

The Wonders of Glass
(And it Immobilizes Nuclear Waste)

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Outline

- History of Glass
- Glass Art
- Glass Science
- Modern Technological Applications

- Nuclear Waste Vitrification
  - Glass chemistry
  - Vitrification process
  - Long term durability

INTERNATIONAL YEAR OF GLASS 2022

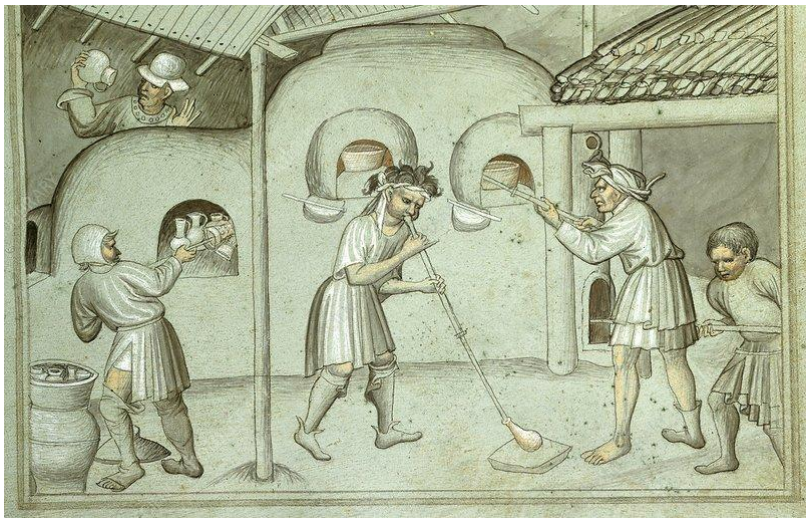
Beginnings

- Volcanic glass billions of years old
- Purposeful Use: Around 2500 BC in *Mesopotamia* and *Ancient Egypt*
- Produced accidentally while making pottery or metal—silica melted with ash and sand
- Earliest glass was glazed beads and decorative objects, not transparent
- Egyptians (around 1500 BC): mastered core-forming to make vessels and ornaments

Glass is one of humanity's oldest and most versatile materials. It has been used for thousands of years for decoration, construction, and technology.

The Romans

- Around 1st century BC, the Romans developed glassblowing, transforming glass production
- Allowed mass production and new shapes
- Spread rapidly through the Roman Empire



Common uses: vessels, windowpanes, mosaics, and jewelry.

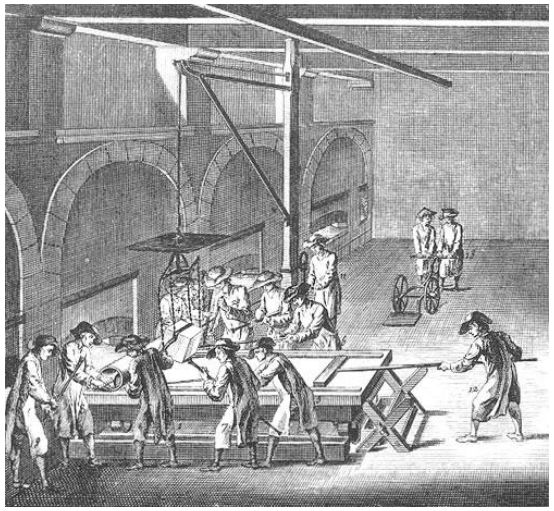
The Middle Ages

- Glassmaking reinvigorated in the Middle Ages
- Venetian glassmakers innovated with:
  - *Crystal-clear glass*
  - *Colored and patterned glass*
- Spread to Northern Europe — stained glass windows became famous art forms in the Gothic period (12th–15th centuries)

Glassmaking knowledge declined after the fall of Rome but revived in Venice, especially on Murano Island

Industrial Developments

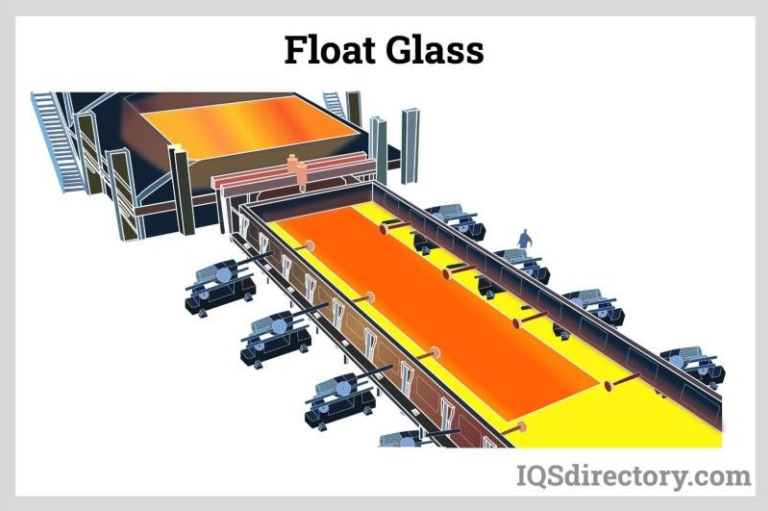
- In the 17th to 19th centuries – uses expanded to science and discovery
  - *Optical instruments*
  - *Scientific measurement*
  - *Plate glass*
  - *Colored and patterned glass*
- Coal-fired furnaces
- Industrialized forming techniques

