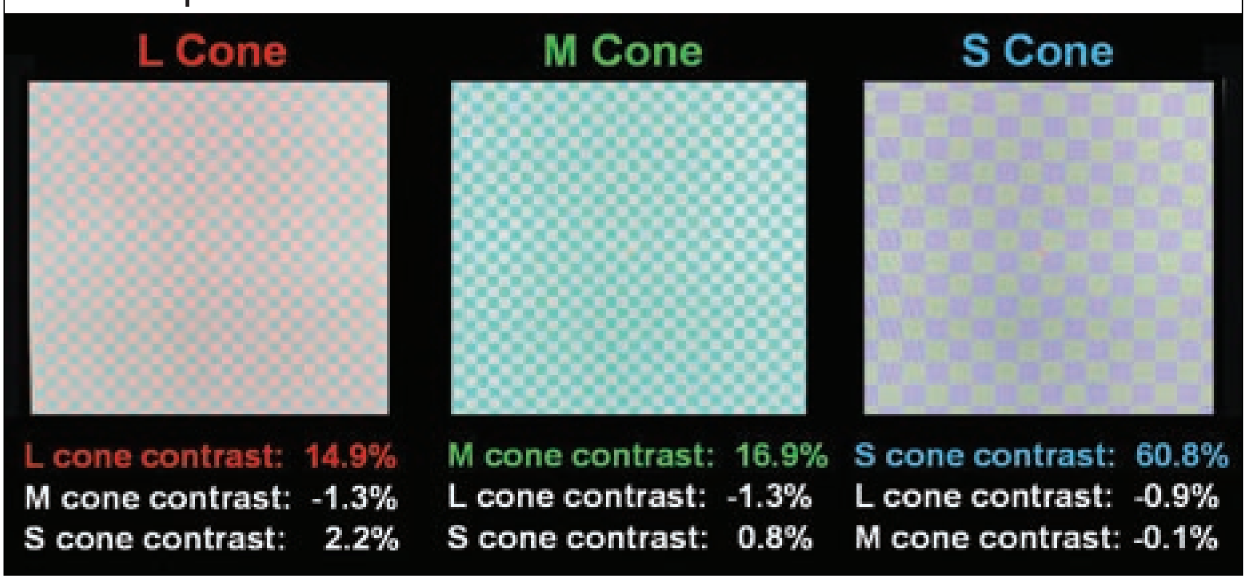


Fig. 1: Cone contrast sensitivity (CS) [3] and color naming accuracy in color vision deficient (CVD) subjects.

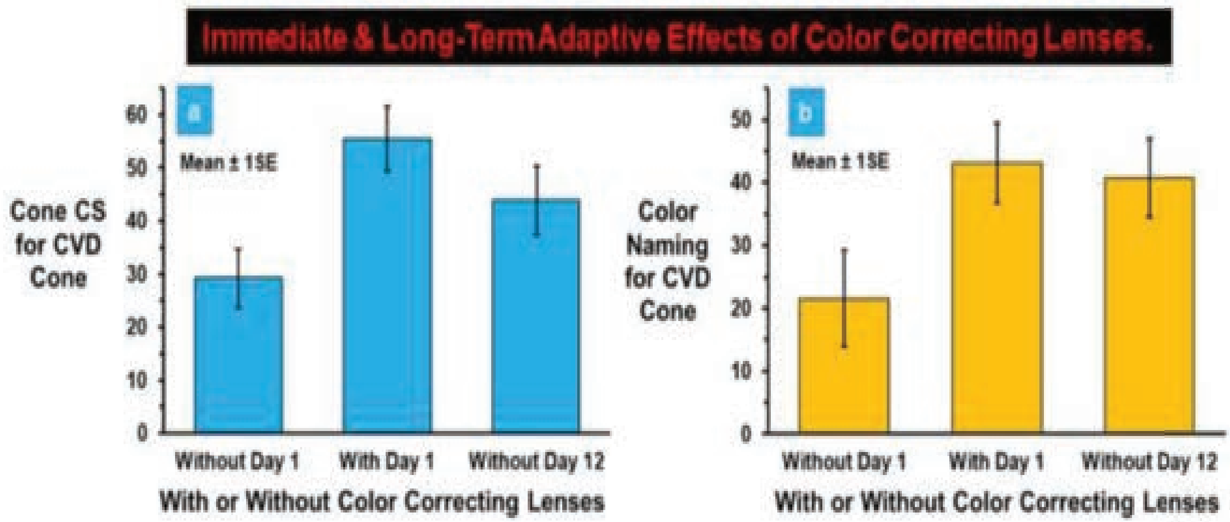
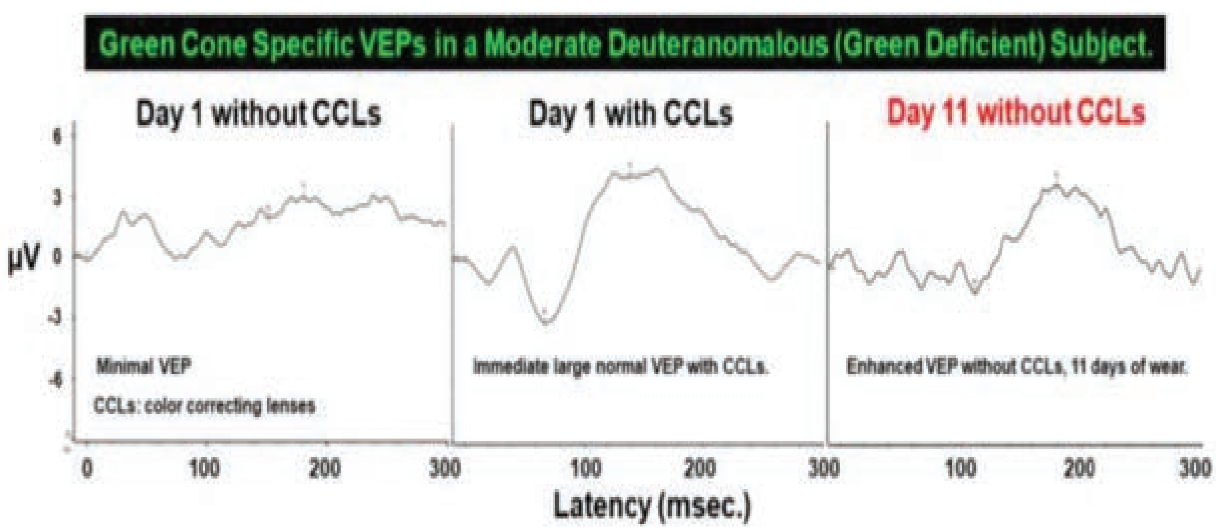
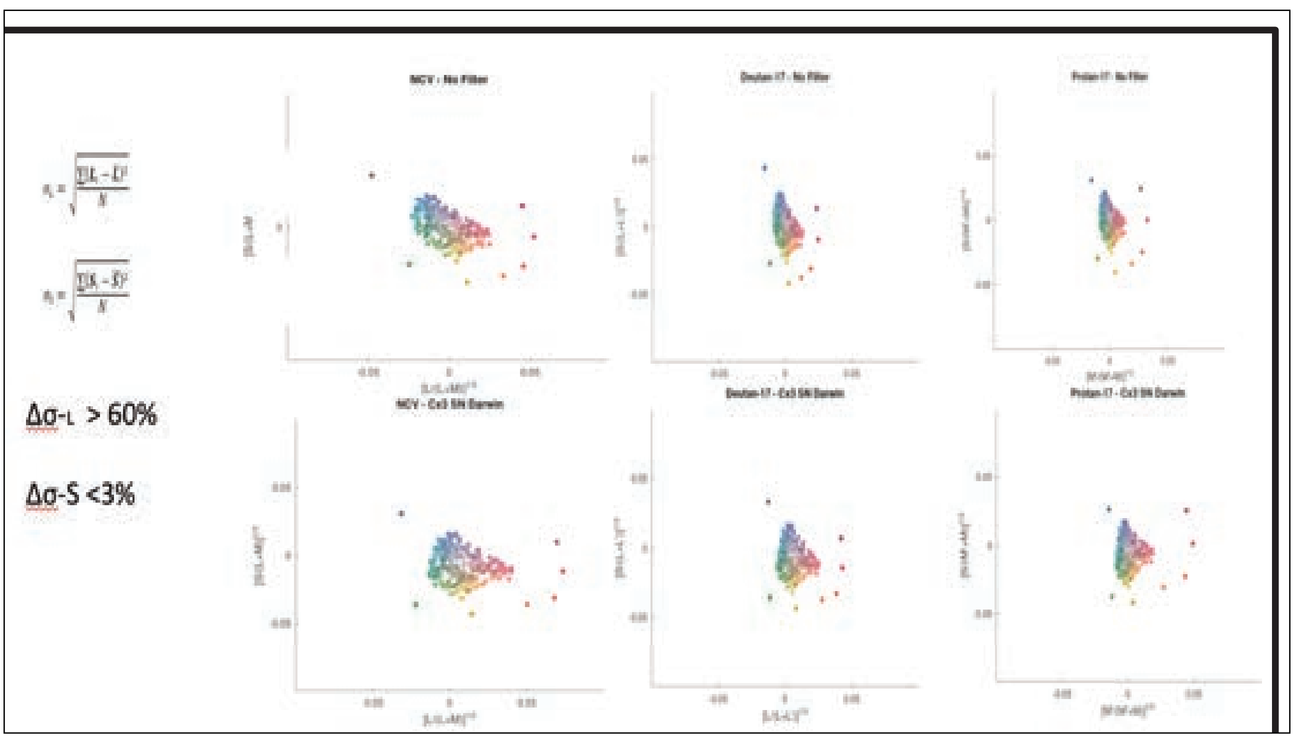
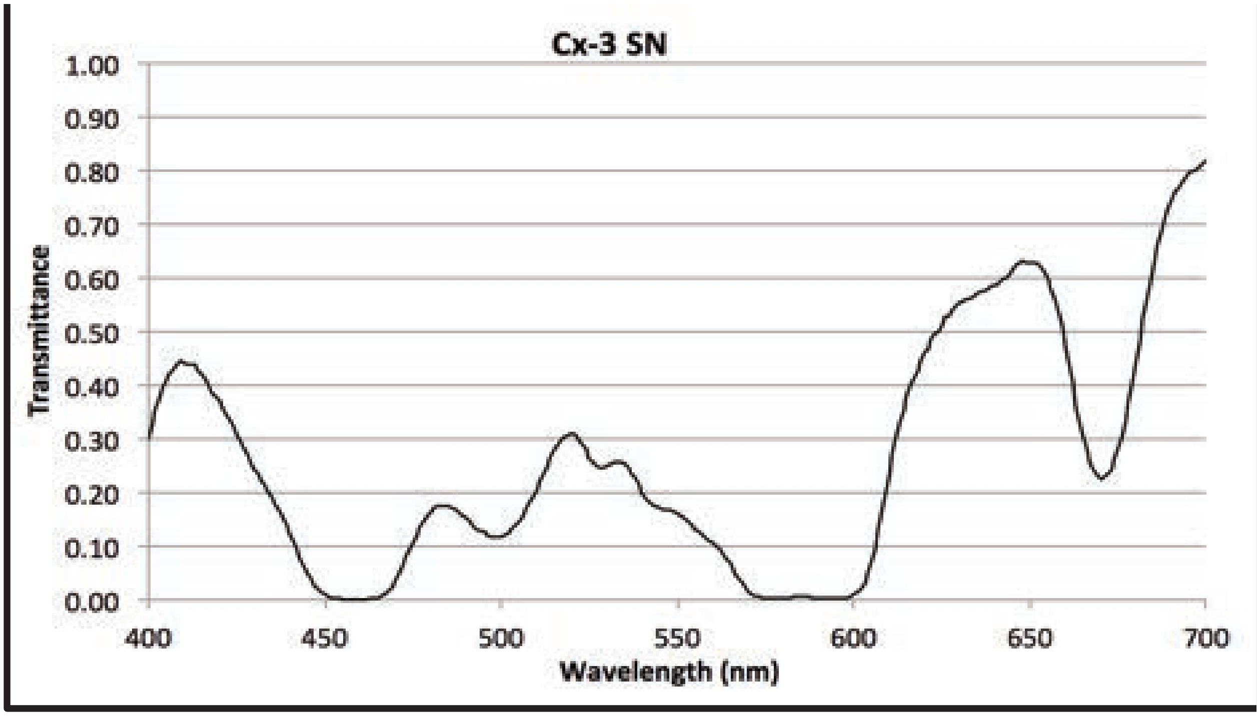


Fig. 2: Immediate and long-term enhancement in cone specific VEPs [4] with CCLs.



- EnChroma eyewear confer information that is usable by the visual system (Somers, et al., ICVS 2019)
- Perceptual learning improves long-term <u>memory color</u> (Werner, et. al., Current Biology 30, 3011-3015, August 3, 2020)
- Enhanced color saturation, esp. at low luminance, leads to enhanced apparent brightness (Helmholtz- Kohlrausch Effect)
- Filter design and performance measure made in Retinal Ganglion Cell-level MacLeod-Boynton Cone Excitation Space
- Evaluate the standard deviation of 275 reflectance surfaces along the L/(L+M) and S/(L+M) directions: Δσ-L > 30%; Δσ-S <10% are acceptable improvements: Δσ-L > 70%; Δσ-S <3% obtained for severe color deficiency.





"How do you know your red is my red?"
(when color deficient and wearing EnChroma glasses)

Peer-reviewed publications showing

- ✓ correct color naming,
- ✓ The color experience is remembered (memory color),
- ✓ Improved threshold and supra-threshold color perception,
- ✓ Evidence of perceptual learning, AND
- ✓ this new information has made it as far as the primary visual cortex, and is therefore most likely perceived.

MISSOURI S&T

mo•sci CORPORATION

From University Research to Clinical Use- A Biomedical Glass Story

Richard K. Brow and Steven Jung

Missouri University of Science & Technology
Rolla, MO 65409 USA

MoSci Corporation
Rolla, MO 65401 USA

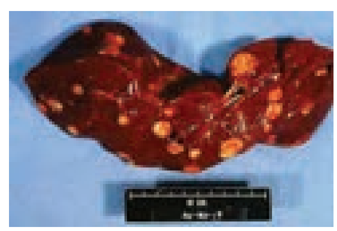
National Day of Glass
Washington, DC
6 April 2022

INTERNATIONAL YEAR OF GLASS 2022

S&T's Biomedical Glass Story Begins with Liver Cancer

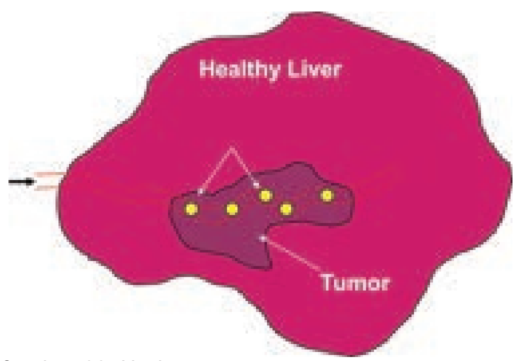
Options for late-stage liver cancer are limited*

- Surgery requires post-operational functionality
- Ablation limited to small tumors
- Transplants are limited by donor availability
- External beam radiation can damage healthy organs
- Chemotherapy can have significant side-effects



Radioembolization is an option.**

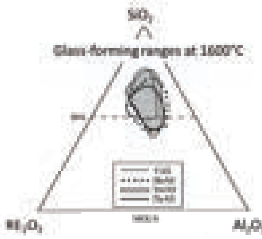
- Deliver radioactive particles directly to the site of the tumor
  - Y-90: β-emitter (2.5-10 cm range, 64 hr half-life)
- Challenge: develop chemically stable materials with the required size and form (20-40 microns).

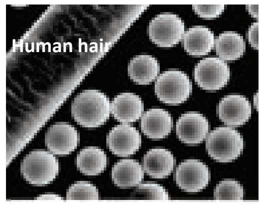


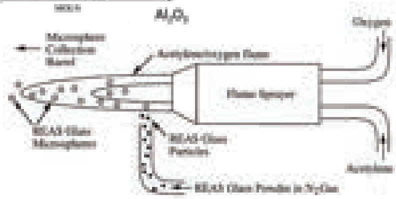
*https://www.cancer.org/cancer/liver-cancer/treating.html
Ehrhardt, G.J. and Day, D.E. (1987) Therapeutic use of yttrium-90. *Nuclear Medicine and Biology International Journal of Radiation Applications and Instrumentation Part B*, **14, 233–242

Rare-earth aluminosilicate (REAS) glasses have the desired characteristics for radioembolization*

REAS glasses have
1. Large concentrations of radioactive ions
2. No other ions that activated by neutrons
3. Outstanding chemical durability
4. Viscosity and crystallization behaviors that allow microsphere processing

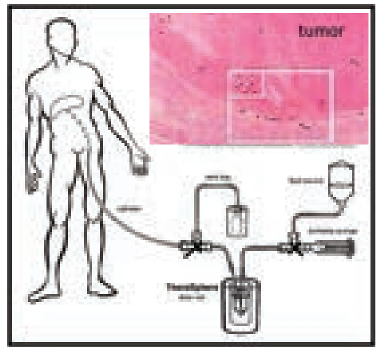






*White, J.E. and Day, D.E. (1994) Rare earth aluminosilicate glasses for in vivo radiation delivery. *Key Engrg Matls*, **94–95**,

Radioembolization with Y-90 doped glass micro-spheres is now a significant treatment option for liver cancer**



In 1985, there were no commercial suppliers for these glass microspheres, so Delbert Day started MoSci Corp. in Rolla, MO, to fill this niche.

**https://www.cancer.org/cancer/liver-cancer/treating/embolization-therapy.html

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3

Research collaborations between Missouri S&T and MoSci have led to the development and deployment of new specialty glass technologies

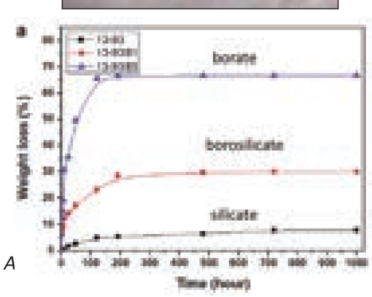
Chemically durable iron phosphate glasses*

- Originally studied to control ion release for biomedical applications;
- Iron phosphate base glasses were found to be chemically stable and could retain large concentrations of other oxides
- Are now available to vitrify radioactive and hazardous wastes.

*DE Day, et al., (1998), Chemically durable iron phosphate glass wasteforms, *J. Non-Cryst. Solids*, 241 1-12; RK Brow, et al., (2020) Iron Polyphosphate Glasses for Waste Immobilization, *Int. Journal of Applied Glass Science*,11, 4-14 (2020)

Soluble borate glasses for tissue engineering**

- Developed in studies to create soluble versions of the radioactive microspheres
- Replacing silica with B_2O_3 significantly increases aqueous dissolution rates
- Borate glass particles and fibers promote regeneration of soft and hard tissue



**MN Rahaman, DE Day, et al., (2011) Bioactive glass in tissue engineering, Acta Biomat., 7, 2355; SB Jung, (2012) Bioactive Borate Glasses, cap. 6 in *Bio-Glasses- A Introduction*, ed. JR Jones and AG Clare, Wiley.

NDOG
4/6/22

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sjung@mo-sci.com

4

Missouri S&T has developed a new type of bioactive material based on soluble borate glasses

13-93B3: $5.5Na_2O$-$11.1K_2O$-$18.5CaO$-$4.6MgO$-$3.7P_2O_5$-$56.6B_2O_3$ (wt%)

Steve Jung, Delbert Day
Missouri S&T/MoSci, Inc.

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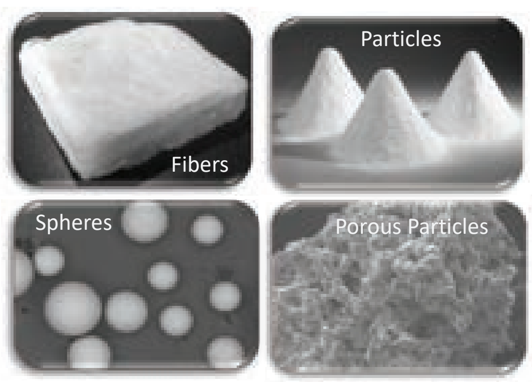
brow@mst.edu
sjung@mo-sci.com
5

What Makes Glass So Interesting As A Material for Medical Devices?

- Chemical Durability
- Chemically Solubility
- Antimicrobial
- May be made Radioactive
- Formable into many shapes; frit, beads, fibers, ribbons, hollow spheres etc.
- Can be Sintered into a complex part
- A wide range of use temperatures
- May be made into porous materials
- Inorganic
- Can be relatively inexpensive*
- Anti inflammatory
- Strong in compression
- Relatively few limitations
- May be chemically strengthened
- Can be drawn/redrawn into various shapes
- Compositions can vary significantly
- Can be Biocompatible
- Can Bond with living tissue
- Properties are, generally speaking, tailorable

Healthcare Glass Form Factors



Healthcare Product Components

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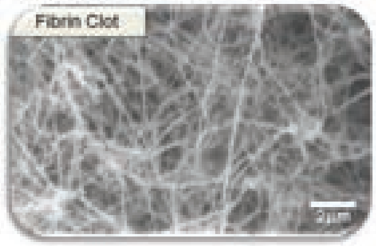
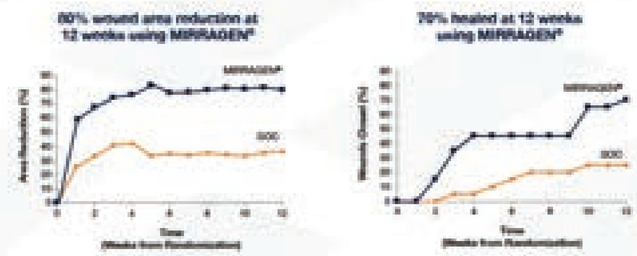
sjung@mo-sci.com
6

Soft Tissue Technology



- Fibrinogen and thrombin react to form cross-linked fibrin matrix
- Fiber mediated healing
- Basic mechanism for all connective tissue healing
- **This is Natures Way of Healing!**

Diabetic Foot Ulcer, RCT Data, N=40



ETS WOUND CARE

*Protected by MO-SCI/Missouri S&T IP

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4/6/22

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sjung@mo-sci.com

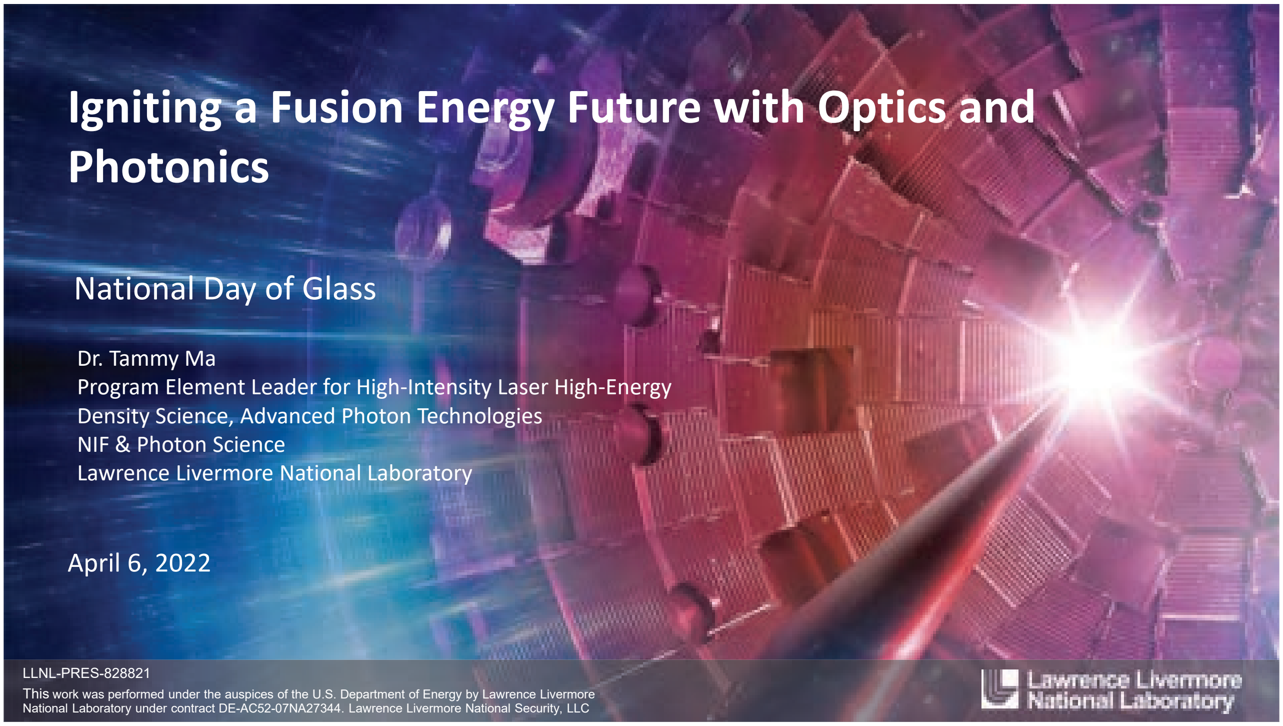
7

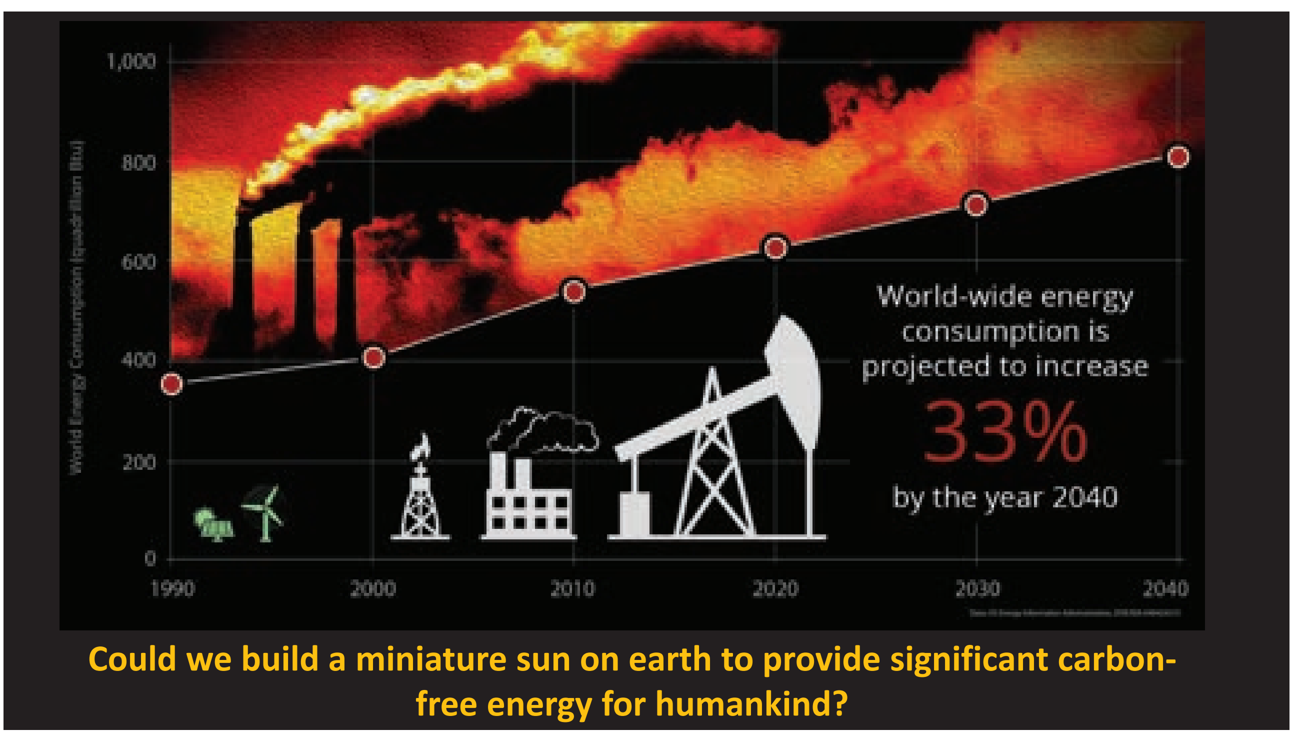
MISSOURI S&T

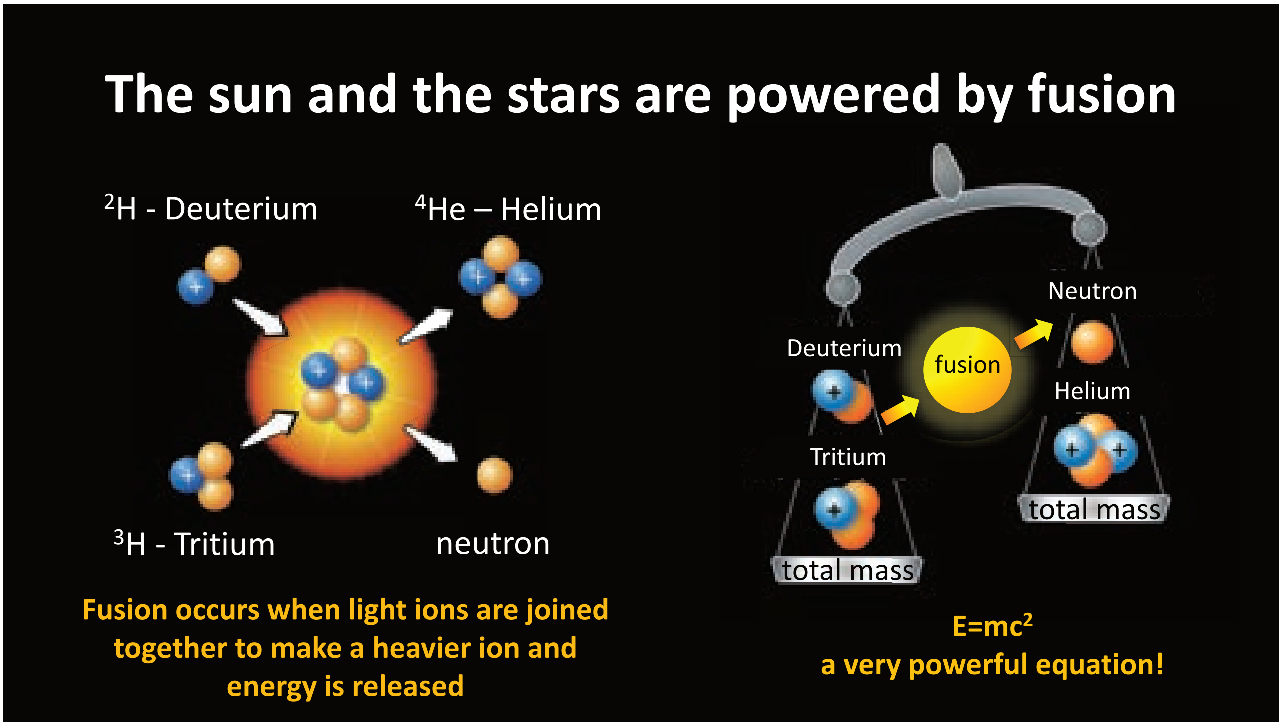
mo•sci CORPORATION

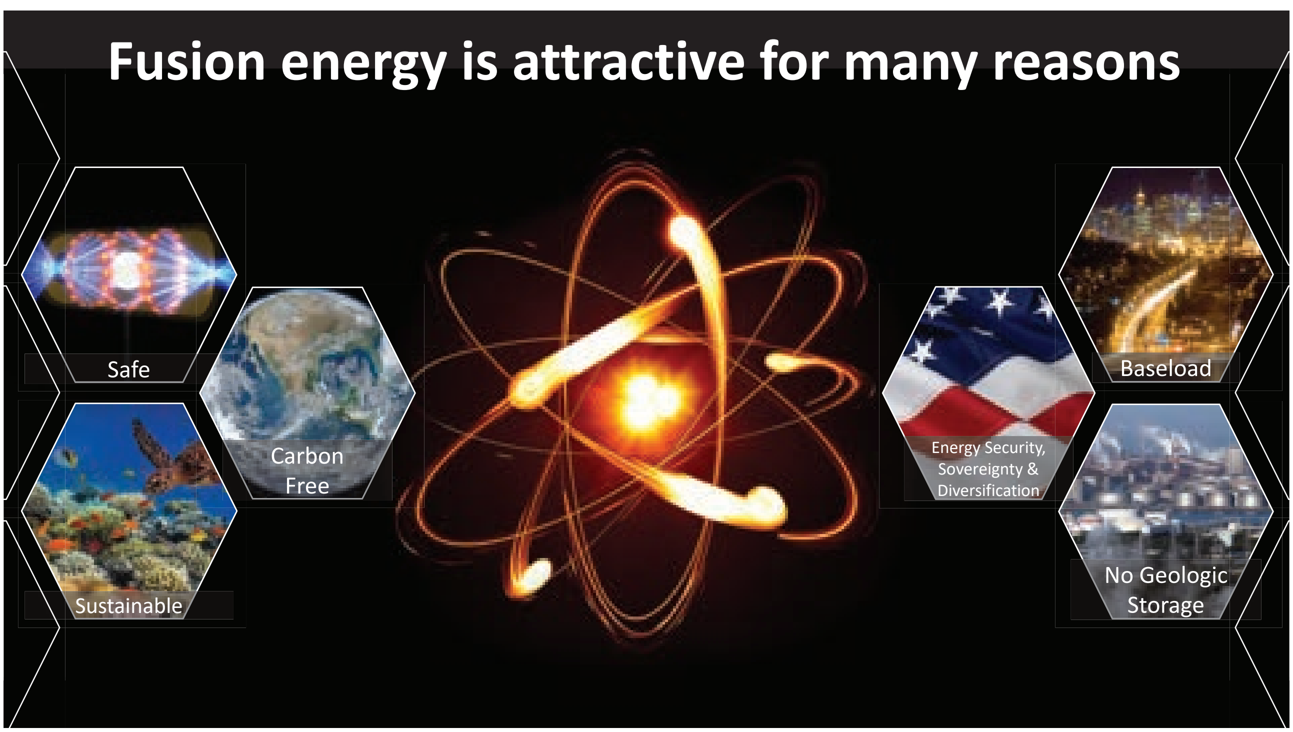
"Glass…is much more gentile, graceful and noble than any Metall, …it is more delightful, polite and sightly than any other material at this day known to the world."
—Antonio Neri, 1612.

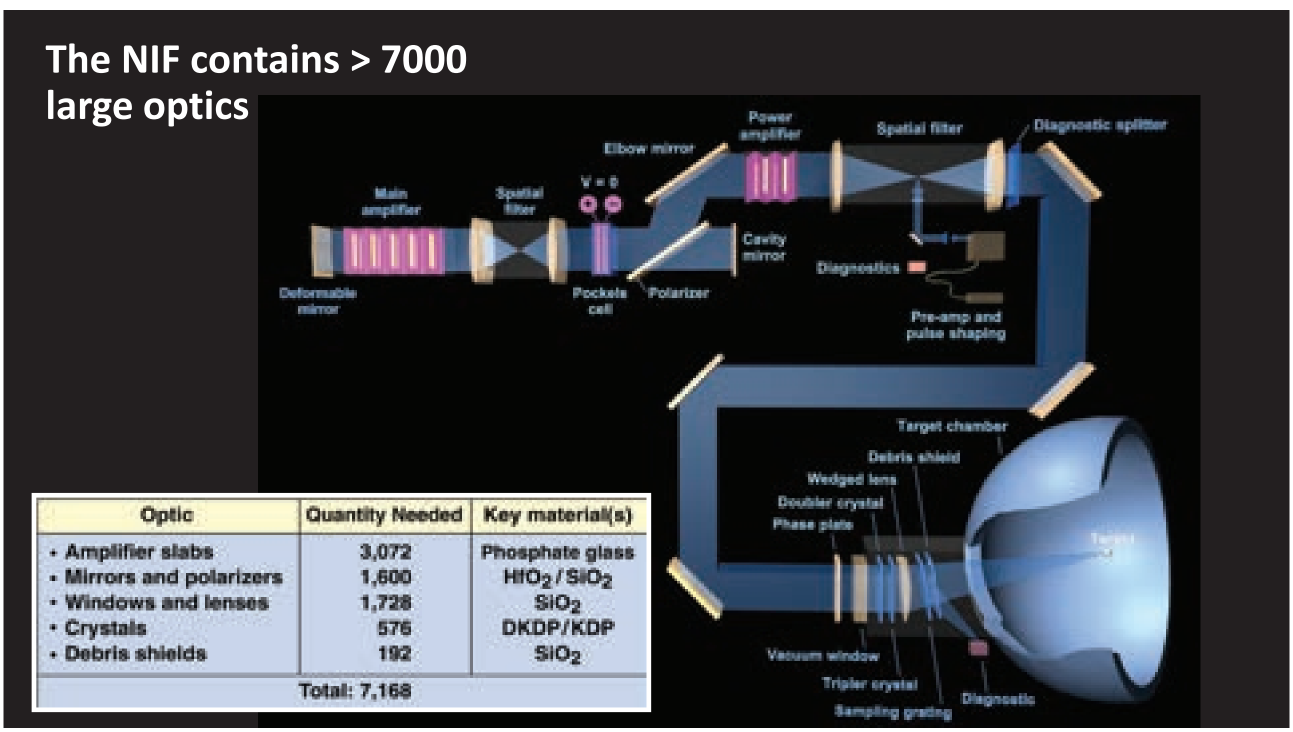
INTERNATIONAL YEAR OF GLASS 2022


Igniting a Fusion Energy Future with Optics and Photonics
National Day of Glass
Dr. Tammy Ma
Program Element Leader for High-Intensity Laser High-Energy Density Science, Advanced Photon Technologies
NIF & Photon Science
Lawrence Livermore National Laboratory
April 6, 2022
LLNL-PRES-828821
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC
Lawrence Livermore National Laboratory

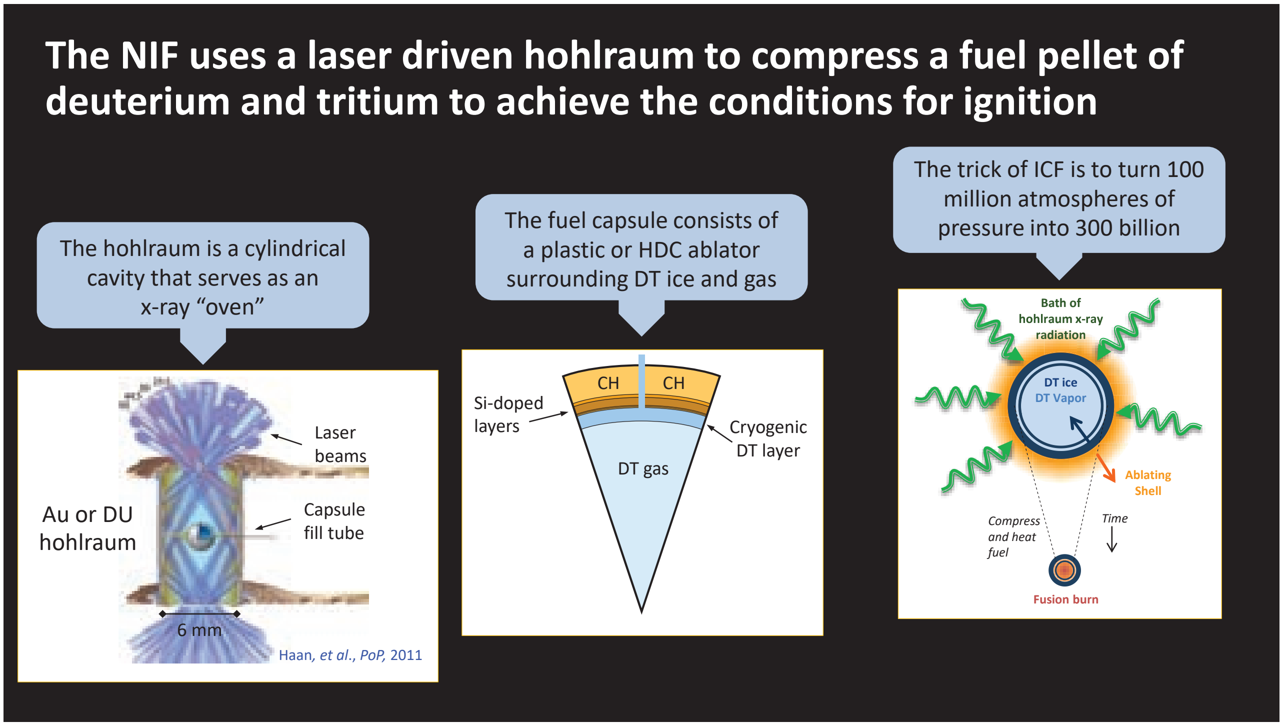

1,000
800
600
400
200
0
World Energy Consumption (quadrillion Btu)
1990
2000
2010
2020
2030
2040
World-wide energy consumption is projected to increase
33%
by the year 2040
Could we build a miniature sun on earth to provide significant carbon-free energy for humankind?

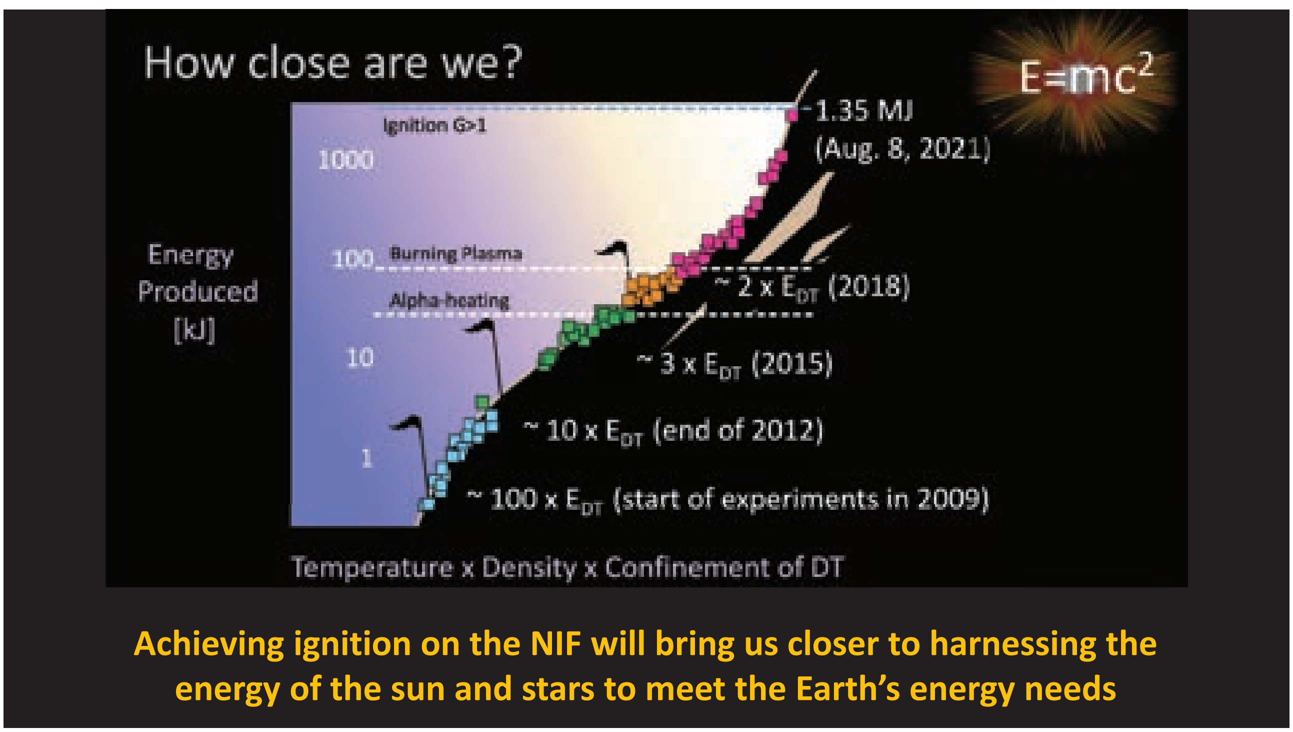

The sun and the stars are powered by fusion
²H - Deuterium
⁴He – Helium
³H - Tritium
neutron
Fusion occurs when light ions are joined together to make a heavier ion and energy is released
Deuterium
fusion
Neutron
Helium
Tritium
total mass
total mass
E=mc²
a very powerful equation!


