Ceramic & Glass MANUFACTURING

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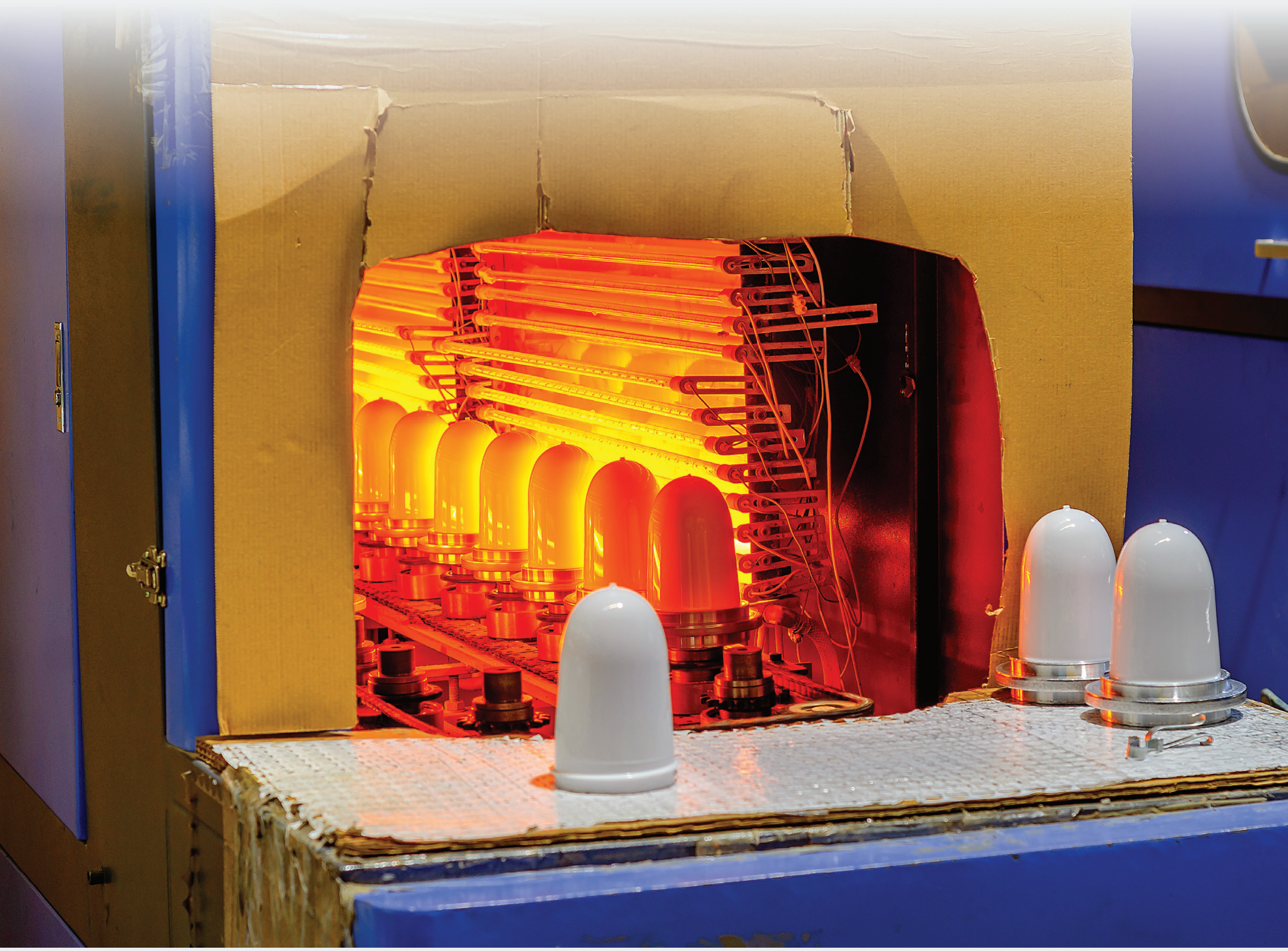

THE FIRE WITHIN: TRENDS IN FURNACES FOCUSED ON LOWER EMISSIONS AND COSTS

THE FUTURE FOR THE GLASS INDUSTRY IS ALL-ELECTRIC

RATH REDUCES CO_2 EMISSIONS BY 70% IN SILICON CARBIDE PRODUCTION

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INDUSTRY NEWS

DURAVIT BUILDS CLIMATE-NEUTRAL PLANT

Duravit AG says it is building the world's first climate-neutral ceramic production facility. It is being built in the Canadian province of Québec. The site will create 240 jobs, with production scheduled to start in early 2025. Ceramic sanitaryware products will be manufactured there using renewable energies. Duravit says it will use the world's first electric roller kiln powered by electricity from hydropower. The parts produced there are planned for the North American market.

