

Trust in the Future

Technologies and Ideas for the Production of Bipolar Plates
for Fuel Cells and Electrolyzers.

Partner with us in Creating the Future. With our Expertise your Ideas Turn into Results.



“Considering ideas thoroughly and with foresight, understanding correlations and developing solutions for your benefit: **This is what drives us in the development of sustainable technologies for bipolar plate production.**”

Fabian Kapp, Managing Director

Our work: Sustainable success from the very beginning.

Metalworking, mechanical engineering, medium-sized business: three characteristics that have been shaping our work since 1921. As a fourth generation family-run company, we develop and manufacture proven solutions for metal forming technology worldwide and across all industries. We are known above all for our precision and attention to detail:

Whoever banks on **Graebener®** relies on a solution that has been thought out down to the smallest detail. It is not for nothing that today we stand for machines with quality and performance that are convincing in the long term – because we know that what we create must also work for our customers in the future.

Trust in the future? With security in the medium-sized business.

Markets are subject to change over time. Social, economic and ecological changes have a direct impact on technologies – and thus on our work. As a medium-sized family business, it is therefore in our nature to evaluate thoroughly which technologies are – and will be – important. Because we see it as our duty to guide our company, our employees and last not least our customers safely into the future.

With regard to the stability and sustainability of our customer relationships, it is important to us to maintain a balance between proven solutions, process reliability, innovation and progress. In other words, to consider all the details that characterize sustainable quality.

It is not without reason that we are one of the first companies to have been involved in research and development of production processes and machines for bipolar plates of fuel cells and electrolyzers for 20 years. We believe that the future belongs to hydrogen. And with this investment we are sending a strong signal for the progress that will shape energy production.

With **Graebener® Bipolar Plate Technologies** we want to make our idea of the future tangible for the present. Not only do we want to create leading and lasting quality for our customers in the spirit of our company's history, we also strive to develop solutions that already provide today what the world needs tomorrow.

Our Declared Goal:

Shaping the Future of Energy Production
in an Economically and Ecologically
Sensible Way.





The metallic bipolar plate – essential for fuel cell and electrolyser

The fuel cell and the electrolyzer are key technologies for an ecologically and economically sensible energy generation in future.

At Graebener® Bipolar Plate Technologies, we focus on the development, optimization and realization of the manufacturing technologies for the bipolar plate, the core of fuel cells and electrolysers. As an elementary component of both the fuel cell and the electrolyzer stacks it helps, on the one hand, to generate clean electricity from hydrogen and air, and on the other hand, to convert electricity (e.g. from renewable energies) into hydrogen.

This makes the fuel cell and the electrolyzer interesting not only for future mobility, logistics or the generation of electricity and heat for buildings, but also for numerous branches of industry, such as the steel, fertilizer and gas industries, which will depend on the production of large quantities of green hydrogen in the future.

The bipolar plate is thus important for all applications of energy generation where environmental aspects, energy efficiency and sustainability are relevant

We are committed to creating the quality standard for technologies for the production of bipolar plates and to developing future-oriented processes and machines which help you produce components for hydrogen-based energy generation, precisely tailored, integrable, scalable and thus economically efficient.

The fact that we are good at this is not only proven by our renowned references, network and research partners, but also – quite pragmatically – by more than 90 bipolar plate designs implemented and over 110,000 plates manufactured on our machines.

Team Graebener® Bipolar Plate Technologies

Certainty from the Very Beginning:

Your Path to the Sustainable Production of Bipolar Plates for Fuel Cells and Electrolyzers.

Expansion into new markets always bears certain risks and uncertainties – especially in mechanical and plant engineering, where investments sometimes only pay off due to capacity utilization and duration.

Even though it is already foreseeable that hydrogen will be one of the most important energy carriers in the future in terms of climate targets and technological efficiency, it is sometimes difficult to define the efficiency and effectiveness of new processes that can be influenced by future changes and developments. In this regard it does not matter whether we are talking about further technological progress, the establishment of industrial and technological standards, any legal requirements or, more generally, supply and demand developments.

For exactly this reason, we at Graebener® Bipolar Plate Technologies have decided not only to develop production lines that are scalable, but also to support our customers from the very beginning with holistic engineering and services such as prototyping and small series production.

1 The Graebener® Engineering Plate Design Analysis and Process Development

We analyze your design regarding **manufacturability** and work with you to develop **modifications** so that your plate can be successfully manufactured – also with regard to the necessary features for an economic series production. You do not have a design yet? We would be pleased to implement your idea as a **CAD model** for you.

For your own production, we analyze all **production steps** – from the coil to the finished bipolar plate – and develop a scalable and future-proof **line concept** based on the analysis and in consideration of your infrastructure.