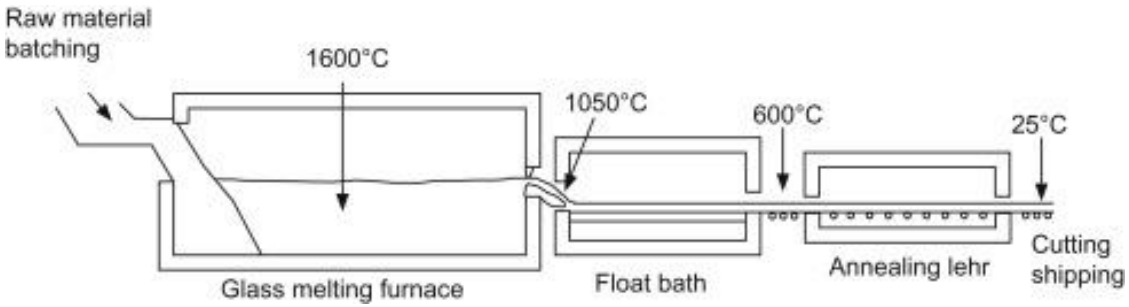


Glassmaking expertise expanded to England, France and Germany

Float Glass Process

- Developed by Sir Alastair Pilkington in 1952 and industrialized in 1960
- Creates perfectly flat glass (no grinding or polishing)
- Process: feed molten glass onto a tin bath at about 1000°C
- Worldwide production method by late 1960s
- Produces glass from 0.4 mm to 25 mm in thickness
- 3-4 m in width by 200 m long!

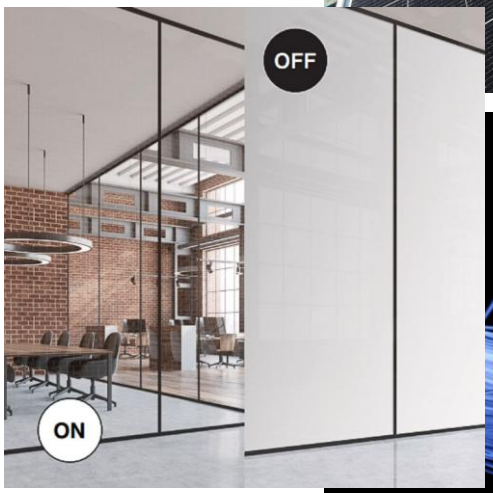




More than 90% of plate glass worldwide produced using float glass process (architectural, automotive, etc.)

Modern Glass Technologies

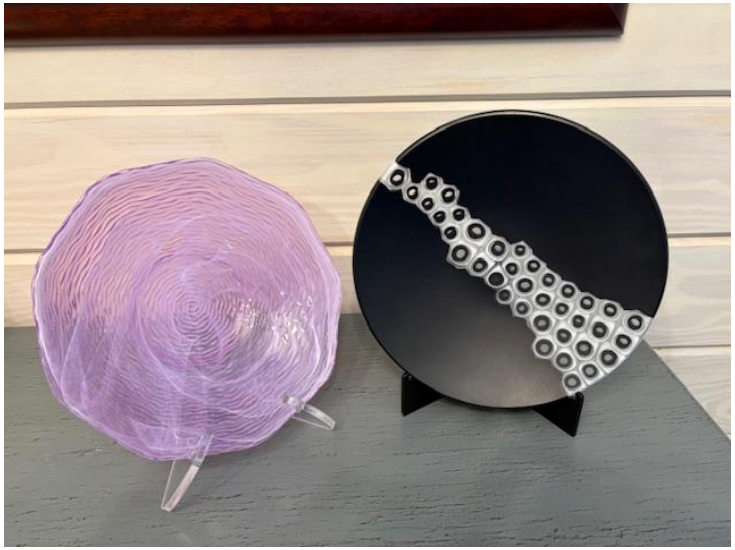
- Science advancement has led to advanced structural and functional glass
  - Smart Glass (switchable from clear to opague)
  - Energy efficient Low Emissivity (Low E)
  - Self cleaning
  - Laminated and tempered
  - Curved and shaped
  - Fiber optics
  - Photovoltaic (solar)
  - Bio-glass and health care
  - Consumer products



Glass is integral to our quality of life!

