REFLEC

An ancient yet modern marvel, the transparent material always remains at the surface of things

BY ALAN H. FEILER

TIONS ON GLASS

LOOK AROUND. Glass is everywhere in our lives, and its utilitarian and creative purposes are endless: It preserves our food and beverages, provides our drinking vessels (which aptly enough are called glasses) and dishes and cookware, helps improve our vision (also called glasses), protects our buildings and vehicles from external intrusions and threats, preserves our photographs and artistic treasures, and greatly assists our scientific endeavors (test tubes, microscopes, telescopes, etc.). And glass optical fibers enable us to take endless reams of data from across the globe and transmit them at the speed of light, via the Internet.

In addition, glass allows us to actually *see* ourselves. After all, what would our lives be like without mirrors? And cameras? Try video-chatting without glass.

Plus, there are centuries of fine artisans and craftsmen who have taken different forms of glass and created spellbinding and exquisite treasures that illuminate the imagination, inspire and fill the human spirit and transcend the centuries.

Today, the countries that are the world's leading exporters of glass—which annually is a $75 billion international industry—are the United States, France, Belgium, Japan, India and Germany. Not surprisingly, North Americans, Europeans and the Chinese are the greatest consumers of glass, accounting for three-quarters of the global demand.

Among the world's leading glass manufacturers are China's Jiangsu Farun Group, France's Compagnie de Saint-Gobain, Asahi Glass of Japan, Pilkington of Great Britain and Guardian Industries of the U.S. Other major glass companies are Schott AG in Germany and Corning, Owens-Illinois and PPG Industries in the U.S.—which are among 1,500 American glass outfits with an estimated combined annual revenue of approximately $25 billion.

Not too shabby for an ancient yet modern material that people generally tend to think of as greatly fragile, highly vulnerable and rather disposable. Glass has been compared to human nature. "People are like stained glass windows," suggested the late Swiss-American psychiatrist and author Elisabeth Kübler-Ross. "They sparkle and shine when the sun is out, but when the darkness sets in, their true beauty is revealed only if there is a light from within."

Today, the countries that are the world's leading exporters of glass—which annually is a $75 billion international industry —are the United States, France, Belgium, Japan, India and Germany.

52.1.93, Collection of The Corning Museum of Glass, Corning, New York, gift of Arthur A. Houghton, Jr.

Left: The Morgan Cup. Roman Empire, first half of the first century AD Opaque white over translucent deep blue glass; blown and cased; carved, ground and polished. Right: A hand-colored engraving, which appeared in *The Universal Magazine* (London, 1760), depicts the manufacture of crown glass by blowing (left) and plate glass by casting (right). Glass workers were susceptible to cataract caused by the glare of the furnace.

Glass manufacturing evolved in Venice during the time of the Crusades (middle to late Middle Ages), and in the late 13th century an elaborate guild system was established there for glassworkers.

REFLECTING ON GLASS'S ORIGINS

Glass exists in nature, most often in the form of obsidian, which is created during volcanic eruptions, notes David Whitehouse, a senior scholar at the Corning Museum of Glass in Corning, N.Y. "People, however, have been making glass for more than 4,000 years," he adds.

Historians believe that obsidian was used by societies around the world during the Stone Age for the manufacturing of cutting tools. Archaeological evidence shows that glass was first made in Mesopotamia (today's Iraq and coastal northern Syria) as beads during the third century BCE. Egypt, Syria and other Mediterranean countries were glassmaking centers in the centuries before Christ, and priests and ruling classes considered glass to be as valuable and prestigious as jewelry.

Obsidian

Besides obsidian, early artisans found that natural glass was formed when lightning struck sand and the heat would sporadically fuse the sand into tubes called fulgurites. These forms of glass were used for jewelry, knives, arrowheads and even currency.

Glass manufacturing is believed to have begun in South Asia around 1730 BCE. During the Roman Empire, glassmaking had many domestic and industrial uses, as evidenced by the objects that have been discovered in areas governed by the Romans. In fact, the word glass was first coined in the latter part of the Roman Empire era, with the term *glesum* originating most likely in the Roman glassmaking center in Trier (now in Germany). The Latin word stems from the Germanic term for a lustrous, transparent substance.

The Romans were the first to use glass for windows, circa 100 AD in Alexandria. They tended to use glass pebbles laid out on a wooden frame. Clear glass panes were first invented in the late third century. Subsequently, mullioned glass was used for windows among Europe's elite and well-to-do, as well as for cathedrals. (It wasn't until the 17th century, however, that glass was commonly used for windows for ordinary houses throughout Europe.)

During the first centuries of the Common Era, the art and production of glassmaking flourished. Glassmakers

devised the process of offhand glass blowing, painting and gilding, and showed how to create layers of colors on glass and cut out designs in high relief.