Fusion energy is attractive for many reasons
Safe
Carbon Free
Sustainable
Energy Security, Sovereignty & Diversification
Baseload
No Geologic Storage



Optic	Quantity Needed	Key material(s)
• Amplifier slabs	3,072	Phosphate glass
• Mirrors and polarizers	1,600	HfO_2 / SiO_2
• Windows and lenses	1,728	SiO_2
• Crystals	576	DKDP/KDP
• Debris shields	192	SiO_2
	Total: 7,168	


The NIF uses a laser driven hohlraum to compress a fuel pellet of deuterium and tritium to achieve the conditions for ignition
The hohlraum is a cylindrical cavity that serves as an x-ray "oven"
Laser beams
Au or DU hohlraum
Capsule fill tube
6 mm
Haan, et al., PoP, 2011
The fuel capsule consists of a plastic or HDC ablator surrounding DT ice and gas
CH
CH
Si-doped layers
Cryogenic DT layer
DT gas
The trick of ICF is to turn 100 million atmospheres of pressure into 300 billion
Bath of hohlraum x-ray radiation
DT ice
DT Vapor
Ablating Shell
Compress and heat fuel
Time
Fusion burn


How close are we?
E=mc2
Ignition G>1
1000
100
10
1
Burning Plasma
Alpha-heating
Energy Produced [kJ]
1.35 MJ (Aug. 8, 2021)
~ 2 x E_DT (2018)
~ 3 x E_DT (2015)
~ 10 x E_DT (end of 2012)
~ 100 x E_DT (start of experiments in 2009)
Temperature x Density x Confinement of DT
Achieving ignition on the NIF will bring us closer to harnessing the energy of the sun and stars to meet the Earth's energy needs

A World Without Waste

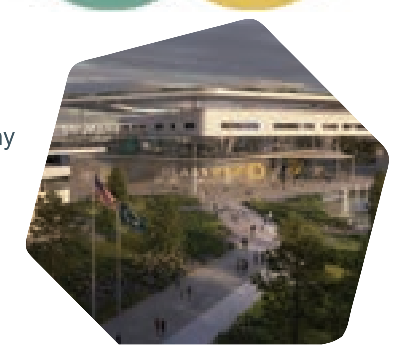
Starting with Glass

Philip Galland
Co-Founder,
GlassWRX

GLASSWRX

Who we are, Why we're here

- We're a close-knit group of **like-minded scientists, engineers, system thinkers, and socially responsible entrepreneurs**. We believe advanced manufacturing, clean energy, low carbon companies will play a leading role in our immediate economic and societal future.
- Our shared vision is a world without waste – **harnessing our collective Superpowers through a shared commitment to do good.**
- Using technology as a design tool, we find novel and effective ways to **"design out" waste** and pollution and **upcycle** recovered materials diverted from waste streams and landfills.
- **We are starting with glass.**
- Today's waste streams are a sad legacy of the industrial revolution – byproducts of a cycle of take, make, and waste. This antiquated philosophy damages and even destroys natural ecosystems that support life on this planet.
- This is literally not sustainable and has brought us to a point of crisis – we now face environmental catastrophe and global infrastructure collapse.

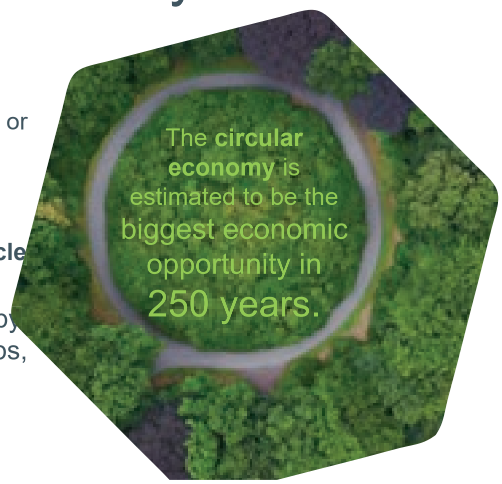


GLASSWRX

Glass And The Circular Economy

- **A circular economy is one that designs out waste and pollution, keeps products and materials in use, and regenerates natural systems.**
- Glass, as you know, is endlessly recyclable. Despite this, 70% or more of post-consumer glass gets landfilled each year.
- Cities are abandoning their glass recycling programs over profitability concerns.
- **We can reverse this trend by making glass easier to upcycle into new materials for a resilient and sustainable future.**
- We can help unlock $4.5 trillion in new economic value by 2030. Reduce CO_2 emissions by 48%, create quality jobs, improve public health, **and heal the planet.**

The Age of Glass – The glass industry is poised to be the de facto 'Global Leader' for the circular economy.

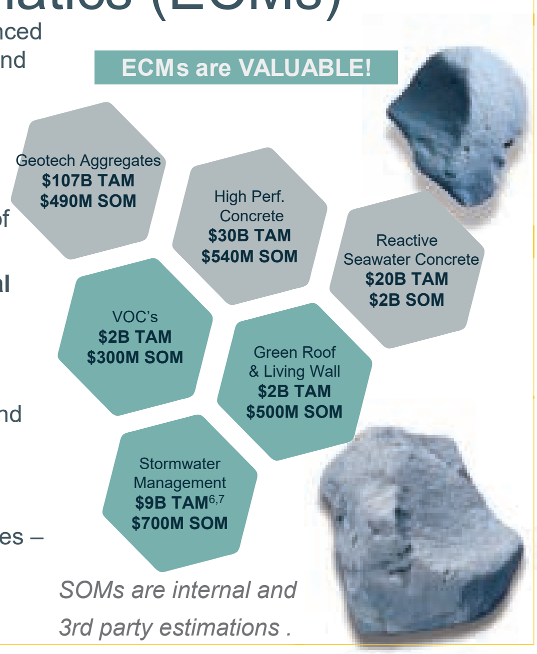


GLASSWRX

Engineered Cellular Magmatics (ECMs)

- Our founders and scientists have invented a new class of advanced sustainable materials with which we can rebuild resilient cities and societies. They are called **Engineered Cellular Magmatics** (ECMs).
- **ECMs** are restorative and regenerative by design.
- Through proprietary **geomimicry,** ECMs can replicate nature's ability to form valuable geological materials in minutes instead of millennia.
- ECMs are made from recovered **post-consumer and industrial waste glass**.
- As the world moves toward sustainability, recovered glass will become a desirable commodity across numerous industries.
- With the assistance of the **Department of Energy (ARPA-e)**, and particularly the help from our **research partners at Savannah River National Laboratory**, we know that we can also produce ECMs with **Municipal Solid Waste to Energy residues.**
- Waste to Energy facilities pay a premium to landfill these residues – **there is a negative market for these materials**.

GLASSWRX



Sustainability & Industry 4.0

- Today, our prototype facility upcycles post consumer waste glass, saving **upwards of 38% to 43% of embodied energy costs** over raw (mined) materials.
- As the world moves toward global sustainability, we are developing new materials and methods that are carbon neutral, with significantly lower embodied energy costs – We have successfully utilized industrial waste materials from **Corning, Boeing,** and **Covanta** to create highly performant ECMs.
- We've already successfully created ECM formulations utilizing mine tailings.
- Our proprietary A.I., (a physics-driven machine learning platform) allows us to engineer unique and economical ECMs – In radically faster development cycles.
- We've engineered unique, purpose-built kilns and furnaces that can monitor inputs, optimize production, and reduce energy consumption (IIoT).

GLASSWRX

Case Study: Ancient Roman Concrete

- As Department of Energy (ARPA-e) program awardee, utilizing our proprietary geomimicry techniques, we successfully **replicated natural magmatics** (a specific species of volcanic tuff) that was key to the production of **Ancient Roman Reactive Glass Concrete.**
- Restored an economical means of making **planet friendly, reactive, ultra-durable concretes** that require little or no steel reinforcement and is **self-healing through post-pozzolanic mineralization**.
- ECM formulation looks to improves durability at – 4 times the typical 50-year cement service life and lower energy and emissions associated with production and deployment by – 85%.
- Project featured in a **Fortune** article guest edited by **Bill Gates.**

- **Lower CO_2 emissions** by utilizing **lightweight ECM formulations**:
  - Lower acquisition costs – no mined aggregates – less CO_2.
  - Lower production costs – less clinker production – less CO_2.
  - Lower distribution and transport costs (fewer trips) – less CO_2.
  - Greater durability and longevity – less CO_2.

THE UNIVERSITY OF UTAH

KMR

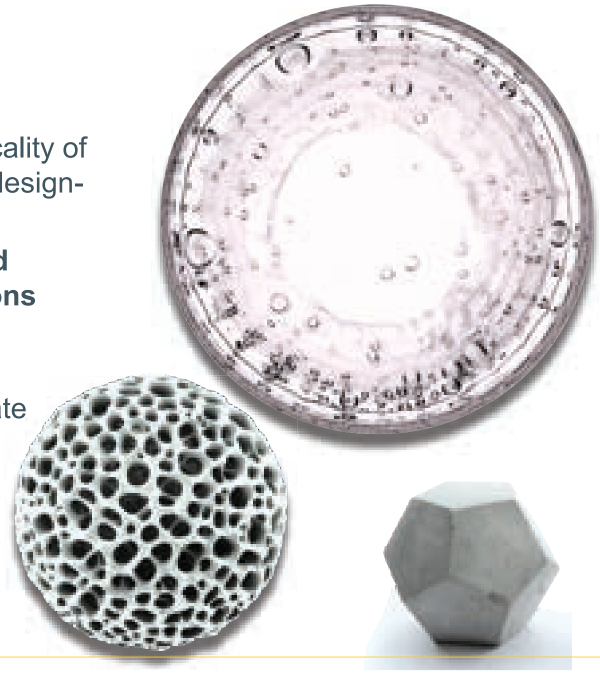
SRNL

SILICA DYNAMICS

GLASSWRX

Beyond ECMs

- ECMs were the first step – These unique substrates underscore the value and practicality of advanced geomimicry, and its place in the design-thinking toolset of the circular economy.
- **While ECMs have demonstrated and hold immense promise, even greater revelations are on the horizon…**
- New substrates born of geomimicry and an overwhelming need to further address climate change, decarbonization, environmental remediation, sustainability engineering, and circular economics.



GLASSWRX

Thank you!

For more information visit https://glasswrx.com
Or, contact **Philip Galland**: 702.708.9325 p.galland@glasswrx.com

*"ECMs would not exist today and would not have been brought to market at this incredible pace without the help and dedication of our partners at **SRNL**, the **Department of Energy (ARPA-e)**, **Pennsylvania State University**, **KMR**, and **Lucas Engineering,** amongst others.*

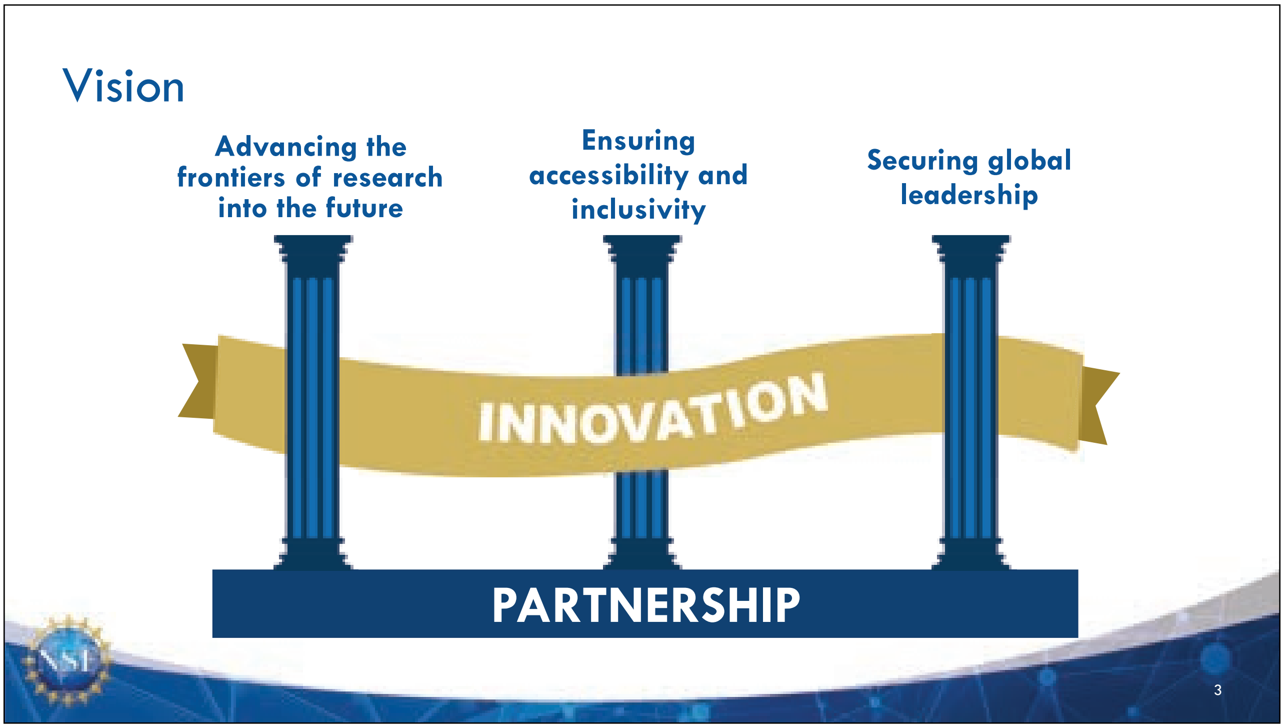
*These partners have allowed our internal team (Robert Hust, Gert Nielsen, Dr. Collin Wilkinson, et al.) to recruit incredible talent and to benefit from the work and insights of doctors **Vahid Majidi, Cory Trivelpiece**, **Carol Jantzen**, **Robin Brigmon**, **Gene Ramsey**, and **John Mauro**, and from the engineering and technology to market expertise of **Thomas Adams**."*

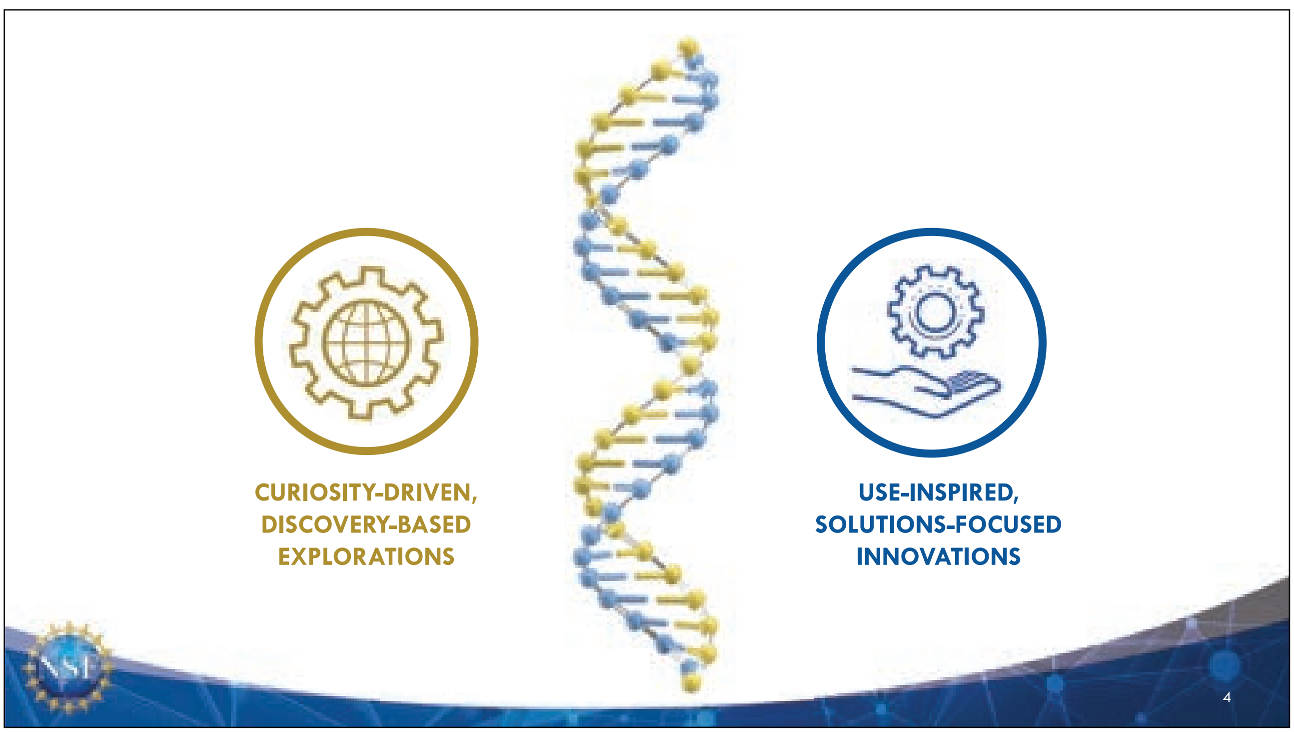
~ Philip Galland

GLASSWRX

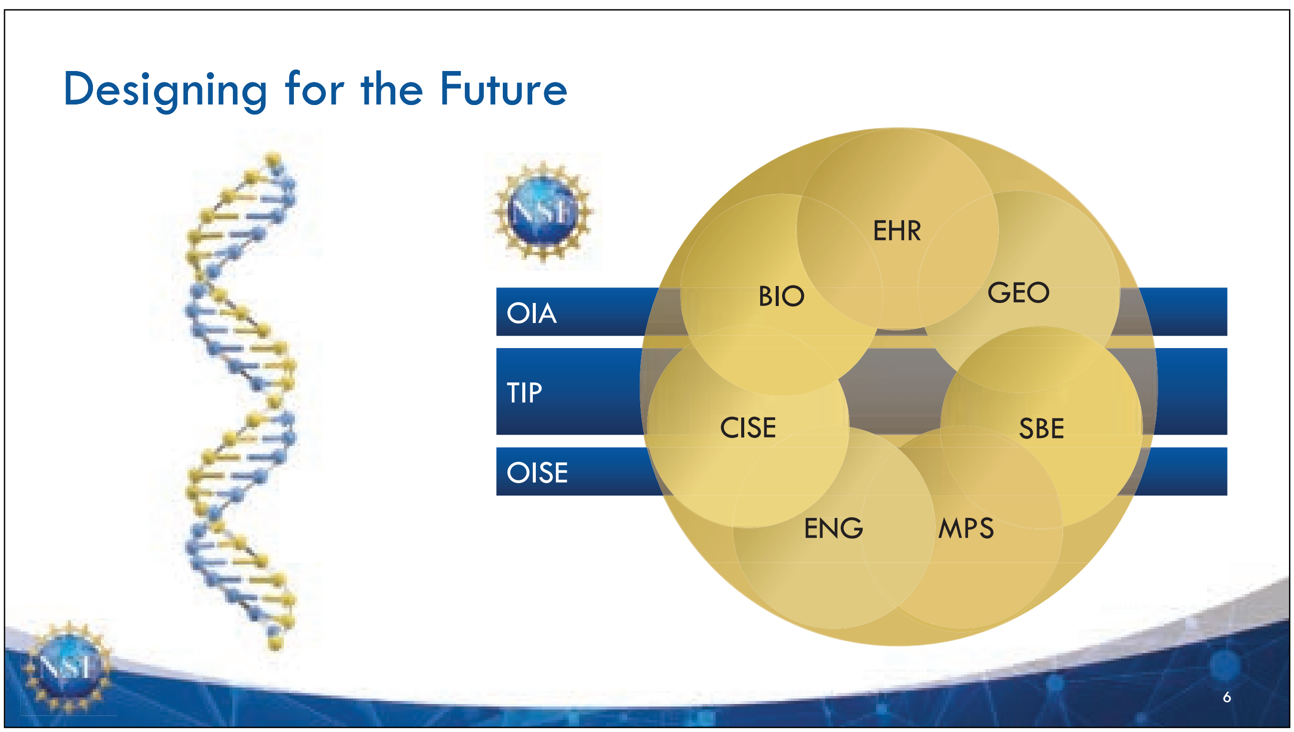

NSF
INNOVATION AND INVENTION:
THE IMPORTANCE OF INVESTMENTS IN FUNDAMENTAL SCIENCE & ENGINEERING
Sethuraman Panchanathan
National Science Foundation
Towards a Seminal Moment in the History of Glass: A National Day of Glass Conference
April 6, 2022


Global Competition
Defining Moment
Missing Millions
Bipartisan Support
NSF
2


Vision
Advancing the frontiers of research into the future
Ensuring accessibility and inclusivity
Securing global leadership
INNOVATION
PARTNERSHIP
3


CURIOSITY-DRIVEN, DISCOVERY-BASED EXPLORATIONS
USE-INSPIRED, SOLUTIONS-FOCUSED INNOVATIONS
4

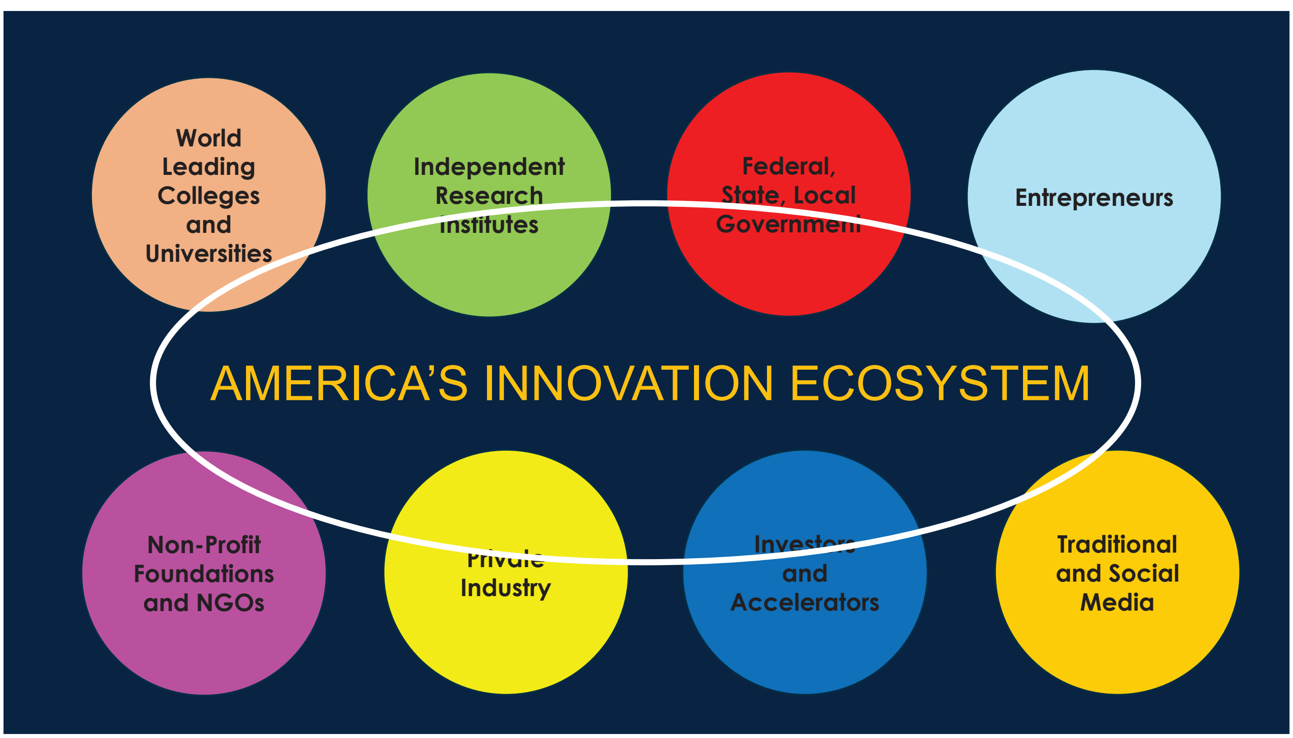

Investment to Impact: Innovations in Glass
1970s-1990s
POLYMERS AND HYDROGELS
1990s-2020s
OPTICAL COATINGS
1950s
METALLIC GLASS
1950s
GLASS FIBEROPTIC CABLES
1970s
CLEAN ENERGY TECHNOLOGIES
NSF INVESTMENTS
CURRENT IMPACTS
PLASTIC EYEGLASSES AND CONTACT LENSES
SCRATCH RESISTANT GLASS
SUPERCOOL METALS
FIBEROPTIC SURGICAL LIGHT SCALPEL
UBIQUITOUS ENERGY STARTUP
NSF
5


Designing for the Future
NSF
OIA
TIP
OISE
EHR
BIO
GEO
CISE
SBE
ENG
MPS
NSF
6


Accelerating Translation
Accelerating Public-Private Partnerships
Pathways to Entrepreneurship
Regional Innovation Engines
Lab-to-Market Platforms
Translational Accelerators
NSF
7


Building Innovation Ecosystems
UNIVERSITIES/COLLEGES
INDUSTRY PARTNERS
COMMUNITY ENTITIES
LOCAL GOVERNMENT
NSF
8

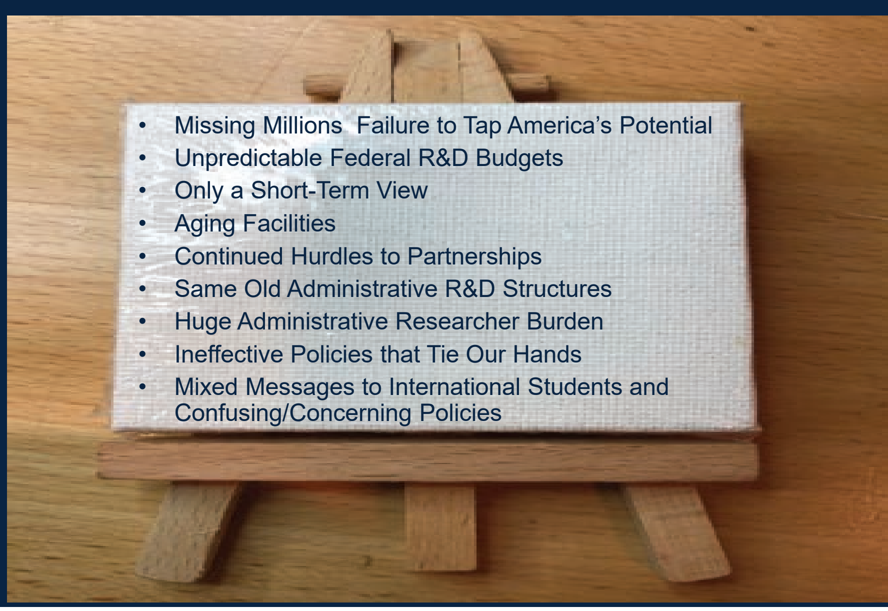

Re-Sketching America's Innovation Ecosystem
Kelvin K. Droegemeier, University of Oklahoma
National Day of Glass Conference
Washington, DC
5-7 April 2022


World Leading Colleges and Universities
Independent Research Institutes
Federal, State, Local Government
Entrepreneurs
AMERICA'S INNOVATION ECOSYSTEM
Non-Profit Foundations and NGOs
Private Industry
Investors and Accelerators
Traditional and Social Media

HOW HAVE WE DONE?

- Seven of the top 10 universities in the world
- Trillion dollar companies
- COVID-19 vaccine in less than a year
- Largest number of Nobel Laureates by far
- Innovations in GLASS that have changed the course of mankind
  - Fibre-Optics
  - Gorilla Glass
  - Thin Eyeglass Lenses
  - Pyrex
  - Neutrino Detectors
  - Laser Fusion Lenses

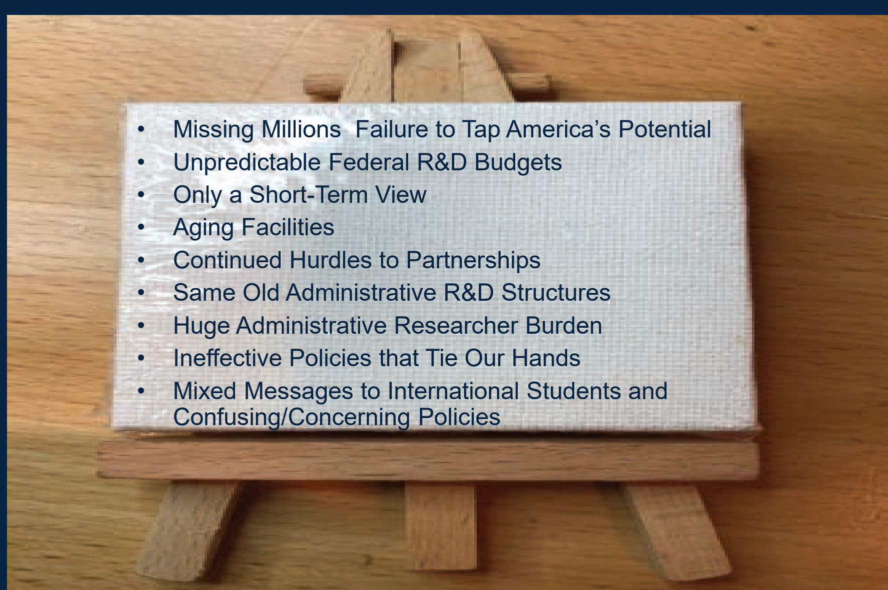
WHERE WE HAVE FALLEN SHORT

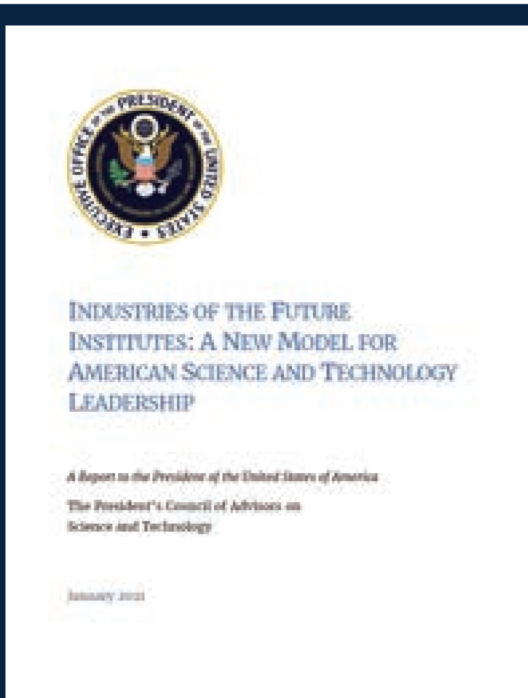


WHAT WE NEED

- To have a nationally successful innovation ecosystem, we need
  - Capable individuals drawn from the broadest cross section of American and foreign talent (students, researchers, technicians)
  - Sustained, predictable funding for R&D
  - Effective facilities and technical support structures
  - Effective policy and administrative frameworks
  - Supportive free market system and regulatory environment for businesses and entrepreneurs

ITS TIME TO MAKE A NEW SKETCH

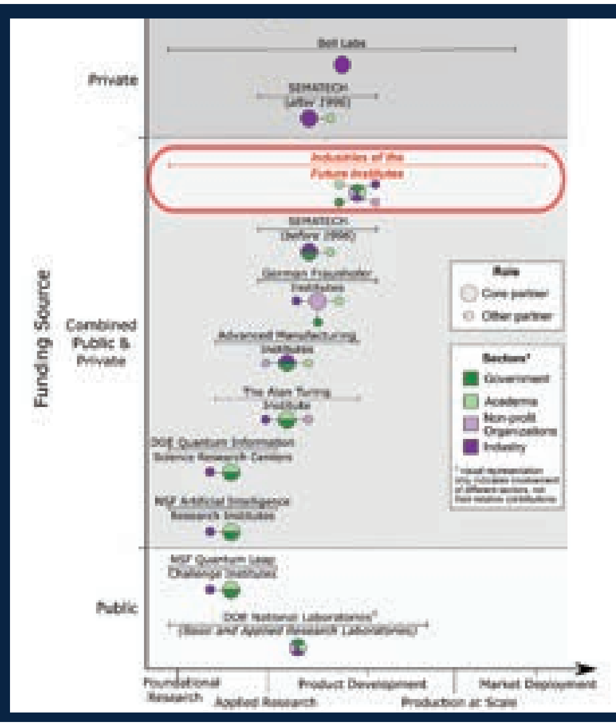



INDUSTRIES OF THE FUTURE INSTITUTES: A NEW MODEL FOR AMERICAN SCIENCE AND TECHNOLOGY LEADERSHIP

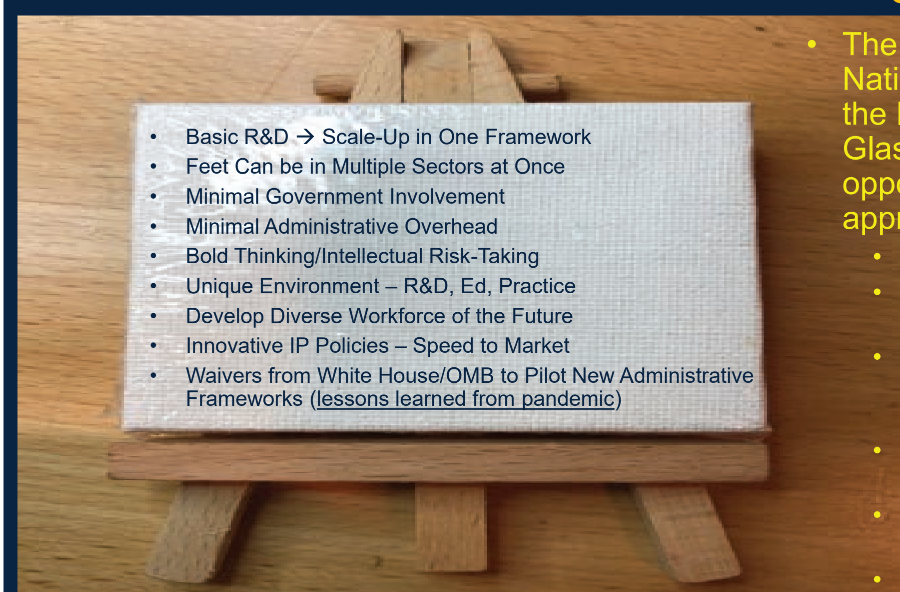
A Report to the President of the United States of America

The President's Council of Advisors on Science and Technology

January 2021



A NEW, FLEXIBLE FRAMEWORK



IMPORTANCE OF YOUR COMMUNITY

- The topic of glass, the National Day of Glass, and the International Year of Glass, represent an ideal opportunity to take a new approach
  - Critical importance to society
  - Spans spectrum from basic R&D to scaled product
  - Not as politically contentious as some topics (e.g., Artificial Intelligence)
  - Close-knit international community
  - Not so huge a community as to be untenable
  - Highly multi-disciplinary

Bending light with glass: Images from the cosmos to the microbe

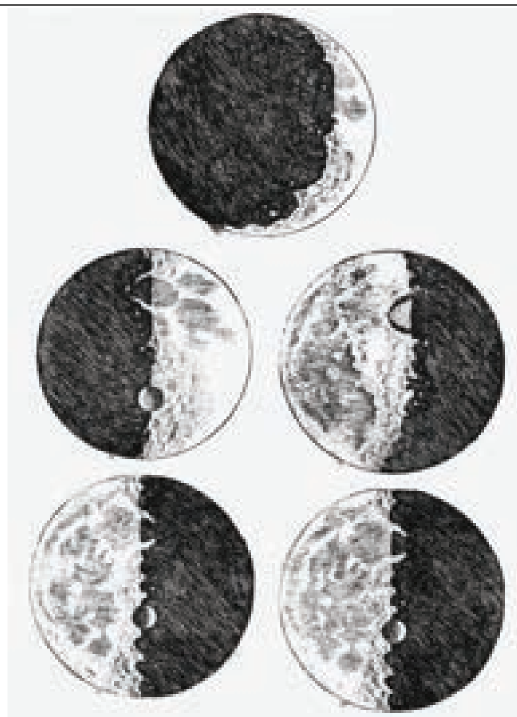
Steve Feller
Coe College

COE COLLEGE

1851

…in 1538 Italian physician Girolamo Fracastoro wrote in *Homocentrica*:

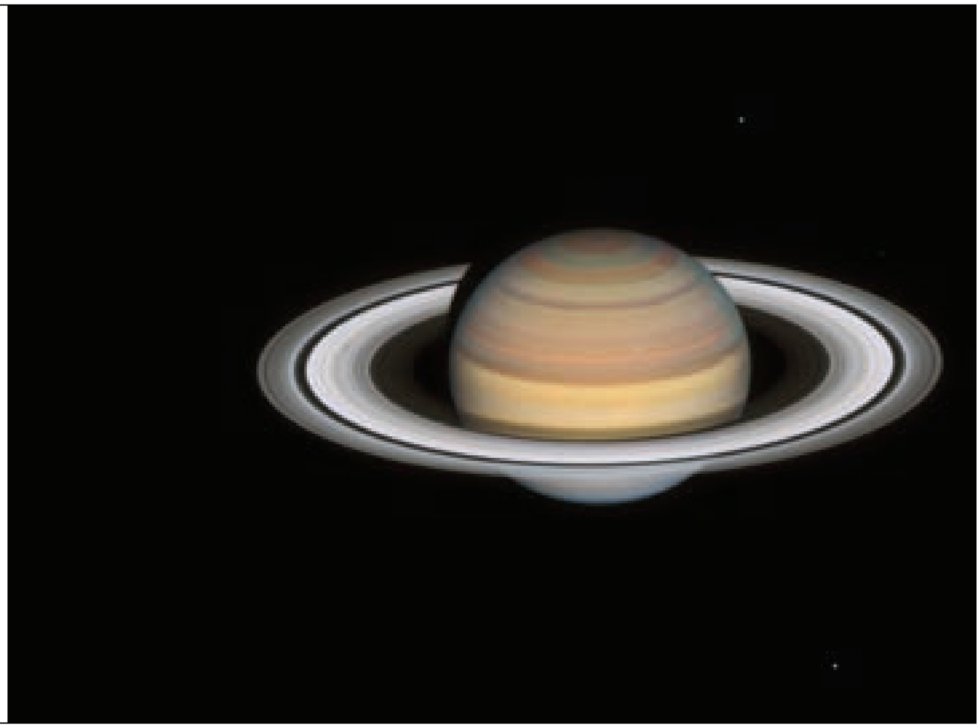
“If anyone should look through two spectacle glasses, one being superimposed on the other, he will see everything much larger.”



Craters on the Moon as seen by Galileo in his telescope from *Starry Messenger* (1610)

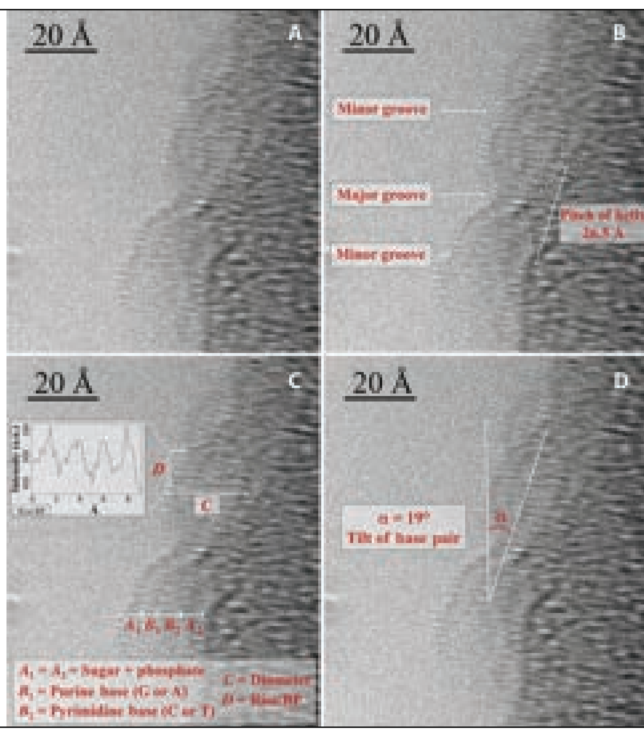
Newton's Reflector
(Copy at the Science Museum, London)

Saturn from the Hubble Space Telescope (NASA)



James Webb Telescope(NASA)

An Athenian Owl circa 450 BC From my microscope



DNA image from an electron microscope (Science Advances, 2015)

Education on "Glasses for Integrated Photonics"

Initiative for Knowledge and Innovation in Manufacturing (IKIM)
MIT

Anu Agarwal
anu@mit.edu
https://photonics.mit.edu/people/principal-investigators/anu-agarwal

1

Education on "Glasses for Integrated Photonics"

— Where is glass education headed? What are innovations that are spurring change in this area?

Research in integrated photonics is driving the need to teach about design and fabrication of new glass compositions for diverse applications. For example,
(i) **mid-IR transparent chalcogenide glasses** for on chip spectroscopy,
(ii) **high index glass metamaterials** for flat optics,
(iii) **phase change materials** for dynamically tunable optics, and
(iv) **CMOS-compatible glasses** for foundry manufacturing and packaging.

For example, for several integrated photonics applications, custom-compositions of bulk glasses from Prof. Kathleen Richardson's group at UCF are converted to thin films in Prof. Hu's, Prof. Kimerling's and Dr. Anu Agarwal's labs at MIT, while maintaining all the desirable glass properties.

anu@mit.edu

— What are the specific needs of the fields that require people with knowledge of glass? How do they differ, and how are the conditions similar across these fields?

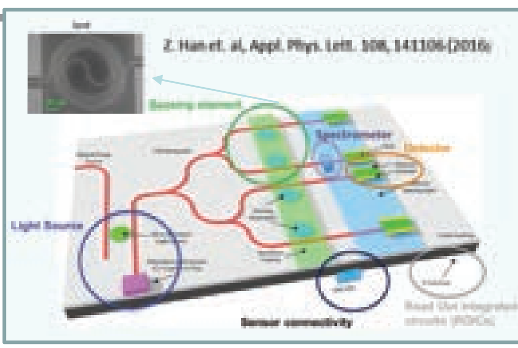
Fundamental knowledge of the effects of temperature, pressure, robustness against environmentally harsh conditions, stability, manufacturability, etc. of glasses, requires contributions from glass scientists and engineers. This **materials study is a common thread**. But diversity of applications will determine educational nuances. For instance, for **phase-change applications we need to focus on glass transition control**.

— Are there educational areas in need of improvement? Are glass specialists lacking instruction in one or more other critical areas?