The plant will be the first production site for Duravit AG in North America.

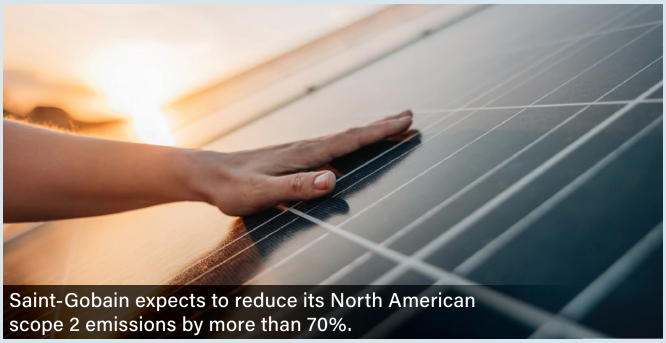

The agreement is designed to meet a demand for materials that survive in ever-harsher environments.

AGREEMENT TO DEVELOP ADVANCED CERAMIC COMPOSITES

Lucideon and the National Composites Center in the U.K. signed a memorandum of understanding to develop advanced ceramic composites. Under the arrangement, Lucideon will focus on providing analysis and evaluation, as well as supporting the development of advanced materials and applications. The National Composites Center will concentrate on full system and product design and industrial scale development.

SAINT-GOBAIN SIGNS AGREEMENT FOR SOLAR POWER

Saint-Gobain signed a 15-year renewable electricity supply agreement with TotalEnergies for the purchase of solar power for its 125 industrial sites in North America. This 100-MW agreement is expected to offset Saint-Gobain's North American CO_2 emissions from electricity by 90,000 metric tons per year. The project is expected to come online by the end of 2024. It is the third power purchase agreement signed in North America by Saint-Gobain.


Saint-Gobain expects to reduce its North American scope 2 emissions by more than 70%.

Saverglass caters to spirit, champagne, fine wine, and sparkling wine brands and industries around the world.

AUSTRALIAN PACKAGING COMPANY BUYS GLASS BOTTLE MAKER

Orora Ltd. acquired Saverglass SAS for 1.29 billion euro. Saverglass designs and manufactures high-end bottles for the premium and ultrapremium spirit and wine markets. Based in Australia, Orora is a manufacturer of packaging products. France-based Saverglass will become the centerpiece of Orora's global glass business unit, the companies say.

OWENS CORNING PROMOTES FISTER TO CFO

Todd Fister

Owens Corning named Todd Fister as the company's new chief financial officer. He succeeds Ken Parks, who stepped down to pursue another professional opportunity. Since 2019, Fister has served as president of the $3.7 billion insulation segment, leading a team of approximately 8,000 employees. Under his leadership, the business grew revenue by 30%. Fister was also instrumental in developing the company's enterprise strategy launched in 2021.

THERMAL BATTERY MILESTONE ACHIEVED

Sunnyvale, California-based Antora Energy says it reached the highest temperature demonstrated to date for thermal batteries at full scale, storing energy above 1,800°C with a thermal battery the company developed. The thermal battery system, which can deliver zero-emissions heat and power, is operational at Wellhead Electric Company, Inc.'s facility near Fresno, California. The company is backed by investors, including Breakthrough Energy Ventures, Lowercarbon Capital, Shell Ventures, BHP Ventures, Trust Ventures, Fifty Years, Grok Ventures, and Impact Science Ventures.

Antora developed a modular, factory-assembled, commercial-scale thermal battery.

Hartmann & Bender was founded in 1897.

LATTIMER GROUP ACQUIRES EQUIPMENT MANUFACTURER

The Lattimer Group acquired Hartmann & Bender, a manufacturer of variable equipment and spare parts for the container glass industry. The acquisition includes Hunprenco, a plunger and cooler manufacturer based in Hunmanby, U.K. Hunprenco also has additional facilities for specialized machining and surface coatings for the glass industry. Lattimer Group companies, Lattimer Ltd., Hunprenco Ltd., and Hartmann & Bender GmbH will remain distinct for the foreseeable future, the Lattimer Group says.

Zeiss head of additive manufacturing technology Claus Hermannstädter, left, and ORNL interim associate laboratory director Rick Raines.

ORNL DEAL TO EVALUATE 3D-PRINTED PARTS

A licensing agreement between the Department of Energy's Oak Ridge National Laboratory and research partner Zeiss will enable industrial X-ray computed tomography to perform rapid evaluations of 3D-printed components using ORNL's machine learning algorithm, Simurgh. The licensing is part of a five-year research collaboration between ORNL and Zeiss, supported by DOE's Advanced Materials and Manufacturing Technologies Office and a Technology Commercialization Fund award.