Glass Art

- From the beginning, glass has served as an artform (color and shape)
- Murano Italy (near Venice) still serves as a center for glass artisans
- Glass artisans practice worldwide
- Glass sculpture and glass blowing are popular hobbies

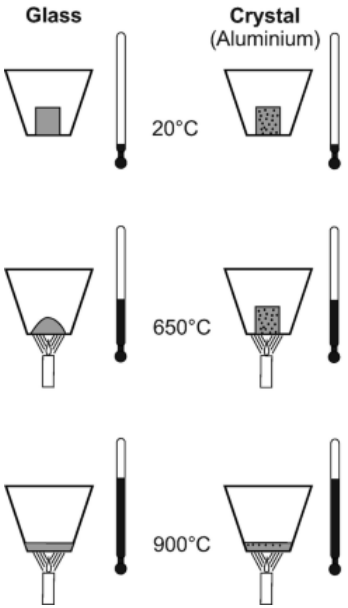


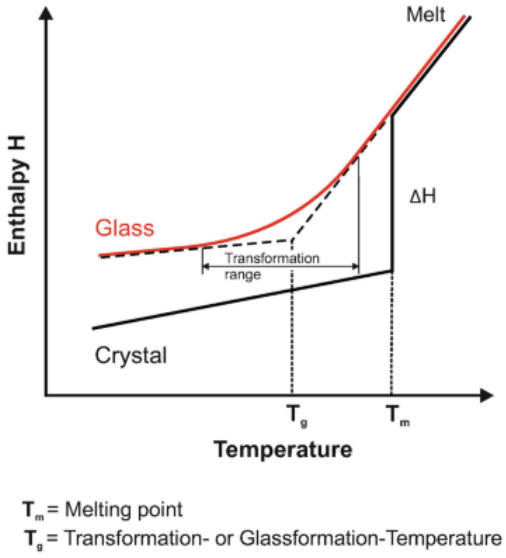
Dale Chihuly

- World renowned American glass artist
- Spent time in Murano and then established a studio in Seattle
- Permanent exhibit in Seattle
- Worldwide exhibitions (Biltmore 2024-2025)
- Large stable of artisans under his tutelage

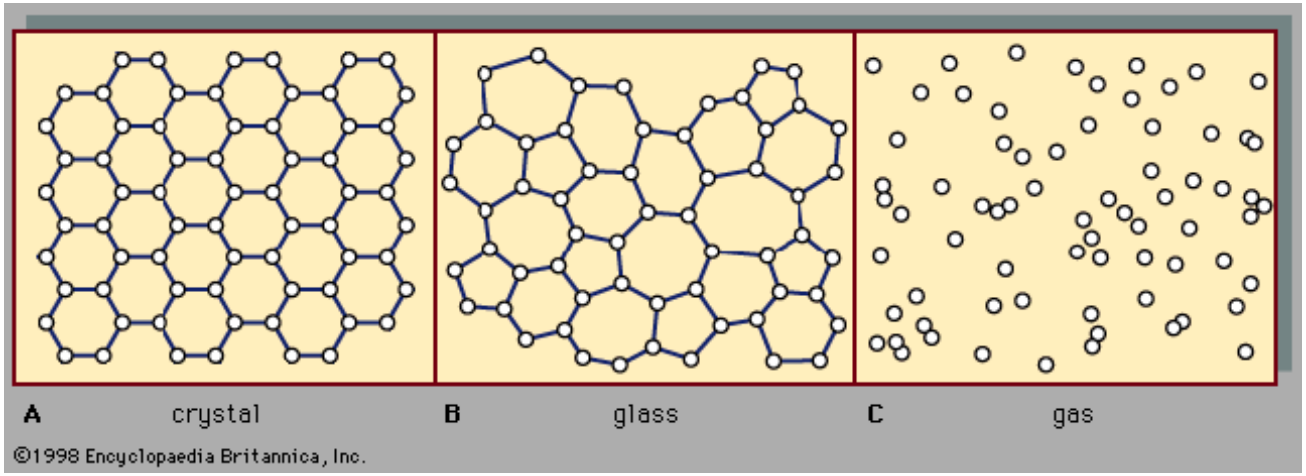
Glass Science

- What is glass?
  - Glass is a **solid**, but **not crystalline**
  - It's an **amorphous solid** → atoms are disordered
  - Behaves like a solid, but forms like a frozen liquid
    Key term: *Amorphous*
  - Understanding of glass structure began in 1920s





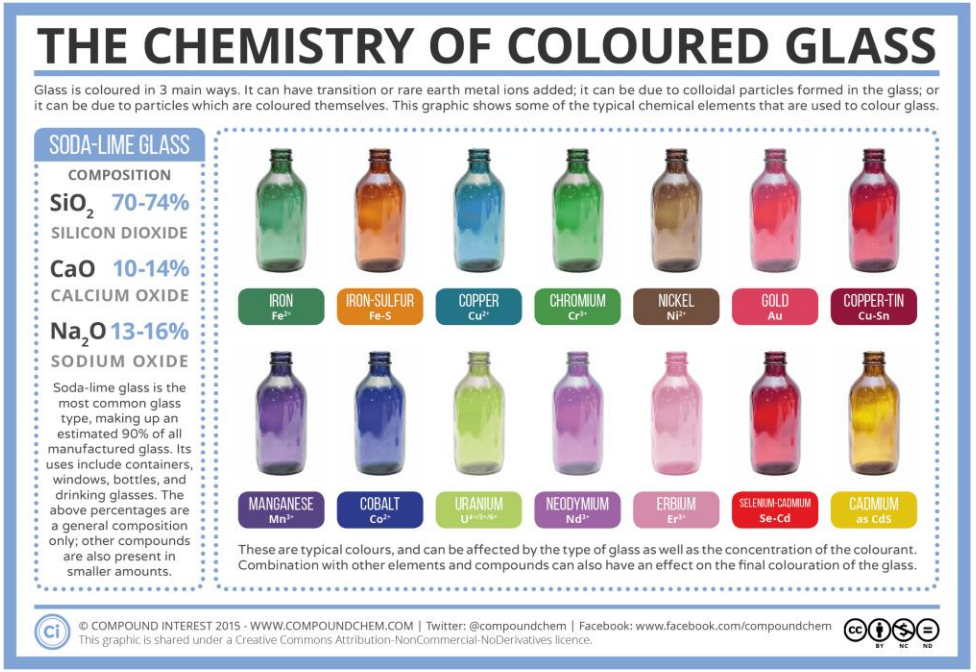
T_m = Melting point
T_g = Transformation- or Glassformation-Temperature