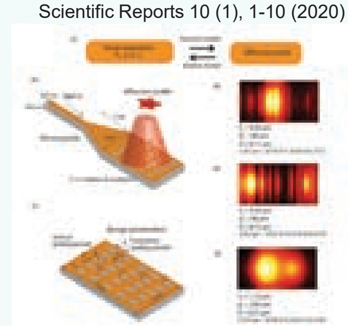
Hands-on training of engineers and technicians is critical. But so is scalability in glass education. We have developed a **blended learning model, which is a three-legged stool** with the legs being a lecture (can be online, scalable, and a part of continuing education), a virtual reality simulation (online, and scalable), and lab training (hands-on work, partially scalable when lab tool simulations are used). Together they build knowledge, intuition, and hands-on ability respectively. We use the **LEAP (lab for education and application prototypes) network in MA for knowledge dissemination,** with labs across the state ready to skill, reskill, and upskill K-12, 2-year community college students, undergrads, grads, and company employees through blended learning bootcamps.

3

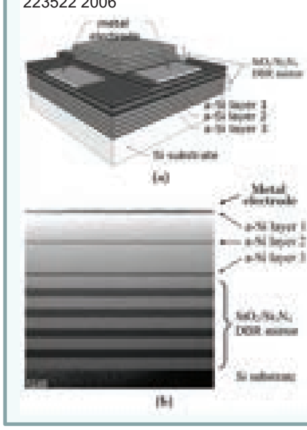
Education through research in glasses for integrated photonics

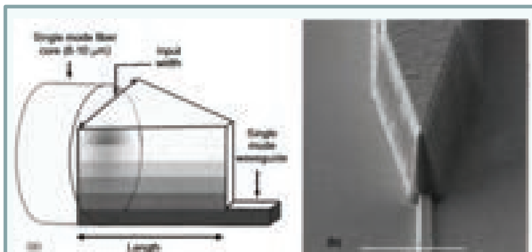


Scientific Reports 10 (1), 1-10 (2020)

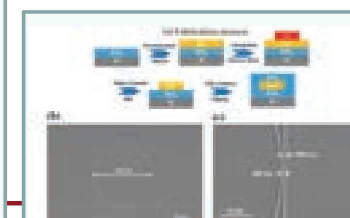


APPLIED PHYSICS LETTERS 89, 223522 2006





APPLIED PHYSICS LETTERS **88**, 081112 2006

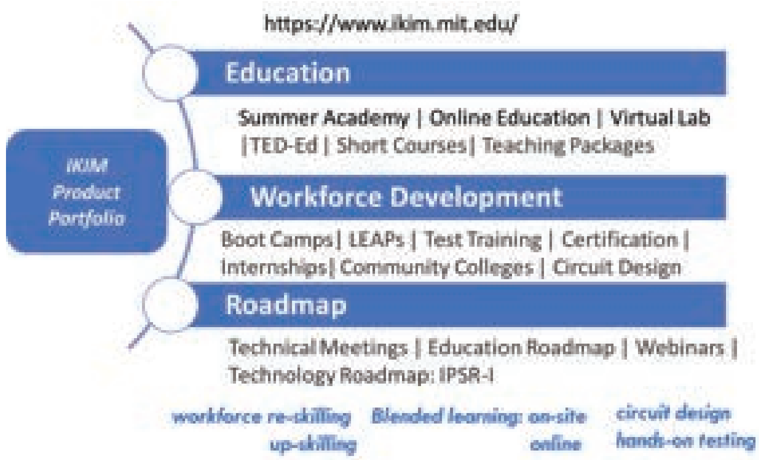


ACS Photonics 2019, 6, 1162−1167

R. Singh, MIT PhD thesis, 2020

Blended learning education and workforce development (EWD) - A three-legged stool approach: in-person/online courses, simulations, and hands-on labs

EWD Program Products

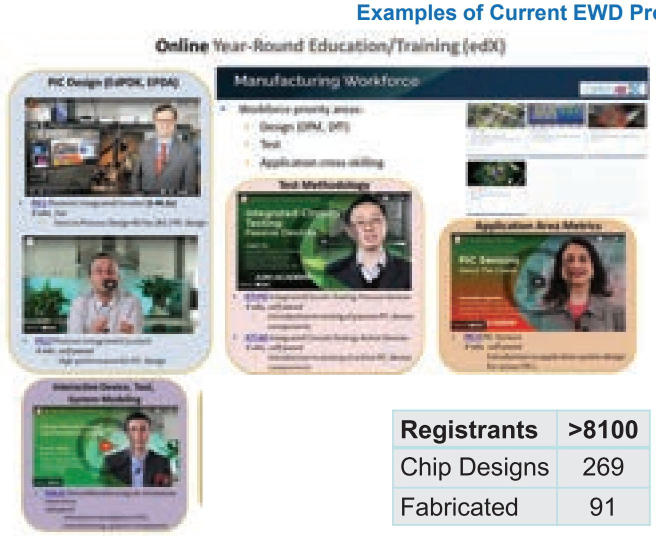


Virtual Reality based device and tool training

anu@mit.edu

5

Examples of Current EWD Products



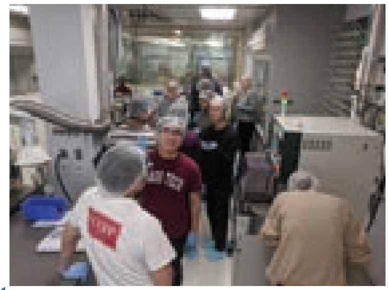
Continuing online education: 10 electronics and photonics manufacturing MOOC courses manufacturingworkforce.org

Registrants	>8100
Chip Designs	269
Fabricated	91

6

Hands-on Bootcamp

Packaging Teaching Lab

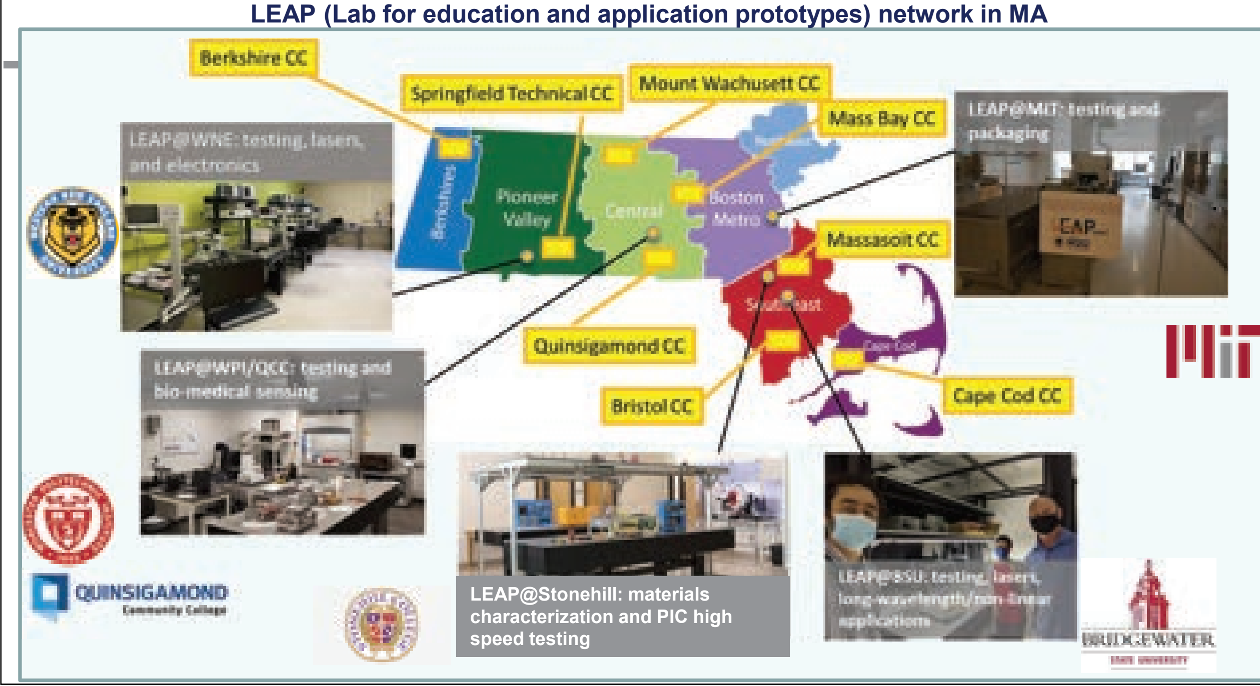


Education: Products and Content

- **Bootcamps**: EdChips, Package, Test - distributed across AIM Academy
- **Summer Academy**: intense 5-day training in design and fab
- **MOOCs**: 10 photonics manufacturing on-line courses on a manufacturing skills DoD platform manufacturingworkforce.org
- **Simulations**: VR/AR, factory floor tool simulators, e.g., die bonder
- **Teaching Packages**: lesson plan, slides, notes, questions
- **MA LEAP Network ($11M)**: application specific labs
- **Certification**: Technician Certificates, Internships and Apprenticeships
- **Roadmaps**: Technology, Education, and Workforce Roadmaps

7

A model for the dissemination of hands-on education through 4-year and community colleges: LEAP (Lab for education and application prototypes) network in MA



ALBRIGHT COLLEGE 1856

Jacquelyn S. Fetrow, Ph.D. '82
President, Albright College

- **Computational Biologist**
- **College-wide systems approach to Creativity and Innovation**
- **Interdisciplinary**
- **Entrepreneurial mindset**

Albright College…

ALBRIGHT COLLEGE 1856

- Albright College has a longstanding commitment of providing an excellent education to students of academic promise in a community where individual students engage their creative and innovative skills, enhance their ability to learn how to learn, to approach challenges from multiple perspectives, and to cross boundaries both in and outside of the classroom and make connections with intellectual confidence.
- By applying creativity and innovation across all disciplines and throughout each learning experience, both inside and outside of the classroom, Albright College helps students to know the world, engage the world, understand the world, and ultimately, to change the world.
- A community of students and faculty with an insatiable curiosity and desire to create and innovate in ways that make the world a better and more vibrant place
- A school with a distinctive approach to education:
    - Creativity and innovation inform and elevate how students learn, what they student and how they engage
    - Total Experience Learning: both at the K-12 level and the college level
    - Unique combinations of liberal arts and workforce ready majors so that s**tudents learn to learn** in the context of professional development

2

Albright College – rankings

ALBRIGHT COLLEGE 1856

Top College for Social Mobility
Albright College ranks among the top 32 national liberal arts colleges for social mobility according to U.S. News & World Report.

High ROI
College Scorecard shows that Albright College's 40-year return on investment (ROI) ranks in the top 17% of more than 4,500 institutions across the country, with graduates reaping a long-term net economic gain of $951,000 outpacing over 4500 non-profit, public and for-profit colleges in the study.

90% Acceptance to Medical School
Albright College's challenging curriculum and personal approach to education prepares students well for professional education in allopathic and osteopathic medical schools. Albright's acceptance rate is more than double the national average of 41%.

A Most Diverse College
Niche.com recognizes Albright College as one of the Most Diverse College in PA.

A "Best Value College"
Based on key statistics from the U.S. Department of Education, Albright College ranks among the Top 88 Best Value Colleges in PA.

3

TOTAL EXPERIENCE LEARNING

SRI ALBRIGHT COLLEGE
SCIENCE RESEARCH INSTITUTE

UNCOVERING THE GENIUS THAT RESIDES IN EVERY CHILD

Adelle L. Schade, M.S., M.Ed.

Dean, Pre-College and Summer Programs
Founder, Science Research Institute

- **Biomedical and Materials Science Research**
- **K to 12 learning and instructional model**
- **Personalization**
- **Innovation, Invention and Solutions-based Education**

WHAT IS…

SRI ALBRIGHT COLLEGE
SCIENCE RESEARCH INSTITUTE

Science Research Institute (SRI)	vs.	Total Experience Learning
Program title, Building or installation name		Instructional and learning model

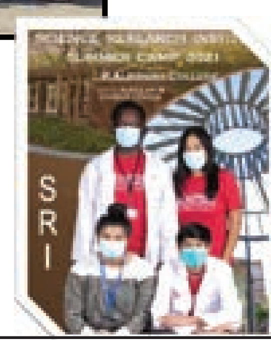
SRI ALBRIGHT COLLEGE
SCIENCE RESEARCH INSTITUTE

Student Programming

- After-school programs
- Summer programs
- During school- Academies
- Dual Enrollment

Educator and Administrator Programming

- 4 Graduate Courses
- Certificate and M.A./M.S. degree in Educational Innovation and Entrepreneurship
- Professional Development
- Affiliate schools



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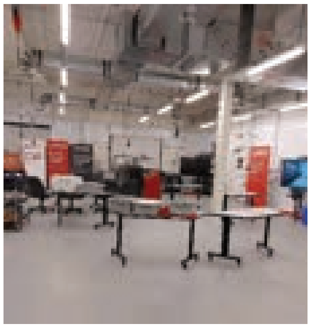
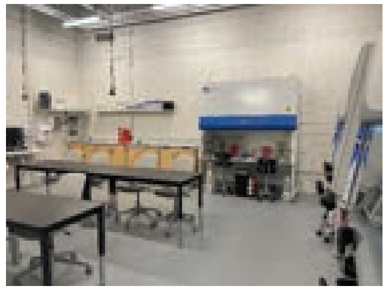
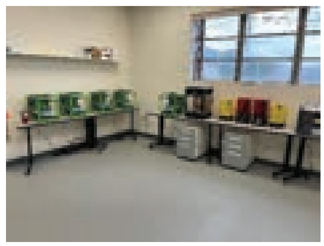
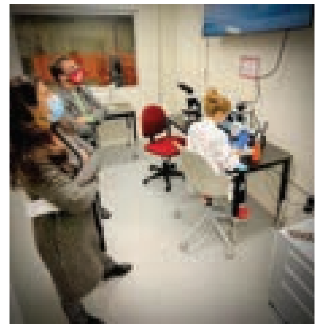
1041 Rockland St., Reading, PA 19604









TOTAL EXPERIENCE LEARNING

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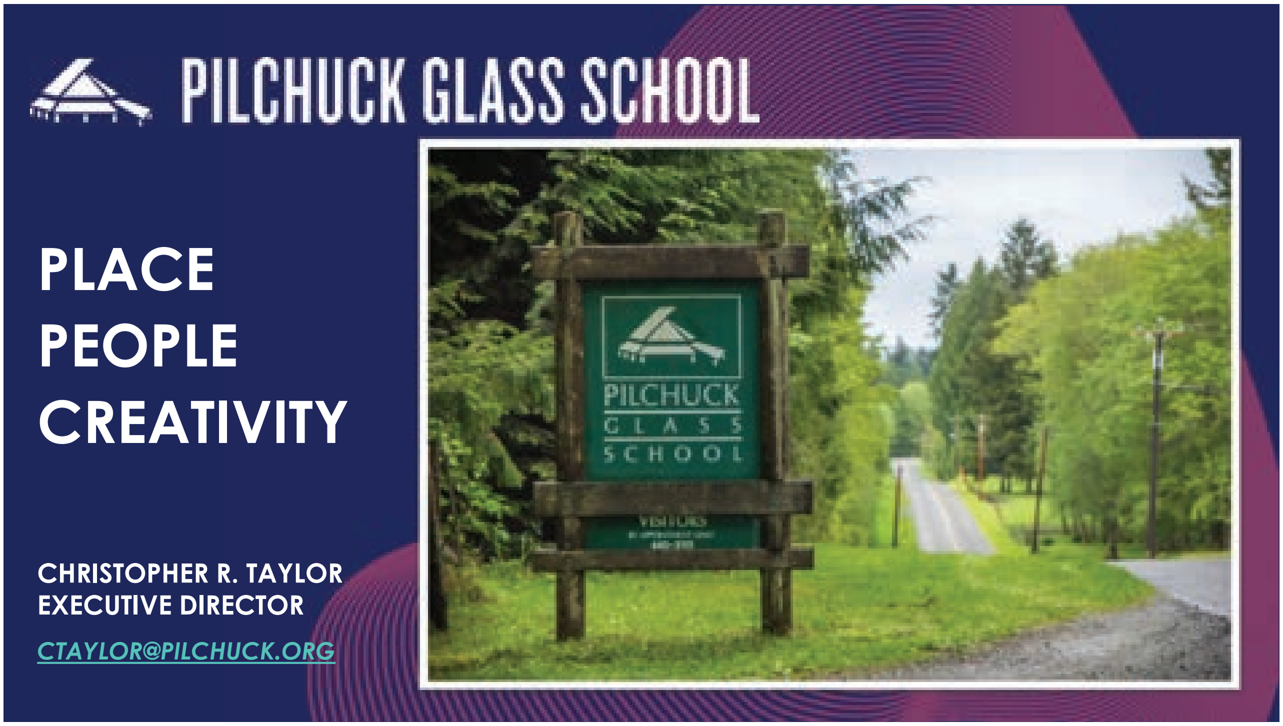
UNCOVERING THE GENIUS THAT RESIDES IN EVERY CHILD


PILCHUCK GLASS SCHOOL
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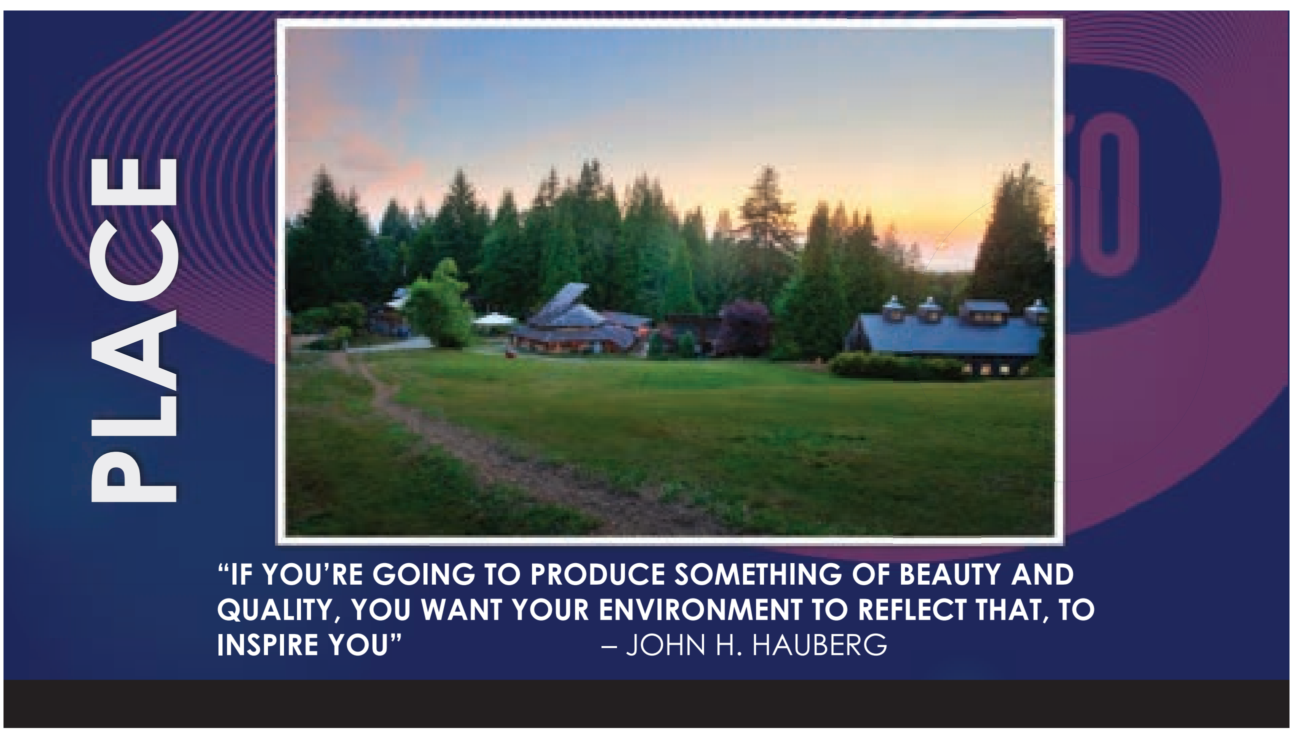

PLACE
"IF YOU'RE GOING TO PRODUCE SOMETHING OF BEAUTY AND QUALITY, YOU WANT YOUR ENVIRONMENT TO REFLECT THAT, TO INSPIRE YOU"
– JOHN H. HAUBERG

Historic Lodge and Hotshop on Campus

Group Photo at Pilchuck's 25th Anniversary

L-R: Ginny Ruffner, Preston Singletary, Dante Marioni, Lino Tagliapietra

What happens at Pilchuck…

- Immersive Experience
- Artists teaching artists
- Experimentation & preservation of techniques
- Infusion of non-glass artist & artists
- Blowing, Molds, Neon, Casting, Carving, Performance, Printmaking
- New Technologies explored
- New outreach programming coming online
- Daily artist slide talks

…goes around the world and back

LEADING THE FUTURE OF GLASS ART EDUCATION

Continue to introduce mixed media and newest technologies

Advance Diversity Equity Access and Inclusion (DEAI) in the field

Employ more environmentally sustainable practices

Continue to steward our historic campus

Engage an ever-widening network of innovation

On the Shoulders of Giants

Arun K. Varshneya
Alfred University &
Saxon Glass Technologies Inc, Alfred NY

L. David Pye
Alfred University, Alfred NY

Charles R. Kurkjian
Rutgers the State University

Over the five millennia, glass as a material has provided innumerous products that improve quality of human living.

No doubt, much of the underlying science, engineering, technology and arts have been developed by individuals whose ingenuity and hard work paved the way. We stand on the shoulders of these Giants.

In this International Year of Glass, we celebrate those US-based glass pioneers who are no longer among us, however, whose legacy lives on.

GLASS SCIENTISTS, ENGINEERS & TECHNOLOGISTS

W. H. Zachariasen (US resident-Atomic arrangements in glass 1932)
B. E. Warren (XRD of glasses)
David Turnbull (kinetic theory of glass formation)
George W. Morey (phase equilibria in SLS and other glass systems)
Arthur Quincy Tool (fictive temperature theory)
Phillip W. Anderson/ John H. Van Vlack (electronic conduction in disordered solids)
S. Don Stookey (Glass-ceramics, 60 patents; “legendary scientist”)
Sheldon M. Wiederhorn (strength of glass)
Stan R. Ovshinsky (400 patents; amorphous semiconductors)
Gordon Scott Fulcher (“Glass hero”: Viscosity vs Temp relationship)
Michael J. Owens (bottle machine)
William J. Woods (design concept Ribbon machine 1926)
Larry L. Hench (bioglass)
Robert A. Weeks (Radiation effects on glass)
J. Douglas Mackenzie (Founder of J. Non-Cryst. Sol)
H. N. Ritland (challenger to single fictive temperature theory)
Nobert J. Kreidl (mentor to Uhlmann, Schultz, Delbert Day, David Pye)
Alfred R. Cooper (mathematical descriptions of glass technology processes; mentor to Varshneya)
Robert H. Doremus (Water in glass)

GLASS ARTISTS

Louis Comfort Tiffany
John La Farge
Frederick Carder
Howard Ben Tre’

William ("Willie") Houlder Zachariasen (1906-1979)

Norwegian-American physicist specializing in x-ray crystallograhy.

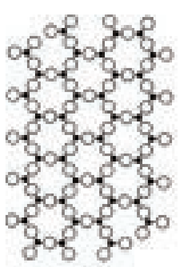
Published his solo authored paper at age 19 at Univ of Oslo.

Received PhD in physics (advisor Victor Goldschmidt) from Univ of Oslo in 1928 as the youngest ever.

Became faculty member at the University of Chicago physics dept in 1930 (at age 24) becoming chair 1945-1950 and again in 1955-1959.

Published over 200 papers over a span of 55 years, most were solo-authored.

We know Zachariasen for his rules of glass formation for an oxide A_mO_n:



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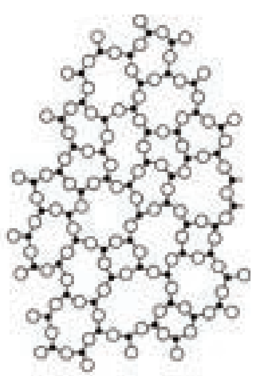


(b)

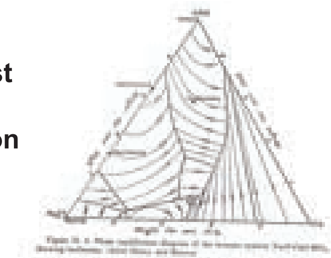
1932 publication (at the age of 26) entitled,

"The Atomic Arrangement in Glass" in The J. Amer. Chem. Soc.

The single most influential paper in all of glass science in terms of our thinking about the structure of glass.

He became US citizen in 1941. Married in 1930 and had two sons. Zachariasen retired in 1974 in Santa Fe NM.

George Washington Morey (1888-1965)



American geochemist, mineralogist, petrologist
1909 BS (chemistry) from Univ of Minnesota
Joined Geophysical Labs in Carnegie Institution Washington DC
(1912) till his retirement in 1955.
Involved in glassmaking projects for military equipment such as rangefinders and gunsights

Groundbreaking (earth-shattering) 1925 paper on phase relationships in soda-lime-silicate glasses co-authored with NL Bowen. (Trans Soc Glass Tech).
Melting behavior of glass, devitrification-temperature relationships were understood.
1938 "Properties of Glass" (most popular glass book of the 1960's)
1939 Doctorate *honoris causa* from Alfred University
George Morey Award of the Glass & Optical Materials Division of the American Ceramic Society

Visitors to his home admired his kitchen garden depicting Soda-lime-silica phase diagram using different colored flower arrangements

Stanford Robert Ovshinsky (1922-2012)

Founder of "Energy Conversion Devices, Inc. in 1964"
Prolific inventor.
Over 50 years, he received more than 400 granted patents.
Semiconduction and dielectric behavior of chalcogenide glass and amorphous solids.
Inventor of devices based on conduction switching from low to high mode.

Revolutionized energy and information technologies.
From batteries, solar cells, to LCD, fuel cells and phase-change memory devices "*ovonics*"). Subsequent miniaturization of computers.

Throughout his life, he fought for social justice, specially for minority groups.
In 1999, *TIME* Magazine called him "Hero for the Planet".
He was a high school dropout.

Michael Joseph Owens (1859-1923)

Born in West Virginia. At age 9, he dropped out from school and joined father working in coal mines.

Injury to eye forced him to seek apprenticeship in 1988 at JH Hobbs Brockunier glass factory in Wheeling WV where children made up ¼ of the workforce.

Got a job at Edward Libbey's Toledo Glass factory in Toledo OH.

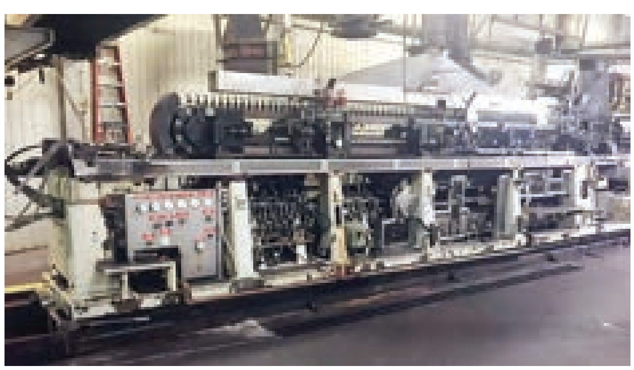
Invented an automatic glass bottle making machine and founded Owens Bottle Machine Company in 1903.

Machine could make 30-35 bottles/minute which revolutionized glass bottle-making. As a result, beer could be sold a lot less expensively.
It is said, Owens' bottle making machine changed the world.
By displacing men and children from the hard task of using lungs to inflate molten glass gob to make bottles in smokey environment, he must have saved hundreds of thousands of human lives.
Owens Bottle Machine Company is now part of Owens-Illinois.

William James Woods (1879-1937)

Ribbon machine for making light bulbs conceived in 1921, at Corning Glass Works
Brought into action 1926. Wellsboro PA
Produced 300 light bulbs per minute.
At its peak of its development, it produced 2000 bulbs per minute.

The ribbon machine brought Edison's light bulb to the world.
American Society of Mechanical Engineers LANDMARKS #81



Larry L. Hench (1938-2015)

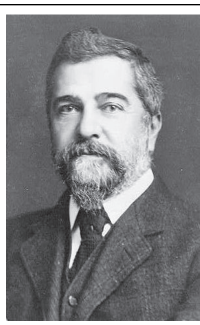
1969 Inventor of Bioglass 45S5
$Na_2O–CaO–P_2O_5–SiO_2$
Bioactive.

Existing issue: Rejection of most other materials by biofluids; non-bonding
When implanted, Bioglass reacts with the surrounding fluid causing the formation of a hydroxyl carbonated apatite (HCA) layer at the material surface which promotes integration with bone.

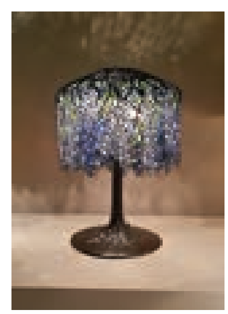
Bioglass commercial applications: bone repair, dental restoration, enamel-healing toothpaste.
Many applications are FDA approved.
PhD from Ohio State University 1964
Professor at University of Florida, Imperial College London and Florida Institute of Technology

800 Publications; 32 US patents, 30 books including
“Boing Boing, the Bionic Cat” (set of 6)

Several international awards of high acclaim
Distinguished Life member of the ACerS
Founder and past president of the Society of Biomaterials
National Academy Engineering
World Academy of Ceramics

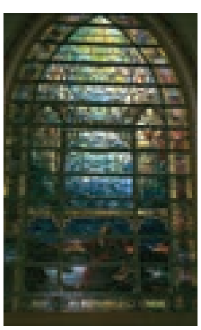


Louis Comfort Tiffany (1848-1933)



Started out as a painter but became a glass artist around 1875.
In 1878 he joined Candace Wheeler, Samuel Colman, and Lockwood de Forest to form Louis Comfort Tiffany and Associated American Artists.
In 1881, Tiffany did interior design for Mark Twain’s house.

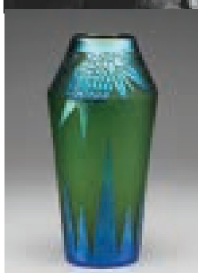
Commissioned to redecorate the White House in 1882 such that President Chester Allan Arthur would move into it. (All removed by Roosevelt in 1902).

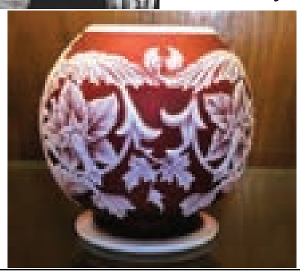


In 1893, Tiffany founded Stourbridge Glass Company, later call Tiffany Glass Furnaces.
In 1902 he became Design Director for his father’s company Tiffany & Co.
Tiffany designed stained glass windows and lamps, glass mosaics, blown glass, ceramics, jewellery , enamels, and metalwork

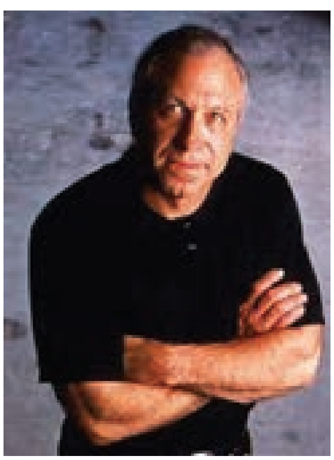
Frederick Carder (1863-1963)

Born in England.
Quit school at early age to work at his father's pottery factory.
Enrolled in night classes at School of Art, Stourbridge to study art, chemistry, metallurgy and electricity.
Started making glass art for Stevens and Williams.
Moved to the US in 1903 to become manager of Steuben Glass Works in Corning.
Designed more than 6000 glass objects in 140 colors for dinnerware as well as decoration over 80 years.
On his 100th birthday, he received greetings from President Kennedy, Queen Elizabeth, and Gov Rockefeller.





Howard Ben Tre' (1949 – 2020)



In 1960's he attended Brooklyn College for two years.
Portland State University in 1970s. BS
Learned to blow glass; Also learned to pour glass
Dale Chihuly recruited him in 1980 to join Rhode Island School of design. MS degree.
He was a political activist

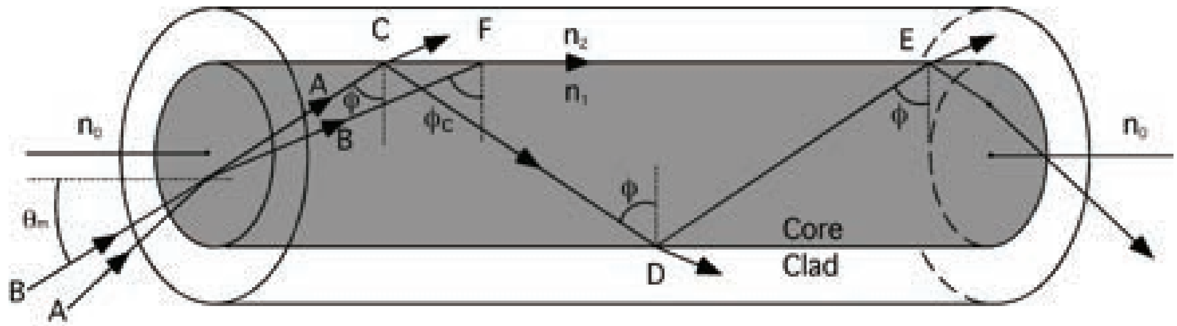
Beautification of decaying urban landscape

Outdoor large scale cast glass art; glass-bronze

Glass had to withstand diurnal temperature changes, UV rays from the sun, and have high chemical durability.

Post Office Square Boston.
The glass engineer was Varshneya

Reflections on Glass



Telecommunication using an optical glass fiber. Internal reflections at the core-clad interface greatly increase percent transmission across miles. *After F. L. Pedrotti and L. S. Pedrotti. Introduction to Optics. Prentice Hall Inc. 1987. Figure 10.1, p. 215.*

"Pillars of Humanity" Installed in Toledo OH during Stained Glass Association of America Conference for IYoG. _ Photo credit Kyle J Mickelson. Courtesy of the Stained Glass Association of America

Coe College

Reflections in Glass

I cannot think of a more fulfilling research career than one that involves researching glass. One can provide many scientific reasons for this bold statement. Glass is one of the few great puzzles remaining in solid-state physics. Its long-term behavior—perhaps its eventual death at the hands of crystallization—is a subject of enormous interest. Glass' unfathomable ability to change properties when doped with a myriad of elements leaves the door open to many experiments and discoveries. But all of these reasons also leave out something quite evident that was strongly highlighted during the National Day of Glass. It is easy to love glass. Why? Not many materials in the history of humanity have engendered the kinds of emotions that glass has. From the spiritual solemnity created by stained glass windows in churches and cathedrals to our many daily feelings as we parse news and messages on our cellphone displays, glass has a way to connect with us. As our art colleague, Narcissus Quagliata, reminded us, glass has a way of painting the world with light.

Let me add one final thought. As a material, glass is unparalleled in its application to science, technology, art, and daily life. But it is also a perfect vehicle for drawing young students into materials science. Semiconductors and single crystals require a fair amount of skill to make them properly. But manufacturing glass samples can be taught to young students, and they can become quite capable at this task. I have seen their eyes light up when they show their professors and peers their first glass sample, just out of a very hot furnace. And then they take *their* sample—with pride—to be measured. Again, not many materials can elicit that personal connection. Add to that the long history of glass—attractive to laypeople and historians alike—and this material has universal appeal. I count myself blessed to be a part of this research enterprise and community.

Dr. Mario Affatigato,
Fran Allison and Francis Halpin Professor of Physics
April 15, 2022

Prof. Mario Affatigato obtained his undergraduate degree from Coe College in 1989, followed by his Ph.D. from Vanderbilt University in 1995. His research focuses on investigating the relationship between the optical properties and structure of glassy materials. He has worked with over 120 undergraduates in projects that include laser-induced modification, bactericidal glass composites, and exotic manufacturing methods like aerolevitation. His research primarily deals with oxide glasses, especially vanadates, borates, and samples with heavy metals. Prof. Affatigato is a past recipient of the APS Prize for Research at an Undergraduate Institution, a PECASE award from the National Science Foundation (NSF), and other research grants in support of his work. He is a fellow of the American Ceramic Society, the UK Society of Glass Technology, and a Research Corporation Cottrell Scholar. Currently, he is the Editor in Chief of the *International Journal of Applied Glass Science*.

Through the looking glass… and through optical fiber

At the time of writing this reflection, I have been privileged to have spent over 30 years developing novel compositions and processing approaches for some of the most advanced optical fibers realized to date. To me, the beauty of this specific field is that the properties and the performance of an optical fiber are based both on the glass from which the fiber is made AND its waveguiding design. The glass core and clad can enable effects that the design cannot and vice versa. Further, optical fibers are both mature technologies, as witnessed by the billions of kilometers of fibers through which all modern data communications course, and "living" laboratories through which we learn something new about light-matter interactions every day.

I hope that my contributions to glass science and its benefits to civilization will be in opening up the richness of the Periodic Table to the world of optical fibers so that they can be even more impactful than they already are. Ultimately, material science is about composition, structure, processing, and property inter-relationships and my work has brought these tools to bear on optical fibers and their applications.

For future readers of this Reflection, I would add that you are standing on the shoulders of Giants and that all the past research on glass has led to its present utility. Many of those Giants grew under the professional nurturing of the American Ceramic Society (ACerS) and its Glass and Optical Materials Division, this my professional home for over 30 years and, hopefully, for another 30 years. In an age where it is easy to do things remotely, never under-value the importance of professional societies and face-to-face meetings. And among all the possible options, there is and has always been something special about ACerS, its staff and its membership whose musings you are now reading in this National Day of Glass Commemorative Book.

John Ballato is a professor of materials science and engineering at Clemson University, where he also holds the J. E. Sirrine Endowed Chair in Optical Fiber. He has published nearly 500 technical papers and holds 34 U.S. and foreign patents. Among numerous other honors, he is a Fellow of ACerS, AAAS, IEEE, APS, Optica (formerly OSA), and the SPIE. He has received numerous ACerS awards including the George W. Morey Award (2022), the Arthur L. Friedberg Ceramics Engineering Award (2014), the Richard M. Fulrath Award (2010), and the Schwartzwalder-PACE Award (2004).

John Ballato

March 23, 2022

DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING
Clemson University, Clemson, SC 29634 USA
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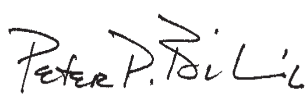
Reflections on Glass

Peter P. Bihuniak

I have been a senior operating and technology executive with extensive global experience in general management and technical leadership in the renewable energy, glass, and inorganic materials industries. I led several technical organizations, ran a glass business and directed market development of specialty materials. I am currently principal with Hidden Point Consulting LLC, providing general and technical management consulting services to a diverse list of clients including industrial products firms, business start-ups, and universities.

I began my career at Corning, Inc. in basic and applied R&D, concentrating on specialty glasses, synthetic fused silica and processing of fiber optics. At Corning I developed a passion for glass research and, with strong support from my manager, Peter Schultz, pursued my PhD at Alfred University while working full time. Glass technology further defined my career as I transitioned to technology management at GE Lighting, focusing on high purity Fused Quartz glasses for semiconductor and fiber optic processing. Fused Quartz crucibles are used in the manufacture of single crystal Silicon, and fused quartz tubing is used as inert, high temperature furniture for the processing of Silicon into chips and also for the manufacture of fiber optics. At PPG I led the specialty glass business which employed unique vacuum refining. My early career in glass proved invaluable preparation for my role as an early contributor in the solar energy space with key leadership roles as VP of Technology for BP Solar, Managing Director of ASI Industries, GmbH, a manufacturer of single crystal silicon wafers for the PV industry and CTO of GT Solar, a manufacturer of multicrystalline Silicon ingot furnaces. While it has taken several decades for the solar industry to become significant, the early leadership, discipline and personnel development I provided was a significant factor in making it a viable alternative energy source of which I am quite proud.



May 16, 2022

UNIVERSITY OF Cincinnati

Department of Electrical Engineering & Computing Systems
Solid State Physics and Electronic Materials Laboratory
University of Cincinnati
PO Box 210030
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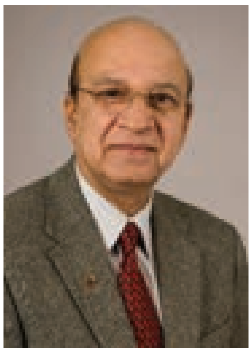
Fax (513) 556-7326



Reflections on Glass: Glasses are non-equilibrium solids and continue to relax with time once synthesized by a water quench, posing challenges to applications. In 1998, one discovered that self-organized glassy networks composed of isostatically rigid local structures form part of Intermediate Phases (IPs) in which network relaxation is qualitatively suppressed- opening a key to applications. Window or soda-lime-silicate glasses at select compositions form a self-organized glass that has shaped human civilization since Christ, although its self-organized nature was recognized more recently. A plethora of flat panel displays including Gorilla glass, have been synthesized as examples.

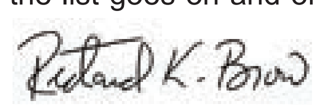
Synthesis of chalcogenide and modified oxides show that their melts undergo delayed homogenization. A new method of ex-situ FT-Raman profiling of melts/glasses was introduced to quantitatively characterize the underlying kinetics by recording observed spectra along the length of a melt column until the observed line-shapes became identical as alloying proceeded. Results show that the kinetics of homogenization are the slowest for the self-organized Intermediate Phase (IP) and mildly increase as one goes away from the IP into either the flexible or stressed-rigid melts. The measured melt fragility index (m), see J. Alloys and Compounds 895 (2022)162645, in such homogenized melts shows a Gaussian-like global minimum of m = 15 near the IP center underscoring the super-strong nature of IP melts.

Boolchand was born in 1944, in Varanasi, India. He migrated to the US in 1965 and received his Ph.D. in Physics from Case Western Reserve, Cleveland, OH, in 1969. He joined University of Cincinnati in 1969 to eventually become Professor of Electrical Engineering and Computer Science and Physics. He discovered the IP: an elastically percolative network glass distinguished from traditional (clustered) liquid–gas spinodals by strong non-local long-range interactions. His experimental data over a 40-year period (1982–2022) formed the basis for the theory of network glasses developed by James Charles Phillips and Michael Thorpe and refined in MD simulations by Matthieu Micoulaut and Mathieu Bauchy.