THE FIRE WITHIN: TRENDS IN FURNACES FOCUSED ON LOWER EMISSIONS AND COSTS

By David Holthaus

The heart of nearly any ceramic or glass production is the furnace, where raw materials are treated with such intense heat that they are transformed into stable, durable, new products. Space shuttle tiles, hip implants, automobile windshields, refractory bricks, and bathroom fixtures must first pass through the fire before they are ready for use.

While the fundamental principles of high-temperature firing remain constant, the methods and equipment employed to carry out the process continue to evolve in response to shifting labor, environmental, and economic conditions. Manufacturers have continued to innovate to meet sustainability goals, reduce energy consumption, and improve the quality of their products.

Nutec Bickley is a furnace maker based in Santa Catarina, Mexico, whose customers include large, advanced ceramic manufacturers. The company manufactures industrial kilns used for refractories, technical ceramics, sanitaryware, electrical insulators, and other products.

Several of the company's biggest customers have committed to transforming their operations over the next two to three decades to become carbon neutral, says Alberto Cantu, vice president of sales. It is a coming transformation that will undoubtedly change their firing processes and fuel sources.

"We are definitely going to see less natural gas in the future," Cantu says.

Moving away from natural gas as a primary fuel is a long-term prospect that will depend on economics and advances in technology. In the near-term, companies are taking other steps to improve energy efficiency.

For example, Nutec Bickley recently installed a 125-meter-long tunnel kiln for an advanced ceramics manufacturing client that produces ceramic cores used in the aerospace industry. The kiln was designed to work year-round at an operating temperature of 1,200°C. Its combustion system uses air traveling back through the

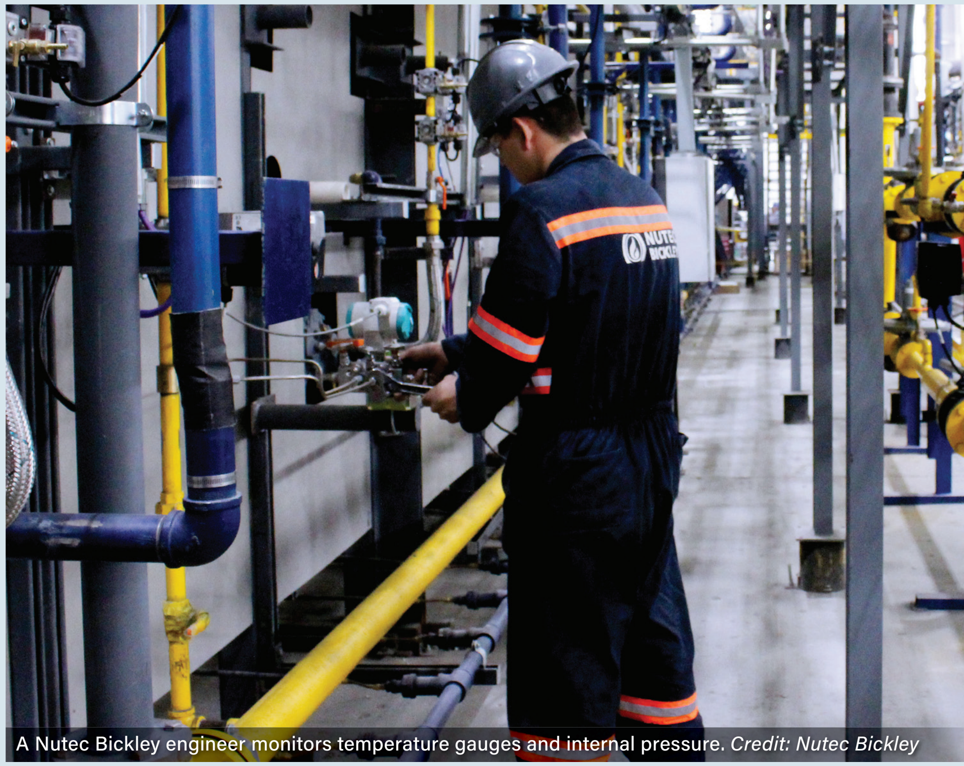
A Nutec Bickley engineer completes a furnace installation. *Credit: Nutec Bickley* tunnel kiln to mix with fuel gas injected through the burners. The system is expected to produce cost savings and a payback period of two years or less, Cantu says.

Manufacturers are increasingly converting their furnace operations to electric to reduce the emissions from their production processes. Cantu says he is seeing conversions in cases where firing takes place in lower temperature regimes at or below 600°C.

"The easiest thing to do is to change everything in your operation to electric," he says.

As a result, his company has seen a surge in the demand for electric kilns.

"We've made more electric kilns in the last four years than in the previous 40," he says.