Glass is not a super slow liquid!

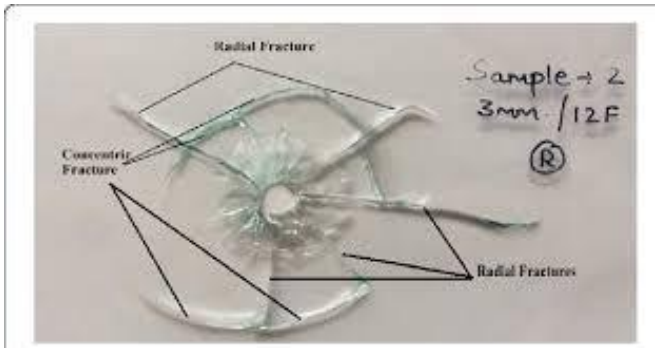
Glass Science

- Main ingredients (traditional soda lime silicate glass used in windows, glassware, art):
  - Silica (SiO_2) – glass former
  - Soda ash (Na_2CO_3) – lowers melting temperature
  - Limestone ($CaCO_3$) – intermediate
- Optional additives:
  - Metal oxides → color
- Other glass types
  - Borosilicate (labware, cookware, nuclear waste!)
  - Aluminosilicate (fiber, structural)
  - Fused silica (optics)
  - Lead crystal (art, optics)
  - Phosphate (bio applications)



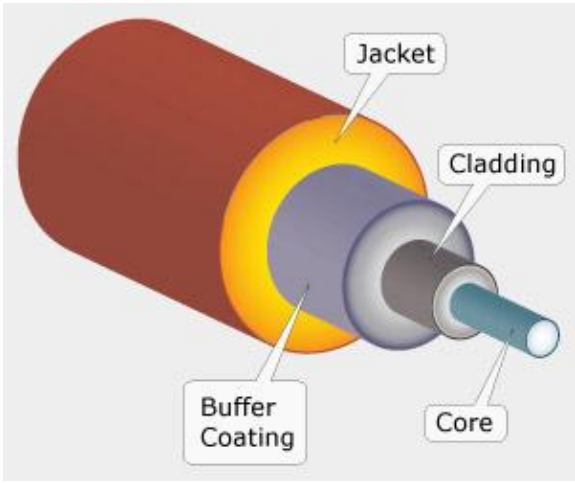
Glass Science

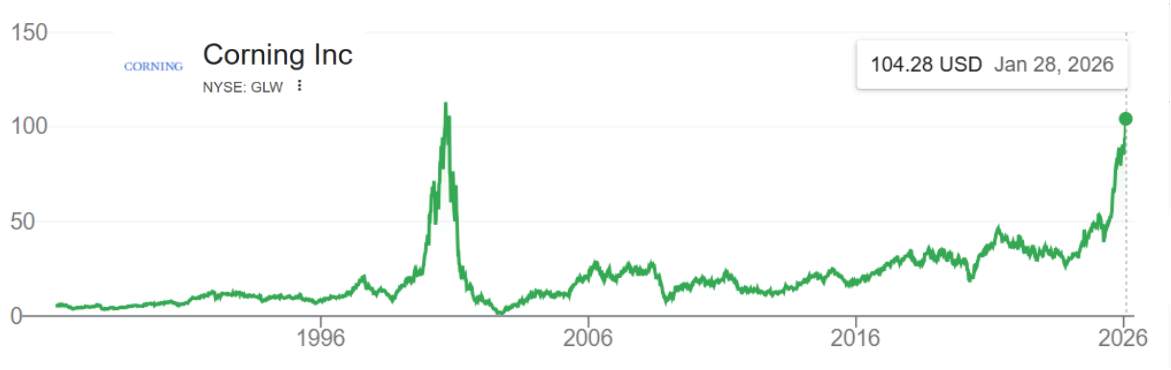
- Properties of Glass
  - Transparent (but can be translucent or opaque)
  - Hard
  - Strong but brittle
  - Can be flexible!
  - Chemically resistant
  - Durable
  - Heat and electrically insulating
- Can be recycled endlessly ♻