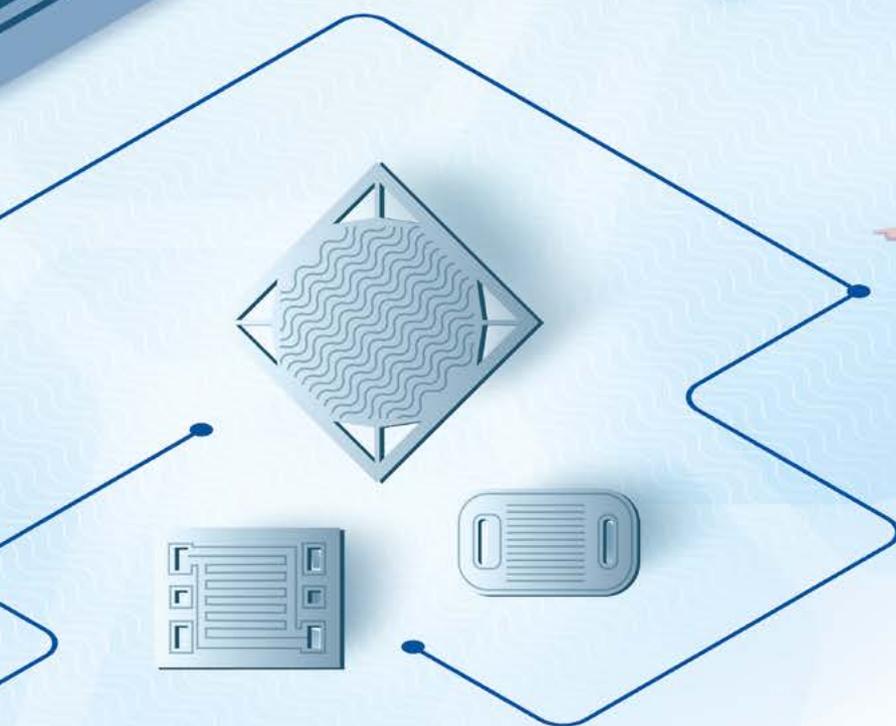
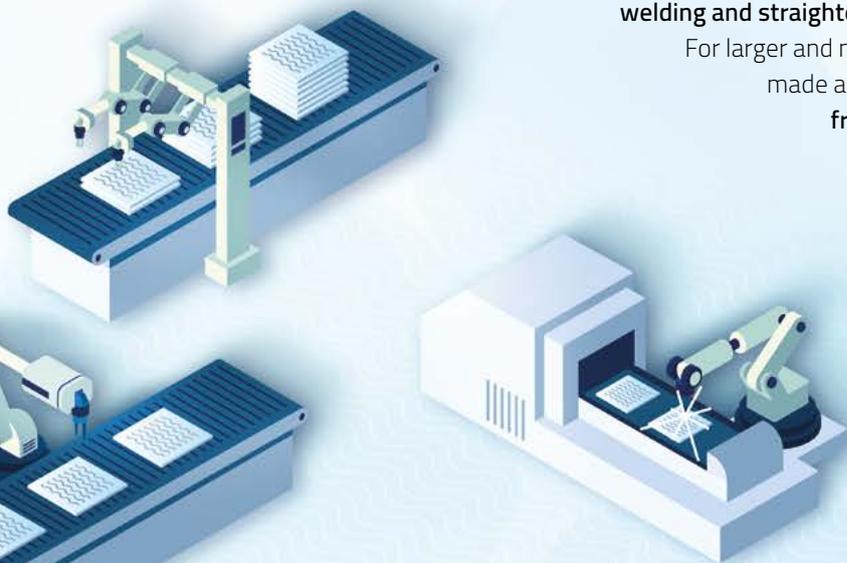


3

Your Graebener® Production Lines From the Individual Machine to the Line

We realize your individual **single machine for hydroforming, cutting, welding and straightening including all tools.**

For larger and more complex projects, we develop tailor-made and **scalable lines for series production – from the coil to the finished bipolar plate.**



The Graebener® Production Laboratory Prototyping and Small Series Production

In our production laboratory, we are able to **verify the manufacturability of your bipolar plate design using a selected area as test geometry** – this way, you obtain initial results quickly and cost-effectively. This also applies to the design optimizations we work out.

With the continuously optimized and patented Graebener® technology used in the laboratory, we are able to produce **smallest lot sizes and small series** of your plate design – and later transfer the production parameters one-to-one to your own Graebener® production line.

2

1 The Graebener® Engineering

From the Start the Optimum
for your Bipolar Plate –
and for the Technology to Start
the Series Production with.

We analyze and optimize
your design with regard
to manufacturability and
economic efficiency



Plate design analysis: The best plate for your requirements

At the beginning of every application is the design of your bipolar plate. Testing and adjusting it with a view to production is part of our expertise. Our focus during **design analysis and optimization** is not only on the **manufacturability** of your plate. We also consider those features for your plate that are crucial for **economical series production**.

If you do not have a finished design yet, we would be pleased to implement your idea as a **CAD model** for you. In this, you will benefit from our many years of expertise in the optimization of bipolar plates as well.

Why do we use metal for bipolar plates?

At Graebener® Bipolar Plate Technologies, we deliberately focus on manufacturing technologies for metallic plates. In contrast to other materials, metal offers more advantages overall for the use of plates in fuel cells and electrolyzers:

- Lighter weight
- Good recyclability
- Homogeneous electrical conductivity
- Good contact material
- High thermal conductivity
- High surface quality
- Good forming properties
- Mechanical stability/elasticity

Process development: The best line for your plate

What makes our line technology special is our approach. Since the production of bipolar plates is especially subject to many variables, we take a very close look at your targets before designing our machines and solutions. What you want to achieve with the bipolar plate is the basis for our work. Therefore, in the first step, we not only analyze and optimize the design of your bipolar plate, but also offer a **well-founded analysis of the individual production steps – from the coil to the finished bipolar plate** – always considering the planned output.