A Nutec Bickley engineer monitors temperature gauges and internal pressure. *Credit: Nutec Bickley*

The conversion to electric can come with tradeoffs, says Doug Jeter. He is director of sales and marketing for Harrop Industries, a Columbus, Ohio-based maker of custom-designed industrial kilns and ovens. Firing with natural gas can mean more uniform and consistent end products, he says.

"Our customers are mostly concerned about a quality product," he says. "With natural gas you get a lot of mixing in the kilns, and heat transfer can be better."

To aid in product uniformity, Harrop built one of the first large-scale kilns using microwave assist technology.

"The bigger your product gets, the harder it is to heat everything uniformly from the outside," Jeter says. "Just like a microwave at home, it heats from the inside out. The benefit is in potentially more uniform firing."

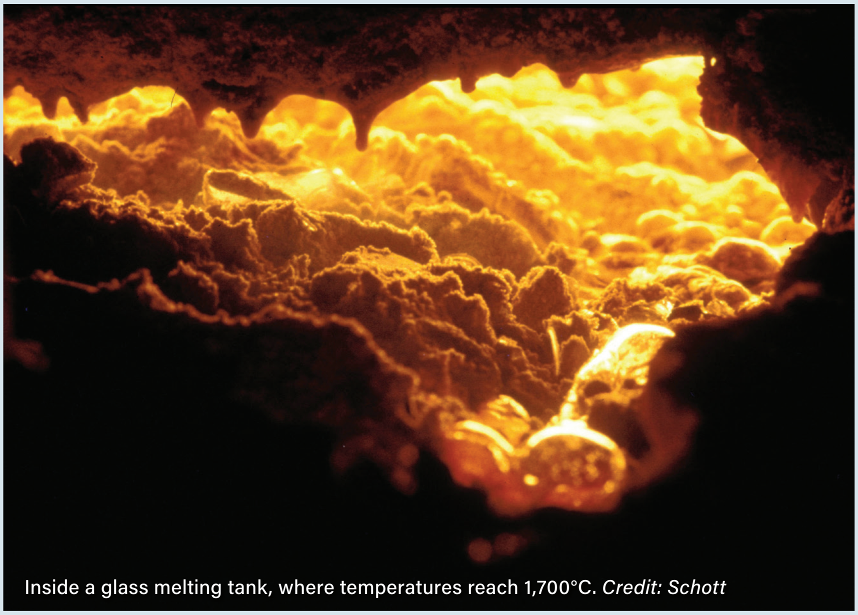
Electric firing could be prone to losing power, which could result in an expensive loss of product, he points out.

"Gas tends to be very reliable," he says.

Natural gas is also relatively inexpensive in the U.S., and, depending on the source of the electric power, converting to electric may not provide the environmental benefits it promises.

"Emission from your stacks may go down, but if the electricity is generated by coal, it's still a carbon emission," he says.

O-I Glass, the Perrysburg, Ohio-based glass maker, is sticking with gas at its new plant in Kentucky on which it broke ground in April 2023. The Bowling Green plant is the first O-I facility built to use the company's MAGMA technology at full-scale.



Inside a glass melting tank, where temperatures reach 1,700°C. *Credit: Schott*

MAGMA stands for Modular Advanced Glass Manufacturing Asset. It is a flexible production system that the company says will allow it to respond more quickly to customer needs and emerging markets.

The MAGMA melter is about a third of the size of a traditional furnace, and its smaller size will allow the addition of more lines as markets grow, or to permit the company to enter new markets, O-I Glass says.

Unlike a traditional furnace, the MAGMA melter can be moved and redeployed to be closer to customer filling lines, the company says. Its size also allows for smaller production runs and adaptability to product changes.

The glassmaking giant piloted the technology at its plants in Streator, Illinois, and Holzminden, Germany. The first phase of construction for the Kentucky facility is expected to be complete in mid-2024, the company says.

While gas remains a reliable and economical fuel source, more companies, particularly those in Europe, are converting their operations to different fuel sources. Hornberg, Germany-based Duravit AG in July 2023 announced that it is building what it called the world's first climate-neutral ceramic production facility. The plant is being built in the Canadian province of Québec and will be the company's first production site in North America.

For the firing process, Duravit will use an electric roller kiln powered by electricity from hydropower. The technology will save 11,000 tons of CO_2 per year compared to a conventional ceramic factory, the company says. The maker of ceramic sanitaryware says the plant is expected to begin production in 2025. The kiln and related equipment are being provided by SACMI, the Imola, Italy-based machine maker.

In Germany, Ardagh Group is nearing completion of a hybrid furnace that will use 80% renewable electricity and 20% gas. Ardagh says the new furnace will invert the current fuel mix of its container glass production, which is a blend of approximately 90% gas and 10% electricity. The new hybrid technology, which the company calls its NextGen Furnace, will reduce CO_2 emissions by as much as 60% in the furnace. The Luxembourg-based maker of glass bottles operates 65 metal and glass production facilities in 16 countries, employs more than 21,000 people, and reports sales of approximately $10 billion.