Yours sincerely

Punit Boolchand
Distinguished University Research Professor (STEMM)
Fellow, American Physical Society
boolchp@ucmail.uc.edu;
Website https://eecs.ceas.uc.edu/~boolchp/
Biography: https://en.wikipedia.org/wiki/Punit_Boolchand

Reflections from a Glass Guy. In September 1978, in a classroom on the third floor of McMahon Hall at Alfred University, **Harrie Stevens** started me on a path that I have been following ever since. His class, “Introduction to Glass Science” (CES302- I still have my notebook), introduced me to the mysterious connections between the compositions, properties, and molecular-level structures of oxide glasses, and understanding those connections to design glasses for various applications have been what I’ve had the good fortune to be doing since then. I have had many guides along the way- undergraduate courses by **Helmut Schaeffer** and **Bill LaCourse** reinforced my glass-centric world view, and having Bill as a research advisor, for both my senior thesis (glass corrosion) and my MS degree (surface dealkalization) made me realize that glass research was fun. **Bob Eagan** convinced Bill to let me work with **Jeff Brinker** at Sandia National Labs for a summer in 1981, and that experience really broadened my perspective on where a research career could lead, and **Carlo Pantano** showed me how to be a competent glass scientist. (I am delighted to be Carlo’s first PhD.) Twelve years at Sandia gave me the opportunity to work with world-class glass scientists like **Ron Loehman**, **Bruce Bunker**, and **Terry Michalske**, to work on cool projects, including glasses that have left our solar system (as part of Voyager I’s power supply) and are in millions of pacemakers. Bob Eagan helped me get involved with the American Ceramic Society, where mentors like **Joe Simmons** and **Chuck Kurkjian** welcomed me to this marvelous community. I grew up as a professional in GOMD with so many colleagues I admire: **Denise Krol**, **Steve Martin**, **Kathleen Richardson**, **John Kieffer, Alix Clare**, **Alastair Cormack**, too many to name. At Sandia, I got to know **Norbert Kreidl**, who paid me the greatest compliment I’ve ever received as a glass scientist when he called me at home after work and said that he just read my latest JACerS paper and that he “learned three new things from it.” I also got to know **Delbert Day** when he spent a sabbatical in my lab, and in 1997, Delbert convinced **Theresa McCarthy Brow** (a pretty good glass scientist in her own right) and me to move to Rolla, MO, a decision we never regretted. Better than anyone I know, Delbert can apply insights from his understanding of glass science to develop novel technologies that solve hard problems, an ability that I’m still trying to develop. At Missouri S&T, I had the opportunity to develop collaborations and friendships with glass scientists from around the world, **Edgar Zanotto**, **Leena Hupa**, **Alicia Duran**, **Wenhai Huang,** and so many others. With **Carol Click**, my first PhD, I got to work with **Jack Campbell** and **Tayyab Suratwala** (LLNL) on their phosphate laser amplifier glass, and then I got to see Carol, now at Corning, help develop the scratch-resistant glass-ceramic now covering the latest iPhones. My students and I have had to chance to work on other phosphate and borophosphate glasses, for applications that range from immobilizing radioactive wastes to regenerating muscle tissue, and to learn from colleagues in the small but vibrant phosphate glass community, including **Uwe Hoppe**, **Ladislav Koudelka**, **Akira Saitoh**, **SW Yung**, **Doris Ehrt, Lionel Montagne**, **Randy Youngman**, the list goes on and on. My heartfelt thanks to everyone for including me in what you do.



Reflections on Glass

Tod Canty PE

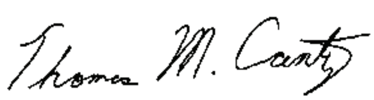
J.M. Canty Inc. Lockport, New York 14094

Canty has developed several unique systems to help in the production of glass that have never been achieved before. This includes a camera to measure Molten level within one-thousandths of an inch from 20 ft away. This makes the thickness much more repeatable allowing for less material in each item whether it is Float Glass -windowpanes, Bottles Glass or Fiber Glass. In addition, we have developed imaging High Temperature Vision cameras that require 90% less air thus reducing the energy consumption and increasing the reliability of the camera imaging. This is then used to control melt line, width and knurl, fiber thickness and speed, Glass gob size, shape and temperature. Our latest advancement is automating the float glass and to make the process much more accurate with imaging sensors and software than any operator's eye.

My passion is automating processes in the Glass industry that have never been done before.

I am a professional Engineer with a BS in Mechanical Engineering and an MBA in Finance. I developed the 1st camera/light for viewing inside of a Chemical reactor which was patented in the 1990s. I am listed as inventor or coinventor on over 22 US patents and several EU patents.

Our young people need to invest their time and energy into long term growth in their industry of choice. The job changeover that is taking place and remote office doesn't advance their professional skills as much as hands on collaboration with experience engineers. There is an intrinsic value in that which benefits employee and company.



Reflections on Glass

Shangcong Cheng

By training, I am not a glass scientist. I am a transmission electron microscopist with a background in physics. Since I started working in the electron microscope lab of Penn State in 1996, then in Corning Inc. in 1999, and today in Lawrence Berkeley National Laboratory (LBNL) as a guest scientist, I have engaged in and became more and more interested in glass science.

Because of my background, I used to work on projects related to crystal materials such as metals, alloys, etc., but not glasses. This was until I met distinguished professor Carlo Pantano in Penn State. Carlo showed me several exciting projects and challenging problems in glass science. I then realized the importance of glass research and its need for various characterization tools. As a result of working with Carlo and his associates I realized that the key to actual TEM application in glass research is not to improve the resolution of the instruments but to find the proper way to prepare thin glass specimens and to avoid artifacts caused by the high-energy electron radiations. I also realized that the valence state and coordination of elements in the glass network structure play crucial roles in the optical and other properties of glasses. The electronic structure of glasses can be investigated by using electron energy loss spectroscopy (EELS). Previously, I studied EELS under the supervision of Prof. R. Egerton, a world-leading scientist in this field, and have gained a strong background in it. EELS can be used for both crystal and amorphous materials. At Penn State, I had a chance to study the interface structure between the glass substrate and thin films, Carbon bonding in C-doped silica glass, and other interesting projects.

At Corning Inc. I continued studying glasses and related materials. Corning Inc. is a manufacturing company with an academic atmosphere, where using new techniques to solve problems is greatly encouraged. The use of EELS to study the absorption edge of fused silica is one example. How to make fused silica glass with high transmission in the ultraviolet is practically vital to optical components in photolithography. It is believed that metallic impurities, hydrides, and certain intrinsic defects affect the transmission ability of silica glass. But how the cooling and annealing process influence the transmission is not clear. In our project, we used EELS to measure the slope of the Urbach absorption edge of glass, which is related to the disorder of the glass structure and transmission in the ultraviolet. We found that the structural disorder in silica glass and the transmission coefficient correlate with cooling conditions. The results are beneficial for improving optical products and also serve as motivation for further study of fused silica structure.

The further questions are, what is the order and disorder structures in silica glass? Since thermal treatments influence the silica structure, when is the order structure formed in the process? These questions are more fundamental and may relate to the nature of the glass state and the glass transition.

I was still interested in these questions after retiring from Corning Inc. about ten years ago. Fortunately, LBNL accepted my research proposals and provided support for my projects. I have proposed a medium-range ordering structure for fused silica and applied it to explain several glass properties. I hope the results will improve our understanding of the long-standing question concerning the nature of glass state and glass transition. *Shangcong Cheng*

THE OHIO STATE UNIVERSITY

College of Engineering
Department of Materials Science and Engineering

Reflections on a Career in Glass Science & Technology

Manoj K. Choudhary, The Ohio State University, Columbus, Ohio

I opted for a career in glass science & technology after the completion of my educational training in Chemical Engineering (ChE) and Materials Science & Engineering (MSE). Inquisitiveness and "knowledge entrepreneurship" had made me go from ChE for B.S. and M.S. to MSE for Sc.D. These same attributes prompted me to explore a career in glass science and technology instead of metallurgy. Specifically, my doctoral and post-doctoral research on electromagnetic processing of materials with late Prof. Julian Szekely of MIT and, through him, some consulting work for the glass industry led me to think that the application of transport phenomena and computational fluid dynamics (CFD) to industrial glass melting processes held great potential for productivity and energy efficiency advancements. So, with Prof. Szekely's blessings, I joined Owens Corning (OC) in 1982 and retired from there in 2018.

At OC, I worked in glass melting and forming areas and was involved in development and optimization of numerous glass fiber containing products, especially in the fiberglass insulation area, and did extensive teaching both inside and outside of OC. I also led several organizations including the International Commission on Glass (ICG), Center for Glass Research at Alfred University, the Glass and Optical Materials Division of the American Ceramic Society, and the Glass Manufacturing Industry Council, of which I was also a founder. After retiring from OC, I became an adjunct professor at the Ohio State University.

My exploratory foray into glass science and technology became a long and committed relationship with glass and the glass community. This happened because the more I learned about glass, the more fascinated I became by its versatility, its combination of beauty and utility, and the collegiality of the glass community. I am especially proud that all my major projects at OC were related to sustainability topics such as reducing energy intensity of processes, reducing / eliminating environmental emissions, reducing waste, and prolonging furnace life in process areas and developing energy savings products and applications. I was also involved in developing a new polymeric foam insulation and the extrusion technology platform that eliminated the use of ozone depleting compounds. I feel honored that I lead several prominent glass organizations and played an important role in the UN International Year of Glass (IYOG) from the exploratory stage to being the Chair of the North American Steering Committee for IYOG.

In "Reflections" the reflector is expected to distill his/her experience and offer some words of wisdom for younger colleagues. In that spirit, my advice is to be a lifelong learner, an explorer, a multi-disciplinarian, and humble in recognition that our knowledge pales in comparison to our ignorance. Above all follow the golden rule.

Manoj Choudhary March 30, 2022

Reflections on Glass

My journey into and through glass science began when I took up a faculty position at Alfred University's New York State College of Ceramics. As an undergraduate at Cambridge University, I had become interested in crystals, pursuing courses in mineralogy and crystallography (amongst others). I extended this interest to solid state chemistry more generally, as a graduate student at the University College of Wales, Aberystwyth. Then, moving to University College London as a post-doctoral Research Associate, I traded experiments for atomistic computer simulations. That was in the very early days of the field, when many of its applications we now take for granted were still being explored. A key realization was that the simulations could be used to predict, or, more accurately, refine, crystal structures through the process of energy minimization.

On arriving at Alfred, I was introduced to a whole new class of inorganic materials, namely glasses, and was soon applying atomistic simulations, with the (then) state-of-the-art interatomic potentials, to develop, systematically, structural models of alkali silicate glasses. With support from the newly formed Center for Glass Research, the range of compositions expanded to aluminosilicates, and then, structurally, to glass surfaces; later on, silica fibers were modelled.

With my crystallographic and solid-state chemistry background, the urge to relate properties to structure was strong; the computer simulations were an ideal tool with which to explore this composition-property-structure space. A key development was to the simulations of multi-component bioactive glasses. This work expanded into bioactive glass surfaces and then to modelling the reactivity of these (and other) glasses with water. What we have been able to contribute over the years is a much deeper understanding of the atomic structure adopted by inorganic glasses and how that structure (and resulting properties) changes with composition.

The field of computer simulations, and more specifically atomistic simulations, is now well-established and seen as symbiotic to experiments. This was certainly not the case when I started!

My advice to young scientists is to follow your passion (which may take a while to discover!) Don't be deterred from going where it takes you, even if into uncharted territory. Shakespeare wrote that tides taken at the flood lead on to fortune, but if omitted, result in miseries.

Alastair N. Cormack
Alfred, NY, USA, June 2022

UNIVERSITY of NORTH TEXAS
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Department of Materials Science and Engineering

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Glass: a window to the future

April 6, 2022

Dear Friends of Glass,

It is with great pleasure to write this letter to you to commemorate the US National Day of Glass and in celebration of the designation of 2022 as the International Year of Glass by the UN. For us who work in the field of glass science and engineering, this is a tremendous recognition from the world on the subject we think, work, model, and study almost every day. It is with great joy and pride to see many of the celebrations from academics, research labs and industry, to museums and art galleries around the world. All of these are because glass as a material has brought transformative changes to our lives. As an ancient, yet still very young material, glass has brought us numerous positive impacts. We cannot imagine to live in a world without window, or optical fiber communication, or computer screen, or touch screens of electronic devices. Furthermore, *glass is indeed a window to the future and future technologies*, for example, from biomedicine, virtual reality, to quantum computing.

This year also marks the 30th years since I first got to know glass science when I started my MS study on chalcogenide glasses with *Prof. Xiujian Zhao* at Wuhan University of Technology. Subsequently, I came to Alfred University to pursue my doctoral degree during which applied molecular dynamics simulations to study glass and glass surfaces under the guidance of *Prof. Alastair Cormack*. During my postdoc time at Pacific Northwest National Lab, I worked on modeling glasses for nuclear waste disposal with *Dr. Rene Corrales*. Working with these great glass scientists have prepared me for my current job as a professor and motivated me to continue my dream in glass. When my first NSF grant on bioactive glass was awarded in 2009 while I was a still junior faculty at UNT, the local news paper wrote a piece on the front page on the award with a title: "*Glass: window to the future*".

I still remember one fall night during my graduate studies, coming out of the lab, I saw a beautiful night sky with many stars. While walking alone on the quiet campus trail back to my dorm with fall insects singing in the night, I could not help to think the stars in the sky as the atoms of a glass. They look random but with certain patterns, as the constellations of stars, as local and medium structure orders in glass from my simulations. Like the stars and space, there are also infinite possibilities in glass structures and their applications. Every time I look up in the night sky, I cannot help to think of the fall night and link it with the favorite material and topic of my research: glass and glass science. I hope you find your way to be inspired and continue to explore the beauty and infinite possibilities in glass, *the window to the future*.

Sincerely,

Jincheng Du, Ph.D.
Professor of Mater. Sci. & Eng.

Dr. Jincheng Du is a Professor at University of North Texas. He received Ph.D. in ceramic science from Alfred University. Dr. Du's research focuses on atomistic simulations of glass structure and structural origin of various properties and their functional applications. He has published 2 books and ~200 papers. He is Chair of TC27 Atomistic simulation of ICG and is past Chair of the Glass and Optical Materials Division of ACerS. He is an elected Fellow of ACerS and Fellow of ASM International. He is a recipient of the W.E.S Turner Award of ICG, Fulbright US Scholar award, Gordon Fulcher Distinguished Scholar of Corning Inc.

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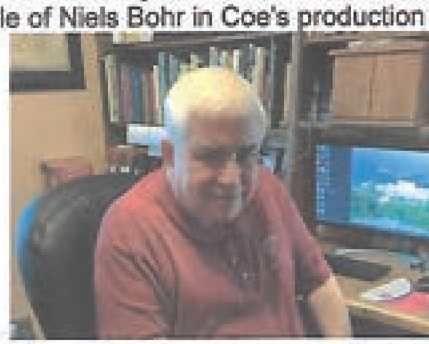
Reflections of Steve Feller, a Lucky Physics Professor Proud of My Students

To paraphrase baseball great Lou Gehrig, today I consider myself the luckiest professor on the face of the Earth. I was lucky to work with Phil Bray at Brown University, pioneer of using nuclear magnetic resonance (NMR) to study glass. I've been lucky to work for 43 years with over 400 students at Coe College on glass. They have gone beyond what I imagined when I came to Coe in 1979. I am proud of each of them. I've been lucky to have the support of my family including my wife Barbara, daughters Heidi and Ray, my four grandchildren and my sons-in-law Howard and Michael. I've been lucky to work with colleagues Mario Affatigato, Ugur Akgun, Caio Bragatto, Firdevs Duru, Jim Cottingham, and Joe Kasper. I've been lucky that nature has been kind to our research and has yielded some secrets on how glasses are built and behave. It has been a good life.

Steve Feller is a physics professor at Coe College in Cedar Rapids, IA. His research is with undergraduate colleagues and centers on the atomic structure and physical properties of new oxide glasses. More than 170 papers in the refereed literature of the field have been published; most with students. Also, he has edited a number of books on glass science and his group has given over 300 presentations at well over 150 conferences. He has been honored by being named, in 2003, *Fellow* of both the American Ceramic Society and the British Society of Glass Technology, *Distinguished Iowa Scientist* by the Iowa Academy of Sciences (1999), and *Iowa Professor of the Year* by the Carnegie Foundation (1995). Also, he was given the 1993 *APS Prize to a Faculty Member for Research in an Undergraduate Institution*. During 1996 he served as a *Fulbright Scholar* to the UK where he did neutron scattering studies of glasses and crystals with Adrian Wright. In 2001 and 2006, he was visiting professor at Sojo University (Japan) and University of Warwick (UK). In 2011, he was a *Fellow* of the Institute for Advanced Study at Warwick. In 2016, he was a visiting scientist at the Rutherford-Appleton Lab (UK), The University of Innsbruck (Austria) and the National Hellenic Research Foundation (Greece). The 2017 International Borate Conference was held in his honor at Oxford University. He was especially gratified to have been awarded the *C.J. Lynch Prize* as Teacher of the Year by the 1993 senior class of Coe College.

In 2011 he played the role of Niels Bohr in Coe's production of *Copenhagen*.



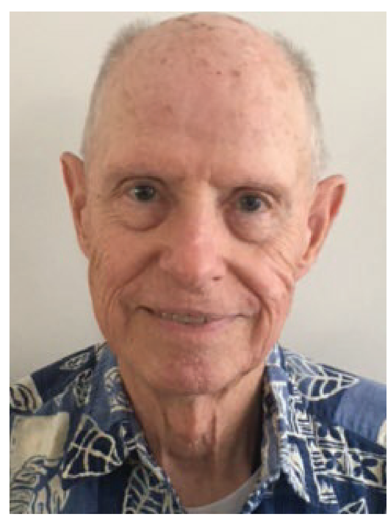
Steve Feller
24 March 2022

Reflections on Microtektites

Billy P. Glass, University of Delaware, Dept of geology, Newark DE 19716

I was a graduate student in marine geology at Columbia University in 1966, when I took a geochemistry course. Toward the end of the course, the instructor asked us to write a term paper on tektites. Tektites are glass bodies found over large areas of the Earth's surface called strewn fields. They are mostly spherical in shape, but dumbbells, teardrops, and discs shapes also occur. Their compositions are like that of the Earth's crust. There are four major strewn fields: Australasian, Ivory Coast, Central European, and North American with ages of 0.8, 1.1, 15, 35 m.y., respectively. Shortly after writing the term paper, I found some small (<1 mm) glass beads in deep-sea cores taken south of Australia. I eventually decided that they were small tektites and called them microtektites. In 1967, I published in Nature where I described my discovery of microtektites. Thus, began over 50 years of research on microtektites and tektites, which continued up to the present. I searched for and found Ivory Coast microtektites in eastern equatorial Atlantic deep-sea cores. Shortly thereafter, North American microtektites were found in the Caribbean Sea. Because of my work on microtektites, I was able to study glass beads in the lunar fines returned by all the Apollo Missions and two Soviet Union missions. The lunar glass beads were mostly of impact origin confirming that the craters on the moon are mostly impact, not volcanic, in origin; although some volcanic glass was also found. As part of a study to determine the feasibility of putting nuclear waste into glass containers and burying them on land or dumping them on the deep ocean floor, I did a study to determine the amount of solution that microtektites (with varying compositions) had experienced between 0.8 to 35 m.y. Most microtektites underwent <5 μm of solution regardless of their age. This paved the way to nuclear waste immobilization using glass as a host.

My advice to the young is find something you love, study hard, and be open to new ideas.



I received a B.S. in geology at the University of Tennessee and a commission as an officer in the Army Corp of Engineers in 1963. I received a PhD in marine geology in 1968 and started my two years active duty in the Corps of Engineers. Thanks to Dr. John O'Keefe for having me assigned to the Planetology Branch at Goddard Space Flight Center for my two years active duty. Subsequently, I got a job teaching in the Geology Department at the University of Delaware where I taught and did research for 35 years.

Billy P. Glass
August 28, 2022

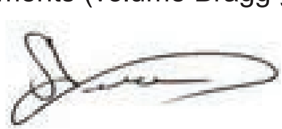
University of Central Florida

CREOL
The College of Optics and Photonics

I am very proud of the fact that nearly all of the lasers that are used around the world for cataract surgery have a very lightweight laser pulse compressor that decreases the probability of failure by at least an order of magnitude. Additionally, narrow-band filters developed by me increase spectral resolution of Raman spectrometers by more than order of magnitude and enabled reliable sensing of food, chemicals, explosives, etc.

My involvement in glass research started at the MS diploma project in Leningrad where I was required to study a nature of short pulses observed in Nd^{3+}-doped glass lasers. It was revealed that the pulsed regime is caused by absorption of color centers that were generated in glass matrix by UV radiation of pumping lamps. This was a pivoting point that converted me from laser spectroscopy to photoinduced structural transformations in glass that I have now studied for more than 50 years. Beside multiple discoveries of new phenomena in interaction of optical radiation with glasses (electron mobility threshold, multiphoton ionization, intrinsic laser induced damage, etc.), the main practical application is creation of photo-thermo-refractive (PTR) glass. This multicomponent silicate glass shows permanent refractive index change after exposure to UV radiation followed by thermal treatment. The glass enables fabrication of highly efficient holographic optical elements that work as unprecedented narrowband optical filters, laser mode converters, and laser pulse stretchers/compressors used in applications mentioned above. Newer and newer features of glass that we continue to discover keep me busy in this area for more than a half of century. I am sure that new generation of glass scientists will find the same great field of opportunities to discover new phenomena and to make new glasses.

I received my Ph.D. in Physics from State Optical Institute, Leningrad, Russia (1976). Since 1995 I have been at CREOL/ The College of Optics and Photonics, University of Central Florida as a Research Professor. I have published a book and more than 400 papers in scientific journals and hold 14 US patents. The main directions of my research are optical properties of glasses, holographic optical elements in glasses, and lasers controlled by these holographic optical elements. I am a founder of OptiGrate Corporation (1999) that develops and fabricates photosensitive optical glasses and holographic optical elements (volume Bragg gratings).



Leonid Glebov, Research Professor

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Glass – A shining part of my life

“Glass is boring!” I have heard this several times in my career. In fact, during my Ph.D. days, a professor told me that glass is an age-old material; there is nothing left to be accomplished in this field. Therefore, I should probably select some other topic for my doctoral research. Being a young student, it scared me a bit, and I gave it a serious thought. However, I could not think of anything more fascinating than glass.

For me, glass is an “unsung hero” that is simple enough for anyone to notice despite its ubiquity, yet complex enough to satiate the curiosity of scientists for more than a century. A material that has enabled several technological revolutions starting from the light bulb to optical fibers, thermometer to bioactive glass, window/container glass to vials for COVID vaccine, vision glass to the lens for Hubble telescope, cathode ray tube to an all-glass phone, but still stays invisible and unnoticed.

I was a physics student at the Guru Nanak Dev Univesity in Amritsar (India). My journey in glass science started in 2004 when I synthesized a fly ash-containing bismuth borate glass – the first glass of my career. This was followed by a Ph.D. in glass science and technology from the University of Aveiro, Portugal. Since then, I have been fortunate enough to receive opportunities that allowed me to explore the various scientific and technological facets of glass, whether establishing composition-structure-property relationships in academia or manufacturing optical fibers from fused silica in industry or immobilizing nuclear waste into borosilicate glass at the Pacific Northwest National Laboratory, or now as a faculty at Rutgers.

Glass has guided the light into my life, helping me build my career. I am sure its luster will remain impeccable for the generations to come ushering in technological marvels that are probably beyond our imagination today.

For those who think “Glass is boring,” think twice!

Ashutosh Goel, Ph.D.
Piscataway, NJ, April 18, 2022

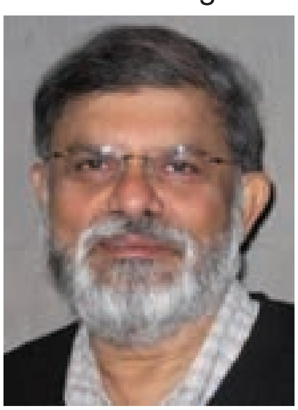
Walking the mathematical trails of glass science

A chance recommendation by my cousin, Arun Varshneya, initiated my migration from a BS in metallurgical engineering at the Indian Institute of Technology, Mumbai, to graduate study in glass science under the mentorship of Professor Alfred R. Cooper at the then Case Institute of Technology in 1966. Cooper was a renowned expert in glass science and engineering but also had a strong interest in the theory of interdiffusion. His teaching style was highly untraditional, teaching mostly from recently published research papers and frequently getting lost in working through mathematical equations on the black board. His mission was to apply mathematical rigor to explain phenomena in glass science and technology. My PhD thesis on the topic of nonlinear effects in Spinodal Decomposition using mathematics of “uphill diffusion” reflected this mission. A second MS in Physics alongside set me up to get postdoctoral at Yeshiva University in 1971 and, subsequently, at Catholic University in Washington DC. Collaboration with Connie Moynihan at CU resulted in our establishing the phenomenological theory of multiple order parameters to describe glassy state contrary to a single order parameter concept. The simplicity, rigor, transparency, and insights of this proof is now a textbook material.

A couple of years later, I joined Owens-Corning Fiberglas Tech Center in Granville, OH which allowed more frequent discussions with Al Cooper. At OCF, I studied strength of melt-formed pristine 10-20 microns diameter E-glass fibers. A collaboration with Phil Bray (an B-NMR expert at Brown Univ) help me develop the now accepted “Random Pair Model” of boron coordination in glass.

I joined Ohio State University and began to have more frequent discussions on various glass science topics with Al Cooper on phone, and published “Topologically disordered networks of rigid polytopes”. It was heartbreaking to see this giant of glass science pass away in 1995.

I was fascinated by the new development of the potential energy landscape (PEL) formalism of glasses and supercooled liquids (specially the work of Frank Stillinger).



“What freezes?” at the “freezing” of a liquid to transition to glassy state is what John Mauro and I presented around 2008 discussing our entropy loss hypothesis in contradiction to a traditional belief in continuation of the entropy. The traditional concept led to an apparent violation of the Third Law of Thermodynamics. More and more physicists are beginning to discard the traditional view and are accepting the concept of entropy loss.

As you can imagine, I have thoroughly enjoyed being involved in rigorous treatment of some of the glass science phenomenology. I suspect glass products will benefit from our improved understanding of Nature.

My message to the young: Develop a passion for rigor, a love of understanding, and meaningful discussions with colleagues. And visit your cousin more often.

Prabhat K. Gupta
Emeritus Professor
The Ohio State University

CORNING

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I knew I wanted to study engineering while in high school, since I enjoyed math and science. I looked at Chem Engineering programs at various schools, but it wasn't until I saw the ceramics program at Alfred University that I felt like I found home. In my first year I learned a whole new vocabulary and putting things into practice in college was a very energizing change. Recognizing that I could design experiments, fix and operate machinery, analyze data and draw conclusions on a whole new level was very exciting and empowering. During my sophomore year, I had a professor, Dr. Jim Shelby, take a personal interest in my academic career and offered me a job in his lab. Not only did I learn the practicalities of the job, I also learned how to apply class learnings to what the grad students were working on. He was a great teacher. He gave each of us a small sample of something and said, "you have 3 weeks," figure out a test plan, conduct all your experiments, try to figure out what it is and write a report on what you've learned. It was exciting and independent work. It emphasized and clarified for me that engineering and science are fun. I was inspired to continue my education and Doc helped me in so many other ways. I'm still in touch with him now, in my professional life at Corning. He taught me how to deal with customers, how to report to people who are paying for work, how to give directions, and how to take directions. All these things matter in the working world.

Since working at Corning, I've had the pleasure of being a liaison with the Corning Museum of Glass on the Specialty Artist in Residence program. To see the artists and scientists use the same language is very interesting to me. They talk about 'unexpected,' 'left turn,' 'discovery,' 'learning,' and 'creativity.' My favorite quote is from Dr. Mae Jemison who said, "arts and sciences are both avatars of human creativity." Wherever we work with glass, we are using our creativity to identify problems, highlight problems or solve problems. It's been a fabulous ride so far to work in and around glass.

Chris Heckle
April 27, 2022

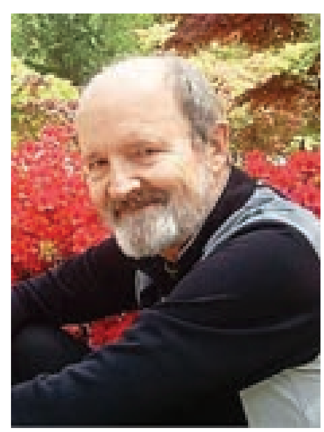
Not all glass is transparent

When my ex-students thank me for positively impacting their lives, my response is that I just convey what I have received from my teachers: it started with high-school teachers and university professors, and continued throughout my life with my mentors, colleagues, junior scientists, and, yes, my students.

I was born in Czechia (then Czechoslovakia). When I recently looked at my first paper, published in 1961, which was based on my master thesis, I saw a text written with youthful vigor and an enviable ease. But I was allowed to aspire for an advanced degree, only after five years of working first in industry and teaching in a college—two experiences that came handy in my later years: familiarity with industrial technology and ability to elucidate complex problems. After finally defending, in 1981, my dissertation on the subject of refractory corrosion by molten glass, a position in the Joined Laboratory of the Institute of Chemistry, Prague, and the Czechoslovak Academy of Sciences afforded me twelve happy years of researching, teaching, and advising students. Yet I was facing a dilemma: wasn't I enabling with my work the parasitic class of power-hungry communists to dominate people's lives in isolation from the free world outside?

So, one February day I landed on the Heathrow airport with £80 in my pocket. Thanks to the kindness of Professor Michael Cable, I spent twenty wonderful months in the University of Sheffield, writing papers and traveling, while waiting for American visa. Then, at the Case Western Reserve University in Cleveland, Ohio, I joined Professor Alfred Cooper, whose work has been my inspiration, starting with my thesis and never ceasing afterward. After seven years, I've got a job at the Pacific Northwest National Laboratory in Richland, Washington, on developing the technology for nuclear waste vitrification, writing weekly, monthly, and yearly reports—managers considered attending conferences and publishing papers a waste of time.

Things changed with the advent of millennium: under the guidance of Albert Kruger, the quality of work became paramount. An international network was established. Once back in England, when asked to report in the BBC broadcast about a Czech glass art exhibit, I mentioned that, unlike other artifacts, glass objects are transparent—one can see what's inside. Glass science should be like that, too.



My work did not stop at retirement. For ten years, 2011-2019, I was teaching classes on glass science at the Advanced Nuclear Division of the POSTECH, a South Korean world class university. Here I am, a retired octogenarian busy working with a host of younger colleagues. Recently, in Japan, when asked what I would recommend to a student, I proposed to emulate a scientist they respect and admire.

Pavel Hrma March 3, 2022

LEHIGH University

Materials Science and Engineering
Whitaker Laboratory
5 East Packer Avenue
Bethlehem, PA 18015-3195

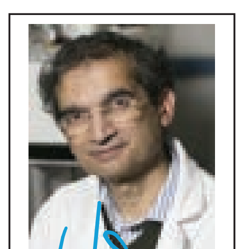
April 19, 2022

Glass: my medium of creativity because it can be reorganized in myriad forms

The three most important factors that determine the destiny of a person are when, where and to whom (s)he is born. I suppose my destiny with glass was set by these facts being born at a time when science was considered the path for India to build herself as an independent self-reliant country, at a place not far from Firozabad - the Murano of India, with father a science teacher and mother a scholar of Jain philosophy. The glass was very fascinating for its appearance and ability to make beautiful shapes, but I could appreciate its technological potential only after taking courses at IIT, Kanpur. I was fortunate to learn the meaning and value of fundamental understanding of quartz crystal from my dissertation adviser, Art Nowick at Columbia University. This integrated foundation and perspective inspired me to understand the science of materials and use it for solving real life problems. As a researcher, my motto became creating new functionality in glass through fundamental understanding of its processing and properties.

I have immensely benefited from the fact that the disordered nature of glass structure offers the possibility of modifying its structure and hence functionality gradually, all the way to a unique single crystal state, using optical, thermal, electronic or chemical stimulus. I have been blessed with a large number of excellent collaborators, visiting scientists and students (>450), who helped me learn and turn my ideas and dreams of introducing new functionalities in real, compact 2D and 3D devices such as biosensor for pathogens, thinnest planar Fresnel lens array for focusing light, active single crystal waveguide inside a glass, etc. Often, but not always, the discoveries were made serendipitously, such as a new class of metamaterial, comprising lattice engineered crystals in glass, while seeking answers to an unrelated fundamental question.

To the younger generation I would like to tell a story. At a banquet in Cairo, Egypt, held for the science advisers of African countries, the next guest at the table remarked that to her glass was no good. Taken aback I asked her to elaborate. She happened to be a prosthodontist engaged in tissue engineering, and was unhappy that the bioactive glass she used in her patients lasted too long. She wanted the glass to dissolve fast, which was opposite of what the glass community has strived for millennia. Challenged by this clinical need, we developed technology for fabricating bioactive glass scaffolds with macro pores 100s μm size for tissue growth and nano pores 10s of nm size for fast dissolution. Later, during a flight to Japan, the neighboring passenger happened to be a cell biologist. He and other collaborators from Portugal joined the team, and a decade later the novel tailored amorphous multi-porous (TAMP) composition proved beneficial to young patients while dissolving rapidly in a clinical trial, and also for treating dentin hypersensitivity in mini swine. Most recently, a company has expressed interest in using it in *in vitro* fertilization treatment. So, I would encourage you to be curious, observant and cognizant of the needs of the society. You will see myriad possibilities in otherwise featureless glass and be able to put them to a greater good while having fun.



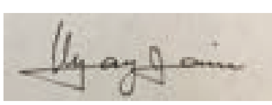
Himanshu Jain
T.L. Diamond Distinguished Chair in Engineering and Applied Science

Savannah River Mission Completion (SRMC), located in South Carolina, USA is dedicated to the reduction of risks through safe stabilization, treatment, and disposition of legacy radioactive waste. At SRMC, glass plays an integral role in our mission to reduce one of the largest environmental risks in the United States. Glass is used to encapsulate liquid radioactive waste (dissolved spent nuclear fuel) in a stable and durable product for a long-term disposal.

High Level Waste Vitrification Melter

While the vitrification technology for encapsulating high-level radioactive waste into glass is used worldwide, the UN declaration of Year of Glass provides a recognition of glass as one of the most transformative materials in the history of mankind to reduce environmental risk and make the universe a safer place.

Vijay Jain, Chief Technology Officer for the Savannah River Mission Closure, has dedicated his career pursuing safe disposal of nuclear waste in glass. He has bachelor's degree in Ceramics from Indian Institute of Technology – Banaras Hindu University, Varanasi, India, master and doctoral degrees in Ceramics from Alfred University, Alfred, NY and an MBA from St. Bonaventure University, St. Bonaventure, NY. Dr. Jain has over 35 years of vitrification research, development, and engineering experience. Dr. Jain's experience includes 25 years at several Department of Energy sites, including Savannah River Site, Aiken, SC; Waste Treatment Plant, Richland, WA; and West Valley Demonstration Project, West Valley NY. Dr. Jain has published over 60 papers in journals, conference proceedings and/or reports. Dr. Jain served as a member of the Board for the American Ceramic Society (2011 -2015) and was elected Fellow of the American Ceramic Society in 1998.



Vijay Jain, PhD

Chief Technology Officer

Savannah River Mission Completion

Savannah River Site
Aiken, SC 29808
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The "Little Book of Glass" and How it Changed My Life Forever

As a child I was always fascinated at how molten magmas flowed down mountainsides. At the time, I had no concept that many lavas were "glassy" flows. I decided to major in geology as my father was an avid rock and mineral collector. I found myself fascinated but limited in job opportunities. I transferred to Materials Science & Engineering and while perusing books in the engineering library, I found the little book entitled "Glass."

The little book entitled "Glass" is, indeed, little (4.5"x4"x3/8"). It was written by G.O. Jones in 1956. As I read the little book, I was again fascinated by the contents and elected to specialize in the study of "glass."

Fast forward to my career after college. In December 1981, I interviewed for a job at the Savannah River National Laboratory (SRNL) in Aiken, South Carolina. SRNL needed a "glass scientist" to work on R&D related to the start-up of the world's largest high-level waste (HLW) vitrification facility which had not yet been built. This included the need for process control models to operate the facility remotely, because of the high radiation fields associated with HLW. In February 1982, I took a chance and wrote a pre-proposal to my interviewer suggesting that I develop process control models based on the "structure of glass." Research was just emerging about the "structure of glass" in the early 1980's. I got the job.

I spent the next 12 years developing the process control models based on the "structure of glass." The facility began operation in 1994 and has vitrified HLW 24/7 ever since, e.g. ~28 successful years. Processing began using my original "structure of glass" models. The safe vitrification and disposal of HLW has benefited all of mankind, as the HLW is a legacy waste that needed stabilization and disposal since WWII (before I was born). I retired 37 years later, delaying, because I truly "enjoyed" my job.

In 1997, I became the first woman president of the American Ceramic Society. Currently, I am a science advisor to GlassWRX, a company that is making foam glass to construct sea walls that can protect low lying communities along the shorelines in the US from sea level rise. Concurrently, I am an affiliate professor at the University of South Carolina, Aiken, where I am creating the "Fredericks Mineral Gallery" on campus. Fredericks is my maiden name and I needed to find a venue to display my father's museum quality collection of rocks and minerals.

My advice to those just starting out on a career path, is to follow your dreams, and it will transform your life. The definition of success (Mary Angelou) "is liking yourself, liking what you do, and liking how you do it." In my case, the "Little Book of Glass" set my career path: even though, at first, I did not recognize that I was "following my dreams."

Carol M. Jantzen

Reflections on Glass

Shibin Jiang, President & CEO, AdValue Photonics Inc, Tucson AZ

Ever since I was a graduate student, I have been studying new rare-earth doped glasses for lasers, amplifiers, and photonics devices. New phosphate glasses were developed for control of the temperature coefficient of refractive index; new silicate glasses for high doping concentrations, and new germanate and tellurite glasses for generating longer wavelength lasers. The rare-earth doping for laser operation included Nd, Yb, Er, Tm, and Ho ions with the maximum doping concentration of 75wt%. My research programs have resulted in more than a dozen innovative products, enabling the establishment of three high-tech companies. Thousands of our lasers are widely used for sensing, lidars, quantum communications, and scientific research projects in commercial companies, universities, and government labs around the world.

I studied chemical engineering and glass materials in China. I joined the college of Optical Sciences of University as assistant research professor in 1996 shortly after I obtained my Ph.D. in Chemistry from Univ of Rennes, France. My research on Er-doped phosphate glass fiber amplifiers at University of Arizona resulted in $1M technology transfer. The technology was used to form NP Photonics Inc in 1998. I founded AdValue Photonics Inc in 2007 to further develop innovative fiber lasers and received the 2018 Corporate Technical Achievement Award from The American Ceramic Society (ACerS). I have built thousands of lasers by using glasses and fibers past fifteen years. Now I am using lasers to build machines that can cut, drill, grind, polish, and weld glasses to modernize the glass machining process. I founded Hangzhou Silverlake Lasers to build laser machines for glass processing used by many glass companies in the world.

I have been awarded with 86 patents, edited 28 proceedings books, and published 150 papers and 3 book chapters. I served as the Chair for 36 technical conferences, as an associate editor for 4 technical journals. I received the Gottardi Prize from the International Commission on Glass (ICG), R&D 100 awards in 2012, 2014, and R&D 100 finalist in 2018. I was the chair of GOMD of the ACerS in 2014. Currently, I am the chair of optical fiber and photonic glass technical committee of ICG. I was elected a Fellow of SPIE, Optica, and ACerS, and academician of the World Academy of Ceramics.

Eighty years ago, almost no one believed that low loss glass fiber with less than 10dB/km would be possible. Nowadays fiber with less than 1dB/km are widely used for communications, enabling the explosive usage of internet. Fifty years ago, almost nobody imagined that glass sheets could be flexible, but nowadays flexible glasses are widely used for display. Twenty years ago, almost nobody thought that glass fibers can produce 10kW laser power, but modern fiber lasers with 30kW power are widely used for laser material processing. We can dream big for glass applications, and these dreams will come true.

Jacqueline Anne Johnson

What have I done with glass that benefits mankind

I spent a large part of my career developing image plates, anything from mammography and dentistry using low energy x-rays to non-destructive evaluation using high energy radiation. More recently I have been researching glass as a material for a battery electrode for a sodium ion battery.

My passion about glass?

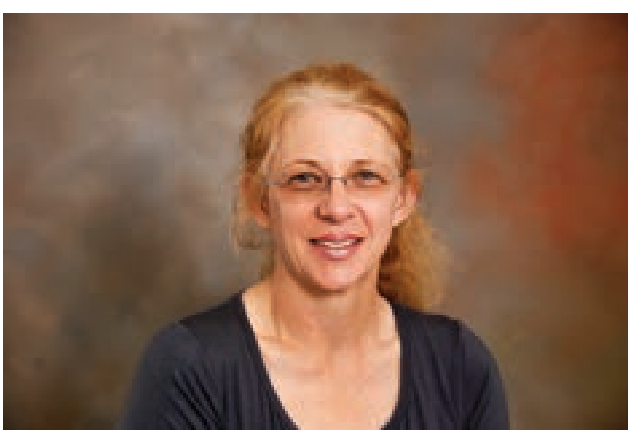
Glass is unique in its versatility. A slight change in composition can drastically alter its properties. It is fascinating to me that a 1-2% change in composition can result in a vastly different material. Beyond windows, furniture, and mirrors as well as basic science, which is interesting and broad, glass lends itself to applications in security, medicine, and safety, which helps mankind.

Bio

I completed doctoral degree in solid state physics in the research area of magnetic phase transitions at the University of Liverpool in 1985. I transitioned to working on glass materials after being approached by Pilkington Glass to solve technical problems. I was a Professor in Liverpool until 1995 when I joined Argonne National Laboratory in the United States, where I was introduced to solving the structure of amorphous materials using neutron scattering. After a 2-year period in administration I returned to research to develop a new mammography system using a glass-ceramic plate. In 2007, I returned to academia at the University of Tennessee Space Institute and continue to synthesize and characterize glasses, glass ceramics and nanomaterials pertaining to medical devices, non-destructive evaluation, and image enhancement. More recently, I have used all the techniques I learned while characterizing glass to work with aerospace materials.

A brief message to the young

Do not be afraid to change field – this is how you become unique and invaluable.



Glass is the Solution

Glass is everywhere. These days, glass is a commodity product fully integrated into our everyday lives. Yet, most people are not aware of how much glass we use. We get up in the morning with the sun brightening up our bedroom through the glass of our windows. We put on our eyeglasses to check our phones, with their thin and durable glass screens. We take a shower in a glass enclosure, look in a glass mirror as we get ready. We take juice from a refrigerator with glass shelves and glass doors, pour it into a drinking glass, and make breakfast on a glass stovetop or glass tray in a microwave oven. We may eat our breakfast with the television on—a television that features a glass flat screen. Then, we may walk through our front door with a patterned glass window and drive to our workplace or school in cars with windows and skylights.

Glass touches every part of our lives. It helps us through our days and connects us to the world around us. But it also does so much more. Glass was the solution when the world was shut down due to the pandemic. Grandparents and sick family members were able to only see each other through a window or a glass barrier, children were introduced to their extended family though video calling, and physical and mental health crises was helped by physicians seeing people through a screen. Glass is the solution for many of the world's issues.

The part of glass that excites me is what we don't see and don't think about— the strength, safety, security, forced-entry resistance, ballistics and blast protection, acoustics, thermal comfort, net zero energy efficiency, sustainability and infinite recyclability. And beyond its physical attributes, glass benefits people—it can lead to improvements in mental health, focus and productivity; to better sleep and body functions; to better grades in schools, faster healing from surgeries, and higher rates for retail with a view.

My career in glass started out with pushing it to the limits, breaking it and all other building envelope products to see if they pass the building standards and codes in a testing laboratory. Now I have the honor to advocate for the use of glass in buildings by helping write standards, codes, best practices, design guidelines for the glass and glazing industry. Glass continues to help solve many of the world's problems, and I look forward to continuing to see where this fascinating material takes us next.

April 24, 2022

Urmilla Jokhu-Sowell

A Brush with Glass

By Kathy Jordan
Director of Art Development - Willet Hauser Architectural Glass, Inc.
President - American Glass Guild

For me, stained glass is the kaleidoscopic interplay between light and color that illuminates the imagination and touches the soul. I am compelled by a greater calling to create new glass art while concurrently caring for the irreplaceable glass heritage that adorns our communities and worship spaces. Sacred buildings are living museums where glass art and architecture meet to create an atmosphere of light, color, and enhancement of the spiritual experience.

