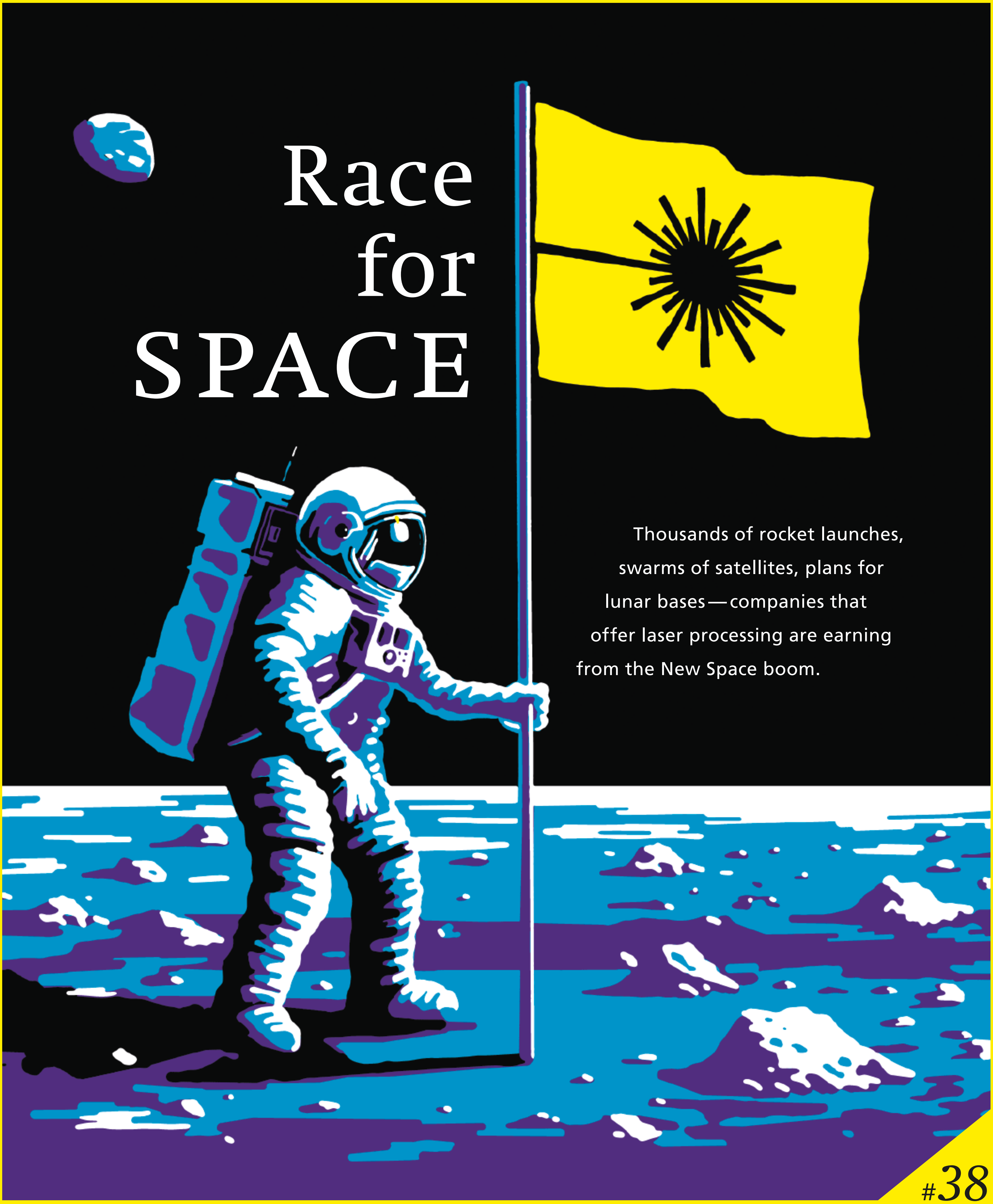
LASER COMMUNITY.
Of people and photons



Race for SPACE

Thousands of rocket launches, swarms of satellites, plans for lunar bases — companies that offer laser processing are earning from the New Space boom.

#38

Infrared image of the Andromeda galaxy.

LASER COMMUNITY. *#38*

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Dear Readers,

At TRUMPF, we too share humanity's dream of exploring space. And while we may not sit at the helm of a spaceship and will most likely never set foot on the moon, we do develop and build the lasers and machines that will help us discover these new worlds.

With private space flight on the cusp of a boom in the U.S., and space start-ups springing up in Europe and Japan, a market worth billions is now emerging. Before long, researchers in orbit will be investigating new drugs on privately financed space stations as pharma and biotech companies dig deep to fund such pioneering work. SpaceX and Amazon, meanwhile, have similar missions in mind. With their Starlink and Kuiper satellite constellations, they are planning to bring fast Internet to the far-flung corners of the globe. Government space programs are also aiming high: NASA, the U.S. space agency, is currently preparing for a new moon shot, the first lunar landing in over half a century. And the centerpiece of the Chinese space program is the Tiangong ("Sky Palace") space station, with which China plans to prepare missions into deep space.

At TRUMPF, we aim to propel this new race for space with our innovative technologies. Using our laser machines and our manufacturing expertise, space companies will be able to build rockets, satellites, and space shuttles that will take them into Earth's orbit and beyond. This fascinating trend also marks a decisive opportunity for our company to help shape a still-fledgling market.

The development of this sector will also open up new applications for lasers that extend well beyond the world of material processing. In the future, for example, satellites in low Earth orbit will use laser signals to exchange data.

I imagine you can already guess the focus of this new issue of *Laser Community*. Our cover story *on page 12* explores the latest trends in the space industry. We discuss the challenges and the opportunities of this new market and take a closer look at some of the projects in which TRUMPF will be involved over the coming years. Our report *on page 6* shows how a laser tech contract manufacturer is benefiting from the commercialization of space flight as companies race to profit from the New Space boom. And *on page 18*, you can read how advanced laser technology is helping researchers shine a new light on the atmosphere of our planet.

I hope you will join us on our exciting journey into space and back, via the moon.
Pleasant reading!

DR. RER. NAT. HAGEN ZIMER

Chief Executive Officer for Laser Technology
Member of the Managing Board of TRUMPF SE + Co. KG

Julian Rentzsch

Photography

Maria Bürger runs the family company together with husband Hans and two of their children. She prefers working behind the scenes but nonetheless granted us a photo opportunity. To see further family members, turn to **page 7**.

Biography

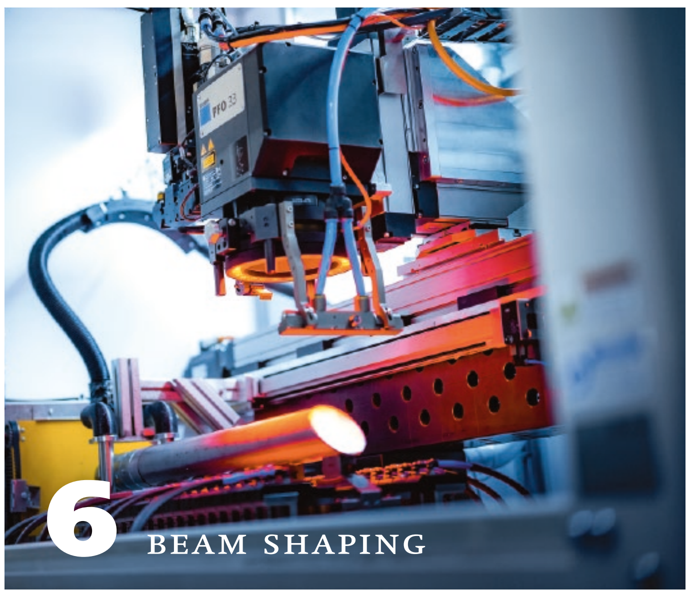
Hiked through Amazonia, camped on mountain peaks, braved polar bears on Spitsbergen—with Josef Höffner, it was difficult focusing on the actual topic. We'll gladly pass on his details to a willing biographer! See **page 18**.

AI-graphy

AI has been a good friend to the *Laser Community* editorial team for some years now. For our big interview, AI delivered an image that was surprisingly close to the real thing. Judge for yourself on **page 20**.

Jan Hosan, Fraunhofer ILT Aachen – Ralf Baumgarten, Die Magaziniker & AI

LASER



Gernot Walter, Jan Hosan

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Jan Hosan

Welding, cutting, drilling—the latest laser equipment and R&D expertise are BBW's recipe for success.

THE JOY OF LASER TECH!

Aerospace, semiconductors, e-mobility—anyone wanting to discover the latest trends in laser processing could do worse than watch this Bavarian manufacturer at work.

Prutting, near Rosenheim, nestles picturesquely in the green countryside of southern Bavaria, between lakes and mountains. It is here that the company BBW Lasertechnik uses high-end lasers and beam shaping to manufacture products that help pioneering technologies achieve their breakthrough. Andreas Bürger, joint managing director of BBW, has a simple formula to express the company philosophy: "We just make sure we've got the latest laser tech, and the rest follows from that." By this, he means orders, research projects, and designs for machines and complex products—in other words, everything that makes BBW stand out from the pool of contract manufacturers that offer laser processing. Anyone curious as to the latest market trends need do no more than take a look at what the company and its 200-strong workforce is currently up to.

BATTERIES FOR E-MOBILITY When the battery boom first began, Andreas Bürger conducted a mental inventory. "We looked at all our machinery and all the know-how we have here, and we quickly realized that we were perfectly set up to produce battery modules and energy storage systems." While others would need to buy new machines and bring in new expertise, BBW already had everything in place. "Our company motto has always been that we aim to give customers something new before they've even asked for it." Underlying this offer is BBW's experience in manufacturing highly complex assemblies and its knowledge of all the various strategies for processing even the most difficult of materials. Whenever things seem to reach an impasse, that's when the company starts to research and develop new approaches and techniques. "We look for the niche in a boom market," he explains. "That's really paid off with batteries for electric vehicles. The cells are incredibly sensitive, so the parameters are very tight when it comes to welding the cell contacting system. And dif-

> *"We've always said that our aim is to give customers something new before they've even asked for it."*

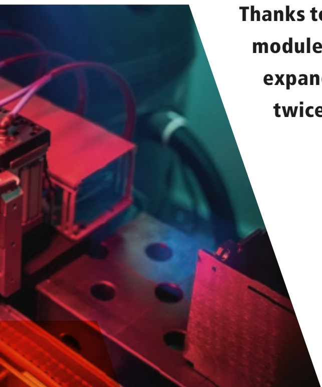
Andreas Bürger, joint managing director since 2015 and son of company founder Hans Bürger

ferent types of cells require different laser sources and processes." Battery modules now account for almost 40 percent of BBW's manufacturing output. But that's not the company's only high-end niche market.