Glass manufacturing evolved in Venice during the time of the Crusades (middle to late Middle Ages), and in the late 13th century an elaborate guild system was established there for glassworkers. Venetian glassblowers created some of the most exquisite glass ever made, according to art historians, including cristallo glass, a transparent, virtually colorless glass that can be created in any shape and to extreme thinness.

Glassmaking became an important trade in Germany and England during the late 1400s and 1500s. In 1674, English glassmaker George Ravenscroft—who had familial ties to Venice's glass artisan community—patented a new type of glass called lead glass. In quantities of 10 to 30 percent, lead oxide was added to improve the appearance of glass and make it easier to melt in furnaces fueled by coal. This process made glass easier to manipulate and decorate, and the production of lead glass galvanized the British economy and allowed England to overtake Venice as the glass industry's capital in the 18th and 19th centuries. Lead glass proved to be invaluable to the optical community, particularly for the manufacturing of optical lenses, telescopes and microscopes.

American glassmaking originated in 1608 in the settlement of Jamestown in the colony of Virginia, and by the early 1800s, window glass—also known as crown glass—was the primary glass in demand in the United States. Glassmakers blew a bubble of glass and spun it until it was flat to create crown glass. By the 1850s, plate glass was developed for mirrors and other products. This glass was made by casting molten glass onto a round or square plate, cooling it and polishing both sides.

Clockwise from left: Mullioned window of the medieval Priori Palace; The Shard, London, the world's tallest glass building; a goblet from London's Savoy glasshouse of George Ravenscroft, 1676-1678. Colorless glass; blown, pattern-molded, applied.

DID YOU KNOW ... ?

- The blowpipe was invented around 30 BCE, probably along the Mediterranean coast. This invention was revolutionary in the history of glassmaking. The craft of glassblowing was passed down from father to son, and from master to apprentice.
- The formulas and procedures used in glassmaking were a closely guarded secret throughout history. At times, the penalty for disclosing techniques was death.
- When breaking, glass cracks at speeds of up to 3,000 miles per hour.
- The Corning Museum of Glass, in Corning, N.Y., with more than 45,000 pieces, possesses the world's largest collection of glass art.
- A modern glass bottle would take 4 millennia or more to decompose.
- Glass has the quickest turnaround of any recycled curbside product. It can be back on store shelves in as little as 30 days.
- The four sectors of the glass industry—container, flat, specialty and fiberglass—produce more than 20 million tons of glass annually, used for myriad consumer products.
- The auto industry uses an estimated 500 million square feet of glass annually. Also, 15 to 20 percent of a car's surface today consists of glass.
- The world's tallest glass building is The Shard in London, which opened in July 2012. Also known as the Shard of Glass or Shard London Bridge, the 95-story skyscraper stands 1,020 feet high and features 11,000 panes of glass.

50.2.2 Collection of The Corning Museum of Glass, Corning, New York

The Secret Behind Bullet-Proof Glass

What gives bullet-resistant glass the ability to stop bullets? While processes vary by manufacturer, the basic strategy involves layering a polycarbonate material between pieces of ordinary glass in a process called lamination. Polycarbonate is a tough transparent plastic—usually between 7 and 75 millimeters in thickness. A bullet fired at a sheet of bullet-resistant glass will pierce the outside layer of the glass, but the layered polycarbonate-glass material is able to absorb the bullet's energy and stop it before it exits the final layer.

SCHOTT AG

Left: Cullet. Above: A melting tank

In the 1890s, the manufacturing of glass changed and increased exponentially. With the advent of machinery (and eventually pipelines that carry petroleum and natural gas to plants), the making of glass—for bulbs, tubing, sheet glass and many other uses—allowed for more precision and mass productivity. In 1904, the first automatic bottle-making machine was invented by Michael J. Owens in Toledo, Ohio, and by the mid-1920s a fully automatic machine to blow electric light bulbs was developed by Corning Glass Works in New York. Elias Snitzer of the American Optical Corp. invented laser glass in 1961. Two decades later, Corning Glass Works introduced transparent glass ceramic cookware.

Today, glass can be recycled to make glass for new containers, particularly when mixed with silica sand, limestone and soda ash. The recycling of glass is relatively easy because glass does not age or diminish with constant usage.

Furthermore, since the 1970s, glass has been utilized to store radioactive wastes. And glass has been used for the creation of specialty glasses, such as an infrared transmitting glass that can be used for lenses in night vision goggles.

MAKING GLASS

Generally speaking, glassmaking has remained the same since ancient times. Most glass contains three primary ingredients: silica (which is usually found in sand), soda or potash (which lowers the temperature after sand melts) and lime (which provides stability to a generally unstable combination).