I am simultaneously a wife, mother, and all things glass – Glass Artist, Glass Conservator, Glass Educator and Glass Entrepreneur. Over thirty-five years the success of my career rests upon my multifaceted aptitude in visual arts, historical research, technology, creating and seizing learning opportunities. This life experience paves the way to volunteer, and to give back to the glass industry that I love.

I am the sitting President for the American Glass Guild, with my final term commencing on this historic International Year of Glass. What an extraordinary opportunity to unite our global glass voices in reverence, creativity, curiosity, and purpose to make our world a better place. I watch in awe as it beckons and inspires us to become involved with the International Year of Glass movement. The originating 'call-to-endorse' touched my heart and without hesitation, I volunteered to work on the North Americas Steering Committee - RO7. The successes that are unfolding is a testament to the collaborative spirit the glass field is known for. ICG's President, Alicia Durán encouraged everyone to "start planning, share your ideas, find working partners, seize new opportunities, tell your stories, and learn new things."

The glass lens of IYoG2022 has placed its rightful focus on a broader appreciation of this noble material and I implore our emerging and future glass artisans to collaborate, embrace experimentation and broadening their repertoire in a new and exciting ways.

Reflections on glass

Steven Jung, Chief Technology Officer, Mo-Sci LLC, Rolla MO

My contributions to the human race include innovations in bioactive glasses for bone and soft tissue healing. These technologies have increased the rate of healing through the use of new compositions of borate bioactive glasses and novel form factors such as porous scaffolds and non-woven fibers. These technological advances improve clinical outcomes in patients and their quality of life. In addition to the science of making new and advanced materials, I support the manufacturing of these technologies and make them available to companies that wish to commercialize them. This step of "making" is critically important and how we collectively impact people's lives for the better.

My journey started in Rolla Missouri, and to this day continues there 22 years later. I went to school at Missouri University of Science and Technology where I earned my B.S., M.S. in Ceramic Engineering, and a PhD in Materials Science and Engineering. After my first year of school I got a job working for Delbert Day in his glass research group doing what I could to help the graduate students. I knew nothing about glass at the time, but over the next nine years that changed significantly. I worked on a variety of glasses for nuclear waste encapsulation, glasses for melting on Mars, Cement additives, and biomaterials. After my B.S., Prof Day offered me one year of funding to try and build enough data to draft a proposal to the US Army for new bone replacement technologies. Fortunately the funding was secured and I was able to finish my graduate work. Along with gaining advanced degrees, I learned a great deal about intellectual property and filed several patents protecting the work. To this day I am still actively utilizing this technology for new medical devices in the areas of bone regeneration, wound care, hemostasis, dentistry, and the animal care.

While I am still early career, just 39 while writing this composition, there are a few things that I think were instrumental in my development worth passing on to students. First, you have to be ok with taking chances on yourself. If you wont, no one else will either. Second, you have to ask questions. Asking questions means you are engaged and actively trying to learn. Third, you should expect change in your career, and some could be pretty drastic. You never know where you will end up. Just be ready to keep learning, because it isn't over. Lastly, as Prof Day says, "There is always a shortage of good people, be one of them".

4/18/2022

UNIVERSITY OF MICHIGAN
COLLEGE OF ENGINEERING

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April 11, 2022

The Shape of Glass …

… makes it a cutting tool or an ornament or a utilitarian vessel. Shaped to within minute tolerances, it becomes a scientific tool that let us discover the cell and understand our solar system. As a sheet it filters the light from the harsh climate in the places of work in the northern parts of this hemisphere, which allowed us to advance into the modern age of commerce a few centuries ago. Drawn out to a thin strand it transmits vast amounts of information at nearly the speed of light, and we no longer worry whether the glass encasing of the device that holds all our data and connects us with the world might break when we drop it. But, as much as humans shape glass objects to serve a purpose, glass has shaped humanity. Without a doubt, glass has had a profound influence on socioeconomic progress. And yet, there remains so much mystery about the amorphous state of matter, prompting an innate curiosity and a resolve for exploration among individuals such as myself and my students. Perhaps it is the power of the unknown that causes the fascination with glass. I believe there is yet another shape of glass, namely the shape it takes in the minds of those who act on their curiosity and dedicate their energy to elucidating the fundamental nature of glass. The greats in glass science that came before us have already revealed the general contours of this enigma. May their work be an inspiration to future generations of curious minds, for up close, this shape of glass still remains delicately veiled.

John Kieffer is a Professor of Materials Science and Engineering at the University of Michigan. He received his M.S. in Metallurgy and his Ph.D. in Materials Science from Clausthal University of Technology. He was a postdoctoral research associate at Arizona State University and at Purdue University, and a research engineer at Saint-Gobain Recherche in Paris. He joined the Materials Science and Engineering faculty at the University of Illinois, and subsequently at the University of Michigan. His research specialty is in molecular simulations, inelastic light scattering, dielectric impedance spectroscopy, and sol-gel synthesis. He is a Fellow of the American Ceramic Society, received the 1999 George W. Morey Award and the 2020 Alfred R. Cooper Distinguished Lecture Award from the Glass and Optical Materials Division.

John Kieffer, Professor
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April 13, 2022

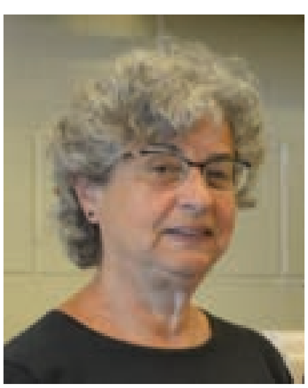
"120 Years of Glass (and Counting)"

Since the establishment of an academic department dedicated to clay working and ceramics in 1902, glass science and engineering has been central to Rutgers University. Under the leadership of Cullen W. Parmelee, who authored the well-known text *Ceramic Glazes*, the Ceramic Association of New Jersey (CANJ) was founded. He enlisted advice from other states, like Illinois and Ohio, where similar programs were emerging. Other pioneers in glass technology who were affiliated with the program included Robert B. Sosman (*The Phases of Silica*) and Charles J. Phillips (*Glass, the Miracle Maker*). The Department of Ceramics officially joined the College of Engineering (now School of Engineering (SOE)) in 1945.

Over the 40+ years that I have been part of the Department, now called Materials Science & Engineering, we have been fortunate to be the home for outstanding glass scientists. These include Harold Smyth and Steve Garofalini, who have focused on glass structure, and Alex Pincus, Rick Lehman and Jack Wenzel, who have focused on the glass industry. In 1980, we hosted a workshop on Glass through Chemical Processing, which looked at new trends in glass technology from sol-gel processing to chemical vapor deposition and emerging non-silicate and non-oxide glasses, with Richard Riman focusing on fluoride glasses.

In 1986, the New Jersey Commission on Science and Technology (NJCST) established the Fiber Optics Materials Research Program (FOMRP), which brought George Sigel, James Harrington, John Matthewson and Eli Snitzer to Rutgers to research waveguide materials, lasers and optical amplifiers. This program received funding from New Jersey, federal agencies and a consortium of participating companies.

In 2013, the Corning Glass Laboratory was initiated with a $500,000 investment. This enabled the recruitment of Ashutosh Goel, who joined Rutgers in 2014. With this dedicated facility and a transformation of our academic program, the pursuit of glass research continues. The graduates of our program at the BS, MS and PhD level populate many of the premier glass companies in the world. We are proud to have trained hundreds of students who work in this field. It is clear that Rutgers University has a long history and an even brighter future in glass.



Lisa C. Klein is the Chair of Materials Science & Engineering at Rutgers University. She received her PhD and BS degrees from the Massachusetts Institute of Technology. Her research focuses on sol-gel processing of silicates and organic-inorganic hybrids. She was the Editor of the *Journal of the American Ceramic Society* from 1998-2019. She is a Fellow of the American Ceramic Society (ACerS) and the Society of Glass Technology (SGT) and a member of the World Academy of Ceramics.

Reflections on Glass

Jeffrey T. Kohli, Corning Research & Development Corp., Corning NY

I have had the good fortune to make significant contributions to the invention and development of glass used for flat panel displays as the sole inventor for the seminal patent family covering Eagle XG® & Eagle 2000® (US 6,060,168, EP 0 960 075 B1, RE38959, RE41127), and the opportunity to work with hundreds of other people associated with Corning's Display business. These flat panel displays and the glass that is used therein displaced bulky CRT technology previously used in televisions and desk top monitors. Moreover, these new glasses optimized for flat panels are significantly more environmentally conscious than those once used by the CRT industry.

I have also had the opportunity to be a major contributor to the development of Corning® Gorilla® Glass for more than a decade, as an inventor, project leader and technology director for the business. Many of us around the globe touch Gorilla Glass every day on touch-enabled consumer electronic devices! Additionally, I made contributions to the development of Er-doped fiber amplifiers, which helped replace copper cable as a primary means of written, voice, and video communication, enabling the Internet as well as modern 5G communications.

For me, glass is an incredibly unique material, used for vessels, windows, mirrors and artwork for centuries. It's use for modern communications, lithography lenses or as carriers in semiconductor processes, modern AR/VR devices, exploration of space, and biomaterials are just a few examples of its value to humankind. I am proud to be an inventor and innovator of glass technologies, and I often reflect on the opportunities and teachers that helped guide me. Glass is my passion and my profession; let it shine light on all of you who are new to its technical and artistic wonders!

Dr. Jeff Kohli is the Director of Glass Research at Corning Incorporated. Prior to his current role, Jeff was Business Technology Director, Corning® Gorilla® Glass, responsible for product and process development for the Gorilla Glass business.

Jeff joined Corning in 1991 and has since worked in research, development and engineering roles as a scientist, a project manager and organizational leader. He won the Science & Technology People Development Award at Corning in 2017. Jeff is a Fellow of the American Ceramic Society and is past chair of the Glass and Optical Materials division of ACerS (2004). He has been a member of ACerS since 1986. Jeff has served on the Ceramic & Glass Industry Foundation Board of Trustees since 2020 and became a member of the advisory board of the Cornell Center for Materials Research in 2021. He has more than 20 publications, including book chapters, technical articles and proceedings, and holds more than 30 U.S. patents. Jeff holds B.S and M.S degrees in ceramic engineering and earned a Ph.D. in glass science, all from Alfred University.

UC DAVIS
MATERIALS SCIENCE AND ENGINEERING

April 14, 2022

Written in glass…

Reflecting on my life in glass, I realize that for about 25 years I was using lasers to write patterns *in* glass but now it is time to write *about* glass… My life in glass began more than 40 years ago when in 1980 I joined the "glass group' at Philips Research Laboratories in Eindhoven, the Netherlands after earning my PhD degree in Physical Sciences from Utrecht University. My thesis dealt with the luminescence properties of crystalline uranium compounds, but at Philips the management believed that it was good practice to venture into new territory at this point in one's career, so I switched to amorphous materials and started to learn about glass. Two of the early books that I remember were by US glass experts, 'Glass Science' by RH Doremus and 'Glass Structure by Spectroscopy' by CA Angell.

My first project dealt with Raman investigations of the chemical reactions during the melting of glass batches that served as model systems for television glass. I often went to the glass factory where they produced tv screens in a furnace the size of a swimming pool, a very hot and impressive sight… In my own lab I also melted glasses but mostly for research samples or for decorative purposes. One item, a beautiful, blue glass hemisphere (doped with Cobalt) sat on my mantlepiece for many years.

I also got involved with studying glass structure as well as the structure of sol-gel materials and to share the results of my investigations I started going to conferences. I still remember my first presentations at the ACerS Annual and Glass Division meetings in 1984, in Pittsburgh, PA and Grossinger, NY, respectively. I was struck by the friendly and welcoming atmosphere in the Glass Division and it has been my main professional home ever since.

In 1986 I became a research scientist at Bell Labs, Murray Hill, NJ and in 1995 I moved to CA and started a joint position at UC Davis/Lawrence Livermore National Lab. At this point my main line of research dealt with laser-induced structural changes in glass, of interest for the fabrication of optical waveguides. As a professor I enjoyed teaching my students about glass and realized that it was as unexplored a topic for them as it had been for me 20 years earlier.

The Glass Division, later renamed Glass and Optical Materials Division, offered excellent opportunities for professional service and after having been program chair in 1996 I became the Division Chair for 2000-2001. Since my retirement, at the end of 2018, I am no longer involved with glass research. Many other fun activities have come in its place, but I cherish very fond memories of my career in glass, especially of all the wonderful glass scientists that I was fortunate to interact with. To the younger generation I would say: Get involved with the larger glass community and become active in its various organizations, it will enrich your career and your life..

Denise M. Krol

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U.S. Department of Energy
Hanford Site

Applying Glass Science in Service to the Environment

Some children know at an early age what career they want to pursue when they grow up. This knowledge can provide a clear path that enables them to focus their energy and dedicate their passion. From the time he started 6th grade, Albert knew that he wanted to be a chemist. Growing up in Brooklyn New York, he was fortunate to be nurtured and encouraged by exceptional teachers in the New York Public School System, such as Mrs. Wolff who taught high school chemistry and encouraged Albert in his studies. Albert experienced similar fortune during his college studies. Based upon his placement in the 29th Westinghouse Science Talent Search, he started his first year in college in Organic Chemistry where professors Indictor and Haberfield opened the door to undergraduate research. This led to the good fortune of placement twice in the National Science Foundation's summer programs. Graduation from college came with honors that included election to Sigma Xi and being awarded the Student Medal by the American Institute of Chemists. Upon completion of the second year of his doctoral studies at Syracuse University, he was offered and accepted a position at Bell Telephone Laboratories in Murray Hill, New Jersey. The chairman of the Chemistry Department, Professor Gershwin Vincow, said Bell Telephone Laboratories would only ask you once. Albert's path led him to the 3M Central Research Physics & Materials Group where his work on the mechanical strength of silica fiber optics attracted the attention of senior management at Saint-Gobain Recherche in Aubervilliers. As a result, in 1982, he relocated to France. His work at Saint Gobain Recherche resulted in over 30 patents world-wide in the field of glass science. These patents cover coatings for flat glass in residential settings, a new generation of lighter and more protective automotive windshields, and coatings for optical fibers used in telecommunications.

Over the course of what my colleagues say is a distinguished career, my enduring contributions to the field of glass science have an impact on the environment. I am told my courageous vision and no-nonsense approach to the cleanup of legacy tank waste at the Hanford Site, where the U.S. Department of Energy is focused on its largest environmental remediation effort in the nation, has contributed to the progress of the vitrification mission. Transforming the radioactive and chemical waste stored in large underground tanks will mark a huge milestone towards the protection of the Columbia River and the surrounding ecosystem. The scientific and engineering accomplishments that I have had the honor of promoting during my tenure at the Hanford Site will have a positive impact on the health and well-being of future generations.

The opinions expressed in this letter are my personal opinions, are for the purpose of the celebration of what glass has done for civilization only, and do not represent an official position of the U.S. Department of Energy or the United States Government.

Albert A. Kruger, Glass Scientist
U.S. Department of Energy

Richland Operations Office
P.O. Box 550
Richland, Washington 99352

Office of River Protection
P.O. Box 450
Richland, Washington 99352

My career in Materials Science began with graduate school at SUNY Stony Brook. My thesis advisor was Sumner N. Levine. Dr. Levine was not known for any work on glass, but he *is* now famous as the founder of the Journal of Biomedical Materials Research, in 1967. My first publication (Materials and Design Considerations for a Compact Artificial Kidney) appeared in the 2nd issue of Vol. 1. – Not a glass topic, though I worked on fiber glass durability for my stipend – was captured forever by that magic material and headed for RPI where my Ph.D. advisor, J. Douglas Mackenzie was teaching. The year was 1968 and Doug was in the process of establishing the Journal of Non-Crystalline Solids. Lo and behold, we published "Effect of O_2 Impurities on the Electrical……. Se", in the first volume of JNCS, a paper cited and discussed by Sir Nevill Mott (Nobel Prize in Physics) regarding our discovery of "impossible" impurity effects in glassy semiconductors. A big thrill indeed.

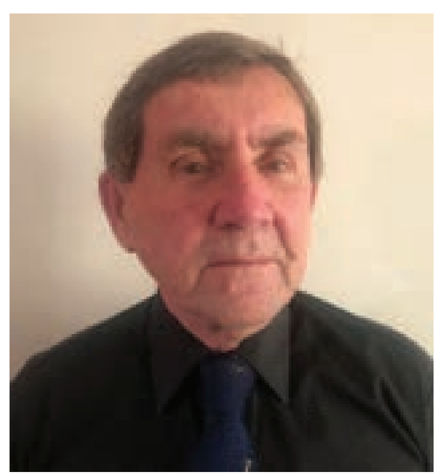
My next stop = Alfred University as a faculty member (thanks to Doug Mackenzie) under the mentorship of Dr. L. David Pye. Upon arrival he invited me to be co-editor and to write a chapter in his (and Prof. Harrie Stevens book Intro to Glass Science). As all know, Dave is "father" of the Int. J. of Applied Glass Science – so I've now worked for the founders of 3 of the most influential journals in materials science.

Dave Pye's offer of a teaching job was a seminal (1 of Dave's a favorite words) moment in my life, and the beginning of a 51-year teaching career. There are too many memories but I want to mention a few of the wonderful people that were important during that time, starting with my wife Pat. Most Alfred grad. engineers will admit Mrs. LaCourse was the most important person in the Engineering School. As Technical Librarian she approved all the grad theses. Also - my children Dr. Brian LaCourse (Ceramic Engineer with St. Gobain) and daughter Elisa LaCourse, now a bigwig Wealth Management advisor who can't take my account because it's too small.

I did get to work with unbelievable colleagues. Arun Varshneya, Alexis Clare and Jim Shelby – wow!! They are not only great glass scientists in their own right, but their Academic Offspring continue to lead in the industry/university glass world.

As Prof. and as self-appointed A.U. Director of Entropy, I've also worked with some wonderful grad students, referred at Alfred as Docs Minions of Entropy. (We store all excess entropy in Dr. Clare's office.) We have an inspiring motto that drives us all: "**We Are the Masters of Entropy - We Make Vitreous Virtuous.**

Many former Entropy Minions have done surprisingly well : J There is the "Royal Professor of Chalcogenides, Professor Kathy Richardson, and Prof. Sanwip Dey, who deserted glass but is an extreme success in electronic ceramics at Arizona, Dick Brow (M.S.) has done pretty well at Rolla after being polished during his Ph.D. work with Carlo Pantano at Penn State.



It's been a long career – but there are remaining jumbled ideas, eager minions, and new colleagues. Hopefully I'll be in the lab with them for a few more years generating more functional entropy, even more virtuous glass, and finishing the experimental portion of our joint project on "Making Prince Rupert's Drops Relevant".

Wiiliam C. LaCourse May 02, 2022 Wm. C. LaCourse

Electric Glass Fiber America, LLC

15 April 2022

Making "Hot Soup"

I'm absolutely thrilled by the dedication of the 2022 International Year of Glass (IYOG) and the National Day of Glass organized by the American Ceramic Society!

My passion for glass research started in 1992 during one of the coldest winters in United States history. Driving a U-Haul 2800 miles across nine states from Reno, NV, to Troy NY, my very first glass research project began at Rensselaer Polytechnic Institute. I was challenged by the extremes of studying SiO_2 glass and 30+ components of nuclear waste glass (a "cold" system). Learning from practice I became a *glass* scientist at the Pacific Northwest National Laboratory (PNNL) in 1994, focusing on "hot" waste glass formulation development. "Making hot soup" daily became my "hobby" at PNNL. One day I started thinking that it would be wonderful to make commercial "hot soup!" With that thought in mind, and luck on my side, I landed at PPG in Pittsburgh, PA. Ever since, my passion has been the discovery of the nature of oxide glasses for commercial applications, mostly for reinforcement glass fibers and some on laser applications (during a memorable, short tenure at SCHOTT). With PPG and presently Nippon Electric Glass, the patented "recipe book for hot soup" is growing thicker, covering applications of wind renewable energy, automobile, print circuit board, chemical transportation, etc. I truly appreciate the mentorship and support from the Glass Family, who have opened the door for me to participate in various society programs as highlighted by my activities in GOMD (past chair 2008-2009) and Council of International Commission on Glass (2010-2021). With the strong global support of my Glass Family, new monographs of ***Fiberglass Science and Technology*** and ***Development History of Ancient Chinese Glass Technology*** were recently published to celebrate IYOG 2022!

Glass has been a wonderful ingredient in my life……and being able to cook this "hot soup" makes me and everybody happy!

Hong Li

Senior Scientist, Nippon Electric Glass Co., Ltd.

GMIC
Glass Manufacturing Industry Council

550 Polaris Parkway, Suite 510, Westerville, Ohio 43082-7045
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American Glass Manufacturing – A Love Letter March 21, 2022

Dear American glass manufacturing,

how I love thee. Let me count the ways. I have loved you since you made the inkwell used at the signing of the Declaration of Independence, to the day man viewed the Earth through the glass ports of our spaceships. Of the many colorful stories in the remarkable history of the United States of America, none are better than those of American glass manufacturing.

The wheels of industry, our very quality of life, is made possible by the products of your factories, stocking the shelves of the world. Large American glass manufacturing companies, you are the powerhouse that supports every facet of modern life. While you, the smaller American glass manufacturing companies, serve our niche needs, laboratory glass and my childhood favorite cats eye marbles.

The very foundation of our global society, information technology, rests on your optical fibers. Your architectural glass has allowed us to transform our environment into living spaces full of light and warmth as well as efficient and attractive workspaces. Your glass inventions have transformed medicine, saving lives. I deeply admire your commitment to sustainable communities.

This is the American glass manufacturing industry I have come to love. You are evident in the Chicago skyline. Under the marquee lights on Broadway. In the dust covered cab of a John Deere harvesting beans. Loading insulation into the beat up bed of a Ford pick-up. You have supported America as it invented assembly lines and personal computers, cell phones, television, and solar panels, sending rockets' contrails racing into space, leaving footprints on the moon.

American glass manufacturing, you cannot be denied, for you are the engine of industry and enterprise, your fires stoked by the fuel of relentless dreams. A cauldron blending myriad tongues and colors into a brash strutting unstoppable parade. I march with you, American glass manufacturing, down the streets of dreams, the boulevards of hope, to the promise of tomorrow.

Sincerely,

Robert E. Lipetz, MBA
Association Whisperer
Executive Director, Glass Manufacturing Industry Council
Founding Executive Director, Society of Chest Pain Centers
Founding Executive Director, Usable Glass Strength Coalition

Glasses to see beyond visible light.

After graduating under the direction of the late C. Austen Angell in 1999, I joined the Materials Science and Engineering department at the University of Arizona and started performing research on chalcogenide glasses. The goal was to do everything from fundamental glass science to fabricating optical sensing devices. One of the unique benefits of chalcogenide over oxide glasses is their wide transparency over the infrared wavelength range. This enables many technological applications such as thermal imaging (as shown below), bio-sensing, environmental monitoring or missile countermeasure among others.

We started developing glasses with the broadest optical window possible and broke the record for widest transparency in the infrared with GeTeI glasses. One of my first students, Allison Wilhelm, was awarded the Norbert Kreidl Award for that achievement in 2008. We also produced glasses that were both conducting and transparent in the infrared and used them as biosensors. They could simultaneously act as an electrode and an optical element to capture microorganisms such as virus or bacteria so we could collect their vibrational signature for selective identification.

One of the drawbacks of chalcogenide glasses is their low glass transition temperature which can limit their range of operation. But when life gives you lemon… it is actually a fantastic opportunity to study relaxation process below T_g without the need for high temperature furnace or to wait for millions of years. We were able to monitor relaxation in chalcogenide glasses at room temperature over 20 years thanks to my friend Jean-Pierre Guin who had carefully stored the samples he made during his PhD degree back in 2000. That allowed us to correlate the relaxation properties to the structure of the glass over a broad range of compositions. Structural relaxation of glasses is proving increasingly critical for technological applications in precision electronics and optics as the size of devices is reaching increasingly minute dimensions and any volume change can have dramatic consequences. It is a fascinating field still in need of much discovery for future generations of glass scientists.

Pierre Lucas, Apr 14, 2022

Lucas

From His Grandfather's Stories of Glass to Solid State Batteries: A Life's Journey in Glass Research and Development

Steve W. Martin, Anson Marston Distinguished Professor in Engineering and University Professor in the Department of Materials Science and Engineering at Iowa State University of Science & Technology grew up in Mt. Vernon, Ohio and within the shadow of the then PPG Glass plant. His grandfather worked at the glass plant and nearly every day after work he would stop by to see his grandchildren and talk about his work at the glass plant. His stories of hot glass and manufacturing glass instilled in the then quite young Martin a fascination with this unique material. Fast forward a few years to the early 1970s and the now graduate school bound Martin was faced with rapidly rising gas prices, quadrupling over night from $0.25/gallon to $1.00/gallon, and he realized that there had to be a better more energy efficient way to power vehicles with much less pollution. His undergraduate job as the Chemistry Department Librarian at Capital University in Bexley, Ohio allowed him to peruse the research journals as they came into the little library. One particular article by one particular physical chemist, Austen Angell at Purdue University, captured his attention: Professor Angell was using glass as a solid electrolyte to rapidly conduct Li^+ ions. One read and Martin was hooked. He could use his fascination with and passion for glass to develop new solid state batteries while working with one of the leading glass scientists in the world. Hence, Martin's lifelong work in glass to break our dependence on fossil fuel powered transportation was born.

Since graduating from Purdue in 1986, Martin has focused his research on understanding the fundamental aspects of how to create loosely bound Li^+ (and Na^+ ions) in glass so that they become so mobile that they can be used as fast ion conducting (FIC) glassy solid electrolytes (GSEs). He has examined the motion of these fascinating glasses using mechanical, thermal, electrical, optical, and magnetic probes to broaden and deepen his understanding of how it is that these mobile ions can become so decoupled, to use his mentor Austen Angell's terminology, from the disordered glassy "landscape" of the host glass. The extent of this decoupling, $\sim 10^{12}$, is equivalent to comparing the relative motion of the International Space Station (ISS) speeding around the earth, once every 90 minutes, to the motion of the earth's tectonic plates, moving about 0.3 m every 100 years. Such decoupling, while essential for FIC GSEs in solid state batteries is an incredibly fascinating problem. This fascination with such highly decoupled motions in glass combined with the incredible opportunity that they hold in breaking a centuries long dependence on fossil fuel powered transportation has driven Martin to not only work towards understanding the fundamental aspects of these fast motions but the technological potential they hold.

PennState
College of Earth
and Mineral Sciences

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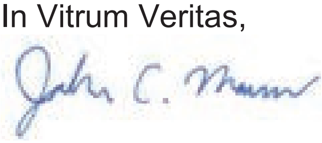
My Heart of Glass

My glass journey began at the young age of six when my parents took me to visit the Corning Museum of Glass. It was love at first sight. Fast forward a dozen years, and I found myself pursuing a double degree in Glass Engineering Science and Computer Science at Alfred University. At Alfred, I had the distinct pleasure of working with Dr. Arun Varshneya, who became my academic father, both as a B.S. student and continuing with my Ph.D. My professional career in glass began at Corning Incorporated, where I spent eleven years in the Modeling and Simulation department and seven years in Glass Research. In 2017, I finally made the leap to academia, becoming Professor of Materials Science and Engineering at Penn State University. Since then, I have published two textbooks (*Materials Kinetics* and *Fundamentals of Inorganic Glasses*, 3rd ed., co-authored with Dr. Varshneya) and been elected to the National Academy of Engineering and National Academy of Inventors.

Throughout my career, I've tried to embrace the whole of glass, including glass physics and chemistry, theory and experiment, and science and technology. I have been granted 65 U.S. patents, including numerous patents for Corning Gorilla® Glass compositions. I have invented new models for liquid viscosity (MYEGA), glass viscosity (MAP), statistical mechanics of glass structure, temperature-dependent constraint theory, and enthalpy landscape models of glass-forming systems. I also developed the theory of continuously broken ergodicity, which provides a general framework for describing glass transition and relaxation phenomena.

My advice to the next generation of glass students is to pursue your dreams. There will be plenty of people who tell you "no" or try to discourage you, but don't let anyone hold you back. If you have the vision and dedication, you can turn your dreams into reality!

In Vitrum Veritas,



Dr. John C. Mauro
National Academy of Engineering | National Academy of Inventors
Professor of Materials Science and Engineering
The Pennsylvania State University
March 23, 2022

Reflections on Glass

James W. McCauley, Johns Hopkins University, Hopkins Extreme Materials Institute
Chief Scientist (ST), Army Research Laboratory (Retired)

My most significant contributions have been to try to improve the performance of existing materials and determine new materials for use in ballistic armor applications, using a *Materials by Design (MbD), approach. This conceptually, describes a process for designing materials from the atomic to the macroscopic scale for a particular suite of mechanisms and properties that are required for defined performance/applications".* This becomes an exciting challenge for glasses since they are unconstrained by a repeatable atomic structure. Glass characteristics (chemistry, structure, defects) at the atomic (short range order), intermediate range order and macro-scale can affect critical mechanisms and properties. Over several decades I have been most passionate about trying to understand the multiscale behavior of materials which led to the study of glass and other transparent ceramics on different scales, from nano to micro to macro, and single crystals. This work demonstrated to me that collaborative, parallel experimental and theoretical (modeling/simulation) research efforts using MbD could be very important for glass. Collaborative research, therefor, was initiated using quantum mechanics, molecular mechanics, network dynamics and continuum finite elements for deformation and fracture studies at the global scale. Using designed and instrumented ballistic impacts, my team was able to demonstrate how wave and damage velocities differ in different glass materials. The results seemed to show that besides macro-defects, the size and distribution of the intermediate range order in the glass structure may contributes to local density fluctuation quasi-plasticity, deformation mechanisms and fracture. My work along with many collaborators, on AlON (transparent polycrystalline Al-O-N-spinel) and various glasses, hopefully, have resulted in saved lives on the battlefield.

I grew up in NY City. After receiving BS in geology from St. Joseph's College (Indiana), I attended Penn State University where I received both my MS and PhD in solid state science. My first employment was with Army Materials and Mechanics Research Center in Watertown, MA in 1968 becoming the founder and Chief of the Materials Characterization Division In 1980. I joined Alfred University in 1990 as the Dean of the NY State College of Ceramics. In 1997, I joined Army Research Laboratory, retiring eventually in 2013. Since 2014 I have been working as an adjunct research scientist at Johns Hopkins. Among other recognitions, I am a Past President and Distinguished Life member of the American Ceramic Society and an Academician for the World Academy of Ceramics.

My advice to the young: Find what you love to do and is challenging and do it regardless of the money. Then do good science/engineering, work hard, and do the right thing!

J. W. McCauley

Washington State University

School of Mechanical and Materials Engineering

Through a Glass Darkly

I never thought much about glass. It wasn't until I joined a microelectronics manufacturing company in the late 1990s that I started seeing it as an engineering material, first as a hermetic sealant for metal packages and pins. In the early-/mid-2000s I learned about glass as an opto-mechanical material, which had specific properties of dispersion for military applications. At the same time I was getting my PhD with (unbenownst to me at the time) a godfather of glass science, Don Uhlmann, then at University of Arizona, and we didn't even work on glass together! My interest was piqued more when I learned about bulk glasses and fibers for transmitting mid-infrared light. In an engineering company, it is often not possible to get materials properties needed for design, so during this time I learned about optical basicity, and found it to be highly useful for designing oxide glasses. Just as I was leaving industry and transitioning to the national laboratory system in 2008, I attended my first American Ceramic Society Glass and Optical Materials Division meeting in Tucson, my then home. I have been hooked ever since, on the material and on the community that is empassioned by it.

I benefited from colleague's previous research on chalcogenide glasses and began to understand structure-property relationships in chalcogenides. Later I learned Raman spectroscopy and grew to appreciate its critical role in understanding glass structure. I soon transitioned to studying nuclear waste glasses, focusing on complex chemistry and the effects of crystallization to understand behavior relevant to the safe disposal of radioactive waste in my home state of Washington.

I have now transitioned to academic life, and have since trained a new generation of glass scientists. One thing I would offer the future, is that glass is the most important material for protecting humanity from radioactive liquid waste, both now and in 10,000 years. Here glass is our protector, albeit dark glass. We cannot see through this glass, but it shields us from harm.

John S. McCloy is Professor in the School of Mechanical & Materials Engineering and Lindholm Endowed Chair in Materials Engineering at Washington State University. Prof. McCloy runs two research groups – the Nuclear, Optical, Magnetic, & Electronic (NOME) Materials Lab and the Institute of Materials Research (IMR). McCloy holds Materials Science & Engineering degrees from the MIT and the University of Arizona. From 2008-2013 he was with the Pacific Northwest National Laboratory.

John S. McCloy, PhD, Pullman, WA March 23, 2022

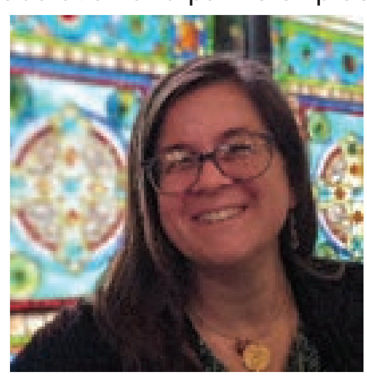
The Art of Glass and Light is a Tradition of Collaboration and Service

In 1903, the major stained glass firms joined together to form the Stained Glass Association of America (SGAA) to improve industry conditions. Many of these larger, older firms had been established by glass masters who had studied the art and business of the craft in Europe and came to America to strike out on their own. Now, 120 years later, the work of the association established by those early firms continues in the hands of their ancestors and talented new voices alike. While the issues and education of the organization have evolved, the need to collaborate and share knowledge has lost none of its potency.

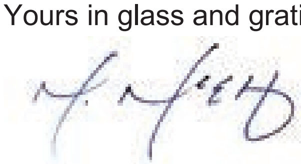
Today, thanks to numerous studies, we know beyond any shadow of doubt that access to light in our great spaces is absolutely essential to the fabric of healthy communities. We celebrate humankind in our buildings—the inescapable environment of monumental stained glass. Whether it is the many-layered opalescent hues of a Tiffany window in a soaring sanctuary or the intricately painted grisaille windows in a humble French chapel, the power of light to heal in these spaces has never been more important to the souls striving to create a better world for the next generation. Glass is the ultimate vessel in our architecture as we strive to uplift our communities with the art of light. The push and pull of industry and art testing the boundaries of the medium allows us to connect to light in ever expanding ways.

Just as it has been for centuries, it is the master glazier's job to give the glass purpose. We stand on the shoulders of the giants who have come before us, knowing in their souls that ours is a task not simply of art, but of service. The finest craftspeople in the field see their work as a gift to the communities where it is installed. And in example after example, the installation of monumental glass in our public, sacred, civic, and private spaces brings communities together, improves education, uplifts the spirit, heals the mind, body, and soul.

It is an honor to continue the SGAA's great traditions of discovery, collaboration and partnership as we enter the Age of Glass, and to advocate on behalf of today's great masters of monumental glass art and the communities we serve.



Yours in glass and gratitude,



Megan McElfresh, *Executive Director*
The Stained Glass Association of America

Megan McElfresh is a third-generation glass artisan who became Executive Director of the SGAA in Fall of 2017. Her background in operations management and art history gives her unique qualifications as the leader for the National Trade Association as it approaches its 125th anniversary of service to the industry.

Jack Mecholsky's Perspective on Glass

The fracture of glass results in one of the most beautiful patterns in nature. The fracture surface is not only beautiful in the patterns developed but is also fractal, which means that the patterns developed contain information that links the macroscopic features to the atomic bonds. I have been blessed to be able to study this phenomenon for over five decades.

My passion in glass research is mainly due to two people: Pete Macedo and Roy Rice. I was a graduate student looking for a research topic and asked my undergraduate advisor to find a person who worked in materials. He suggested that I visit Dr. Macedo in the physics building at The Catholic University of America. I walked into the lab of Dr. Pedro Buarque de Macedo, a Brazilian professor who received his doctorate at the age of 19 and possessed great insight into the research process. Pete interrupted what he was doing to talk with me. He asked whether I knew anything about glass. I did not. He then proceeded to enrapture me with the beauty of glass structure and properties. Soon after, I started my Ph.D. research on chalcogenide glass and glass ceramics for infrared transmitting materials used in missile domes and IR windows with Dr. Macedo as my mentor. He taught me the importance of accurate experimental data. Once assured, he could develop a theory to align with the physical data. During my Ph.D. studies, I started part time work at the Naval Research Laboratory (NRL). There, I met my future lifelong friend, Dr. Steve Freiman, and Roy Rice. After a few days at NRL, I walked into one of the labs where Roy was working. He was on the microscope viewing a fracture surface. I asked if I could look. It was love at first sight! After many years of searching, I finally discovered an area of scientific study that would enthrall me. Pete Macedo and Roy Rice introduced me to the combination of a material that has endless potential and a research area that would consume me for the rest of my life. The fracture surface of brittle materials like glass contains the entire history of the fracture process in an artistic and informatively beautiful way. Mirror, mist, and hackle powerfully engage us in identifying the secrets of the fracture process. Steve Freiman and I combined fractography with fracture mechanics to produce a methodology I labelled Quantitative Fractography. Using the forensic tools we developed, we have aided the production of optical fibers for communication, the protection of solar mirrors for energy, and the forensic analysis of commercial glass products to improve production in industry. I always get excited when I look at a fracture surface. There is so much information present if we only take the time to look. I would encourage students to seek their passion and follow it. If you are not passionate about your work, you have not looked hard enough. Keep searching! As I discovered looking through Roy's microscope, once you find your passion, everything in life will appear much clearer; you can find happiness. There is so much beauty and information in nature that you will never be bored if you always continue to explore. There is so much more to learn about glass structure, properties, and applications that you can never stop learning, if you keep your mind open to it. Education is not the accumulation of facts, but rather the discovery of the passion around which you focus your life.

John J. Mecholsky, Jr.

Glass Age Collaborations

When I reflect on glass, I think of collaborating with Dr. L. David Pye. I first worked with David in 2005 on the launch of the first International Congress on Ceramics, and we continued to work on many projects together.

In late 2008, ACerS Past President David Pye and I met in my office in Westerville, Ohio. At that time, he proposed launching a new journal on applied glass science. Having worked with David before, my immediate answer was, “Great. Let’s make it happen.” The rest is history.

In the inaugural issue (2010) of IJAGS, David states, “The remarkable nature of glass itself dictates the need to publish the *International Journal of Applied Glass Science*… With its extraordinary flexibility in composition, methods of fabrication, and optical, chemical, electrical, thermal and mechanical properties, glass is arguably the most versatile material known to mankind…Yet, glass is the eye of science through which we focus on the microscopic universe and the cosmos and is regarded by many as a quintessential example of nanotechnology.”

David went on to edit many issues of IJAGS, contributing to its growth and success. In December 2016 issue, he announced his retirement as editor-in-chief. He also assembled a seminal issue of IJAGS proclaiming the arrival of the “Glass Age.” In his introduction (IJAGS, 7 [4] 407–408 (2016) DOI:10.1111/ijag.12258), David wrote the following: “…we are at a special moment in time where the arrival of the Glass Age can be declared with certainty and pride…Clearly glass has played a major role in advancing civilization and mankind throughout recorded history be it in the arts, architecture, transportation, medicine, communication, and, especially important, other branches of science.”

In closing, when I was asked to write about my involvement with glass, my thoughts immediately turned to my work with Dr. L. David Pye and our publication of the *International Journal of Applied Glass Science*. I am very proud that I played a role in helping to make this important journal a reality.

Mark Mecklenborg is the Executive Director of The American Ceramic Society (since 2019). Mecklenborg started with ACerS in 1995 as Director of Publications and served in various capacities, including Director of Meetings, Membership and Technical Publications, for the past 26 years. Prior to joining ACerS, Mecklenborg worked as product manager for SAE International. Mecklenborg started his professional career as a high school English and journalism teacher. He has an MBA from The Ohio State University and BS in English Education from Miami University.

Throughout my career and despite the great diversity of my scientific contributions, one mainstream objective has inspired my research activities from the very beginning: synthesizing new optical glassy materials for the fiber optic telecommunications technology, in particular glass compositions for the infrared region. Passive and active rare earth doped fibers for signal amplification have been developed in collaboration with industrial partners, as well as innovative fiber-based components to improve network capacity and meet the ever-growing market demand. For the renewable energy sector, fiber optic cables capable of transmitting focused sunlight beams have been developed and are being evaluated in operational systems. For medical applications, optogenetic probes are under development for neuroscience studies.

During the years of my scientific journey, though still underway, I was able to contemplate how far glass technology has faced challenges and is still in a state of growth and development. Each new glass composition developed and tailored to meet the specific needs of applications invokes the potential correlated with improvements and expectations. Supported by the continuous development of novel processes, glass materials and their related components promise to continue their rapid evolution. This is what drives my passion day after day.

I started my university career in Physics and chemistry at the Université de Rennes 1 (France), where I obtained my PhD degree in solid state chemistry in 1990. During my thesis, I explored new glass compositions, which led to the discovery of fluoroindate glasses and to the production of optical fibers for long-wave infrared applications. Several patents have been issued and a technology transfer to the French company Le Verre Fluoré has been completed. My postdoctoral studies led me to the Sao Paulo State University (UNESP, Brazil-1991), where I started my academic career and established strong partnerships with several persons from both the academic and industrial sectors. Among those, a visiting Professor at National Inorganic Materials in Tsukuba Japan (1994). In 2010, I was awarded the prestigious Canada Excellence Research Chair in Photonic Innovations for information and communication, which allowed me to pursue my research activities at the Centre for Optics, Photonics and Lasers (COPL) of Université Laval (Canada). My research team and I strive to push the boundaries of knowledge in the field of glassy materials and specialty optical fibers in order to provide innovative solutions to current societal challenges.

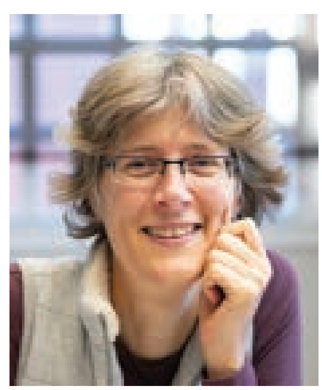
Glass has shaped the world more than any other material. The potential of glass materials is enormous and there is still much to be discovered and exploited by the next generation of researchers. Young scientists should keep in mind that glass and its by-products contribute significantly to the health, environment and telecommunications sectors, which have great impact on the society. They will need to dig deeper to explore new compositions, new properties and perhaps develop ingenious manufacturing processes to contribute to the society of the future.