Modern Glass Applications – Fiber Optics

- What is fiber optics?
  - Technology that transmits data as light
  - Uses thin strands of glass
  - Enables high-speed, long-distance communication
- Why fiber optics matter?
  - Faster internet & communication
  - Backbone of the internet
  - Supports streaming, cloud computing, 5G, and AI
- How fiber optics work
  - Data converted into light pulses
  - Light travels through the core using total internal reflection
  - Receiver converts light back into data



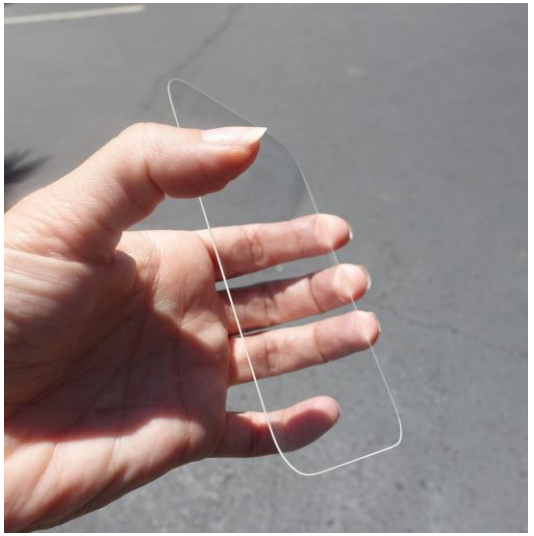


Modern Glass Applications – Fiberglass

- What are fiberglass materials?
  - Fine glass fibers that are woven together or combined with other materials (resin, epoxy, metals) as a composite
  - The glass is melted and drawn into thin fibers
- Key properties
  - High strength-to-weight ratio
  - Corrosion resistant
  - Electrical insulator
  - Heat and weather resistant
  - Can be molded into many shapes
- Uses
  - Construction (roofing, insulation)
  - Boats and marine parts
  - Automobiles and aircraft components
  - Sports equipment
  - Pipes and storage tanks

Modern Glass Applications – Gorilla Glass

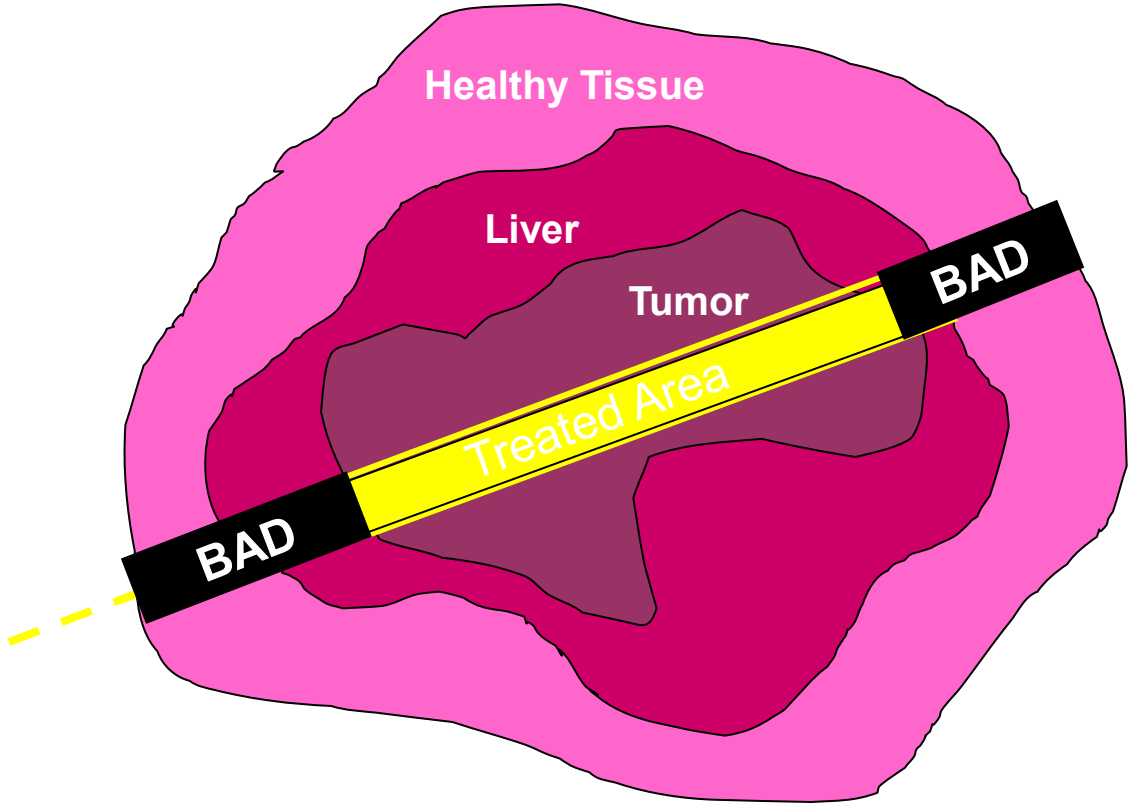
- What is Gorilla Glass?
  - Gorilla Glass is a chemically strengthened glass
  - Developed by Corning Incorporated
- Why needed?
  - Regular glass scratches and breaks easily
  - Modern devices need thin, touch responsive, scratch resistant and tough glass
- How is it made?
  - Chemical strengthening where glass dipped in molten salt bath
  - Larger potassium atoms replace sodium atoms in glass (ion exchange)
  - Creates compressive stress on glass surface