After being stored in silos, prepared and mixed, the raw materials (called the batch) for glass are transported to a furnace. Cullet (recycled glass or waste glass) is added to the batch to accelerate reactions. Melting the raw materials requires temperatures of 2600 to 2900 Fahrenheit (1427 to 1593 C), depending on the composition of the materials. Particularly large quantities of glass are made in furnaces known as day tanks. Most glass, however, is made in large furnaces known as continuous tanks, where 400 to 600 tons of flat glass can be melted per day for production.

In the case of soda-lime glass—which is largely composed of silica and sodium oxide from soda ash, as well as lime and other additives, and is used for drinking bottles and windows—mass production is conducted in gas-fired units. For specialty glasses, smaller scale furnaces are used, including electric melters, pot furnaces and day tanks.

Glass blowing furnace

Schott Glass manufactures the world's first borosilicate glass, Borofloat, using a microfloat process.

After the melting process, the glass is formed after undergoing homogenization and the removal of bubbles. In the case of flat glass for windows and other uses, a floating glass process is employed in which the top surface of the glass is subjected to nitrogen under pressure to obtain a polished finish. Glass for bottles and jars is produced by blowing and pressing processes.

Four methods exist for the shaping of glass: blowing, pressing, drawing and casting. Blowing is conducted through the ancient practices of a blowpipe. Pressing is done by dropping a hot glob of glass into a mold and then pressing it with a plunger until it fills the mold. In the drawing process, molten glass is drawn in an upward fashion into a sheet through rollers, with the thickness of the sheet determined by the speed of the draw itself and by the configuration of the draw bar. Casting occurs when molten glass is poured into molds with ladles—or straight from the furnace.

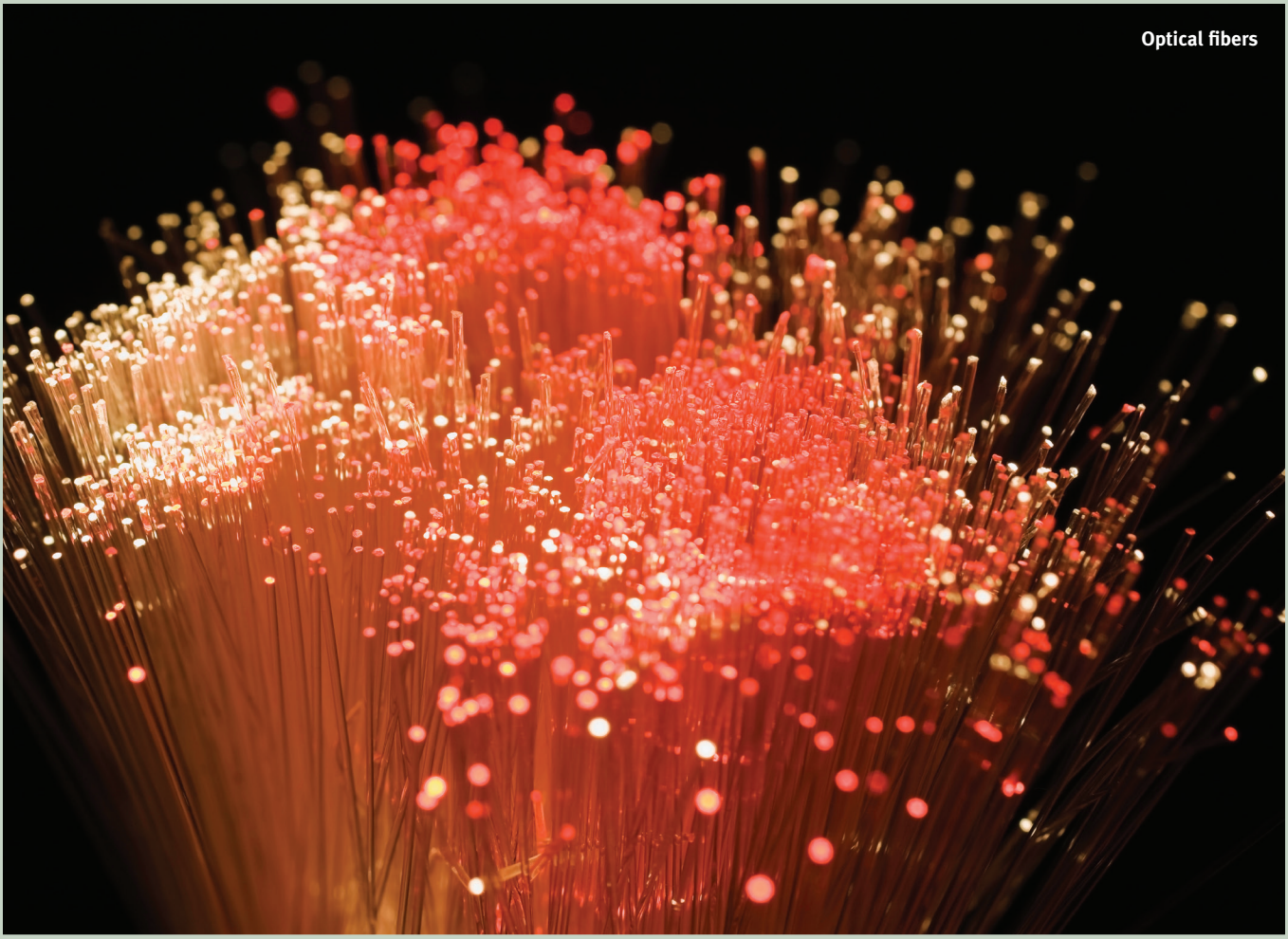
Generally speaking, glassmaking has remained the same since ancient times. Most glass contains three primary ingredients: silica, soda or potash, and lime.