Professor Younès Messaddeq
Centre d'Optique, Photonique et Laser (COPL),
Université Laval, QC, Québec, Canada

Following an Academic Career as Unstructured as Glass

Doris Möncke, Associate Professor of Glass Science, Alfred University

Looking back on 25 five years in glass science, I am grateful for all the random coincidences that brought me to where I am today, Alfred University in western New York. Unstructured like glass, my international career gave me tax IDs in 5 countries and may never work as a blueprint for young talent, though it worked perfectly for me. After studying chemistry in Germany, interspersed with studies abroad in Australia and Finland, my love for inorganic over organic chemistry led me to apply for a PhD position at the Otto-Schott Institute for Glass Chemistry—not having a clue what glass chemistry is and that I would be hooked for live. Dr. Ehrt was a great *Doktormutter*, teacher, and mentor in science. My thesis on *Irradiation Induced Defects in Glasses* introduced me to (fluoride-)phosphate and (boro-)silicate glasses, dopants, and spectroscopy. I still follow the long-term stability of irradiation defects of my samples. Dr. Kamitsos became my *PostDoc-Father*; we collaborated on structure property correlations of these glasses and increasingly of more complex systems including many induced structural modifications. I worked four years in Athens, Greece and I was honored as e*xternal scientific collaborator of NHRF* in 2016. Here started my most interdisciplinary achievement, fascinated by glasses from Roman and even Mycenean times, I was fortunate to conduct archaeometric research in Greece, and are now able to collaborate with the Corning Museum of Glass. For science, from photo-ionization to preferential bonding, I cannot pick a favorite. Much is summarized in my *habilitation* on the *"The Role of Modifier Cation in Various Glass Systems*" which I defended successfully 2017 in Germany. Though I had known about Alfred for many years before my first actual visit in 2016 as docent, it took another half year as visiting researcher in Sao Carlos, Brazil and one year as visiting professor in Sweden, before settling in New York. I did not know that twenty years after my first conference in the USA, the Borate Conference 2002 at Coe College, I would be on the organization committee that will host the Borate Conference 2023 in Corning, NY. In these years, ICG, SGT, and later ACerS welcomed me with open arms, as conference organizer, committee member, and today I am suddenly involved in CGIF and act as GOMD liaison to the ICG. The SGT designated me a fellow in 2018—before I started at Alfred, ACerS awarded me this honor this year. Now, with its long a tradition in glass engineering sciences and in glass art, I found the perfect place: to explore all aspects of glass science, work with industries, returning even to my early ambitions on environmental chemistry via contributions to a project on recycling, teaching and mentoring the next generation, including artists who crave the science of glass making. Alfred offers a crossover of glass makers and formers hardly found anywhere else. From where I am now, I can only tell those of you who are at the start of their careers, pursue your passions, take a risk, go abroad, learn from experts in the field. Be curious — take up the challenge of unproven hypotheses — a literature search of the original sources can reveal surprising openings to explore and enjoy. Everything else will fall into place.



Alfred, May 17th 2022

Reflections of glass

OS Narayanaswamy, Dearborn MI

I have an unusual background for a contributor to Glass Science. I got my bachelor's degree in Mechanical Engineering from the University of Madras, India. Then I went for higher studies in Canada. I got a Masters in Mechanical Engineering from The University of Saskachewan. The subject of my thesis: "Differential Shrinkage Stresses in a Composite Slab"! Next, I enrolled in a doctoral program in Engineering Mechanics at Case Institute of Technology (now part of Case Western Reserve University). I loved studying Continuum Mechanics and it proved useful later on. My formal education ended with a doctoral degree from Case. I began sending my resume to companies big and small.

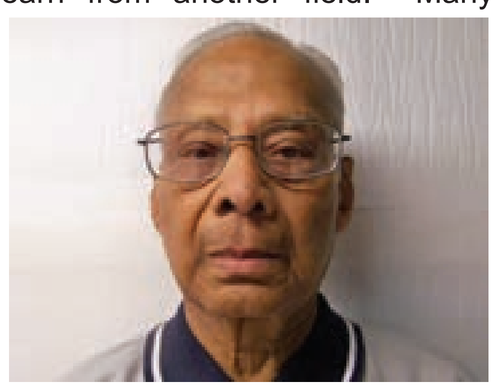
I got a call for an interview from Scientific Research Laboratory of Ford Motor Company. Dr. Gardon who hired me showed great interest in my master's thesis during the interview! I joined the research lab. with zero knowledge of Glass Science. Soon after joining I developed a passion for modeling various glass manufacturing processes. In the case of tempering and annealing processes I realized that I needed to learn some Glass Science which I did by reading the literature. I benefited greatly by reading Goldstein's review paper, "Modern Aspects of the Vitreous State". After a great deal of digesting glass literature, I came up with a model that yielded results in agreement with Dr. Gardon's experimental data on tempering and annealing of glass. I published the now famous paper: "A Model of Structural Relaxation in Glass". The paper had a significant impact on Glass Science and to my surprise influenced polymer scientists also.

After I retired, I consulted for Ford's Glass Division for few years and then for Asahi Glass of Japan. With the end of Asahi consulting contract, I retired for good. I believe my work for Ford and Asahi has enabled them to make safer glass products at lower cost.

Looking back, I count as my career highlights receiving Ross Coffin Purdy Award of The American Ceramic Society, getting selected fellow of The American Ceramic Society and authoring a Chapter on Annealing of Glass in a reference text.

My advice for young aspiring scientists: get a sound grasp of the fundamentals of subjects you are researching and be open to learn from another field. Many breakthrough discoveries were made by multidisciplinary approach. It has worked for me. Finally, I wish you all great success in your chosen careers.

June 25, 2022



14 April 2022

A Touch of Glass

Congratulations to the National Day of Glass in the celebration of International Year of Glass 2022!

I am very proud of being a member of Glass Family for 39 years, working at Nippon Electric Glass Co., Ltd (NEG). Focusing on manufacturing and commercial application of fiber glass products, I have seen the tremendous growth of fiber glass production and applications in the reinforced composites along with the worldwide growth of fiber glass industry in the past four decades. The strong market growth of fiber glass reinforced composites comes from a combined unique property set, including lightweight, strong, durable, stable, environmentally friendly, etc. It is a great honor for me to lead NEG's fiber glass business operation in the United States. A wide range of fiber glass products made in the US has been produced and used in the markets of automobile, housing, construction, wind generated energy, etc., NEG fiber glass manufacturing process continues seeking technology improvements on increasing glass melting efficiency and CO_2 emission reduction. Each of the fiber reinforced composite applications and production technology progress are essential in the contribution to the United Nation's Sustainability Development Goals.

Glass and Fiber Glass are wonderful for improving people's life around the world for centuries to come!

Hiroaki Nomura
Vice President / Glass Fiber, Nippon Electric Glass Co., Ltd.
President / Electric Glass Fiber America LLC

Ian L. Pegg
Vitreous State Laboratory
The Catholic University of America
Washington, DC

The use of glass for treatment and immobilization of hazardous and radioactive wastes is probably one of the less-well-known uses of this very versatile material. But it is a very important one. As a physical chemist, my own introduction came when I was a postdoc at the National Bureau of Standards (NBS, now NIST) doing research in phase transitions and critical phenomena. One of my collaborators, Professor Paul Meijer, a professor of physics at The Catholic University of America (CUA) and a Guest Scientist at NBS, introduced me to one of his faculty colleagues, Professor Pedro (Pete) Macedo, and I was hooked. Pete lived and breathed glass and all the things one could do with it (and many, it turned out, that one couldn't!). I ultimately moved over to CUA and joined the Vitreous State Laboratory (VSL) and the Physics faculty. There was an intriguing immediacy to the problems being worked that I found attractive and refreshing, with basic science entwined with real-life applications. In my first project, we developed the glass that was used to vitrify 600,000 gallons of HLW at the West Valley reprocessing site; that waste is now safely immobilized in 275 canisters. Interesting and challenging science while meeting new friends and colleagues, and the additional satisfaction of contributing to the mitigation of major environmental threats. I went on to work on many of the nuclear waste vitrification projects around the world and, with the enormous volumes of those waste and the sometimes frustrating pace of those projects, with many others, we're still at it. And lots of interesting and fulfilling challenges left for young glass scientists.

Dr. Ian L. Pegg is Professor of Physics and Director of the Vitreous State Laboratory (VSL) at CUA where he manages and directs a staff that has reached 110 scientists, engineers, and technicians. His research has spanned various areas of materials science including the optimization of processes and glass compositions for use in nuclear waste disposal, demonstration and scale-up of Joule-heated melting processes, geopolymers, nano-materials, and thermoelectrics. Dr. Pegg has served as a technical team member on several successful multi-billion-dollar treatment facility proposals, including the WTP privatization at Hanford and the AMWTP privatization at Idaho. Dr. Pegg directs the Hanford WTP vitrification research and technology support effort at VSL and similar R&D efforts for the DWPF at the Savannah River Site, the Rokkasho vitrification facility in Japan, and the Sellafield site in the UK. Dr. Pegg has been a frequent participant on expert review teams for the Department of Energy, the National Academies of Sciences, the GAO, and the IAEA. He is the Chair of The International Advisory Committee for the UK TRANCEND Programme for waste management technology development, a partnership of eleven UK universities, Sellafield Ltd, the UK National Nuclear Laboratory, and the UK NDA. He is the co-founder of three advanced materials and green-tech companies. He has directed Ph.D research in both physics and chemistry. He previously held positions at NIST and in the Department of Chemistry and Biochemistry at UCLA. He holds a Ph.D in physical chemistry as well as MBA and B.Sc degrees. Dr. Pegg's publications include over 250 papers, over 30 patents and patent applications, and over 600 refereed technical reports.

Civilization, Glass and Science

James Charles Phillips, Physics Dept., Rutgers Univ.

While metals were first made ~10,000 years ago, glasses began to be made only ~ 5000 years ago. Metals crystallize, and crystals are easily studied by X rays. In 1932 W. H. Zachariasen published "The Atomic Arrangement in Glass", an X ray article that described glass as a randomly disordered network. In 1972 Phil Anderson discussed ordering of spins on a lattice, and was rapidly awarded the Nobel Prize in 1977. The basic question about glassy materials is why they don't crystallize, but instead solidify without crystallizing. In 1979 I found some simple examples of covalently bonded alloys of S and Se with Ge and/or As, where the glass transition occurs best at a certain average coordination number, which was calculated successfully: Topology of Non-Crystalline Solids, JNCS 34,153-181. On re-reading this paper today with its 12 figures, I was struck by how much was already known even then about the complex chemistry and physics of covalently bonded networks.

Since then, a lot has happened, especially strong and flexible Gorilla glass. Phase changes in new chalcogenide alloys (near $Ge_2Sb_2Te_5$) are very fast (as short as 1 ns), and these nonvolatile NAND and DRAM devices are today at the cutting edge of computer memory technology.

Of course, such industrial success is gratifying, but it also suggests theory could look for new directions. There are two broad classes of self-organized, off-lattice networks: glasses and proteins. The 21st century database for proteins is vast, and much of it is available online, where it is very well organized. It includes data on static structures, as well as amino acid sequences derived from the DNA of many species. If one thinks in Newtonian terms, one can obtain dynamics by putting modern computers to work with interatomic forces determined empirically. This now can work for proteins containing up to 100 amino acids, but the average protein size is 350 amino acids. Simplifying tricks have turned out to be (1) proteins function reversibly, and hence evolve towards critical points of phase transitions, and (2) all proteins are shaped in water. Results: many, such as accurate predictions of evolution of Coronavirus (1200 amino acids) contagiousness (Phys A 2021 and arXiv 2020-2022).

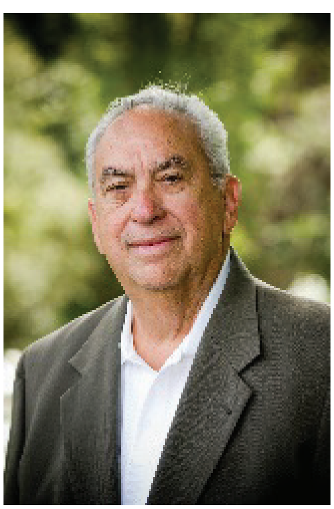
Phillips received PhD from Univ of Chicago 1956 (Physics, M. H. Cohen) and had postdoc positions at Bell (with Herring), Berkeley (with Charles Kittel), Cambridge (with Sir Nevill Mott). He joined Univ of Chicago as Physics faculty 1960-68), Bell (1960–1996; we did develop the internet), and Rutgers Physics (1996-present). He has published more than 500 papers and authored four books. His rigidity percolation concepts are some of the more researched and discussed topics in condensed disordered solids such as glass since the 1980s.
March 28, 2022

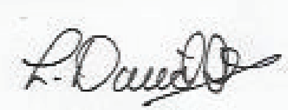
Reflections – Taking a Look Back

L. David Pye, Dean and Professor of Glass Science, Emeritus, Alfred University

The 5 year period following graduation from Alfred University with a BS in Ceramic Engineering included employment as a research engineer with Pittsburgh Plate Glass Co. and Bausch & Lomb Inc., graduate studies at the University of Rochester, and service as an Officer in the US Army. After receiving a PhD from Alfred, accepted appointment as Assist. Prof. of Glass Science, Chair of the Department of Glass Science, and charged with revitalizing the glass science programs at Alfred. In this professorial role, convened several inaugural conferences, co-led the establishment of an Institute of Glass Science, and the winning of a national competition to organize an NSF Center for Glass Research at Alfred. Additionally, co-led the creation of a PhD program in Glass Science; served as GOMD Chair and Trustee of ACerS; collaborated with colleagues across the globe on a variety of initiatives; and served as thesis advisor to 10 PhD and 36 MS students. As Dean of the College of Ceramics, conceived and dedicated the Van Dereck Frechette International Friendship Park; finalized funding for the John F. McMahon Chair in Ceramic Engineering; explored new programs in materials science and electronic arts; celebrated the Centennial Anniversary of the College; and served as President of the International Commission on Glass. Upon retirement from Alfred, served as President of ACerS and Founding Editor of the International Journal of Applied Glass Science and pursued stained glass artistry. Following conceptualization, co-led and achieved something akin to a professional capstone or, if you will, a personal magnus opus, i.e., making possible The United Nations declaring 2022 the International Year of Glass. The pursuit of this initiative gave rise to new forages into professional organizations, glass-themed museums, libraries, universities, and collaborating with some extraordinary individuals across the globe.

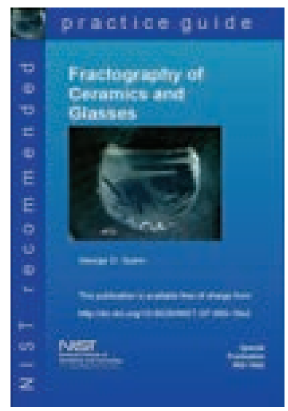
The above journey was made possible by the tremendous support and encouragement received from friends, students, past giants in glass science, art, engineering and above all - family. Special thanks are given to those students who chose to become part of my professional life, and let me become part of theirs. As for game changers/mentors in this journey, there were many including my high school English Teacher, Catherine Steinert who convinced me to enroll at Alfred University. Then there was Norbert Kriedl, Larry Lawrence, Van Frechette, William Prindle, Harrie Stevens, William LaCourse, James McCauley, Innocent Joseph, Margaret Rasmussen, Alex Marker, Kathryn Logan, Arun Varshneya, Manoj Choudhary, Charles Craig, Kathleen Richardson plus the faculty/staffs of the College of Ceramics and ACerS. Adding to this list are many overseas friends - Alicia Duran, Helmut Schaeffer, Angelo Montenero, Jorge Loredo, Adrian Wright, John Parker, Edgar Zanotto, Naohiro Soga, Alev Yaraman, Fabiano Nicoletti, Ivan Gutzow, Oleg Mazurin and many, many others. In preparing the above remarks, I can only conclude I was blessed, perhaps, for “having done something good in my childhood.”





George D. Quinn
National Institute of Standards and Technology
Stop 8520
Gaithersburg, MD 20899-001

My most gratifying contribution to glass science has been in fractography, the field of study of fracture in components and structures. Building on the accomplishments of predecessors such as Frank Preston and Van Fréchette, I extended the state of the art and distilled it into one definitive publication: a *Guide to Fractography of Ceramics and Glasses,* a free publication of the National Institute of Standards and Technology. This document blends materials science with practical applications. It has brought me great joy to "get my arms wrapped around" this important minor branch of physical science and to share the knowledge with scientists, engineers, and students worldwide.



Some erroneously regard fractographic analysis as a subjective practice. It is in fact very objective to an experienced fractographer. The curse of brittle materials such as glass is that they are prone to catastrophic fracture. Nature has compensated for this by furnishing clear fracture patterns and fracture surface markings that provide a wealth of interpretable information. These patterns and markings are the direct consequence of crack perturbations during propagation. In many respects, fractographic analysis of glasses is easier and produces more quantitative information than fractographic analysis of metals or polymers.

Why did it break? What was the origin of failure? Did it break as expected or from an unexpected cause? A fractographer is a detective who knows how to look, where to look, what to look for, and how to interpret what he or she sees. The pieces tell a story. The detective uses powers of observation to study the "scene of the fracture" and meticulously collects and preserves the evidence. The clues are contemplated and weighed against the available background information. Keeping an open mind for all possible scenarios, the detective formulates a hypothesis and checks it against the known facts. Definitive fracture origins and causes of fracture can be found in many cases.

It has been my great pleasure to expand this scientific knowhow and to share it with novices and pros alike, either through the book or through the many topical courses on fractography that I have taught.

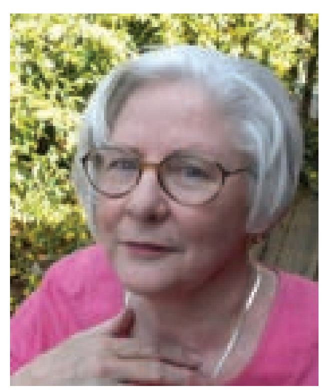
May 26, 2022

Reflections: Margaret Byrd Adams Rasmussen

With diploma in hand from the University of South Carolina in 1964, the world was wide open for a cum laude, Phi Beta Kappa graduate. Photojournalist, freelance writer, and author, I entered the field of public relations and marketing at institutions of higher education. In 1985, I came to Alfred University to develop the public relations program, transferred to the New York State College of Ceramics on the staff of the Center for Advanced Technology as a technical writer before moving to the Center for Glass Research.

When the New York State College of Ceramics at Alfred University met the criteria, the National Science Foundation Industry-University Center for Glass Research (IUCGR), I signed on as assistant director for communications to offer my experience in journalism and public relations to help bring the industry-university collaboration to fruition. With a US Department of Education fellowship for technical information research to the University at Buffalo, I earned a masters degree to advance my skills in technical writing and publishing. As founding editor of *the GlassResearcher: Bulletin of Glass Science and Engineering* for 13 years, I collaborated with a dedicated Editorial Advisory Board to publish the cutting edge research of glass scientists and engineers. They pioneered development of advanced glass material for nuclear waste containment, bio-medical applications, communications, harsh environments, and optics and other unimagined applications. *the GlassResearcher* was privileged to share their collaborations and vision on its pages to advance the progress of glass material into the 21st century.

With past presidents of the International Commission on Glass (ICG) L. David Pye and Helmut A. Schaeffer, I edited "Proceedings of the First International Workshop on the Photonics Revolution," (May 28-29, 2002, Bad Soden, Germany), a milestone in glass history. The volume is a permanent record of the forum that brought together the best minds in glass with the best minds in photonics from around the world to build a foundation for joint research. With masters degrees in history from Alfred University and University of Rochester, I studied the founding in 1900 of the School of Clayworking at Alfred by Englishman Charles Fergus Binns as the only institution in the US to offer both science and art of ceramics in one college. When 1929 alumnus Paul Vickers Gardner, first curator of glass and ceramics at the National Museum of Natural History, endowed the PVGGC for history and education of glass science and art, I was named founding executive director.



Retired from the Center for Glass Research in 2004, I have been honored as a Fellow of the American Ceramic Society, New York State Chancellors Award for Excellence, and the privilege of working with the world's finest minds in glass science and engineering.

Margaret B.A. Rasmussen

My most exciting journey: Crossing the bright and dark side of glass science, engineering and education

Kathleen A. Richardson

I didn't know that a multitude of experiences and special people would come together enabling me to see the bright and dark sides of glass – *literally and figuratively,* traveling the globe. Firstly, let me be clear on '***dark***' – I made the choice in my late 20's, when I chose to leave a 'real' job at the University of Rochester's Laser Laboratory (UR-LLE), and return to Alfred University to get my PhD that I would work on non-oxide, chalcogenide glasses. While I loved laser glass which took me Hoya Optics working with Dr. Tetsuro Izumitani and Schott AG in Germany, I needed a new challenge in optical glasses. I recognized then that the infrared portion of the electro-magnetic spectrum would eventually become important. So ***dark*** here means black glass – as chalcogenides often are. I was fortunate to have wonderful mentors and collaborators who aided in my glass science foundational skills - now 40 years since graduating with my BS in Ceramic Engineering from Alfred University. ***Bright*** is in having had amazing partners and collaborators – firstly my husband who saw me as the only woman engineer at LLE and said, "of course you can do this and our Optics community needs new materials." Then, there was the cold call from my collaborators of now almost two decades, from the μ-Photonics lab at MIT, who decided they wanted to integrate infrared (IR) glass into their planar devices. Drs. Kimerling, Agarwal and Hu have become great partners who have pulled glasses with diverse and unique properties, out of lab and onto chips that now have resulted in commercialized products, numerous 'firsts and bests', international awards and most importantly, a cadre of motivated and cross-disciplinary students from our labs. It is these 'formers' that have gone on to do great things, largely in industry and labs where they too practice their craft in IR glasses, that I am perhaps most proud of.

So. my glass life is full, thanks to this wonderful medium of optical glass. With it, I've served our community in various leadership roles, first in the American Ceramic Society (ACerS) as GOMD chair and then ACerS President, and on the other side of my optical materials fence, in Board and leadership roles in SPIE and Optica (OSA). These opportunities have taken me far from Rochester, New York, to places I could have only dreamt of as a high school junior attending Explorer camp in Kodak's laboratories. Fortunately, due in part to Lou Shayler, my grade school next door neighbor from Bausch & Lomb and a fellow Alfred University glass alum, L. David Pye my undergraduate advisor, and my very special first boss, the late Stephen D. Jacobs, my journey has been a brilliant one. And so, with the IYOG in full swing, the journey continues.

Kathleen Richardson
Pegasus Professor of Optics and Materials Science & Engineering
CREOL, The Center for Optics and Photonics
University of Central Florida

Reflections on Glass

Subhash Risbud

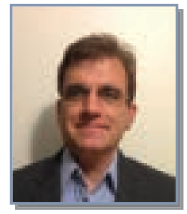
Over the last 45 years I have been involved in a variety of glass projects that have benefitted mankind in various ways. Examples include promoting more use of recycled cullet in glass production, making non-oxide glasses and most of all educating students at multiple universities in glass science and technology. It has been a joy to share my passion for glasses emanating from the enduring appeal of age-old colorful glass windows that adorn churches and temples.

Brief Bio: After my B.Tech degree in Metallurgical Engineering from IIT Bombay in 1969 I arrived in Berkeley and got my M.S. degree in Ceramics with Dick Fulrath. Eager to get some work experience, I worked for 2 years as a Crystal Grower at Stanford and Ceramic Engineer at GTE Sylvania before returning to Berkeley to finish my Ph.D. with Joe Pask in 1976. I have enjoyed a 45-year academic career in glass research and teaching at the University of Nebraska, Lehigh, Illinois at Urbana Champaign, Arizona in Tucson and the University of California at Davis. At UC-Davis my roles include: Department Chair, Blacutt-Underwood Endowed Chair, and Director of the Internship and Career Center. For some 10 years I was a Visiting Professor at Stanford University. My early work on was on phase separation in silica-alumina glasses followed by oxynitride-oxycarbide glasses, and semiconductor quantum dots in glasses. Recently we studied effects of femtosecond laser pulses on glass structure/properties, nanoporous silica glasses and aerogels. My collaborative work has resulted in about 300 publications, seven patents, and the book ***Introduction to Phase Equilibria in Ceramics.*** Awards include the Ross Coffin Purdy Award, Fulbright Lecturer, CEC Outstanding Educator Award, Norbert Kreidl Award, Academician of the World Academy of Ceramics and the W.D. Kingery Award.

Message to the Young: Get involved with glass research as undergraduates..

Professor Subhash C. Risbud
University of California at Davis
Davis CA

June 8, 2022



Glass Reflections

Glass has enabled our scientists and societies to observe and better understand the worlds that exist in a small drop of pond water to as far away as galaxies tens of billions of light years distant. Glass is also a functional material present in many of the objects we utilize daily. The past decades have seen transformative changes in the glass industry. Innovations related to coatings on glass in addition to the physics and chemistry of glass processing provide/enhance many of the modern day glass functionalities. For example, in today's automotive glass business, manufacturers use more glass surface area and complex shapes. Over the past 30 years, slower less energy efficient gravity-sag forming processes have evolved into high speed press bend forming operations for more precise shape control, deeper more complex bend shape capabilities, quick change tooling, and faster rates. Glass-ceramic enamel coatings printed around the periphery are fused and sintered to the glass substrate during these forming operations. These black glass-ceramic enamel coatings provide UV protection for the underlying adhesive that bonds the glass substrate to the vehicle frame for structural strength. The black enamels also provide decorative functionality by hiding the unevenness of the adhesive bond layer and are often overprinted with hidden conductive silver pastes for electronics, antennas, defrosters. Evolution of the low temperature glass in the enamel has led to improvements in more environmentally sustainable, faster reacting, higher chemical durability systems that no longer require a rubber strip around each piece of glass in a vehicle for the approximately 90 +- Million cars and trucks produced each year.

I am proud to see our contributions to low melting specialty glasses result in more environmentally sustainable automotive enamels that have been applied to a very high percentage of the automobiles produced in the world for the last 25 years. I am also proud to have helped evolve sustainability with contributions to glass forming, sealing-bonding, finite element modeling, sol-gel silica processing, glasses for electronic materials, and glass coating technologies for: art, wall tiles, packaging, table ware, ceramic glazes, lighting, display glass, appliance glass, architectural glass, laser bonding, bio-glass, and solar energy generation. I have been blessed with opportunities to work with brilliant and inspirational colleagues over the past 40+ years in R&D, sales, manufacturing, as well as academia, and professional organizations (such as ACerS, CGR, GMIC, SGCD, etc) to be able to implement these innovations. None of this would have been possible without these global glass industry colleagues and team work.

Thinner, lighter, stronger glass for improved vehicle fuel and building efficiencies as well as improved structural integrity and compatibility with other functional coatings continue to evolve. Photo-voltaic glass may hold solutions to our energy needs. Future generations are encouraged to pursue a career in Glass as there are still many possibilities to be discovered for a safer and more sustainable planet.

Dr. George E. Sakoske is Glass Coatings & Concepts President and General Manager. He earned a Ph.D. and M.S. from Case Western Reserve University, a B.S. and B.A. from Alfred University. He worked 11 years at GE Lighting as an Edison Engineer and Scientist. He next joined Cerdec's Glass Systems R&D as a Staff Scientist progressing to Global Director of Glass Development. Next, he became Ferro's Global Technology Director Glass Systems, then Global R&D Director Color Solutions. George holds 63 US patents in these glass technology areas.

3/21/2022

George E. Sakoske

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CORNING

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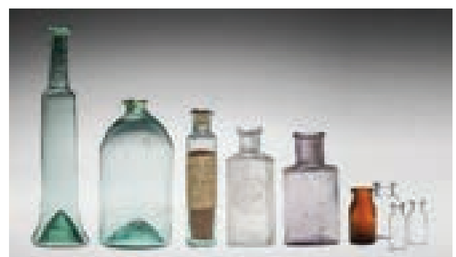
Biography Dr. Robert Schaut was appointed Scientific Director for Pharmaceutical Packaging in 2019, supporting the Corning Pharmaceutical Technologies business, and is a Research Fellow in the Science & Technology division at Corning Incorporated. In these roles, he brings materials science expertise for glass pharmaceutical packaging - identifying new materials and working to describe technology advances to pharmaceutical manufacturers and regulatory agencies.

Robert earned his B.S. in Ceramic Engineering & Glass Science from Alfred University in 2002 and his Ph.D. in Materials Science and Engineering from The Pennsylvania State University in 2008. Since joining Corning in 2008, Robert has researched glass ceramics, Corning® Gorilla® Glasses, and borosilicate and aluminosilicate glasses for pharmaceutical packaging. He is a co-inventor of Valor® Glass and has co-authored 14 peer-reviewed articles, two book chapters, 115 technical reports, and more than 100 patent applications. Robert has been granted 66 patents and is a member of the American Ceramic Society and the Parenteral Drug Association.

Personal reflections



I first became interested in materials and their properties by my exposure to stained glass and ceramic arts during high school. My curiosity about the origins of glass color and about the material changes occurring during firing led me to explore glass science at Alfred and Penn State Universities. Even today, my fascination with glass science is a gateway to continue exploring glass and ceramic arts.

Over the years, my exposures to chemical strengthening of EpiPens, artistic glassblowing, borosilicate flameworking, corrosion mechanisms, and boron chemistry at surfaces had serendipitously prepared me to innovate new glasses for pharmaceutical packaging. These experiences helped the Corning research team understand the origins of surface chemistry changes during tube-to-vial converting that cause delamination flakes and enabled the invention of boron-free glasses with excellent chemical durability that can be chemical strengthened.

During the invention of Corning Valor® Glass, no one anticipated a pandemic would occur where glass packaging became a critical resource for the distribution of life-saving treatments and billions of doses of vaccines. I am proud of Corning's role in introducing an innovative packaging solution such as Valor® Glass and Velocity® Vials and expanding existing capacity to alleviate pharmaceutical manufacturing constraints and accelerate delivery of medicines across the US and worldwide.

In the coming years, innovations in drug formulations and delivery – including self-dosing pen autoinjectors, intradermal injections, lipid nanoparticle-based formulations, and cell & gene therapies – will place new and increasing demands on glass components. Engineered surfaces, innovative coatings, and new glass compositions will all be needed to fulfill these demands. I am excited to work with the next generation of scientists and engineers to develop these innovations and ultimately deliver life-saving medications with improved quality to patients around the world.

29 April 2022

In the fall 1960, not quite 18 years old, I was the first in my generational blue-collar family to enter college (Rutgers University College of Engineering). A dream come true thanks to scholarships and a big step up from my eighth-grade guidance counselor's advice that I was not "college material". In my sophomore year I chose ceramic engineering (intrigued by ceramic rocket nose cones and exhaust nozzles) and in my senior year (1964) I was awarded an NSF Fellowship paving my way to a PhD in ceramics science. That year I met Professors Norbert Kreidl and CJ Phillips who introduced me to the magical world of glass technology. I was hooked and have followed that glassy path ever since. Little did I know then what an exciting, challenging and rewarding path that would be!

My PhD thesis was on growing lithium ferrite crystals in silicate glasses (a serendipitous discovery when I overloaded a glass batch with iron) and subject of my first patent. Armed with my doctorate diploma in 1967, I accepted an entry level research scientist job at Corning Glass Works (the "mecca of glass technology" according to my thesis advisors and mentors Kreidl and Phillips) and assigned my own lab and the wonderful exploratory research opportunity to "see what you can do with the flame hydrolysis process used to make fused silica". I began to "dope" fused silica with everything but the kitchen sink and measure the properties of the resultant glasses (most had never been made before). Soon afterwards, Corning physicist Bob Maurer asked for my assistance in a project to try to make low loss glass optical waveguides (what fiber optics were then called). A small team was created (adding physicist Don Keck and draw engineer Frank Zimar). Learning from numerous experimental "failures", we succeeded in making a breakthrough low loss 17 dB/km fiber in 1970. Finally, after creating the OVD process and using GeO_2 as the core dopant, we achieved 4 dB/km in 1972. To this day, almost every fiber manufactured and deployed (now in the billions of kilometers) employ these basic processes and compositions. What a joy to have been an integral part of those inventions, discoveries and developments! Low loss, high information capacity fiber optics have transformed the world of communications. Combined with personal computers, user friendly software, smart phones and tablets, the world is now truly interconnected.

After 17 years as a researcher at Corning, I left to work at a startup fiber optic company in Massachusetts (SpecTran). Thanks in part to this risky career move, I was hired in 1988 by Heraeus Quarzglas GmBH to be President of their American operations, a position I held until retiring in 2001. Since "retiring" I continue to work almost full time as an independent technical consultant (see www.peterschultzconsulting.com) for numerous international companies, almost always dealing with fused silica and fiber optics. After 55 years (1967 to 2022) I continue to pursue my dream of helping to solve technical problems in this field (even though I'm "not college material"!).

Peter C. Schultz

Reflections on Glass

Sabyasachi Sen, University of California, Davis CA

What have you done with glass that benefits the human race:

Investigated the structure-property relationship in glasses and the relaxation mechanisms of their parent liquids for the optimization of their processing and compositional engineering for a wide range of technological applications including ultra-low loss telecommunication and flat panel display.

What is your passion about glass

To understand the fundamental origin of non-exponential, non-Arrhenius and non-linear relaxation phenomena in this intriguing class of materials.

How did you get to be where you are

Sabyasachi Sen obtained his M.S. in Geological Sciences from University of Houston where he got interested in natural glasses formed during volcanic eruption and meteorite impact. That interest eventually led him to glass science and technology. After finishing a short stint working with Prof. Alex Navrotsky in Princeton University on thermodynamic measurements on glasses and glass-ceramics, he moved to the west coast to follow his passion to pursue NMR spectroscopic studies of glass structure and relaxation and completed his Ph.D. in 1996 from Stanford University under the guidance of Prof. Jonathan Stebbins, where he was a postdoctoral fellow until 1997. He then joined the Faculty of Physics at the University of Wales in UK, where he was until 1998 and worked with Late Prof. Neville Greaves on various glass-related problems. From 1999 until 2004, he was a senior scientist in the glass research group at Corning Incorporated, where he focused on developing glasses for long-distance telecommunication and TFT display. He joined the Faculty of Materials Science and Engineering at UC Davis in 2004, where he served as the vice-Chair and now holds the Blacutt-Underwood Professorship. His current research interests include the development and application of state-of-the-art spectroscopic, diffraction and rheological techniques to study atomic structure and dynamical phenomena in amorphous and crystalline matter. He has authored/co-authored more than 250 scientific papers on glasses and ceramics and is the recipient of several awards in glass science.

Any message to the young

Don't take established ideas for granted- question the status quo.

Reflections on Glass

Glass has been an extremely important part of my life; the art, science, manufacturing processes, useful applications and more. Probably my most important contributions to those fields, and perhaps to mankind itself, were made as an employee of Corning Incorporated. They include photochromic glass (smart sunglasses that darken in sunlight and clear in the shade), glass optical polarizers (Polarcor™) used in optical fiber communication and information technology, high purity silica glass found in stepper camera lenses used in IC (integrated circuit) manufacturing, and more.

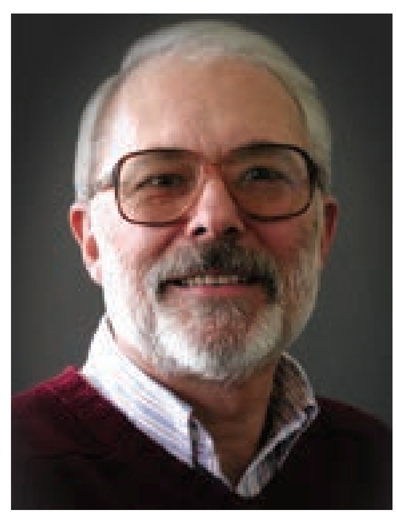
My passion has always been to understand the behavior of multi-phase glass-based materials and discover useful properties and applications that could be derived from them. Much of my career involved phase-separated glasses (two glass phases) and glasses containing dispersions of nano-scale metal and halide phases. I also had a passion for making things. So, when the properties led to products that could be made by unusual or unique processes, so much the better.

While in graduate school, my thesis advisor, David Turnbull, told me of his belief that any liquid could be formed into a glass, if only it could be cooled rapidly enough to avoid crystallization. This intrigued me and ultimately led me to pursue the study of glass as a career. This choice was complicated because of a concurrent interest in solidification processes in metal systems, perhaps stimulated in part by studying Bruce Chalmers' fascinating book *Solidification*; my career could have gone in either direction. It turned out that these fields ultimately melded together when I started working professionally with multi-phased oxide glass-based systems.

I was fortunate to have joined Corning (then Corning Glass Works) at a time when the company allowed and even encouraged researchers to explore ideas outside their assigned project areas. Reporting to managers who generated and pursued new ideas themselves, and who led by example, was a great help too. I was again fortunate, later in my career, to spend time sharing ideas and experience as a faculty member at Alfred University.

My advice to young scientists and engineers would be to find subject areas and an environment where you are happy in your work at least half the time, where you have the freedom and facilities to pursue new ideas some of the time, and where your employers/sponsors recognize and reward your value. If not, find a way to move on.

Thomas P. Seward III, Ph.D.

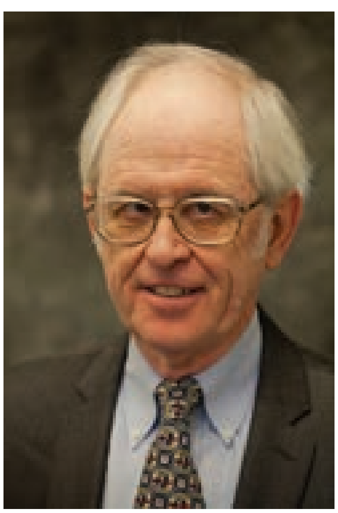


Gas Transport and the Glass of Wine

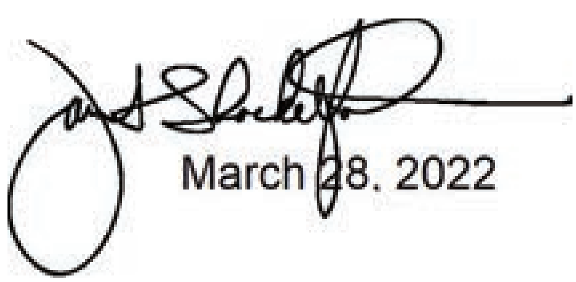
My fascination with glass began as an undergraduate major in Ceramic Engineering at the University of Washington and continued at the University of California, Berkeley, where I did my PhD thesis under Richard Fulrath on the transport of gases through glass, focusing on the solubility of gasses in vitreous silica. I found that solubility could be nicely modeled with statistical mechanics, providing quantitative values for the size distribution of interstices in the glass. This information was timely as such medium range order was of great interest in the 1970s. I continued to focus on this topic and its applications for the next 40 years during my time on the faculty at the University of California, Davis. Much of this work is summarized in a 2011 review paper.[1]

Ironically, the topic of gas transport arose in a very different context when my wife, Penelope, and I produced a book for Wiley/ACerS on the intersection of the glass and wine industries.[2] This was a natural topic for us, given our wine travels (often in conjunction with attending glass conferences around the world) and the fact that UC Davis is home to the leading wine program in America. The *lack of oxygen transport*, as well as culture and tradition, have made glass bottles the standard container for wine for centuries. *So, let us raise a glass of wine to the National Day of Glass!*

James F. Shackelford is Distinguished Professor Emeritus in the Department of Materials Science and Engineering at the University of California, Davis. He arrived at UC Davis after BS and MS degrees at the University of Washington, Seattle and a postdoctoral fellowship at McMaster University in Canada. He is the solo author of "*Introduction to Materials Science for Engineers*" now in its 9th Edition and which has been translated into Chinese, German, Italian, Japanese, Korean, Portuguese, and Spanish. He is also a co-editor of the *CRC Materials Science and Engineering Handbook* now in its 4th Edition



[1]J.F. Shackelford, *Intl. J. Appl. Glass Sci.*, **2** 85-95 (2011).
[2]J.F. Shackelford and P.L Shackelford, *The Glass of Wine*, Wiley/ACerS (2018).



Reflections on Glass
James E. Shelby

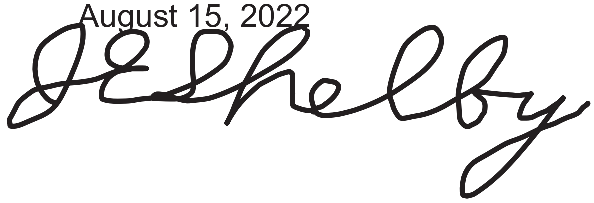
I taught for 26 years at Alfred University, where I advised over 70 graduate degrees. After noting that women were sadly underrepresented in graduate school as opposed to undergraduate school, I made it a goal to recruit as many women into graduate work as possible. As a result, I advised 35 M.S. and 6 Ph.D. degrees by women students. I have continued this support by funding an endowed scholarship for women undergraduates in Materials Science and Ceramic Engineering at MS&T. I consider this support for women student to be one of my major contributions to the field of glass.

I have authored approximately 300 journal and proceeding articles and book chapters on glasses and glass-ceramics. I also authored 2 books: Introduction to Glass Science and Technology (Eds. 1, 2, &3) and Handbook of Gas Diffusion in Solids and Melts, and edited a third: Rare Elements in Glasses. My research included major contributions in understanding gas permeation and diffusion in glasses and glass-ceramics, hydrogen reaction with glasses, gas solubility in melts, water diffusion and solubility in glasses and melts, rare elements as components of glasses, properties of silicate, borate, and germanate glasses, with emphasis on the roles of aluminum and gallium on glass properties and structure, and the effect of phase separation on the properties of glasses.

I discovered the wonders of glass science as an undergraduate at U. Missouri at Rolla in an introductory class taught by Delbert Day. (I never ceased to be fascinated by the incredible range of behavior of glasses and their intrinsic beauty.) I continued under his advising for my M.S. and Ph.D. in Ceramic Engineering, with a thesis on the internal friction of mixed alkali silicate glasses. I then worked at Sandia National Laboratories in Livermore, CA from 1968 to 1982, where I developed a method for measuring gas permeation in glasses which greatly expanded the range of compositions which could be studied. In 1982, I moved to Alfred University, where I served as a professor of glass science and as the McMahon Professor of Ceramic Engineering until retirement in 2011.

My message to young people considering a career in glass science and technology: If you find, as I did, a career where you love going to work every morning, you will be able to retire knowing that your life was successful.

August 15, 2022



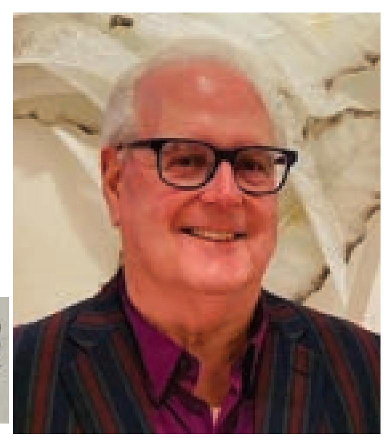
Reflections on Contemporary Glass Art
Laurence A. Sibrack, MD, PhD

My interest in the medium of glass as an expression of contemporary art started over 33 years ago. Initially, we collected vessels and vases of cased glass manufactured in the 1950s and 60s primarily from the American midwest. Our attraction was to the form of the vessel and the extraordinary vibrant exterior color and its interaction with light.

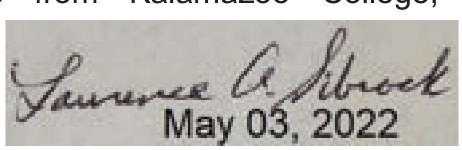
Soon, thereafter, we frequented craft fairs, art fairs and galleries where our passion for collecting expanded to sculptural forms created by individual artists in their personal or institutional studios. The art made from glass represented all of the processes of glass making. There were objects made by blowing and sculpting, casting, lamp working, kiln formed, and stained glass. There was a broad range in scale with works that were figurative, abstract, geometric, and amorphous. The art works ranged from a strong narrative concept to an attraction of simple or complex form.