There is also a trend toward incorporating more automation in furnace technology, Jeter says. Newer furnaces are equipped with sensors and control systems that enable real-time monitoring and adjustment of temperature, atmosphere, and other parameters, improving process control, reducing downtime, and improving the consistency of the products.

Manufacturers are seeking ways to control their processes remotely, either from a booth in the plant or from their mobile phones. Increasing automation minimizes the demand for labor and the need for manual intervention, he says, which can help as businesses try to navigate the nationwide shortage of trained specialists.

The leading edge of furnace technology may be the experiments in using hydrogen as a fuel. Research into whether hydrogen can be used consistently as a fuel and how it might affect the products has been under way.

Jeter says his company has not had any firm inquiries about building a kiln using 100% hydrogen as fuel. Cantu says he is skeptical about the promise of hydrogen as major challenges exist to its adoption.

But major manufacturers have invested in pilot projects. In July 2023, the Schott group announced it had succeeded in producing a test melt using 100% hydrogen. The test was a leap forward from its tests conducted 2022, in which 35% hydrogen was added to a melting tank that had previously been operated exclusively with natural gas.

"For the first time, we succeeded in completely using hydrogen for a holding time of 10 days on a laboratory scale," says Matthias Kaffenberger, melting technology manager at the Mainz, Germany-based glass maker.

In December 2022, Encirc, the U.K.-based glass manufacturer, and Diageo, the spirits giant responsible for Smirnoff, Johnnie Walker, and many other brands, announced a partnership to create the world's first net-zero glass bottles at scale by 2030. An ultralow carbon hybrid glass furnace at Encirc's plant in Elton, England, is expected to begin glass production in 2027. By 2030, the partnership expects to produce up to 200 million net zero bottles of Smirnoff, Captain Morgan, Gordon's, and Tanqueray per year.

The companies say the furnace will reduce carbon emissions by 90%, with an energy mix of green electricity and low-carbon hydrogen. It is expected that carbon-capture technology will harness the remaining carbon emissions by 2030. The furnace will be powered by zero-carbon electricity and hydrogen from a nearby plant.

The expanded hydrogen supply at the Mainz plant enabled the longer test and solved one of the biggest challenges in hydrogen firing.

"The real issue is: what is your source of hydrogen?" Jeter says. "Where are you going to get hydrogen at a regulated pressure and a regulated flow and enough of it to heat your kiln?"

Schott officials also point out that green hydrogen produced from renewable energy is not yet available in sufficient quantities largely due to the lack of an extensive infrastructure for an industrial hydrogen supply.

"We urgently need to take further steps and come up with timely solutions for a functioning infrastructure," says Jens Schulte, a member of the Schott board of directors.

But the trend toward carbon neutrality is expected to move forward, as companies continue to make long-term commitments to making their operations more environmentally friendly. Many observers say they expect to see a mix of technologies, including carbon capture, be used in the efforts.

THE FUTURE FOR THE GLASS INDUSTRY IS ALL-ELECTRIC

By René Meuleman

Meuleman is the solutions and technology lead for green glass at Paris-based Schneider Electric. This article was originally presented at the 14th International Seminar on Furnace Design at Vsetin, Czech Republic, in 2017. View the original article at https://www.eurotherm.com. Reproduced with permission.

Glass melting has been carried out for nearly 6,000 years, and, for most of that time, wood was used as the energy source. It was only comparatively recently, around 1880, that the industry began to use fossil fuels like oil and natural gas. At this time, the regenerator had already been invented to improve the efficiency of steel blast furnaces, and this invention was soon adapted by the glass industry on the early port furnaces, very similar to how we know them today. During those thousands of years of glassmaking, less than 150 years' worth of fossil fuels were used, and it is possible that they will not be around for another 150 years.

Although new fossil fuel resources have recently become available, the world has at last begun to understand that burning them results in unavoidable carbon emissions, and therefore this method must come to an end. Glass melting still needs to continue at this point in time because we have not yet discovered a viable replacement material. It is therefore likely that glass will be around for many centuries to come and that the inevitable future for a carbon efficient glass industry will be "all-electric."

HISTORY

With no disrespect to past furnace design developments and the great achievements that have been made, they are mostly still based on original technology. Traditional side and end port furnaces are proven technology that has been developed and tweaked to a level of efficiency, low emissions, and life expectancy that simply cannot be improved any further. Since the efficiency level came down to 2.4 MWh/ton in around 1990, no big improvements have been achieved. Consequently, further CO_2 and NO_x emission reductions slowed to halt as well.