EXPERTISE FOR AEROSPACE At its plant in Prutting, the company has some 50 laser machines for welding, drilling, ablating, texturing, precision cutting, and cleaning, all spread across various production halls. According to Bürger, however, there are customers who expect more than just a big machine park. "We operate in some highly complex industries—battery production, medical technology, electronics for the semiconductor industry, and aerospace," he explains. "So we have to find other ways of convincing our customers." That's why the company has its own development department and metallography department—that and the Bürger family's own insatiable interest in laser processing. At the start of each project, the company conducts an in-depth feasibility study and preliminary tests in its own lab.

Jan Hosan

Proven technology remains in service. In parallel, BBW continues to invest in the latest laser systems and steadily expand its portfolio.



Thanks to the boom in battery modules, BBW has had to expand its production facilities twice in a short space of time.

“We like to do things ourselves, so that it all works perfectly in the end.”

Andreas Bürger, joint managing director of BBW

In many cases, BBW will take on a number of laser-processing steps and also do the post-processing or even manufacture complete assemblies. “We like to do things ourselves. That way, we can be sure that it will all work perfectly in the end.” In the highly demanding, highly specialized markets that BBW serves, that’s a vital consideration. Certification for the aerospace industry, in particular, is not easy to obtain. “In some cases, every weld seam is x-rayed. We have to train our workforce accordingly and document this in full. But it’s all worthwhile, if the quality’s right.”

To ensure that such high standards can be met, the company also has its very own engineering department. Many of the company’s laser systems are made in Prutting, with the laser source bought in, but the machine itself designed and built in-house. “And if today’s technology places a limit on what we want to do, that’s when we start researching.”

Tireless efforts to enhance and innovate — that keeps customers happy and won the company a “Bavaria Best 50” award in 2023.

PLUS: LASER RESEARCH Because it’s impossible to develop everything in-house, BBW also collaborates on international research projects. As part of the LaserComposite research project, funded by a German government innovation program for SMEs, the company looked into the use of green and infrared lasers for welding aluminum-copper hybrid joints. BBW was able to show that this method largely prevents the two metals from mixing in the seam to form unwanted intermetallic phases—i.e., alloys. In another—in-house—development project by the name of Weldshape, the company tackled the problem of hot cracks that arise when welding the aluminum alloy AW6060, which is highly prone to this issue. The solution is to use dynamic beam shaping in a process based on a self-constructed laser system featuring a 16 kW single-mode laser and high-end scanner.

Beam shaping? Correct. BBW is at the very cutting edge of laser processing. Beam shaping is naturally part of that mix. As Bürger explains, of the 50 or so laser systems in operation at BBW, a number of them are earmarked for developing this technology. “There’s a lot riding on beam shaping. It provides a way of dealing with a number of thorny issues, such as ensuring that the weld pool remains stable during laser welding. At BBW, what we really need is variable beam shaping. That’s because fixed optics are not economical for the small batches that we produce for our niche markets.” In other words, it’s only when the optics can be individually adjusted for each batch that it becomes worthwhile for BBW. “So we’re looking closely at how we can make best use of this technology. Apart from us, as far as I know, there’s no other laser welder with a beam shaper on the premises. At the end of the day, however, that won’t make any difference if we can’t provide a clean and proper production environment. As well as investing in the development of technology, we also need to ensure that we have the right setup for manufacturing, and that includes cleanroom and material analysis facilities. But all of that goes hand in hand here.” ■

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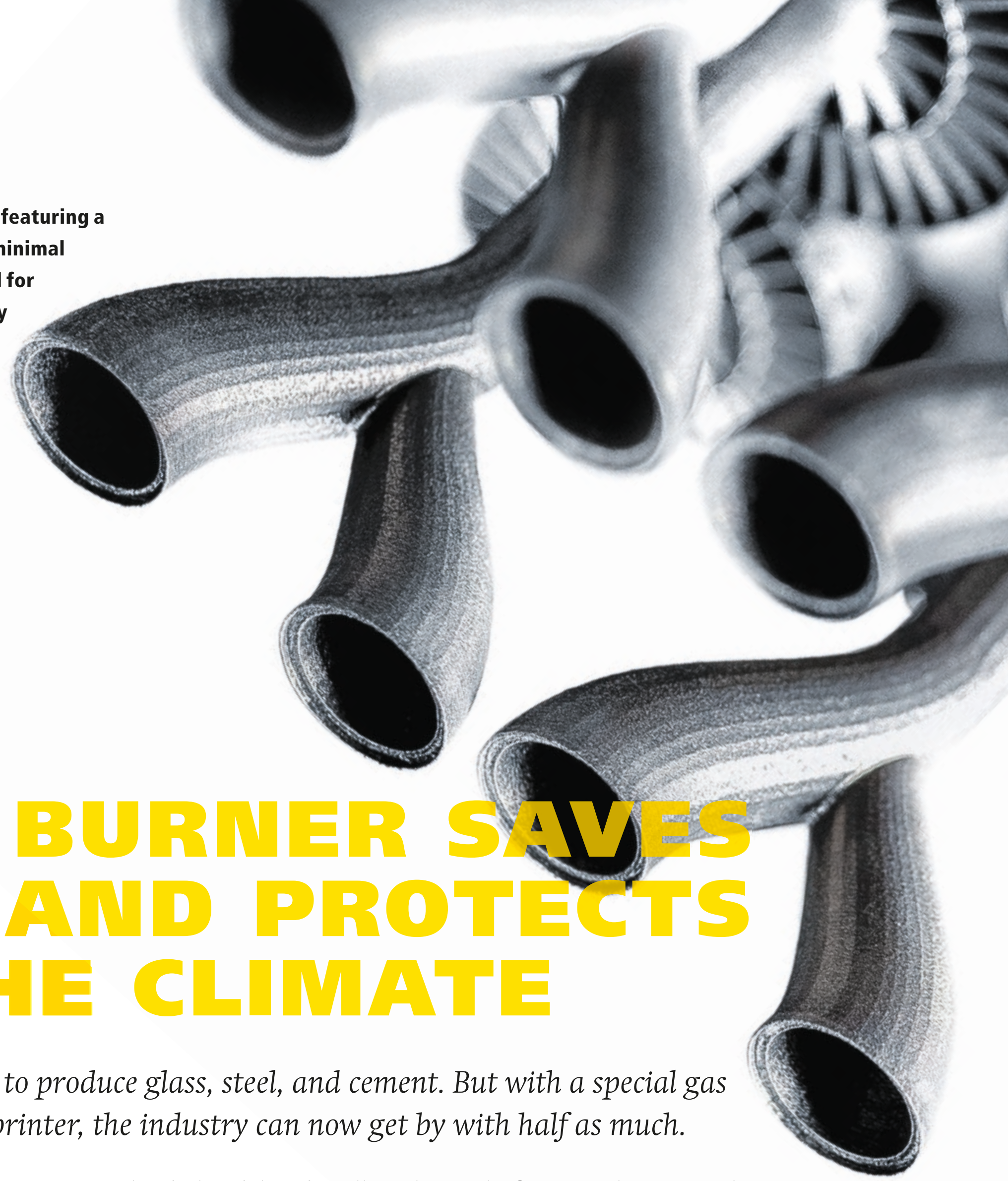


A structure featuring a triply periodic minimal surface (TPMS) is ideal for gas burners. This can only be produced by additive manufacturing.

LMF BURNER SAVES GAS AND PROTECTS THE CLIMATE

It takes a lot of energy to produce glass, steel, and cement. But with a special gas burner from a 3D printer, the industry can now get by with half as much.

Engineers Bernd-Henning Feller, Jens te Kaat, and Dan-Adrian Moldovan were nominated for the 2023 Deutscher Zukunftspreis for their gas burner. The award is presented by the German Federal President for particularly innovative achievements.

To produce glass, steel, or cement, you need an industrial furnace and, above all, one thing: energy, lots of energy. It takes 500 kilowatt-hours to produce a metric ton of molten steel—enough power to supply a two-person household for around three months. Around 30 percent of the energy consumed in steel production comes from natural gas. This, however, is costly and fuels climate change. Industry is therefore looking to cut its consumption of gas wherever it can. In Germany alone, there are around two million industrial burners in operation at present, with a power ranging from 25 to 300 kilowatts. New and efficient burner technology would enable industry to slash costs and cut CO_2 emissions.

Recuperation burners promise to do just that. These use the hot exhaust gases from an industrial furnace to preheat the cold air used in the combustion process. Kueppers Solutions has now developed an exceptionally efficient example of this technology. The burner in question is fabricated by the Swiss company Oerlikon, using the 3D-printing process of laser metal fusion (LMF). Without the use of this additive manufacturing technique, the new burner would never have seen the light of day. Its secret lies in a heat exchanger that features a triply periodic minimal surface (TPMS). This structure is like a net that expands in all directions, forming the smallest possible surface area. Such surfaces are frequently found in nature and in science—in cells and crystals, for example. Its complex structure offers some key advantages. It enhances the flow of exhaust gases, thereby reducing pressure losses and optimizing heat exchange within the recuperator. For burner manufacturers, however, this surface structure poses a severe headache. It comprises numerous metallic surfaces of varying thicknesses, all intertwined with one another at different angles. It is impossible to produce such a component by milling or turning.

The only option is to use an additive manufacturing process and fabricate the TPMS structure from powdered metal on the basis of a CAD model. But the result is hugely impressive: compared to conventional burners, the new technology reduces natural gas consumption by between 12 and 50 percent. Moreover, nitrogen oxide emissions are in some cases more than halved. At an exhaust gas temperature of 1,000 degrees Celsius, conventional recuperators are able to preheat combustion air to a temperature of 600 degrees Celsius, an efficiency of 60 percent. By contrast, the LMF burner achieves a temperature of 900 degrees Celsius. The hotter the combustion air, the more efficient the production of steel, glass, or cement. And when, in the future, producers opt to switch from gas for good, they can continue to use the new technology, as the LMF burners can also be operated with a gas-hydrogen mixture or with pure hydrogen. ■

TRUMPF, Maximilien Brice (CERN)

GLORY

TWO KINGS OF HEARTS

In a development that will revolutionize diagnostics, Zeev Zalevsky and Javier Garcia Monreal have developed a new noncontact method that uses a laser to measure and evaluate heart and lung parameters.