Modern Glass Applications – Bioglass

- What is Bioglass?
  - Bioactive material used in medical applications
  - Bonds directly with bone and soft tissue
  - First synthetic material to show true bioactivity
  - Phosphorus pentoxide (P_2O_5) added to typical glass formers
- How does it work?
  - Reacts with body fluids after implantation
  - Forms a **hydroxyapatite layer** on its surface
  - This layer is similar to natural bone
  - Enables strong bonding with bone tissue
- Applications
  - Bone grafts and bone repair
  - Dental implants and fillings
  - Treatment of bone fractures
  - Middle ear implants
  - Wound healing materials

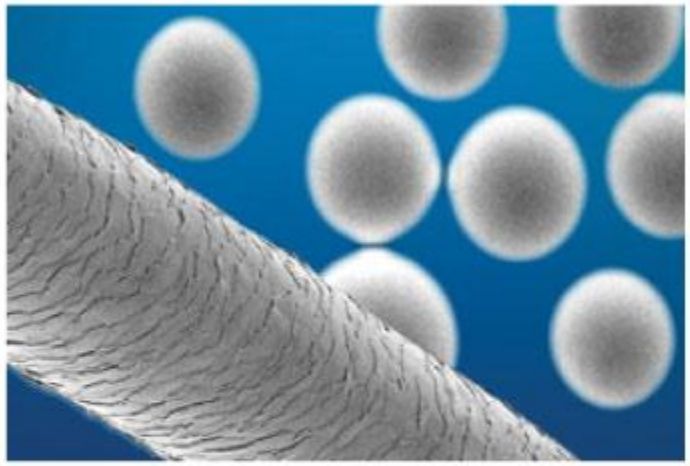
Modern Glass Applications – TheraSphere



TheraSphere™ is a targeted **radioembolization therapy** used primarily to treat hepatocellular carcinoma (HCC), the most common form of primary liver cancer.

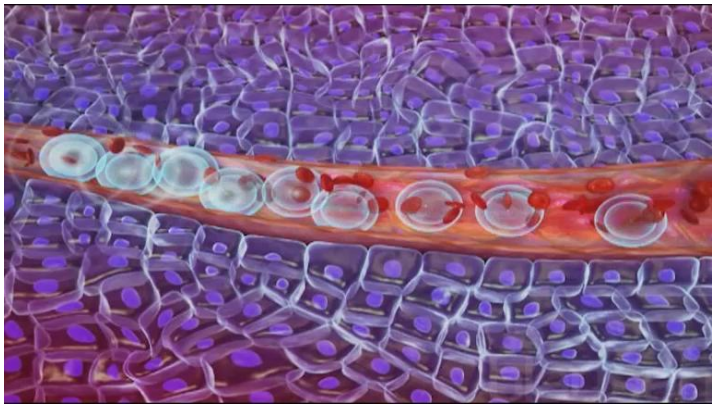
Glass Microspheres for Liver Cancer Treatment

- Rare earth containing aluminosilicate glass melted, crushed and flame spheroidized
- Microspheres are sized and packaged for activation
- Bulk container of glass microspheres is neutron activated
- Specific patient dose measured out based on activity desired 1 week hence and shipped to hospital