With the focus on economical and sustainable production, we also develop a **scalable concept for your production lines** that can grow with your requirements. This way, we offer you security for economical and sustainable production with regard to production, process, product and performance. When implementing your line technology, we will of course take care of the optimal integration into your infrastructure and create the appropriate installation and assembly plan for you.

2 The Graebener® Production Laboratory

Your Idea Made Tangible.

Prototyping: Safety for fuel cell and electrolyzer

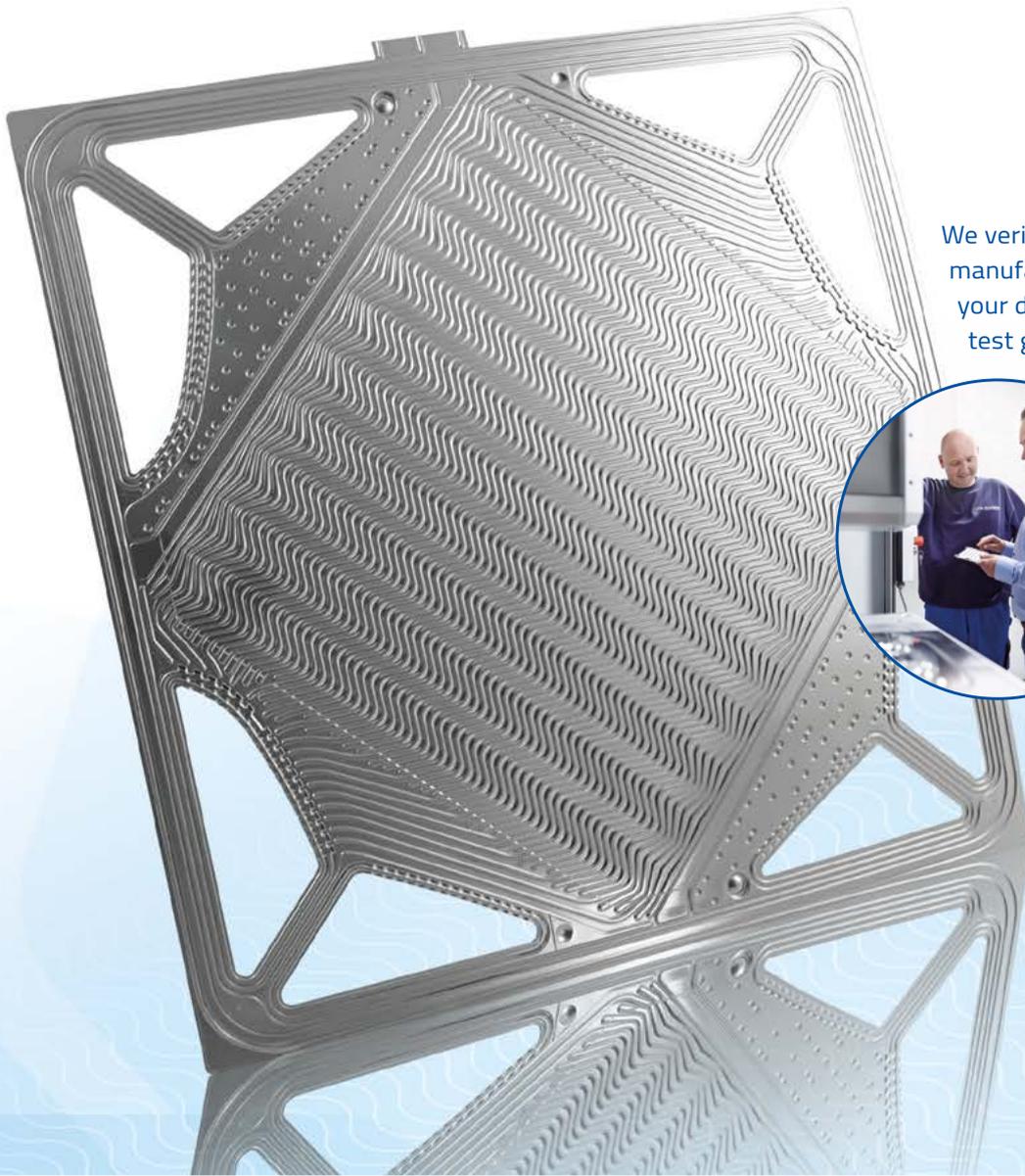
In our **Graebener® production laboratory** we are able to make your ideas tangible even before production. Our machinery used for prototyping is constantly being further developed in view of growing market requirements. Thus, we deliver tangible, high-quality results to **verify the manufacturability of your bipolar plate design**. To help you decide quickly and cost-efficiently whether your original design or our optimization ideas are actually feasible, this is examined using a selected area of the plate as test geometry – saving you time and money.

For verification purposes, we work with our own especially developed and patented machine concepts – consisting of Graebener® hydroforming presses, Graebener® cutting machine, Graebener® welding machine and Graebener® straightening machine – which are **ideally suited for a wide range of plate dimensions and materials from a foil thickness of 50 µm** and which can realize the narrowest radii.

Small series production: Fast practical results

Before you take the next step and invest in your own Graebener® manufacturing technology, we would be pleased to support you in the **production of your plate** within the scope of our services – **from smallest lot sizes to small series** with capacities of up to 50,000 parts per year. Our quality speaks for itself: so far, we have realized more than 90 customer designs and have produced more than 110,000 parts.