Imagine your living room telling you to eat less red meat. Or dispatching, upon request, key medical data directly to your physician. Such a scenario is made possible by a new technology developed by Professor Zeev Zalevsky, from the Faculty of Engineering at Bar-Ilan University in Israel, and Professor Javier Garcia Monreal, from the University of Valencia in Spain. Their method uses a laser to measure vital physical parameters at a distance. It even works through clothing. Initial clinical studies have already demonstrated that the new technology works.

The two professors developed the photonic sensor system at Bar-Ilan University in Tel Aviv. It registers tiny vibrations in human tissue and thereby a range of vital parameters. For this purpose, an infrared laser is aimed at the patient from a distance of one to three meters. "A dedicated camera with special optics then measures the laser light reflected back from the patient and translates this information into a chart showing breathing patterns, heartbeat, and blood pressure," Zeev explains. "It's similar to an ECG but much more granular."

An algorithm developed by Zeev and Javier is used to analyze these highly complex datasets. Trained with diagnostic know-how, it can identify any deviations from healthy charts and deliver information on all measurable cardiac diseases. "If the algorithm detects something, then there really is something wrong," Javier adds.

The handy device is about the size of a smart-home speaker, compact enough to stand on a doctor's desk. Yet the idea is that the technology should also find its way into the home. "Plenty of people are housebound," they say. "Our device will help improve their quality of life."

Zeev and Javier have been collaborating successfully for 30 years. Each sings the other's praises: "Javier is a one-man team—he knows everything!" says Zeev. "And Zeev is amazing," Javier responds. "He's always up to something new!"

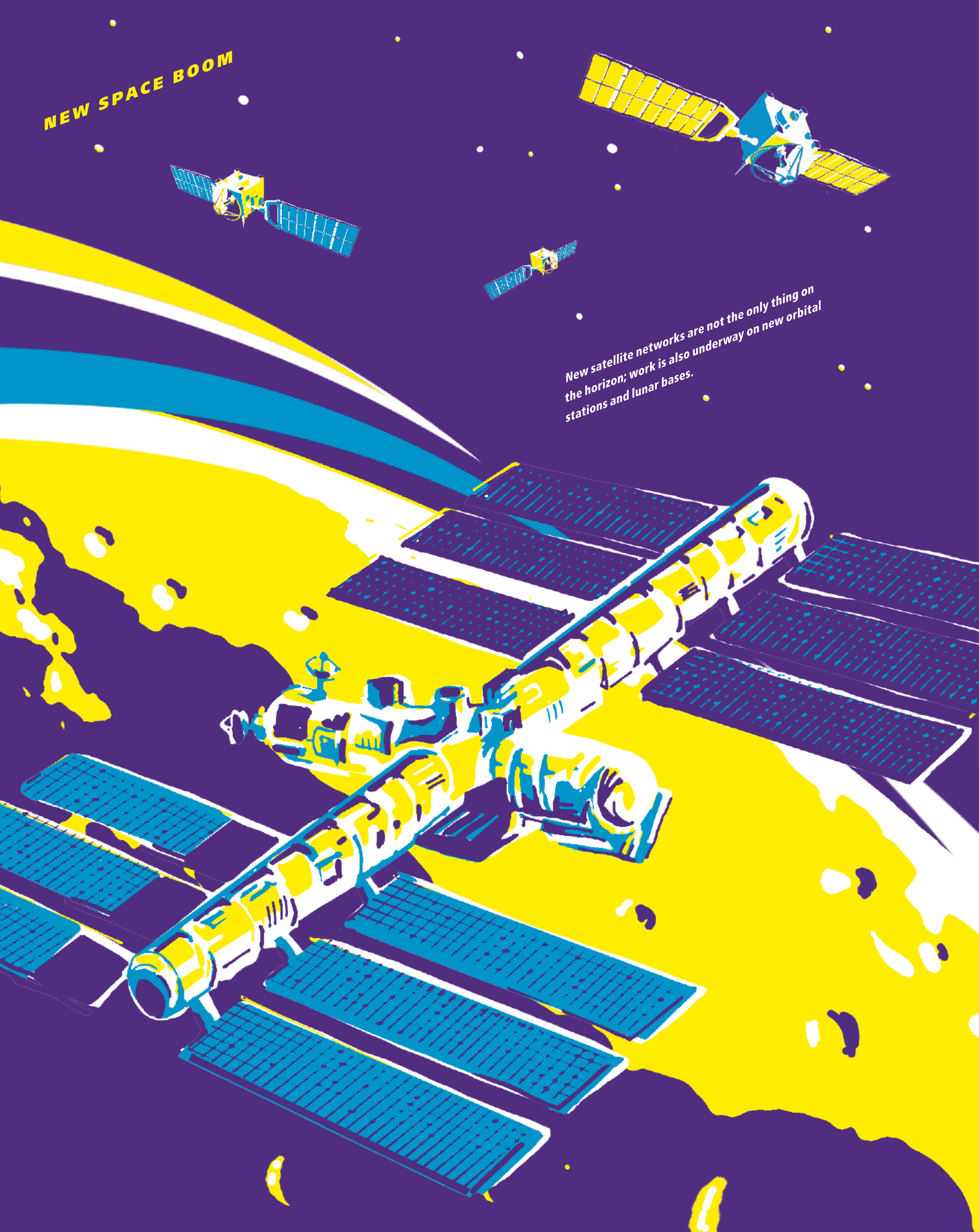
For this project, they won second place in the 2023 Berthold Leibinger Innovationspreis and 30,000 euros in prize money. ■

Your next appointment? Right away! In the future, patients can also record key medical parameters at home.

Maximilian Schlosser

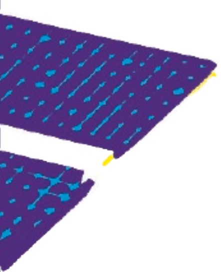
NEW SPACE BOOM

New satellite networks are not the only thing on the horizon; work is also underway on new orbital stations and lunar bases.



THE BEST DEALS IN THE UNIVERSE

Companies that join the space boom now can make a fortune with laser processing!

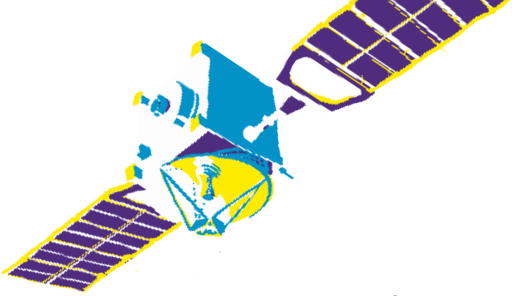


Somewhere in the middle of Germany, a tractor is towing a slurry machine back and forth across a field. This comprises a slurry tank, disc harrow, and injectors. The harrow cuts slits into the ground, 20 centimeters wide and 25 centimeters deep, into which the injectors then shoot a twelve-centimeter strip of liquid manure before the harrow refills the ground. High above, satellites in orbit determine the exact position of the slurry strip and transmit this data to the farmer in the cab. A few weeks later, it is time to sow the corn. Again with satellite support, the sowing drill places each seed right in the middle of the buried slurry track to an accuracy of two centimeters. Soon afterwards, the first corn plants begin to shoot. This technique reduces the use of liquid manure while also cutting nitrate levels in the soil. And, best of all, crop yields actually increase. Throughout the rest of the year, satellites are on hand to help with other tasks. They monitor how the corn is growing, for example, and provide data that tells the farmer precisely how much water, fertilizer, and pesticides the crop needs. Instead of erring on the side of caution and administering too much of a herbicide, the farmer can therefore intervene exactly when and where required. Across the vast agricultural expanses of Brazil and the U.S., autonomous agricultural machinery is already in operation—guided by satellite and not a person in sight.

A WHOLE SWARM OF SATELLITES At present, there are some 6,000 satellites in orbit around Earth. With 2,000 or so new satellites now scheduled for launch each year, this number is set to grow to more than 15,000 by 2030. Almost all of these will be small satellites, some the size of a mere soccer ball. They will perform their job in low Earth orbit (LEO)—high enough not to be dragged back down by gravity, but low enough to ensure ultra-fast data transfer to and from the ground. Within three to five years, they will have come to the end of their service life and fall from orbit in a controlled manner, burning up upon reentry. New LEO satellites will then be launched to replace them.

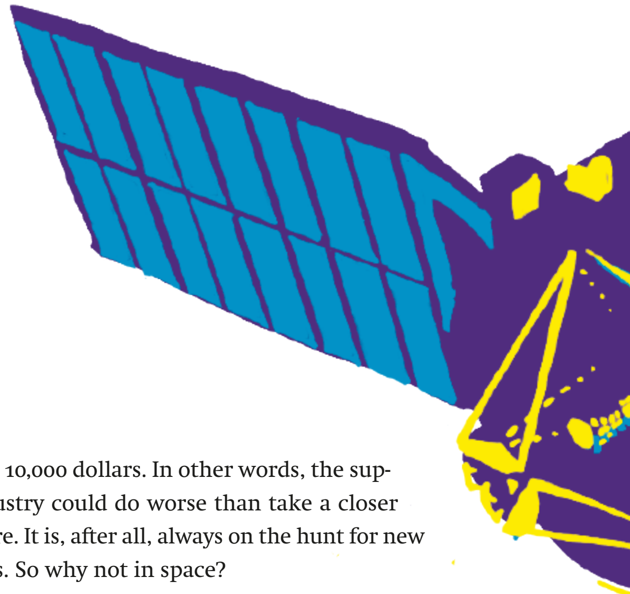
THIS IS WHAT WE WANT! Everyone knows that the navigation system on their cell phone gets its positional data from a satellite. Increasingly, too, we will stream our favorite podcasts or TikTok videos from space. Outside of urban centers, a tipping point has already been reached: when it comes to classic Internet provision, it is now cheaper to launch a bunch of satellites into orbit than lay fiber-optic cable to every last village—no need to dig up the ground, no need to amplify the signal every couple of miles. And even when high-speed Internet has reached the last corner of the remotest jungle, there will still be a demand for satellite communications, providing data for self-driving vehicles steering their way through our cities or for agricultural companies looking to boost their yields. Global warming is also driving

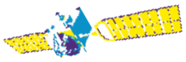
Gernot Walter



LEO satellites have a life of around five years and are then replaced.

The supply industry is always on the hunt for new markets. So why not in space?





demand for observation satellites. These enable precise monitoring of, for example, soil composition, nitrogen content, weather patterns, surface temperatures, and the risk of forest fires. Data from these satellites is of interest not only to scientists but also to major insurers, deep-sea fishermen, and energy providers.

