Centorr Vacuum Industries: Celebrating 60 years of innovation in vacuum furnace production

Centorr Vacuum Industries is one of North America's largest manufacturers of standardised and custom high temperature vacuum furnaces and the company has supplied furnaces to the MIM industry for nearly 30 years. During this period the company's product range has continued to evolve as MIM has transformed into a dynamic global industry. Nick Williams interviewed Centorr's Bill Nareski and Scott Robinson and reports on the company's history, its long association with the MIM industry and the unique perspective that the company can offer on technical and commercial developments.

This year Centorr Vacuum Industries (CVI), based in Nashua, New Hampshire, USA, celebrates sixty years of vacuum furnace production. Over this period the company has installed over 6500 furnaces worldwide. The MIM industry is an important market for the company and over the last year more MIM furnaces were commissioned than any other product line in the company's diverse offering, accounting for 25% of its total equipment sales.

Centorr Vacuum Industries was actually formed in 1989 following the merger of two separate furnace companies, Centorr Furnaces, founded in 1962 in Suncook, New Hampshire, a maker of small laboratory and R&D furnaces, and Vacuum Industries, a manufacturer of large production vacuum furnaces founded in 1954 in Somerville, Massachusetts.

Bill Nareski, CEO of Centorr Vacuum Industries, told *PIM International*, "It was the perfect fit between the two companies. It gave the business an extremely broad product line from the smallest laboratory furnace to large production-sized industrial equipment. Our experience in laboratory furnaces and working with corporate laboratories, as well as many major universities with a materials science programme, allowed us to get in on the ground floor of new breaking technology and, when customers are looking to take a new advanced material from the laboratory to full scale commercial production, we can be there with the large scale equipment which we tailor as needed to run the customer's process."

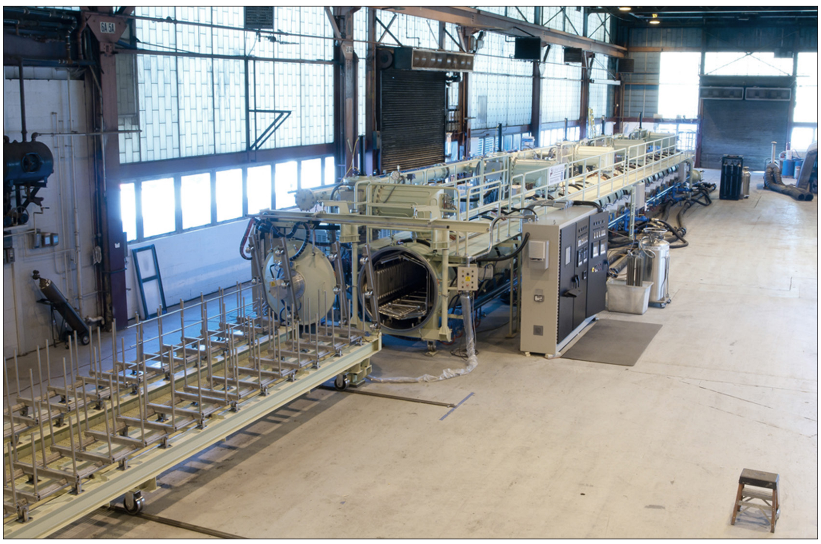

Fig. 1 Centorr Vacuum Industries manufactures some of the world's largest vacuum furnaces, including several 30 m long furnaces for the nuclear industry