If you intend to set up your own production in the future, the process parameters from our production laboratory can be transferred one-to-one to your own Graebener® lines. From the initial consultation to the feasibility analysis and tooling up to the optimal production, our experience is incorporated into your individual line solution.



We verify the manufacturability of your design using a test geometry



From test geometry to small series: What we do for you in the production laboratory

Material	Diverse, such as stainless steel, titanium, copper, clad materials; also pre-coated (e.g. Alleima Sanergy®)
Forming	Table surfaces of up to 6 x 2.2 m and foil thicknesses from 50 µm
Cutting	Partial and final cuts using laser fusion cutting
Welding	Using laser scanner technology
Straightening	Using self-developed straightening technology
Measuring/testing	Detailed evaluation using microsection and microscopic measurement
Leak testing	Leak test of all media areas of the final plate
Coating	Trouble-free use of pre-coated material; alternatively desired post-coating carried out by our partners

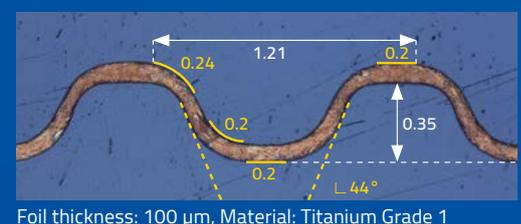
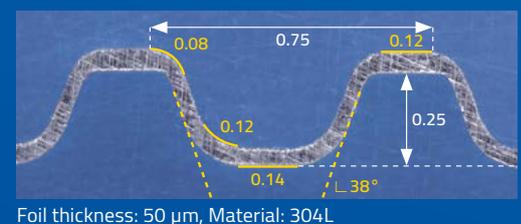
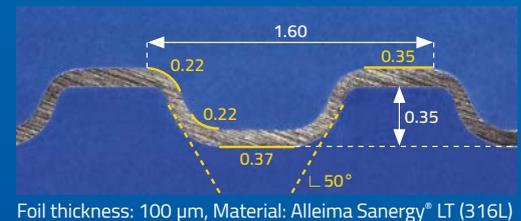
The Technology for Optimum Performance: With Hydroforming to a Better Product

As a pioneer in hydroforming, we deliberately rely on the process for which we are known worldwide as experts for the production of bipolar plates. The advantages of hydroforming are obvious:

With so-called **external high-pressure forming**, extremely filigree structures can be realized in series using extremely thin **materials from 50 µm**. In contrast to mechanical forming, which at first glance may seem more cost-effective, especially for series production, hydroforming offers numerous advantages that pay off in the long term. Since bipolar plate production is all about **repeatable precision, attention to detail and high value**, we believe that hydroforming is the optimal process – and one of the quality features that makes Graebener® Bipolar Plate Technologies your sustainable competitive edge.

Criteria	Graebener® hydroforming plate	Mechanically produced plate
Repeat accuracy in the process	Very high	Good
Elasticity after forming	Highly elastic through gentle forming with integrated cooling	Significantly reduced through strain hardening
Wall thickness variation	Very homogeneous over the entire duct cross-section	Heterogeneous (constrictions)
Suitability for pre-coated materials	Ideal: no friction on the water side	Only limited use due to friction in the tool
Contact areas	Almost ideal shaping of the flat contact surfaces	Good shaping
Use of different material thicknesses in one tool	Flexible: different material thicknesses can be used per tool	Not possible
Adaptation of the manufacturing parameters in the forming process	Flexible	Not possible
Tool costs	Low: less wear and fewer tools	High
Number of tool stages	One	Several (multi-stage forming tool)

Exemplary Graebener® hydroforming plates



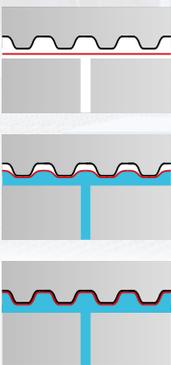


Patented technology by Graebener®

We have developed our patented Graebener® hydroforming press especially for the economic production of metallic bipolar plates and have made it ready for series production.

With our sandwich tool, several plates can effortlessly be produced simultaneously per stroke, e.g. the cathode and anode side.

In detail: What is hydroforming?



Hydroforming – or external high-pressure forming – is an active media forming process. A metal foil is inserted into a tool gravure and expanded into the forming tool with very high pressure by means of a water-oil-emulsion (see sketch).

Thanks to the even pressure distribution over the entire foil surface, an homogeneous material thickness distribution is achieved, and abrupt stress transitions are avoided. This allows forming even the smallest radii. The material spring back remains low.

Tool contour — Bipolar plate — Active medium —

The Technology for More Precision: Our Experience in Laser Cutting

Since the cut edges of the single resp. bipolar plates are used, among other things, as alignment elements in downstream processes and any deviation between the cutting contour and the formed channel structures can lead to problems during the operation of the fuel cell or electrolyzer, special precision is required when cutting the plates. The quality of the cutting edge has also a significant influence on the quality of the final product.

With **laser fusion cutting**, we use a process in our production laboratory that achieves precisely this high level of accuracy and quality. And this is achieved without significant maintenance costs or tolerance problems due to tool wear. This ensures fitting accuracy even for complex structures.