At the same time, private industry is now planning to build its own space stations, financed by innovative business models (see interview on page 20), as well as lunar bases. But how will this great boom in rockets and satellites ever get off the ground? With a lot of money is the answer. Companies backed by venture capital are racing to bring the latest design concepts and the most productive manufacturing methods to the space sector. In particular, engineers are excited about laser processing and additive manufacturing, both of which have a long and successful history in the automotive, aviation, and med tech sectors. They offer that rare combination of design freedom, maximal safety, and high productivity.

A GOLD MINE FOR SUPPLIERS The space sector is currently awash with money. This is destined to land with those companies that possess the right manufacturing skills—including any one or more of the top five laser applications used in this industry (see page 16). In 2021, the private sector invested well over ten billion dollars in the space industry. This comes on top of generous state subsidies and expanding budgets for the traditional space agencies. For all the current boom in satellites and rockets, however, space is not about to become a mass market like the automotive industry. On the other hand, it is very profitable. A quick rule-of-thumb comparison shows how much suppliers might expect to extract from the space sector. Manufacturers spend around one cent to move a single kilo by car. For an aircraft, that figure is 1,000 dollars. And for a rocket, 5,000 to 10,000 dollars. In other words, the supply industry could do worse than take a closer look here. It is, after all, always on the hunt for new markets. So why not in space?

RECENTLY ON THE MOON Somewhere near the lunar south pole, Odysseus, a probe from the private U.S. company Intuitive Machines, was preparing to land, the trickiest part of its mission. The moon has no atmosphere, so parachutes are of no use here. Instead, the probe has retro-rockets to cushion the landing. In order to deliver the required amount of thrust, it is vital to know the exact distance from the surface of the moon. For this purpose, Odysseus was equipped with a laser-guided range finder that was programmed to take measurements every tenth of a second. In advance of the launch in February 2024, however, engineers had neglected to unlock the laser's safety catch. This only came to light when the probe was just hours away from its final descent. With the range finder inoperable, they had to find a work-around. Fortunately, there was another laser system on board, intended for a completely different purpose. As Odysseus hurtled toward the surface of the moon, engineers hastily reprogrammed the other laser. It worked, but not perfectly: the lunar lander touched down without crashing but, in the process, broke one of its legs and tipped over. As a result, its antenna is now pointing away from earth, severely compromising the quality of communications. Nevertheless, this was the first successful moon landing by a private company. And, once again, it showed that lasers play an essential role in space travel.

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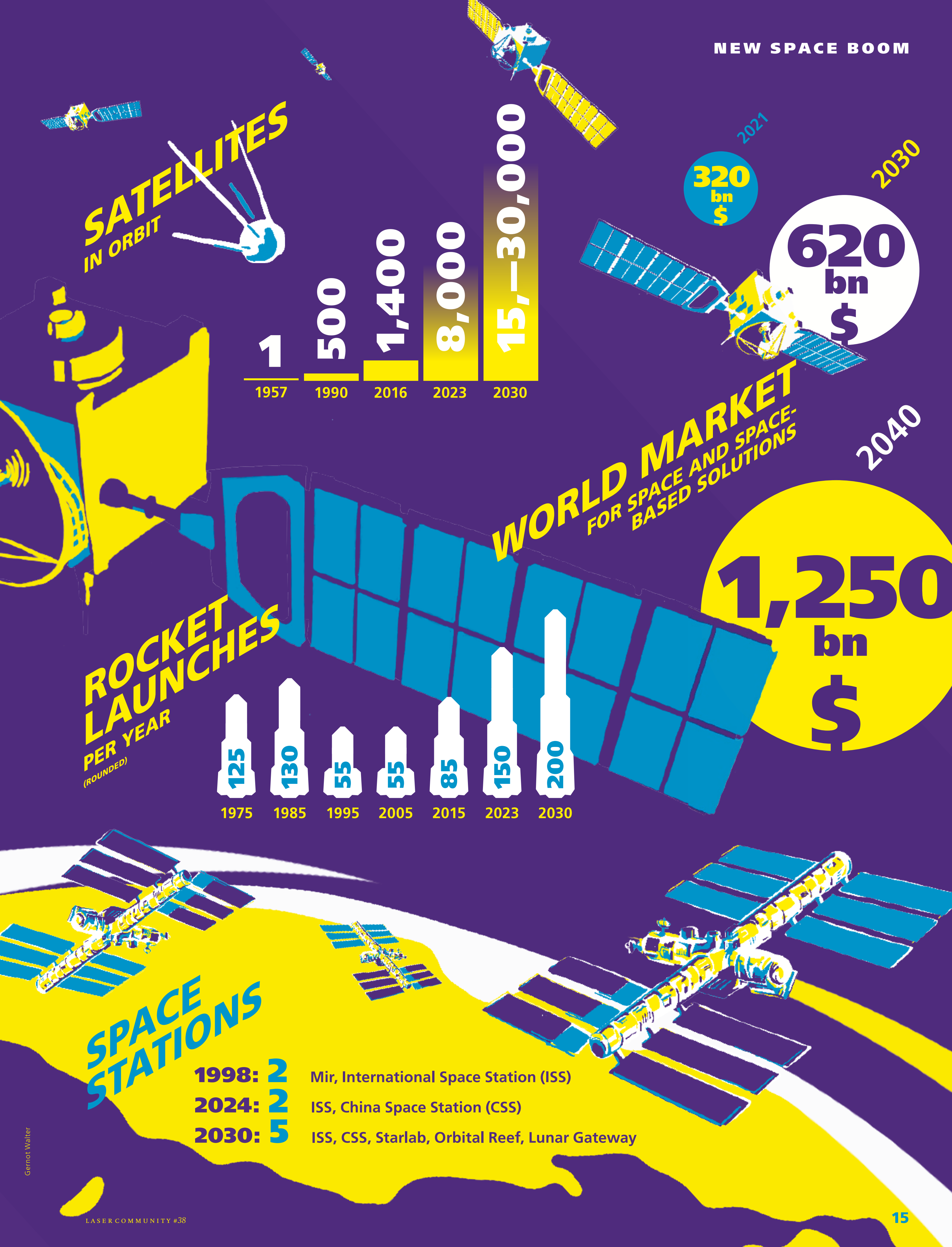
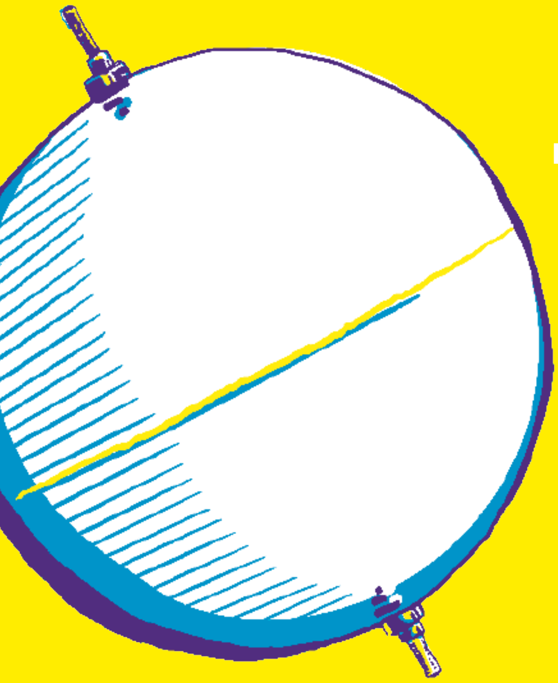


Gernot Walter

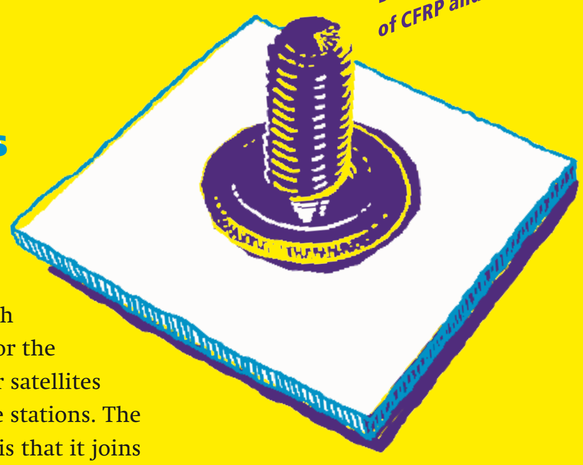
Top 5
laser applications for space

EXTREME SEAL WELDING

Two products brought the breakthrough for high-precision laser seal welding: first pacemakers and then electric car batteries. And now the space industry is exploiting this know-how to join materials such as stainless steel, aluminum, titanium, and superalloys like Inconel. The chief benefits are high process speed, which can reach as much as several meters per minute, and neat, smooth seams, achieved thanks to the use of sensors to control the application of energy. Laser seal welding is rapidly becoming standard practice in one area of particular importance: rocket tanks. If service engineers discover even the tiniest of leaks, the launch has to be aborted. If it remains undetected, disaster will strike as soon as the engines are ignited. Which is why aerospace companies prefer to play it safe and use lasers.



Seal-welded spherical tank

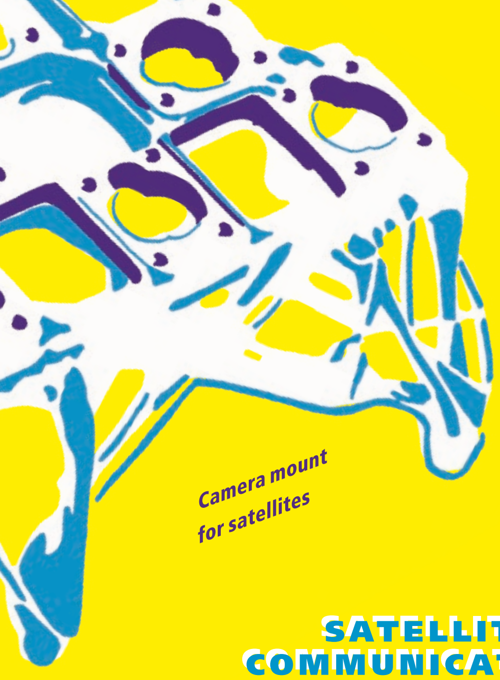


Direct joining of CFRP and metal

HYBRID JOINTS

Ultrashort pulse lasers apply their energy so precisely that they can be used to join different materials with a gastight, fracture-proof weld. For example, glass and metal. Such combinations are especially attractive for the manufacture of optical components for satellites and perhaps even for the windows of space stations. The prime virtue of this type of laser weld is that it joins the two materials directly. In other words, there is no need for laborious screw joints or temperature-sensitive adhesives—both of which also add weight. NASA has already tested an ultrashort pulse laser to weld glass and Invar, a special alloy, and is now planning to make use of this technique. In many cases, the only way to use glass in space is to directly join glass to other materials or to use a glass-glass joint. Increasingly, conventional screw joints are also being replaced by directly welding, with a short-pulse laser, metals to carbon fiber-reinforced thermoplastics and other plastics.