Fig. 2 A Centorr MIM-Vac furnace under construction

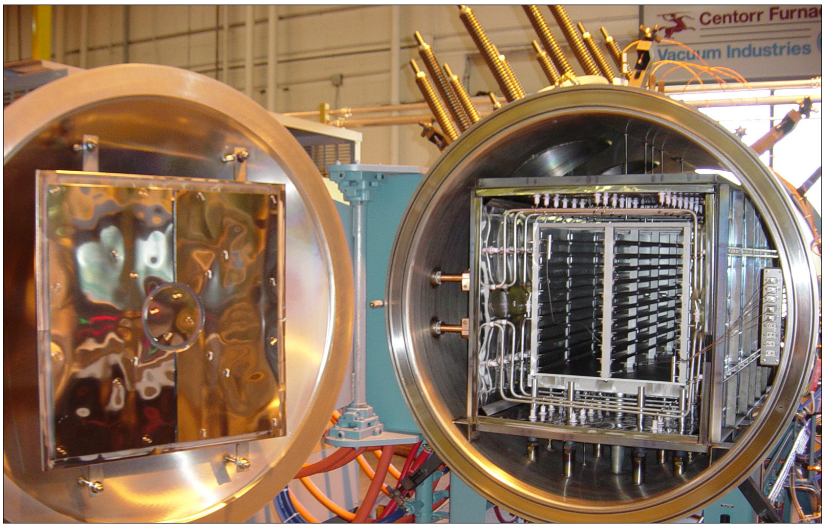

Fig. 3 A Centorr MIM Gas Plenum Retort constructed of advanced Lanthanated Molybdenum (ML) and TZM compositions for improved strength and durability

CVI employs approximately sixty people at its Nashua facility, with around twenty additional sales and service agents representing the company in Europe, Asia, Australia and South America. The Nashua facility has a 2,790 m^2 manufacturing and laboratory area plus an additional 1,860 m^2 of office space. A large 3 x 3 x 3 m pit in the main facility allows for development of tall equipment, essential to support the company's optical fibre drawing furnace product line which supports the photonics and telecommunications industry, as well as the construction of metal wire annealing furnaces.

Over the past ten years, CVI's MIM furnace business has grown to between 15 and 25% of the company's total annual sales. "While this may seem low compared to other vacuum furnace companies, who specialise in only one or two product lines or serve a single main industry and live or die on the strength of that business, in CVI's case - with sales of between \$25 and \$30 million annually - our MIM sales at 25% match or exceed the annual MIM output of most of our competitors. Our MIM numbers are just dwarfed by our higher sales figures for the over 65 different styles of furnaces that we offer for hundreds of applications in the metals and ceramics industry." The company exports approximately 40 - 50% of sales, with most of these furnaces being to Asia, Europe and Canada.

In January 2002 CVI completed a new building at its Nashua headquarters which includes a tower facility with 5 ton hook and crane with 1200 amp service and 350 KVA chilled glycol system. This enables CVI to design and build large Vacuum Hot Presses, Chemical Vapour Deposition and Chemical Vapour Infiltration furnaces as well as other vertical furnace designs for custom applications in the nuclear industry.

"This investment in facilities and testing is necessary in order to support ongoing interest in advanced ceramics for the semi-conductor, automotive and armour markets," stated Nareski. "To-date the new building has been used for the construction of two large scale vacuum/controlled atmosphere hot presses for advanced ceramics for use in China and the United States, a tall vertical furnace for a proprietary process, a SiC CVD furnace and a host of other furnaces."

For large furnace projects that do not fit in the company's existing building, CVI has access to another site in Nashua with up to 3,715 m^2 of manufacturing space. Since 2008 this facility has been used to construct a number of large 30 m long furnaces, some of the largest vacuum furnaces in the world, for processing nuclear tubing for zirconium fuel rods and Inconel power water reactor tubing.

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MIM furnace development at Centorr

Centorr was an early entrant into the market for Metal Injection Moulding furnaces. "We broke into the field by being the first company to offer MIM process and cycle support in our Applied Technology Center. Our early work for some of the MIM industry's pioneers turned into our first orders from companies such as Remington Arms, Megamet, Porite and Moldmasters," stated Scott Robinson, Market Manager for the PIM and PM sectors.

CVI's first dedicated design for the growing MIM industry was the Injectvac™ furnace, introduced in the 1980s, which included a graphite hot zone and a revolutionary gas plenum retort design with hole pattern designed to ensure proper flow dynamics of the inert and process gases over the surface of all the parts. The Injectavac™ furnace processed MIM parts from wax-polymer binder removal through to sintering in one continuous cycle and included a dual pumping system (high-vacuum and low-vacuum) which allowed it to be used to remove both the first stage wax binders as well as the second stage polymers, before going up to sintering temperatures.