More precise cutting

Our Graebener® cutting machine is equipped with a cartesian laser system as well as a fiber laser with the latest cutting optics. **From the smallest foil thickness from 50 µm up to massive plates** (for high-pressure electrolysis applications), you get highly precise, economical and absolutely reliable results.

Despite **high cutting speeds** of up to 2 meters per second, we achieve **extremely high cutting quality** with minimal burr formation and roughness. This applies not only to 2D but also to 3D cuts – e.g. for the most filigree geometries in the port area of the plate.

Use our production laboratory and our many years of expertise to solve your complex challenges. We develop concepts for your **individual process and clamping technology** and always place the utmost importance on the positioning accuracy, repeatability and long-term stability of the system.

Laser cutting head



100 µm plate, cut

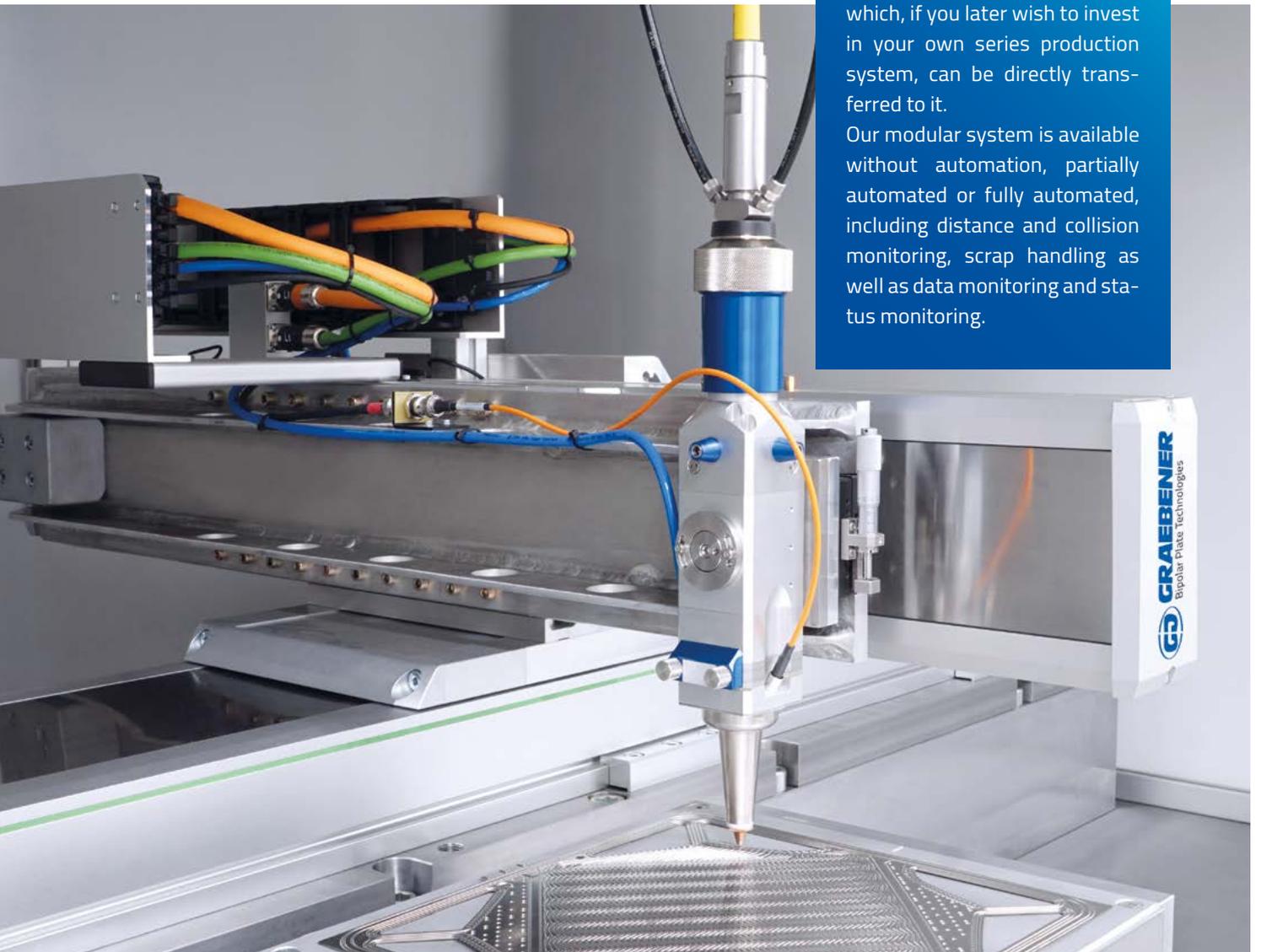




Prepared for the future

During prototyping, we already generate all process parameters which, if you later wish to invest in your own series production system, can be directly transferred to it.

Our modular system is available without automation, partially automated or fully automated, including distance and collision monitoring, scrap handling as well as data monitoring and status monitoring.



The Technology for Shorter Cycle Times: Fast Results thanks to Laser Welding

Not only do we form your bipolar plate for fuel cells and electrolyzers precisely. As an experienced technology and equipment partner, we are also at your side for the subsequent welding process.

As with cutting, we also use the advantages of **laser technology** here. Benefit from our many years of practical experience.