Once the form for glass is achieved, it is annealed (heated and then slowly cooled) to remove strains and stresses. This process might also include surface treatments, and coatings and/or lamination to enhance the chemical durability, strength or optical properties. If not annealed, glass may shatter from tension caused by uneven cooling. Annealing involves reheating glass and cooling it according to a planned timetable and temperature schedule.

After this long process, glass plant engineers inspect the glass by testing samples for quality and desired properties. With blown glass items, excess glass is often removed by scoring the pieces with a diamond or steel wheel, and snapping them off with sudden pressure. If glass edges are too rough, they are usually polished with abrasives or flames from a fire-polishing instrument.

After the finishing process, glass is decorated in various fashions. The etching process requires that glass be

From left to right: A vase is shaped through glass blowing; raw material that has been melted in the pot at Schott in Mainz, Germany, is rolled to flat glass.



Optical fibers

WORLD GLASS INDUSTRY STATS

- **ANNUAL INTERNATIONAL GLASS INDUSTRY REVENUE:** $75 billion
- **LEADING GLASS EXPORTERS:** U.S., France, Belgium, Japan, India and Germany
- **LEADING SPECIALTY PRODUCTS:** Lenses, optic fibers, mirrors, glassware, TV tubes (all of which account for 60 percent of global glass revenue)
- **LEADING GLASS COMPANIES:** China's Jiangsu Farun Group, France's Compagnie de Saint-Gobain, Asahi Glass of Japan, Pilkington of Great Britain, Germany's Schott AG and Guardian Industries, Corning, Owens-Illinois, and PPG Industries of the U.S.
- **PRODUCTS IN GREATEST DEMAND:** Containers, bottling, automotive and construction industrial needs
- **VALUE OF GLASS PACKAGING MARKET:** $35 billion
- **BIGGEST CONSUMERS:** North America, China and Europe account for 75 percent of global demand for glass.

dipped in or sprayed with hydrofluoric acid and some of its compounds etched. The surface may be frosted, rough or opaque, or it could have a translucent, smooth quality. Sandblasting can also be used to give glass a translucent design; the process involves blowing compressed air and sand against the glass while using a rubber stencil to create an image.

In addition, enamels and lusters can be applied to glass by hand painting or the process of transferring decals, or by silk-screening. When the decorations are heated, they fuse to the glass and become part of the piece. This is how many glass products—such as jugs, pitchers and lighting devices—are decorated.

A CLEAR VISION

What is the future of glass? In his book *Glass: A Short History*, David Whitehouse makes it clear that predictions aren't easy to make.

"The speed of change today makes forecasting a risky business," he writes. "It is almost certain that new generations of glass and products that incorporate glass will appear. As scientists make increasing use of nanotechnology [the manipulation of matter on a molecular scale] to improve existing types of glass and devise new ones, the pace of change is likely to become even faster."

The glass industry must continue to devise superior products (translation: lighter and stronger) that will appeal to the consumer base. Innovations will be needed to support the proliferation of glass products in new markets and industries, especially with the advent of the information age.

In particular, glass industry observers say, more research is needed for new glass processing technology to reduce greenhouse gas emissions, waste and energy use while increasing the productivity of glass furnaces. Improved melting and refining processes will be necessary to alleviate environmental concerns while increasing product yield, lowering energy demands and reducing production costs. All these issues will help improve the competitiveness of glass products and create a leaner, cleaner processing system. And of course, the recycling of glass will be key to that mission.

More than 2 millennia ago, the Roman author, naturalist and philosopher Pliny the Elder observed, "*Neque est alia nunc sequacior materia aut ... accommodatior*" (Today no other material is more pliable ... or adaptable than glass).

Those words about the unique and eternal nature of glass are as true today as when they were penned during the Roman Empire. Like love and art, glass is here to stay and will remain a critical part of our lives. Just look in the mirror.