The first stage wax binders were removed using a diffusion pump (sub-atmospheric evaporation) at dewax pressures less than 10^{-3} torr. The second stage polymers, on the other hand, would clog the diffusion pump but thermally break down at temperatures over 350°C into compounds with relatively high vapour pressures. The high vapour pressures allow the use of CVI's proprietary Sweepgas™ BRS™ (Binder Removal System) to carry the vapours away from the parts in the direction of the pumps. Inert gas is bled into the furnace chamber and the retort plenum, where it entrains polymers vapourised from the work pieces and carries them out towards the BRS pump. "The unit was very successful at the time," commented Robinson, "and CVI enjoyed the largest installed base of graphite MIM furnaces worldwide with over 20 units installed in the USA and Europe and an additional 22 units in China, Korea, and Japan sold through CVI's licensee."

Fig. 3 A MIM-Vac furnace installed at Dynacast's US MIM operation

Fig. 4 A MIM-Vac furnaces at Dynacast's Singapore operation

As processes and technologies evolved the MIM industry moved away from first stage thermal debinding in batch furnaces and relied more on hot water or solvent debind in the case of traditional wax/polymer binder systems, or catalytic debinding for polyacetal feedstocks. This processing of first stage binder offline meant that MIM vacuum furnaces no longer needed to handle the lengthy wax debind portion of the cycle. This allowed furnace manufacturers to focus on second stage debinding followed by sintering, where such expensive capital equipment could be better utilised.

As newer, higher quality MIM feedstock materials entered the market more stringent demands on physical properties such as carbon control became important and new designs utilising a refractory metal hot zone were needed to process these materials in a cleaner environment.

Leaning on its experience in high temperature refractory metal furnace designs for high temperature sintering at temperatures from 1600°C to 2600°C, and its experience in debinding of over 200 different types of organic binders, CVI introduced its new line of Metal Hot Zone MIM units, named the MIM-Vac, in 1999. "Today's MIM-Vac™ furnaces

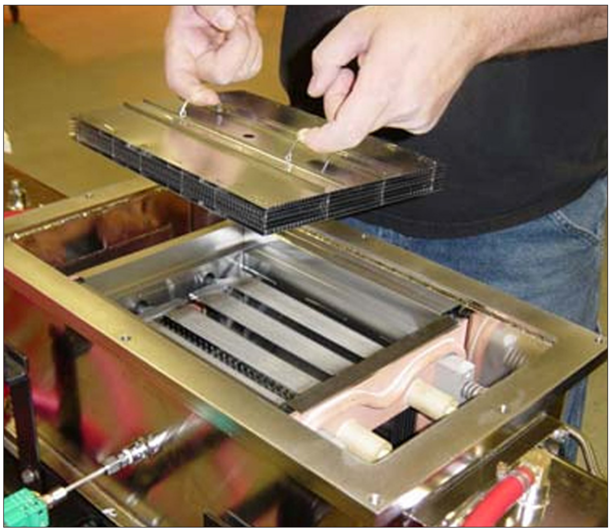

Fig. 5 Refractory metal hot zones in Centorr's small continuous belt furnace designed specifically for the micro-MIM market

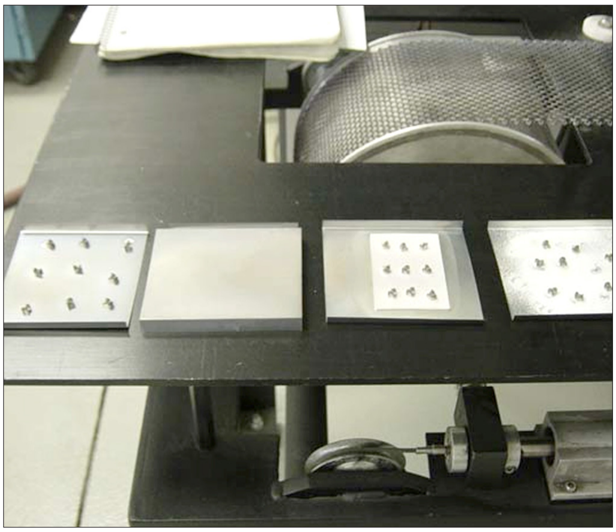

Fig. 6 Trays of small hinges on varied ceramic setter materials including sapphire, ceramic paper and alumina powder

are the result of almost 30 years of experience in PIM technology and over 40 years debinding and sintering experience in metals and ceramic parts. The core design is based on our Workhorse® Metal Hot Zone furnaces which have been sold worldwide for the sintering of PM parts, with over 350 units in the field, and a variation of the binder removal technology from Sintervac® units that were developed for the tungsten carbide industry with over 600 units in use worldwide," Robinson stated.