Data transfer via laser



Camera mount for satellites

3D-PRINTED COMPONENTS

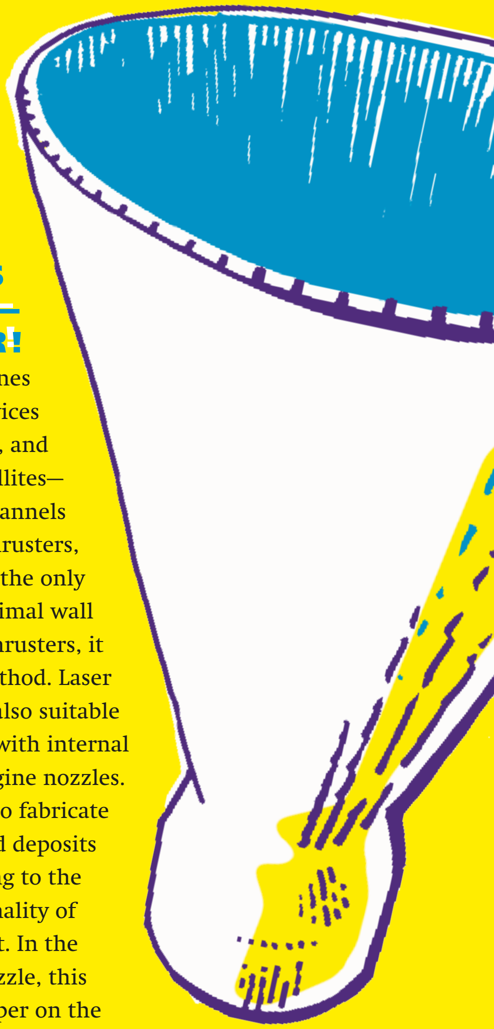
Every kilo saved makes space flight cheaper. This applies to rockets, because a lower weight means they can carry a greater payload; and it also applies to the payload itself, the cost of which falls with decreasing weight. This was what first drove the introduction of additive manufacturing for structural components such as camera mounts, which use as little material as possible and are constructed along purely functional lines. It is now clear that this approach has made components not only lighter but also more robust, because it enables better designs. What's more, additive manufacturing with temperature-resistant superalloys such as Inconel turns out to be substantially cheaper than conventional mechanical processes such as turning. When it comes to space, 3D printing is almost always the best option.

SATELLITE COMMUNICATIONS

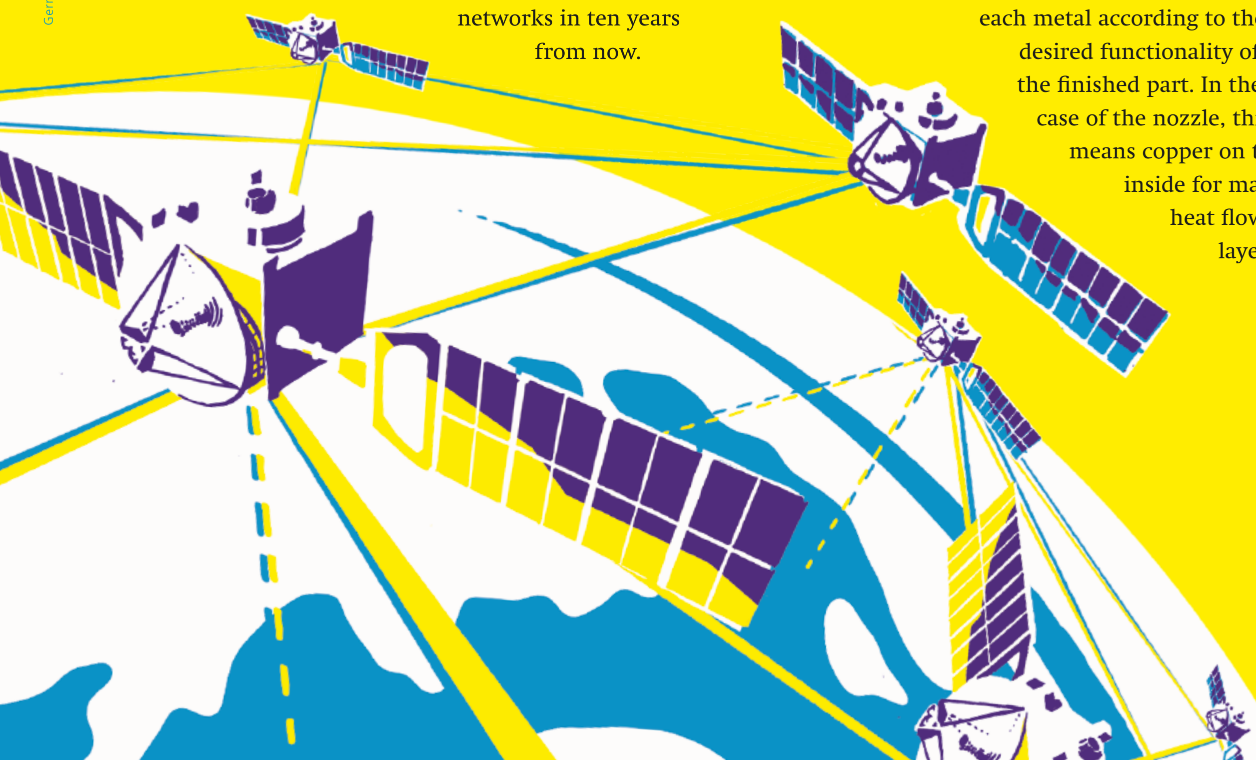
In the future, laser signals will be used to transmit data in space. LEO satellites race around the globe at around 7,800 kilometers per second—much too fast for stable data transmission. That's why contact to a network of several LEO satellites is always required, as one of them is always just flying out of range. In the future, LEO satellites will use laser beams to exchange data while in orbit, across thousands of kilometers. And data transfer from satellite to ground will also switch to this technology, as lasers transmit at a rate of up to 100 times faster than radio waves. With data transmission increasing rapidly on account of streaming, AI cloud computing, the Internet of Things, and a host of other data services, that has to be good news. What's more, physical constraints prevent laser communications from being intercepted. Any attempt at espionage would be detected immediately. High-tech military satellites already employ satellite-to-satellite and satellite-to-ground laser communications. Experts forecast that the technology will also become established in commercial networks in ten years from now.

ADDITIVE MANUFACTURING FOR ENGINES AND THRUSTERS—WITH COPPER!

To function properly, rocket engines and thrusters—small propulsion devices to control orientation, acceleration, and deceleration of probes and satellites—feature a system of fine cooling channels for the propellant. For mini-thrusters, additive manufacturing is the only option on account of the minimal wall thickness; and for larger thrusters, it represents the cheapest method. Laser metal deposition (LMD) is also suitable for larger components with internal channels, such as engine nozzles. Equally, LMD can be used to fabricate bimetal structures and deposits each metal according to the desired functionality of the finished part. In the case of the nozzle, this means copper on the inside for maximal heat flow and a tough layer of Inconel on the outside for strength.



Bimetal rocket nozzle



Gernot Walter

A BETTER THAN EVER VIEW OF THE HEAVENS!

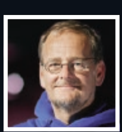
Thanks to a new lidar system, atmospheric researchers like Josef Höffner can take a closer look at the boundary layers of our planet.

Mr. Höffner, what's so interesting about the atmosphere?
Well, everything really! You can picture the atmosphere like an ocean, with waves, currents and even tides. The boundaries between the different layers of the atmosphere rise and fall. These waves trigger further waves, thereby giving rise to currents. If we can understand this process, we will be able to produce better models of the climate and the weather. What fascinates me in particular is the mesosphere. That's the uppermost layer of the atmosphere, at an altitude of between 80 and 150 kilometers. This is the boundary layer of the atmosphere, the interface to space. Believe it or not, there's a lot to discover there.

What exactly?
Earth is continuously bombarded by meteorites. These vaporize in the mesosphere, which is why we rarely notice them. But they leave behind metal atoms, which trickle down through the atmosphere. That's how some of the metals we have today arrived on early Earth over millions of years. In other words, what happens up there has an impact on us down here, and vice versa. That's why we investigate any changes.

How can you investigate something that is so far away?
We use spectroscopy, which is a kind of remote diagnostics based on wavelength measurement. Or, to be more precise, we use lidar systems, which function as follows. A laser beam

Höffner tests his innovative lidar system. The hope is that it will revolutionize atmospheric research.



JOSEF HÖFFNER As an expert in optical sounding, Josef Höffner's line of work is anything but a lab job. For especially precise measurements, he regularly travels to Antarctica, Spitsbergen, and mountain ranges.

ALEXANDRITE LASER An alexandrite crystal covers a broad spectrum of wavelengths and delivers high pulse energies. Yet it is also tricky to handle and must be pumped, for example, with great precision and in a special way.

Fraunhofer ILT Aachen; Ralf Baumgarten

AHEAD

excites, for example, potassium or iron atoms in the mesosphere. These atoms scatter the laser light, and telescopes then capture these scattered photons. This enables us to calculate the type of particle together with its density, its temperature, and its speed and direction of motion. The project has been running since the 1990s. Back then, our lidar system was the size of a shipping container. It consumed tons of diesel and needed a huge generator. Plus it only ever worked for a short period of time and was highly maintenance-intensive. What we really wanted was a more compact, more reliable, more powerful system. So my team and I began developing a completely new version, together with Fraunhofer ILT. That was over ten years ago. And now it's ready—an innovative, custom-made alexandrite laser.

Which is easier to operate?

Absolutely! It's diode-pumped, which is what makes our new lidar system so compact as well as robust and reliable. And in terms of its spectroscopical properties, the laser is virtually perfect. That means we can take more precise measurements across larger areas of the mesosphere. In the past, we needed a dedicated lidar system for each measured variable. But with the new system, we should be able, at some point, to measure a variety of parameters simultaneously and around the clock. In other words, we'll have a better than ever view of the heavens!

And what will this information tell us?

Well, right now, we humans are having a massive impact on the composition of the mesosphere. We need to monitor that. There's a rocket launch almost every week. That introduces new material into the atmosphere through propellant combustion and during reentry. The same applies to satellites, which fall back to the mesosphere after two to three years, burn up, and then leave behind metals and other substances. It's important to remember that within the entire mesospheric layer, which is huge, there are just three kilos of potassium. That's not very much at all. So it really doesn't take much addition to change the particle mix significantly. In chemical terms, many of the exotic metals found in satellites are catalysts; i.e., reaction enhancers. It's therefore a huge experiment, and we don't yet know how it is all going to turn out. That's why it's important to continuously monitor changes in the atmosphere.