TheraSphere Y-90 Glass Microspheres compared to a strand of human hair

TheraSphere™ Delivery

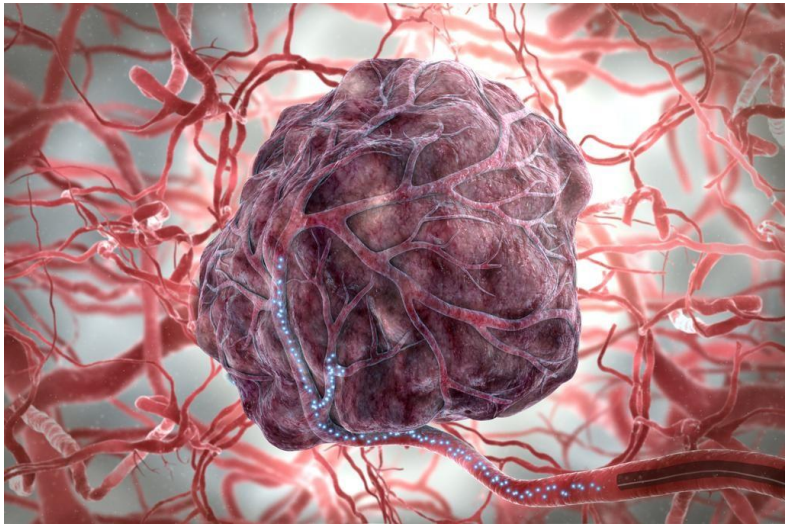


Patient is catharized and glass microspheres are injected

Microspheres lodge in small vessels in liver and stay there forever

Deliver a targeted radiation dose to the tumor

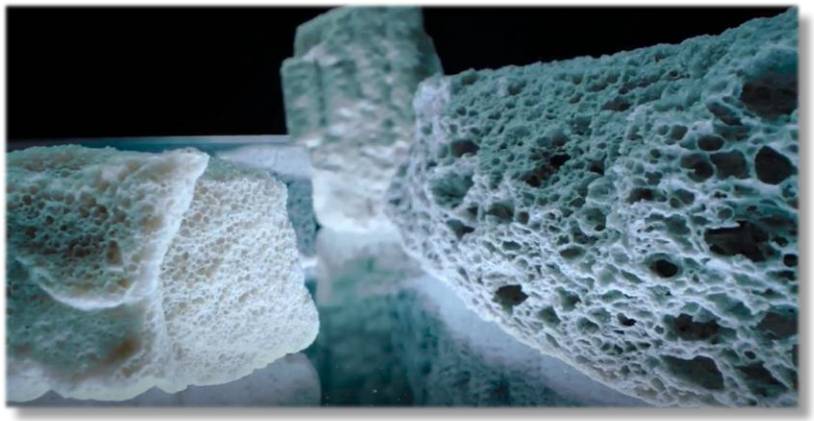
Minimizes radiation exposure to healthy tissue

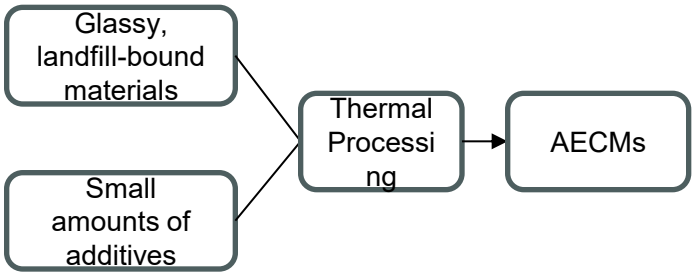


TheraSphere™ has been used to treat over 100,000 patients globally

Modern Glass Applications – Advanced Engineered Cellular Magmatics (AECM)

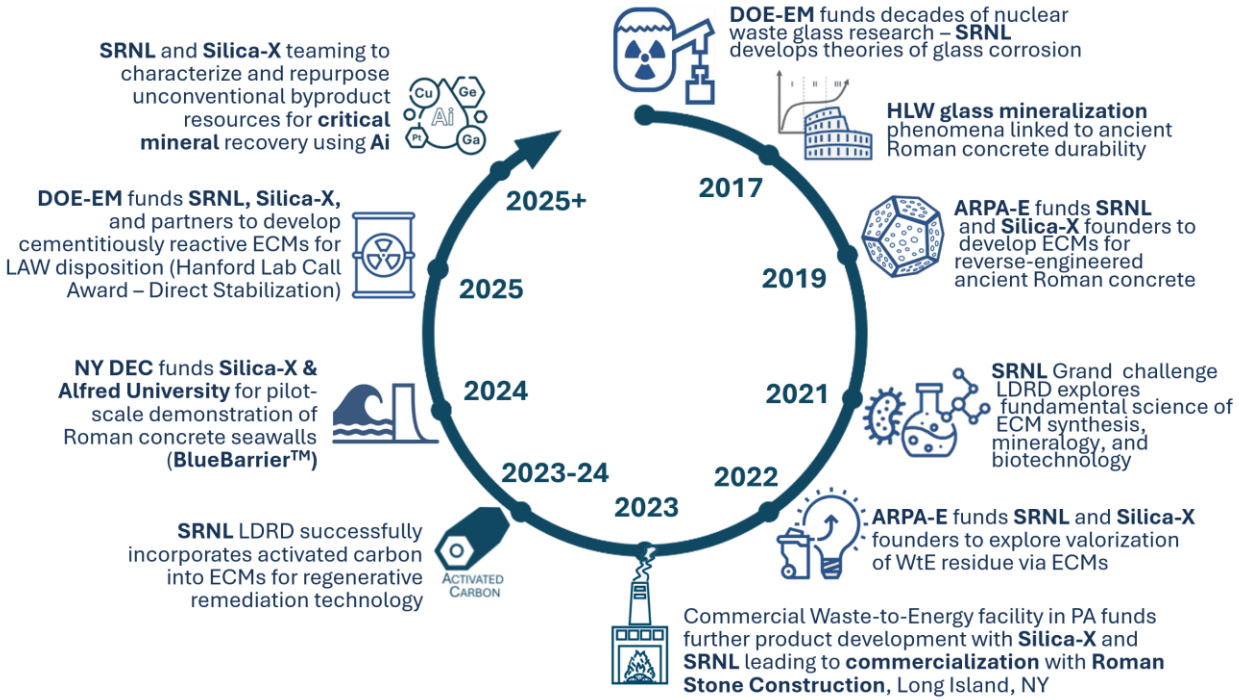
- AECMs are synthetic, pumice-like materials made almost entirely from materials that would otherwise be disposed of in landfills
  - Example feedstock materials:
    - Recycled container glass (bottles, jars, etc.)
    - Combustion ashes (waste-to-energy ash, coal ash)
    - Industrial waste glass (fiber glass, flat glass, CRT glass)
- Modify the initial chemistry with additions or altering the process parameters yields products with wide-ranging applications