Oxy-fuel firing, batch preheating, waste heat recovery, submerged burners, etc. are great advances, but the bottom line remains the same: they all increase the complexity of the melting system and CAPEX, do not avoid CO_2 emissions, and in most cases cannot reduce NO_x emissions any further. The use of fossil fuels has become the fundamental problem and technology cannot overcome these issues sufficiently.

THE FUZZINESS OF POLITICS

Just as with many other raw materials, as soon as we start believing that resources are coming to an end, we find new ones. That is also applicable for fossil fuels. So why should we even start considering diverting from fossil fuels? Science has proven that CO_2 emissions are related to global warming, which will likely lead to serious environmental issues for humanity. Legislation, customers, and common sense will force the industry to step away from fossil fuel firing sooner or later.

By 2050, the EU aims to cut greenhouse gas emissions to 80% below 1990 levels. Milestones to achieve this goal are 40% emissions cuts by 2030 and 60% by 2040. All sectors need to contribute. One famous Dutch beer brewer is putting a lot of effort into reducing its carbon footprint and estimates that 53% of this footprint is related to its packaging material. The pressure to reduce emissions comes from many sides. No matter which side we agree or disagree with, it will impact how glass is melted in the future.

TECHNOLOGICAL EVIDENCE

Most glass melting furnace technology goes back 100 years or more. Over the years, different developments have led to huge energy efficiency and emission improvements, and many furnace suppliers are still working on enhancements, forced by the fact that fossil fuel energy remains cheap. However, that will change, and probably much faster than many of us expect.

As previously mentioned, most of those improvements implicate a more complex technology that results in additional maintenance and CAPEX, the use of nonenvironmentally friendly chemicals, and limitations to equipment lifespan. Most glass smelters perceive their melting process as complex enough and are not keen on modifying it further. They want to focus on their core business, without the issues of managing and maintaining complex industrial installations requiring high numbers of technical personnel. Keeping the system simple has been a key argument for many decades.

Now that the world around us seems to be changing rapidly, our efforts to extend the lifetime of furnaces up to 15 years or more is working against us. In fact, most glass manufacturers only have one opportunity every 10 to 15 years to introduce a new innovative melting process, so it is not surprising that having to

Credit: Ardagh Group

live with that decision for the next 15 years makes them extremely risk averse. Who can blame them? It reminds me of a comment made by one of our customers: "In God we trust, but here you have to come with facts." Technological research and development needs to provide evidence of improvements, otherwise politics forces us to rely on expectations.

ELECTRICAL HEATING

Electrically heated furnace technology is almost as old as regenerative furnace technology. In fact, the first furnace patent on electrical melting was issued to Sauvageon in France, in 1907. A first successful cold top furnace ran in Norway from 1920 to 1925 using carbon electrodes. Cornelius in Sweden had operating furnaces as early as 1925, producing amber and green glass.

In 1952, the industry started to use molybdenum electrodes, and around 1975 high current SCR's (thyristors) became available, leading to the principle of solid-state furnace boosting systems we know today. Most modern traditional container, fiber, and float furnaces are now equipped with electrical furnace boosting, contributing 10% to 50% of the melting power.

THE EFFICIENCY OF ALL-ELECTRIC MELTING

Even in the early days, all-electric melting efficiency at 4.4 GJ/ton (1.3 MWh/ton) was already close to today's most efficient fossil fuel fired furnaces at 4 GJ/ton (1.1 MWh/ton). Since the introduction of all-electric furnaces, huge efficiency improvements have been achieved, reducing energy usage levels to 2.8 GJ/ton (0.78 MWh/ton) (20% cullet) or less. The power consumption is not likely to go below 2.6 GJ/ton (0.72 MWh/ton). Most of the electrical power ends up in the melting process anyway, and only relatively low energy losses come from transformers, busbar, and control efficiency. Compared to traditional fossil fuel heating at 4 GJ/ton (1.1 MWh/ton), energy use is around 35% less.

An electrical furnace is naturally easy to control and maintain, but it is important to consider the engineering of the electrical system alongside the furnace design. Like a burner system for a traditional furnace, the electrical system is not a sub system but should be part of the total design and needs to be fully integrated. Bringing steelwork, refractory, cables, busbars, electrodes, transformers, and control together in one design is essential for the efficiency success of the whole system.

ADVANTAGES OF ALL-ELECTRIC MELTING

Compared to high-efficiency, fossil-fuel-fired smelter systems, all-electric furnaces are sophisticated but very straightforward in design. Regenerators or burner skids are not required, and expensive high-temperature crowns are not necessary. Higher pull rates can be achieved without any problems. No combustion related CO_2, thermal NO_x or SO_x emissions are released. Potentially less evaporation of volatile and expensive raw materials, such as boron and lithium, will occur, which makes exhaust filtering much easier. Also, the carryover problem will almost vanish. Smaller furnaces could be considered. For example, one furnace that feeds one forehearth which feeds one IS machine might become a new concept for bottle manufacturing.