"The MIM-Vac™ furnace is designed primarily for second stage binder removal and sintering, and has a number of design improvements specific for use with MIM feedstock. Tight partial pressure control and even gas flow, in conjunction with effective event-based programming and sound retort design, allows the entire load to view the same series of conditions as a function of time. This results in consistent microstructures and repeatable carbon control. The judicious use of advanced molybdenum alloys in the hot zone and retort, such as Lanthanated Molybdenum and TZM, offers excellent creep resistance, higher recrystallisation temperatures and longer service life. Our revolutionary new gas-plenum retort has rows of perforations allowing even gas flow across all the work trays and now includes removable plenum panels inset in a strong structural molybdenum framework that allows fast and easy removal and replacement of individual panels, minimising repair costs and downtime."

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The company states that the use of a heavy duty molybdenum skeleton framework with large cross-section structural members results in less warping and creep over the life of the retort, as evidenced by current units in the field which, CVI claims, are providing two to three times the life expectancy of competitive designs.

A unique perspective on MIM industry growth

Equipment suppliers are well placed to understand industry growth trends and Centorr Vacuum Industries is no exception. Nareski told *PIM International*, "We are encouraged by the recent period of high growth in MIM over the past three years, spurred in part in the US by the rapid increase in the firearms business. It is also refreshing to see firms new to MIM, such as Dynacast International, embrace this technology as a way to increase their product offering and provide their customer base with new materials and improved physical properties."

As reported in the December 2013 issue of *PIM International (Vol. 7 No. 4, p 16)*, CVI received orders for four MIM-Vac M furnaces for Dynacast's new MIM operation in 2013. "In our opinion, Dynacast was a savvy purchaser who had tremendous production experience as an international investment casting firm operating 22 manufacturing facilities in 16 countries. In February 2013 they announced they would be adding MIM to their service offering and the addition of MIM as a manufacturing process meant that the company could expand its ability to produce small, complex components using a far wider variety of metals," stated Nareski.

"Their new twist on the MIM process involved the use of their own revolutionary die-casting machines, modified to run conventional MIM feedstock. We believe it was their desire to have equally high performing furnace equipment to go along with their new process. After a few in-depth meetings where we discussed the features and benefits of our design we agreed that, while cost was an important factor in any purchase decision, Dynacast should take all factors into consideration including overall cost of ownership and life expectancy of the expensive hot zone components."

CVI also commented that it is reassured by ongoing growth and follow up orders from well established firms in the MIM industry such as Parmatech Corporation, which is continuing the growth and expansion plan that it started in 2010. There is also optimism about the growth of MIM in Asia.

Trends in materials

Commenting on trends in MIM feedstock usage Robinson stated, "The range of MIM feedstock on the market truly offers MIM producers a wide choice of materials. We continue to be surprised at the differences that various feedstock systems have on the day-to-day operation of MIM furnaces and their impact on maintenance schedules. We have some customers who are cleaning traps every one or two cycles, whilst others just check the traps once a quarter!"

In terms of the evolution of MIM material grades, CVI sees progress in MIM titanium. "As the technology for stainless steels and low-alloy steels and their applications becomes saturated, it is only natural that the industry will look to new materials for this innovative processing technique. Titanium MIM presents its own barriers to commercialisation but it is impressive to see the progress that has been made in powder and feedstock formulations."

Opportunities in micro-MIM

Centorr is following the technical work done in the micro-MIM field very closely as it believes that this will continue to grow into one of the largest and most profitable segments of MIM. The company has recently enhanced its MIM furnace portfolio with the further development of a small continuous belt furnace designed specifically for the micro-MIM market. Based on CVI's standard continuous belt furnace design the furnace is constructed in a similar way to a vacuum furnace, with water-cooled chamber and refractory metal hot zone. It can achieve a hydrogen gas dew point of -60°C in the main chamber after as little as 45 minutes of purging with inert gas. Unlike conventional belt or pusher furnaces, the hot zone can be brought up to maximum temperature in as little as 60 minutes and the unit can be turned off at night and is cold within an hour.