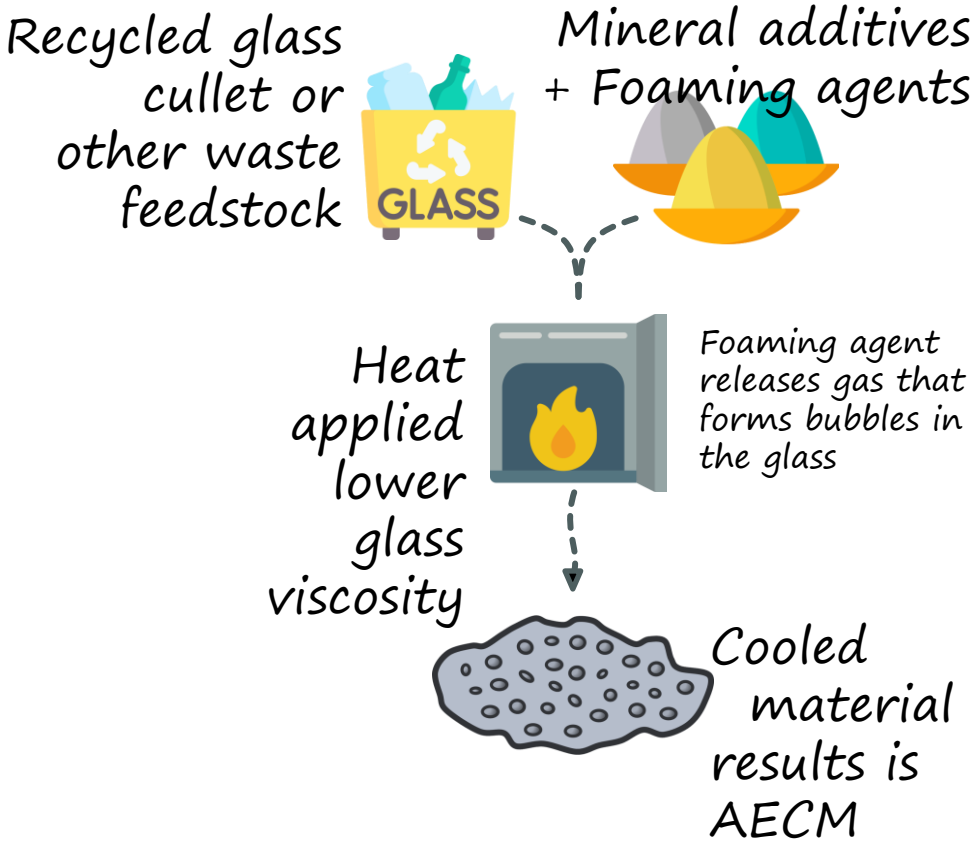
History of AECMs

- Initially invented to mimic volcanic tephra used in ancient Roman concrete.
- Expanded application portfolio through SRNL LDRD
- Continued development with funding from DOE, industry, and other sources



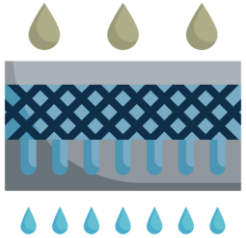
How are they made?

- Glassy materials (recycled glass, ash, etc.) are processed to a particle size distribution that meets the application
- Additives are combined with the glassy materials to impart additional tailored properties (chemical and mineralogical) to the product
- Foaming agents are added in amounts that also affect the physical properties of the material
- Entire batch is thermally processed to achieve two goals:
  1. Lower the glass viscosity to a point where it starts to flow but does not fully melt
  2. Cause gas-release from the foaming agent that forms the pores in the glassy materials

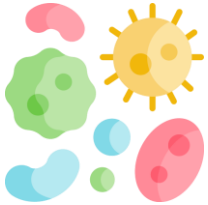


Applications of AECMs

Reverse-engineered Ancient Roman Concrete



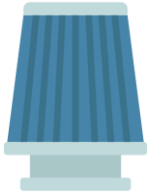
Wastewater Filtration



Biological Substrates

Radioactive Waste Disposal

Agricultural Amendments



Air/Off-gas Filtration

2025 R&D 100 Award

- The “Oscars of Innovation”
  - Awarded for past 60 years
  - SRNL inventor and SilicaX (industrial partner) recognized in Mechanical/Materials Category

Summary

- Glass formed naturally from volcanic eruptions
- Purposeful uses starting in Egyptian age
- Continued refinement for centuries
  - Artform
  - Utilitarian uses
- “Modern glass science” only about 100 years old
  - Understanding of glass structure
  - Industrial float glass process
  - Specialized applications