A kind of atmospheric weather service?

You could put it like that. Our goal is to build a global network of lidar systems. We're currently working to establish a number of lidar systems at various locations in Europe. These will then monitor the atmosphere at no great effort. But it will still take a few years before this is in place. ■

COMBINED KNOW-HOW Lidar technology brings together the Fraunhofer Institute for Laser Technology ILT (Aachen, Germany) and the Leibniz Institute of Atmospheric Physics (Kühlungsborn, Germany): 35 years of laser expertise plus a wealth of experience in atmospheric research.

“Soon we’ll be delivering to the Moon

Maximilian Strixner is in charge of additive manufacturing at the Exploration Company, a Franco–German start–up. Here he explains why commercial space travel is booming and why it depends on 3D printing.

Florian Jaenicke

M

Mr. Strixner, does it bother you that people call your company the European SpaceX?
Not at all. I take it as a compliment that people talk in the same breath about us and the U.S. space giant. We don't make rockets, like SpaceX. But we do make space capsules. And we're both part of the New Space movement.

What does "New Space" mean?
A new era in space travel! In the past, this was the domain of state companies: NASA, ESA, Roscosmos, and so on. They opened up the cosmos to the human race and were able to use a lot of public funding to do so. Now private companies like ours are entering the arena. And our aim is to make money. All of a sudden, things are moving fast: SpaceX is revolutionizing rocket construction; and Blue Origin, also from the U.S., is building a commercial space station for up to ten people. Around the world, some six to eight privately operated space stations for Earth orbit are currently under construction and also two lunar bases. And all within the hitherto inconceivably short time frame of five to ten years.

Okay, but how do you go about making money with a space station?
Good question. One answer is space tourism. →

That might sound a bit outlandish, but there are enough rich people around who would be prepared to pay for that. The second answer is research and development for industry. There's always been some of that in space and on the ISS. But things are going to change soon. People operating space stations or lunar bases will either conduct research themselves and then market their results. Or companies and institutes will rent space for their own researchers or commission experiments for which they will then pay. We know, for example, that the pharmaceutical and biotech industries are prepared to pay a lot of money for this.

What's so great about expensive experiments in space?

In conditions of weightlessness or the reduced gravitational force on the moon, you can conduct completely different experiments than here on Earth. For example, cell growth and the aging process operate differently there. The scientific community hopes that this will promote discovery of innovative biological and chemical substances and materials through, for example, novel methods for cultivating crystals. And there will be buyers for this. Thirdly, there are commercial ideas that might only pay off in the distant future—for example, the mining of raw materials and production of propellants on the moon, thereby providing a stopover for onward flights to Mars.

"As a private company, we need to rapidly progress ideas to the product stage."

And what about the Exploration Company's own business model?

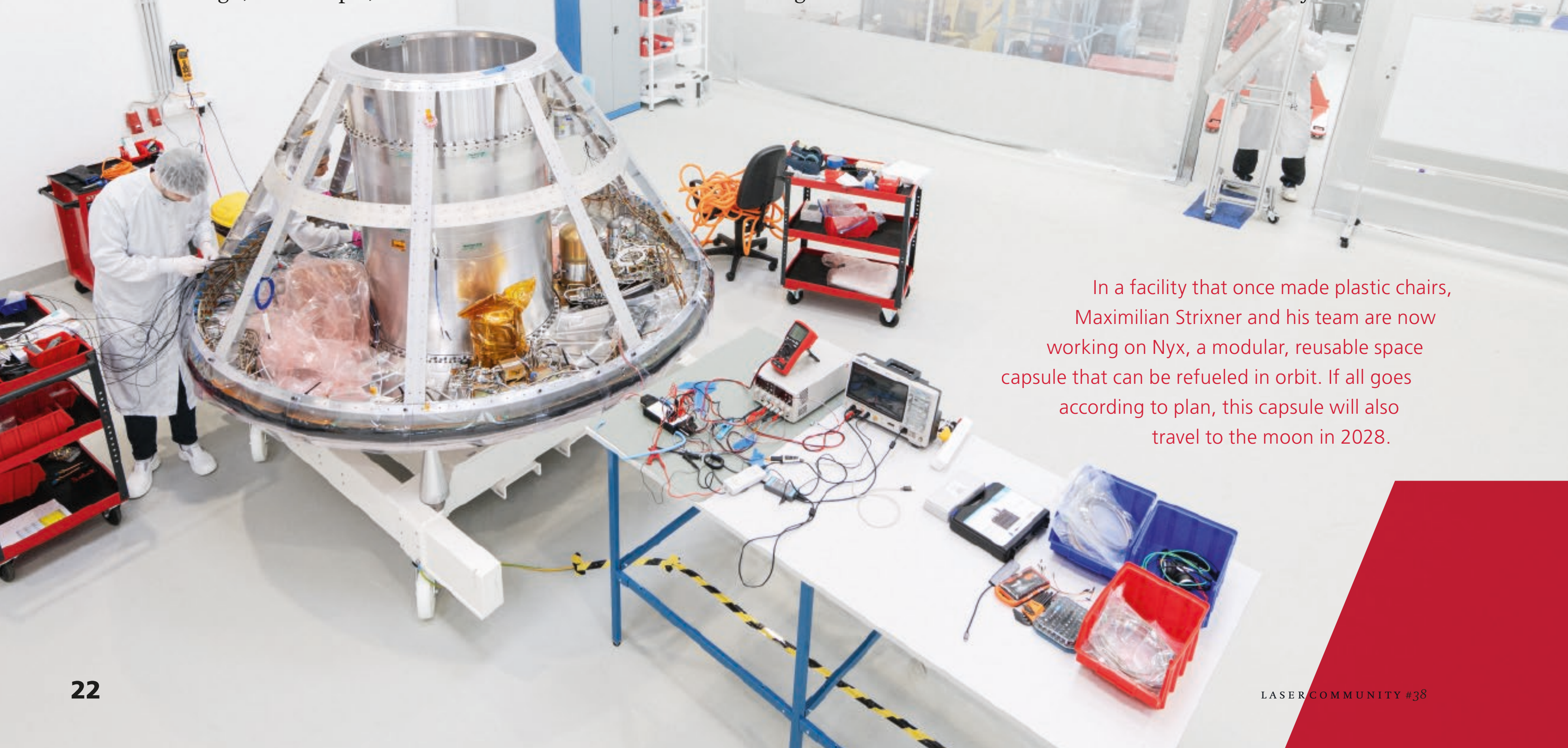
That's easy. Whenever something needs transporting into space or bringing back to Earth, that's when our space capsules come into play. Initially, for transporting things, but later perhaps also for people. In the coming years, we're going to see a massive expansion, driven by private companies, in the network of near-Earth satellites. This will boost demand for cargo transport into space—as will the construction and operation of planned stations in orbit and on the moon. So we're going to be delivering cargo to the moon! Our capsules will even form part of an orbital refueling network, where spacecraft will take on new propellant shortly after launch. That will mean they can take off from Earth with less weight.

How does it impact your work that you have private investors who need to see a return at some point?

We need to rapidly progress ideas to the product stage. It took us three years to build the small Bikini capsule and to develop most of the first mission. Our maiden demo flight is planned for 2025, with the first real six-month mission in orbit to follow in 2026. We then plan to land a capsule on the moon in 2028. Our investors know that not everything happens overnight in this industry. But if not tomorrow, the day after that would be nice. So we need to get a move on.

How do you manage to develop your products so quickly?

We use cutting-edge methods such as additive manufacture. That saves us a lot of time, particularly at the prototype stage. The best example of this was when we were developing the thrusters that are used to propel and orient the capsule in space. We were able to complete the various iteration stages—simulation, prototype design, prototype construction, testing, and then repeating over and over again—in a matter of days and weeks rather than the months it usually takes in



In a facility that once made plastic chairs, Maximilian Strixner and his team are now working on Nyx, a modular, reusable space capsule that can be refueled in orbit. If all goes according to plan, this capsule will also travel to the moon in 2028.

the aerospace industry. With additive manufacturing, design changes can be made in a flash. Then you simply fabricate the modified component overnight. And you don't have to wait for the toolmakers! Besides, for the design and construction of rocket engines of this type, there's no real alternative to additive manufacturing.

Why is there no real alternative?
A rocket engine of the type we need for our capsule is all but impossible to fabricate using conventional methods. We're talking here about cryogenic engines that feature regenerative cooling. This means that the propellant itself is used as a coolant before being combusted. The propellant we use is liquid biomethane. This initially flows as a coolant through internal channels surrounding the combustion chamber. Then it is fed into the combustion chamber, mixed with liquid oxygen, and ignited. It's not a new principle. And you can certainly use conventional fabrication methods to build this type of rocket engine. But that's incredibly time-consuming and expensive. It takes months to build a single prototype, and we always need new ones. From an economic point of view, it's not at all competitive with additive manufacturing. And it's the death of any design freedom. Our engines can't be any bigger than 40 centimeters. The only way to fabricate at this scale and ensure a minimal wall thickness between the internal channels is to use additive manufacture.

And additive manufacturing doesn't kill design freedom?
Additive manufacturing is design freedom! It's what allows us to design components solely in view of optimal temperature absorption and mechanical load flows. We don't need to factor in any limitations associated with particular fabrication processes, such as the fact that a milling machine cannot make an undercut around a curve. With additive manufacturing, there are no such limits. The machine doesn't mind complex geometry. Design complexity comes free of charge, which means you almost automatically end up with the most lightweight version of the component. And that's the holy grail of commercial space travel.

Why holy grail?
The keyword here is "payload": every kilo of the transport capsule costs money, every kilo of payload earns money. To put it another way, every kilo you save on the final weight of the transport capsule means you can carry more bought payload into space. And you can do that on every flight. What's more, since additive manufacturing gives you the most lightweight design possible, you also save on material. That's vital, because the special alloys we use are really expensive. It all adds up! Furthermore, this approach is more sustainable.