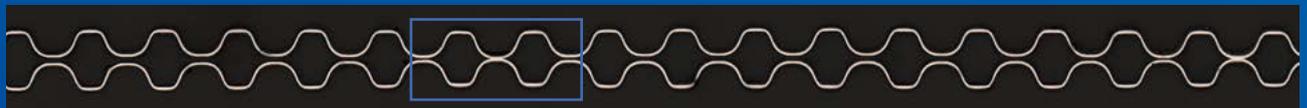
Faster welding

With our Graebener® welding machine, we rely on a **combination of the latest fiber laser and laser scanner technology**. With this method, the welding optics are not moved mechanically, and thus time-consuming. Instead, the beam is directed to the respective welding spot via a mirror system. Thanks to the static structure of the laser, our welding technology enables **extremely high speeds** – and thus saves valuable time. For example, speeds of up to 0.8 meters per second can be reliably achieved with stainless steel foils 100 µm thick. A major advantage over a conventional laser processing machine.

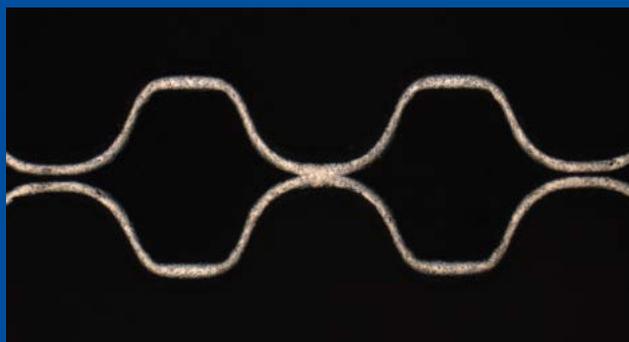
At the same time, the **smallest spot sizes** of the laser beam ensure that we also weld reliably in the channel structures. With the help of our individually designed **welding device** and ideal control of all process gases, we ensure a stable welding process.

We can process a **wide range of different metals**, from stainless steels to titanium and pre-coated materials, starting at a thickness of 50 µm.

50 µm bipolar plate, welded



15x magnification



50x magnification



200x magnification



Production ready for series

If you wish to invest in your own production, we can provide you with an advanced and economic solution for your welding process that is individually adapted to your requirements: with or without automation, including process sensors, inline process monitoring via camera and multi-field system for large components.

The process parameters previously determined in the production laboratory can later be easily transferred to your own Graebener® welding machine.



The Technology for More Economic Efficiency:: Our Worldwide Unique Straightening Technology

In the production of metals and in their further processing, residual stresses are introduced. With very thin material thicknesses, as is the case with metallic bipolar plates, these residual stresses become particularly visible. In addition, the complex three-dimensional geometry of the bipolar plates leads to a further asymmetrical distribution of residual stresses.

As a result, metallic bipolar plates always contain a certain residual stress despite all technological and process precision. This shows up in the form of **warping** or deviation from an ideal flatness.

More efficient and economical stacks through straightening

For use in fuel cells and electrolyzers, metallic bipolar plates are stacked and pressed together in stacks of sometimes several hundred plates. In addition to the bipolar plates, extremely flexible and sensitive components such as membranes, gas diffusion layers and seals are also installed.

If the bipolar plates are not flat but warped, this leads to an inhomogeneous distribution of pressure between the components when a stack is pressed together, which has a negative impact on the **effectiveness and durability** of the stack. If the resulting transverse forces are too great, this even leads to microcracks in the sensitive components, and total failure of the stack can occur.

Warped bipolar plates also reduce the overall **economic efficiency** of stack production, as they require more effort in all processes following the welding process, i.e. in seal testing, post-coating, seal application and stacking.

100 µm bipolar plate, not straightened



Highest quality with full flexibility

With our specially developed and worldwide unique technology for straightening metallic bipolar plates, these **residual stresses** can now – depending on the geometry – either be significantly reduced or even **almost completely eliminated**.

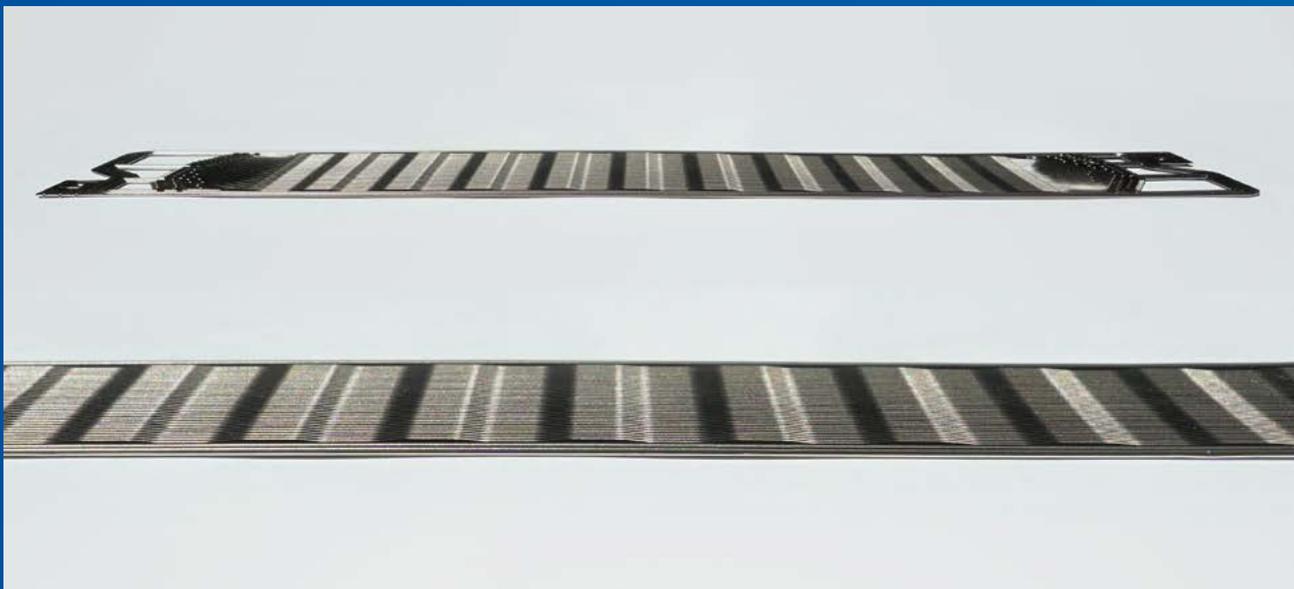
Our technology is designed in such a way that the straightening process is **contactless**. Thus, it neither influences the surface and a possible coating nor the moulded geometry of the metallic bipolar plates.