DISADVANTAGES OF ALL-ELECTRIC MELTING

Although all-electric furnace concepts are very simple in principle, there are some implications to consider when changing over to this technology. At room temperature, glass or glass compositions are electrical insulators. To start the electrical heating process, it needs to run through a preheating sequence similar to the method used in container and float furnaces.

An all-electric furnace also needs a stable, reliable power grid, and due to different melting and fining behaviors, the glass composition needs to be changed. Electrical tariffs need to come down in price, and in order to lower the carbon footprint, electricity would need to come from renewables instead of coal-fired power plants.

Electrodes need to be maintained by advancing them in case wear leads to higher resistance. There are new methods to counter electrode wear, which would need to be investigated further. Another issue, especially for the container industry, might be how this kind of furnace would handle extremely high amounts of cullet, which may result in different ways cullet and batch are managed.

FLEXIBILITY IS REQUIRED

Electrical power tariffs are strongly related to availability, and the electrical energy market is changing rapidly. Suppliers and utilities subsidized by government grants are investing in wind, biomass, and solar power generation. Citizens also invest in solar panels instead of keeping their money at zero interest in banks. Buzzwords such as "smart grid," "tariff tweaking," "peak shaving," and "frequency control" have become familiar terms, and it is recognized that money can be saved if our electrical energy consuming system becomes more flexible.

To lower the risk of total grid failure, some utilities offer money to be in control of huge industrial loads, to be able to temporarily switch them off when needed. More refined is the method of controlling the network's frequency (dynamic fractional frequency reuse) by tweaking the power consumption of some massive power consumers. Basically, electrical power consumers are financially rewarded if they make part of their electrical power consuming system available for remote power control. Lower peak power demand can lead to lower tariffs. In that case, a dynamic load management system capable of controlling parts of the electrical system to ensure that agreed peak power levels are not exceeded will lower the overall cost of electrical energy.

A glass furnace, containing a huge amount of molten glass, can or should be able to accommodate the flexibility needed to profit from these rewards, grants, and lower electrical tariffs. Glass manufacturing, being part of the high energy consumer community and rapidly changing energy market, needs to look for furnace designs that better fit both today's and tomorrow's requirements. Sophisticated data analysis and (model-based) control strategies should help operators to calculate the available freedom of control, allowable melting energy fluctuations, allowable fossil-to-electric ratio fluctuations, and predict the impact on glass quality. The bottom line is that there is no escape from thinking "out of the box" and stepping away from tradition.

RATH REDUCES CO_2 EMISSIONS BY 70% IN SILICON CARBIDE PRODUCTION

By Heinz Wallner

Heinz Wallner is head of production at RATH's Krummnußbaum plant in Lower Austria. View the original article, published on the RATH website in October 2023, at https://www.rath-group.com/en/news. Reproduced with permission.

At the RATH plant in Krummnußbaum, two new vacuum nitriding furnaces, used exclusively for the production of silicon carbide plates and bricks in a nitrogen atmosphere, are now being operated with electricity. The result: CO_2 emissions are around 70% lower than with the previous gas-fired furnace, and fossil fuels are reduced to a minimum. By operating these furnaces electrically, RATH is taking a global pioneering role in the refractory industry.

Efficient, resource-saving use of materials and a sustainable approach to the environment in the manufacture of its premium products for application temperatures up to 1,800°C are highly relevant to internationally operating refractories manufacturer RATH. Great focus is therefore being placed on the continuous and innovative optimization of production.

This focus can be clearly seen at RATH's Krummnußbaum plant in Lower Austria: Two furnaces, in which silicon carbide plates and bricks for the lining of domestic waste incinerators are produced in a nitrogen atmosphere, have been operated electrically since February 2022. Only thermal post-combustion is still gas-powered. In other words, three out of 10 industrial furnaces are now operated electrically at this RATH plant.

Encouragingly, CO_2 emissions have been reduced by around 70% in the electrically powered furnaces compared to our gas-powered furnace. For SiC production, this means a CO_2 reduction per ton of fuel of about 1.9 tons.

Moreover, the electric operation of these two furnaces makes RATH a pioneer in the industry when it comes to silicon carbide production in a nitrogen atmosphere.

LOWER ENERGY REQUIREMENTS THANKS TO HEAT TREATMENT PROCESS CONVERSION

By changing the heat treatment process from gas to electricity, the existing material and geometry of the firing boxes were adapted and integrated into the firing chamber. To enable the products inside the boxes to be exposed to a nitrogen atmosphere, the firing boxes have to be subjected to high temperatures. The aforementioned changes allow for shorter heating and firing times for this energy and time-intensive process, which in turn results in lower energy requirements.

In terms of product quality, the balance is also positive.