Well, sustainability is not really what comes to mind when you think of space travel!
You might think so, but actually the reverse is true. Sure, every rocket launch releases huge amounts of CO_2. That's undeniable. But because there has been a steady increase in the number of launches in recent years, the New Space companies are doing all they can to cut their use of resources. There are hard and fast economic reasons for this. Sustainability is a fundamental part of corporate strategy at the Exploration Company. I already mentioned that we use biomethane and oxygen as fuel for propulsion in space. Both of these can be produced using renewable energy. And New Space has given rise to another key sustainability trend: recycling. At present, rockets and transport capsules are disposable items. Once used, they're scrap. But our capsules will fly to space and back a number of times. A few of the components, such as the heat shield, will have to be replaced. These, unfortunately, do not survive reentry, so there's nothing we can do about that. Besides, there's another aspect: space travel can also contribute to sustainability. For me, the best example of this is precision farming, with Earth observation satellites being used to bring about unprecedented improvement in agriculture. This alone will save us so much fuel, fertilizer, and pesticides that it will more than compensate for the emissions released by the rockets used to launch the satellites. And leaving aside all the financial considerations, I think it's also important to say that space exploration is an educational and cultural project—and therefore of importance politically and for the advancement of humanity.

"Additive manufacturing saves us a lot of time, particularly at the prototype stage."

The Exploration Company is a Franco-German company. Why's that?
Not Franco-German but European. And quite deliberately so: we want to be Europe's alternative gateway to space. There are political reasons for this, but also practical ones. In Bordeaux, they have big expertise in propulsion technology, whereas, here in Munich, we are experts in production technology. Since the beginning of this year, we've also had a site in Turin, another European center for space travel.

Mr. Strixner, would you like to travel to space yourself?
No thank you! I'm quite happy down here on Earth. That said, space travel is not about to become normal just yet, but it will soon be much less uncommon than it is right now. So ask me again in 30 years' time!
Deal! ■

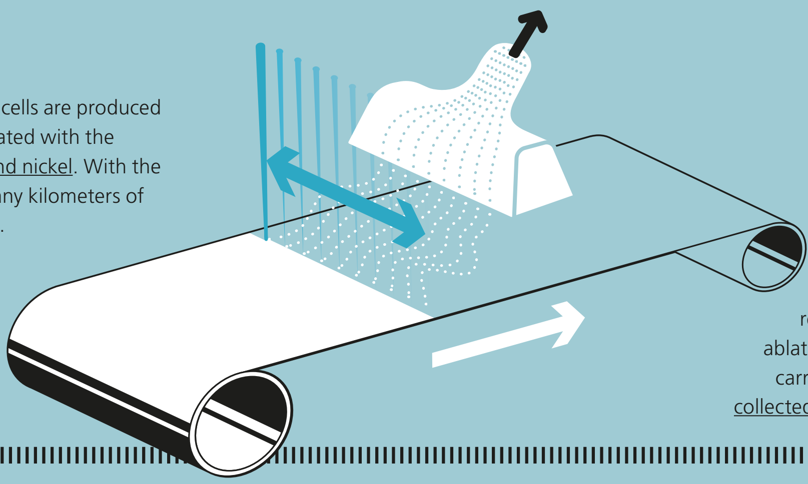
Florian Jaenicke

The Exploration Company Founded in 2021 by Hélène Huby and a group of experienced space engineers. Since then, the company has been raising capital from private investors. The aim is to develop, build, and operate transport capsules for payloads and people. The flight of a demo capsule is scheduled for 2024. In 2026, a real Nyx capsule will then transport a 4,000-kilogram payload into space. The company is based in Bordeaux (France) and Planegg, near Munich (Germany).

Recovery of raw materials in electrode manufacture

PROBLEM

The electrodes for new battery cells are produced as a continuous strip of film coated with the costly metals lithium, cobalt, and nickel. With the quality standards very high, many kilometers of film repeatedly end up as scrap.



IDEA

Ablate and recycle: in future recycling, laser technologies could ablate the wafer-thin coating from the carrier film. This precious dust will be collected and processed for new coatings.

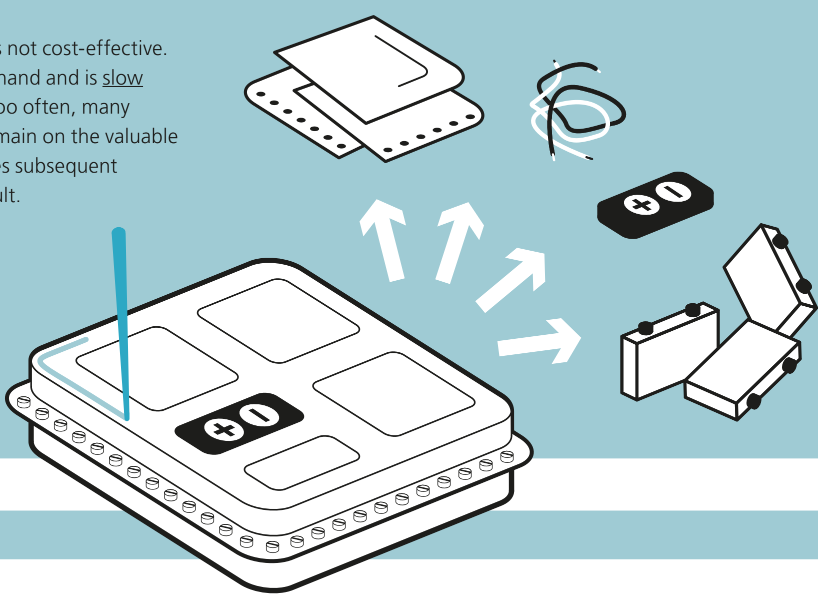
Reclaim those raw materials!

The batteries for electric cars are full of precious raw materials. The EU therefore requires they be recycled. But how best to extract these treasures?

Efficient disassembly at the recycling center

PROBLEM

Dismantling batteries is not cost-effective. It can only be done by hand and is slow and complex. And all too often, many unwanted materials remain on the valuable battery cells. This makes subsequent processing more difficult.



IDEA

In the future, laser recycling machines could economically disassemble the valuable batteries. In a highly automated process, they cut cables, remove covers, and dismantle contacts. The raw materials could then be recycled with a greater degree of purity, singling out and recycling still usable battery cells.

Gernot Walter

SERVICE AS REQUIRED

By using cloud-based technology to monitor its laser systems, Mercedes-Benz can reduce downtime for maintenance work and still play it safe.

Dynamic maintenance means that Mercedes-Benz has its laser systems serviced only when absolutely necessary rather than at scheduled intervals.

Across its global production network, Mercedes-Benz has more than 400 laser cells from TRUMPF in action. In such a high-tech manufacturing operation, resilience is the name of the game: by avoiding unscheduled machine downtime, hugely expensive production outages can be averted. In the past, the automaker had its laser systems serviced at fixed intervals. Playing it safe like this came at a price, however: work got done on machines that would have continued to run trouble free for some time before maintenance was actually required. But is there any alternative?

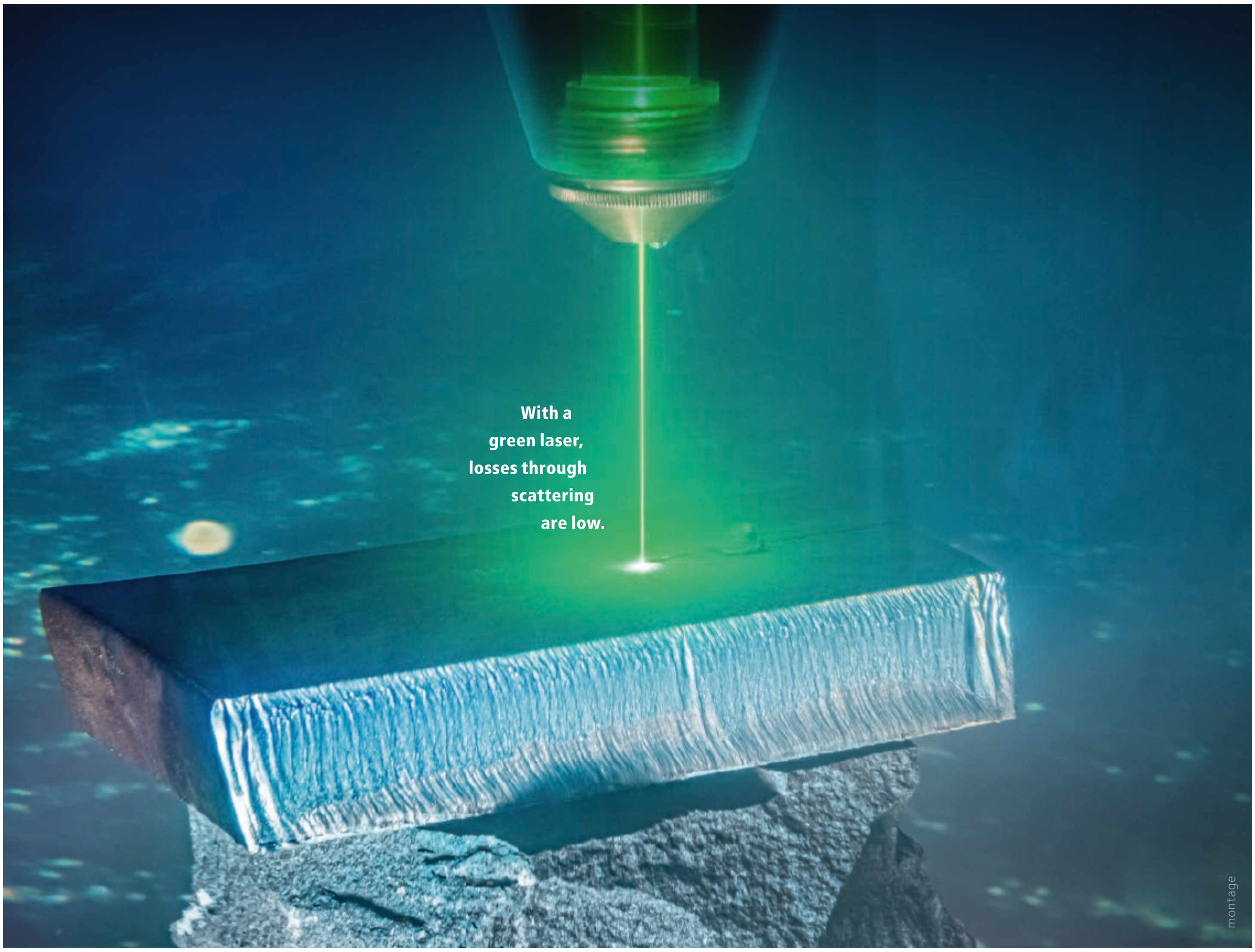
Thanks to condition-based services from TRUMPF, 200 laser cells at Mercedes-Benz are now remotely monitored in real time and analyzed by smart algorithms and experienced service engineers. If a system displays abnormal behavior, Mercedes-Benz is immediately notified and given clear instructions on what action to take. This brings big savings, since it means that a service engineer only gets called out when this is absolutely necessary. At the same time, it eliminates a further cost factor: now that cloud-based condition monitoring is an integral part of the company's digital ecosystem, tasks once performed manually by service engineers—updating master data, completing documentation, and transferring data—are now processed automatically. Jörg Burzer is a member of the Board of Management of the Mercedes-Benz Group and responsible for production, quality, and supply chain management. "The future of automaking lies in the use of preventive, digital processes, along with dynamic maintenance and maximum protection against machine failure," he explains.