Furthermore, our technology can be used **for all metallic single and bipolar plates**, without geometrical restrictions in the X and Y directions.

For the first time, the Graebener® straightening machine enables you to produce flat bipolar plates – a necessary requirement for both economical stack production as well as high performance and durability of the stacks.

Our machine can be operated either as a single machine or as part of a fully automated production line. Thanks to our in-house production laboratory, we determine the corresponding process parameters in advance in a prototyping.

100 µm bipolar plate, straightened



3 Your Graebener® Production Lines

From the Individual Single Machine up to the Scalable Production Line.

From our experience as custom machine builder, we know that there is no such thing as “the one” machine – because technologies and processes change with market requirements. At Graebener® Bipolar Plate Technologies, we endeavor to respond as flexible as possible to present and future requirements of our customers.

Regardless of whether you are looking at **a single machine** tailored to your objectives, **a complete production line** or **an extension of an existing line**, and regardless of whether you want to manufacture **fuel cell or electrolysis components**: In all these cases we are your flexible performance partner and realize your individual production line from coil to finished bipolar plate in close cooperation with you.



Our individual machines: Patented technology

Our patented Graebener® machines for hydroforming, cutting welding and straightening are ideally suited for manufacturing projects with clearly defined goals. Based on your specifications and with regard to the production parameters determined in our production laboratory, you will receive machines perfectly tailored to your needs including the necessary tools for the production of high-quality bipolar plates.

Turn our innovations into your competitive edge: e.g. with our patented combination of sandwich tool and Graebener® hydro-forming press, which allows you to simultaneously form several plates per stroke.

Growth as standard: With scalable production lines – from coil to finished bipolar plate

Thanks to our many years of experience in mechanical engineering, we are able to develop **line concepts that can grow with time**. With a view to your increasing quantities or changing component geometries, we develop production lines for bipolar plates that can be scaled precisely and sustainably. **The modular design of our lines guarantees a cost-efficient expansion of your production line.** From the very start, our concept accompanies you safely into the future.

We determine all necessary process parameters in advance in our Graebener® production laboratory and thus realize a fast start-up of your production lines on site.



As a strong performance partner for the development of your bipolar plate production, we offer you the following advantages in close, constructive cooperation:

- Analysis, modeling and optimization of your bipolar plate design
- Tool engineering
- Prototyping as well as production of smallest lot sizes and small series in the Graebener® production laboratory
- Analysis of the production steps from coil to finished bipolar plate
- Determination of requirements of individual machines and necessary handling and automation systems
- Preparation of the technical specifications/specification sheets
- Creation of the 2D/3D line layout including installation plan
- Analysis of the interfaces between the respective line sections and to the primary control
- Preliminary planning of the foundations
- Assembly and start-up
- After sales service

Achieving More with Strong Partners

As a medium-sized company, we are proud to push forward research and development in the production of bipolar plates for the energy generation of the future together with strong partners from politics, industry and science.

You will also benefit from the close interconnections in our network: Due to the continuous exchange with industry experts, we always have an eye on the latest technological and political developments and can use this knowledge for your benefit.

Our network

NRW.Energy4Climate

www.energy4climate.nrw

Graebener® is member of the NRW Network Energy and Climate Protection.

Forschungszentrum Jülich

www.fz-juelich.de

Graebener® works together with Forschungszentrum Jülich (Jülich Research Center) in the field of electrolysis.

VDMA AG BZ

<https://bz.vdma.org>

Graebener® is a member of the board of the VDMA (German Engineering Federation) Fuel Cells Working Group.

ZBT

www.zbt.de

Graebener® is a member of the support organization and cooperation partner ZBT (Hydrogen and Fuel Cell Center).

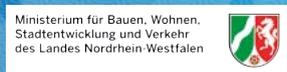


Our references (selection)

Project BREEZE! Graebener® proves marketability

Graebener® inside: With the successful completion of the project BREEZE! we proved the marketability of our technology already in 2014. Together with further project partners we realized a 30 kw Range Extender for a Fiat 500.

Within the scope of the project we supplied the metal bipolar plates as proof of concept of our patented manufacturing technology and also contributed to the project with our many years of experience in the area of further value-added chain steps. Today, we have vast experience along the entire value-added chain, from the coil up to the functional fuel cell system.