As the depth of our collection evolved, we started traveling internationally with other collectors and galleries. We met most of the artists directly who are represented in our collection. This lead to a greater depth of understanding of the narrative behind their work and their inspiration. We became part of the community of collectors through the Art Alliance for Contemporary Glass in 2013. Also, for at least 15 years, I have been an art docent at the Baker Museum in Naples, Florida. I would often lecture, tour, or be a panel member focusing on exhibits related to contemporary art made from glass. Furthermore, I have lectured for the Creative Glass Center of America (Wheaton Village of Art, New Jersey) and at the Glass Art Society Annual conference on the relationship of art made from the medium of glass and its relationship to the broader contemporary fine art world.

Our passion for glass as an art medium was influenced by the unique expression that glass allows from the fire to the form. The interaction of light creates a unique visual experience through transparency, translucency, reflection, and refraction. The surface cold working of glass creates a textural and transformative quality that can mimic other mediums like stone, metal, clay, and even wood. Contemporary art made from glass has expanded to 21st century fine art manifested as conceptual, architectural, installations utilizing all of the current technological modalities which is accessible to today's artist. The International Year of Glass in 2022 will launch even greater creativity into the future.



Laurence A. Sibrack is the President of the Art Alliance for Contemporary Glass (AACG) whose mission is the further the development and appreciation of art made from glass.
He is also on the Board of the Friends of Art, Chair of Programming of the Visual and Performing Arts and an art docent at the Baker Museum in Naples, Fl. He is a retired dermatologist with degrees from Kalamazoo College, University of Michigan, University of Pennsylvania, and Yale University.



Alfred University

INAMORI SCHOOL OF ENGINEERING
AT THE NEW YORK STATE COLLEGE OF CERAMICS

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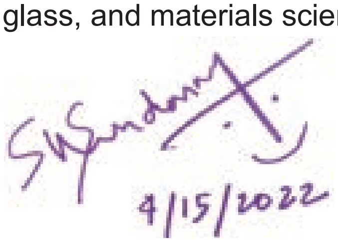
Through my looking Glass

Understanding glasses require thinking fast and slow involving relaxation time (τ) and observation time (t). I look at glasses in ultrafast time scales, e.g., femtosecond (10^{-15}s), attosecond (10^{-18}s), and beyond. We have recently shown glass structure and properties can be modified in a few femtoseconds and clustering of silica nanospheres can happen in a few attoseconds[1]. With the Nobel prize in Physics 2018 recognizing Gérard Mourou and Donna Strickland "*for their method of generating high-intensity, ultra-short optical pulses*," and advances being made in generation of ultrashort laser pulses world-wide with a push for Extreme Light Infrastructure (ELI), these tools provide unprecedented access to study, understand, and modify matter including glasses and discover new forms of matter or glasses in a fraction of a second in the future.

Glass melting and forming are thermally intensive processes. Besides fundamental understanding of glasses in ultrafast time scales, my contribution is specifically towards reducing thermal penalty of these processes by applying ultrashort pulses to form, control, and modify the glass structure and properties that will reduce environmental impact of these processes, thus extending and improving the comforts of human existence. My message to the younger generation is glasses can be produced with the least environmental impact to our Earth. Ultrashort pulses can help. The future of the glasses is extremely bright.

I am an Inamori Professor of Materials Science and Engineering (Endowed Chair) at the Inamori School of Engineering, The New York State College of Ceramics at Alfred University appointed in 2011. Prior to joining Alfred University, I was a Chief Materials Scientist over 2002-10 serving the Pacific Northwest National Laboratory for over 16 years. My major areas of interest and contributions are millimeter/THz wave science and technology, ultrafast materials science and engineering, extreme materials processing, and additive manufacturing, focused on glasses and ceramics. I have published over 150 papers and scientific and reports, made over 200 scientific/technical presentations, edited/contributed to 21 books, and taught, mentored, and supported over 200 students in ceramics, glass, and materials science and engineering.



Laser Reflections

Tayyab Suratwala, Lawrence Livermore National Laboratories, Livermore CA

Being a Materials Scientist trained in glass & ceramics with a concentration in optics, I found myself at the right place and the right time to contribute to the advancement of cutting-edge glass optics for use in high power & energy laser systems. At the LLNL, I help build the world's most powerful laser system, the National Ignition Facility (NIF) to conduct high energy density physics & fusion energy research. The NIF has 192 laser beams with an aperture size of ~35 cm, housing >7000 ~0.5m scale optics. The NIF needed optics with 7.5x more beam area which had to survive 12x the laser fluence (energy/area) than its predecessor laser system (Nova): two daunting challenges!

Glass processing materials science was a key component of what was needed to make this a success, which included solving technical challenges such as developing & fabricating the Nd-doped phosphate laser glass and improving the laser damage resistance of fused silica glass optics. Today, NIF successfully and routinely operates at these high power & energy levels (500TW/1.8MJ). Recent laser shots have put us within grasp of fusion ignition (i.e., more energy generated relative to the input laser energy). I am proud to be part of a great team that made this happen, from R&D into production, and I am equally driven to aid in the future advances for even higher power-energy levels.

Advice to the next generation scientists: I recommend striving for a career/research area that has the combination of doing something that you: 1) love and are excited about (i.e., what gets you up in the morning!), 2) have a talent for, and 3) can make a living with. You need to interface with folks both in your field and even other fields of research. Get involved with the community (conferences, societies, etc.). Finally, on a more tactical note, I recommend learning to 'tell-a-direct-story' when presenting your work. Tell the final 'story' as a straight path from the beginning to the end showing the interconnections, not necessarily the complex path you followed. Also, have your 'story' conclusions.

Bio: Tayyab Suratwala has been at LLNL for the last 25 years and is currently the Program Director for Optics and Materials Science & Technology (OMST) in the NIF & Photon Science Directorate. Tayyab earned a B.S. in Ceramic Engineering from the U. of Illinois at Urbana-Champaign in 1992 and a Ph.D. in Materials Science & Engineering from the U. of Arizona in 1996. His research interests include: grinding and polishing, deterministic finishing, laser damage initiation and growth, chemical and thermal based mitigation of damage precursors and damage sites, fracture behavior in glasses and ceramics, slow crack growth, glass chemistry, optical properties of glasses, and sol-gel chemistry. Tayyab has 100+ peer reviewed publications including 8 patents/patent applications, 4 R&D100 awards,1 book chapter, and 1 book (*Materials Science & Technology of Optical Fabrication*). Tayyab is a Fellow of Optica. For more information visit https://people.llnl.gov/suratwala1

Tayyab Suratwala (May 2022)

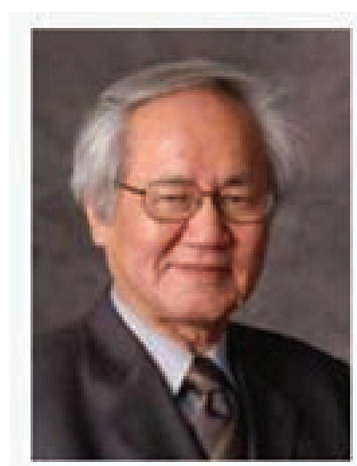
Water in Glass and I

Minoru Tomozawa, Rensselaer Polytechnic Institute, Troy NY

After graduating from a University in Japan, I was employed as a material engineer at Nippon Electric Co. (NEC). It was a time when materials called “semi-conductors” became new fashionable materials and I was one of those who were attracted to the fashion. But at NEC I was assigned to an old factory where traditional electron tubes were produced. Many electron tubes were made of evacuated glass tubes and my job was to investigate glass properties such that glass vacuum tubes can be made without leakage or breakage. By reading relevant literatures, I learned of some glass scientists in places such as Sheffield University in UK, RPI in USA and Kyoto University in Japan. Occasionally, I attended meetings of the Japanese Ceramic Society but had no experience of presenting my own research result. From these activities, I realized how little I knew about glass. In NEC, there was a research building where scientists with Doctors’ degrees were working and I visited one there occasionally to ask questions. Around that time, I had seen a new device called a laser and heard about a color television being produced in USA. It was clear that world was changing rapidly. In 1965, I was admitted to the graduate school of University of Pennsylvania in Philadelphia as a research assistant and received a travel grant from Fulbright program. At the graduate school, I was the oldest graduate student in my class since I spent five years at NEC in Japan.

While I was a Post-Doc at RPI under Professor MacCrone, in 1969, Professor Mackenzie moved from Rensselaer to UCLA, and I was hired as a new assistant professor on glass science. I was not sure, whether I will be able to teach properly in English and get research funds from any sponsor.

Somehow I got interested in the effects of water in glass on properties stimulated by Professor Scholze’s article (Glass Industry (1966) 546). While I was planning to write a proposal on the subject, I met a new, young professor in Geology, Bruce Watson, who joined our university. When I mentioned my interest, he told me that he can put a large quantity of water into glasses under high pressure and we decided to collaborate. Metallurgists use electron microscope to magnify the structures of metals. With glasses, we cannot do the same but we can magnify the effect of water by adding large quantities of water. Our collaboration continued for several years and led to various interesting phenomena of water-containing glasses including radiation-coloration-resistance.



Throughout my research career on glasses, I found it most interesting to find the cause of some mysterious phenomena. I came across the following ancient Roman message: “Happy is the man, who finds the cause of things”, which represents my pleasure in glass research.

Glass Reflections

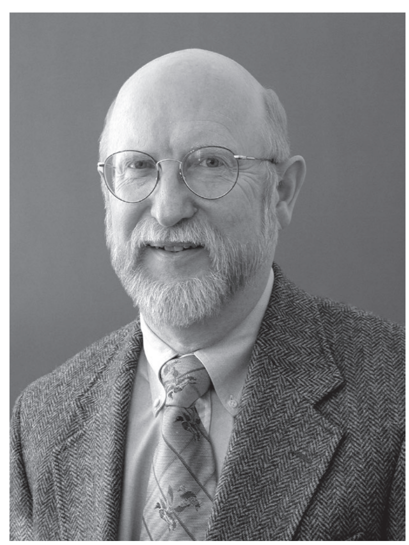
James R. Varner, Hornell NY

My passion for glass dates back to when I was a high-school student and was given a tour through the Brockway Glass bottle factory in Brockway, PA (now owned by Owens-Illinois). The sight of and the heat of hot molten glass in the tank and in the gobs sliding down the troughs into the molds, with finished bottles coming out, captivated me. That decided me on Ceramic Engineering, and I found my way to the New York State College of Ceramics at Alfred University, where I got my B.S., M.S., and Ph.D. in Ceramics. My senior-thesis advisor was Prof. Van Derck Fréchette, and my passion for glass deepened through working with him. He introduced me to the world of glass fracture, specifically fractography – how to study fracture, analyze it, and prevent it.

Prof. Fréchette was a pioneer in fractography of glass (and ceramics), and I followed in his footsteps, beginning with my senior thesis, and continuing with my PhD research on slow crack growth in glass. At the time, Alfred University was one of the very few places where scientists knew how to produce and observe slow crack growth in glass. I still remember watching a crack grow at 1 mm/sec or less. Astonishing!

I think I have two things with glass that have benefitted mankind. One is my research, including that done by my students, that helped explain how contact cracks are produced on glass surfaces, how these cracks affect glass strength, and what can be done to glass surfaces to minimize contact damage. The second is my teaching others how to do failure analysis (fractography) of glass. Over 30 years or so, I have introduced several hundred people to fractography, working with Prof. Fréchette before his retirement, and then with George Quinn for 25 years.

My advice to the young is to develop their own passion for this most remarkable material, to participate in conferences, and to cultivate friendships with fellow glass scientists and engineers in the United States and around the world. Truly become a member of the worldwide glass community.



Reflections on Glass

I consider four items my own contributions to the world of glass.

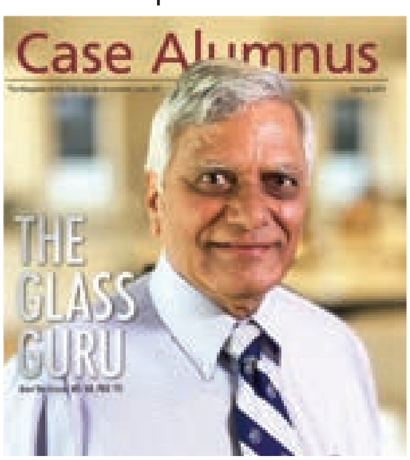
(1) When you see an EpiPen® or an Amneal® autoinjector to combat life-threatening anaphylaxis shock from severe allergies to bee-stings, peanut, and shell foods, it works reliably since my understanding of glass science and technology has gone into ensuring that the chemically strengthened borosilicate glass cartridge which delivers the epinephrine has very little risk of glass fracture during the device administration. In supplying nearly 0.5 billion of these glass cartridges over the past 25 years, the staff of Saxon Glass Technologies helps save thousands of lives each year and I am proud of it.

(2) I contributed heavily to the understanding of glass chemical strengthening science and technology. I will leave it to you to guess if Saxon Glass and Alfred Univ were where chemical strengthening of the cell phone cover experiments originated.

(3) Go ahead and pick up a textbook on glass to educate yourself. Chances are you would love it when you read, "*Fundamentals of Inorganic Glasses*", now in its 3rd edition, co-authored with my own former student, John Mauro. The book is written in simple and clear English. It covers fundamentals in breadth but then goes into deep science when needed. I am quite proud of it.

(4) My former students from those thirty years at Alfred University; many opening new horizons in glass. Oh wow, what a pleasure and what a treasure! I have enjoyed receiving the label "Glass Guru".

Despite wealthy parents, my beginnings in India were humble from US standards. I survived a seriously malfunctioning liver at around 3 years of age. But the love and dedication of parents (and a dose of 8 oz cow urine each day for 6 months) cured me. Sure, I was a great student and loved by most of my teachers in India. My dad told me to go study glass technology at the University of Sheffield in 1962. Never looked back. Just happened to be running into Professor Alfred R. Cooper who brought me to Case Western Reserve for graduate school in 1965. After Ford Scientific Labs and GE Lighting, I became a teacher myself. What a karma? Destiny! No matter which way I look, the World of Glass has been quite kind to me so far. And I hope the love is mutual.



My message to the young: Contrary to the popular belief that grass is always greener on the other side, grass is uniformly brown everywhere. Work with what you have.

AKVarshneya
March 23, 2022

Arun K. Varshneya
Professor of Glass Science & Engineering, Emeritus
Alfred University
President, Saxon Glass Technologies, Inc., Alfred NY

Eva M. Vogel contributed to the enhancement of worldwide communication.

Ph.D. (1994) Technology of Silicates, Slovak Technical University, Bratislava, Slovakia.
B.S./M.S. (1969) Chemical Engineering, Slovak Technical University, Bratislava, Czechoslovakia.

1970-2006 at AT&T Bell Labs, Bellcore, and Lucent – Bell Labs.

Eva M. Vogel is internationally recognized in the glass community for the demonstration of all-optical switching devices based on high optical nonlinearities. Her approach to optimize the glass composition for high optical nonlinearities summarized in an invited review paper "Nonlinear Optical Phenomena in Glass" is cited in many of the publications about novel optical devices. Her key collaborators were, Denise Krol, Marvin Weber, and Janet Jackel. Vogel's article "Glasses as Non-linear Photonic Materials" was selected for "Glass: Then and Now" highlights by ACerS Journal editors in the January 2022 ACerS Bulletin.

Eva M. Vogel's contribution to materials engineering spanned many fields from discovery of new composition of glasses to development of electronic ceramics, including ferrites and superconductors. As a result of her contribution to the reliability of the optical devices she was invited to serve as Senior Expert Adviser in Quality Assurance of Optical Fiber Systems, Equipment, and Cables within the International Telecommunication Union (ITU) Program for India and Brasil.

Eva is featured in the book *Successful Women Ceramic and Glass Scientists and Engineers: 100 Inspirational Profiles*, (Wiley 2016).

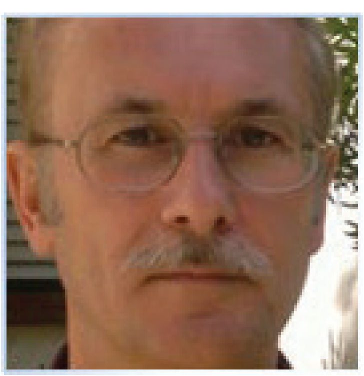
A brief message to the young: To be excited about your work, you have to love science. You define what success is for you—teaching a science class, synthesis of a new compound, or be a CEO of a company. Do not have other people define your success.

Going without the flow – making odd glasses

Glass is amazing stuff. Its composition is unconstrained, its properties isotropic, and its structure rather indeterminate. In addition to its enigmatic traits, glass can be worked into complex shapes by blowing, drawing, pressing, rolling or even floating on liquid tin! Glass is often transparent to the eye. It can host all sorts of additives to provide valuable properties. The majority of glass is formed by supercooling liquids. I study liquids that don't easily make glass. These "fragile liquids," as Austen Angell termed them, often crystallize rather than form the viscous, sluggish materials that typically make glass. By avoiding contact during melting and importantly cooling, many fragile liquids from pharmaceutical compounds through molten metal oxides and some metallic alloys can be coaxed to make glasses. Even though it might not be possible to make them in large pieces, these glasses are useful performance benchmarks. They can guide R&D to improve the high-volume materials and suggest areas to search for new ones.

My research on fragile liquids uses a variety of techniques including levitation melting with laser beam heating, synchrotron x-ray and neutron scattering and nuclear magnetic resonance to investigate liquid and glass atomic structure, and experiments on the International Space Station to measure liquid transport properties. I have been fortunate to work with extremely talented colleagues at MDI and collaborators in universities, national labs and industry. It is particularly enjoyable to work with students. Their ideas, like a glass composition, are unconstrained. I encourage anyone who enjoys exploring new areas and solving puzzles to look into glass. While it often appears to be perfectly transparent, it hides its secrets well.

Richard Weber founded Materials Development, Inc. in 2006. MDI develops, uses and sells innovative instruments for processing and investigating materials in extreme environments. In addition to commercial work, current research and collaborations include investigations of properties and structure of molten nuclear fuels, pharmaceutical materials and microgravity measurements of thermophysical properties of molten metal oxides. Prior to forming MDI, Weber was VP for Research at Containerless Research, Inc. a company that he co-founded and where he led the team that developed REAl(TM) Glass. Weber is an Argonne Associate at DOE's Advanced Photon Source. He earned a BSc first class in Metallurgy from Sir John Cass College London in 1983 and a PhD and DIC from the Department of Materials, Imperial College London in 1986 and became a Chartered Engineer (CEng) in 1990. He has authored/co-authored about 200 publications and 5 patents.



April 03, 2022

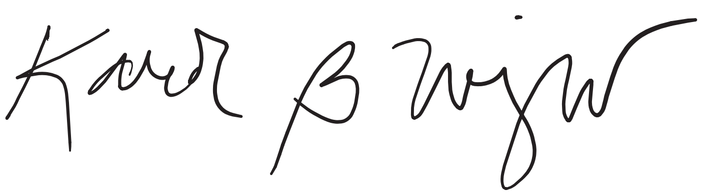
Richard Weber
President

Reflections on Glass Artifacts

Dr. Karol B. Wight, President and Executive Director, The Corning Museum of Glass

At The Corning Museum of Glass, our mission is to inspire people to see glass in a new light. Since it opened to the public in 1951, The Corning Museum of Glass has become a place where visitors, artists, scholars, scientists and collectors can learn about glass from all eras. The Museum's campus is home to the world's most comprehensive collection of glass, the world's foremost library on glass (the Rakow Research Library), and one of the top glassmaking schools in the world (the Studio). With over 50,000 objects representing more than 3,500 years of history, the Museum aims to be the authority on glass art and its history.

I hold a Ph.D. in art history, and as part of my academic training at UCLA, I studied the cultural remains of the ancient Mediterranean world. This led to a position as a curator in the Antiquities Department at the J. Paul Getty Museum, Los Angeles, where I specialized in the study of ancient Roman glass. My work focused on the history of glassmaking techniques, and in particular, the making of mold-blown glass of the first century CE. I was fascinated to learn that even more than 2,000 years ago, innovative glassmakers collaborated with ceramics manufacturers to design molds for glassblowing, and then created shapes and designs with function in mind. This specialization ultimately led me to my current role at The Corning Museum of Glass. Through our print publications, programs, exhibitions and virtual offerings our vision is to be the international leader in transforming the world's understand of the art, history and science of glass. What a career in a museum can offer is an opportunity to share the narratives of the past with the audiences of today and create ties across time that bring the past closer to the present. We aim to share the versatile material that is glass in all of its manifestations and hope to spark the next student, artist, scientist or engineer to fall in love with this material as deeply as we have in order to discover the next application for glass that will change our lives.



Oldcastle BuildingEnvelope
A CRH COMPANY

My Years in Flat Glass

In this UN designated 2022 Year of Glass, what could be more exciting then working in architectural flat glass! You see it everywhere you go, as it is used in essentially every building. And it provides so many services and benefits, from keeping weather out, providing daylight and its many benefits, to providing comfort, safety and security.

Despite embarrassing my very understanding and forgiving wife of 50+ years, Malinda, I continue to look for the Oldcastle name on glass products everywhere we go.

My interest in glass started with my BS degree in Ceramic Science from The Pennsylvania State University in 1969. That is also where I first learned about the sport of fencing and went on to become Penn State's first fencing All-American.

After initial positions in ceramic research with Boeing Aerospace and Owens-Illinois, I started my flat glass career with CE Glass in Cinnaminson, NJ, in float glass manufacturing in 1973. In 1981 I entered the flat glass fabrication industry with Hordis Brothers in Pennsauken, NJ, which after many acquisitions grew into Oldcastle BuildingEnvelope, the largest glass and glazing fabricator in North America with over 80 locations. As the Director of Technical Services for over 25 glass fabrication plants producing tempered, heat-strengthened, insulating, laminated, spandrel, silk-screened and decorative glass products, I lead a team providing technical support and training to production, sales., customer service, marketing and management. I like to think that I have contributed in some small way to the architectural landscape of North America.

My position has enabled me to travel the world, be a guest speaker for many glass related associations and companies, and be active in many associations including SIGMA, GANA, NGA, IGCC, SGCC, Center for Professional Advancement, American Ceramic Society, and ASTM where I have been the Chairman of Committee C14 on Glass and Glass Products for 12 years, and the Chairman of Subcommittee C14.08 on Flat Glass for 29 years.

Finally, to those looking for a career in an exciting, fun, challenging, interesting, and very visible part of our world, I strongly suggest considering the world of architectural glass.

Rick Wright

April 23, 2022

1273 N. Church Street ▪ Suite 100A ▪ Moorestown, New Jersey 08057 ▪ www.obe.com ▪ Phone (856) 642-0900 ▪ Fax (856) 642-0810

DALHOUSIE UNIVERSITY

GET THE LEAD OUT!

One contribution I've made in glass science that I'm particularly proud of is our work on the influence of lead-containing compounds on the properties of glass, and particularly, the development of design rules to find other, less toxic replacements that give the same properties. This work involved a deep dive into the chemistry and physics of something well-known in glass engineering, that is, that lead confers attractive optical properties in glass. We were able to devise a highly predictive correlation between the chemical bonding types in a glass formulation and its likely optical and stress response, and then using chemical intuition, find and make many lead-free alternatives. This approach leads ultimately to safer and long-term more sustainable glasses for use in many different optical and communications systems.

Glass science has been a highly rewarding area to work in, and I'd encourage young researchers in chemistry and physics to consider it strongly. Some materials become trendy for a while, and then people move on, but glass as a research topic is especially rich, and evergreen, because there is a wealth of practical, empirical knowledge about how to make it and what additives to try, but surprisingly little chemical and physical understanding as to how and why the various formulations behave the way they do.

My undergraduate education was in chemistry at the University of Chicago, and my PhD is from Cornell University, where I studied molecular spectroscopy with Ed Grant. I wanted to make a change as a post-doctoral researcher, and was fortunate enough to work with Alex Pines at Berkeley, where I learned about and developed methods for solid-state NMR. At my first faculty position, at Indiana University in 1990, I wanted to apply NMR to a difficult problem, and that's when I began glass research. This led into complementary work with neutron and x-ray diffraction. Eventually in 2003 I moved to Dalhousie, to take up a Canada Research Chair, and that's where our stress-optic research on lead-free glass really took off.

Josef W. Zwanziger
Professor of Chemistry and Canada Research Chair in NMR Studies of Materials
Dalhousie University
Halifax, NS B3H 4R2 Canada

Photo Gallery

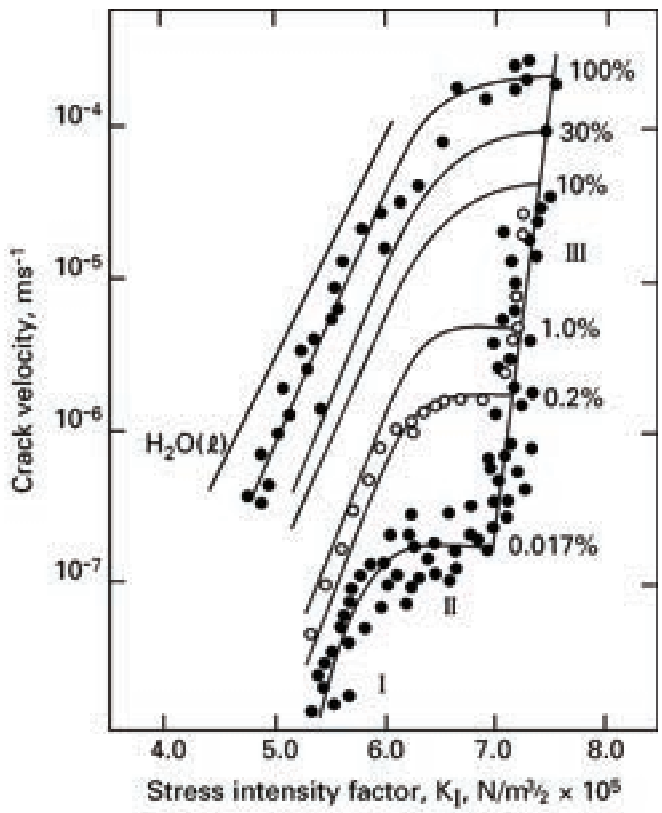
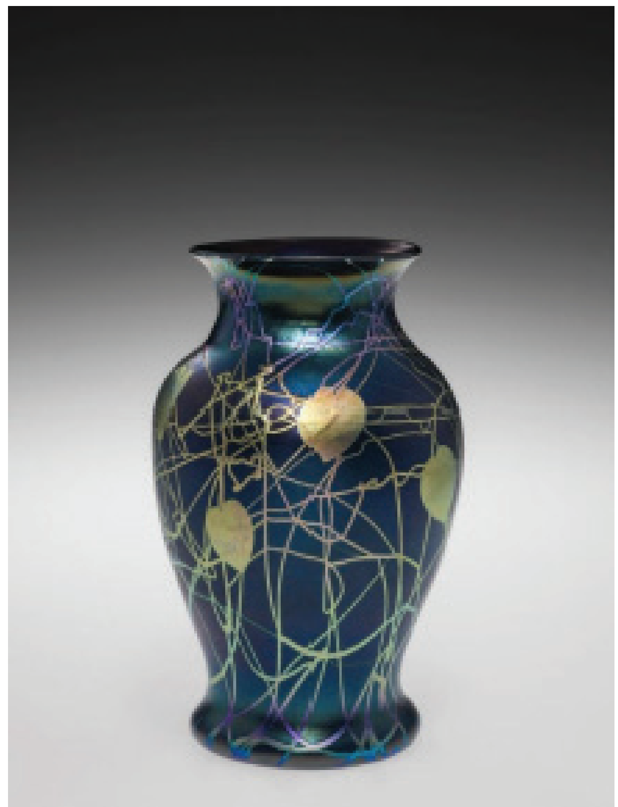


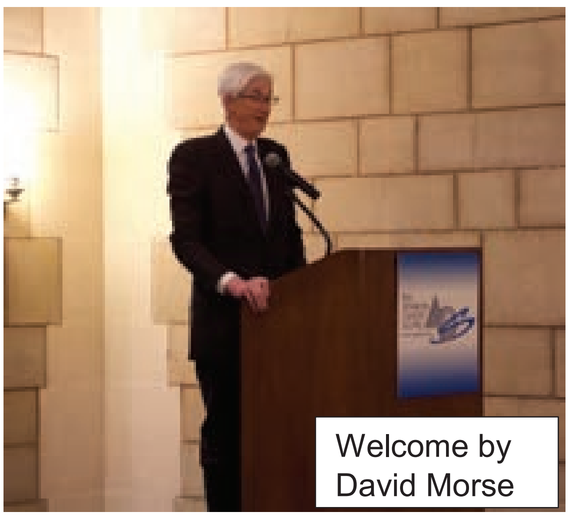
Figure describing how tiny cracks in glass propagate under applied stress and humidity level, hence, control glass strength. *After S. M. Wiederhorn, J. Amer. Ceram. Soc. 50(1967) 407.*



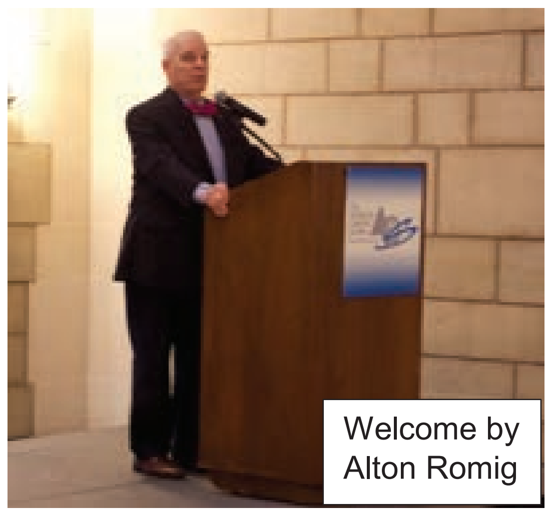
Gift of Corning Glass Works. Courtesy of The Corning Museum of Glass, Corning, NY

Welcome Reception
April 05, 2022
National Academy of Sciences

Conference co-chairs:
Kathleen Richardson
Mario Affatigato



Welcome by
David Morse



Welcome by
Alton Romig

Gang Chen and Kathy Jordan

Stephen Eskilson

Steering committee chair Manoj Choudhary

Welcome by Kathleen Richardson


Corning Inc president Wendell Weeks


ICG president Reinhard Conradt


Schott AG R&D VP Matthias Mueller


Manoj Choudhary and Kathy Jordan

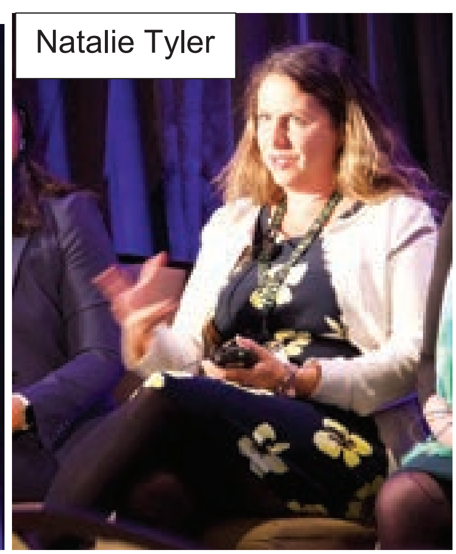

ACerS president
Elizabeth Dickey
Lisa Klein


Santokh Badesha
Matthias Muller
Arun Varshneya

Ludovic Valette VP, Global technology O-I


Mathieu Bauchy

Kelvin Droegemeier


Natalie Tyler

Sethuraman Panchnathan
Director NSF

Tammy Ma
Dy Dir, LLNL

Richard Brow

Manoj Choudhary

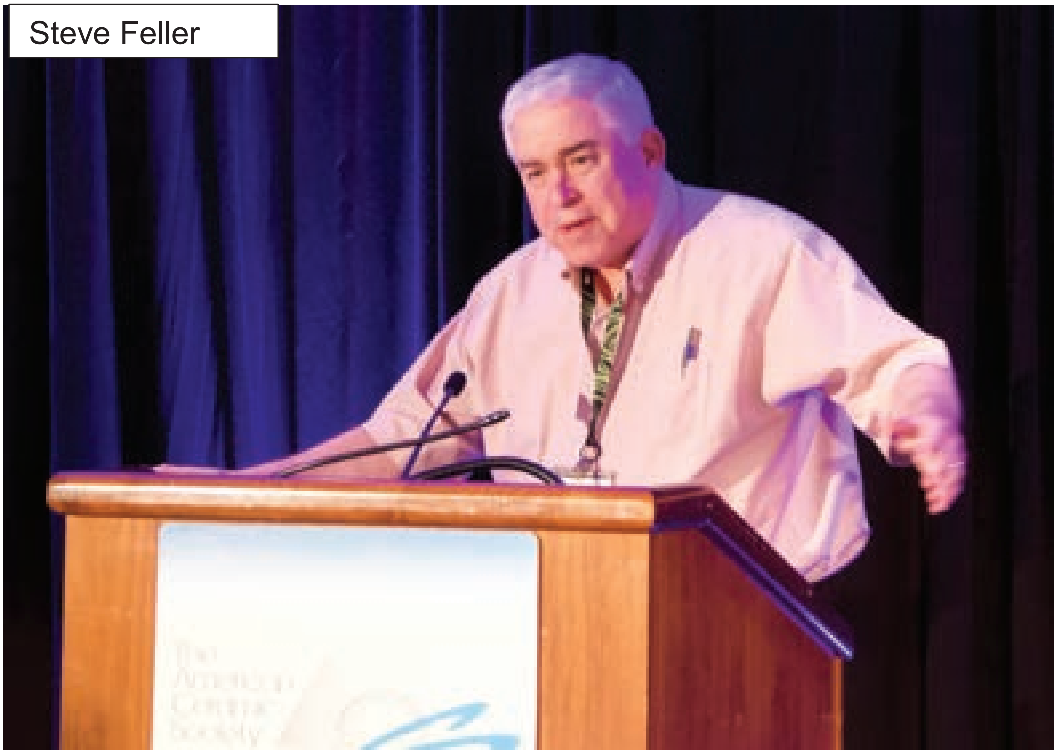
David Pye

Robert Lipetz

Christopher Taylor

David Pye
Alicia Duran (IYOG Chair)
Lower left: Santokh Badesha


Jeff Kohli



Steve Feller

James Warren

Karol Wight
Director, Corning
Museum of Glass

Panel session II: Christine Heckle (chair).
Left to right: Himanshu Jain, Judy Schaechter, Anuradha Agarwal, Scott Cooper, Jacquelyn Fetrow, Adelle Schade

Himanshu Jain explaining his point of view. Judy Schaechter getting ready to comment…

Alfred University school of engineering dean Gabrielle Gaustad was taking no chances

Panel session IV: Urmilla Jokhu-Sowell, Natalie Tyler, Megan McElfresh, Ashutosh Goel, Robert Schaut

Marina Pascucci (Former ACerS president)

Urmilla Jokhu-Sowell National Glass Association

Kathy Jordan (president, American Glass Guild)

Left: Welcome at banquet by Yasundo Ariga of AGC.

Above: Arun Varshneya

Anuradha Agarwal looking over.

Left: Reinhardt Conradt, president ICG

Mario Affatigato extending welcome at the banquet

Glass artist Narcissus Quagliata delivered banquet lecture

Above: Arun Varshneya delivers “On the Shoulders of Giants”

Below: Naoki Sugimoto of AGC talked about glass windows: past, present and future

Left: Nomura Hiraoki
Electric Glass Fiber America

Above: Phillip Galland
GlassWRX

Above: John Ballato
Clemson University

Left: Vahid Majidi
Savannah River National Laboratories

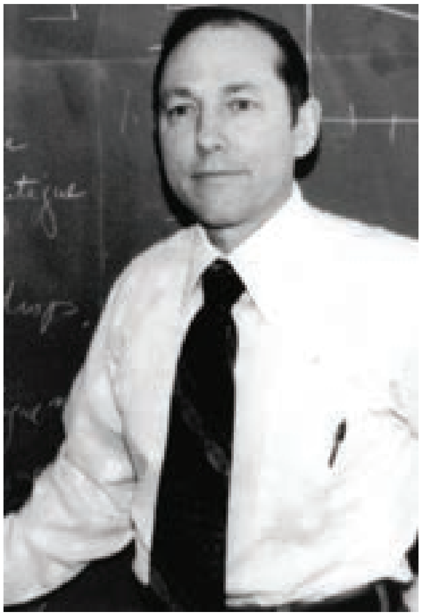
Above left: Sam Rubin, LightPath Technologies

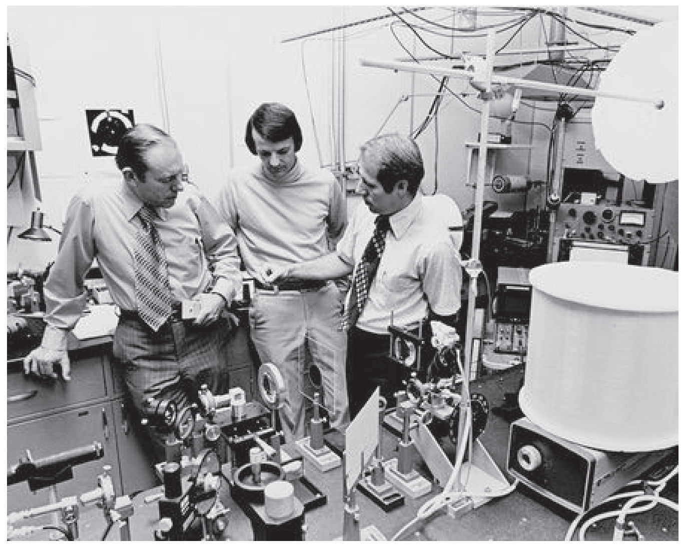
Above: Gang Chen, Ohio University, Chair, Glass & Optical Materials Div

Lower left: Mark Zupan, Alfred University

Steven Jung, Mo-Sci Corp.

David Pye (former ICG president and Reinhard Conradt (current ICG president) going over the ICG book, “**Welcome to the Glass Age**”.





Dr. Robert D. Maurer

Corning Glass Works;
Above right: With Peter C. Schultz (middle) and Donald Keck (far right). The trio that developed the silica-germania core of optical fibers and revolutionized the way the world communicates.

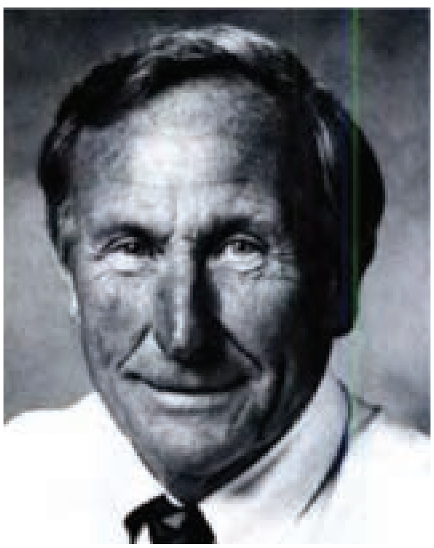
Dr. Robert J. Eagan

Former president, American Ceramic Society

Professor Donald L. Kinser

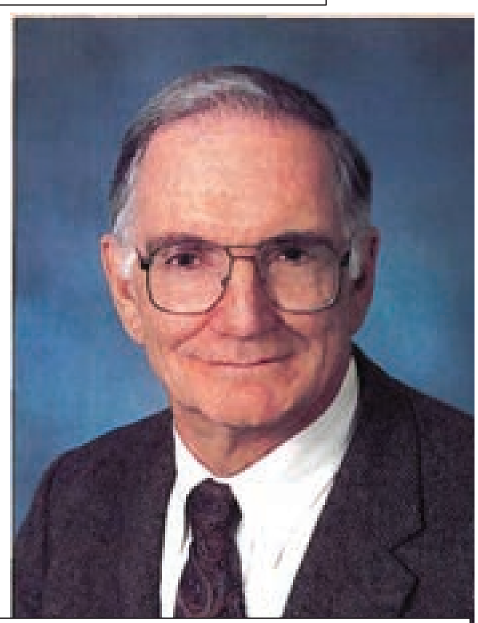
Vanderbilt University
Former editor of the Journal of Non-Crystalline Solids

Professor Carlo G. Pantano (Emeritus)
Penn State University
Studied surface properties of glass



Dr. Marvin Weber (retired)

Lawrence Livermore National Labs
Pioneer of glass host for laser; authored several books on laser applications of glass



Dr. George Beall

Corning Inc.
Inventor of several glass-ceramic products

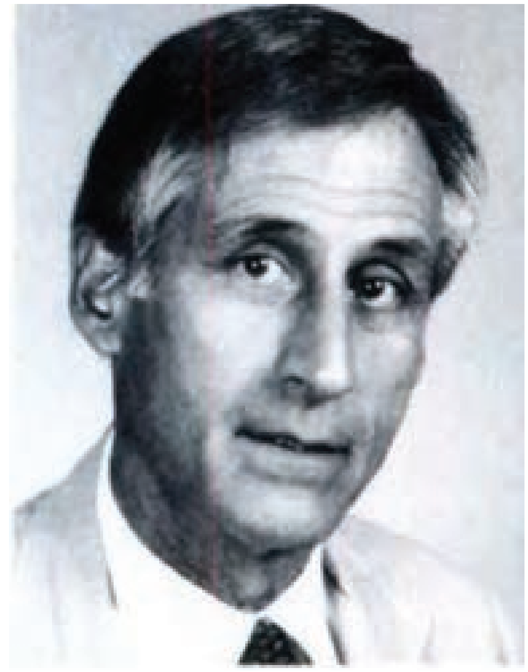
(Left) Dr. Steven W. Freiman (Retired)
National Bureau of Standards (now NIST)
Studied strength and fracture of glass

Professor Donald R. Uhlmann

MIT, Univ of Arizona

Proponent of the kinetic theory of glass formation; co-author/editor of several books.

Below: With Edgar Zanotto



Dr. Charles R. Kurkjian

Bell Laboratories, Rutgers

Studied strength of optical communication glass fibers
Below: Seated with (late) Alfred R. Cooper; standing (L to R): David Pye and Don Uhlmann

Dr. Matthew J. Dejneka

Corning Inc.
Glass composition development

Dr. Randall E. Youngman

Corning Inc.
NMR spectroscopy of Glass

Professor Gabrielle Gaustad

Dean, School of Engineering
Alfred University, Alfred NY
Studies glass recycling

Professor Alexis G. Clare

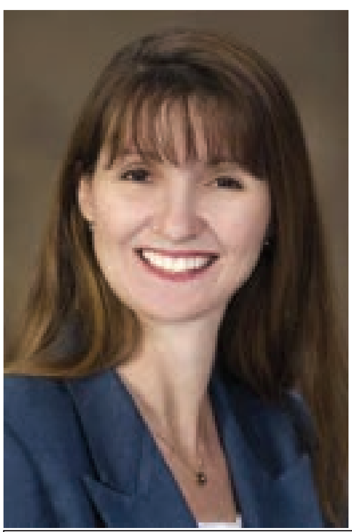
Alfred University
Studies bioglass, rare earth in glass

Professor Joseph H. Simmons

University of Arizona
Past Chair: Glass and Optical Materials Division (ACerS)
Editor: Journal of Non-Crystalline Solids
Research: Nonlinear viscosity and phase separation in glass.