Condition monitoring not only gives Mercedes-Benz the confidence that unscheduled downtime is a thing of the past. It also provides extra leverage to fine-tune the manufacturing process. This is because condition monitoring also detects and logs minor issues such as incorrect control of the laser. Production engineers then use this data to make adjustments across all the company plants and thereby continuously improve processes. ■

Mercedes-Benz

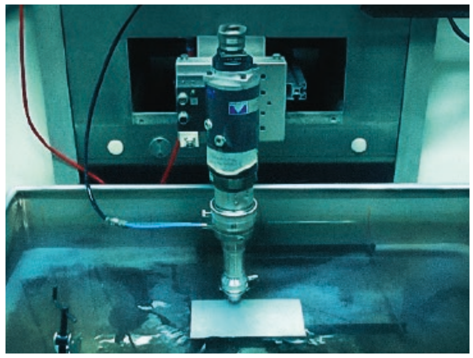
Underwater lasers: a deep dive

As a rule, lasers rapidly run out of steam underwater. However, scientists have now figured out how to ensure full laser power in a submerged environment. At the heart of their breakthrough is a green laser.



Fraunhofer IWS

The submersible system simply blasts away the melt with a jet of water.



Why on earth would you want to use a laser underwater anyway? Well, there are plenty of cutting and welding jobs on wind turbines, for example, or on ships and in locks, harbor basins, and hydroelectric power plants. There are old oil rigs to be dismantled and fuel rods to be stripped down in the cooling ponds of decommissioned nuclear plants. Experts say a massive expansion in offshore wind can help meet humanity's growing demand for energy in an environmentally friendly manner. In other words, there is a wide range of underwater applications for laser cutting and welding, and the potential market for them is huge. Naturally, there are already various techniques suitable for underwater use, such as manual arc welding. But back on dry land, lasers are almost always the favored option for cutting and welding. So why not underwater too? Furthermore, if lasers are consistently the best choice for use with robots, then why not with submersible robots as well? These were the thoughts of researchers at the Fraunhofer Institute for Material and Beam Technology IWS in Dresden. So they decided to take a closer look at the underwater laser.

GREEN BEATS BLUE The problem with an underwater laser is that the light is absorbed and scattered in all directions. This is particularly true of long wavelengths such as infrared and of short wavelengths such as ultraviolet. Both are therefore unsuitable for underwater use. On the other hand, lasers with visible light, such as green or blue, penetrate water without significant scattering and could therefore be used in underwater applications. Green and blue lasers are thus the most promising candidates for this type of work. To date, it has proved impossible to focus the power of a blue laser as finely as that of a green laser. A focused green laser currently achieves an energy density 100 times greater than that of a blue one. However, applying this laser power at the exact point is tricky underwater, because the ambient conditions, including water movement, affect precision. Alongside accuracy, it is also crucial to ensure sufficient laser power. Only green lasers with over one kilowatt of power have the energy to cut underwater. The Fraunhofer researchers therefore opted to use a two-kilowatt green laser from TRUMPF.

WATER IN PLACE OF GAS Most of the ideas for underwater laser cutting are essentially based on processes used on dry land: the laser cuts the material, and an auxiliary gas jet blows out the melt from the kerf. Anyone who has ever exhaled underwater will recognize the problem: when air or gas meets water, a cloud of bubbles is formed. This turbulence interferes with the laser beam, depriving it of accuracy and a large part of its power within a short distance. Patrick Herwig and his team at Fraunhofer IWS have therefore taken a pragmatic approach: if gas is causing the problem, then replace it with a medium that is already available in abundance—water.

TESTS IN THE BATHTUB As on dry land, a laser beam used underwater heats and melts the workpiece at its point of application. In place of gas, however, a powerful jet of water is now used to blow away the melt. There are a number of advantages to this technique. Firstly, there is no longer any need for long pipelines to supply gas to the workpiece from the surface or from tanks. Secondly, as soon as the jet of water hits the hot melt, it turns immediately into steam. Since the volume of water vapor is 1,000 times greater than that of liquid water, this steam propels the melt out of the kerf in a fraction of a second. In the initial moment of impact, the jet of cold water does draw some of the power from the cutting process. But this is only around 200 watts and is therefore not critical. The trick is to precisely control the water jet so that as little power as possible is lost but there is still enough speed of flow to blow out the melt. Herwig and his team put this to practice in a bathtub and are confident that it can be scaled up for commercial use.

MINI-SUB WITH LASER When it comes to the underwater removal of steel fixtures, a laser is superior to conventional methods such as sawing or blasting. Not only is the laser more environmentally compatible; it also offers greater efficiency in terms of both resources and energy. Saw blades, for example, wear out, whereas light does not. And compared to other thermal processes, the laser produces the smallest kerf and therefore uses the lowest amount of energy per meter cut. Moreover, there is also potential for miniaturization. The Fraunhofer team envisages the use of highly compact underwater robots equipped with a laser cutting head that could handle steel parts to a thickness of 50 millimeters. The actual laser would remain aboard a ship and be transmitted to the depths via a laser light cable. Herwig anticipates that more-powerful laser sources suitable for such submersible applications will soon be available. ■

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Thanks to condition monitoring, Ibrahim Yorulmaz from Gedia has already been able to prevent serious machine damage.

LESS FAIL, MORE RUN

The laser systems at automotive supplier Gedia are in operation around the clock. If one were to unexpectedly fail, the ripple effect would be immense. Happily, this is no longer a plausible scenario.

Most small and medium-sized manufacturers of mass-produced items operate what is known as a run-to-fail strategy. In other words, the machines are left to run until at some point they fail. At automotive supplier Gedia, a specialist for lightweight parts, things are great when production is running smoothly, but less so when a machine fails. For this reason, Ibrahim Yorulmaz, laser tech manager at company headquarters in Attendorn, is now looking to eliminate "failure" as much as possible and thereby get maximum "run" from his machines. At Gedia, six 3D laser-cutting machines give the final contours to hot-formed components for automobile bodies and chassis. "If these laser systems malfunction," Yorulmaz explains, "that impacts the entire manufacturing process." The ideal is therefore to reduce machine downtime to an absolute minimum.

SEEING FAULTS IN ADVANCE Gedia is among the first cohort of manufacturers to opt for cloud-based condition monitoring of their laser systems. This digital service from TRUMPF monitors and analyzes machine operation in real time. A team of company experts and a smart algorithm detect and report any process anomalies well before they become manifest at the actual laser cell. Supplied with tips on what action to take, service engineers at Gedia can then carry out the appropriate maintenance work before the laser system actually fails.

At Gedia, they manufacture around the clock, in three shifts. Depending on the tolerances of a specific component, workers may need to make adjustments to the cutting program. Mistakes are unacceptable. If, despite everything, an issue does arise, things are doubly bad when the customer is the first to notice. "In the past, to find out why an adjustment had been made," Yorulmaz explains, "we had to identify the shift on which it occurred and then the employee who was working at the time. There was a real postmortem." Now, however, this painstaking process is a thing of the past: the production documentation contains not only real-time status reports but also full details of the actual production process. "I use it every day," Yorulmaz says.

MORE DATA FOR BETTER MANUFACTURING For Yorulmaz, the stream of data generated by condition monitoring also provides a welcome new resource. "If the report for a particular component indicates recurrent problems with micro-collisions, that tells me the software has a bug," he explains. "But now we don't need to hunt around for long, because the report identifies the exact programming block where the problem originated." In other words, a system designed to avoid machine downtime has, within just a few weeks, developed into a highly effective tool to boost productivity. ■

Six laser cutting cells for hot forming are in operation 24/7. Thanks to cloud-based real-time condition monitoring, Gedia no longer needs to worry about unscheduled downtime.

Fiumu

Singapore

OVERVIEW OF THE ECONOMY

Over the past decades, Singapore has built up a range of **high-end** industries: aerospace, semi-conductors, chemicals, and biomedicine. Electronics, in particular, is growing strongly.

Advanced manufacturing: in Singapore, a number of global corporations such as Hyundai are currently developing particularly advanced production methods involving automation and AI.

In the Bloomberg Innovation Index of 2021, Singapore's workforce ranked **top in the world for skills, competitiveness, and adaptability.**

WELCOME TO SINGAPORE, LAND OF LASER TECH!

5.7 m inhabitants

Nominal GDP per capita

82,808 U.S. dollars

Industry as a proportion of GDP

22 %

LASERLAND

The city-state is a powerhouse for additive manufacturing techniques such as **3D printing.**

In Singapore, lasers are mainly used in **high-end, fully automated manufacturing facilities** for the aerospace and med tech sectors. The use of laser technology in mass production is more likely to be found in neighboring Malaysia.

In Singapore, there are **three world-class universities and research institutes** that use or develop laser technology for scientific purposes.

Hyundai, Adobe Stock / wootthisak

Fendt

WHERE IS THE LASER?

In green tractors. Anyone with a two-year-old knows that the word “tractor” is an early addition to infant vocabulary. After all, apart from customers, manufacturers of agricultural machinery also have genuine fans, both young and old. Take Fendt, for example: devotees of the iconic brand with its distinctive green color buy not only toy tractors but also branded underpants, lunch boxes, and birdhouses. Yet fan merchandise alone does not make a company rich; the actual product must also be first class. Right now, demand for Fendt products is booming. At its facility for the production of outer body panels for the cab and hood (ready for painting in that beautiful green), the manufacturer became the first TRUMPF customer to install the new TruLaser 8000 Coil Edition. This machine cuts directly from a sheet-metal coil, while a robot automatically removes and sorts the finished components in a highly productive process. ■

One million

JOULES

"Aim, fire!—192 high-power UV lasers applied, for one billionth of a second, around two million joules of energy to a raindrop-sized capsule filled with a hydrogen mixture. The lasers heated the contents of this capsule to 100 million degrees Celsius. The mixture shrank by the same order of magnitude as a basketball to a pea. The reduction in mass resulted in the release of three million joules of energy—a million more than were supplied by the lasers! This was the first ever successful nuclear fusion experiment with energy gain, conducted at the National Ignition Facility (NIF) in California at the end of 2022. Since then, scientists have been able to replicate the experiment a number of times, thereby taking a decisive step toward tapping this inexhaustible source of energy.

Don Jedlovec