"Our belt furnace has been used successfully to process small MIM parts, such as orthodontics, in our Applied Technology Center using a 100% hydrogen environment and has achieved product densities of up to 98% theoretical density in 17-4PH and 316L parts with cycle times under 120 minutes door-to-door. Future work in this field will centre around further optimising cycle times," stated Robinson. "We believe that this new small inline continuous MIM belt furnace design could be a real game changer in terms of reducing manufacturing costs and provide a greener footprint for MIM parts makers."

Efficiency gains and process improvement

Centorr has worked with a number of key customers to improve the debinding efficiency of their process and explore ways to tighten up the hot zone and retort to ensure a higher degree of carbon removal. "In one case the collaboration resulted in a reduction in the carbon content in stainless steel parts by over 50% and reduced the effect of carburisation of the hot zone components, increasing

Fig. 7 The MIM-Vac 'T/P' Trap (Trap Over Pot) for easy wax/polymer removal features a double O-ring groove seal for H_2 safety

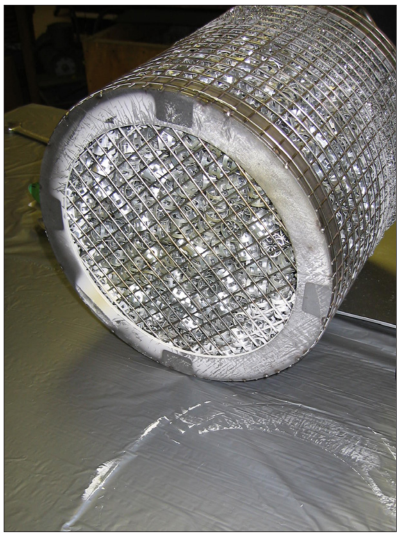

Fig. 8 A basket of dual mechanical filtration media is claimed to be more efficient that condensation-based trapping approaches

hot zone and retort lifetimes," stated Robinson. "Other work in this area has primarily centred on improving trapping efficiencies and looking for ways to reduce the downtime caused by maintenance tasks, all in an effort to shorten MIM cycles and the turnaround time between runs. To do this we have been working closely with vacuum dry pump manufacturers to find ways to improve the robust operation and service life of their equipment."

CVI's Applied Technology Center undertakes all in-house research

Fig. 9 MIM-Vac furnaces are conveniently mounted on a skid which allows for full unobstructed access to the chamber and surrounding equipment

Fig. 10 A MIM-Vac control panel

and is regarded as a major asset to the business. The Applied Technology Center can simulate processes from high-vacuum to positive pressure inert gas and operation in 100% hydrogen gas, with capabilities from 1000°C to 2800°C. This allows customers to test run their materials in different gas atmospheres, vacuum levels and hot zone materials when making the final adjustments to a new process.

"Process evaluation is an important aspect of customer service, enabling prospective users of high-temperature equipment to test ideas and perfect operating procedures so that equipment can be properly specified to perform planned operations. Testing in our Applied Technology Center's continuous furnace has allowed several MIM manufacturers to produce high-quality materials in a quarter of the time required in a conventional batch furnace design due to the reduced furnace cross-section and lower thermal mass. Because of the tightness of the vacuum-tested chamber and refractory metal hot zone inside and use of a proprietary patented molybdenum mesh belt design, these belt furnaces can operate in 100% hydrogen atmospheres at dewpoints as low as -60°C, offering cleanliness unlike traditional continuous furnace designs. The variable and programmable belt speed allows for fast ramp rates and the small cross-section uniform temperature hot zone at < +/- 3°C means that parts can be processed in a quarter of the time when compared to batch furnace cycles."

Furnace maintenance

CVI strongly emphasises the importance of good training and maintenance procedures in order for MIM part producers to achieve the highest levels of efficiency, productivity and reliability from a MIM vacuum batch furnace. "For any company installing vacuum batch units for the first time there will definitely be a learning curve as they get to know the furnace and develop a plan for its maintenance. These units are not heat treatment furnaces where you fill up the vacuum pumps with oil once a quarter and "let 'em run". These furnaces process several kilograms of nasty plastic binder residue each and every cycle and they do it in such a way as to keep the internals of the furnace clean enough to process low-carbon grades of expensive materials. Traps need to be emptied and cleaned, manifolding needs to be checked at major preventative maintenance campaigns and dry pumps need to be cleaned periodically, either manually or with routine solvent flushes."