Project MetaBPP

Combination of metallic bipolar plate and seal

Elaboration of the technological boundary conditions for the integration of a fuel cell suitable seal. Successful realization with an industrial partner.

Project Ekolyser

New economic, sustainable materials for PEM electrolysis

Extension of the competence for forming and cutting of a bipolar plate for the application of highly dynamic PEM electrolysis.

Project PreCoat

Pre-coated materials for bipolar plates

Elaboration of the boundary conditions for tool, machine and devices for processing pre-coated, fuel cell suitable pre-material.

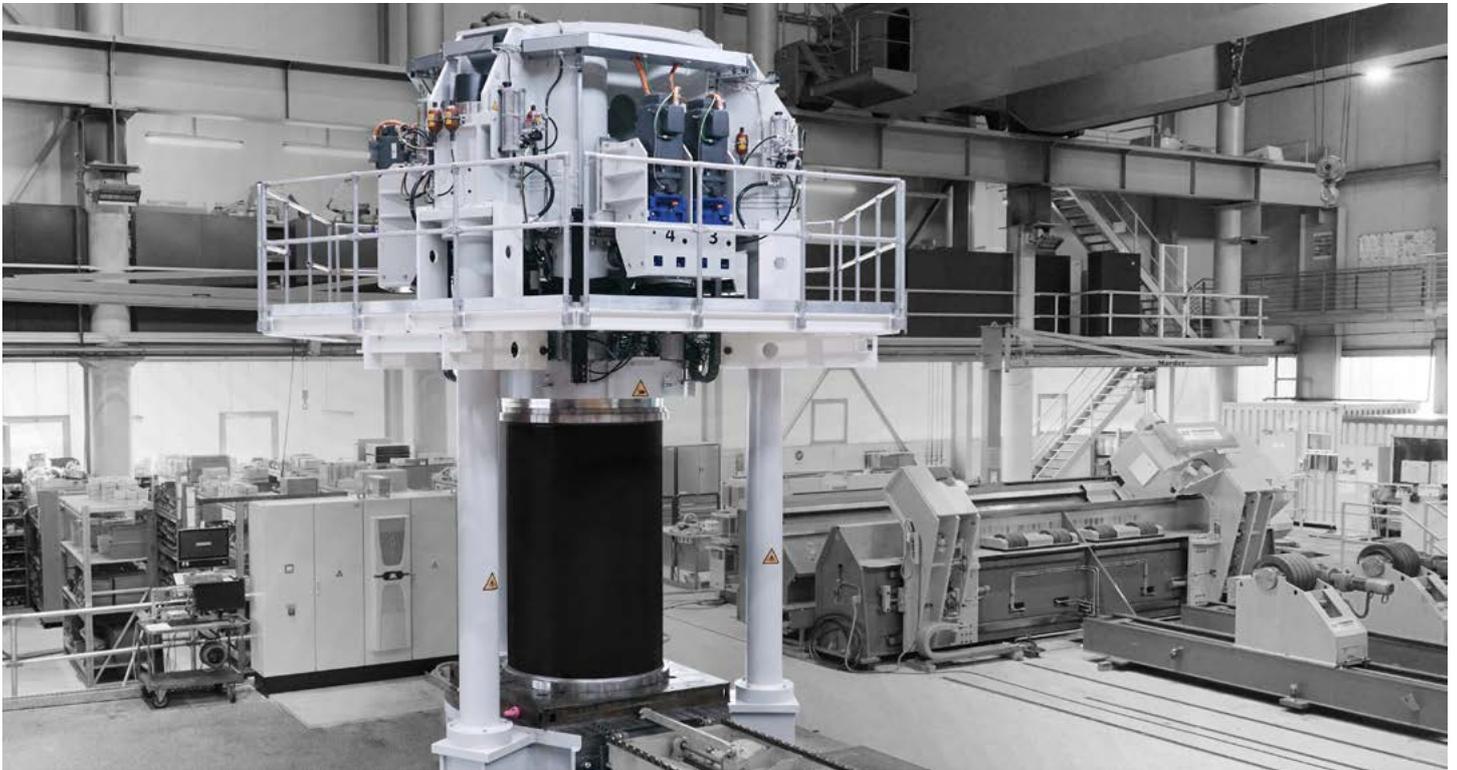
Project RoBiPo

Metal bipolar plate for high-temperature fuel cell

Extension of the competence for forming, cutting and welding of a bipolar plate for the application of a high-temperature fuel cell.

Graebener® Stack Presses

Technology to Support Stack Testing
for Fuel Cells and Electrolyzers.



Graebener® stack press for electrolyzers

Graebener® stack presses are always designed specifically for the application. Each customer is provided with a tailor-made solution. Therefore, our machines can be used for fuel cell stacks as well as for electrolysis stacks.

Tasks of the machines

- Pressing of a pre-assembled stack
- Maintaining the pressure for several hours while performing various tests
- Final stack assembly by means of tie rods or tension straps

Special features

- Compensation of lateral forces caused by tolerances in the stack
- Homogeneous compression of the stack by means of synchronized servo-motor spindle units



Gräbener Maschinentechnik GmbH & Co. KG
Am Heller 1
57250 Netphen-Werthenbach
Germany

info@graebener.com
+49 2737 989 0