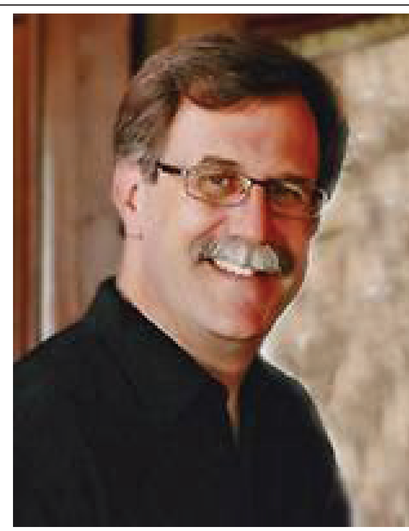
Catherine J. Simmons

University of Florida
Past Chair: Glass and Optical Materials Division (ACerS)
Research: Chemical durability of non-oxide glass.



Professor Kelly Simmons-Potter

University of Arizona
Past Chair: Glass and Optical Materials Division (ACerS)
Research: Linear and nonlinear optical properties of glass



Professor Barrett G. Potter Jr.

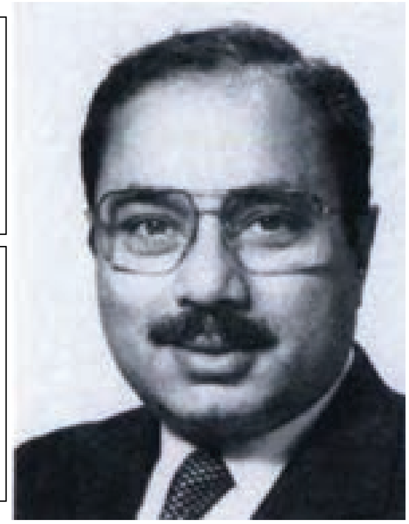
University of Arizona
Past Chair: Glass and Optical Materials Division (ACerS)
Editor: Journal of Non-Crystalline Solids.
Research: Optical and electronic properties of glass

Left: Professor Harrie L. Stevens

Alfred University
Co-editor of “Introduction to Glass Science”

Right: Edward N. Boulos

Ford Motor Glass
Division Former Chair,
NSF-University-Industry Center for Glass Research at Alfred



Left: Richard Zallen

Xerox Corp
Author of “Physics of Amorphous Solids”

Professor David Green

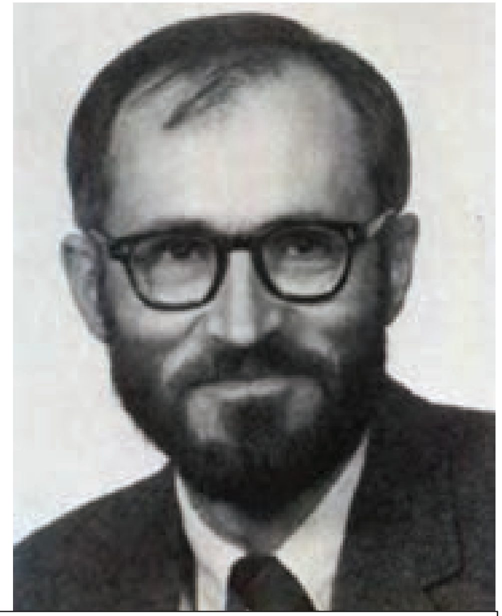
Penn State University
ACerS past president
Studied glass chemical strengthening

Narottam P. Bansal

NASA Glenn Research Center
Author of: Handbook of Glass Properties

Bulent Yoldas

Westinghouse Electric Research Labs
Early developer of glass by sol-gel route



E. Lowell Swarts

PPG Industries
Past Chair, Glass Division
Studied glass melting reactions, bubbles, and batch dissolution

Stanley M. Ohlberg

PPG Industries
Past Chair, Glass Division
Studied Light scattering, phase separation and ion exchange strengthening

M. Krishna Murthy

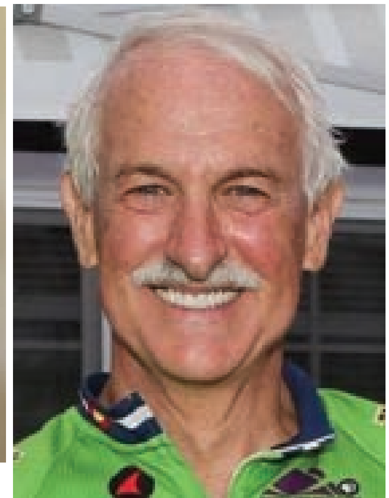
Ontario research Foundation, Director
Glass & Ceramics
Developed germania, vanadium oxide and phosphate glasses

Dr. Brad W. Bowan, Sr.
VP Atkins Global Technologies
Developed nuclear waste

Professor Murli H. Manghnani

Hawaii Inst of Geophysics and Planetology

Studied volcanic glasses



Dr. Carrlane Quackenbush
Chairman/CEO, MOMI Brands Inc

Developed silica crucible products for melting silicon

Dr. Innocent Joseph
Atkins Global Technologies
Developed nuclear waste vitrification

Richard E. Mould
Past Chairman, American Glass Research
Past Chair, Glass Division
Demonstrated static fatigue in highly loaded glass rods.

Wendell Weeks

President, Corning Inc

Charles R. Craig

Senior VP, Corning Inc- Science & Technology, Administration and Operation. A key person to advance the concept of IYOG.

John R. (Jack) Hutchins III

Past president, Corning Glass Works
Past Chair, Glass Division

David L. Morse

Corning Inc. Executive VP and Chief Technology Officer

Terry A. Michalske

Past Director, Savannah River National Labs
Developed atomic mechanism of fracture in glass

George G. Wicks

Savannah River National labs
Past president ACerS.
Studied nuclear waste immobilization in glass; and hydrogen storage in glass microspheres

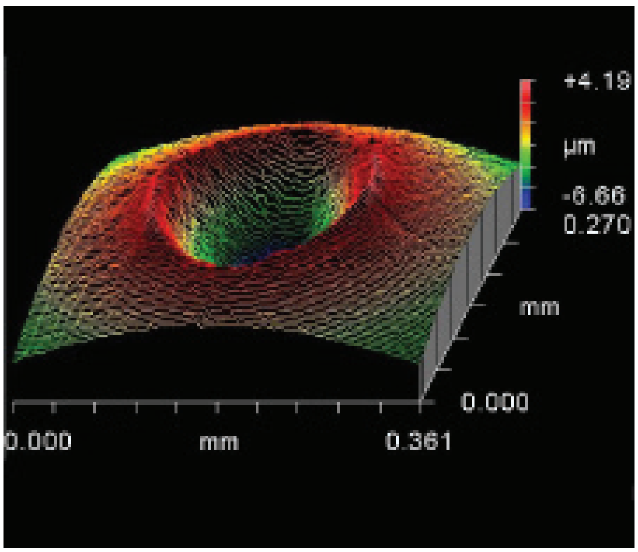
Dennis F. Bickford

Westinghouse Savannah River Co.
Studied nuclear waste immobilization in glass

Edwin R. Fuller

National Bureau of Standards (NIST)
Past president ACerS
Studied fracture mechanics in glass

Recent
but not forgotten memories



Ball indent in a chalcogenide glass. Note crater around the rim

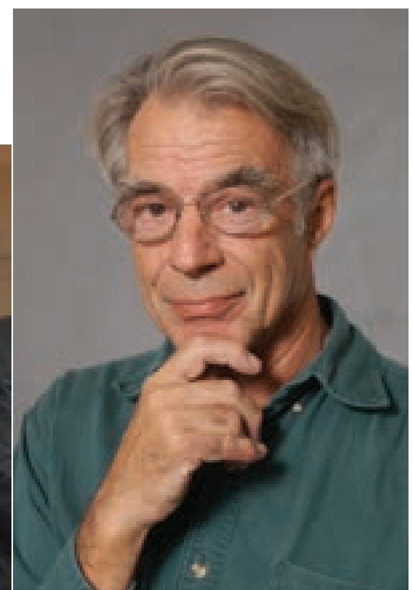
Stained glass art: "*Native American*". Courtesy Kathy Jordan

Professor C. Austen Angell (1933-2021)

Professor of Chemistry, Arizona State University

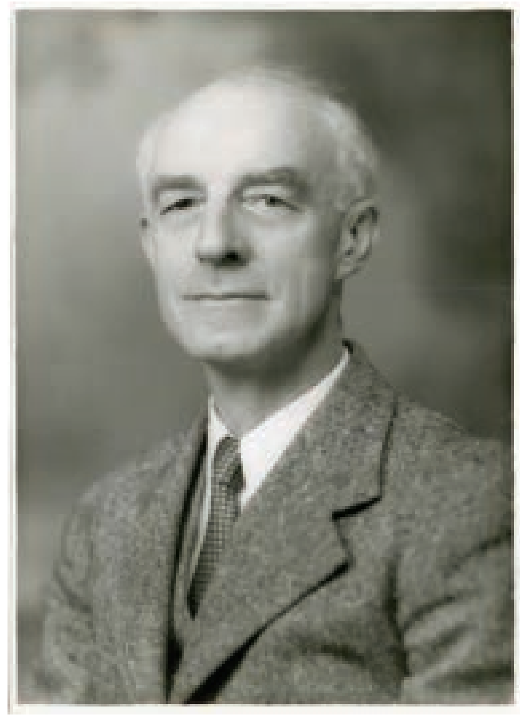
Left: With student Steve Martin

Lower left: With Walter Kob and Pierre Lucas



Phillip J. Bray (1925-2004)

Brown University
Pioneering work on NMR characterization of glass structure



Dr. Samuel R. Scholes (1884-1974)

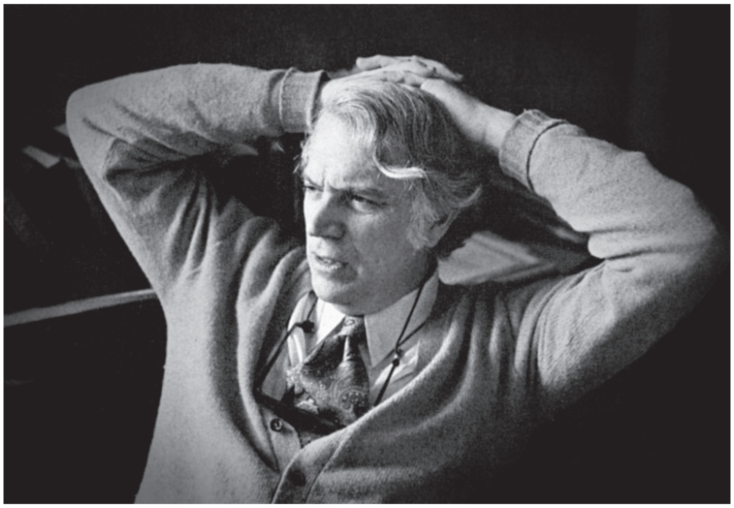
Established glass education and research at Alfred University in 1932

Richard J. Charles

General Electric Company
Only person receiving two Morey Awards: Phase separation and electric conduction

Ted Day (1960-2020)

President Mo-Sci,
ACerS Treasurer,
generous supporter



Professor Alfred R. Cooper (1924-1996)

Professor of Ceramics, Case Western Reserve University

Above right: With Professors Alan Owen and Harold Rawson at Sheffield University

Left with Prabhat Gupta

Below: with Arun Varshneya (MS degree 1968)

Dr. Emil W. Deeg (1926-2004)

American Optical Company
Studied optical properties and indentation behavior

Dr. George R. Irwin (1907-1998)

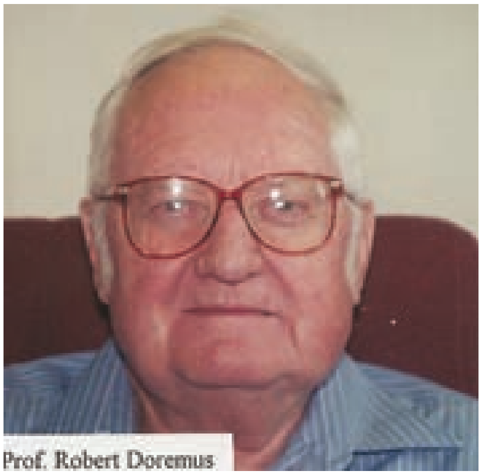
US Naval Research Labs
Univ of Maryland
"Father of fracture mechanics"

Dr. John A. O'Keefe (1916-2000)

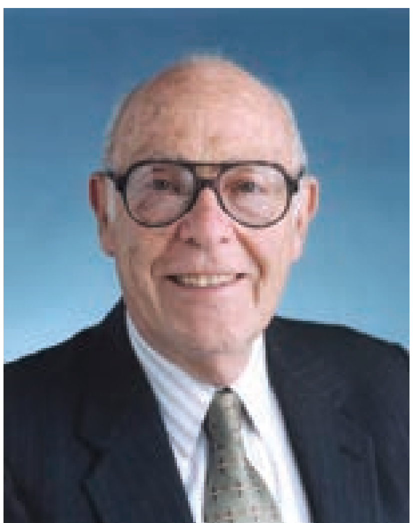
Head of R&D, Goddard Space Flight Center
Advanced the lunar origin theory of tektites; and the pear-shaped earth.

Dr. Howard R. Lillie (1902-1961)

Corning Glass Works
Pioneering studies of glass viscosity;
Former president ACerS; ICG president
(died in plane crash at Brussels on way to attend ICG executives meeting).



Professor Robert H. Doremus (1928-2008). Rensselaer Polytechnic Institute. Leading expert on diffusion of water in glass. Photo on right showing Doremus receiving Morey Award from GOMD chair Dick Brow.



Left: Professor John W. Cahn (1928-2016). MIT

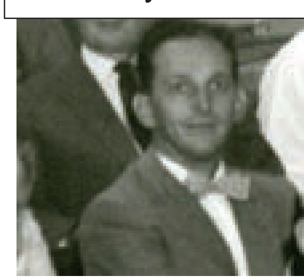
Known for thermodynamics of phase separation in glass.

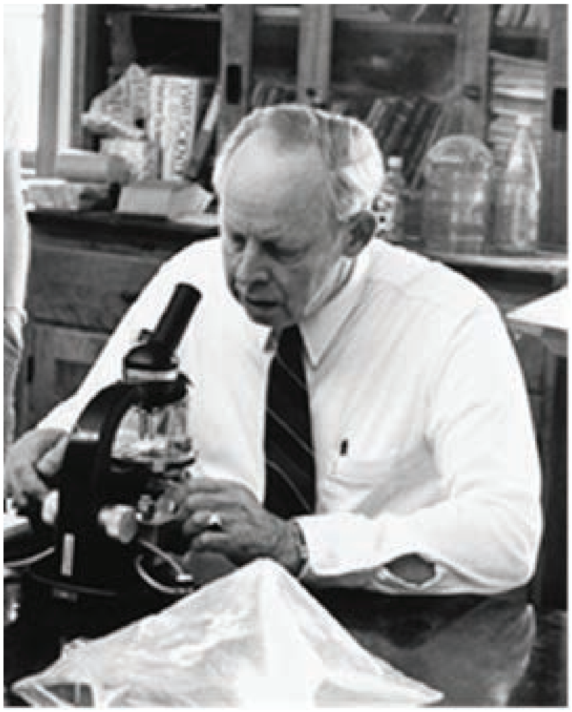
Right: David Turnbull (1915-2007). Harvard University

Architect of the kinetic theory of glass formation

Below: Professor Guy E. Rindone (1922-2015)

Penn State University
Known for study of internal friction in glass.
Right: With Delbert Day and Arun Varshneya





Professor Van Derck Frechette (2016-2001)

Alfred University
Perhaps the most renowned fractographer world ever knew

Roy V. Harrington

Ferro Corp
Director, Glass R&D

Left: Gail P. Smith
(1915-2001)

Corning Glass Works
Developed glass structures for outer space and oceanic explorations; photochromic glasses

Dr. Norbert J. Kreidl (1904-1994)

Bausch & Lomb, Rochester NY; Rutgers the State University, Univ of Missouri-Rolla

Top left with Eva Vogel; right with David Pye

Middle left with Bill LaCourse; Right with Wolfram Höland on 90^{th} birthday.

Below left with Peter Schultz.

Jesse T. Littleton (1887-1966)

Corning Glass Works
Known for Littleton Softening Point

Helmut Franz (1931-2007)

PPG Industries
Studied glass surfaces and coatings

James A. Pope (1944-2012)

Westinghouse Savannah River National Labs
Worked extensively on nuclear waste vitrification

Joseph J. Hammel

PPG Industries
Former Glass Division Chair
Studied light scattering from controlled phase separation in glass

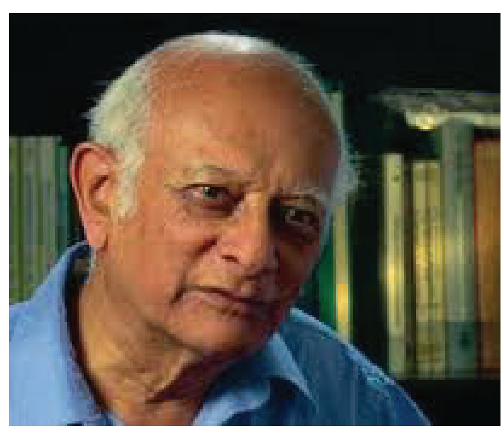
Professor Pedro B. Macedo (1938-2016)

Director, Vitreous State Labs, Catholic University
Nuclear waste vitrification

Professor Charles H. Greene III (1904-1990)

Chaired glass program at Alfred University; studied properties of glass

Professor Rustum Roy (left; 1924-2010) with Dr. Robert Newnham (1929-2009) and Dr. Jim McCauley; Penn State University
Nominated 21 times for a Nobel Prize.
Glass making by sol-gel, glass under high pressure; co-founder of MS&T.



Dr. Alexander J. Marker III (1947-2019)

VP R&D
Schott North America, Duryea PA

Dr. Mark J. Davis (1960-2021)

Principal Scientist
Schott North America, Duryea PA
Studied Crystallization and Glass-Ceramics

Dr. Henry H. Blau (1897-1980)

Ohio State Univ; VP Federal Glass; Corning Inc.

Studied properties of glasses

Dr. Wolfgang Haller (1923-2016)

National Bureau of Standards
Pioneering studies of phase separation in glass

Frank W. Preston (1896-1989)

Founder of Preston Enterprises (now AGR International)

Fractographer

Arthur Q. Tool (1878-1967)

Developer of the single fictive temperature theory for glass transition

Robert Gardon

Ford Scientific Labs
Explained radiative transfer of heat in glass

Walter J. Kauzmann (1916-2009)

Famous for Kauzmann Paradox and thermodynamics of supercooled liquids

Cornelius T. Moynihan (1939-2015)

Right: With Prabhat Gupta
Known for concepts relating to calorimetry of glass

Dr. Games Slayter (1897-1964)

VP, Owens-Corning
"Father of Fiberglas"

Professor Joseph Pask (1913-2003)

UCLA
Studied glass-to-metal sealing

Professor J. Douglas Mackenzie (1925-2020)

UCLA
Studied electric and electronic conduction in glass.
Founder of J. Non-Crystalline Solids,
Editor of "Modern Aspects of Vitreous State"
Above with Prof Jong Heo

Dr. Robert A. Weeks (1924 – 2012)

Vanderbilt University
Known for radiation effects in glass; Editor of Journal of Non-Crystalline Solids
Right: With David Pye (seated left); Gunther Frischat (right); Don Uhlmann (standing on left)

Dr. Frederick M. Ernsberger (1920-2003)

PPG Industries
Known for study of glass strength; Author of “Polarized light in glass research”

Dr. Elias Snitzer (1925-2012)

Rutgers University
Inventor of the fiber laser

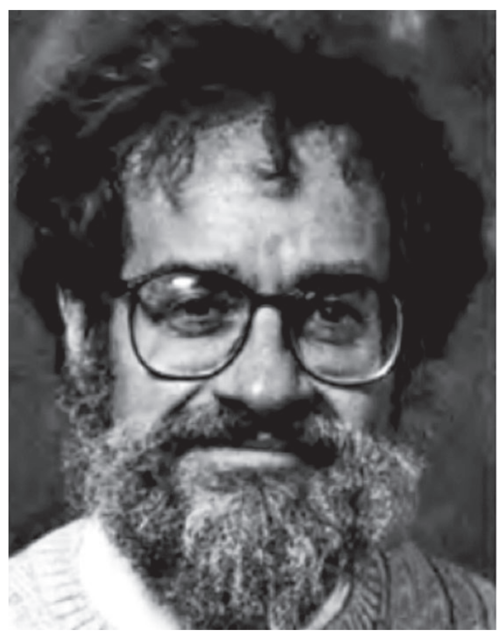
Professor Fay V. Tooley (1908-1992)
University of Illinois, Urbana-Champaign
Author of Handbook of Glass Manufacture

Professor Floyd A. Hummel (1915-1992)

Penn State University
Author of “Introduction to Phase Equilibria in ceramic Systems”

Henry E. Hagy

Corning Glass Works
Glass products developer



Professor Michael Weinberg (1941-2002)

University of Arizona
Bubbles, nucleation and crystallization in glass

Professor Woldemar A. Weyl (1911-1975). Penn State University. Known for "Colored Glasses" and the Weyl Award at the ICG.

Professor Bertram E. Warren (1902-1991) Massachusetts Institute of Technology

Known for the XRD support to the Random Network Model of glass structure

Gordon Scott Fulcher (1874-1971)

Corning Glass Works

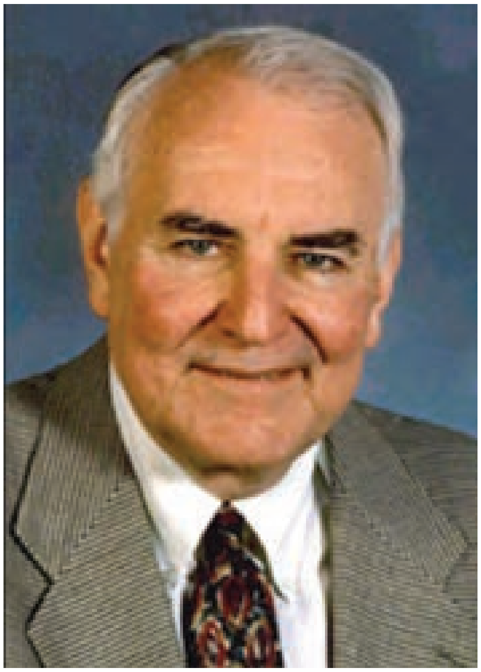
Known for the viscosity-temperature relationship

Dr. Sheldon M. Wiederhorn (1933-2021)

National Institute for Standards and Technology

Above with Satoshi Yoshida on left

Lower left with Arun Varshneya



Dr. Warren Wolf (1941-2014)

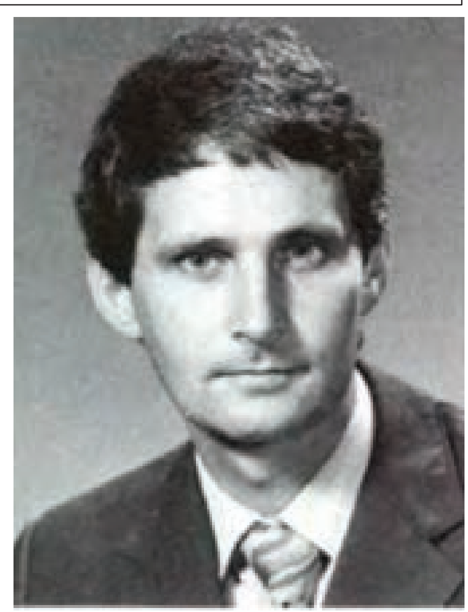
Director R&D, Owens-Corning
ACerS past president
Photo above shows receiving 2006
Phoenix Award from Mike Nelson.

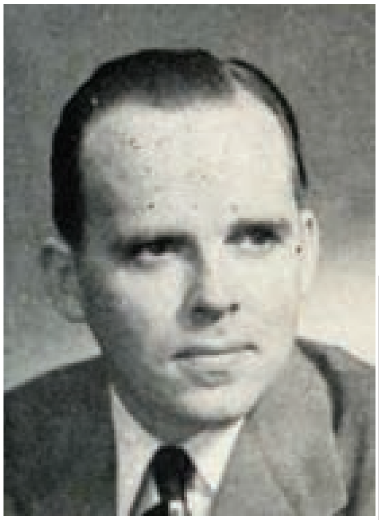
Professor Martin Goldstein (1919-2014)

Yeshiva University
Light scattering and relaxation
phenomena in glass

Dr. Anthony G. Evans (1942-2009)

National Bureau of Standards
(NIST), Rockwell Science Center
Guru of fracture mechanics;
indentations in glass



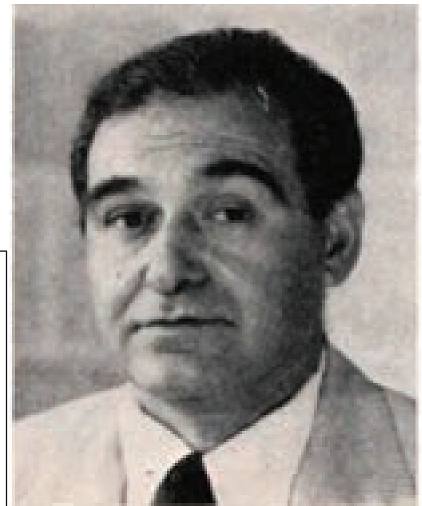


Left: Harold N. Ritland

Corning Glass Works
Showed inadequacy of single fictive temperature concept

Right: Sam Spinner

National Bureau of Standards (now NIST)
Conducted “crossover experiments” to decisively strike down single fictive temperature concept



Dr. Orson L. Anderson (1924-2019)

Professor of Geology, Columbia University

Former Glass Division Chair

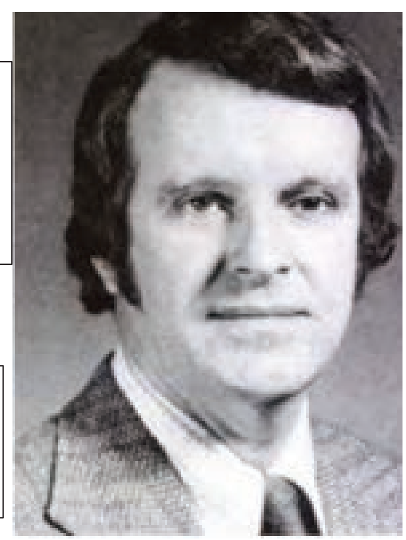
Developed energy requirement for ions to “squeeze” through interstitial doorways during diffusion

Left: Errol B. Shand

Corning Glass Works
Author of “Glass Engineering Handbook)

Right: A. David Pearson

Bell Labs
Developed glass fiber optics



The Editors are pleased and honored to include photos of early women researchers who were employed at Corning Glass Works and who conducted pioneering studies in glass. Their memory lives on. Courtesy Corning Museum of Glass.

Evelyn H. Roberts (1893-1991)

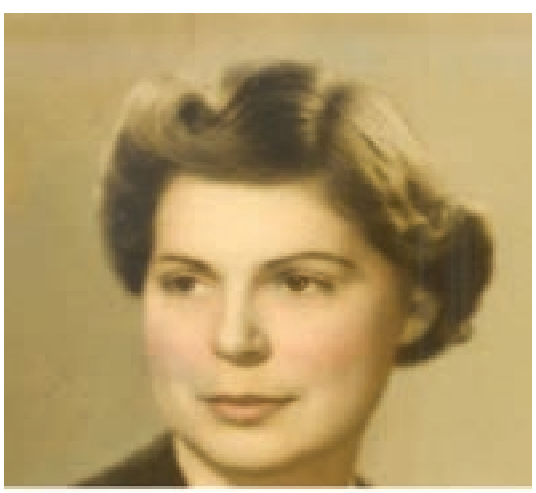
Corning Glass Works
Pioneering work on annealing point measurement

Mary Purcell Roche (1917-2011)

Corning Glass Works
Worked on optical waveguides

Daphne L. Rothermel (1915-1995)

Corning Glass Works
Worked on glass durability



Ellen L. Mochel (1914-1984)

Corning Glass Works
Pioneering work on glass chemical strengthening

Professor Clifton G. Bergeron (1925-2016)

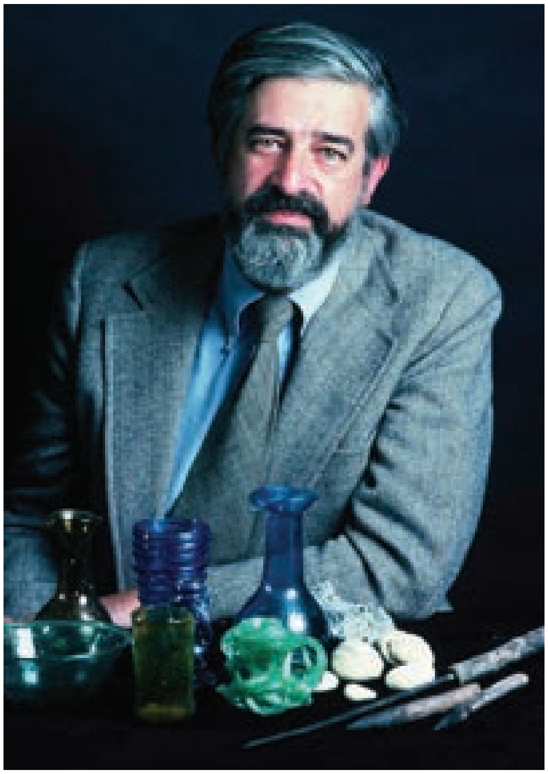
University of Illinois
Department Chair, studied properties of glass and crystallization kinetics

Raymond V. Hensler (1924-2022)
Director, Materials Development Labs
Bausch & Lomb
Past Trustee and Chair, Glass Division
Developed gradient index lenses

Franklin J. Hyde (1903-1999)

Corning Glass Works
Developed flame hydrolysis of $SiCl_4$ method to manufacture high purity silica glass for optical fibers

Professor Harold E. Simpson (1904-1980)
Alfred Univ
Department Chair
Studied glass durability and glass fibers



Dr. Robert H. Brill (1929-2021)

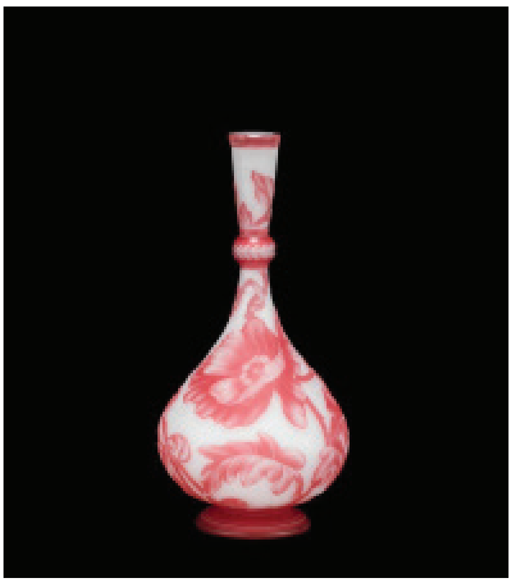
Corning Museum of Glass
Known for archaeometry of glass
Courtesy: Corning Museum of Glass

Right: Doris L. Evans (1923-1989)

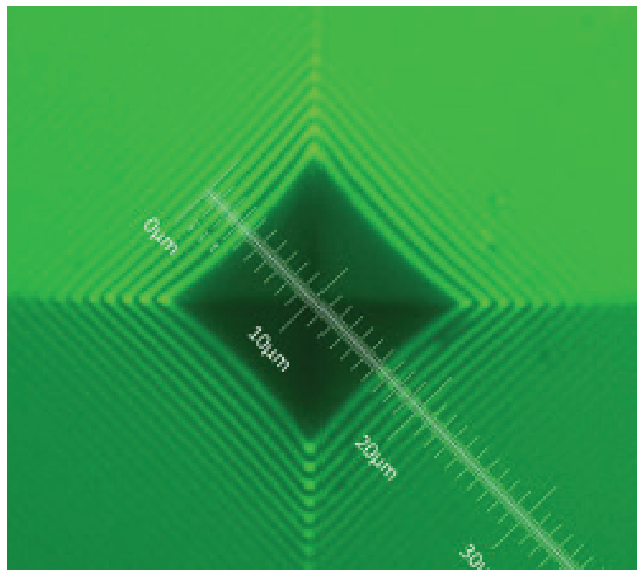
Corning Glass Works
Constructed room sized model of silica glass using tetrapods and springs.

Courtesy: University of Toledo
Symposium dedicated to DL Evans 1991

Thank you



Cameo Vase (about 1870–1899). CMoG 69.2.46. Bequest of Gladys Carder Welles. Courtesy of The Cor ning Museum of Glass, Corning,



Newton's interference fringes defining the separation between the contours of glass and Vickers indenter at the point of losing contact during retraction. Courtesy Satoshi Yoshida.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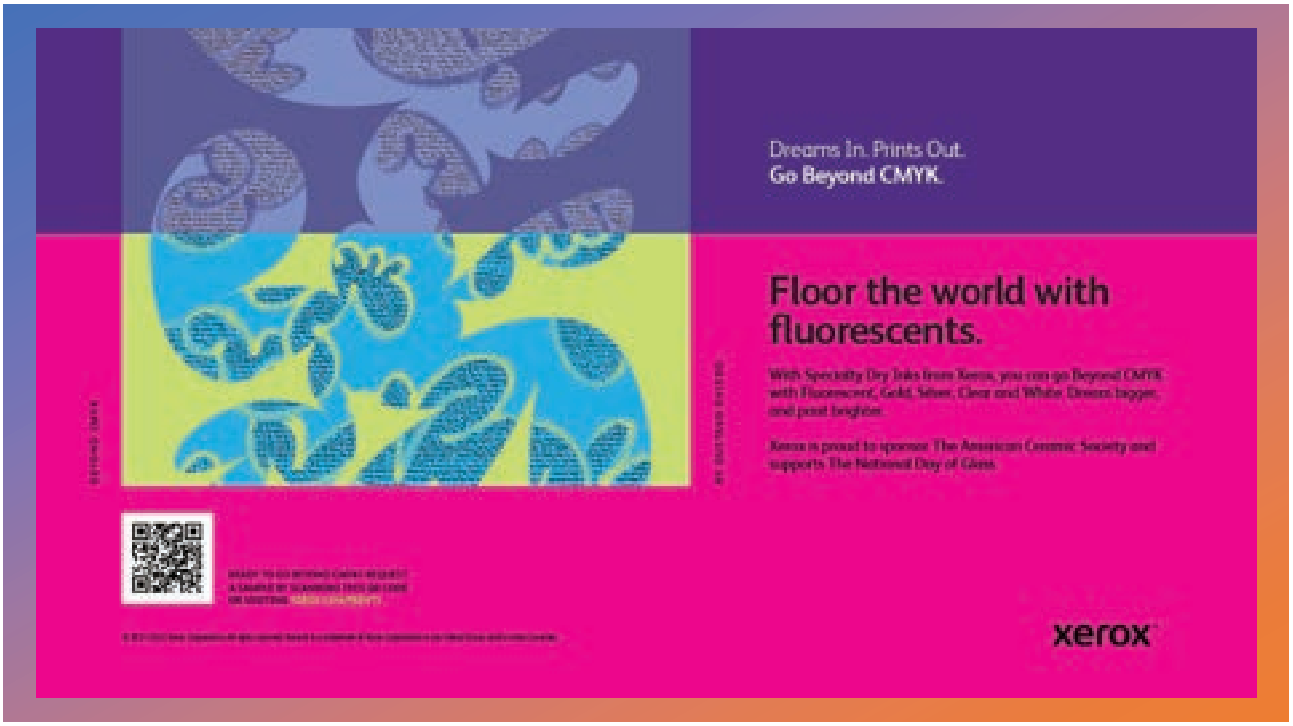
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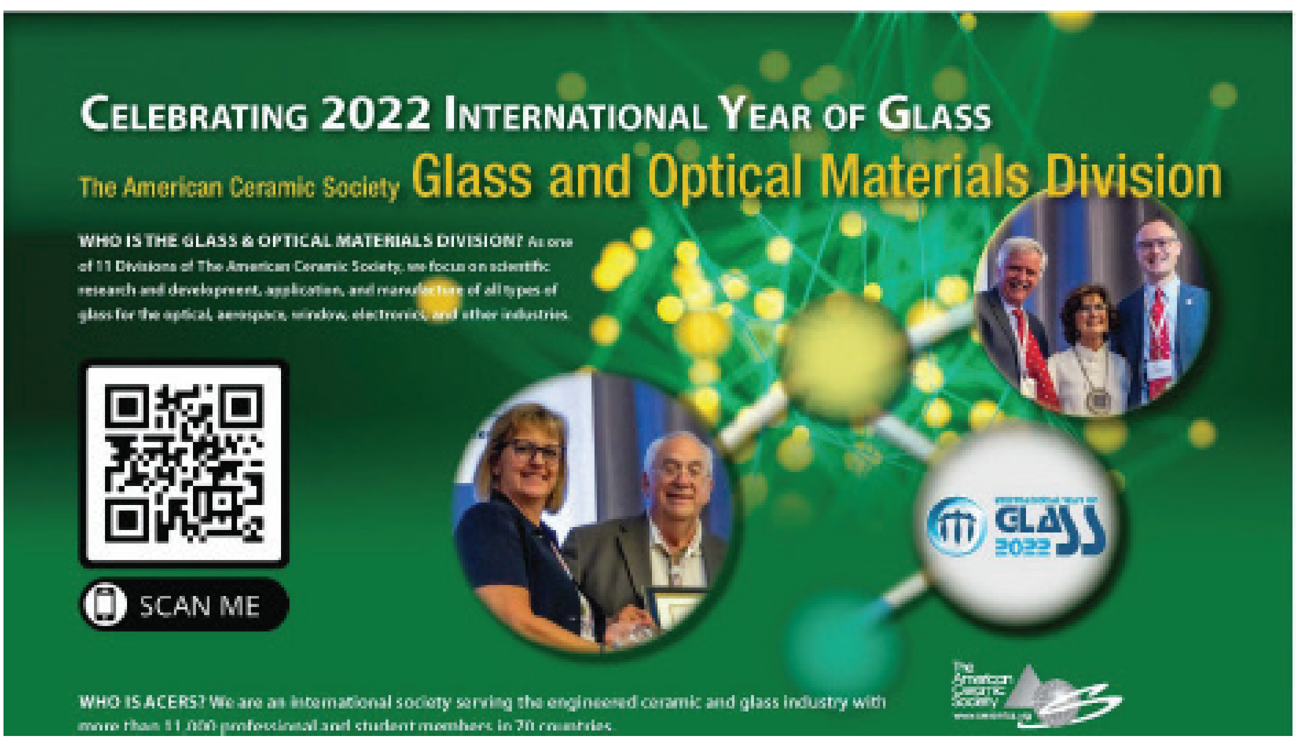
CELEBRATING 2022 INTERNATIONAL YEAR OF GLASS
The American Ceramic Society Glass and Optical Materials Division
WHO IS THE GLASS & OPTICAL MATERIALS DIVISION? As one of 11 Divisions of The American Ceramic Society, we focus on scientific research and development, application, and manufacture of all types of glass for the optical, aerospace, window, electronics, and other industries.
SCAN ME
GLASS 2022
WHO IS ACERS? We are an international society serving the engineered ceramic and glass industry with more than 11,000 professional and student members in 70 countries.
The American Ceramic Society

About the Editors

Arun K. Varshneya is Professor of Glass Science & Engineering, Emeritus, NY State College of Ceramics at Alfred University. He is also the president of his entrepreneurship company, Saxon Glass Technologies Inc., of Alfred NY supplying chemically strengthened articles such as the borosilicate cartridge for the life-saving autoinjector, EpiPen. He is a product of Sheffield's Dept of Glass Technology having obtained his B.Sc. Tech. with honors in glass technology in 1962, subsequently earning MS and PhD from Case Western Reserve University. After working at Ford Scientific Laboratories, Dearborn MI and GE Lighting Business Group, Cleveland OH, he joined faculty ranks at Alfred University in 1982. As a teacher, he taught nearly all of the required glass engineering science courses both at the undergraduate and the graduate levels and the much-needed business basics. Arun is admired worldwide for his textbook, "Fundamentals of Inorganic Glasses", now in its third edition. For his teaching efforts and the textbook, students affectionately call him "Glass Guru". He is the invited author of the 13-page article on "Industrial Glass" in Encyclopaedia Britannica, an Honorary Fellow of the Society of Glass Technology, a Distinguished Life Member of the American Ceramic Society having served as its Treasurer, and recipient of the 2007 President's Award of the International Commission on Glass. In 2011, the local media in Agra (India) cited him as one of the 25 crowning stars of Agra. His former students and friends organized a festschrift in his honor at the 2019 International Congress on Glass in Boston MA. Most recently, he was elected the 58th President of the Society of Glass Technology. His "Reflections on Glass" profile with photo is on page 286.

Manoj K. Choudhary is Adjunct Professor of Materials Science and Engineering at the Ohio State University (OSU), a position he has held since retiring from Owens Corning (OC) in 2018 as a member of OC's Senior Technical Staff. He obtained his B. Tech. (Honors) in Chemical Engineering from Indian Institute of Technology, Kharagpur. He got his M.S. in Chemical Engineering from the State University of New York at Buffalo and Sc.D. in Materials Science and Engineering from Massachusetts Institute of Technology (MIT). After post-doctoral research at MIT, he joined OC Science and Technology Center in Granville OH in 1982. Dr. Choudhary is a Fellow of both the British Society of Glass Technology and the American Ceramic Society. He has presided over several organizations including the International Commission on Glass (ICG), Center for Glass Research at Alfred University, the Glass and Optical Materials Division of the American Ceramic Society, and the

Glass Manufacturing Industry Council, of which he was also a founder. He has received numerous awards and honors including, most recently, the ICG President's Award, Dr. Atma Ram Memorial Lecture (Central Glass and Ceramic Research Institute, India), and the Samuel R. Scholes Lecture Award (Alfred University). He is pleased and proud that the unifying theme of his long industrial career in glass was sustainability. His "Reflections on Glass" profile with photo is on page 230.

L. David Pye is Dean and Professor of Glass Science, Emeritus, The New York State College of Ceramics at Alfred University. An honored teacher, scholar, and researcher, he has served as President of The American Ceramic Society (ACerS) and The International Commission on Glass (ICG). He is a Distinguished Life Member of ACerS, Honorary Member of The German Society of Glass Technology, and Honorary Fellow of The British Society of Glass Technology. His professional achievement awards include The 2010 ICG President's Award, The New York State University Chancellor's Award for Scholarship and Creativity, and The Phoenix Award for Glass Person of Year. He played major leadership roles in establishing at Alfred, the only PhD Glass Science program in United States and the National Science Foundation Industry-University Center for Glass Research. He also led efforts in founding several continuing conference series including Advances in the Fusion and Processing of Glass and The University Conference on Glass Science. He was the Founding Editor of The ACerS International Journal of Applied Glass Science and in 2018 a special festschrift was convened in his honor by the ACerS Glass and Optical Materials Division in San Antonio TX. In 2019 the Division inaugurated The L. David Pye Lifetime Achievement Award. As Chief Executive Officer of Empire State Glassworks LLC, he is also an aspiring stained-glass artist. His "Reflections on Glass" profile with photo is on page 269.

Commemorative Stained-Glass Piece
Crafted by L. David Pye and
Presented September 2016 by
the American Ceramic Society to the
Society of Glass Technology on its Centennial