"Centorr has learned these facts since our development work in the 1980s and we have found several ways to reduce the time required for these maintenance tasks and make them easier to accomplish. We all know that you could write the best SOPs for your team to follow, but the more difficult something is to maintain, the less likely it will get done right, or done at all! Our MIM furnaces have easily accessible large water-cooled traps with a removable basket filled with two different types of filtration media, including a simple binder pot on the bottom that can be removed and cleaned after each run. While one trap is good, two are even better, and we include a second trap on the exit-end of the dry pumping system to catch any residual binder that makes it through the manifolding and dry pump. With this design smelly binder off-gas and small pieces of uncombusted residual binder that make it past the flame tower exhaust, don't rain down all over your nice clean furnace room," commented Robinson.

CVI's Engineering and Aftermarket Field Service Group plays an important role in maintaining a reputation for high quality capital equipment. Nareski stated, "Our customers know that we will be around for the long term providing spare parts, hot zones and field service, as well as furnace maintenance programmes, upgrades and retrofits, rebuilds and controls. In a recent informal survey, we found that nearly 70% of the equipment we have built since 1980 was still up and running and we routinely provide spare parts for some equipment built during the 1970s. It is this attention to quality that allows our capital equipment to perform under all types of conditions with repeatable and reliable service."

'The need for this type of equipment is only going to grow in the future and we're going to be prepared to meet that need'

Selecting the right MIM furnace

CVI states that, when planning a MIM operation, of utmost importance is being sure of the actual material types that a part producer will be processing. Low-alloy steels are commonly processed in simple large sintering furnaces outfitted with small traps and no retorts, using vacuum or low partial pressures of inert gas, because the debinding step is less critical due to the high carbon content in the remaining parts.

Higher grades of stainless steel such as 17-4PH and 316L require more precise operating conditions with higher partial pressures (from 100-300 torr) of typically Hydrogen gas and require more consistent gas flow across the surface of the parts; hence expensive refractory metal gas plenum retort designs, to ensure low carbon content in the finished parts. This can be below 0.03% in the case of some 316L applications. Likewise, titanium MIM grades also require the cleanliness that only a vacuum batch MIM furnace can provide in order to process end product with acceptably low oxygen levels.

"When the end-user considers the overall capacity required, they need to factor in their product mix. Large volumes of only one or two different parts can point towards using continuous furnaces, while a mix of several different product grades or part sizes usually requires the flexibility that only vacuum batch MIM units can offer with their ability to vary cycle times and temperatures for each individual need. While small lower-cost box furnaces of 1 to 2 ft^3 are prevalent in the industry and used by firms as they gear up their production line, once volumes increase it can make sense to consider larger vacuum/hydrogen MIM furnace designs that routinely process 6 or 9 ft^3 of material at a time and offer active fan-cooling features that can drastically shorten overall cycle times producing higher output," stated Robinson.

"When it comes to understanding total cost of ownership, a MIM firm needs to understand their costs for power and gas usage and weigh this against their production schedule. While vacuum batch MIM furnaces typically have larger power supplies than continuous furnaces, they are only operational during heating and not on 24/7 as with continuous pusher designs. Hydrogen gas usage for an average MIM cycle in a 9 ft^3 furnace could be as low as 25,000 litres for some alloys where reduced hydrogen flow is used to prevent decarburisation of the parts, and up to 80,000 litres per cycle for other grades like 17-4PH. Vacuum batch units additionally do not require 24 hour operation as the units can be scheduled so that loading and unloading can occur at defined times."

Outlook

"CVI has been at the forefront of high-temperature vacuum/controlled atmosphere furnace manufacturing for decades and we have no intention of slowing down. My long-term goal for the company is to build on the position of strength we already have and bring Centorr Vacuum Industries to a point where we are considered universally the primary resource for ultra-high-temperature equipment in all the significant applications," stated Nareski. "The need for this type of equipment is only going to grow in the future and we're going to be prepared to meet that need."

"Our depth of experience in engineering and manufacturing has resulted in several new advancements and technologies for the processing of MIM parts. We have excellent financial stability and a history of offering customers a long-term partnership so they can be assured of a ready supply of spare parts and frequent upgrades and improvements to the design in order to keep their equipment operating on the cutting edge."

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