In the run-up to the acquisition, RATH carried out trials in small batches in collaboration with the furnace manufacturer. The furnaces were ordered after numerous tests had been carried out in external laboratories and had yielded optimum quality. The procedure has paid off—the product quality is outstanding.

The biggest challenge was to define the best process parameters for the firing. In addition, the electrical infrastructure (transformer station) had to be expanded and a cooling system had to be installed for the two furnaces.

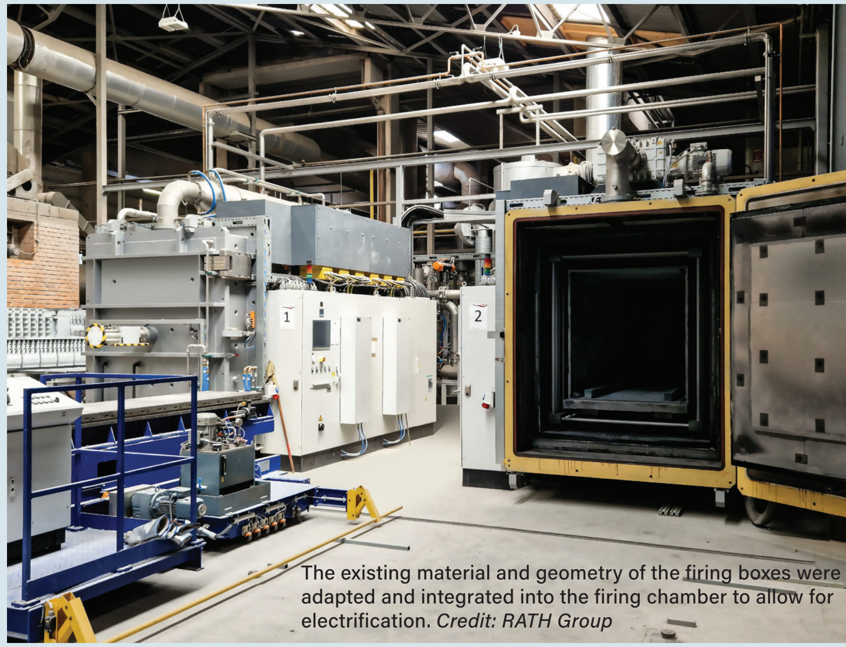
An electrically operated furnace at RATH's Krummnußbaum plant in Lower Austria. *Credit: RATH Group*

ELECTRICITY FROM THE COMPANY'S OWN PHOTOVOLTAIC PLANT

When it comes to energy generation, RATH in Krummnußbaum is also future-oriented.

A photovoltaic system was erected on the roofs of the factory halls and put into operation in 2020. This 696 kWp photovoltaic plant generates up to 700 MWh per year, which means that around 20% of the daily electricity requirement currently comes from solar energy. The photovoltaic system results in a reduction of around 350 tons in CO_2 emissions per year.

Since 2020, around 99% of the electricity produced annually by this self-consumption plant has been used directly at the Krummnußbaum plant. Any surplus energy is fed back into the grid.



The existing material and geometry of the firing boxes were adapted and integrated into the firing chamber to allow for electrification. *Credit: RATH Group*

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- Density variations in materials made using advacned synthesis process such as freeze casting, tape casting, injection molding, etc.
- Interfaces in laminated tape-cast parts and in other dissimialr materials joints
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- Utilizes a simple process through which a liquid, melt, paste, or gel is dispensed from a material cartridge through a needle tip from a 3-axis system, for a maximum build volume of 150 x 150 x 140 mm.
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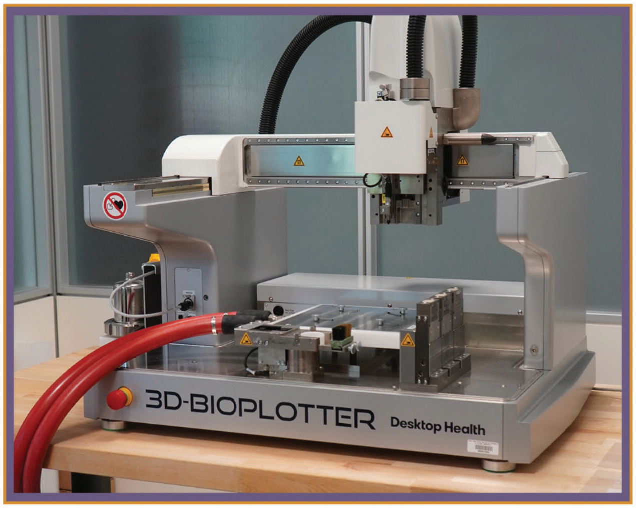
- Can print parts for a wide range of biomedical applications, including hard and soft tissue regeneration, scaffold supports, hydrogels, and non-degradable device components.



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